GUIDELINES FOR ROAD DESIGN, CONSTRUCTION, MAINTENANCE AND SUPERVISION

Volume I: DESIGNING

Section 3: DESIGNING STRUCTURES

DESIGN GUIDELINES (DG 1.3.5)

Part 5: CUT-AND-COVERS AND GALLERIES

INTRODUCTION

Cut-and-covers and galleries are reinforced concrete civil engineering structures intended to protect the road body in deep cuts, which are backfilled after completion of the structure, or to protect the road body in natural or artificial cut-and-fills.

Such structures are designed and constructed in cuts measuring 10 – 30 m in depth, where the cuts for the road body are either independent structures or pre-cuts at tunnel entries of gentle slope. A reason to foresee a cut-and-cover can also be a poor geological composition of the soil, a difficult and expensive establishing the cut slope stability, or a costly maintenance. Deep cuts require a wide zone of the terrain and represent an artificial deep obstacle for natural migration of humans and animals in such an area. Therefore, deep cuts can be considered as a brutal intervention in the natural environment.

At tunnel entries with gentle slope in geologically poor ground, deep cut-and-covers make possible to achieve an overlay of sufficient thickness above the tunnel arch, thus allowing, in dependence on the geological soil composition, the excavation for the tunnel and the casting of the lining in accordance with the approved methods of tunnel construction.

Galleries are civil engineering structures ensuring protection of both traffic and road body from being covered with the material arising from either natural or artificial slopes, or with the snow in mountainous regions. The outer surface of galleries is completely or partly opened for the natural illumination and ventilation, as well as for better service conditions.

C O N T E N T S

1 SUBJECT OF DESIGN GUIDELINES

The present guideline is intended for the participants in planning, designing, and maintaining both roads and civil engineering structures on roads.

The goal of the present guideline is to analyse and point out the morphological and geological characteristics of the ground, the conditions of protecting the natural environment, humans, and animals, as well as the methods of securing stability of the road body and protecting the road traffic.

Cut-and-covers and galleries are relatively new structures foreseen particularly on roads of higher ranking, which are constructed in hilly or mountainous regions.

There are no textbooks, manuals, or guidelines available, which would integrally deal with the subject of this guideline. Therefore, the guideline for structures in open cuts and galleries is based on the past experience and knowledge in the field of the structural design in Slovenia, as well as on certain information published in professional reviews.

Section 4 Conception and Design of Cut-and-Covers and Galleries provides a classification of these structures in five groups, as well as adequate design lines.

In section 5 examples of specific reinforced concrete structures at tunnel portals in difficult and specific geological / geo-morphological conditions are discussed.

In section 6 lines for designing and constructing short tunnels with insufficient overlay thicknesses are provided. Tunnels executed in deep cuts and backfilled with the excavated material are in question.

In section 7 lines for reinforced concrete structures in shallow cuts are dealt with, which might have multiple functions such as protection of environment, passages below existing traffic surfaces, etc.

Section 8 provides examples of partial or complete covers to deep cuts including some lines for both design and construction.

Section 9 deals with structures - galleries for protection of both traffic and road body from being covered with the material arising from either natural or artificial slopes.

The construction of civil engineering structures in open excavations and of galleries is characterized by certain specificities, which arte discussed in the present guideline.

The supervision during construction and the inspection during maintenance of these structures resemble to the bridges and other civil engineering structures. Consequently, they are not specially dealt with in the present guideline.

2 REFERENCE REGULATIONS

Both design and construction of reinforced concrete cut-and-covers and galleries is based on different rulebooks, regulations, and standards, similar to reinforced concrete bridges and other civil engineering structures:

- Rulebook of technical norms for assessment of magnitude of loads on bridges dated 04.01.1991;
- Rulebook of technical norms for foundation of structures, Official Gazette of SFR Yugoslavia No. 15-295/90;
- Rulebook of technical norms for concrete and reinforced concrete made of natural and artificial lightweight aggregate filler, Official Gazette of SFR Yugoslavia No. 15-296/90;
- Rulebook of technical norms for designing, production, and construction of structures of prefabricated non-reinforced and reinforced concrete elements, Official Gazette of SFR Yugoslavia No. 14-146/89;
- Rulebook of Yugoslav standards for timber structures, Official Gazette of SFR Yugoslavia No. 48-497/84;
- Rulebook of technical norms for steel wires and strands for prestressing the structures, Official Gazettes of SFR Yugoslavia No. 41-530/85 and No. 21-276/88;
- Rulebook of Yugoslav standards for structural design bases, Official Gazette of SFR Yugoslavia No. 49-667/88;
- EN 1990:2002 Eurocode 0 Basis of design;
- prEN 1991 Eurocode 1 Actions on structures;
- prEN 1992 Eurocode 2 Design of concrete structures;
- prEN 1997 Eurocode 7 Geotechnical design;
- EN 1537:2002 Execution of special geotechnical work – Ground anchors;
- EN 206-1:2003 Concrete - Part 1 Specification, properties, production, and conformity;

- Design guideline 1.2.1 General guideline for structures on roads (bridges);
- Design guideline 1.2.9 Joints in concrete bridges and structures;
- Design guideline 1.3.1 Deep foundation on bored piles and on wells;
- Design guideline 1.3.3 Gravity walls;
- Design guideline 1.3.4 Anchored retaining and supporting walls.

3 EXPLANATION OF TERMS

Cut-and-covers are civil engineering structures intended for protection of road bodies in cuts, which are backfilled with the material won from the excavation.

Galleries are civil engineering structures intended for protection of road bodies and traffic from being covered with material or snow arising from natural or artificial slopes of cuts.

Tunnels are closed structures allowing a road to pass through a hill. They are executed by excavation within the tunnel pipe.

Portals are entries to and exits from the abovementioned structures. They are designed according to the morphological – geological site conditions as well as to the conditions of the transition of the road to the structure.

Deep cut is a cut for the road body deeper than 10 m in natural level or inclined ground, from above downwards, with simultaneous protection.

Backfill on lateral sides and above the upper slab or arch of a reinforced concrete structure executed in a cut is soil or stone material excavated in the cut, which is used for backfilling in layers to be adequately compacted.

Drainage of a structure is the evacuation of the surface water, of ground water, as well as dewatering of the carriageway surface.

Protection of slopes of a cut are all technical measures intended for ensuring natural stability of the slopes of a cut up to the completion of the structure and backfilling of the latter.

Segment is a portion of the structure between adjacent construction or expansion joints.

4 CONCEPTION AND DESIGN OF CUT-AND-COVERS AND GALLERIES

4.1 Introduction

The reasons in favour of designing and constructing cut-and-covers or galleries can be classified in five groups:
- Where tunnel entries (portals) are located on gentle slopes in poor geological conditions, special design solutions are required to ensure structurally and technologically reliable construction.
- Construction of short tunnels with insufficient overlay height might be more economical, if the cut excavation method is introduced, followed by the construction of one or two tunnel pipes, and, finally, by backfilling the pipe(s) with the material won upon excavation.
- Construction of reinforced concrete structures in relatively shallow cuts with the goal to minimize the impact on or to prevent the cutting-off of the urbanized or natural (rural) ambient.
- Covering the portions of deep cuts and construction or reinforced concrete structures with material laid-on. The aim of this solution is to reduce consequences of the ground interruption, and to allow continuity of the nature as well as to enable movement of both humans and animals.
- For the protection of the road body and of the traffic on the road from active or potential covering with the material arising from natural or artificial slopes of cut-and-fills, specific reinforced concrete or steel structures called galleries are planned, designed, and executed.

4.2 Bases for Designing Cut-and-Covers and Galleries

Similarly to bridges, the bases for designing cut-and-covers and galleries are integrity of geodesic, geological – soil mechanical, hydrological, water economy, road, traffic, meteorological, spatial, and town planning data for the entire influence area of the particular structure. In addition, bases for the protection of natural or urbanized ambient are required as well.

Geological – soil mechanical bases, which are discussed in special guidelines, are of particular importance to the design of cut-and-covers and galleries.

Prior to commencement of the design, the investor shall work out adequate terms of reference comprising all the available information, geotechnical categories, the information to be acquired by the designer, and other conditions required for structural design and execution.

Suitability, reliability, and economy of a design solution directly depend on the knowledge, experience, and ability of the designer, on the accuracy and comprehension of the field data. Such data can only be acquired by authorized experts permanently cooperating with the designer, who shall be well experienced in all the abovementioned interdisciplinary domains, especially in the fields of geology, soil mechanics, and civil engineering structures.

The bases for design are presented in detail in section 4 of the DG 1.2.1 General guideline for designing structures on roads (bridges).

4.3 Geotechnical Categories of Construction Sites

The geotechnical category of a construction site is of substantial importance when specifying the extent of investigations, assessing adequacy of the structure and the foreseen construction technology, estimating the costs, appointing the designer, and selecting the contractor. The geotechnical category depends on the degree of risk during execution of the works, on the type of soil, as well as on faults upon design and construction.

The geotechnical category shall be specified prior to commencement of the design. In the next stages of the implementation of the planned structure it may alter by no more than one category.

Eurocode 7 Geotechnical Design foresees the following geotechnical categories:

4.3.1 Geotechnical Category 1

To the geotechnical category 1 minor and simple structures, where the excavations in shallow stable cuts do not jeopardize the stability of the slopes in terms of additional deformations and exceeding of limit states of nearby structures, infrastructure, phenomena of a global instability of slopes, etc.

A classification of structures in the geotechnical category 1 is only permitted when for the actual foundation ground comparable and documented experiences exist proving that the required procedures of designing and constructing are sufficiently simple to allow an introduction of empirical methods.

Excavations of cuts as well as structures in the zones of active, resting and potential landslides must not be classified in this category.

4.3.2 Geotechnical Category 2

To this category such structures belong, which do not represent an unusually high risk as well as extremely unfavourable geotechnical conditions and load cases.

Structures of the geotechnical category 2 require precisely determined qualitative and quantitative data and results of geo-mechanical analyses. To classify these specific structures in a higher geotechnical category, geotechnical reasons usually prevail over the constructional ones.

To this category, cut-and-covers of 15-20 m depth belong, with or without anchors, in flat land or slope locations, without explicit discontinuities, where no active, resting as well as fossil and potential landslides of greater dimensions or depths above 5 m are noticed. To the stability and limit state verification, standard methods and computer software are applicable.

4.3.3 Geotechnical Category 3

To the geotechnical category 3 structures of extremely high risk and with special requirements belong. This category is characterized by very severe ground and geo-mechanical conditions.

When classifying the structures into the category 3 the following shall be taken into consideration:

- risks related to public safety;
- risks related to severe economic consequences;
- considerable risks due to reduced reliability of geo-mechanical design data;
- risks related to the reliability of the design solution, when the structural reliability depends on the function of drainage systems or when the reliability of the solution cannot be verified by geo-mechanical analyses and calculations, etc.;

- risks due to a very high degree of seismic hazard.

Structures of the category 3 differ from those of categories 1 and 2 in the extent, quantity, and quality of investigations, as well as in the adopted methods of geotechnical analyses such as non-linear and time dependent analytical models, as well as construction monitoring including execution of measures prescribed in advance.

For structures belonging to the highest geotechnical category, monitoring of both structure and ground in the influence area shall be provided during the construction as well as after completion of the works.

4.4 Cut-and-Cover and Gallery Design

The investor, in cooperation with the designer, shall plan, work out, and interpret the bases for individual design stages. In dependence on the nature of the planned structure, special attention should be paid to the geological – soil mechanical bases.

Same as in bridges, the design documents for cut-and-covers and galleries comprise the following:
- conceptual design
- preliminary design
- building permit design
- tender design
- execution design.

In the conceptual design, essential layout characteristics of the intended structure in several alternatives are defined.

A preliminary design includes basic drawings allowing the investor to select the most appropriate solution of the planned construction.
A construction permit design is a systematically arranged composition of drawings enabling the relevant authority to estimate all circumstances essential to issue the construction permit.

A tender design is a systematically arranged composition of drawings enabling the bidder to offer a realistic price and time schedule, and the investor to select the most appropriate contractor.
An execution design is actually a construction permit design supplemented by detailed drawings (reinforcement, tendon, and workshop drawings) enabling execution of works in accordance with the conditions indicated in the construction permit.

Technical documents for cut-and-covers and galleries are the same as those for bridges and other civil engineering structures:
- as-built design
- maintenance and operation plan.

An as-built design is actually the execution design supplemented by presentation of all the works executed as well as of eventual modifications of any constituent part of the execution design that might have occurred during the construction.

A maintenance and operation plan is systematically arranged composition of figures, drawings and texts in a form of warranties, certificates, lists, catalogues, schemes, instructions and similar documents allowing correct operation and maintenance of the executed structure.

4.5 Cut-and-Cover and Gallery geostatic analysis

Geostatic analysis reinforced concrete structures in cut-and-cover and gallery is very sophisticated and depend on model and dimension of structures.

The reliability verification of an structures is a constituent part of both the preliminary design and the building permit design.

It shall be conceived on the basis of the results of geological - soil mechanical investigations, assessment of soil mechanical ground properties as well as spatial and town planning, traffic, surveying, road, hydrological/hydro-technical, meteorological-climatic, and seismic data.

The required reliability of structures shall be verified for transient, persistent, and accidental design situations occurring during construction, service, maintenance, and in exceptional conditions in the entire service life of a retaining/supporting structure.

The term reliability comprehends safety, serviceability, and durability of retaining/supporting structures.

Each geostatic analysis of an structure shall take account of at least the following design situations:
- Design situation of the initial condition of the slope, existing structures, and infrastructure in the influence area prior to commencing construction works;

- Technological design situations, which can include construction of access roads and working fields, pit excavations, and working stages during the anchored wall execution;
- Design situations of a permanent exploitation of the structure in its design service life;
- Seismic and accidental design situations.

When more sophisticated mechanical models of the ground and retaining/supporting structures are introduced, several design situations can be gradually analysed by simulating individual construction stages at simultaneous verification of all the ultimate limit states and serviceability limit states.

In accordance with the European geotechnical standard prEN 1997-1:2001 the following limit states are distinguished:

- Loss of overall stability of the foundation ground mass including retaining/supporting structures, which causes excessive ground movements due to shear deformations, settlements, vibrations or uplifts, damages or reduction of serviceability of adjacent existing structures, of roads and other infrastructure due to ground movement. To verify the considered case the most important factors are the ground strength and the stiffness or bearing capacity of individual structural elements;
- Internal failure or excessive deformations of structures or structural elements including foundations, piles, walls, anchors, etc., where the strength of structural materials is of essential importance to establish the required resistances (STR);
- Failure or excessive deformations of the ground where the strength of soils or rocks is the most important factor to establish the required resistances (GEO);
- Loss of equilibrium of geotechnical structures or ground due to uplift caused by water pressures (UPL);

To select suitable methods for the verification of the overall stability limit states the following shall be taken into consideration: stratification of slopes, phenomena and directions of discontinuities, seeping of ground water and pore pressures.
The GEO limit state deals with the danger of failure or excessive deformation of the ground where the strength of soils and rocks is important to ensure the resistances.
In retaining/supporting structures the GEO limit state considers, as a rule, the following: ground bearing capacity, determination of earth pressures and activated resistances, external resistance of structure.

The STR limit state deals with the internal failure or with the excessive deformation of a structural element including foundations, piles, walls, and anchors where the material strength prevails in the bearing resistance verification.

In retaining/supporting structures with the STR limit state, sufficient bearing resistance of cross sections of structural elements shall be considered and verified with regard to tensile, compressive, flexural and torsional loading, as well as to combinations of these actions.

The UPL limit state considers failure of the ground and/or retaining/supporting structure due to the loss of the vertical equilibrium where the ground stiffness is of a minor importance only.

In reinforced structures cut-and-covers and galleries, the serviceability limit states shall be considered in both transient and persistent design situations. The serviceability limit states particularly refer to deformations of retaining/supporting structure and ground, as well as of other structures and infrastructure in the retaining/supporting structure influence area.

For more complex concrete structural elements, limit states of cracks shall be verified, including a special argumentation of expected events at inaccessible places as well as in the area of construction joints foreseen.

4.6 Clearance Gauge in Cut-and-Covers and Galleries

A clearance gauge of the road in cut-and-covers and galleries is the space above and at the traffic profile, i.e. the traffic profile enlarged by both safety width and safety height. The clearance gauge in cut-and-covers and galleries is identical with the clearance gauge in tunnels. It is shown in Fig. 4.1.

The clearance gauge height amounts to 4.70 m. Its width is the same as that of the carriageway plus maintenance footways measuring 0.85 m in width, located at a height of 2.0 m, and 15 cm above the road carriageway.

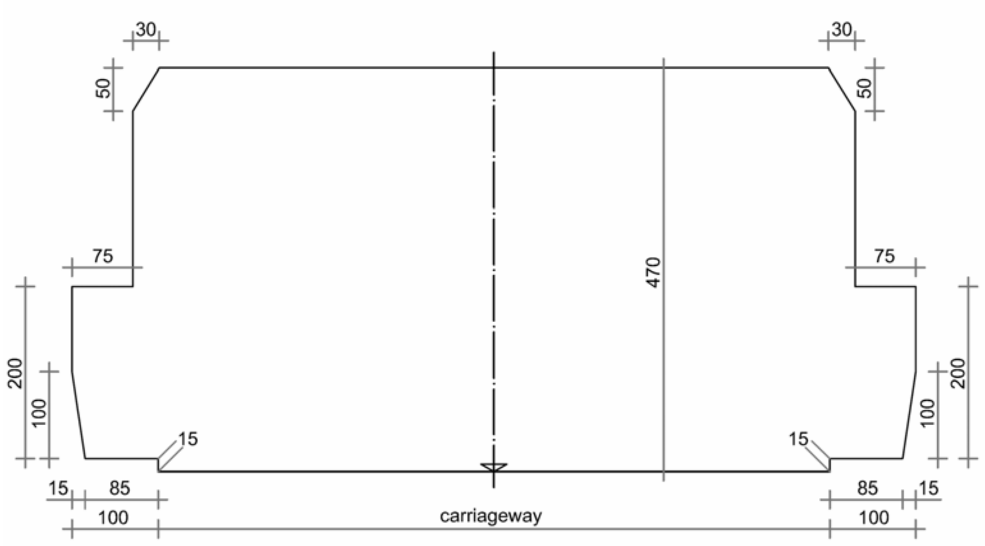


Fig. 4.1: Clearance gauge in cut-and-covers and galleries

5 CUT-AND-COVERS IN UNFAVOURABLE GEOLOGICAL CONDITIONS AT TUNNEL PORTALS, AND OVER THE ENTIRE LENGTH OF SHORT TUNNELS WITH SMALL HEIGHT ABOVE THE ARCH CROWN

Where tunnel portals (entries) are located on front sides of massive hills composed of rocky material with a thin surface layer of non-cohesive materials, the excavation for the tunnel pipe as well as the concreting works shall commence next from the portal. Both design and construction of tunnels is dealt with in a special guideline, where cut-and-covers are mentioned in a brief section 7.5.3 only.

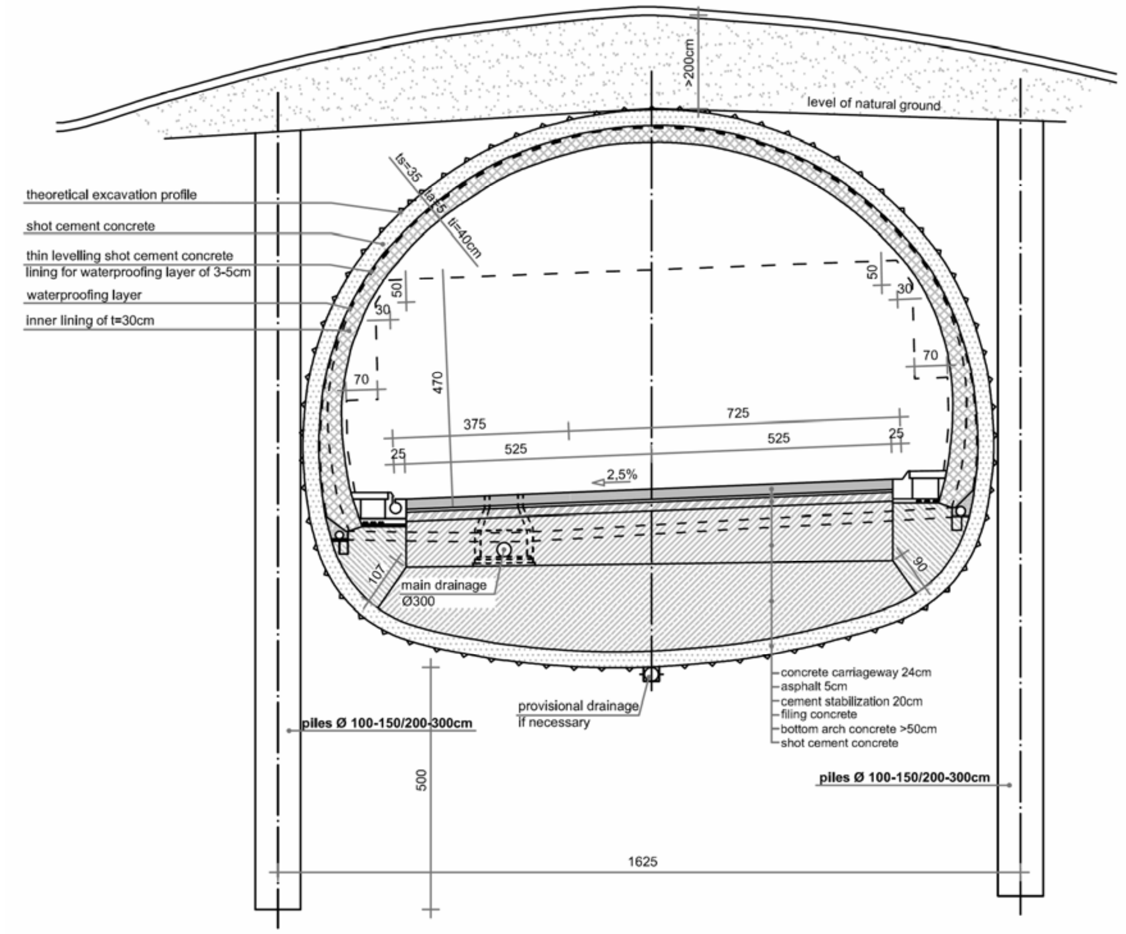
Where tunnel portals (entries) are situated on relatively gentle slopes of poor geological composition on the front or lateral sides, then it is impossible to excavate and construct the tunnel pipe at the beginning of the tunnel in the same way as it applies to the remaining part of the tunnel.

In dependence on the natural or urban environment, as well as on the geological composition of the ground, a great number of cuts, particularly in stony cohesive materials in front of the tunnel entries, remain permanently uncovered, on condition that this is acceptable in view of the environment protection and of the aesthetic design of the road. Slopes of such cuts shall be overall and locally stable, and protected from material falling on the road. Condition for their maintenance shall be established as well.

When cuts, which should enable the access to the tunnel, are constructed in geologically poor ground, where it is difficult, uneconomical, and often unfeasible to introduce retaining walls to ensure stability of slippery ground, then, prior to execution of the cut, protective structures according to the underground railway principle shall be constructed.

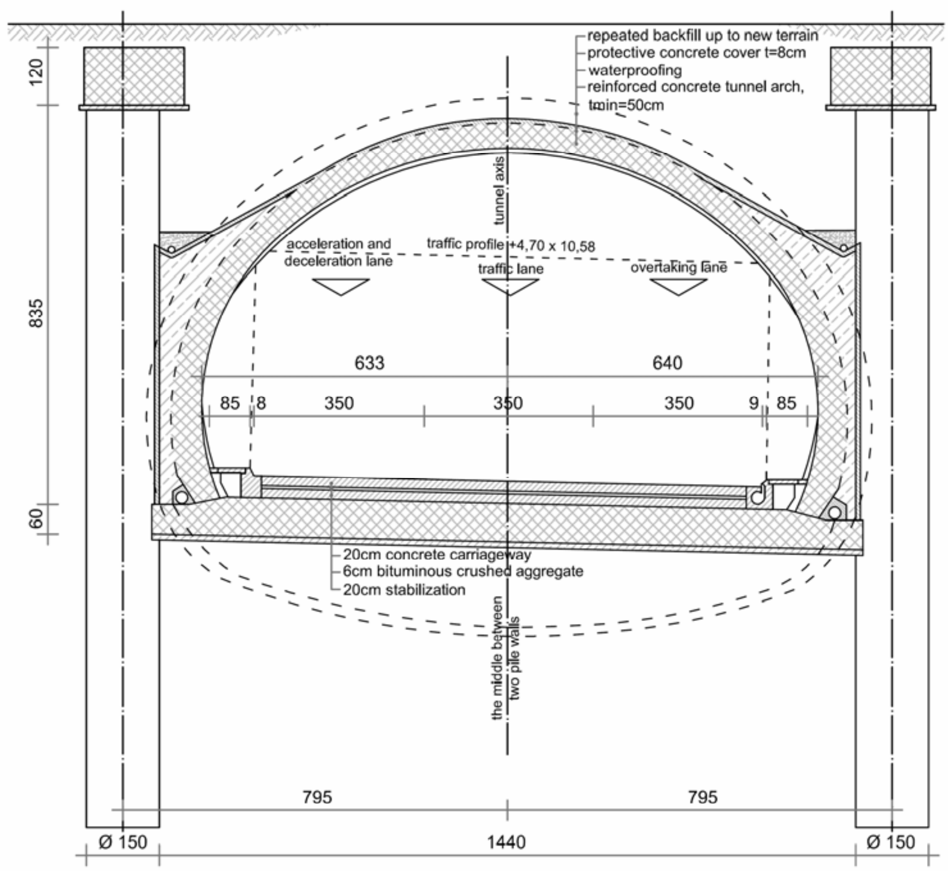
Protective structures are generally solid or discontinuous reinforced concrete walls in a form of diaphragms, or discontinuous walls made of piles of diameter 100 – 150 cm, with or without anchoring in the rear slope, bracing by means of beams, or arching.
In Fig. 5.1 a relatively simple method of protecting a cut for the tunnel pipe is presented, introducing bored piles of diameter 100 – 150 cm, spaced at 2.0 – 3.0 m, and anchored 5.0 m beneath the bottom arch, without any connecting beam and anchors on top. Cantilever piles anchored in the ground take forces due to the earth pressure.

In deeper cuts in poor soil, where earth pressures are substantial and the piles of ∅ 150 cm (Fig. 5.2) cannot take the horizontal forces without being linked to a connecting beam of section 150-200/120-150, then the excavation works and construction of the tunnel pipe is carried out in segments measuring 8-10 m in length, under protection of pile walls.



level of natural ground
>200cm
theoretical excavation profile
shot cement concrete
thin levelling shot cement concrete lining for waterproofing layer of 3-5cm
waterproofing layer
inner lining of t=30cm
ts=35
ti=40cm
470
375
725
525
525
25
25
2,5%
main drainage Ø300
provisional drainage if necessary
piles Ø 100-150/200-300cm
concrete carriageway 24cm
asphalt 5cm
cement stabilization 20cm
filing concrete
bottom arch concrete >50cm
shot cement concrete
piles Ø 100-150/200-300cm
500
1625

Fig. 5.1



repeated backfill up to new terrain
protective concrete cover t=8cm
waterproofing
reinforced concrete tunnel arch, tmin=50cm
tunnel axis
acceleration and deceleration lane
traffic profile 4,70 x 10,58
traffic lane
overtaking lane
120
835
60
633
640
85
8
350
350
350
9
85
20cm concrete carriageway
6cm bituminous crushed aggregate
20cm stabilization
the middle between two pile walls
795
795
Ø 150
1440
Ø 150

Fig. 5.2

By increasing the cut depth, particularly in geologically – soil mechanically unfavourable conditions, earth pressures augment as well. Therefore it is indispensable to introduce bracing to pile walls on their top, as well as reinforced concrete bracing above the tunnel arch. Only after such double bracing it is possible to start the excavation for the tunnel pipe, casting the bottom strutting slab (or arch), and concreting the inner lining.

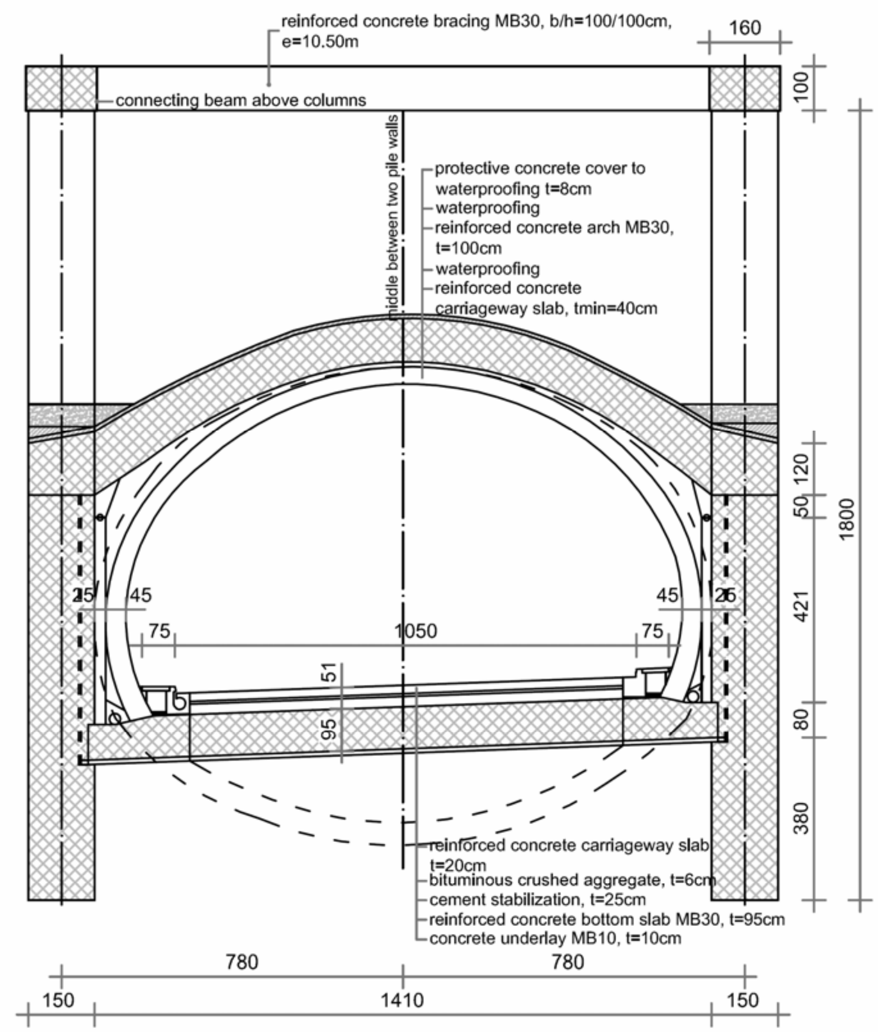


Fig. 5.3

6 SHORT TUNNELS WITH LOW OVERLAY EXECUTED IN DEEP CUTS IN FAVOURABLEGEOLOGICAL CONDITIONS

Where short tunnels are designed, especially for double-pipe tunnels on motorways, with the vertical alignment located at a depth of up to 50 m from the ground surface, in favourable geological conditions, it is often competitively to execute a tunnel in a deep cut, which shall be demonstrated by an alternative design solution. The economy of construction of tunnels in deep cuts is, among others, particularly affected by the extent and method of provisional securing of cut slopes.

The excavation of a cut is carried out in steps by both height and length. The height of terraces amounts to 6-8 m, whereas the length of longitudinal segments to 10-15 m.

By favourable arrangement of terraces or by omitting both terraces and longitudinal segments it is possible to reduce the extent of the transportation to temporary deposit areas.

The construction of double-pipe tunnels in deep cuts on motorways does not require spacing between both pipe axes of approximately 40 m, which is indispensable in the tunnel excavation. Joined pipes allow continuity of the motorway geometry in the zones of shorter tunnels as well.

In Fig. 6.1 an example of construction of a double-pipe tunnel on a motorway in a 46 m deep cut made in flysch, without terracing.

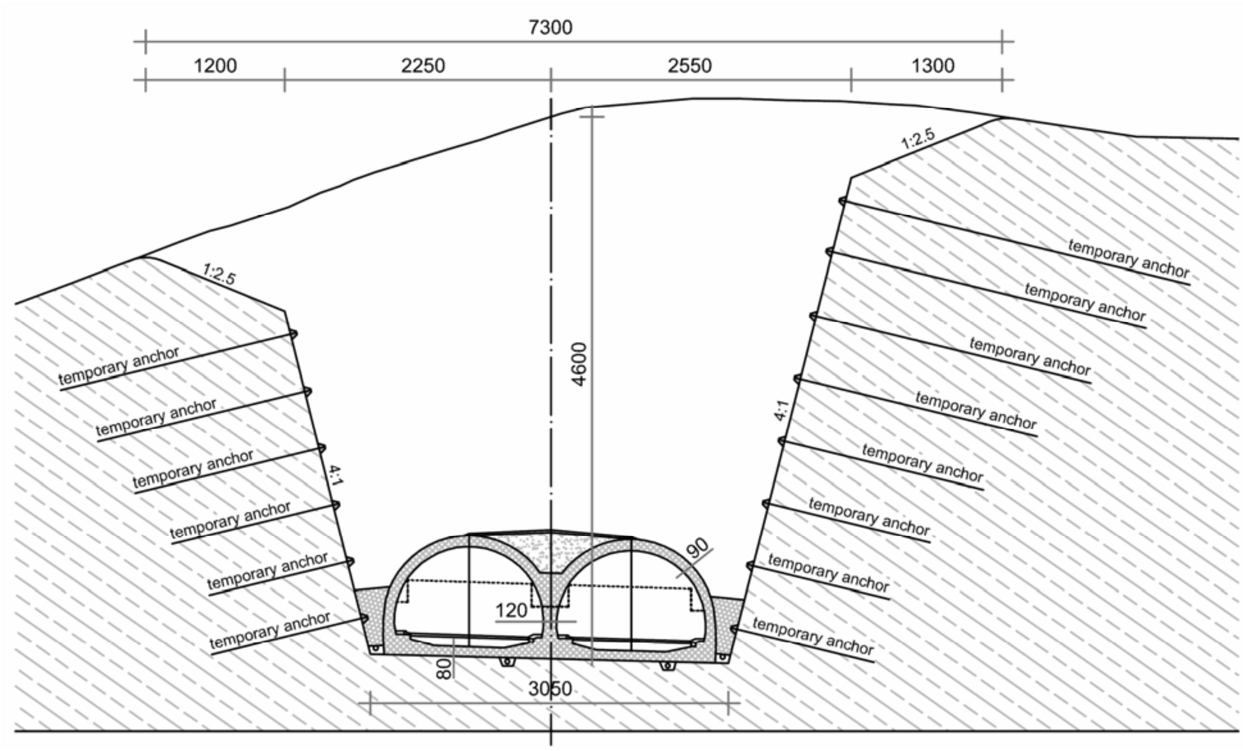


Fig. 6.1

7 REINFORCED CONCRETE STRUCTURES IN SHALLOW CUTS

The most frequent reasons for the construction of reinforced concrete structures in shallow cuts are:

- protection of natural or urban space and ambient;
- passages and split level interchanges below existing or future roads;
- establishing stability of road bodies in unstable ground.

Reinforced concrete structures for motorways are conceived and constructed as two-cell open or closed frame structures of an opening of 2x(10-12)/(5.50-6.50) m. For other roads, such reinforced concrete structures are single-cell closed or open frames of an opening of (10-12)/(5.50-6.50) m.

These frame structures can be founded on strip foundations, on a slab below the entire structure, or on bored piles. The foundation method depends on the geological composition of the ground and on the construction technology.

In addition to designing the structure in shallow cuts it is also required to solve the problem of drainage, i.e. draining the ground out of the structure and draining the road carriageway of the road within the structure. Both drainage systems shall be connected to the road or motorway dewatering system. For longer structures is necessary to provide a solution of both lighting and traffic signalization as well.

In Fig. 7.1 an example of cross-section of a two-cell frame reinforced concrete structure in a cut of 8-10 m depth is shown. Level cross-sections of structures with voutes are economical for fills of 2-4 m above the structure. The slopes of the cuts shall be harmonized with the characteristics of the ground strata. Backfilling of the structure shall be carried out in layers accompanied by mechanical compaction.

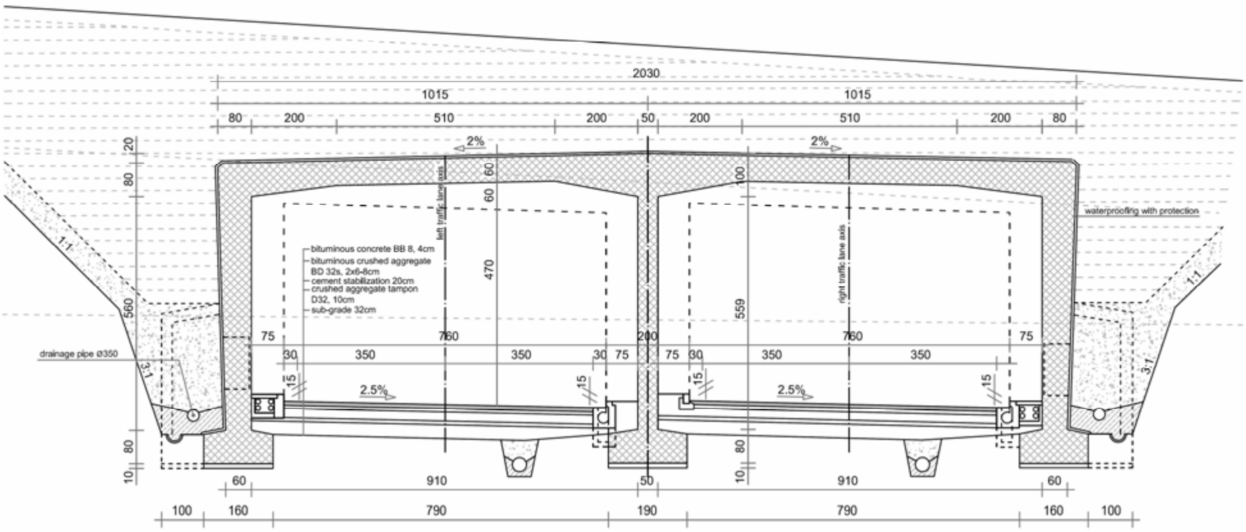


Fig. 7.1

In Fig. 7.2 an example of cross-section of a two-cell reinforced concrete closed structure with modified form of the upper slab and accentuated voutes is shown. Such or similar structural type is recommended for cuts measuring 10-12 m in depth, with 4-6 m high material layer above the structure.

After excavation of the cut and protection of slopes, the structure is constructed in segments measuring 8-12 m in length, with construction joints situated between adjacent segments. Waterproofing shall be applied to the outer surface of the structure. The waterproofing layers shall be protected by concrete cover of thickness 8-10 cm, which shall be reinforced with meshes or with prefabricated slabs for vertical surfaces.

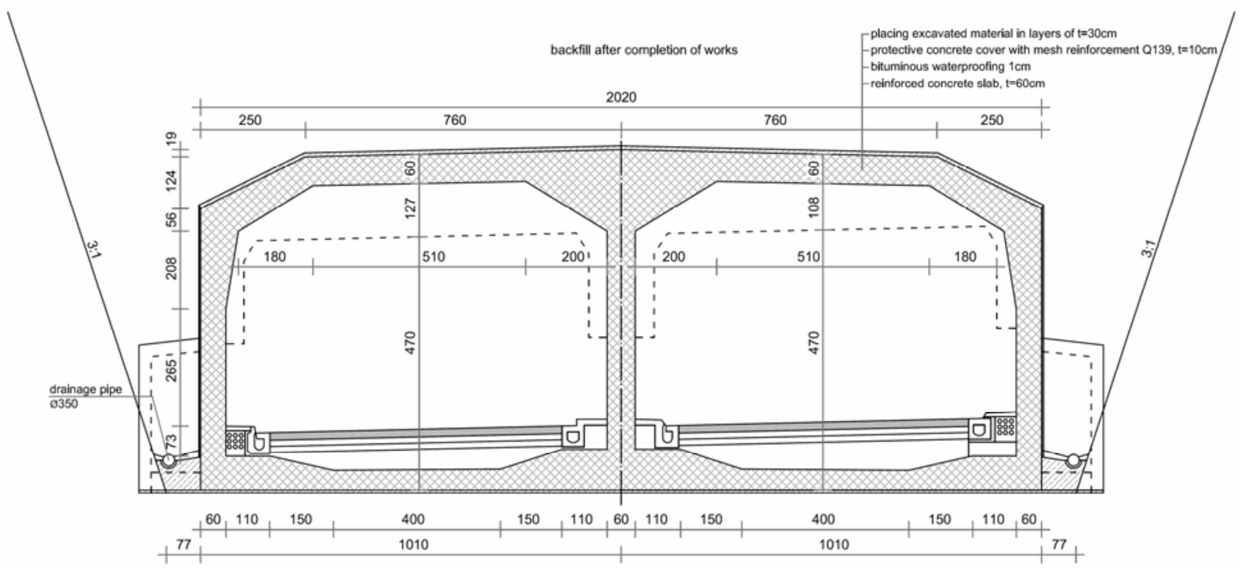


Fig. 7.2

In Fig. 7.3 both construction method and the cross-section of a two-cell reinforced concrete frame structure on inclined ground with unstable upper strata in a cut of depth of 9-14 m is shown. Such a structure can be considered as a multipurpose one: it provides permanent protection of the unstable slope, enables the excavation of a cut (or cut-and-fill), allows establishing of natural terrain, and protects neighbouring settlement from noise.

An anchored wall made of piles of ∅ 150 cm spaced at 2.0 – 2.5 m shall be executed from the natural ground level in a height of 25 m. The wall is anchored in a marl geological stratum. Every second pile ends below the frame slab level, and every second one at the ground level. On the top of the piles a reinforced concrete beam is placed, via which the pile wall is anchored by means of permanent ground anchors in the load bearing ground. Structural design, construction technology, and stability verification ads explained in detail in the DG 1.3.4.

After boring (ramming) and anchoring the piles, a wide excavation is made feasible at the top up to the lower edge of the lower connecting beam. On the lower level, a safe wide machine excavation below the cut (cut-and-fill) up to the ground level is enables after completion of anchoring the pile wall.

The structure is presented in Fig. 7.3. The frame structure and the pile wall are rigidly interconnected to structural whole thus ensuring together the motorway stability on an unstable slope.

Above the waterproofed upper slab a layer of deposited material from excavation shall be applied, and the ground shall be brought to its original natural condition.

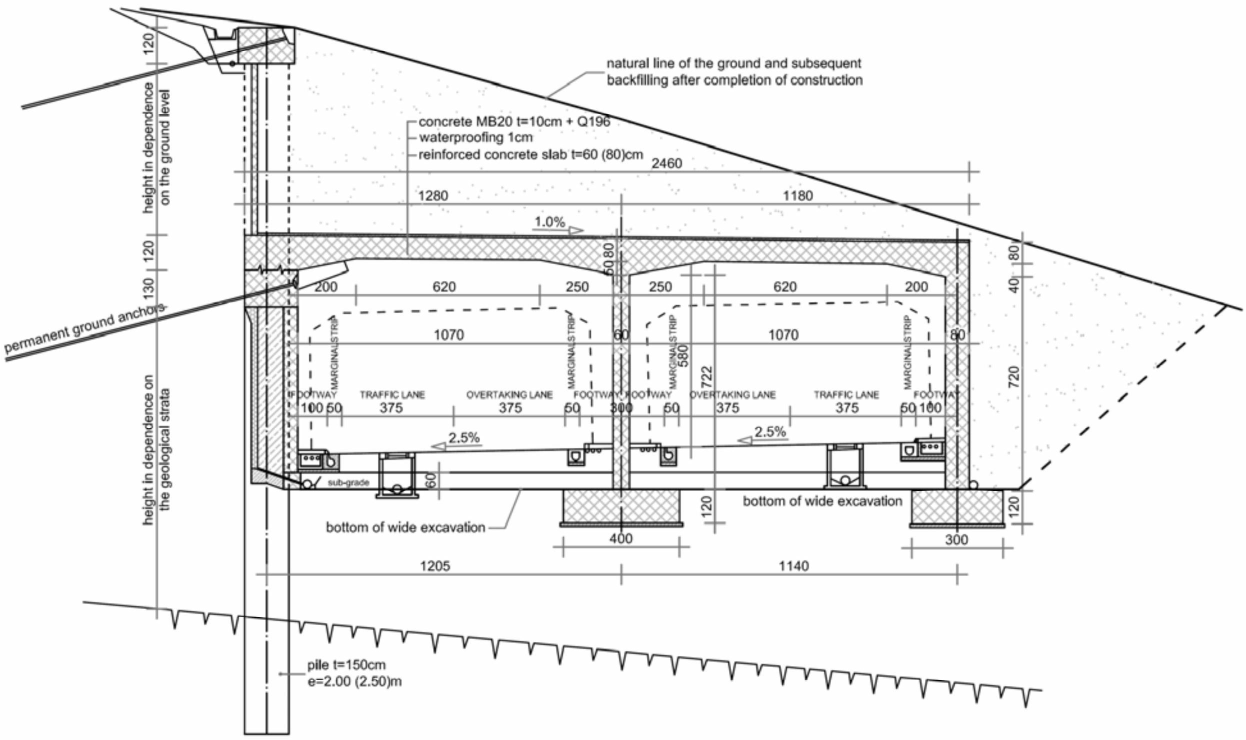


Fig. 7.3

Structural and technological solutions of reinforced concrete structures in shallow cuts are very specific and various. They primarily depend on the geological strata in the cut, and to what extent other roads or structures occupy the ground.

In Fig. 7.4 a characteristic cross-section of a reinforced concrete structure in a cut measuring approximately 10 m in depth in urbanized space including roads on both sides of the cut-and-cover are shown.

In difficult traffic conditions it is possible to design and construct reinforced concrete frame structures with two openings of a gauge of 2x9.42/6.16 m. The walls of the frame structure consist of piles of ∅ 100 cm spaced at 2.00 m. The upper slab of 90 cm thickness is cast in situ after completion of excavation up to a depth of 4.00 carried out under protection of Larssen steel sheet piles.

The material from the cut-and-cover opening is excavated subsequently as it is practicable in the tunnel construction. The lower slab is cast after completion of excavation from the cut-and-cover. From the structural point of view the fixed interconnection of the lower and the upper slab by means of piles, as well as the filling-up of voids between piles is characteristic.

After casting of the upper slab and its waterproofing the (backfilling is carried out, Larssen sheet piles are removed, and the original condition is established.

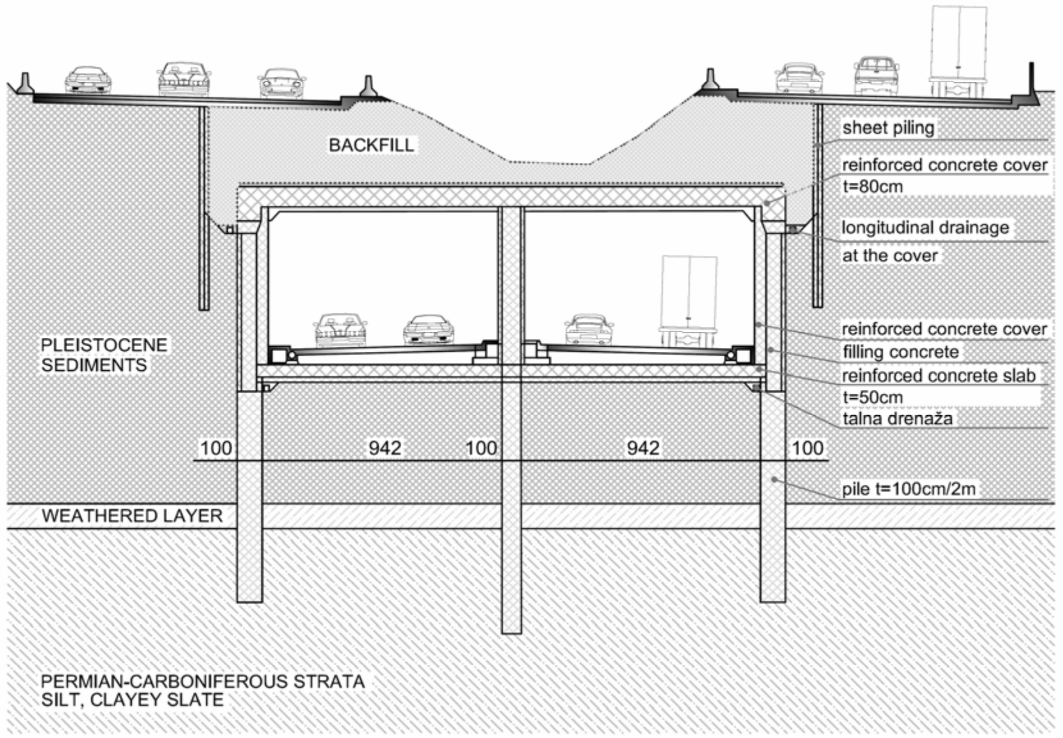


Fig. 7.4

8 REINFORCED CONCRETE STRUCTURES IN DEEP CUTS

Reasons to design structures on parts of, or on the entire length of deep cuts are the following:

- passages over deep cuts for other roads as well as for domestic animals and game;
- protection of the nature;
- permanent protection and stability of slopes of a cut.

It is frequently the case that all the abovementioned three conditions are fulfilled when executing such structures.

Reinforced concrete structures in cuts deeper than 14 m, with a fill above the structure measuring 6 m or more in height, are designed and constructed as arch closed or open frame structures. Such type of cut-and-covers is mainly applicable to motorways with two separated carriageways, each of them consisting of two or three traffic lanes. The structural design of a cut-and-cover shall also include a design of temporary securing the slopes of the cut as well as provisional and permanent drainage of both cut and structure.

For cut-and-covers executed in cuts of non-cohesive material it is recommended to introduce arch frame structures with two openings. The size of openings and the shape of arches shall be adapted to the width and gauge of the motorway.

In Fig. 8.1 an example of the characteristic cross-section of a reinforced concrete cut-and-cover structure with two openings is shown. As the foundation conditions are relatively favourable, the structure can be founded on strip foundations. A disadvantage of such a solution is the impossibility of inspection and maintenance of dewatering the void between the arches.

The cut-and-cover structure is executed in approximately 10 m long segments using mobile or portable falsework. After completion of the structure, suitable waterproofing shall be applied. The latter shall be protected by mans of prefabricated reinforced concrete slabs. The executed structure shall be backfilled symmetrically in 0.3 – 0.5 m thick layers using the material from the excavation. The layers shall be adequately compacted.

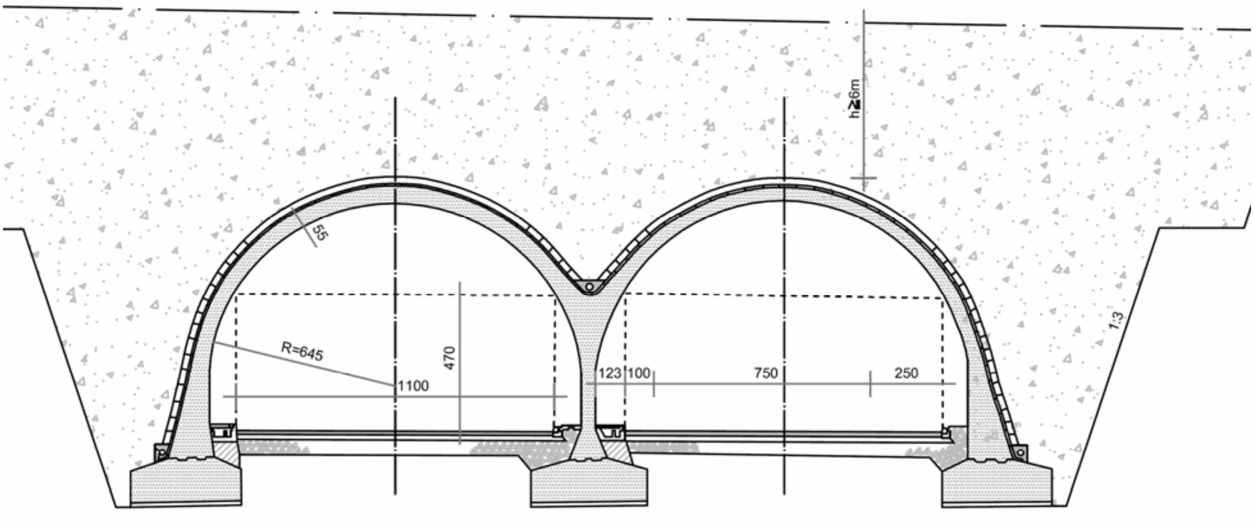


Fig. 8.1

In Fig. 8.2 an example of the cross-section of a closed reinforced concrete arch structure with two openings is presented. Such a solution is applicable in case of unfavourable geological conditions in view of foundation. The void between the arches is filled-up with non-reinforced concrete, and a thin reinforced concrete slab is placed on the top to simplify the drainage.

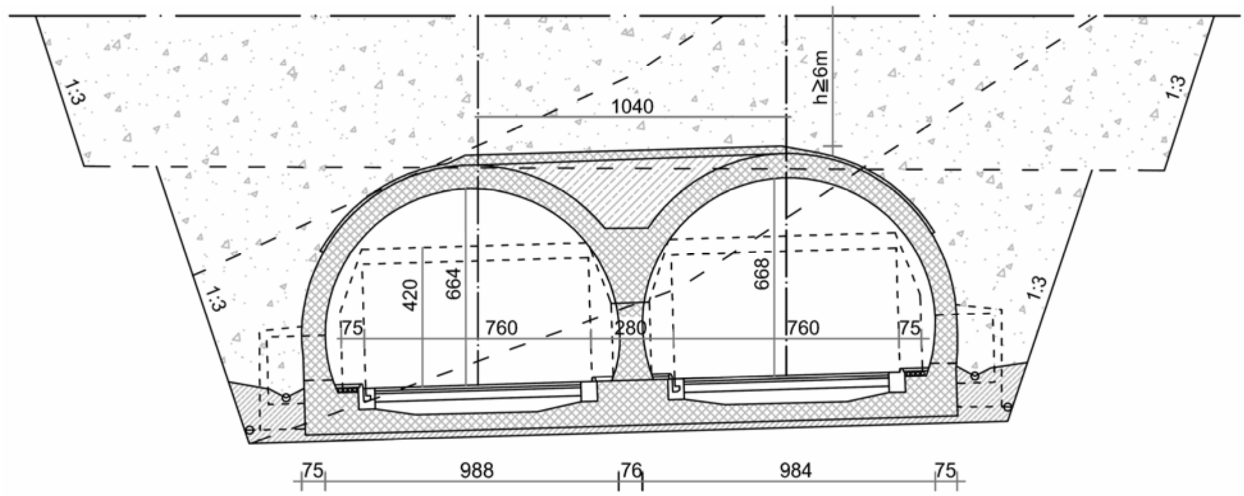


Fig. 8.2

For structures built in deep cuts of stony materials, arch structures of one opening of 30 – 40 m span are recommended. Strip foundations of the arch structure, which are adequately designed to take the loading from the structure and to transfer it to the rock mass, are of relatively small dimensions. A temporary securing of the slopes of cuts in stony materials is simple, especially where the cut has been executed accurately and in accordance with the geological conditions.

In Fig. 8.3 and example of an arch structure in a deep stony cut of 39.0 m span is shown. Here a possibility of increasing the motorway width by a third traffic lane is given. The structure is simple for the execution, dewatering, and maintenance. The entrance portals shall be adequately designed to ensure natural and pleasant transition from the open motorway to the cut-and-cover.

Reinforced concrete structures of smaller spans and increased curvature can be foreseen in cuts of non-cohesive materials as well (Fig. 8.4). Here, the foundation slabs are substantially wider, and they shall be executed on suitably compacted substrate.

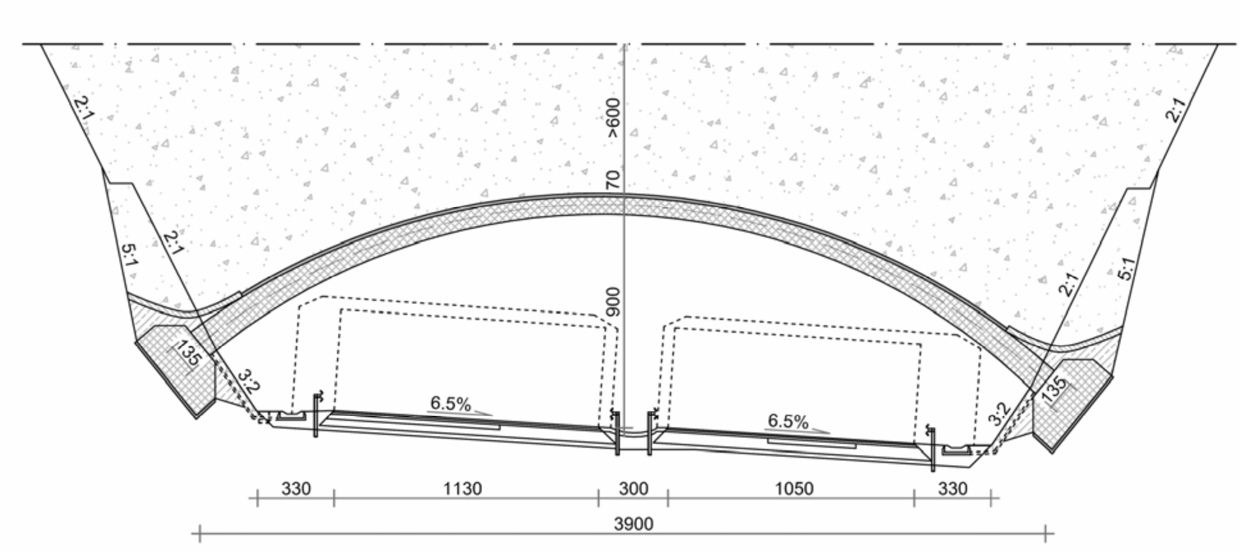


Fig. 8.3

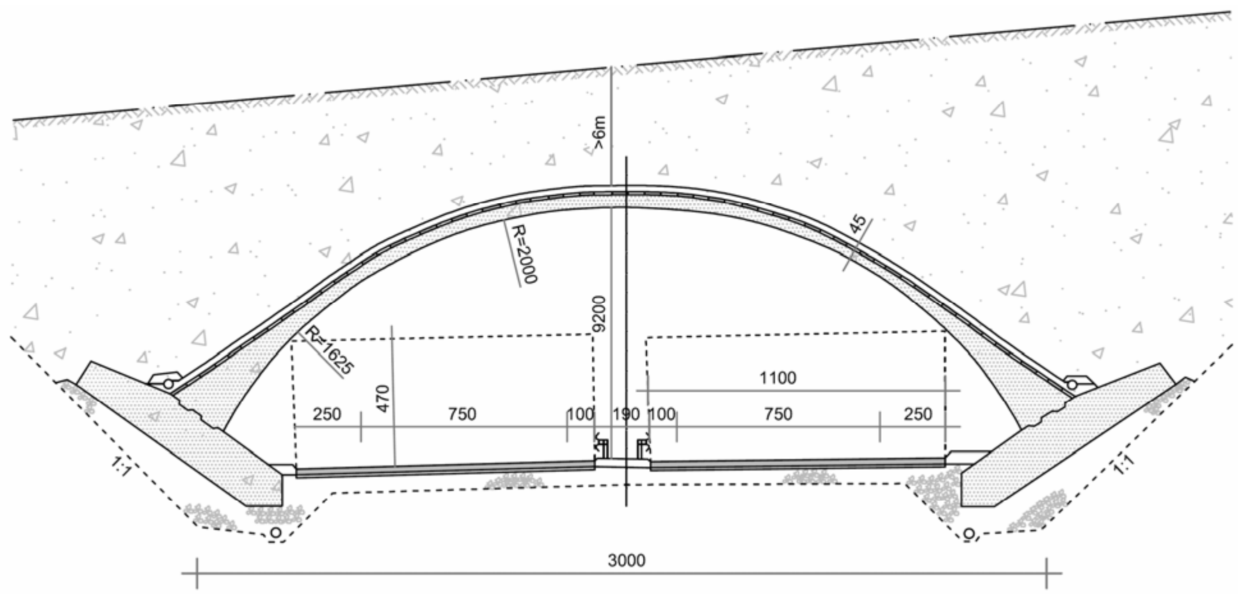


Fig. 8.4

9 GALLERIES FOR PROTECTION OF NATURAL OR ARTIFICIAL SLOPES OF CUT-AND-FILLS

To protect the road or motorway body as well as the traffic on the road or motorway from active or potential filling-up with falling material, galleries are designed and constructed.

Galleries are specific reinforced concrete monolithic or semi-prefabricated structures. The design solutions of gallery structures are very specific and various, as they depend on several factors, in particular on the following ones:

- shape and inclination of natural or artificial slope,
- geological composition of the slope material and of the area on which a gallery construction is
- planned,
- shape and composition of falling material,
- extent and method of temporary slope protection during the gallery construction,
- size of the structure, technology, and construction programme.

In Fig. 9.1 an example of a gallery structure for protection of a main road and the traffic on the road from falling stone material of larger volume, from earthquake, temperature changes, and snow avalanches is shown.

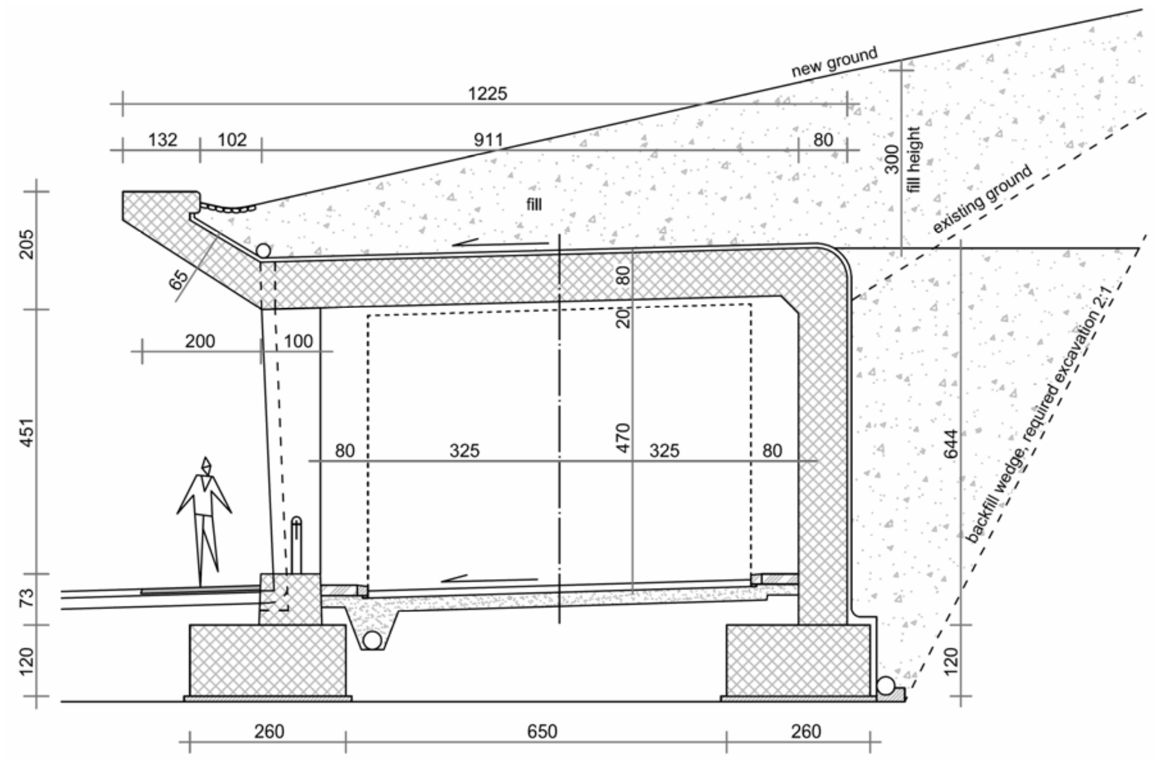


Fig. 9.1

A frame monolithic reinforced concrete gallery structure of an opening of 8.10/4.90 m consists of a solid wall on the slope side, an upper slab measuring 80 cm in thickness, and columns of cross-section of 1.00 (0.70)/0.50 spaced at 3.00 m on the front, i.e. open side. The cantilever part of the upper slab allows construction of a fill above the gallery, and protects pedestrians walking on the footway out of the gallery. At the contact with the rear and the fill, the structure is waterproof. The fill above the gallery is of variable thickness of 1.00 – 3.00 m.

In Fig. 9.2 a solution of a gallery structure to protect a main road from snow avalanches and landslides on a steep slope is shown.

A monolithic arch structure of a tunnel shape with open front side is favourable to take the forces from the ground, and fits pleasantly in the natural ambient.

The inclined supports of the gallery shall be attached to the structure as tangentially as possible to reduce bending moments.

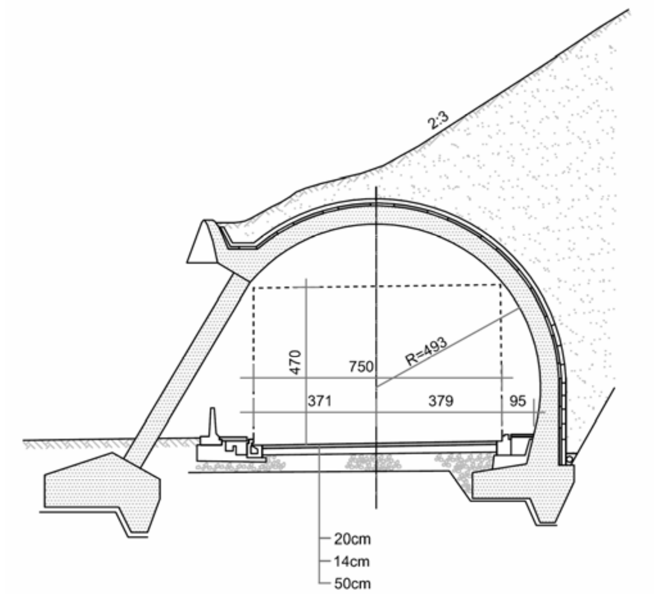


Fig. 9.2

Galleries are constructed in segments of 10 – 15 m length. Prior to commencement of the construction, the stability of the cut-and-fill shall be ensured. Backfilling shall be executed successively in fair and constant weather. Thanks to the front open side no artificial illumination and ventilation is necessary.

To ensure stability of steep slopes and to protect a motorway from potential falling material from the cut-and-fill slope or a steep unstable slope, reinforced concrete frame structures of two openings of 2x(10-14)/6.0 m are designed and constructed. The size of openings depends on the motorway width. The wall on the slope side is solid, whereas the other two supports are on columns spaced at 3-5 m o ensure natural illumination and ventilation. The foundation depends on the quality of the load bearing ground, and can be:

- strip foundation as indicated in Fig. 9.3, where flysch is the predominant geological base,
- pile foundation, where the geological load bearing base is located at greater depths, or
- slab foundation in case of poor foundation conditions.

Slab structures of galleries are suitable and recommendable, where the horizontal forces due to the earth pressure are greater than the vertical forces arising from both structure and fill laid-on.

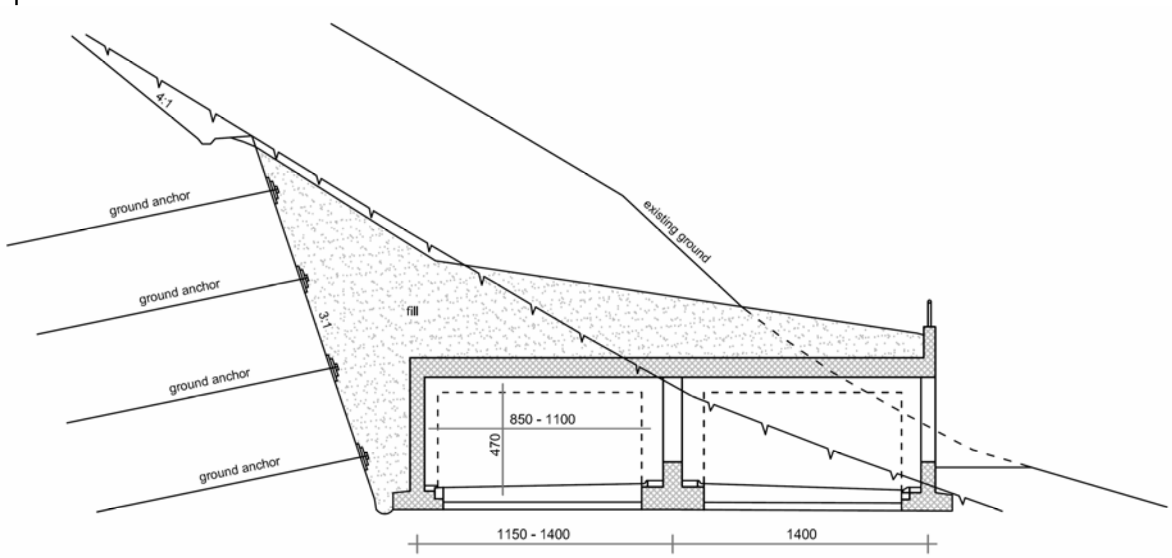


Fig. 9.3

In Fig. 9.4 a semi-prefabricated reinforced concrete gallery structure intended to protect the traffic is shown. The wall at the slope side is a retaining wall at the same time, which is constructed first thus allowing further execution of the gallery. The upper structure of the gallery is made of prestressed reinforced concrete girders and a cast-in-situ reinforced concrete slab. The minimum thickness of the fill laid-on to protect the gallery structure from dynamic impact of rocks falling from a steep slope into the gallery rear amounts to 1.00 m. It has been experimentally demonstrated that the dynamic force of the impact does not considerably depend on the thickness of the fill situated above the upper slab, however on condition that the fill thickness amounts to at least 1.00 m.

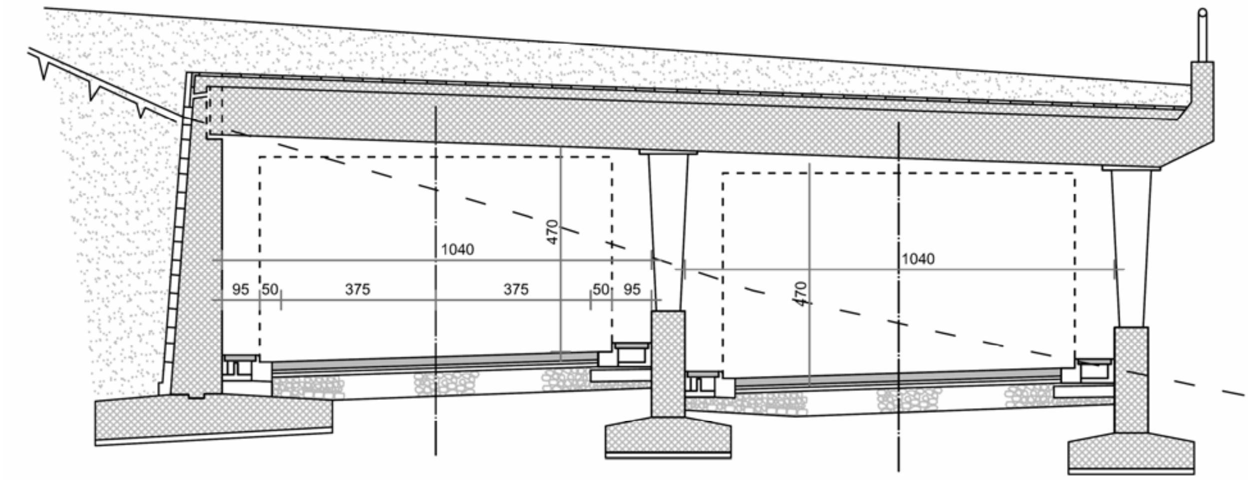


Fig. 9.4

For an accurate structural analysis of galleries it is of great importance to select correctly the static model of the structure, which should be as close as possible to the actual structural behaviour. Galleries are loaded by their dead weight, earth pressure acting from the rear of the gallery, the weight of the fill laid-on to the upper slab, and dynamic force due to rock falling onto the gallery.

According to experimental investigations carried out in Japan (H. Yoshida, IABSE 3/1988) the impact force of a falling rock amounts to:

$$P = 2.42 \times 10^{-3} (m/T_0) (2g H)^{1/2}$$

where

m	mass of the rock
T_0	time of falling
H	height of falling
g	gravitational acceleration.

The abovementioned experiments showed that a fill laid-on in a thickness of 90 cm is sufficient for a rock weighing up to 1,000 kg, whilst the thickness shall be 120 cm for rocks of 1,000 – 3,000 kg. The influence of the shape of the falling rock can be neglected.