2022.

Guidance for Local Roads Design

(GLRD)

4. DESIGN OF BRIDGES AND ENGINEERING STRUCTURES

Content

List of tables

List of figures

1 INTRODUCTION

1.1 General

These guidelines of the GLRD (Guidance for Local Road Design) are to serve for the design of local roads. Local roads are, according to their function and technical sense, regarded as public roads; as a rule they have one lane, each outside and inside the area with organized side construction[1], having intersections in one level. Local roads most often connect settlements, parts of settlements, as well as represent the connection of a settlement or some urban content with the state road network. They are characterized by a smaller volume of traffic with the participation of vehicles with a higher axle load. Shorter sections with double lanes can be included into the category of local roads and they are primarily part of the local road network of large agglomerations (Belgrade, Novi Sad, Nis, etc.). Sections with double lanes are classified as highways and are planned and designed according to the methodology and regulations intended for state roads of the first order.

1.2 Guidelines subject

These guidelines represent a single technical standard for the design of bridges, taking into account the economic requirements for achieving high technical quality. The goal is to achieve the high quality of bridge facilities based on economic efficiency in order to prolong overhaul cycles.

These guidelines are designed to help investors, designers and contractors.

Guidelines for the design of bridges and engineering structures on local roads are written in accordance with the Manual for the design of roads in the Republic of Serbia - PE Roads of Serbia (SRDM), which is referred to in some parts. This document provides specific conditions for bridges on local roads.

Guidelines for the design of bridges and engineering structures are used for the design of bridges and supporting structures and similar structures on the local road network. When designing facilities within other infrastructure carriers, other existing regulations must be respected (e.g. regulations for planning railway bridges, etc.).

Unless otherwise specified, these guidelines are used in their entirety for the planning of new bridges.

When using the guidelines it is necessary to check the current edition or current status. If new, invalid or updated principles affect the specifications in these Guidelines, coordination with the client is required.

Local roads are roads that, according to their function, are significantly adapted to geographical, terrain, and urban conditions, and thus pass through areas that are exposed to increased risk. Within these zones, roads and structures are particularly exposed to risks caused by climate change.

Climatic changes first of all require the modification of design guidelines in order to ensure sufficient capacity for road drainage and prevention of erosion and landslides, defining qualitative requirements for increasing soil and structures stability, the resistance of the pavement structure to greater temperature fluctuations, and more rigorous application of environmental protection measures

These guidelines are intended for the designers in the initial stages of bridge design.
The guidelines emphasize the importance of making and properly using design bases that significantly affect the correct choice of building concept. Geometric elements of roads, traffic and free profiles and widths of bridges affect the correct conception of the geometry of bridges. The reliability of bridges consists of safety and durability, which are influenced by the designer. The phases of bridge design are coordinated with the phases of road projects. The most economical solutions for buildings are obtained when the road, in the design sense, is already completely defined.

1.3 Terminology

(Basis: SRDM 9-1 General guideline, applicable legislation)

Target state
Planned condition at the time of construction including all renovations, upgrades and repairs.

Investment maintenance is the performance of construction works, craft works or other works, depending on the type of the structure, in order to improve the conditions of use of the structure during its operation.

Ongoing (regular) maintenance of the facility is the performance of works that are undertaken to prevent damage caused by the use of the structure or to eliminate such damage: and it consists of inspection, repairs and undertaking of preventive and protective measures, i.e. all works that ensure the maintenance of the structure at a satisfactory level of usability.

Adaptation of the bridge includes works that change the organization of space on the structure, replacement of equipment and installations that do not affect the stability and safety of the bridge, do not change structural elements, do not change the appearance and do not affect the safety of neighbouring buildings, traffic, fire protection and environment.

Rehabilitation is the performance of construction and other works on the existing structure that includes repair of devices, plants and equipment, i.e. replacement of structural elements of the structure, which do not change the external appearance or affect the safety of neighbouring structures, traffic and environment and also do not affect the protection of natural and immovable cultural property i.e. its protected environment, except for restoration, conservation and revitalization works.

Rehabilitation of the bridge includes repairs (rehabilitation) of damaged parts of the supporting structure and repair or replacement of bridge equipment.

Landslide rehabilitation includes all works that remediate landslides caused by building, forest, agricultural, road or other types of land. These works include clearing and removal of sediments caused by landslides, design, and provision of necessary technical documentation, necessary construction conditions and execution of construction works necessary for rehabilitation and protection against the occurrence of a new landslide.

Reconstruction of the bridge includes extensive reconstruction and replacement of load-bearing parts and equipment of the bridge in order to adapt to the new purpose, increase load-bearing capacity and eliminate damage that occurred during the operation of the bridge. After the reconstruction of the building, the building structure (which is its integral part) must have the technical properties prescribed by the Rulebook for building structures.

Reconstruction of linear infrastructural object is the execution of construction works in the protection zone, in accordance with a special law, which may change the size, volume, position or equipment of the existing structure, as well as execution of works involving large-scale works, replacement of elements on existing linear objects, which do not change their overall functioning.

Replacement of a bridge is the removal of a complete bridge or a dilapidated span structures and the construction of a new bridge or a new span structure.

Bridge maintenance represents a combination of all technical and administrative measures during the life cycle of a structure that serve to maintain its functionality or restore its functional condition so that it can fulfil its required function. Local self-government training, as an integral part of maintenance, is a combination of all structural and administrative measures as well as management measures to increase the functional reliability of the structure, which is considered without changing the function required of it.

Separate relating to the technical conditions of construction (hereinafter referred to as: separate), is in fact a document issued by the holder of public authorizations within its competence when the planning document does not provide for the conditions, i.e. for the data regarding the preparation of technical documentation and which contains the appropriate conditions and data necessary for preparation of the technical documentation, especially regarding the capacities and place of connection to the communal and other infrastructure facilities, according to the classes of objects and to the parts of areas for which it is issued.

Holders of public authorizations are the state authorities, authorities of autonomous province and local self-government bodies, special organizations and other persons exerting public authority in accordance with the law.

Conditions for design, or for connection are actually the conditions issued by the holders of public authoritizations in an unified procedure of issuing the location conditions at the request of the competent authority, in accordance with the planning document, which are in fact not issued in the form of an administrative act by which the structure whose construction is defined by the planning document can be realized, and the same represent an integral part of the location conditions.

Demolition of the bridge, i.e. removal of the building structure is performed according to the object demolition project, while the removal or replacement of certain parts of the building structure during the reconstruction of the structure is performed according to the structure reconstruction project. (Article 25 of the Rulebook for building constructions).

2 Bases for bridge design

(Basis: SRDM 9-1 General Guideline)

2.1 Introduction

The design of bridges is based on spatial - urban, traffic, geodetic, road, geological - geomechanical, hydrological - hydrotechnical (water management), meteorological - climatic bases, seismological data and the project task.
Criteria for bridge design:

- Functionality for users and maintenance
- Technical quality
- Long-term repair cycles and optimal maintenance cost for the projected life of the structure
- Robust and durable bridges with timely fracture indication and their ductile behaviour.
- Structures with the lowest possible risk of incorrect damage assessment during construction inspections.
- The integrated construction method has priority over other construction methods. Serbian as well as international reference norms for the design and construction of integral bridges must be taken into account.
- Aesthetics

2.2 Spatial - urban bases

In the case of larger structures (bridges, viaducts, galleries and tunnels) and if the bridges and viaducts stand as independent structures in cities and towns, special spatial and urban conditions, i.e. location documentation are issued for such structures. The spatial and urban bases cover the location and purpose of the bridge and other framework conditions for the inclusion of bridges in spatial and urban plans.

The choice of the crossing is considered as the final one, due to the fact that during the rehabilitation of the road, the previously built crossings are usually used. The first duty of the designer is to examine directly in the field the possibility of the most suitable position of the bridge in terms of all the requirements that were previously stated.
The fact that the favourable position of the bridge does not have to be a priority compared to the entire road construction project should be taken into account. Therefore, for roads of higher

design class K (K1 and K2) preference is given to the route of the road, and the bridge should fit as well as possible. For local roads of lower design class K, preference is given to the position of the bridge, and the route of the road will be adjusted to the bridge.

If the architectural aspect of the design is important, experts for the aesthetic component of the project should be involved at an early stage (i.e. at the beginning of the design), and then it is necessary to consider the entire project of the bridge-road structure.

2.3 Traffic bases

For larger self-supporting bridges, and especially for the city bridges, the intensity and type of traffic during the construction and operation of the bridge is determined in the traffic base. Traffic data on the bridge represent the basis for determining the number and width of lanes, pedestrian paths, bicycle paths, etc.

For road facilities that are an integral part of the new route or are included in the reconstruction of existing roads, no special traffic base is required, as bridges must be harmonized with the conditions applicable to roads. Fences on the bridge, as well as side protection, must not reduce the capacity of the lanes.

The basic data on traffic should contain the information on its intensity, number of vehicles expressed in the average annual daily traffic rate (AADT), structure of the vehicle type and traffic growth forecast within the intended period. The speed of vehicles on bridges is an important feature for determining the width of the road and edge lanes, types of fences, height of curbs and other equipment on bridges.

2.4 Geodetic bases

The preparation of the geodetic study consists of the preparation of a situational plan and longitudinal and cross sections.

Geodetic measurements begin with the quality control of the existing geodetic network.

Realization of field geodetic measurements consists of terrain measurements, existing structures (roads, facilities, approaches, etc.).

Detailed cross-sections of the terrain should be recorded in the area of all piers.

Elements of geometric monitoring during the operation and maintenance of the bridge may be included in the geodetic study.

2.5 Data on the road on which the bridge is to be designed

(Basis: GLRD Road Design Elements; SRDM 9-1)

The design of bridges is preceded by the design of roads. The situation of the route, the longitudinal profile, the transverse profiles on the part of the bridge and the normal transverse profile contain basic data on the geometry of the road that enable the design of bridges and engineering structures. In all phases of the road design, the participation of the bridge and building designer is necessary and useful in order to enable favourable geometric elements for the design of bridges. In the chapter GDLR Design elements of the road, the geometric elements of the road on bridges are analyzed in detail.

2.6 Geological - geomechanical bases

Geological-geomechanical bases for bridges and engineering structures must be made in accordance with the standard SRPS EN 1997. Geological structure of the terrain at the location of bridges significantly affects the choice of the load-bearing system, depth and method of foundation.

The number and depth of geological wells must be defined in accordance with SRPS EN 1997. All relevant geological and geomechanical data are important for the design, as well as data on the condition of the groundwater level.

The complete Study on geotechnical conditions of construction includes:

- determination of soil layers;
- determination of the physical properties of earth materials;
- analysis and interpretation of data and formulation of structure foundation solutions.

Geotechnical issues that may affect the project can be grouped as follows:

- Foundation issues - Including determination of load-bearing capacity, stability and deformation of the substrate material under the load imposed by the foundation structure;
- Ground pressure problems - Including loads and pressures imposed by earthen materials on foundations and load-bearing structures;
- Construction considerations - Characteristics of excavation materials and conditions affecting deep foundations or soil improvement;
- Groundwater issues - including occurrence, hydrostatic pressures, flow and erosion.

Geological and geotechnical characteristics of the location are the bases that directly affect the choice of the type of foundation, the method of building the foundation and the price of the bridge and engineering structures. Conditions below the surface of the terrain and the foundation often directly affect the route and the choice of the type of bridge and engineering structures.

2.7 Hydrological - hydrotechnical (water management) bases

While building a bridge or an engineering structure over or next to a watercourse, it is necessary to collect data on their flow, water speed and changes in the riverbed. The hydrological study for the design of the bridge mainly deals with the properties, distribution and circulation of water on the surface of the earth. For the bridges built over rivers and other water barriers, the required opening of the bridge is determined by way of hydraulic calculations. The size of the bridge opening is influenced by the amount and speed of water, the shape and geological structure of the riverbed, as well as the location and position of the bridge axis in relation to the river axis, the allowed height of high water deceleration within the bridge profile. When considering the construction of the bridges, the height of the free profile is to be determined, which would enable the safe flow of high waters and contain the appropriate safe height between the required water level and the lower edge of the structure (LES).

For regional and local roads, the competent water management company issues water conditions in which the parameters are defined on the basis of which the required level of relevant calculated high waters is determined, as well as the gap to the LES. The elevation of the lower edge of the bridge structure should be provided with the required safety height - the gap above the level of the relevant calculated large waters in the profile of the watercourse (i.e. in relation to the channel profile), in accordance with the valid criteria given in the LC (or water conditions).

Solutions to minimize flushing and scouring damage:

1. Simplified bridge elements to minimize flow obstructions;
2. The foundations of the bridge piers are deep enough not to require preventive measures (min. 1.5–2.0 m below the bottom of the riverbed);
3. Bridge crossing should be executed with as few piers in the riverbed as possible, so that the axis of the bridge is perpendicular to the river flow, and the axes of the bridge piers are placed in the direction of streams so as not to cause deep erosion (along the riverbed), local erosion (around the bridge piers) and lateral erosion (on the banks) which could endanger the stability of the bridge and its structures, land, etc.;
4. The foundations of the shore pier below the estimated local depth of scouring;
5. For torrential and larger watercourses, it is recommended to perform deep foundation on piles.

Data on weather changes in water levels are important in the construction of bridges over large rivers.

2.8 Meteorological - climatic bases

Appropriate European standards and national annexes (snow SRPS EN 1991-1-3, wind SRPS EN 1991-1-4 and temperature SRPS EN 1991-1-5) should be used to determine the effects on the structure, which represent the consequence of meteorological and climatic conditions.

2.9 Seismological data for the location of the bridge

Seismological data for smaller bridges are processed in the geological-geomechanical study. For larger and more significant bridges at the locations with pronounced seismicity, it is necessary to prepare a special study to determine the level of seismicity (microseismic zoning).

2.10 Project task

The project task is prepared by the Investor, i.e. the authorized representative of the Client in cooperation with the designer. The project task is an integral part of the design contract, i.e. the construction contract.

In order to implement these measures, it is necessary to outline and oblige, first of all, the designer, to implement and process the impact of climate changes within the design documentation. The local road administration is responsible for this process.

3 Geometric elements of roads to be built on the bridges

(Basis: SRDM 4.0 and GDLR Project road elements point 4.6)

3.1 Choice of angle of the bridge crossing over obstacles

The geometric elements of roads, axles, levels and widths determine the type, geometry of the structure, the appearance of bridges and affect the cost of construction, traffic safety and maintenance costs.

The position where the bridge crosses the obstacle is determined as the final solution, because the old crossing positions are usually used in the reconstruction. It is necessary for the field designer to consider the possibilities of the most suitable position of the bridge. During the reconstruction, it is necessary to harmonize the existing position of the bridge with the route of the road, primarily taking into account the aspects of traffic safety.

When designing structures on the local road network of the lower design class K (K3 and K4), the aesthetics and position of the bridge have priority in relation to the route and geometry of the road.

The axis of the road should intersect with the axis of the obstacle at an angle of 90° or less. As the angle of intersection decreases, the length of the structure increases, the construction becomes more complicated and the price of the bridge increases.

In general, it is best to place the bridge directly on the obstacle, because then the construction of the bridge is the simplest, and at the same time the shortest. However, one should not try at all costs to place the bridge directly on the obstacle. The routes of modern roads have their own laws (radii of curves, lengths of crossings) which often need to be changed at a very great distance in order to place the bridge perpendicular to the obstacle. Sloping crossings and sloping bridges are very common on local and city roads. At sloping intersections, we can predict a sloping but also an "upright" bridge in the direction that follows the geometry of the local road, but then the spans of the bridge increase.

Crossing angles less than 45° should be avoided. It is recommended that the angle of intersection be greater than 60°.

From the point of view of design, considering the size of the angle α, the following possibilities of crossing can be distinguished (Figure 1):

- Crossing area 90° to 70° - according to vertical solutions, differences in bridge structures are insignificant;
- Crossing range from 70° to 40° - bridge structures are usually similar to vertical bridge structures, but the influence of slope must be taken into account when controlling the load-bearing structure;
- Crossing area below 40° - regularly requires the provision of some special solutions, either in the construction of the bridge or in the realization of watercourses, i.e. the lower road.

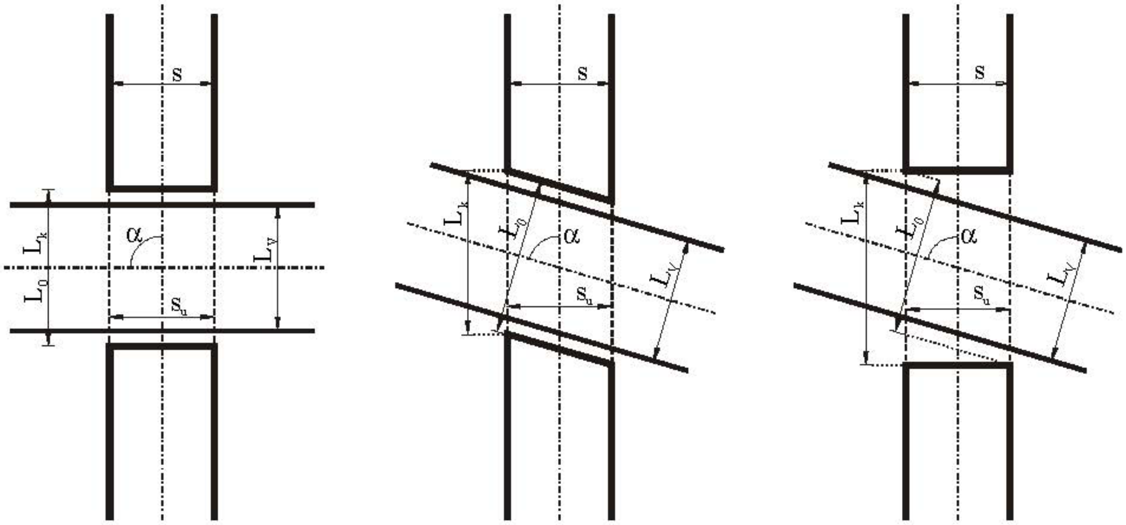


Figure 1 Possible types of bridge crossings and obstacles

If we contemplate a vertical bridge at an oblique intersection, we have: a longer bridge, a larger structure span, higher girder heights; which means that this type of bridge will be more expensive than the one with the perpendicular crossing.

If we contemplate a sloping bridge at an oblique intersection, we have: a longer lower structure, different flanks of the shore pier, a more complicated structure, more extensive calculations, and in general the bridge will be more difficult to implement than a vertical bridge. In addition, there are some difficulties in designing the bridge. The problems that arise with bridge builders can be complex. There are also problems with providing good visibility on the road / watercourse that passes under the bridge. Such problems are usually solved by thin individual piers that create open vistas.

3.2 Choice of level

The level is, in principle, the axis line in the middle of the road. For the value of the bridge, especially the aesthetic one, the shapes of the surface are important when viewed from the side of the bridge, and their reflection is exactly the level. In addition to its aesthetic value, the level is important for maintenance costs, crossing comfort and the traffic safety.

When forming the level, one should take into account the required free profile under the bridge, the height of the supporting structure, the terrain relief. It is also important to distinguish whether the bridge is an integral part of the road or stands as an independent object. The level and axis of self-supporting bridges is designed more freely, it adapts to the nature of the bridge and the specific requirements of bridges.

While the design of roads is elaborated, the cooperation between the designers of roads and bridges is a necessary condition. Sometimes minor corrections of the road level and axis make it easier to design and build the bridges. The level of roads, especially the parts above watercourses and other roads cannot be defined without making simultaneous solutions of the bridge layout, by which (among other things) the opening of the bridge, the constructive height and the common level are determined.

Efforts should be made to keep the level of elevation above the surrounding terrain as low as possible in order to reduce lost ascents and slopes, shorten access ramps and reduce embankment volumes. When crossing deep bays, it is recommended to place the load-bearing structure below the road, while at the crossing of shallow bays, this is very difficult to achieve, so the load-bearing structure is placed above the road.

Important aspects of the bridge level are its basic shape, ascent and slope and the height of the rise, the radius of curvature, the length of the easement, as well as the relations on the approaches. In the case of road bridges, short easements and sudden changes in the level should be avoided, care should be taken to drain the road surface and good visibility on the bridge should be provided (Figure 2).

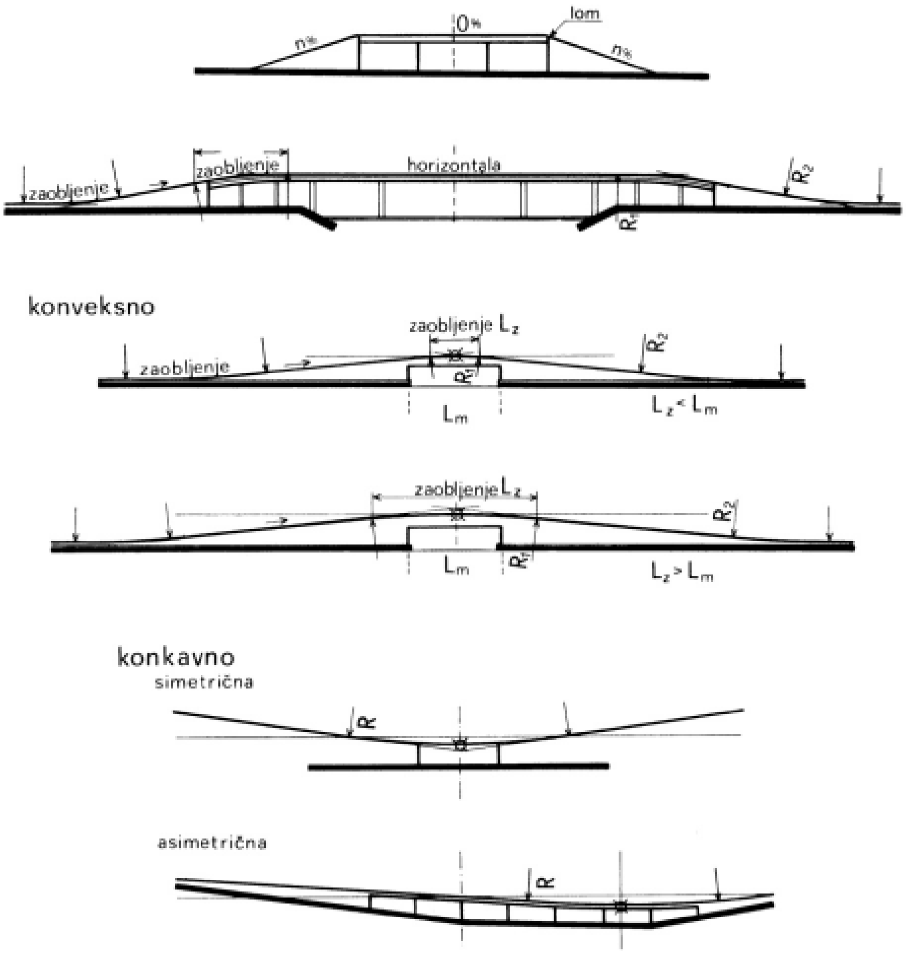


Figure 2 Basic forms of levels and their specifics

a) In the case of road bridges, the traffic area must be provided with a longitudinal drop of at least 0.5% due to the drainage. It should be taken into consideration that the road bumps, which occur during its utilization, increase the water retention on the road. The height relationships between the ends of the bridge, the free profile or other reasons may cause the one-sided or two-sided alignment of the level.

b) The convex shape of the level is suitable for both the appearance of the bridge and the drainage. If the culmination point is in the bisection of the bridge, than the structure will be symmetrical. Easements must not be strong due to the visibility of the road. It is recommended that the ascent and slope do not exceed 3%, especially if we have pedestrian traffic on the bridge.

c) The concave shape of the level is applied in places where the road descends on both sides towards the crossing (bridge). It is very favourable due to visibility, but unfavourable for drainage (in the lowest part it is necessary to increase the number and size of drains and quality maintenance is required). The drainage problem can often be avoided by placing the lowest point outside the bridge.

d) Complex forms of level are applied to long bridges. Wavy shapes of the level can be formed (combinations of convex, concave and level in one direction). There are many combinations of shapes, especially at intersections where the forks of the road intertwine in terms of layout and height.

It is desirable that the axis of the bridge is in a straight line or a simple circular curve. The combination of direction, transition curve and circular curve in the bridge zone creates certain difficulties in design and construction. The combination of horizontal and vertical curvature within the bridge zone should be avoided. Exceptionally, in the case of bridges within interchanges, this undesirable combination of curves must also be accepted.

3.3 Choice of direction

From the point of view of construction, we strive for the simplest possible bridges, which are of course the cheapest. Therefore, it is most convenient that the bridge is in one direction. However, individual bridges must be located in different curves, crossings and intermediate directions (Figure 3). In that case, in addition to the complications that arise on the structure itself, there are also problems with providing good visibility, which is closely related to the type of traffic that takes place on the bridge. In curves, the road surface is inclined towards the centre of the curve, but sidewalks with curbs do not have to follow such a slope, so the height relations between the base lines change in relation to when the bridge is in one direction (problems of entering the free profile - visually and factually).

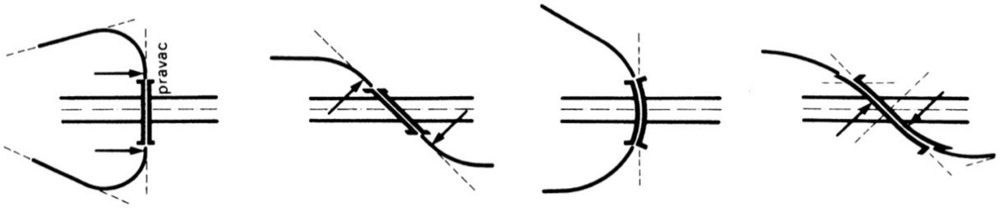


Figure 3 Possible situational solutions for crossing the bridge over the obstacle

The transverse slope of the road on the bridges is a consequence of the winding of the road and the same is solved in the longitudinal profile of the road. It is desirable that the change of the transverse slope (twisting) is done outside the bridge itself. As far as the urban bridges are concerned, a double-sided transverse slope should be adopted.

The combination of a large longitudinal and transverse slope on the road can cause uncomfortable slipping on wet, icy or snow-covered roads.

The bridge widenings in curves with smaller radii should be executed fully along the entire length of the structure, in contrast to the roads where the transition from zero to full value of widening is usually performed.

In case of smaller structures (underpasses, pedestrian passages and shorter bridges) with a length of 5 - 10 (15) m, the upper surface of the structure can be lowered below the level by 40 - 60 cm (i.e. for the thickness of the road structure), thus avoiding the unpleasant consequences of subsidence of the road on the bridge structure (Figure 4). Fences and other road equipment are not changed in short sections.

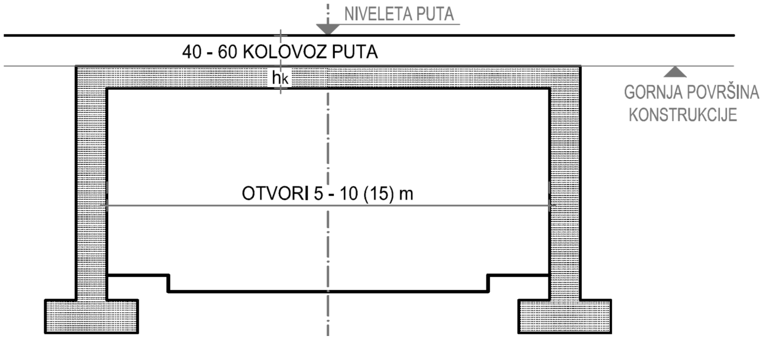


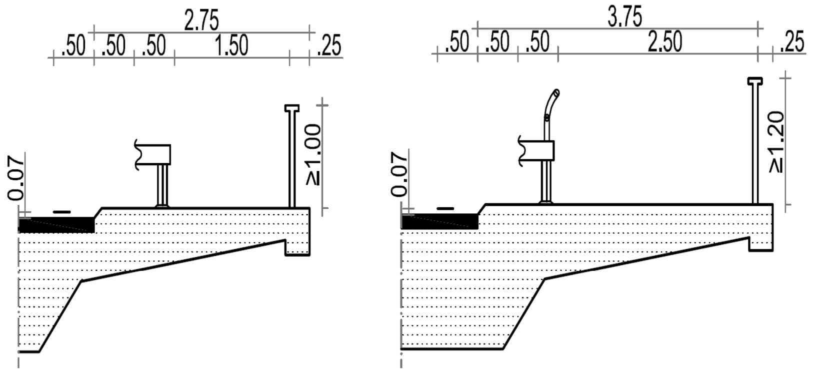
Figure 4 Relationship between the level of the road and the upper surface of the structure on smaller objects

4 Traffic profile

(Basis: GLRD Project road elements point 4.6)

4.1 Transverse profiles (TP) and bridge widths

Normal transverse profiles and widths of bridges on roads with two or more lanes must be harmonized with the geometric elements and TP of roads, as well as with the traffic and free profiles of bridges according to GDLR Road Design Elements.
<u>The width of the bridges consists of:</u>
Two or more lanes on the same road width with or without a median strip.
The edge parts of the bridges have a minimum width of 1.75 m for bridges on roads with Vp > 50 km/s, and 1.25 m for bridges with Vp < 50 km/s.
The edge parts of bridges are constructed according to SRDM 9.12.1 and SRDM 9.12.2 depending on the speed of the vehicle on the bridge, the height of the curbs, types of fences and their purpose. The purpose can refer only to a 0.75 m wide lane for officials or to one row of pedestrians, several rows of pedestrians, cyclists and a combination of pedestrians and cyclists (Figure 5).



a) Pedestrian lane

b) Bicycle or combined lane

Figure 5 Pedestrian and bicycle paths on bridges for Vp> 50 km/h with a curb height of 7 cm and steel safety barriers

5 Design of bridges within the local road network

Due to the economics of construction and maintenance of bridges, massive concrete structures with a smaller length and number of spans are recommended when planning facilities on the local road network.

The length and number of spans of the bridge structure depend on the functional, aesthetic and economic requirements. The minimum span lengths are determined by the dimensions of the obstacle. When the minimum span length is not determined by the free profile; span lengths, and the number of columns that depend on them should be chosen in such a way so that the total cost of construction and maintenance of the supporting structure and foundation is minimized.

The span construction determines the spans. Depending on the size of the span, the cross sections of the span structure are chosen.

5.1 Load-bearing structures of bridges

The types of bridges according to the type of load-bearing structure that are most often used on local roads are:

- Beam bridges
- Rigid-frame bridges (recommendation with vertical piers)

Beam bridges, in the form of a simply laid beam with one field, is the simplest static system of massive bridge structures.

The advantage of this static system is its simple execution either on scaffolding or with mounting brackets. This enables the engagement of local construction capacities, which is why it is especially applicable for the construction of bridges on the local road network.

The disadvantage of this static system is the higher consumption of materials.

Rigid-frame bridges, with one or more fields, are basically beam bridges in which the load-bearing structure is rigid or hinged to the piers. With the choice of various static systems, the stiffness of the piers and the choice of the bearing, the cross-sectional forces can be influenced.

Closed rigid-frame bridges are mainly designed for culverts with a span of up to 5m and bridges with a span of up to 10m, when they are founded on weak bearing soil.

Integral rigid-frame bridges are bridges without expansion joints and bearings.

Vertical piers in frame structures are recommended for simpler construction.

On the network of local roads, these types of piers are suitable for crossing long obstacles. Construction can be on scaffolding, with piers of lower height. They are also suitable for construction with prefabricated girders.

5.2 Types of cross sections

The types of cross-section that are desirable for use in the local road network are:

- Slab bridges (solid and hollow)
- Ribbed sections
- Ribbed slab
- Mounting prestressed beams

Slab sections

The simplest span construction is a solid slab (Figure 6). The reinforcement is simple, the smallest amount of formwork is required and the deposition of concrete is easy. On the other hand, it requires a large amount of concrete, which increases its own weight. In terms of aesthetics, trapezoidal cross-sections have a favourable effect.

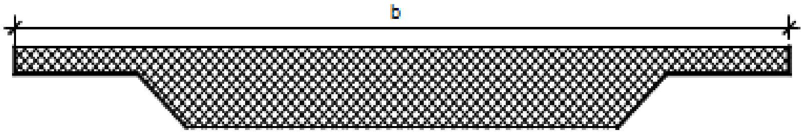


Figure 6 Slab cross section of the bridge

Ribbed sections

Ribbed cross-sections consist of one or more ribs (main girders) interconnected by a pavement slab and transverse girders. These are very economical structures. The upper deck serves not only to transfer the load in the transverse direction to the ribs, but is an integral part of the bridge superstructure. Favourable properties of these bridges are relatively small amounts of concrete and steel, or cables, and thus low weight that burdens the substructure as well as the possibility of prefabricated construction.

Reinforced concrete ribbed bridges are economical up to a span of about 30 m.

Ribbed slab

In the case of flexible cross-sections of bridges in the transverse direction or the bridges that are basically strongly curved, cross-beams should be provided mainly in all axes of the support, and if necessary in the span (Figure 7).

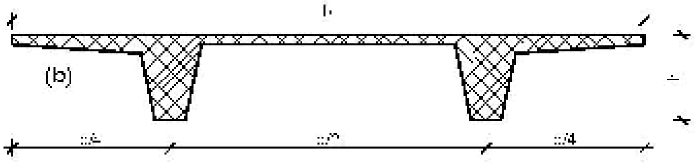


Figure 7 Cross sections with ribs

Mounting prestressed beams

(1) For bridges with prestressed concrete girders, the same principles of design, accessibility, testing, substitutability and durability must be observed as for the bridges made of concrete cast on site.

(2) In the case of prefabricated structure, it should be noted that the superstructure consists of several components of different ages of concrete, strength of concrete and possibly quality of concrete (bridge deck, transverse girders).

(3) The advantages of prefabricated in relation to the concrete structure cast on site can be:

- Omission of expensive load-bearing and protective scaffolding;
- Shorter construction time;
- Possibility of prefabrication in controlled conditions, which ensures good quality;
- Reduced traffic restrictions.

(4) The disadvantages of prefabricated in comparison with concrete structure cast on site can be:

- Restrictions due to standardization and shorter consoles,
- Difficulties of adjustment in curved and inclined structures,
- Larger concrete surface due to multiple longitudinal beams,
- Request for larger crossbeams,
- Consideration of higher structural tolerances due to different behaviour of individual beams in deflections,
- Additional reinforcement to transmit force between the prefabricated element and the concrete on site,
- Increased concentration of reinforcement in transverse girders.

The approximate dimensions of the load-bearing structure are shown in Table 1.

Table 1 Approximate dimensions of the load-bearing structure depending on the cross-section, number of spans and materials of the load-bearing structure

UNIT LENGTH	HEIGHT	NUMBER OF FIELDS
Reinforced concrete slab		
L=5 - 15m	L/12 – L/16	one field
L=15 - 20m	L/15 – L/20	several fields
Prestressed concrete slab		
L ≤ 25m	L/18 – L/25	one field
L ≤ 25m (L ≤ 40m with haunches)	L/25 – L/30	several fields
Reinforced concrete beam slab		
L=10 - 25m	L/10 – L/15	one field
	L/15 – L/20	several fields
Prestressed concrete beam slab		
L ≤ 30m	L/15 – L/20	one field
L ≤ 40m	L/15 – L/25	several fields
Prestressed prefabricated elements		
L ≤ 35m	L/15 – L/20	one field / several fields

Regarding the static system on the local road network, it is recommended to build bridges with the rigid-frame static system, vertical piers and one or more fields (Figure 8). In terms of cost-effectiveness of maintenance on the local road network, integral or, for more spans, semi-integral bridges are recommended.

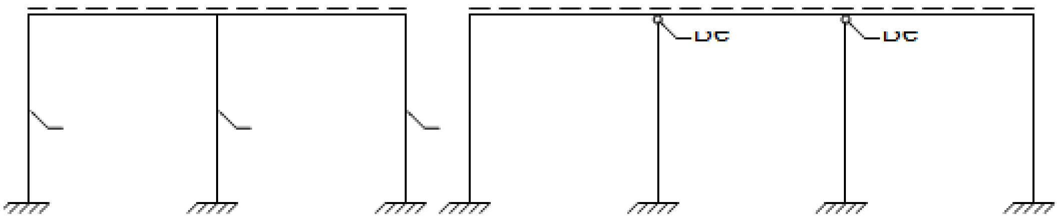


Figure 7 Rigid-frame systems

Depending on the above factors, slab and ribbed girders should be used for the cross section.

6 Data for project development

6.1 Traffic loads

Load models according to Eurocode SRPS EN 1991-2 are used for evidence in the ultimate limit state of bearing capacity and usability (including fatigue). The load models defined within the same standard are used for the design, calculation and dimensioning of road bridges.

6.2 Meteorological - climatic loads

Appropriate European standards and national annexes (snow SRPS EN 1991-1-3, wind SRPS EN 1991-1-4 and temperature SRPS EN 1991-1-5) should be used to determine the effects on the structure, which are a consequence of meteorological and climatic conditions.

6.3 Seismic load

(Basis: SRPS EN 1998-2, earthquakes)

For the dynamic analysis of bridges in accordance with the standards SRPS EN 1998 design of structures resistant to earthquakes, seismological maps are used according to which the zone is determined, i.e. the value of the projected acceleration a_g.
Generally, bridges as part of the local road network are assigned II class of importance (average importance), unless the importance of the obstacle over which the bridge crosses requires a higher class; in which case the consent of the Client is required.

6.4 Bridge waterproofing

(Basis: SRDM 9.12.3 Waterproofing)

As a measure of resistance to climatic changes, it is necessary to provide a type of waterproofing with appropriate physical and mechanical characteristics in case of extreme precipitation and extreme temperatures.

All based on SRDM 9.12.3 Waterproofing

6.5 Bridge drainage

(Basics: SRDM 9.12.4 Drainage and sewerage, GDLR Drainage)

Drainage systems must be taken into account in a timely manner in the overall planning of the bridge, in order to properly and sufficiently determine its dimensions.

As a measure of resistance to climatic changes, it is necessary to ensure the stability of the drainage system in case of extreme precipitation (showers or prolonged rainfall).
When the new bridges are built, surface water must be collected if there is no official approval for free fall discharge. In case of repair, the change of the existing drainage system of the bridge can be carried out only in cooperation with the Client.

Carrying out installations (internal drainage, collector) in hollow boxes is generally not allowed (special solution is to be made only after consulting the Client).

6.6 Carriageway

(Completely processed in GDLR Pavement structures)

6.7 Expansion joints

(Basis: SRDM 9.12.6 Expansion joints)

For expansion joints, it is necessary to use products with a valid approval or, alternatively, products can be installed for which the suitability and usability is confirmed by individual verification. As a rule, waterproof transitional structures are used.

The direction of movement of the expansion joint is defined by the direction of the bearing and should be as parallel as possible to the axis of the bridge.

In the case of the expansion joints of the carriageway along which the traffic is carried out directly, the angle of intersection between the shore pier and the axis of the carriageway should be (if possible) > 65°. Adjustment angles of the left slope between 45° and 70° in relation to the direction of traffic movement are unfavourable for winter service and should be avoided if possible. If this is not possible, appropriate protection against snowploughs and traffic signals must be applied at the crossing of the traffic lane over the expansion joint.

The design of the carriageway expansion joint must be coordinated with the responsible department of the company that maintains the road in terms of cleaning.

In the case of an expansion joint, a watertight sealing joint must be made on both sides. Any connection of installation channels in the area of the transition slab of the beams must be watertight.

For all the above mentioned reasons, an asphalt expansion joint is recommended for bridges on the local road network.

Table 2 shows the types of expansion joints.

Table 2 Overview of types of expansion joints depending on the calculated displacement and length of strain

	Type of expansion joint	**Approximate length of the strain of the object**	**Displacements in the expansion joint**			**Expansion joint materials**
			u (direction X)	**v (direction y)**	**w (direction z)**	
5.2	Expansion joint for minimal displacement (end of the carriageway)	up to 20 (30) m	20 mm [1] (± 10 mm)	5 mm [1]	5 mm [1]	steel end profiles and bituminous grout
5.3	Expansion joint for small displacements	up to 50 (70) m	50 mm (± 25 mm)	5 mm	1 mm [2]	polymerized bituminous mass, elastomeric filling, rubber, steel
5.4	Expansion joint for medium displacements	up to 150 m	150 mm (± 75 mm)	5 mm [3]	1 mm [3]	rubber seal, clamp profiles, steel anchors, anchor bolts, etc.
5.5	Expansion joint for large displacements[4]	up to 300 m	300 mm (± 150 mm)	5 mm [3]	1 mm [3]	rubber seal, steel anchors, steel load-bearing elements, steel combs, heavy slabs, elements made of synthetic materials, etc.
5.6	Expansion joints for very large displacements[4]	more than 300 m	≥ 300 mm (± 150 mm)	5 mm [3]	1 mm [3]	

[1] Displacements are approximate; they are secured with asphalt concrete wedges.

[2] The 1 mm limit applies to bituminous expansion joints (e.g. Thorma Joint). Construction without rubber seals is less sensitive to vertical displacements.

[3] The data are approximate as the displacement capacities in the "Y" direction for certain types of expansion joints differ greatly in relation to the specific features of the structure.

[4] Expansion joints for large and very large displacements are often water permeable. In such cases, safe drainage and access below the expansion joint must be provided.

As a measure of resistance to climatic changes, it is necessary to provide expansion joints adapted to extreme expansions at maximum temperature and number of consecutive hot days (heat wave).

6.8 Curb blocks

(Basis: SRDM 9.12.1 Curb blocks, curbs and sidewalks)

Curb blocks are placed on the edges of the bridge. A project without edge beams should be avoided.

It is recommended that the outer curbs be designed and anchored in such a way that a noise protection barrier of the prescribed height can be erected at any time. Bridges on K3 and K4 class roads are excluded from this.

The edge curbs are designed without expansion breaks. In order to reduce the impact of shrinkage, edge curbs are made as soon as possible, i.e. after the completion of the construction of the supporting structure.

6.9 Bearings

(Basis: EN 1337 parts 1 to 11; SRDM 9.12.5 Bearings)

In the case of shore pier and piers, one transverse fixed bearing should be designed. That bearing should be movable in the direction of the traffic movement, if possible in the direction of the carriageway axis, also taking into account expansion joints.
As far as the entire bridge is concerned, it is necessary to make a plan relocation of the bearing.

To replace the bearing, it is necessary to provide mounting plates for placing the press on the bearing beams and cross beams.

6.10 Retention systems

(Bases: GDLR Traffic Signs and Equipment; Technical Instruction for the Application of Vehicle Retention Systems on State Roads of the Republic of Serbia, March 2021, JPPS; SRDM 9.12.2 Fences)

Retention levels must be defined in accordance with applicable regulations.

6.11 Pedestrian-bicycle fences

(Bases: GDLR Traffic Signs and Equipment; Technical Instruction for the Application of Vehicle Retention Systems on State Roads of the Republic of Serbia, March 2021, JPPS; SRDM 9.12.2 Fences)

As a rule, installation is done from above on the edge beam. In exceptional cases, side mounting is possible.
If there is grounding on the bridge, the fences must be integrated into the grounding system. The grounding system must be designed by an authorized designer in accordance with applicable regulations. When attaching other components to the fence (splash guard, fall protection), appropriate protective measures must be taken to avoid corrosion damage.

6.12 Spray protection

In the zone of bridges over roads, and if necessary over watercourses (if specified in the LC), protection against splashes must be provided. Height: usually 1.00 m or up to 1.80 m as specified by the client or the competent water management company.

Installation rule: Inside the pedestrian fence.

6.13 Noise barriers on bridges and other engineering structures

(Basis: SRDM 9.12.2)

6.14 Grounding

As a rule, lightning protection systems and appropriate grounding are not required for road bridges.

If electrical or electronic components are installed in the bridge structure, it is necessary to install the grounding system in accordance with the applicable regulations. If bridges are in the zone of influence of electrified track systems, overhead lines of trolleybuses or high-voltage systems, further grounding measures may need to be planned and implemented.

6.15 Lighting

Local road lighting is generally not used. In case there is an explicit request for lighting on the bridge, then lighting is an important factor in the overall value and aesthetics of the bridge. With lighting, we strive to increase traffic safety and enable faster driving. At the same time, we strive to achieve the most uniform lighting with a suitable choice of light source, arrangement of lamps and height position of the light source with the greatest possible economy of installation. Lighting calculations rely on the illumination of the road in all weather conditions (dry weather, fog, rain). The lighting project is done by the competent electrical designers during the process of bridge designing.

It is necessary to harmonize the lighting with other parts of the bridge, especially when the lighting is placed on high pillars on the bridge or next to the bridge. This means that when choosing the longitudinal and transverse layout of the bridge, the position of the pillars must be chosen, i.e. the method of bridge lighting and the bridge approaches. The proposed lighting solutions for the bridge must to be harmonized with the local self-government.

7 INTEGRAL BRIDGES
(As information only)

7.1 Integral bridges

7.1.1 Introduction

Integral bridges, or as some call them robust bridges, are the result of the efforts of bridge builders to lower rising maintenance costs and increase the durability of bridges. In the case of integral bridges, the supports, the substructure and the superstructure of the bearing span are monolithically interconnected. Therefore, they do not have bearings and expansion joints. Displacements and rotations as a result of temperature fluctuations have an increased impact on the substrate and the embankment behind the shore (end) pier.

In static terms, the difference is that in integral bridges, deformations from temperature, shrinkage and flow are prevented, which is why parasitic forces (compression forces) are created in them, while in conventional bridges these deformations are enabled and no forces are created.

Semi-integral structures are rigid-frame structures that are not integral structures, and in which the piers are monolithically connected to the superstructure in at least two axes, and the bearings are arranged on other piers and supports.

Positive properties of integral bridges:

- Reduction of construction costs;
- Reduction of repair costs due to elimination of components that require intensive maintenance;
- Simplified and faster construction process thanks to the elimination of bearings and expansion joints;
- Monolithic connection of piers provides creative possibilities in terms of pier design;
- Greater driving comfort and lower noise emissions due to the elimination of vehicle crossings over the expansion joint;
- Avoiding direct access of thawing agents (salt) to structural parts below the carriageway;
- Compared to bridges with conventional girder connection, a larger centre span with shorter edge spans is possible;
- Bridges in horizontal curves are especially suitable for integral bridges. In them, forced changes in length turn into radial deformations.

Negative properties of integral bridges:

- Increased requirements for geological research and geotechnical interpretations and calculations;
- More complex calculations, taking into account the interaction between the bridge and the ground;
- Presence of planned parasitic static influences due to temperature changes, concrete rheology and prestressing;
- Requirement for a foundation that is not sensitive to subsidence with the required horizontal stiffness at the same time;
- Correction of design and construction errors is more difficult;
- Not recommended for inclined bridges, where there is significant subsidence or displacement of the ground, in weak bearing soil where the piles carry friction, because due to cyclic displacement their bearing capacity is not reliable.
- They are extremely sensitive to all the consequences of climate change, such as the increase in maximum temperatures, the length of heat waves and subsoil erosion due to extreme rainfall.

7.1.2 Specific features of integral bridges

(1) In case of the integral bridges, geotechnical action is considered not only as an effect on the bridge system in terms of EN 1990, but also a component of the static system and flows into the static system with soil properties as a building material.

(2) In case of the integral and semi-integral structures, load-bearing capacity, including fatigue and usability, must be verified by way of design approaches that comprehensively and realistically demonstrate the interaction between the structure and the ground. Access to "unfavourable" soil properties, which are usually given in the geotechnical report for non-integral structures, is not sufficient, as it is not necessarily on the safety side.

(3) In the case of integral and semi-integral structures, unequal vertical subsidence and rotation caused by parasitic influences may be decisive for the feasibility of this method of construction.

(4) The design planning should take into account the construction procedure, constructive and chronological order of construction of the object and backfilling.

7.1.3 Geotechnical report

(1) Integral and semi-integral structures determine the type and scope of soil research. A geotechnical expert must therefore be involved at an early stage.

(2) In order to ensure the realistic recording of the layers and properties of the soil, it is necessary to perform soil research tailored to the integral or semi-integral method of construction. The results are summarized in a geotechnical study.

Deformations due to the action of temperature and shrinkage of concrete are prevented and forces are created in the span structure and soil, which significantly affect the construction of these bridges.

7.1.4 Bases for designing the integral bridges

7.1.4.1 General

(1) If the shore pier is inclined towards the axis of the structure <80 gon, the system must be spatially modelled and calculated.

(2) Special provisions are required if significant parts of the embankment from the shore pier can be temporarily removed during its working life, e.g. for laying lines at greater depths. These provisions should be noted in the construction log and technical conditions.

7.1.4.2 Influence on parasitic (forced internal compressive forces)

The geometry of the bridge, the method of construction and the conditions of the foundation determine the size of the parasitic forces in the frame structures.

Internal forces are essentially caused by temperature loads, prestressing, flow and shrinkage. Some of the constructive parameters that affect the magnitude of internal compressive forces are:

<u>Prestressing time</u>

In terms of internal forces, bridges with prestressed concrete elements have advantages over prestressed concrete bridges on site, because the elastic part of the prestressing and the part of flow and shrinkage do not affect the whole system. The dissipation of the prestressing force into the ground must be tested statically.

<u>The base of the bridge</u>

Integral bridges in curves react more favourably to the influence of temperature and shrinkage of concrete compared to bridges in one straight direction, which is why integral structures can be applied to bridges in curves of greater length. Basically, curved bridges have a horizontal deformation so that they are less affected by forces due to changes in temperature and rheology of concrete. The change in the length of the bridge in the curve next to the shore piers occurs along the entire length of the bridge.

Choice of cross sections of piers

The shape of the cross-sections of the piers can significantly affect the internal forces in multi-span semi-integral bridges. Thin, flexible piers reduce internal compressive forces.

Notes on pier sizing

During the pier sizing, two competing tasks must be solved. By reducing the thickness of the pier, a lower bending stiffness can be achieved, which has a favourable effect on parasitic forces.

However, reducing the thickness of the pier can lead to high levels of reinforcement. For this reason, the feasibility must be checked by showing in detail the reinforcement, overlap and, if any, penetration with the prestressed cables of the superstructure.

Stiffness of the foundation

Parasitic forces can be reduced by choosing the right substrate. Foundations with one row of piles are more favourable than a group of piles or shallow foundations.

Shore pier construction:

The constructive design of the shore pier has a significant impact on parasitic forces in integral structures. With short hanging flanks or separating the flanks from the wall of the shore pier, the compressive forces are significantly reduced. On the other hand, box-shaped shore piers increase parasitic forces.

Coastal pillars with low height significantly reduce parasitic stresses.

The dimensions of the shore piers are determined by the allowable bearing pressure of the ground.

Order of construction:

Parasitic influences can be controlled by choosing the appropriate order of construction. Thus, for example, by changing fixed points, pre-deformations and backfill times, parasitic influences are reduced.

Reducing the impact in the load-bearing structure by applying classical prestressing on site is in general economically unjustified.

7.2 Crossings from the bridge to the road

In the case of integral structures, the embankment behind the shore pier suffers both negative and positive wall displacements depending on the corresponding temperature change.

Despite the compressive force, integral structures generally show approximately the same changes in length due to temperature effects as conventional bridges. Periodic repetition of movements as a result of temperature fluctuations causes progressive compacting of the embankment. Possible consequences are the subsidence of the embankment.

The size of the displacement of the shore pier that must be compensated in the embankment determines the type of crossing from the structure to the road. For this, the total displacement at the appropriate end of the structure with characteristic values must first be determined.

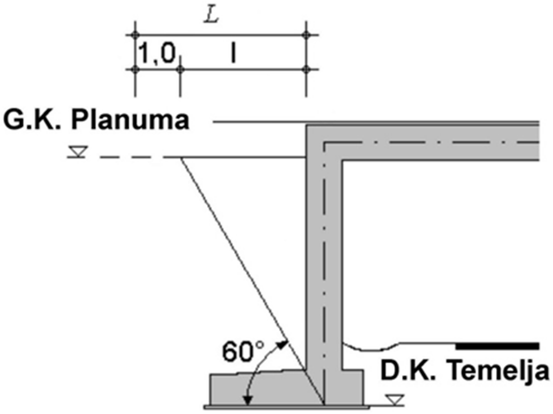


Figure 8 Method of length determination of the transition plate

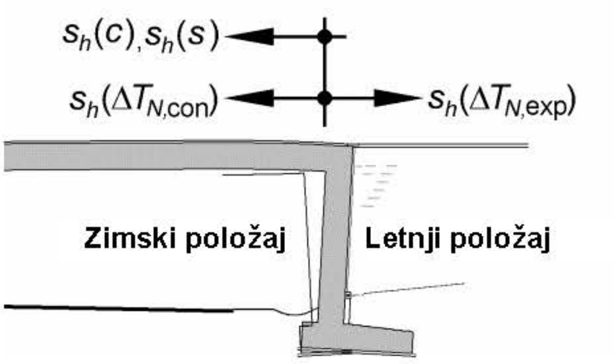


Figure 9 Displacements of the integral structure during the winter and summer periods

The length L of the transition slab can be determined according to Figure 9. However, the length should be at least 3.50 m. The recommended minimum thickness of the transition slab is 40 cm for the transition slabs with constant thickness and 30 cm for the transition slabs with variable thickness. At its top, the transition slab must be tilted by at least 3% in the longitudinal direction from the object. The transition slab should be dimensioned as a self-supporting slab with 2/3 L stretched in the longitudinal direction of the bridge.

The exposure class, the class of concrete requirements of the transition slabs is chosen as for the foundations and the strength of the concrete is chosen as for the shore piers.

Inserts that are not sensitive to moisture are used at the joint between the transition slab and the wing (e.g. hard foam inserts).

As with conventional bridges, the transition slab must also meet the following requirements for integral bridges:

- Compensation for subsidence behind the shore pier;
- Compensation for differences in stiffness between the carriageway and the bridge structure;
- Drainage of collected water, away from the shore pier.

In addition, the following requirements are set regarding the integral structure of the bridge:

- Reducing or transferring the changes in the superstructure length to the pavement structure in order to avoid the appearance of large cracks in the carriageway.

It is generally recommended that the transition slab should be monolithically connected to the frame structure, but not rigidly. It is also generally recommended that the waterproofing should be placed over the entire structure to prevent water leakage.

7.2.1 Transition slab for integral bridges as per German regulations

(Basis: Richtlinienfürden Entwurf, die konstruktive Ausbildung und AusstattungvonIngenieurbauten, Teil 2 Brücken, Abschnitt 5 Integrale Bauwerke, RE-ING, 2016)

The German standard proposes different types of transition slabs according to the length of the bridge, the extension, the type of construction and the category of traffic (Table 3). It is not necessary for smaller bridges to have transition slabs.

Table 3 Types of transition slab depending on displacement, type of supporting structure and length of the symmetrical bridge

Transition slab type	Elongation [mm]	Bridge length for symmetrical structures [m]		
		Prestressed concrete	Reinforced concrete	Composite (steel - concrete)
Type I	≤ 25	≤ 50	≤ 60	≤ 65
Type II	≤ 37,5	≤ 50	≤ 60	≤ 50
Type III	≤ 65	≤ 95	≤ 115	≤ 130

The type I transition slab is connected to the shore pier with a hinge by means of cross reinforcement (Figure 11).

In type II, an asphalt plug is placed between the joint of the shore pier and the transition slab, while the transition slab is still connected to the shore pier (Figure 12).

Type III uses expansion joint equipment built into the concrete between the corner of the shore pier and the transition slab. In this case, the transition slab is separated from the shore pier by placing a sliding material between two concrete surfaces (Figure 13).

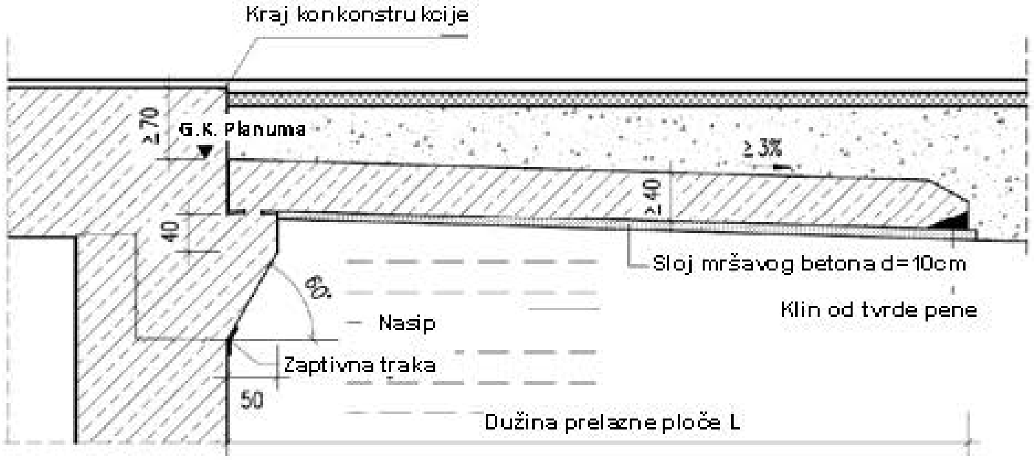


Figure 10 Transition slab Type I from German regulations

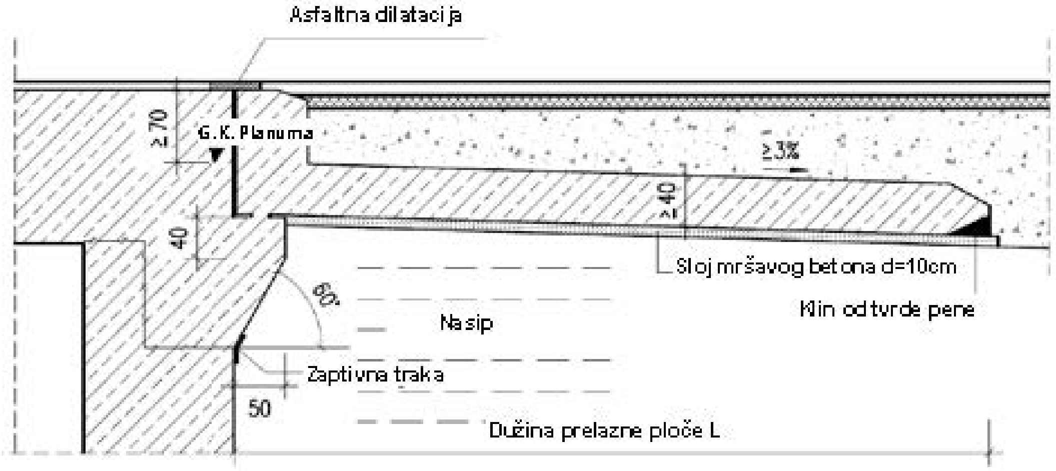


Figure 11 Transition slab Type II from German regulations

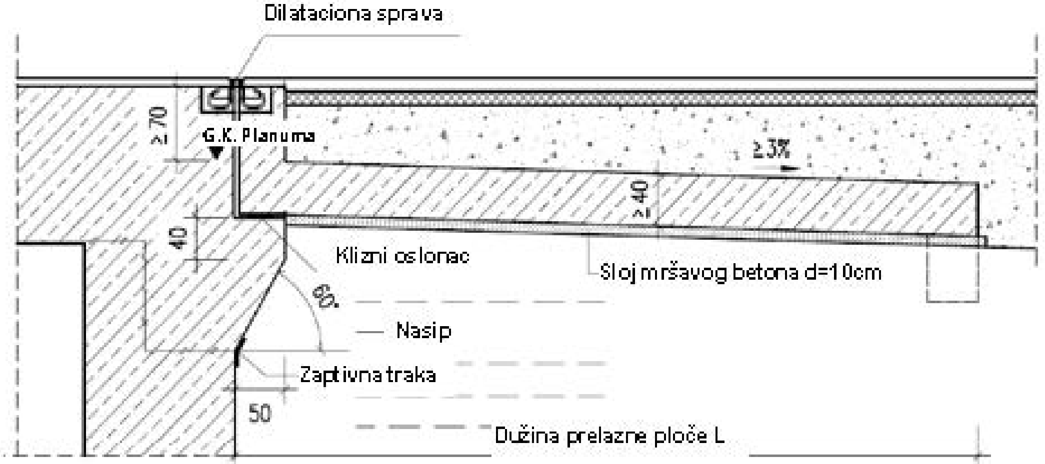


Figure 12 Transition slab Type III from German regulations

7.2.2 Expansion joints within integral bridges

Depending on the type of carriageway on the bridge and the road, it is necessary to make an appropriate bridge-road crossing that will satisfy the allowed stresses, driving comfort and endurance. The ends of the bridge move due to the action of temperature and humidity, so additional stresses occur in the carriageway. The carriageway on the bridges usually consists of an insulating layer, a protective layer and a wearing layer of bituminous concrete or cast asphalt. The road structure usually consists of a wearing layer, upper and lower bearing layers. The upper bearing layers usually consist of bituminous mixtures, and the lower bearing layers of hydraulically stabilized mixtures or unbound stone mixtures. The pavement structure of the road can also be made of concrete, which is less common. Due to the connection of the protective and insulating layers with the supporting layer, the pavement of the bridge must be accompanied by deformations of the span structure. Classical expansion joints of the carriageway (steel or neoprene) between the paving at the ends of the bridge can be omitted for integral bridges if the paving of the road structure can withstand additional forces from the movement of the bridge. Elongations of the span structure must be compensated in the bridge-road crossing (i.e. the carriageway), in order to avoid wide cracks or bumps. Behaviour at the contact of the paving and the bridge structure is important for the stress calculation. Assuming that there is a full joint between the paving and the extremely rigid base and in the case of the base displacement, a stress concentration occurs and regardless of its highly elastic characteristics, the paving breaks even with small changes in length.

In reality, there is an elastic coupling with friction, and the limit conditions in practice are between the limit values of rigid and elastic coupling. The area of the bituminous pavement that is activated to cope with the changes in length increases if the forces of coercion from the structure, which occur until the tensile strength of the pavement is achieved, locally overcome the friction. Asphalt has a complex deformation behaviour that contains elastic, plastic and viscous deformations and the same is significantly dependent on temperature and load length, i.e. load frequency. For short-term operations, the behaviour of the asphalt is approximately elastic, and for long-term operation, viscoelastic. First of all, plastic deformations occur with large changes in load, and the ruts are formed; and in the case of a change in wavelength, cracks or fissures appear.

Expansion of the span structure during the summer period usually causes low stresses, because asphalt has the ability to relax, still waves can form. When shortening the span during the winter period at low temperatures, the elasticity of asphalt decreases due to low temperatures, therefore its strain ability is reduced, so that the cracks occur if the tensile stress is exceeded. Although according to theoretical and experimental results, bituminous pavement can compensate for the strain of the bridge structure with smaller spans in most cases, it is necessary to perform a calculation check in relation to the allowed strain in the asphalt layer at critical temperatures; assuming that a decrease in flexibility will occur due to the oxidation of the binder.

Asphalt expansion joints or elasto-bituminous expansion joints are produced from polymerized bitumen with increased elastic properties (Figure 14). They are installed in the asphalt pavement so that they become an integral part of the road. Fastening is provided by gluing the expansion joint mass on the lower side to the concrete base, and on the sides the mass is glued to the asphalt-concrete layers. Asphalt expansion joints are also recommended for shore piers with fixed bearings and at the places of joints (bearings).

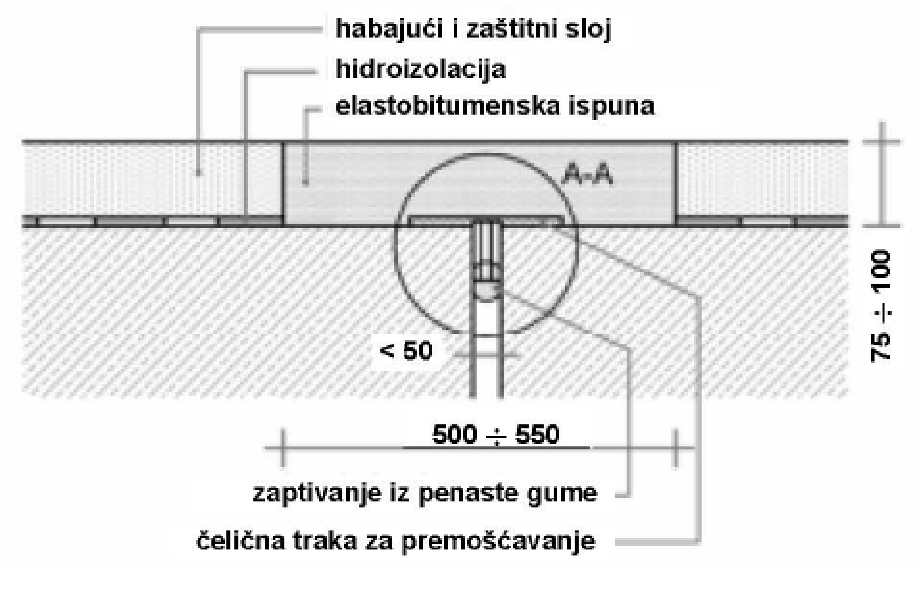


Figure 13 Detail of the asphalt expansion joint

8 Engineering structures

(Basis: SRDM 10. Design of engineering structures 1-6)

Engineering works include, but are not limited to:

- Securing the foundation pit for buried structures or foundations
- Slope protection
- Landslide stabilization

On the local road network, the supporting structures are the most common engineering structures.

8.1 Supporting structures

8.1.1 Purpose of supporting structures

Supporting structures serve for lateral support of the ground, and their main role is to prevent the collapse of a steep notch of the terrain or road embankment material. On the roads, the supporting structures can be independent or part of a building. These structures are used to permanently or temporarily support the mass of earth or other material that could not ensure their natural slope. The cost of their construction is significantly higher than if the embankment is made in its natural slope. Such structures can be made of different materials, different static systems and for different purposes. Their structure secures the slopes of the terrain and creates free spaces for the construction of roads or serves as a secure structure for the regulation of watercourses.

By building supporting structures, we achieve and ensure the stability of the height difference between the two levels of the terrain. The embankments in front of the bridges, which provide access to the bridges, end with supporting structures on which the load-bearing structure of the bridge rests, so we call these supporting structures the shore piers of the bridge.

Supporting structures that represent an integral part of the construction pit can be temporary or permanent, depending on a way that fit into the structural system of the future object (e.g. in the case of culverts or underpasses).

Construction pits in case of small excavations can be protected with different types of formwork that are supported by sprags. However, for deeper and more complex types of construction pits, especially when it comes to limited space in cities, we use diaphragms, rows of piles, jet grouting and the like.

Very complex supporting structures are those in which the excavation and foundation are located deep below the groundwater level. These supporting structures are, among other loads, loaded with significant hydrostatic pressure, so that the protection of such construction pits is mainly done with the help of reinforced concrete diaphragms, coffer dams or caissons.

Supporting structures also include various types of coffer dams that are mainly loaded with hydrostatic pressure, i.e. they bear the pressure of groundwater from which they protect the construction pit.

All supporting structures suffer from loads originationg from earth, water or other material or some static or dynamic loads, which are located behind the supporting structure. Special attention should be paid to the measures which are used to drain the water behind the supporting structure, because the hydrostatic pressure creates a large horizontal load. For these reasons, a filter layer and drainage are carried out behind the supporting structure, which will drain the water behind the supporting structure and thus reduce the influence of the hydrostatic pressure force.

According to the method of construction, supporting structures can be divided into:

- Backfilled (these structures are backfilled after their construction and their construction requires free and the soil that does not press on them)
- Built-in (no special space is required because they are built into the ground using special technology either before or during excavation of the ground around them)
- Special

Backfilled supporting structures include massive load-bearing or gravity walls, reinforced concrete L- and T-shaped walls, various types of prefabricated walls, gabions and reinforced ground structures.

Built-in supporting structures are walls made of broken sheet piles, reinforced concrete diaphragms or continuous walls made of broken or drilled piles. No free space is required for their execution (except for the necessary mechanization). For the construction of roads, they can be used in all engineering works, near existing roads or objects, below the water level.

All supporting structures are extremely sensitive to all the consequences of climate change, such as subsoil erosion due to extreme precipitation.

8.2 Backfill support structures

The load-bearing wall represents a building that is located in the group of backfill support structures and its structural capacity carries the load of the ground, i.e. it represents a building that serves to overcome height differences on the surface of the terrain. The load-bearing wall supports vertical or steep cuts of the terrain or some loose material, so the surface of that material behind the wall is at a higher elevation than the elevation in front of the wall. Depending on the type of foundation ground, they can be based on shallow foundations or piles.

Load-bearing walls form parts of many road structures:

- Flanks of the bridge shore piles
- As a means of protecting the tunnel entrances
- Buildings that are built in notches or cuts
- As a means of protecting the embankment foot

Typical backfill walls: mass gravity concrete wall, reinforced concrete T-shaped wall, reinforced concrete L-shaped walls, and gabion wall. For the construction of these walls, it is necessary to free up the space where they can be built without hindrance, so that after the completion of the construction, the space behind the wall is covered with some suitable or convenient earth material.

Load-bearing walls are used on the roads, which can be constructed as rigid single units, such as gravity concrete walls, reinforced concrete walls with or without buttresses.

Also, flexible structures made of special elements are used, such as gabion elements, prefabricated concrete elements or reinforced earth elements.

8.3 Mass gravity wall

Mass gravity wall represents the simplest type of wall. It was named after the cause of its stability, which is the weight of the wall itself. In the past, such walls were made of stone or brick, but today they are usually made of unreinforced concrete.

8.4 Gabion gravity wall

Gabion gravity walls represent a special type of gravity walls that are often used on the road network. They are built by stacking gabions (square boxes), usually measuring 1 x 1 x 2 m, made of braided nets of galvanized, and sometimes plastic-coated, steel wire. The box, as a finished element, is stacked on the spot and filled with appropriate broken or convenient stone. This type of wall is very suitable, because it ensures good drainage of the ground behind the wall, and its flexibility allows application in soils that have unequal stiffness that can cause problems with rigid walls.

Empty boxes are placed at the site of wall formation and in the horizontal direction, so that the vertical joint of one row is in the middle of the gabion of the second row. Its height can be arranged by stacking the boxes one above the other or in horizontal rows,and as they climb upwards, they are stacked away from the edge of the previous gabion row (Figure 15).

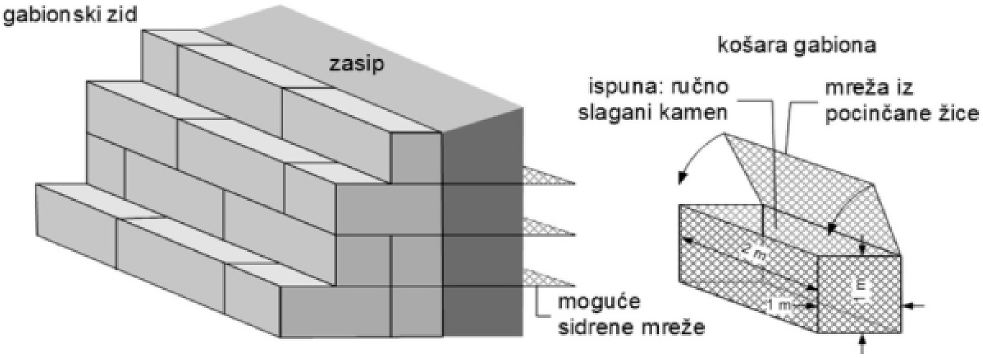


Figure 14 Gabion wall

The gabion wall works as soon as it is built, so it is suitable for quick stabilization of small landslides and road cuts. Since they are water-permeable, a geotextile filter is placed behind the wall to prevent leaching of particles from their back side. To obtain a higher wall height, it is possible to install anchor nets, which receive part of the pressure from the wall.

The negative side of their construction is that filling with stone requires a lot of manual work, which is becoming more and more expensive today. The durability of such walls is also questionable. For this reason, the steel wire used must be protected as well as possible so that it does not corrode over time and wall loses its stability.

8.5 Walls of prefabricated elements

Walls made of prefabricated elements represent very suitable systems for construction because, in principle, they are made without the use of fresh concrete by the method of dry construction.

Prefabricated elements are made industrially, and can be cross beams, elements from concrete blocks, prefabricated concrete slabs.

The main advantage of such walls is that their construction is simple with the use of light machinery, in almost all weather conditions, and thus the cost of construction is reduced.

Considerable flexibility gives them a variety of options when it comes to aesthetics.

8.5.1 Prefabricated reinforced concrete beams

Prefabricated reinforced concrete beams form a spatial structure (grill), which is filled with crushed stone or gravel. In this way, sufficient weight is achieved to receive ground pressures and water permeability, which makes good back side drainage.

The dimensions of these elements are up to 2m. The height of the wall can be up to 10m (Figure 16).

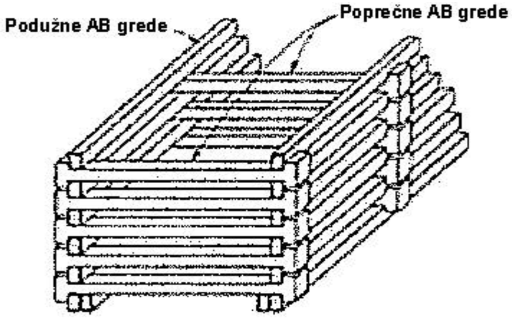


Figure 15 Prefabricated reinforced concrete beams

8.6 Reinforced earth walls

Reinforced earth load-bearing walls consist of or without outer cladding and reinforcement that is installed in the backfill behind the cladding. The load transfer from the reinforcing to the ground is achieved by friction at the place of their contact (Figure 17).

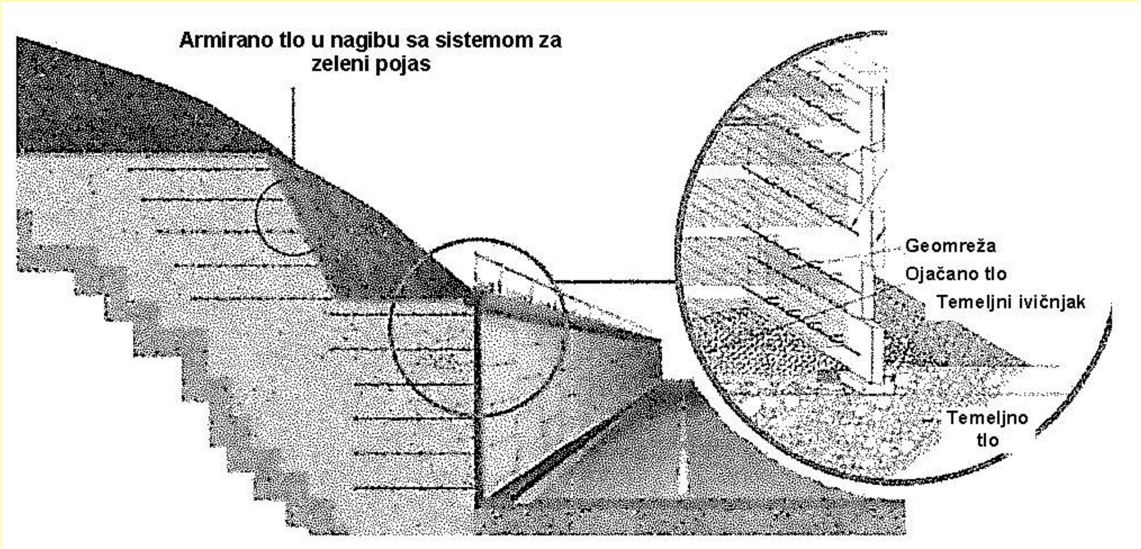


Figure 16 Method of making the reinforced earth walls

For the material that is filled behind the cladding, natural incoherent material is most often used. The material content must be carried out and controolled as according to the defined manufacturer's prescriptions all the time during the construction phase (Figure 18).

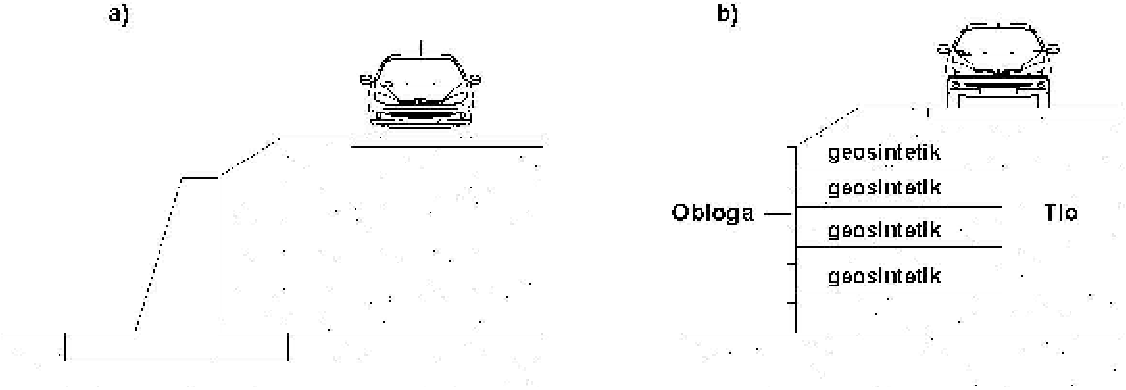


Figure 17 Support structures: a) concrete support wall b) reinforced ground

8.7 Built-in supporting structures

The built-in supporting structures are characterized by the fact that their construction does not require the ground to be dug out beforehand and later buried behind the finished wall, but they are performed directly into the ground by means of special technologies. Such structures can also be performed in circumstances that are unfavourable for gravity walls, for example in the immediate vicinity of existing buildings or in case of the construction in water and the like. Built-in supporting structures are usually built in such a way that either prefabricated elements are driven into the ground with special machines or trenches are made, again with special machines, in which reinforcement is installed first, and then fresh concrete is poured. The first group includes walls made of nailed steel sheet piles, and the second group includes reinforced concrete diaphragms and a wall made of piles.

9 Design of supporting structures according to EC7

(Bases: SRPS EN 1990-1998 and SRDM 10)

Eurocod 7 (EC 7) consists of two parts:

1) EN 1997-1 Geotechnical Design - Part 1, General Rules

2) EN 1997-2 Geotechnical Design - Part 2, Soil Research and Testing.

The following limit states must be taken into consideration when designing all types of supporting structures:

loss of general stability

- fracture of the supporting structure itself, such as a wall, anchor, connecting beam or gap, or fracture of the joint between these parts;
- simultaneous breakdown in the foundation soil and bearing component;
- fracture caused by hydraulic lifting of the soil and erosion (leaching);
- displacement of the supporting structure, which may cause collapse or otherwie affect the appearance or effective use of the structure or adjacent structures or installations that rest on it;
- unacceptable leakage through or under the wall;
- unacceptable leaching of soil particles through or under the wall;
- unacceptable change in groundwater levels.

In case of the massive gravity walls and complex supporting structures, the following limit conditions have also to be considered:

- loss of soil bearing capacity under the supporting structure
- breakage by sliding along the base joint
- breakage due to overturning

For flexible load-bearing walls, the following should also be considered:

- fracture as a consequence of displacement (translatory motion) of the load-bearing wall
- fracture as a consequence of insufficient balance in the vertical direction

For all types of supporting structures, if relevant, combinations of the above limit conditions must be taken into account.

EN 1997 should be used in conjunction with EN 1990: 2002 which sets out usability and safety requirements, and provides guidelines for structural reliability and design basis. For each projected geotechnical condition, it must be proven by calculation that certain limit conditions do not occur according to the provisions of EN 1992.

Also, EC 7 refers to the requirements regarding the strength, stability and durability of geotechnical structures. Since EN 1997 is used in conjunction with EN 1990: 2002, assumptions based on the EN 1990: 2002 standard have been introduced, as follows:

- the necessary design data are obtained and interpreted only by experts of appropriate qualification,
- designers are persons with the necessary experience and appropriate qualifications,
- supervision and quality control of performed works in the field and in laboratories and workshops are carried out only by qualified professionals,
- building materials and equipment used must be in compliance with the provisions of EN rules or with the provisions of the appropriate standard for building materials,
- the maintenance of the geotechnical structure must be carried out in order to ensure its usability during its planned service life.

According to EC 7, the following definitions of necessary terms related to the design, construction and maintenance of geotechnical structures are provided:

a) **Geotechnical action,** i.e. the influence of soil, embankment, still water (hydrostatic load) and groundwater, and which are transferred to the geotechnical structure.

b) **Construction soil** is ground, rock or embankment that is located on the site before the beginning of construction works on the geotechnical structure.

c) **Comparative experience** represents the established information related to the construction soil that we consider in the project and which includes the same types of rocks and soils for which similar geotechnical behaviour is expected, in interaction with similar geotechnical structures.

d) **Geotechnical structure** represents a system of parts assembled as a whole, including the embankment that is installed during the construction of the structure itself, and which is designed so that it can absorb the loads acting on it.

e) **Resistance** represents the possibility of cross-section of a geotechnical structure (or one of its parts) to accept and withstand without fractures its bending, tension, or buckling strength and the like.

When designing geotechnical structures, each designed geotechnical condition must be verified so that certain limit conditions do not occur in accordance with the provisions of EN 1990: 2002. When determining the projected geotechnical conditions as well as the limit conditions, we must take into account the relevant influences and factors, such as:

- size of geotechnical structure,
- necessary environmental conditions such as infrastructure, occurrence of hazardous chemicals, etc.,
- condition and level of groundwater,
- seismicity of the location where the geotechnical structure is being built or is already located,
- local influences such as surface waters, changes in air temperature and humidity at the site of construction of the geotechnical structure, hydrological parameters, possible occurrence of soil subsidence.

In general, certain limit conditions can occur in the soil itself, in a geotechnical structure, or as a fracture state in both soil and geotechnical structure. Limit conditions should be determined by calculations, based on experimental modeling and the application of monitoring. In geotechnical practice, it is mostly determined on the basis of experience which type of limit condition will be relevant for design.

For geotechnical structures of low complexity and lower risk, including earthworks, simplified design procedures are also allowed.