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IRGO CONSULTING d.o.o.

Technical Report

Second Track of Divača – Koper Railway Line, Lot 1

Structure	**Tunnel T1**	
Structure Part / Content	**Karst Formations**	
Project No.	190175/1	
Plan No.	ic 337/19	
Stage	PZI	
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1 GENERAL

The T1 tunnel is part of the single-track railway connection Divača-Koper on the section Divača-Črni Kal. The tunnel comprises a main tunnel tube GC with a length of 6,726.8 m and a parallel service tunnel tube SC with a length of 6,683.1 m. Both tunnel tubes are interconnected with thirteen adits, in a total length of approximately 325m.

1.1 Content of the design

The subject of the design in the field of construction are karst formations, which can be expected in the area of the excavation of T1 tunnel. Depending on the phased construction and the content, the design is divided into several volumes or. sub-volumes, which must be read together for a full understanding of the design solutions for the T1 tunnel.

Notebooks	Description
0	Text part with inventory of works and design estimate
1	General drawings
2	Temporary portals
3	Excavation and support
4	Geotechnical measurements
5	Inner lining
6	End portals
7	Other facilities
8	**Karst formations**

Table 1: Contents of the design with the volume under consideration

The technical report in volume T8 deals with karst formations. The content includes descriptions of karst characteristics, measures for the protection of groundwater during construction in the karst environment, ways of detecting karst formations, categorization of karst formations and their remediation.

General descriptions and characteristics of the tunnel are given in the general technical report or in the technical reports of other volumes that make up the content of the design for the T1 tunnel. In the case of karst formations, the requirements in the Technical Specifications for excavation and support (TS - document no. 3) and other measures (TS - document no. 8) must also be taken into account.

1.2 Contents of the report

The technical report of the considered volume deals with karst formations with designed measures for overcoming karst formations.

The general characteristics of the tunnel are given in the leading technical report of the tunnel [5]. In the case of karst formations, the requirements stated in the Technical Specifications must be observed, in particular the part related to excavation and support **Error! Reference source not found.** and special measures [13].

1.3 List of references and standards

The following is the information on the basic documents that were taken into account in the preparation of the design documentation.

Design shall include the following documentation:

[1] Project task for the preparation of a design for obtaining a building permit for the second track of the Divača-Koper railway line, Črni Kal-Koper section, Republic of Slovenia, Ministry of Transport, Directorate of the Republic of Slovenia for Investment Management in Public Railway Infrastructure.

[2] Decree on the national location plan for the second track of the railway line on the section Divača - Koper (Official Gazette of RS, No. 43/05).

[3] Geological and geotechnical data obtained on the basis of geological and geotechnical surveys for the PGD design phase in the area of the T1 tunnel, collected in the geological and geotechnical report for the T1 tunnel (ZAG, November 2010, no. Pr. T1-2003353 / 7),

[4] Geological-Geological-geotechnical study with synthesis of all investigations for the T1 tunnel, PZI phase (GI ZRMK, February 2019, no. Pr. 2006190-1 / K-T1).

[5] Environmental Impact Report for II. track of the Divača railway line. Koper, PRO LOCO, d.o.o., November 2004, no. 26-06 / 04-9).

[6] 2TDK_IRG_PZI_GR_S1-x2-03_T0_XX_TR_XX_EN_0001_0_002: Design of Tunnel T1 - Technical report - General text part

[7] 2TDK_LEA_PZI_XX_S1-EL-01_XX_XX_TR_XX_EN_1001: Interpretation of karst conditions for the construction of tunnels T1 and T2

[8] 2TDK_IRG_PZI_GT_S1-EL-02_XX_XX_TR_XX_EN_0001: GG Study for tunnels T1 and T2,

[9] 2TDK_IRG_PZI_XX_S1-EL-05_XX_XX_TR_XX_SL_0001_0_002: Technical monitoring plan for the construction of tunnel T1

[10] Safety concept of tunnels T1 and T2 phase PGD (No. TP_VK_1.3; BTC, Elea Ic, Gruner GmbH, June 2011).

[11] Risk analysis for groundwater pollution and water catchment in Rižana due to the construction of the 2nd track of the Divača - Koper railway line, Geological Survey of Slovenia and Institute of Mining, Geotechnology and Environment, no. K-II-30d / 1-1 / 62, dated 6.12.2012.

[12] 2TDK_PZI_LEA_TS_DOC_3: Tunnel excavation and support - Technical specifications

[13] 2TDK_PZI_LEA_TS_DOC_6: Technical observation - Technical specifications

[14] 2TDK_PZI_LEA_TS_DOC_8: Special measures for tunnel construction - Technical specifications

1.4 List of applicable standards, regulations and guidelines

The following legislation, standards and guidelines were also followed:

[15] Building Act GZ (Official Gazette of the Republic of Slovenia, No. 61/17 and 72/17 - amended)

[16] Eurocode structural design standards (SIST EN)

2 DESCRIPTION OF THE CHARACTERISTICS OF THE KARST AREA

2.1 General

The chapter summarizes the technical report on basic geological and geotechnical properties in the T1 tunnel area [3] and the technical report on geological and geotechnical properties in the T1 tunnel area, which was written on the basis of supplementary investigations [[4]] and the unification of interpretation of geological and geomechanical construction conditions, which was made in the framework of the production of PZI (Executive design).

The area of the section of the future Koper-Divača railway line between Črni Kal and Divača is mostly built of water-permeable carbonate rocks, with appears in occasional outcrops and in which we find many karst caves.

The planned route mostly runs in highly permeable carbonate rocks, in which underground water flow predominates. Surface waters from the very poorly permeable flysch border also sink at the contact with the karst. Karst waters, which disappear underground in the area in question, is spread to the wider area of southwestern Slovenia and supply some important karst springs from the water supply point of view, while supplying a common underground karst aquifer, which is an important source of drinking water in this part of the country.

Based on previous experience, we expect with certainty that several empty and alluvial-filled caves will also be opened during earthworks on the facilities of the future railway line.

2.2 Karstification of tunnel T1

Useful data for the assessment of karst permeability, obtained in the framework of karst investigation in the area of the route, are sufficient for the general assessment of karstification. The data mostly speak of karst permeability mainly in the epi-karstic zone and in the zone below it, i.e. up to a depth of a few tens of meters. The assessment of permeability at greater depths, i.e. also at depths where the tunnel line will run can be given as a prognosis or on the basis of the current knowledge on the development of karst and the results of karstological-geological, geomorphological, speleological and geomechanical investigation in this field.

Based on the collected data, the tunnel route was divided into 10 typical sections, which represent different levels of karstification along the T1 tunnel route.

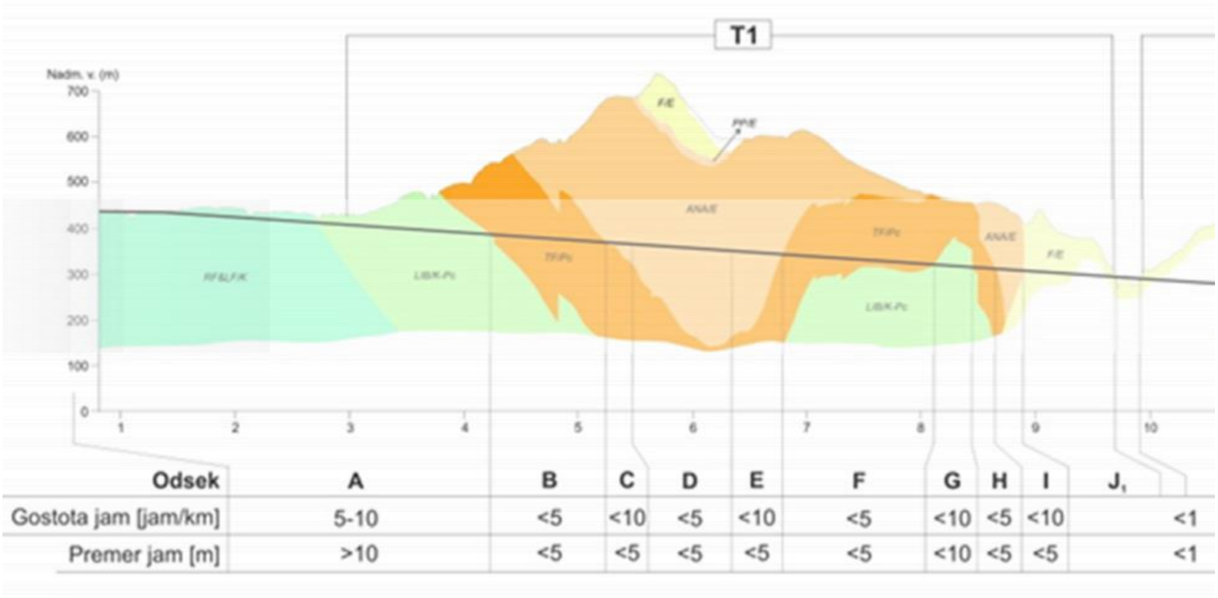


Figure 1: Predicted karstification / permeability along tunnel T1

Section A (km 0.00 - 4.23)

Section A runs along the Cretaceous limestones and limestones of the Liburnian formation. In the cave cadastre, 11 caves were recorded in a two-kilometer strip along the route of the railway line, and 15 caves were discovered nearby in the same rocks during the construction of motorways.

It is expected that 5 to 10 caves / km will be find on this section. Trenches (dry old ones, formed due to the former flow of water in a predominantly flooded zone; example: Divaška jama) will be able to have larger diameters (even over 10 m). We anticipate that half to two-thirds of the karstic features will be filled with fine-grained sediments and gravel (just below the surface), and deeper also with residue solution. In the meantime, (sub) recent vadose abysses may appear, up to 5 m in diameter. Their cross-sections will be round or slit with pronounced cracks. The caves will be above the regional height of the karst groundwater, and we can expect more pronounced water inflows in the tunnel after the rain and locally trapped water.

Greater permeability is expected at the Cretaceous-Paleocene boundary at the transition of Section A to Section B.

An average of 5 to 10 caves / km is expected, some can be over 10 m in diameter.

Section B (km 4.23 -5.24)

Section B runs through Paleocene limestones. Knowledge of lithology and borehole data indicates a lower frequency of caves in these limestones. No caves were recorded in the cadastre of caves in the two-kilometer strip along the route, and several smaller caves were discovered on the motorway section, most of which were filled with sediment. Most karstic features are expected to be up to a few meters in diameter and filled with fine-grained sediments. Vadotic abysses, up to a few meters in diameter and a few tens of meters deep, will also appear.

The possibility of trapped water is small, but in terms of volume greater than in the previous section. Greater karstification is expected on the broken part of the station 4.69 km and km 4.83.

An average of up to 5 caves / km with a diameter of up to 5 m is expected.

Section C (km 5.24 - 5.47)

Section C passes through Eocene limestones, which are not covered with impermeable rocks on the surface. These limestones are generally more karstified, as shown by data from the Črni Kal area. Nevertheless, there are no recorded caves in the cave cadastre in this area.

The concentration of vertical abysses will decrease towards the end of the section, as the vadose speleo-genesis becomes shorter due to the synclinal geological structure.

Up to 10 caves / km with a diameter of up to 5 m are expected on average.

Section D (km 5.47 - 6.35)

Section D runs in Eocene limestones, which, however, are covered with impermeable Eocene marls and flysch. Since carbonate rocks are covered with flysch, vadose abysses are not expected. There is a greater possibility of locally trapped water in this area. We expect karstic features, a few meters in diameter, exceptionally over 10 m, in the case of less expected remains of the old, now relict caves. Such a cave has also been confirmed by drilling (eg T1-13) as part of supplementary investigation.

Due to the shorter time of speleogenesis, lower permeability of karst is expected, higher permeability is possible only on locally severely limited inflows of surface waters from the flysch roof. Due to the synclinal structure, subvertical groundwater flows may occur, especially at the edges of this section.

It is expected to average up to 5 caves / km, which will have a diameter of up to 5 m.

Section E (km 6.35 - 6.78)

Section E is, in terms of geological structure, the same as section C. We expect caves formed in the phreatic or epiphreatic hydrological zone, whose tunnels are (sub) horizontal, and vadose abysses. Due to the length of speleo-genesis, the density of the abysses should increase from the beginning of the section towards the end.

Given the high karstification of limestone on the Karst Edge, we can expect a higher karstific of this area than shown by the condition of the recorded caves near the section. Namely, the Karst edge was much more studied due to numerous interventions in it (quarry, construction of the motorway).

It is expected to average up to 10 caves / km with a diameter of up to 5 m on this section.

Section F (km 6.78 - 8.11)

Section F runs in Paleocene limestones. Lithological data and data obtained from drilling indicate a lower frequency of caves. No caves have been recorded in the cave cadastre on this section, and several caves have been discovered on the motorway section, which have been partially filled with sediments. Most of the tunnels are expected to be a few meters in diameter. Some caves may also be filled with sediments. A vadose abyss up to a few meters in diameter is expected.

According to the geological profile, higher turbidity is expected at the fault zones at the km 7,090 and km 7,310 stationations.

It is expected to average up to 5 caves / km with a diameter of up to 5 m.

Section G (km 8.11 - 8.44)

A short section G runs through the Cretaceous limestones. In the cave cadastre, one cave is recorded directly along the route. In this section, sections of larger (sub) horizontal phreatic and epiphreatic caves are expected, the diameters of which can reach up to 5 meters. We also expect vadose abysses with a break of a few meters.

Higher density of tunnels is expected at km 8.30 and km 8.44, as strong fault zones are expressed here.

In general, an average of up to 10 caves / km with a diameter of up to 10 m is expected.

Section H (km 8.44 - 8.65)

Section H runs through Paleocene limestones. No caves were recorded in the cave cadastre on this section, and individual caves were discovered on the motorway section, most of which were filled with sediments. Most of the karstic features are expected to be a few meters in diameter. Some caves may also be filled with sediments. A vadose abyss, up to a few meters in diameter, upright, narrow and long crevice caves are expected, formed by pronounced faults and cracks in the SE-NW. They can be up to 2 m wide and 10 and more meters long.

Greater turnaround is expected at the km 8 + 440 station, where the route crosses strong fracture structures.

Up to 5 caves / km are expected on average, which can have a diameter of up to 5 m.

Section I (km 8.65 - 8.89)

Section I runs through limestones of Eocene age. In the cave cadastre, one cave is recorded along the route. We expect vadose abysses of a few meters in diameter. Greater permeability is expected at the contact of limestone with transition layers and flysch at chainage km 8.93.

In general, an average of up to 10 caves / km with a diameter of up to 5 m is expected.

Section J1 (km8,890-9,679)

Section J1 runs through impermeable Eocene flysch rocks and transition layers. Despite the significant carbonate binder in flysch rocks, we do not expect greater permeability.

In general, an average of up to 1 cave / km and a diameter of up to 1 m is expected.

2.3 Karst hydrology

Due to the nature of the karst aquifer, the hydrogeological interpretation of investigation is the most demanding in terms of inflows and possible water intrusions during construction and water pressures on the tunnel tube. These predictions have already been made in the investigation phases for PGD [3] and additional investigation [4] has significantly improved the reliability of these predictions.

This report summarizes the forecasts, which are important mainly from the point of view of construction of the tunnel in terms of protection against hydrostatic pressures, drainage, including exposed zones of maximum probability of water intrusion during tunnel excavation and construction of possible water diversions around karst channels past the tunnel tube.

The most reliable information on the directions and characteristics of the underground flow of karst water can be obtained through the follow-up tests. For the northern part of the tunnel, based on the results of tracking the underground flow of river Reka, we could conclude that groundwater flows through the Karst aquifer, especially towards the springs of the Timava, and only a small proportion of this water can occur in springs in the Gulf of Trieste. Through the most permeable areas of the underground flow of the River, the apparent speed of water flow at different water levels ranges between 40 and 200 m/h. Through less permeable zones within the aquifer, these velocities are lower.

When tracking in the southern part of the tunnel by injection in borehole T1-8, we proved a lateral flow towards the Boljunec spring (approximately one tenth of the injected trail was recovered). Based on the known hydrogeological characteristics of this part of the karst, we conclude that the main flow of groundwater is directed towards the sources of the Timava.

The new tracking, in which we injected a trace of uranium into the water flow in the Davorjevo abyss cave, east of the T1 tunnel, at the end of November 2018, is not yet complete and we have only preliminary results confirming the main flow of karst water from the T1 tunnel towards Cave 1 in Kanjaducah and the Labodnica cave and on towards the Timava springs in Italy and the side stream (only a small share) towards the Boljunec spring. However, no trace indicated that the water from the area of the T1 tunnel would also flow towards Rižana.

2.3.1 Groundwater level fluctuations

The water level minimums measured so far are lower than previously estimated, but most at the site of the new borehole T1-7 / 10, where in the previous investigation we could predict the water level only by interpolation. This difference is significantly smaller at the borehole sites from previous surveys. In the next piezometric borehole T1-8 / 10 is only 16 m, and in T1-10 / 10 only 2.5 m. The lowest measured and prevailing levels given in 2012 are similar to the prevailing levels measured as part of multiannual monitoring until 2018. In the area of the T1 tunnel route, low water actually drops below the level in piezometers T1-7 / 10 and T1-8 / 10 tunnel. It was also confirmed that the base level of karst groundwater is below the level of the tunnel, namely on boreholes T1-7 / 10 and T1-14 / 17. During downpours, the level also rises above the level in these piezometers. The highest values of overpressures were measured in the borehole T1-7/10, where the groundwater level rises 99 m above the level, and in the dry season it falls 39 m below the level (the total range of level fluctuations is therefore 137.80 m). Piezometers T1-8 / 10 and T1-10 / 10 show water overflow formations up to 30 and 40 above the level, otherwise the groundwater level prevails between 15 and 25 m above the level. This means that large amounts of karst groundwater are stored or flow in this pressure range above the tunnel elevation.

The course of the piezometric groundwater level along the T1 tunnel can be determined with greater reliability when measurements of groundwater level fluctuations at different water conditions in the new piezometers T1-12 / 17, T1-13 / 17 and T1-14 / 17 are still available. Previous measurements in the new piezometers show that in the central part of the syncline on the section between stations 5 + 500 and 6 + 500 (layers ANA / E) the groundwater level is even below the level of tunnel T1 (borehole T1-13 / 17). This is significantly more favourable for tunnel construction, but it is also the area of the highest probability of the occurrence of karst zones, where we can expect the overflow of high karst waters.

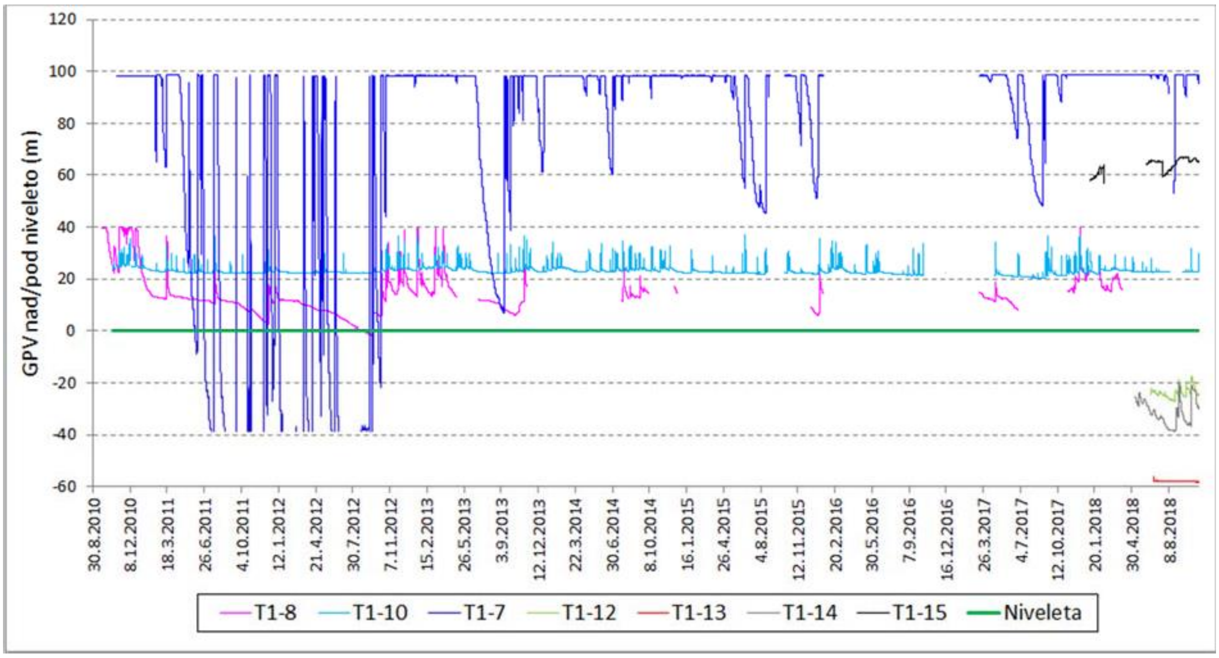


Figure 2: GPV oscillation above / below the level in the piezometers of tunnel T1.

Monitoring of groundwater level in piezometers in the area of the T2 tunnel route in Alveolinsconumulite limestones (ANA/E) showed that karstic aquifer horizons (caverns and/or cracks) occur at an altitude of about 245.5 m (T2-9/10). The presence of a cavern at a depth of approximately 40 m below the ground angle (angle 551.34 m above sea level) was also shown during the pouring experiment on borehole T1-12/17. When performing a pouring tests on borehole T1-14/17, the cavern was confirmed at a depth of 133 m below the ground (angle 392.68 m asl) in two separate experiments. The highest measured rate of pressure rise was in borehole T1-7 / 10, where the groundwater level increased by 68.80 m in one hour. Rapid pressure increases were also recorded at boreholes T1-14/17, T1-10/17 and T1-15/17, namely between 5-7 m/h.

2.3.2 Estimation of expected inflows

The longitudinal section of the considered tunnel shows the highest measured and predominantly measured groundwater levels in all the operating piezometers along the route. In the areas between piezometers, the levels, as in the PGD phase, are interpolated and partially adjusted according to the knowledge of the permeability of individual lithological members, taking into account the vertical distribution of hydrogeological units and the depth of the tunnel level. In this way, the piezometric level along the entire tunnel is estimated. Due to a more transparent interpretation of the piezometric level distribution within individual hydrogeological units, it makes sense to consider the routes of both tunnels T1 and T2 together.

As karst-fissure dominated aquifers are governed by a markedly localized increase in permeability in tectonic affected and/or karstic zones, the pressure wave propagates at a rate that depends on the resistance (inverted permeability) of the porous medium during infiltration of precipitation and generally vertical runoff. As a result, at relatively short distances along the level, rapid jumps in piezometric pressures can occur, as borehole as pressure jumps along the known thrust structure and preferential outflow paths also occur in the vertical direction. It is also evident from the analysis below that we are actually dealing with such a localized system of pressures along the level in the considered area.

In the area of tunnel T1, the course of piezometric levels after performing additional investigations is indicated by a light blue line (with a scale on the right) in the diagram below. The difference between the two predictions (comparison with PGD) is given by a thicker dark blue line (with a scale on the left side of the diagram), with negative values indicating lower newly predicted levels and positive ones indicating higher new predictions. The position of older piezometers is indicated by gray vertical lines, and the position of additional piezometers by purple vertical lines.

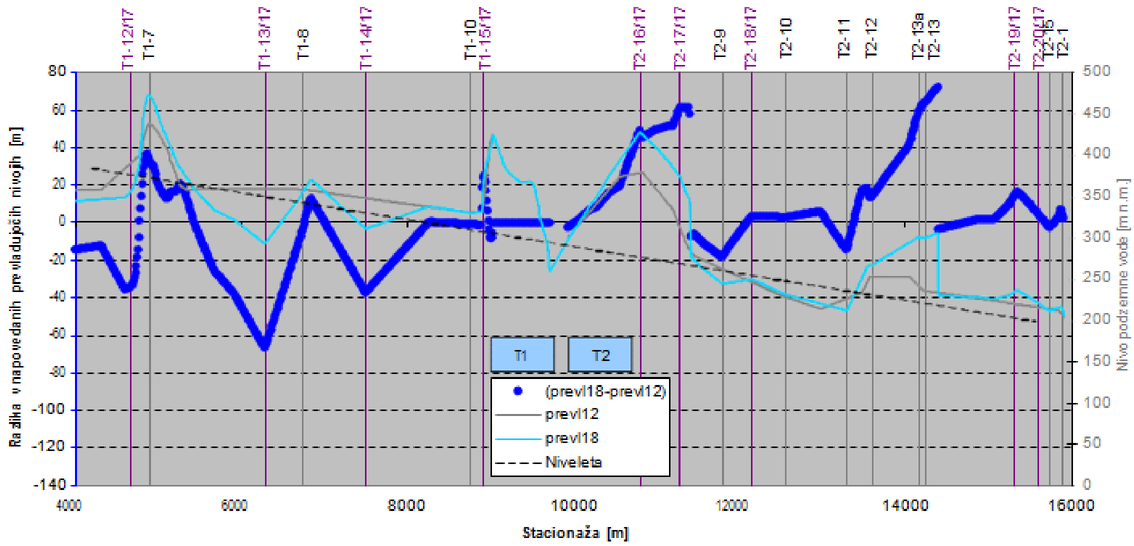


Figure 3: Predicted predominant groundwater level along tunnels T1 and T2.

With such sets of boreholes carried out in two phases, we can conclude that both forecasts of the highest groundwater levels roughly follow similar dynamics along the levels of both tunnels. However, there are significant local deviations between the two forecasts: in the T1 tunnel, these are mainly reflected in significant local reductions in measured groundwater levels (T1-12 / 17, T1-13 / 17 and T1-14 / 17) compared to the previously forecast namely both maximum and prevailing groundwater levels. In the area of flysch rocks (lower part T1 and upper part T2), both the highest and the predominant level appear higher than previously predicted. Due to the low permeability of flysch rocks, such an increase does not have a significant impact on the amount of inflows into the tunnel, nor on the choice of tunnel construction (drained, non-drained), but still indicates the difficulty of interpolating levels over long distances.

Due to the above, the estimated piezometric groundwater levels along the route of tunnels T1 and T2 between individual measuring points should be considered as rough estimates of possible values. The perceived variability of piezometric pressures in space probably indicates only a part of the complexity of the karst-fracture system.

From the results of basic and supplementary hydrogeological investigation, we can conclude that the construction of the T1 tunnel will mostly take place in dry to wet conditions, and to a lesser extent in wet or leaking conditions, and only in some places in water flow conditions.

2.4 Impact of groundwater on tunnel construction

2.4.1 Estimation of inflows during excavation

Non-stationary calculation methods were used to estimate the expected inflows on an individual 25 m long tunnel section. Also in the case of the Lembke calculation, we assumed two variants of the permeability value (Ksrednji + st. Dev and Ksrednji). As can be seen from the results, a wide range of inflows in the T1 tunnel route can be expected. Due to the characteristic variable permeability and the appearance of tectonic zones, pressure relief will occur only at the point of penetration through the tectonic or some more permeable zone. In these cases, larger point inflows can be expected, at least in the form of a leak or even a water flow.

It should be noted that in some places the hydrogeological conditions can be significantly worse in the case of clash with caverns or karst caves filled with water. Larger sudden inflows of water can also be expected from caverns already filled with water. Point inflows in such zones could, according to a rough estimate, reach intrusions of hundreds of liters per second of flow, which would decrease significantly over time (on the order of 10 days) due to the discharge of more porous parts of geological strata, depending on the volume of voids and trapped underground water.

Complementary investigations have confirmed that the T1 tunnel in the limestone massif will run in the area of intense groundwater fluctuations, and in individual sections it will be constantly below the groundwater level. To date, the highest expected pressures in the limestone part of the tunnel reach approximately 99 m above the level of the T1 tunnel. During intense rainfall events, a rapid increase in pressures of up to 69 m/h can be expected locally, but mostly around 5 m/h.

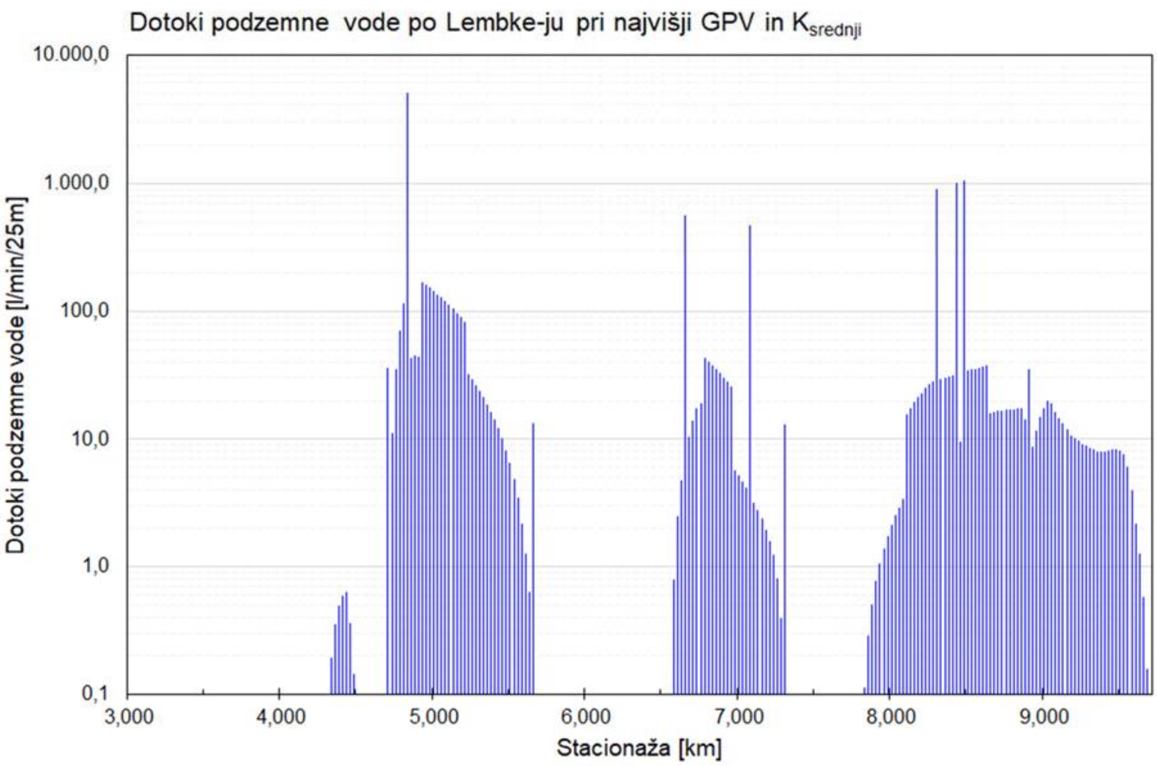


Figure 4: Lembke water inflows at the highest GPV and K mean.

On the longitudinal geotechnical profile, 13 sections are marked, where greater precautionary measures against water intrusions must be foreseen in advance. Water intrusions at the breakthrough of these zones can reach an instantaneous flow of even hundreds of litres per second.
Taking into account that the construction of the T1 tunnel will take place from both directions, we can predict the occurrence of such sections at the following stations (± 50 m):

- Progress from the north: km 4 + 700, km 4 + 825, km 5 + 250, km 5 + 650, km 6 + 250.
- Progress from the south: km 8 + 900, km 8 + 650, km 8 + 475, km 8 + 300, km 7 + 300, km 7 + 075, km
- 6 + 675, km 6 + 650.

On these sections it is necessary to epect that the inflows of water from the aquifer will be larger and more constant, which is why it is necessary to envisage undrained tunnel construction at individual sections (without external drainage and with the tunnel lining resistant to expected hydrostatic pressures).
With the planned construction of drained and non-drained sections, between 69 - 133 l/s at the highest groundwater level and approximately 56 - 106 l/s at the prevailing groundwater level would flow out of the entire tunnel during the excavation. Significantly lower inflows are expected during the operation, or in the long run, namely approximately 13 - 21 l/s at the highest groundwater level and 11 - 17 l/s at the prevailing groundwater level.

2.4.2 Estimation of the amount of water intrusion during tunnel excavation

Possible water intrusions must be taken into account in the event of excavation penetration into caverns filled with water and on the section defined by chainages km 8 + 840 and 8 + 980 (or in the opposite direction in case of advance from the south), where the lithological boundary has been established between limestone (ANA / E), transition layers (PP / E) and flysch (F / E). When excavating from limestone to flysch layers, we can expect poorer rocks in flysch layers and a relatively high initial water pressure (up to 120 m), which is relieved very quickly. When penetrating from flysch layers into limestones, we expect more favourable rock and a smaller difference in pore pressures, but these can be also within the karstic zones with very high permeability.

In the PGD phase, therefore, estimates of the initial amounts of water intrusion were made according to the Perrochet equation. Calculations were performed for different input data and are therefore representative even after supplementary investigation, as the input data did not change. Calculations show that the initial inflows can be very large if there is a 20 m wide zone with good permeability K> 10-5 m/s.

Values for time t = 3,600 s (1 hour), which are more appropriate due to the excavation speed of the tunnel, indicate very high inflows of water into the tunnel, even up to 400 l / s, taking into account good permeability.

Table 11: Calculations of water inflows into the tunnel according to the Perrochet method.

Parameter	Values for different input data			
S - storage coefficient	0,00	0,001	0,0001	0,00001
t - time [s]	10	10	10	10
L - section length [m]	20	20	20	20
K - permeability coefficient [m/s]	1,00E-	1,00E-05	3,00E-06	2,43E-07
h - height from the center of the tunnel to the groundwater level [m]	120	120	120	120
r - tunnel radius [m]	4,7	4,7	4,7	4,7
Perrochet				
q- inflow of water into the tunnel [m^3/s]	1,52	0,353	0,069	0,006
t - time [s]	360	3600	3600	3600

q- water inflow into the tunnel [m3 /s]	**0,43**	**0,063**	**0,015**	**0,001**

2.4.3 Probability of water intrusion locations through karst canals

The current monitoring, in combination with supplementary investigations, enables a more definite interpretation of the connection between structural geological elements and the occurrence of fissure systems and karst caverns. The exact position of the karst canals cannot be predicted, but it is possible to point out the conditions that increase the probability of such a formations:

- Larger inflows or intrusions of water through karst canals can also occur in the unsaturated zone, but only during major infiltration and subsequent seepage.
- In the saturated zone, intrusions may occur after the transition of the top heading from solid limestone to cracked or karstic, which is most likely to cross fracture zones or karstic cracks, especially between differently permeable layers.
- there is a higher probability of water intrusions or increased inflows also in the zones of increased infiltration in the areas of karst fields, or dry karst valleys and joints of flysch and carbonate layers.

Based on the above findings, the areas of probability of water intrusion through karst canals were classified into four classes (small, medium, large and highest probabilities). It should be noted that intrusions in other areas are also possible, but less likely.

1. Area of low probability of water intrusions through karst channels: flysch area in the rear part of the tunnel, from km 8 + 960 onwards.
2. Areas of medium probability of water intrusion through karst channels were determined according to the surface karstification, estimated according to the IDPR method and karstification estimated according to the relief on the TTN5 map.
3. Areas of higher probability of water intrusion through karst canals were determined according to the identified possibilities of the occurrence of empty spaces below the surface based on the results of geophysical investigation
    - km 4 + 400 to 4 + 600, 4 + 900 to 5 + 500 and 6 + 700 to 7 + 700: the presence of more pronounced karst formations is assumed, even at greater depths,
    - km 3 + 725 to 3 + 900: an area where, according to geoelectrical investigation, open underground spaces of larger dimensions are expected. The karstification on this section is also assessed by IDPR analysis, and this section is also defined as very karstified in terms of the number of caves (ZRC SAZU) and the density of sinkholes (ZRMK),
    - km 7 + 800 to 8 + 000 and 8 + 350 to 8 + 800: determined on the basis of geoelectric profiles. We assume that in these zones there is a stronger infiltration of rainwater from the area of Vrhpolje field and Krvavi potok.
4. Areas of the highest probability of water intrusion through karst canals were predicted in sections where fracture zones (based on forecast geological profile) and caverns are expected at the level of the caves filled with water. Due to the fault zones and the width of these, the areas of the highest probability of water intrusion through karst canals were widened for 50 m on the each side of the predicted stationing of the karstic formations.

2.5 Measures to reduce impacts on groundwater

2.5.1 Technical design of the tunnel

The T1 tunnel will take place in the jointed rock within the zone of occurrence of fissure systems and a relatively well-karstified massif. The interpretation of structural geological investigation shows that most of the T1 tunnel will be excavated within limestones of the Cretaceous, Paleocene and Eocene ages. Layering is present in these limestones, but there are no physical discontinuities in the form of appertures within the layer. In the LIB/K - Pc formation, lamination of different rock colours is visible, which is not reflected in physical discontinuities. Cracks are the most important element for the formation of the initial horizons and the karst channels. These are usually subvertical, that is, they are more important in the subvertical direction and much less in the subhorizontal direction in terms of transmissivity. The fracture zones in the tunnel are connected mainly to subvertical fault zones or thrust structures, and to a much lesser extent to stratification. Cretaceous and Paleocene limestones include a significant proportion of organic matter, which means that the process of dissolution in these layers is even more bound to fissure zones or cracks. The proportion of organic matter does not change within an individual stratigraphic sequence, so that the deviations may be more pronounced in the vertical direction.

The findings so far show that more developed karst channel networks are expected mainly in ANA/E strata and Cretaceous limestones, while in Paleocene limestones karst channels are more locally limited, but this feature decreases with depth below the surface and near sinkholes or drainage zones.

In the area of the tunnel, it is expected that the systems of cracks and karst caverns may occur mainly at faults and fracture structures, which are predominantly subvertical in the considered area. In the subhorizontal direction, we can expect the appearance of karst cracks and caverns, especially along the lithological boundaries. During construction, we expect likely intrusions of karst groundwater from karst canals (depending on water levels), especially:

- at break zones,
- at the transition between reed (TF) and alveolar numulitic layers (ANA / E),
- at the transition between the transition layers (PP / E) and the alveolar numulitic layers (ANA / E),
- on a section approximately at km 6 + 650, where the karst channel is drilled through with a T1-8 borehole.

On such sections, we envisaged the implementation of groundwater bypasses, as they can be largely correlated with the development of drainage systems and the development of cave spaces/channels.

Undrained sections with the implementation of the culvert were planned wherever we can expect more significant fissures with larger water inflows, taking into account the condition that the expected height of the water column on this section does not exceed 100 m. In cases where the height of the water column exceeds 100 m, contact grouting will be carried out with the aim of reducing the water permeability of the rockmass to a satisfactory level. However, since the fissuring of the rock mass is not continuous, but occurs in some places related to subvertical fissures, cracks and joints, we envisaged the changing of undrained and drained parts in individual sections along the tunnel. Drained sections of the T1 tunnel are planned on those sections where lower permeability or lower fissuring and karstification have been determined, i.e mainly in flysch and transition layers, and longer individual sections in low water permeability limestones. It should be emphasized that the occurrence of sections with karst canals cannot be accurately predicted, as they can occur anywhere on the route, including sections where a drained tunnel is planned. It follows that it is during construction necessary to carry out groundwater bypasses in all sections where the tunnel will cross the karst channel with a constant or occasional flow of groundwater. In sections where the route of the tunnel will cross the fault zone or in sections where karst channels appear, for which it is clear that no water flows in them, a by-pass will most likely suffice.

In the event that the tunnel crosses a karstic feature with a constant or occasional flow of water, a bypass along the tunnel tube (bypass) will also have to be carried out. The bypass must be constructed in such a way as to enable the flow of water in the same cross-section as the karstic feature had in its natural state or with a maximum of 10% reduction in transmissibility. Such karstic feature must not be backfilled, even if they clash with the tunnel, without ensuring by-pass capacity for an equivalent outflow of water.The possibility of the occurrence of cave channels with the flow of water must also be taken into account between the exposed thirteen sections and even in such cases groundwater by-passes must be carried out. From the site investigations we were able to predict in the T1 tunnel only one such cavern filled with water at a station of approximately km 6 + 600.

2.5.2 Implementation of groundwater by-pass in karstic canals

In areas where the tunnel tube will clash with and partially or completely cover the existing groundwater conductor (cavern, cave, abyss), a by-pass for groundwater circulation is envisaged. The main purpose of the construction of the by-pass is to ensure the smooth flow of groundwater through the existing conduction channels, thus ensuring:

- the water protection aspect, ie. maintaining the groundwater flow regime, and
- geotechnical aspect or prevention of stagnation of vertically permeating water and creation of additionally elevated hydrostatic pressures in the karst aquifer with a low degree of highly localized porosity.

Due to the appearance of conductive structures of different sizes and directions of propagation, the cross-sections of these structures with a tunnel tube will be able to cover a relatively large range of possible values, which will dictate the size of the required by-pass. Also, when sizing them, it is necessary to take into account the size of the highest flows through the natural conductor, as well as the location of the conductor (saturated, unsaturated zone) and the presence of accompanying cracks or other small connected joints in the immediate vicinity.

In the area of the T1 tunnel, we have identified 13 such sections where groundwater by-passes may be required. These sections are defined as the sections with the highest probability of groundwater intrusion through karst canals. In each such section, we anticipate the need to make by-pass by providing at least the same cross-section as the intersected natural karst channel. It should be emphasized that the occurrence of karst channels is not exclusively related to strong fissure zones, but can also develop in the case of weakly expressed fissures. Due to this, the tunnel can also encounter the karst channel on intermediate, presumably drained sections. Also in this case, a by-pass will have to be carried out if the tunnel closes the karst channel with a constant or occasional flow of groundwater.

2.5.3 Other measures

Restrictions are mainly related to protective measures during construction and partly also to the conditions of design of the tunnel tubes themselves, as follows from the hydrogeological conditions and the adopted conditions on the protection of water resources.

In order to protect the good quantitative and chemical status of groundwater in the area in question, it is necessary to implement the following measures during construction, which are partly listed in the Decree on the national location plan for the second track on the Divača - Koper section. (Ur.l. RS, No 43/2005):

- the composition of the excavated material is monitored in terms of the content of hazardous substances. In the event contents exceeding the limit values for excavated material, which are determined in accordance with the provisions of the regulations of the Republic of Slovenia, another method of disposal of excavated material determined by regulations shall be defined before continuing excavation
- the transport of excavated material to a temporary and permanent landfill must be ensured along already used paths in the area of the railway line construction site (in the tunnel and in the area of temporary landfills and transport routes) and only faultless machinery and transport equipment may be used
- maintenance of devices and equipment in the construction site is carried out only on paved platforms, which must have arranged drainage and collection of rainwater and other liquids, which is regulated by a suitable system of collection and drainage of rainwater with a settling tank with hardened bottom and oil trap
- if cracks and other forms of inhomogeneity of geological substrates are discovered during the excavation of the tunnel, which may lead to the direct contact with groundwater, excavation on this section must be suspended until an assessment of the threat to groundwater has been made
- Only construction and insulation and other materials may be used which, due to their chemical properties, do not pose a permanent danger to soil and groundwater.
- In the event of groundwater intrusions, the contractor is obliged to stop the works and take all measures to reduce the damage and to continue the work after checking their effectiveness
- Waste and precipitation wastewater must not be discharged into the ground. Waste and storm water must be treated so that the level of pollution does not exceed the limit values defined in the applicable regulation. For these purposes, it is necessary to build appropriate settling tanks (if necessary with oil traps), to carry out neutralization or to meet the requirements of the said regulation with the help of other appropriate technology.
- Specific substances to be used in construction, such as concrete admixtures, etc., must be specifically mentioned in both the design and construction phases
- in case the excavation technology will involve blasting, it is necessary to use such explosives that do not cause emissions of harmful substances before, during or after use
- In order to ensure the quantitative status of groundwater in karst aquifers, the tunnel must be constructed in such a way that it will not drain the aquifer. It is also mandatory to bridge the caverns during construction, thus maintaining the natural flow regime
- Due to the construction in the water protection area, it is also necessary to prepare a risk analysis for groundwater pollution, which will confirm the adequacy of protective measures for the protection of groundwater. In the considered area, in order to determine the quantitative state of groundwater, it is necessary to perform monitoring on all performed piezometers via electronic limnigraphs.

3 PROTECTIVE MEASURES DURING CONSTRUCTION AND DESIGN REQUIREMENTS

For the needs of safe construction of the second track of the Divača-Koper railway line, and from the point of view of the impacts on water resources »Analysis of the risk for groundwater pollution and water catchment of Rižana due to the construction of the 2nd track of the Divača - Koper railway line, no. K-II-30d / 1-1 / 62, dated 6.12.2012, Geological Survey of Slovenia and Institute of Mining, Geotechnology and Environment [10] was prepared. It provides for measures to protect water resources during the construction of the facilities. The meassures are listed below.

The construction site must be arranged in such a way that the probability of pollution is reduced to a minimum. Soil interventions and the implementation of the designed works are to be carried out in such a way that the smallest possible surface area will not be affected. All areas of soil interventions must be defined before the start of the works. They can only be carried out under the constant supervision of the site manager.

For temporary traffic and construction areas, priority should be given to existing infrastructure and other handling areas, which must also be defined before the start of work.

Contractors, supervisory staff, workers and anyone coming to the site must be made aware of groundwater protection measures. In case of unforeseen events, such as an oil spill or pollution of the soil surface with petroleum products or any other hazardous substances, the rules of procedure (rules, contingency plan) must be prepared, which must also be harmonized and linked to the HACCP design of the water resources manager Rižanski vodovod Koper. All such events must be recorded in the construction log. This document must specify the authorized persons who are responsible for organizing the intervention 24 hours a day.

During construction, it is necessary to provide regular hydrogeological control and monitoring, and in karst areas also karst control and monitoring.

The composition of the excavated material in terms of the content of hazardous substances must be monitored regularly. In the event that contents exceed the limit values for excavated material in accordance with the provisions of the regulations of the Republic of Slovenia, another method of disposall of the material determined by regulations shall be defined before continuing the excavation.

The transport of the excavated material to the temporary and permanent landfill must be ensured along already paved paths with regulated drainage of wastewater.

Maintenance of devices and equipment in the construction area is to be carried out only on paved platforms, which must have a regulated drainage and collection of rainwater and other liquids, which is regulated by a suitable system of collection and drainage of rainwater with a hardened bottom settling tank and oil trap that can retains the total amount of fuel flowed to supply the working machine.

Only construction and insulation and other certified materials, which due to their chemical properties do not pose a permanent danger to soil and groundwater, may be used. If during the excavation of the tunnel open rock joints and other forms of inhomogeneity of the geological structure are detected, which may mean direct contact with groundwater, excavation on this section must be stopped until an assessment of the threat to groundwater has been made.

In the event of a groundwater intrusion, the contractor is obliged to stop the work and take all the measures to reduce the damage, and to continue the work after checking their effectiveness.

To ensure the quantitative status of groundwater in karst aquifers, the tunnel on critical sections will be constructed in such a way that it will not drain the aquifer. Bridging (bypasses) will also be carried out in the cavern areas, which, in addition to the non-drained construction, will also preserve the natural regime of groundwater flow.

Rapid and effective action is very important in the event of a hazardous accident. At the same time, we must be aware that on the karst soil between Divača and Koper, the pollutant can immediately drain through the jointed and karstified rock to a greater depth. Subsequent remediation works are practically not feasible. In the Rižana water protection area, the pollutant can reach water supply catchments within two days and endanger the safe water supply of the Slovenian coastal area.

Regular hydrogeological control and monitoring will be provided for the entire construction period, as well as karst control and monitoring in karst areas.

Action in the event of an accident depends on the location and extent of the pollution, and any spillage must be handled in accordance with the following measures:

a) Secure and mark the scene of the accident accordingly.
b) If possible, remove all contaminated soil immediately.
c) Prevent fire.
d) In case of fire, it is not recommended to extinguish with water, but with powder or foam.
e) Sprinkle the spill site with absorbent.
f) Depending on the characteristics of the absorbent substance (when saturated, it changes colour) remove the absorbent substance in such a way that it does not pollute the environment.
g) In the event of a spill of a hazardous substance, the absorbent must be spread thickly along the edges of the spill to prevent the spread of the stain.
h) The accident must be notified to the construction information and control centre.
i) Immediately after the accident, it is necessary to inform the operator of the Rižana water source that it is necessary to start the implementation of preparations and measures, which must provide that the first arrival of pollution is possible within 35 hours after the spill.
j) The contractor must immediately excavate the contaminated soil and take it outside the water protection area (to a hazardous waste landfill, or temporarily to a paved and covered area) and in accordance with the Rules on Waste Management (Ur.l.RS, No. 84/98).

In the event of the penetration of fuel, lubricant or other substances, which could not be completely removed by absorption and excavation in the karst terrain, it is necessary to determine how much pollutant was lost. The authorized laboratory of ZZV KP and hydrogeological control prepares a program for further monitoring of the situation to determine the possible penetration of pollution into the pumping station on the target parameters that could be due to pollution. At the same time, it is necessary to take a soil sample and perform an analysis of the contaminated soil so as to ensure the traceability of the actual pollution from source to source.

3.1 Excavation material and transport

Safeguard measure	Design and contractual requirements
The composition of the excavated material in terms of the content of hazardous substances must be monitored regularly. In the event that contents exceeding the limit values for excavated material are established in accordance with the provisions of the regulations of the Republic of Slovenia, another method of disposal of excavated material determined by regulations shall be defined before continuing excavation.	The contractor is in charge of monitoring, who must prepare a monitoring and reporting program before the start of the excavation, which must be approved by the Engineer.
The transport of excavated material to a temporary and then permanent landfill must take place along paved paths with regulated drainage of storm water.	The requirement is met in the design of access roads, which provides for asphalting and appropriate drainage.
On existing sections of paved paths that will be used for transport, it is necessary to restore drains, strengthen culverts and ensure safe transport over existing facilities (strengthen bridges, viaducts).	Before using the existing infrastructure, the contractor must carry out an inspection and inventory of the existing condition and proposals for possible preliminary improvement or subsequent remediation. The analysis of the condition and the remediation design are approved by the engineer.
Emissions of dust and construction materials from transport and construction surfaces must be prevented by wetting these surfaces in dry and windy weather.	For this purpose, the contractor must provide all the necessary machinery and means for operation.

3.2 Construction machinery and cement plants

Safeguard measure	Design and contractual requirements
Only faultless construction and other machinery and transport equipment may be used in the construction area of the railway line for the second track (in the tunnel and in the area of temporary landfills and transport routes).	Duty of the contractor.
Maintenance of devices and equipment in the construction site is carried out only on paved platforms, which must have regulated drainage and collection of rainwater and other liquids, which is regulated by a suitable system of collection and drainage of rainwater with a settling tank with hardened bottom and oil trap, which can hold the entire amount of fuel flowed to supply the working machines.	The contractor is responsible for the preparation and implementation of the construction site. To this end, the construction site development design must provide for appropriate work platforms for this purpose and take them into account in the costs of construction site development. He is also obliged to regularly or, if necessary, clean platforms and separators and check their operation.
Municipal wastewater will not be discharged by sinking.	The Contractor shall take due account of the arrangement of construction sites and costs.
Rainwater will be treated so that the level of pollution does not exceed the limit values defined in the applicable regulation. Appropriate settling tanks (if necessary with oil traps) will be built for these purposes, neutralization will be carried out or it will be necessary to meet the requirements of the said regulation with the help of other appropriate technology.	As part of the arrangement of construction sites, the contractor must provide all the necessary facilities.
During standstill (non-operation), construction machinery will be parked on a paved surface with regulated controlled drainage (retention, cleaning) of water.	It is the duty of the contractor, who must also take this into account in terms of costs and time norms.
During pre-drilling in areas with a higher probability of karst formations filled with water, all construction machinery that is not necessary in the pre-drilling process must be	It is the duty of the contractor, who must also take this into account in terms of costs and time norms.

removed from the tunnel or at least behind the water door.	
Waters containing cement laitance (water from cement plants, washing vehicles from the construction site ...) are decanted and subsided up to a maximum of 1,000 l/day after settling. If sinking is not possible, the said waters may be discharged into surface waters, but not more than 1,000 l/day, or may be discharged. Drainage of these waters into surface waters is prohibited without prior permission. In sensitive areas (VVO, karst areas) and areas where sinking is not possible, wastewater from cement plants and washing water must be properly treated. The purpose of water treatment is to neutralize and purify water, which must be proven by regular measurements of pH value and content of suspended particles.	The contractor must envisage appropriate facilities for this purpose in the construction site development design and take them into account in the costs of construction site development costs. Regular cleaning and operation checks are required.
The flow of fuel into construction machinery will be carried out only on paved surfaces with regulated drainage of water through settlers and oil traps. Fuelling is prohibited in the tunnel.	It is the duty of the contractor, who must also take this into account in terms of costs and time norms. The permitted amount of fuel in the tunnel is 200 l.
Biodegradable lubricants and oils should be used as much as possible.	Duty of the contractor.

3.3 Building materials

Safeguard measure	Design and contractual requirements
Only construction and insulation and other materials will be used which, due to their chemical properties, do not pose a permanent danger to soil and groundwater.	The contractor must offer and install the appropriate materials and elements in accordance with the list of works, technical specifications and the request.
Only non-alkaline accelerators will be used when using shotcrete.	The contractor must use only non-alkaline accelerators in accordance with the list of works, technical specifications and the requirement.
When injecting, the use of substances that do not affect the quality of water in the aquifer is permitted.	Prior to carrying out the work, the materials must be approved by an engineer.
Sealants, sealant pastes and corrosion protection will not contain PCBs.	The contractor must take this requirement into account when choosing the equipment and technology of execution.
The use of construction waste to fill sinkholes and caverns is prohibited.	The design does not envisage filling caverns with construction waste. These must be properly processed and deposited.
As part of the implementation design, a concrete design must be prepared, in which additives that do not cause the leaching of substances dangerous to the aquatic environment and human health will be envisaged. The concrete design must be properly revised.	The Contractor shall take the requirement into account in the tender estimate and, prior to the execution of the works, provide an appropriate concrete design approved by the Engineer.
The use of auxiliaries (oil, lubrication of formwork, etc.) must be provided in such a way that it is not possible to rinse these agents into water.	The tender will require the use of biodegradable lubricants. During the execution, the Client will control the use.
Concrete admixtures should not be stored in tunnels or anywhere where they could come into direct contact with water.	The additives shall be stored appropriately in the area of the concrete plant, where all protective measures against spillage are provided.
There must be no loss of cement laitance or grout during the construction of the tunnels. If there is a loss of injection mass, the grouting technology or injection mass must be replaced immediately	The injection mass and grouting technology will be determined during construction according to specific conditions, taking into account the stated protective measure.

3.4 Hazardous and other substances that may cause pollution

Safeguard measure	Design and contractual requirements
For the needs of hazardous waste disposal (used oil, emulsions, decanter contents, oil trap filters ...), special containers will be present on the construction site.	The contractor must arrange the construction site in accordance with the protection measure, remove this hazardous waste from the protected area on an ongoing basis and take these costs into account in the costs of arranging construction sites.
Waste separation is carried out at the construction site. In particular, separation is foreseen for recyclable waste. These are: plaster, insulation, paper and cardboard, iron and other ferric metals, non-ferrous metals, glass, etc.	The contractor must separate and dispose of waste and take these costs into account in the costs of arranging construction sites.
A special space for storing hazardous substances (oils, emulsions, cleaning agents) will be ordered at the construction site. The space will be covered and equipped with a tank to hold the entire volume of substances stored in it. The storage of such substances in the tunnel is prohibited.	As part of the site development design, the contractor must arrange an appropriate space on the portals with a facility that satisfies the measures.
Storage of explosives in the tunnel is allowed only in places where there is no direct connection to groundwater. It is essential that the explosives are stored on the dry side of the water gate and at the same time in the most suitable area with the lowest probability of water inflows and intrusions.	As part of the site development design, the contractor must arrange an appropriate space on the portals with a facility that satisfies the measures.
Neutralization equipment will be present at the construction site throughout the construction. The amount and location of equipment should be determined depending on the sensitivity of the location and the amount of the substance that may cause contamination.	The contractor must provide in the TEE appropriate protective measures with regard to his equipment and construction technology.
After the use of neutralizing agents, the soaked agent is immediately removed, stored in plastic barrels and taken to a suitable location (hazardous waste management centre).	The contractor will take these works into account in the construction site costs.
At each construction site, one person will be in charge of handling all substances that may affect surface or groundwater. This person must always be available.	The client provides a competent service and a responsible person.
The contractor must have a list at the site of all substances and hazardous substances that can spill into the ground and cause groundwater pollution. Safety data sheets and toxicity data must be available on site for all toxic substances.	Provided by the Contractor as part of the security design.

3.5 Drainage of wastewater and backwaters

Safeguard measure	Design and contractual requirements
To prevent the loss of wastewater into the aquifer, the drainage ditches must be hardened and sealed. The water that will appear at the head of the tunnel will be treated as wastewater due to the presence of construction machinery, drilling and blasting residues. All collecting drainage shafts at the front of the drill must be properly dimensioned and watertight. All water must be pumped up the tunnel or drained by gravity through paved or sealed channels.	At the head of the excavation or in the area where the works are carried out, the contractor must ensure the separate collection of technological water and its pumping through tubes to the neutralization facilities on the portal. Gravitational descent through water canals is also allowed.
In the event of any intrusion of water and sludge, all water	In the VVO areas, the excavation will be carried out only

must be channelled and drained outside the tunnel in such a way that this water does not leak into the aquifer.	upwards in such a way that, in the event of water intrusions, it will gravitationally drain out of the tunnel.
Temporary wastewater collectors will be present on all portals of tunnels T1 and T2. Their implementation will be waterproof. The volume of the temporary reservoir varies from location to location. Due to the way the tunnel is built, the temporary reservoirs on the southern portals of the tunnel will be larger than the northern ones, as they will take over the gravity-drained wastewater from the entire length of the tunnel and the service tube after the breakthrough.	The contractor must envisage appropriate facilities according to his technology of execution of works.
During construction, regular chemical monitoring is required at the outflows of the hinterland waters. The purpose of monitoring is to verify the suitability of backwaters coming from the site in the tunnel before discharge into surface waters.	Monitoring will be provided as part of the technical monitoring of the construction [8].
In the event of an intrusion of groundwater, all the water that has accumulated between the top heading and the water gate will need to be pumped out immediately so that the accumulated water does not drain lower into the aquifer. The water is pumped into a temporary reservoir in the area of the nearest portal.	As part of the design, the contractor will provide funds for the installation and use of the pumping system.

3.6 T1 tunnel excavation dynamics

Safeguard measure	Design and contractual requirements
The dynamics of construction of the secondary lining should follow the primary lining as much as possible and as much as possible in the sense that the quantities of drained water are reduced as much as possible.	The measure is sufficient for the contractor, who must take into account the requirement as much as possible with the phased construction.

3.7 Monitoring of groundwater chemical status during construction

Safeguard measure	Design and contractual requirements
During construction, the quality of the discharged water at the discharges from the reservoirs into the environment and at the Rižana spring is regularly monitored. The pH, turbidity, water conductivity and water temperature are continuously measured and automatically recorded. Water samples for analysis for mineral oils, aluminium, lead, lithium, nitrogen (nitrate, nitrite, ammonium), sodium are taken regularly once a month. Occasionally, with significant changes in pH, turbidity, water conductivity, and additional water samples are taken and analysed for the previously listed parameters.	Appropriate supervision is provided by the Client through a separate contract for technical monitoring of construction. In addition, environmental monitoring and monitoring of the RV operator are carried out.
A more detailed monitoring program must be developed in the PZI. The program is adjusted during the construction works according to the actual situation. Adaptation is proposed by hydrogeological monitoring and an accredited chemical laboratory.	The proposed program is set out in the technical observation design for the construction of the tunnel and will be determined by a tender for a separate contractor for technical observation.
In the case of water inflows into excavations, in-situ measurements of Eh, oxygen content, conductivity, pH and temperature control the possibility of an unstable water composition that could be aggressive to concrete or subject	See instruction above.

to salt deposition. If necessary, such waters shall be analysed in more detail and additional protection measures shall be envisaged.	

3.8 Measures to protect the maintenance of the quantitative status of groundwater during construction

Safeguard measure	Design and contractual requirements
If during the excavation of the tunnel open rock joints and other forms of inhomogeneity of geological bases are discovered, which may mean direct contact with groundwater, excavation on this section must be stopped until an assessment of the threat to groundwater has been made.	Groundwater management is defined in the Technical Specifications Tunnel excavation and support **Error! Reference source not found.** and Special measures for tunnel construction [13].
In the event of groundwater intrusions, the contractor is obliged to stop the works and take all measures to reduce the damage and to continue the work after checking their effectiveness.	See instruction above.
To ensure the quantitative status of groundwater in karst aquifers, the tunnel on critical sections will be constructed in such a way that it will not drain the aquifer. Bridging (bypasses) will also be carried out in the cavern areas, which, in addition to the non-drained construction, will also preserve the natural groundwater flow regime.	The tunnel lining is dimensioned to the anticipated hydrostatic pressures. Additional measures are also provided to seal transitions from non-drained to drained sections.
In the event that the tunnel crosses a cavern with a constant or occasional flow of karst water, a bypass will be made along the tunnel tube, which will maintain the same cross-section of the cavern for the flow of karst water as it was in its natural state.	The design solutions envisage the installation of a bypass, which will enable the flow of water in the same way as before the intervention.

4 DRAINED AND NON-DRAINED SECTIONS

4.1 Transition between the drained and non-drained (undrained) part of the tunnel

4.1.1 General

From the point of view of impacts on water resources, the "Analysis of the risk for groundwater pollution and water catchment of Rižana due to the construction of the 2nd track of the railway line Divača - Koper", no. K-II-30d/1-1/62, dated 6.12.2012, was written up by Geological Survey of Slovenia and the Institute of Mining, Geotechnology and the Environment, hereinafter referred to as Risk Analysis [10]. It derives measures for the protection of water resources during the construction of the facilities that have been used to develop several design solutions for the tunnel. The first design solution envisages the construction of a drained section of the tunnel, namely only in areas where, with the help of geological and geotechnical monitoring and hydrogeological measurements, it has been established that the permanent intake of water from the environment will be negligible or within permitted scope.

The design solution in the form of a drained section of the tunnel is based on the need to release hydrostatic pressures, because otherwise they would have to be taken over by the inner lining. The release of hydrostatic pressures has a significant beneficial effect on the durability of the tunnel, while at the same time reducing the cost of its construction. For this reason, most tunnels are designed as drained with the help of a drainage system comprising a waterproofing layer (waterproof membrane and geotextile or plug foil) and longitudinal side drainage tubes as shown by the characteristic cross section of the tunnel.

Another design solution is a non-drained (also referred as undrained) section of the tunnel, which is planned in areas where, with the help of geological and geotechnical monitoring and hydrogeological measurements, it has been established that the permanent intake of water from the environment is not negligible, ie. exceeds the allowable range set by the Risk Analysis. Based on previous geological and hydrogeological surveys, certain sections of the tunnel were designed in a non-drained design, with the inner lining dimensioned in such a way that it can withstand the hydrostatic pressures of the water. There were two reasons for this:

a) in given karst conditions, the water flows through a network of connected vessels, so fluctuations in the water level can be very fast, which makes the tunnel drainage capacity temporarily inadequate, and
b) if the drainage of the tunnel causes intake of too much water, it can deplete water resources in the long run.

For the non-drained section, the tunnel was designed to be almost circular in shape, and the inner lining was appropriately dimensioned so that it could take up to 100 m of water column pressure. A sealing area within the rock mass, utilised with cement grouting, is provided between the drained and non-drained tunnel section. The rock mass at the transition area is injected over a larger length if necessary to ensure virtually complete water-tightness.

The need for a drained or non-drained section of the tunnel will be preliminarily determined during the pre-drilling, during the excavation of the top-heading. The final decision on the type of section (drained or non-drained section) will be confirmed after the completion of the hydrogeological monitoring, which will be explained in detail below. The following influencing factors will also be taken into account when deciding on the type of tunnel: a) passage of the tunnel through or near the karst formations, b) passage of the tunnel through strongly fissured or jointed rock mass and c) passage of the tunnel through the intertwining presence of karst formations and strongly fissured or jointed rock.

The expected water pressure levels on an individual section play an important role in making a decision (drained vs. non-drained). In the event that the passage of the tunnel through areas where water pressures may be higher than those that the inner lining can safely withstand (the upper limit is a pressure of 10 bar, which corresponds to a water column height of 100m) is necessary, using appropriate grouting measures, to reduce the water permeability of the surrounding rock so that the permanent intake of water from the environment will be negligible or within permitted scope. Once this condition is met, a drained variant of the tunnel can be constructed on this section. Given that the effective uptake of high water pressures is only possible with an approximately circular shape of the inner lining, the grouting process is also used for all adits between the tubes and also where niches are provided which cause the inner lining to deviate from the circular shape. Additional geological, hydrogeological and karstological analyses will be carried out, if necessary, to reach a final decision.

4.1.2 Section type selection method (drained vs. non-drained)

The choice of a suitable variant of the tunnel shape is related to the type of permeability of the surrounding rock, taking into account the proximity of karst formations. The porosity that leads to permeability of rock can be matrix (with low cracking and absence of karst formations), fissure (predominant in relation to the matrix in the absence of karst formations) and channel (the predominant water flow is through karst formations).

Figure 4.1 shows a decision diagram that deals with individual cases, taking into account the interplay between different types of porosity. There are two key criteria in decision-making:

a) the possibility of extracting large quantities of water from the aquifer; and
b) the height of the water pressures, where a value of max p = 10 bar is accepted for the upper acceptable limit for a non-drained tunnel.

In case the intake of water quantities at an individual section is permissible, the tunnel will be built as drained. In case the water pressure is higher than 10 bar, the tunnel will also be built as drained, with low intake of water provided by pre-grouting and post-grouting measures applied to the surrounding rock. In all other cases, the tunnel will be built as non-drained.

The longitudinal geological and hydrogeological profile (graph. annex 3238) envisages the following hydrogeological areas in terms of aquifer withdrawal: 1) drained (free water intake for low flows), 2) non-drained (no water intake due to high inflows, with water pressures lower than limit pressure max p = 10 bar), 3) karst channels (isolated karst formations where both variants are possible eg. drained or non-drained, according to the criteria given in the decision diagram) and 4) non-drained/drained (interplay of the presence of karst channel and larger fissures and fractures porosity, where both variants are possible, according to the criteria given in the decision diagram). All four manifestations are elaborated in terms of deciding on the choice of variant, with decisions based on meeting or failing to meet individual hydrogeological criteria.

Each of the four manifestations must be identified on the basis of hydrogeological monitoring, taking into account individual hydrogeological criteria. Hydrogeological data will be obtained in different phases of tunnel construction (pre-drilling, excavation, excavation of bench and invert, and continuous monitoring outside the tunnel) so that certain deviations of categorization are possible due to different reliability of data obtained from different sources. In case it is found that the manifestation is incorrectly recognized due to the previous low reliability of the obtained data, the manifestation must be reclassified and then addressed through the new branch of the decision diagram shown in Figure 4.1.

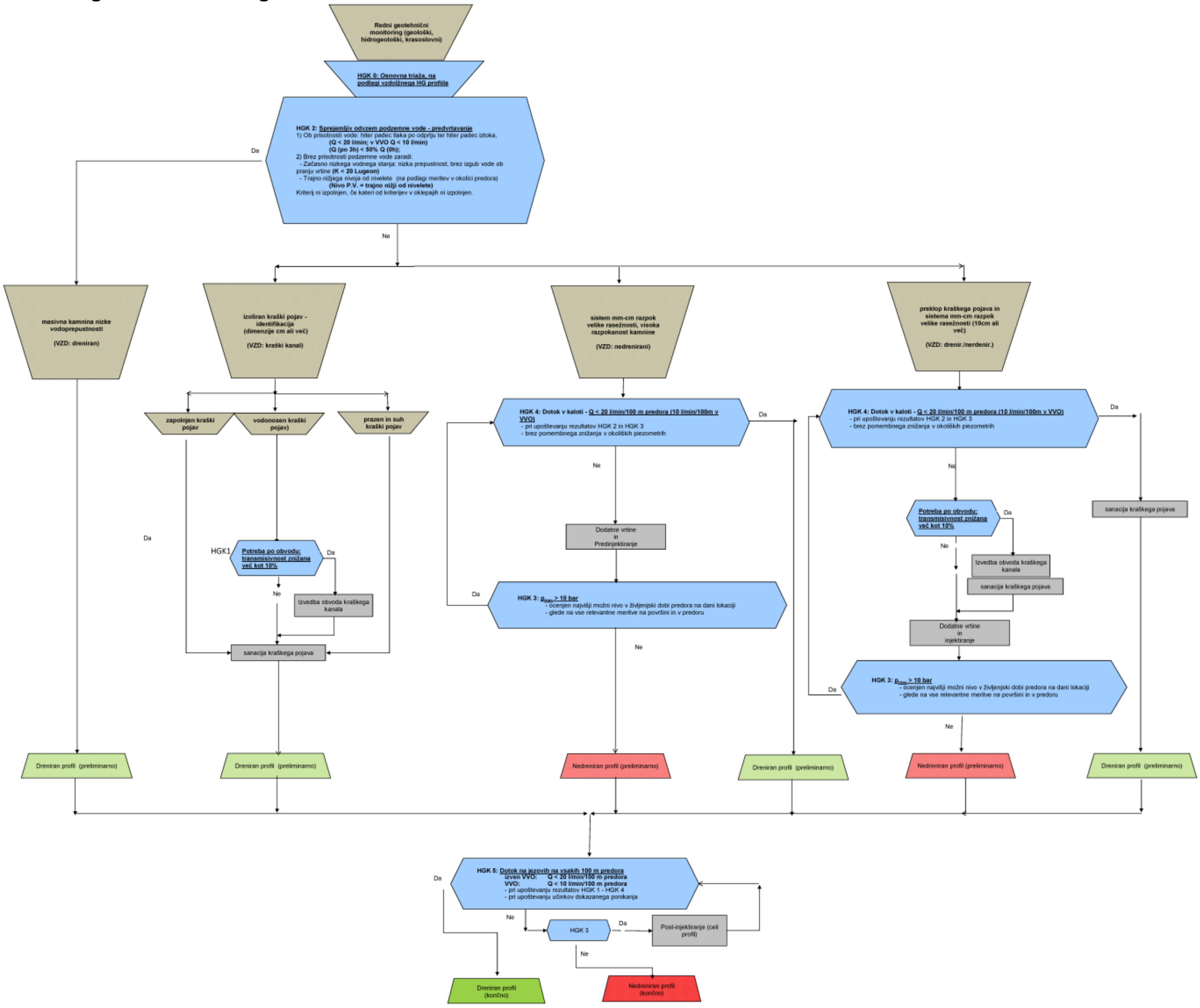


Figure 4.1: Diagram for deciding on the choice of tunnel type according to the type of water permeability, the possibility of water withdrawal from the aquifer, the presence of karst formations and the magnitude of water pressures (the diagram is shown on a larger scale in graphic appendix 3240)

Figure 4.2 shows the hydrogeological criteria that will be applied in the construction phase of the tunnel on the basis of geological, hydrogeological and karst observations. These are the same criteria as shown in Figure 4.1 so that the diagrams are fully aligned in this regard. The following is the concept of hydrogeological monitoring providing with detailed explanation of hydrogeological criteria.

Hydrogeological criteria (HGK1-5 and HGK permanent) are given for individual formations and refer to groundwater in an important karst fissure aquifer during the construction of tunnels T1 and T2. Hydrogeological criteria represent partial quantitative norms for determining the acceptability of drained or non-drained tunnel variant on a given section. As a whole, they are used to submit a final proposal for the implementation of internal lining (drained or non-drained sections), and in preliminary form also to support the decision making regarding the implementation of the excavation of the top heading, bench and invert. In all phases from pre-drilling to installation of secondary lining, hydrogeological criteria are also the basis for justifying the use of additional measures to protect the quantitative state of groundwater (pre-grouting, post-grouting, construction of karst canal drains, etc.).

Permitted groundwater intakes are defined on the basis of the amount of predicted water intake from the combined drained/non-drained sections in the tunnel as defined in Risk Analysis. Based on the given Risk Analysis, an amendment to the Decree on the water protection area for the Rižana aquifer water body was adopted (Official Gazette of the Republic of Slovenia, nos. 49/08, 72/12 and 69/13) to this end.

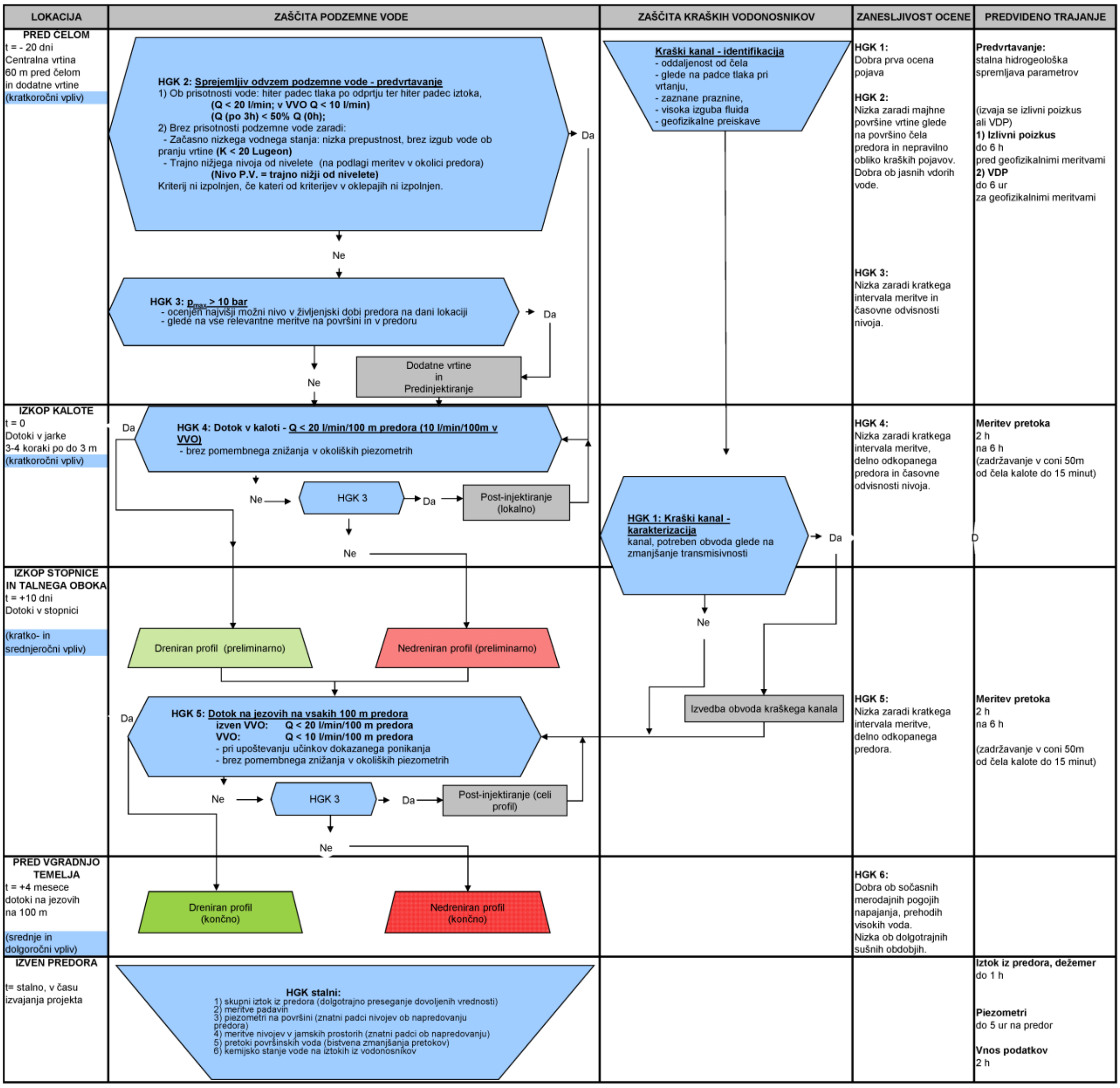


Figure 4.2 Scheme of hydrogeological monitoring of construction to determine compliance with the requirements of the Decree on the water protection area for the water body of Rižana aquifers (Official Gazette of the Republic of Slovenia, No. 49/08, 72/12 and 69/13)

Outflows into the tunnel are converted into litres per minute per 100 meter sections of the tunnel for comparability with the data ranges for tunnels with the limitations of permitted groundwater intakes given in the professional literature. If during the construction of the tunnel it is established that despite the provision of reduced intakes from the surrounding water sources, significant changes in quantitative or chemical status occur due to circumstances unknown from the phase of basic and supplementary investigations, the values of permitted intakes may be further reduced.

Hydrogeological criteria are divided into five (5) categories according to the type of hydrogeological manifestations and are presented in the table together with the time component, which is related to the schedule of tunnel construction and the length of the measurement. The schedules of tunnel construction are influenced only by the criteria HGK 2 and HGK 3, which are related to pre-drilling investigations and are expected to last up to 6 hours. HGK 2 and HGK 3 are carried out from a horizontal pre-drilling borehole with a predicted frequency of 1 measurements every 10 days or more, depending on the rate of excavation progress. Measurements to determine the remaining hydrogeological criteria do not affect the schedule of construction. In these cases, the Contractor's activity will be required in terms of timely installation of drainage tube or plug foil (criterion HGK 4), the invert dams (criterion HGK 5) and ensuring the presence of a hydrogeologist who will perform regular measurements within the geological-geotechnical observation. Details for the construction of the dam, which are necessary for the implementation of the hydrogeological criterion HGK5, are given in the design documentation (graphic annex drawing8017).

The following are more detailed descriptions of the individual hydrogeological criteria:

- **HGK 1** is bound to karstic cracks or contacts, which represent a significant groundwater conductor. If the conductor is clashed by the tunnel in such a way that its transmissibility is reduced by more than 10%, a bypass must be made at this point to ensure the same conductivity regime as before construction. HGK 1 can be determined in time during the excavation of the dome and bench, indications (detected gaps in drilling, their distance from the top heading, pressure drops during drilling, high fluid loss, geophysical investigations) can be collected from pre-drilling.

- **HGK 2** gives the acceptability of groundwater pressure reduction based on pre-drilling. In areas with groundwater present, the pressure drops at the measured flow, which must not exceed 20 l/min (within the water protection area, must not exceed 10 l/min) is determined through discharge tests. The drop of the flow rate should be faster than condition Q (after 3 h) <50% $Q_{initial}$. If water is not currently present, but other indications suggest that it may occur at higher seasonal water levels, a VDP experiment (Lugeon test) is performed to determine the permeability, which determines the potential inflow at different possible hydrostatic pressures. In the case of areas with a proven permanently lower groundwater level relative to the level of the tunnel, a drained version of the tunnel is permitted.

- **HGK 3** gives an indication of the highest possible pressures on the considered section pmax = 10 bar and can be authoritatively determined only during pre-drilling, when the impact of the tunnel construction on the aquifer in front is the smallest. It is necessary to ensure that protection against the leakage of groundwater from the borehole (by means of a packer or a preventer) is applied during the pre-drilling, so that the relevant groundwater pressures in front of the face can be measured. The measurement result is analysed in the context of simultaneous measurements of levels in piezometers on the surrounding surface and cave interiors.

- **HGK 4** is carried out in such a way that the short-term impact of tunnel excavation with measurements of inflow changes on the length section of the tunnel (100 m) depending on time and precipitation events is traced in the top heading, namely at points of inflow along the borehole) or in places of larger drainage areas (the contractor installs a plug-in foil with a fold for catching and draining water at one point of outflow). At the same time, the groundwater levels in the surroundings are monitored, and this criterion, together with HGK 3, specifies the need for local grouting and the basis for a preliminary decision on drained/non-drained tunnel section, for the excavation of bench and invert.

- **HGK 5** represents the longest available period of flow measurements on dams with standardized triangular overflows every 100 m of tunnel before the closure with inner lining. Approximately, the implementation period of HGK5 is estimated at 4 months, or longer, depending on the schedule of the contractor in the construction of the inner lining. Outside the water protection area, the undrained section in the tunnel is carried out if the average inflow exceeds 20 l/min/100 m of the tunnel, (in the water protection area the limit value is 10 l/min/100 m of the tunnel), where the pressure on this section must be less than pmax = 10 bar. To determine outflow of water from the aquifer in the event of precipitation events, the measurement of flows at dams is performed with a frequency between 6 and 12 hours. The capacity of proven effective downstream outflow can be deducted from the measured upstream intake. At the same time, the groundwater levels in the surroundings are monitored, where there must not be a significant reduction in groundwater levels.

- **HGK permanent** is a set of criteria that are permanently monitored outside the tunnel. Such criteria make an important contribution to the interpretations of hydrogeological measurements in the tunnel and are the basis to the final proposals made by the hydrogeologist. HGK constants are related to measurements of total outflows from the tunnel tubes (to determine long-term exceedances of permissible values), precipitation measurements to determine the correlation with groundwater levels and inflows, measurements of water levels in piezometers on the surface and in cave interiors (significant declines as a direct impact on quantitative status of the aquifer), surface water flows (significant reductions in flows as an indirect indicator of impact) and changes in the chemical status of groundwater at aquifer sources.

As can be seen from the decision diagrams, the decision-making process is multi-stage and begins with the pre-drilling process in front of the top heading (HGK2 and HGK3), measurements obtained by excavating the top heading (HGK4) and, in addition, excavating the bench and invert (HGK5), while hydrogeological observation outside the tunnel takes place continuously (HGK permanent). For this reason, a final decision will have to be made in certain cases only after the excavation of the invert of the tunnel through an area that is either close to a karst formations or strongly fractured rock, after additional in-situ geological, hydrogeological and karst analyses.

HGK5, which covers the observation of water inflow after excavation of the full tunnel profile, is crucial for the final assessment. This kind of observation can take several months or can last until the installation of the foundation for the inner lining. The observation lengths of the tunnel in this case are 100 m long, and the inflow of water from the rock-mass will be observed by means of dams equipped with a V-shaped overflow. The inflow of water to the dam must be carefully conducted so that no losses occur and has to be separated from the technical water used for drilling.

4.1.3 Influence of the choice of drained / non-drained variant on tunnel tubes and passage construction

In order to ensure the smallest possible impact of decision-making on the schedule of tunnel construction, excavation will take place in the top heading in an non-drained form. In the bench and invert, the excavation will take place on the basis of a preliminary decision, as shown in the decision diagrams, that is, based on a preliminary prediction as to which variant is appropriate on a given section. In certain cases, if necessary, there will be a need to expand the profile (re-profiling) for the needs of a wider geometry of the invert for the drained sections. This case is possible in that a non-drained variant was envisaged and it was finally decided that a drained variant would be implemented. This is also the only example of the need for re-profiling, which is thus minimized through the preliminary decision procedure. For the purposes of re-profiling the tunnel, a special item is specified in the bill of quantities. The contractor will be given additional time if the re-profiling works are on a critical construction path.

One of the key technological procedures for successful tunnel construction in both variants is rock grouting. Grouting reduces the permeability of the rock in the immediate vicinity of the tunnel to the extent that: a) it allows the reception of groundwater with a drained inner lining or b) it allows the uptake of hydrostatic pressures of groundwater with a non-drained inner lining. We distinguish between the pre-grouting process, which aims to limit water inflows into the tunnel during construction and enable the construction of a drained variant. The second process is the post-grouting process, the purpose of which is to reduce the permeability of rock mass after excavation of the tunnel. In both cases, grouting is the only way to enable reduced intake of water from the aquifer at locations where water pressures are greater than the allowable maxP = 10 bar. Grouting is addressed in Chapter 7 of this report and in the Technical Specifications: Special measures for tunnel construction [13].

4.2 Transition between the drained and non-drained (undrained) sections

The transition zone between the drained and non-drained part must be sealed watertight. The measure is carried out in the middle of the border non-drained section, as shown in graphic annex drawing 8015. It consists of an grouted rock mass ring that fills the cracks around the tunnel and a bentonite strip that prevents the passage of water behind the waterproofing membrane. The grouted ring is made after the excavation is completed and the entire cross-section is supported, ie. top heading, bench and invert, through the primary lining. It runs along the entire circumference of the cross-section and consists of two grouting planes, with an grouting length of 4 m. Before installing the waterproofing membrane, the geotextile and dimpled membrane are stopped at the grouted site and a bentonite strip of min length of 1.0 m is installed around the entire perimeter. The bentonite ring in contact with water swells and becomes impermeable. This prevents the flow of water between the primary lining and the waterproofing along the tunnel into the drained section.

The non-drained cross-section, which bridges the karst formations or passes through a strongly karstified area where the occurrence of groundwater is possible, is extended at least by the length of the section on each side into compact limestone. Prior to the transition to the non-drained part of the tunnel, inspection shafts shall be provided upstream in which the lateral drainage leads to the central collecting tube.

4.3 Geological monitoring of tunnel excavation

Geological monitoring of tunnel excavation must be carried out daily during excavation of the tunnel top heading. All observations related to the geological-geotechnical conditions must be given in regular weekly reports, and in the case of observations of major changes in the geological structure, also in a shorter time interval. Given the length of the facility and the complexity of the geological structure, it is necessary to ensure a minimum number of geologists and hydrogeologists who will cover the excavation of the tunnel in its entirety.

Pre-drilling and implementation of geophysical measurements in pre-cuts, which are treated in Chapter 5, must be performed in full coordination with the geological and geotechnical monitoring of the tunnel excavation.

4.4 Hydrogeological monitoring during tunnel construction

Risk Analysis was taken into account in determining the hydrogeological monitoring during the construction of the tunnel. During the construction of the tunnel it is necessary to carry out the following activities:

- continuous mapping of the positions of all inflows and quantities of water in excavations and tunnels and monitoring of inflow trends.
- in-situ measurements of basic physicochemical parameters for all inflows: pH, Eh, oxygen content, temperature, electrical conductivity.
- accurate mapping of geological conditions, lithological changes, position and orientation of fissures and joints.
- karst monitoring of all karst formations and their characteristics, especially water flow indicators.
- in case of discovery of a cavern, measurements and plans of cave interiors are to be made.
- upon detection of cavities or open cracks, the suitability for the return of drained water is determined and, if necessary, a follow-up test is performed to determine the impact of water return.
- on the basis of monitoring, the actual situation is determined in relation to the forecast and, if necessary, the optimization of the distribution of drained and non-drained sections of the tunnel is prepared.
- continuous monitoring of pre-drilling and determination of the effects of tunnel drainage and updating of forecasts of possible water intrusions.

As explained in the previous chapters, hydrogeological monitoring during tunnel construction is crucial in reaching a decision on whether a particular section of tunnel will be constructed in a drained or non-drained variant.

4.5 Groundwater monitoring

During the construction of the tunnel, the contractor must take water samples from the excavation face and along the tunnel and perform chemical analyses to determine the impact of water aggressiveness on cement concrete in accordance with DIN 4030.

Taking into account the study: "Analysis of the risk of groundwater pollution and water catchment of Rižana due to the construction of the 2nd track of the railway line Divača - Koper", no. K-II-30d / 1-1 / 62 [11], it is necessary to monitor the quantitative and chemical status of groundwater during construction.

During construction, the flow of water to the reservoirs is regularly monitored, where measuring points were made. The water level is measured and automatically recorded at the measuring point. At the same time, the monitoring established in the observation network of piezometers and water resources in the phase of geological and geotechnical investigation for PGD continues.

During construction, the water quality at the discharges from the reservoirs into the environment and at the Rižana spring is regularly monitored. The pH, turbidity, water conductivity and water temperature are continuously measured and automatically recorded. Water samples for analysis for mineral oils, aluminium, lead, lithium, nitrogen (nitrates, nitrites, ammonium), sodium are taken regularly once a month. Occasionally, with significant changes in pH, turbidity, water conductivity, and additional water samples are taken and analysed for the previously listed parameters.

The program is adjusted during the construction works according to the actual situation. Adaptation is proposed by hydrogeological monitoring and an accredited chemical laboratory.

In the case of water inflows into excavations, in-situ measurements of Eh, oxygen content, conductivity, pH and temperature control the possibility of unstable water composition, which could be aggressive to concrete or subject to salt deposition. If necessary, such waters shall be analysed in more detail and protective measures shall be determined.

In addition, the following investigations need to be carried out:

- measuring the flow and amount of water in channels, caverns and other karst formations. The scope and method of measurements are not planned in advance, because the measurements depend on the position, size, location and abundance of the karst formations. With the measurement it is necessary to obtain the best possible information about the flow and amount of water in the karst formations.
- measuring water pressures. For the purpose of dimensioning the tunnel structure, it is necessary to perform measurements of water pressures in karst formations that intersect the route of the tunnel, and for which there is a possibility that water will stagnate in them and thus burden the tunnel structure.
- cave investigations of karst formations. Karst formations will be investigated by seismologists, which will collect data on possible connections with other cave systems and consequently the possibility of water flow between different cave systems.

Chemical analysis of water are carried out systematically, and all other investigations as necessary.

4.6 Grouting to reduce the water permeability of the surrounding rock

The grouting of the rock is envisaged as one of the necessary measures to reduce the permeability of rock mass in the vicinity of the tunnel. In the remediation of karst formations, it is envisaged as one of the auxiliary technological procedures that enable the consolidation of the rock or the filling of cavities or improving the properties of sediments trapped in karst formations. In this case, however, the grouting task can also be used in order to reduce the water permeability of the rock. The grouting is dealt with in full detail in Chapter 7.

5 DETECTION OF KARST FORMATIONS DURING THE CONSTRUCTION OF THE TUNNEL

5.1 Description

Based on geological and hydrogeological investigations, sections have been identified in the construction area of the T1 tunnel, where during the excavation of tunnel tubes there is a high possibility of crossing karst formations, which are in the form of full or empty caverns of various shapes and dimensions. Wider areas where caverns are possible are basically built of limestone. The caverns can be filled with sediments (clay or coarse-grained materials such as sand or gravel), liquid soil and water, which can also be under relatively high pressure.

The term "karst formations" is used for the purposes of this design as a term for underground spaces that are typical of the karst world and are in any way related to the construction of the T1 tunnel, either crossing the tunnel route or being so close to the tunnel so that they can affect it. This treatment also includes karst formations, which, due to the fact that they are interconnected, can affect natural formations far from the tunnel route.

Due to the relatively limited capabilities for detecting karst formations, there is a high possibility that the karst formations will be detected only when excavation occurs (in the case of karst formations clashes directly with the tunnel profile), or later during the use of georadar or during the installation of support measures (anchors). In that case the top heading of the excavation will already be away from the karst formation, but still they will have an impact on tunnel construction.

In any case, any detection of a karst formations exceeding 2 m3 outside the contour of the tunnel, or a filling with low-bearing material or water, or voids connected to other underground spaces, must be entered in the construction log, and in the case of major remediation works, which are defined below.

For this purpose, the design envisages measures for the detection of karst formations in front of the tunnel and methods on the basis of which to determine their degree of karstification.

5.2 Technological procedures for the detection of karst formations

The design envisages three procedures for the detection of karst formations, taking into account the data obtained during the interpretation of geological and geotechnical reports for the T1 tunnel. These procedures are:

- Horizontal borehole pre-drilling
- Boreholes on the top heading with a fan arrangement
- Geophysical measurements in boreholes

In order to ensure safety during the excavation of tunnel tubes, a system of prior detection of these formations should be provided at the design stage. The simplest and most effective system for detecting formations in front of the excavation face is pre-drilling using horizontal borehole. Pre-drilling will be used to detect karst formations on the tunnel route as well as for regular geological-geomechanical and hydrogeological monitoring during the construction of the tunnel. Regardless of the probability of the karst formations, one horizontal borehole will always be drilled along the entire length of the tunnel, 100 m long and 114 mm in diameter (eg. above 100mm in diameter), with a minimum overlap of 5 m. Pre-drilling must be carried out in full accordance with the Technical Specifications, book No. 8. A more detailed description of pre-drilling and its use for geological-geomechanical and hydrogeological monitoring is given in the geological-geotechnical monitoring design for the T1 tunnel [8] and in the Technical Specifications **Error! Reference source not found.**.

Georadar measurements (reflection method) will be used in parallel to detect various karst formations and cahnges in the lithological structure in front of the top heading. The georadar image covers a profile of the surroundings, s at a distance of 0.5xD, D is the diameter of the tunnel.

The following geophysical surveys are planned in the boreholes, namely:

- Reflective measurement technique
- Cross-hole method
- Georadar

In the event that larger karst systems are identified by pre-drilling, which, due to their location or size, may jeopardize the excavation of the tunnel, geophysical measurements are used, if necessary, to determine them more accurately. Geophysical measurements are carried out according to a program prepared by a geologist and a hydrogeologist within the framework of geological monitoring of the works. When carrying out procedures and measures for the remediation of karst formations, it is also necessary to take into account the provisions of technical specifications, document No. 8, Other Measures.

5.3 Division by degree of karstification (low, medium, high)

In order to ensure safety during the excavation of tunnel tubes, a system of preliminary detection of karst formations should be envisaged in the design phase. Given that caverns will appear during excavation in limestone, which represents a good rock base, the system or method of excavation is designed in accordance with established principles for excavation and primary support for stable rock materials.

Taking into account the density of karst formations, three different scenarios are envisaged for determining the degree of karstification in front of the excavation face. The type of individual scenario is determined by the geologist, hydrogeologist and karstologist within the framework of geological-geotechnical monitoring. Scenarios are set for:

- low probability of karst formations - low level of karstification
- medium probability of occurrence of karst formations - medium degree of karstification
- high probability of karst formations - high degree of karstification

On the longitudinal geological-hydrogeological profile of the T1 tunnel, forecast areas are given regarding the probability of occurrence of karst formations (graphic appendices 3238 and 3239). Such preliminary information will be used for the basic categorization of formations, and only this will be finalized on the basis of geological-geotechnical monitoring, as explained below.

5.3.1 Low probability of occurrence of karst formations

In order to detect karst formations, even with a low probability of their occurrence, a horizontal hole in the top heading, 100 m long and 114 mm in diameter, is predicted. The borehole is drilled by percussive rotary drilling with temporary protection using pipes, if necessary. Drilling equipment must allow continuous measurement of drilling speed and pressure. The minimum overlap of boreholes is 5 m.

If necessary, georadar (refractive method) and hydrogeological surveys are carried out in the borehole, as described in the geological-geotechnical observation design [8]. In the zone of low probability of occurrence of karst formations, it is anticipated that a georadar refraction method will be performed at 20% of the given length. No other georadar surveys are planned in this zone. In order to identify karst formations outside the range of the horizontal borehole, from the position of the top heading to approximately 80% of the length of this zone, boreholes with a fan arrangement will be drilled. A total of 4 boreholes, 20m long with a diameter of 51 mm, will be drilled by percussive rotary drilling, with spatial placement as presented in graphic annex drawing8002. The estimated total length of the zone with a low probability of karst formations in tunnel T1 is approximately 1600m.

5.3.2 Medium probability of occurrence of karst formations

This scenario is an upgrade of the scenario for a low probability of occurrence of karst formations. Here, too, a horizontal borehole is envisaged as explained above, with the georadar refractive method predicted to be carried out at about 40% of the length of this zone. No other georadar surveys are planned in this zone either.

In the zone of medium probability of occurrence of karst formations, four boreholes with a fan distribution are also planned, as previously explained (graphic appendix 8002), and it is estimated that they will be carried out at approximately 60% of the length of this zone. In the event that they need to be carried out continuously, a minimum overlap of boreholes of 4 m in the longitudinal direction is envisaged. The total expected length of the zone with a medium probability of karst formations in tunnel T1 is approximately 2300 m.

5.3.3 High probability of occurrence of karst formations

This scenario is an upgrade of the scenario for the medium probability of occurrence of karst formations. In the existing horizontal borehole from the previous scenario, a georadar refraction method is performed at approximately 80% of the length of this zone. In the zone of high probability of karst formations, four boreholes with a fan distribution are also planned, as previously explained (graphic appendix 8002), and it is estimated that they will be carried out at approximately 50% of the length of this zone without georadar surveys.

Boreholes with a fan layout will be complemented by georadar surveys in the boreholes using the cross-hole and dawn-hole method. Two scenarios are envisaged here, with a total of 5 boreholes (graphic annex drawing 8003) of 28 m in length with a diameter of 76 mm being carried out according to scenario 1. The boreholes will be drilled with impact rotary drilling, protected by PVC tubes d=60 mm, if needed. Refractive measurements are made in each of the five boreholes. In addition, cross-hole measurements are performed between individual boreholes, where basic and additional measurements are provided.

According to scenario 2 (graphic annex drawing 8004), a total of 5 boreholes, 38 m long and 76 mm in diameter, are drilled. The boreholes will be drilled with impact rotary drilling, with PVC tube and 60 mm. Refractive measurements are made in each of the five boreholes. In addition, cross-hole measurements are performed between individual boreholes, where basic and additional measurements are provided.

Georadar measurements enable the detection of karst formations larger than 1x1x1 m. In the zone of high probability of occurrence of karst formations, it is estimated that out of the total number of georadar measurements in boreholes, which will be approximately 20, 50% of surveys will be conducted according to scenario 1 and 50% of percentages according to scenario 2. Total expected length of the zone with high probability of occurrence of karst formations in tunnel T1 is about 2300m.

5.4 Geophysical surveys in front of and behind the top heading - crosshole method

5.4.1 Basics

Georadar (Ground Penetrating Radar) is a physical method based on the emission of its own high-frequency electromagnetic waves and is used to detect poorly dielectric materials and to determine the boundaries between electromagnetically different materials.

Capacity and resolution of georadar measurements in the borehole:

- detects and dates faults and karst formations the size of a meter upwards;
- gives a quantitative assessment of karst formations and cracks;
- gives a quantitative assessment of karst areas, including the type of filling (empty, filled with material);
- the depth of investigations around the axis of the tunnel is from a few decimetres upwards.

Implementation requirements:

- horizontal, inclined or vertical borehole with a minimum internal diameter of 60 mm;
- contact between the investigation probe (sensor) and the investigated rock must be possible;
- possibility of measurements in dry or wet borehole.

Methods of georadar measurements in boreholes are:

- Reflective measurement technique
- Cross-hole method

5.4.2 Reflective measurement technique

In the case of performing a reflection measurement technique, the georadar transmitter (T) and the receiver (R) are located in the same investigation borehole. Measurements along the borehole can be performed continuously or in stages. At each T-R position, the transmitter emits an electromagnetic pulse (frequencies: 22 MHz - 250 MHz) that travels through the surrounding rock. In the case of the presence of discontinuities (layering, cracks, voids), part of the waves is absorbed and part is reflected back into the receiver.

The result of the measurements is a radargram showing point and plane reflections (wave reflections). The method with the reflection measurement technique is suitable for determining the geological and tectonic conditions in the vicinity of the borehole. In the case of karst formations, information is provided about the distance from the borehole, but without orientation.

5.4.3 Cross-hole method

In the case of the cross-hole method, measurements are performed between the transmitter and receiver, which are located in two separate boreholes. The wave emitted by the transmitter travels through the rock to the receiver, which measures two basic parameters: travel time and wave amplitude. In the case of cross-hole measurements, the position of the transmitter and receiver is at the same depth (they are parallel).

The result of cross-hole method measurements is a depth diagram as a function of the wavelength and velocity of georadar waves traveling through the rock between the transmitter and receiver. Using this method, the data on the locations and depths of anomalies (karst formations) are obtained, but it is not possible to identify the size and shape of the anomaly.

5.4.4 Georadar

The size and shape of karst formations can also be determined with the help of georadar. Georadar is a non-invasive method that does not require a borehole and can be used to check if an individual karst formation, which can be located under the invert. Georadar is based on the emission of its own electromagnetic field for the needs of investigation of poorly dielectric materials and the determination of boundaries between electromagnetically different materials. The emitted electromagnetic signal can penetrate into a poor dielectric substance only to a certain depth before it is absorbed within the karst formations. When the transmitted electromagnetic signal traveling from the transmitting part of the antenna reaches the electromagnetic border, part of the energy is reflected and registered by the receiving antenna, and the rest continues to propagate through the medium to the next electromagnetic border, where part of the energy is reflected and registered. In this way, it is possible to detect boundaries and to a certain extent the dimensions of karst formations under the invert. The georadar system used must have a guaranteed power and frequency on the basis of which it is possible to determine the approximate size of the karst formations to a minimum depth of 4 m.

In accordance with scenario 1, the area of the invert is not investigated by georadar investigation in the boreholes, so it is necessary to subsequently check it for the possibility of karst formations. Measurements with georadar can be performed after the invert has been made and before the installation of the inner lining. After the installation of the inner lining, the usability of the georadar will be significantly limited and therefore unsuitable. The use of georadar is envisaged along the entire length of the tunnel, where it is located within the limestone geological sequence.

6 CATEGORIZATION OF KARST FORMATIONS

6.1 General information on karst formations

Based on the results of geological and hydrogeological investigation, there are certain sections of the T1 tunnel route, where during the excavation of tunnel tubes there is a great possibility of crossing karst formations that appear in the form of caverns of different shapes and dimensions. The wider area where cavernous occurrences are likely is basically built of limestone. Inside the caverns, the occurrence of liquid soil and groundwater is possible, which can also be under relatively high pressure.

The term "karst formations" is used for the purposes of this design as a term for underground spaces that are typical of the karst world and are in any way related to the construction of the T1 tunnel, either crossing the tunnel route or being so close to the tunnel that they can affect it. This treatment also includes karst formations which, due to the fact that they are interconnected, may affect natural rock formations far from the route of the tunnel.

The term “karst formations”, hereinafter referred to as karst formations, is used in the report as a term for karst canals, caverns and caves, empty or filled with water or low-bearing material, and in a broader sense as a term for other formations such as fissures, joints and fractures causing high water permeability of the rock and the connection of the caves to the cave system, where groundwater can be integrated by flow.

In general, karst formations can be classified according to the cases of possibility and timeliness of perception as follows:

- The karst formations was previously detected in the direction of the tunnel and is an empty underground space.
- The karst formations was previously detected in the direction of the tunnel and is full of poorly bearing material or water or both.
- The karst formations was previously detected laterally and near the tunnel and is an empty underground space.
- The karst formations was previously detected laterally and near the tunnel and is full of poorly bearing material or water or both.
- The karst formations has not been previously detected

Each of these cases will have to be investigated under different conditions under construction conditions. Its remediation will depend on which category this karst formations belongs to, as will be explained below.

6.2 Classification of karst formations

For the needs of the design, the karst formations that can be encountered in the construction of tunnels were divided into two main groups, namely:

- karst formations crossing the route of tunnels,
- karst formations close enough to the tunnel to be affected.

Each main group has four subgroups of karst formations, where they are organized by logical groups according to the principle that they require the same or at least similar treatment. Tabular distribution of karst formations is made according to the size of the formations and their distribution, as shown in the graphic appendix 8008.

In the following, possible scenarios are envisaged according to the scope of procedures and measures that need to be implemented as part of remediation.

6.2.1 Karst formations, previously detected, in the direction of the tunnel as an empty underground space

In this case, the excavation is temporarily stopped and an inspection by a designer, geologist, hydrogeologist and engineer is carried out, where it is necessary to envisage investigation works by entering in the construction diary, which will help determine the extent and shape of the underground opening. Investigation work must be carried out as soon as possible. When they are completed, the inspection is carried out again by the designer, geologist, hydrogeologist and engineer, where the method and pace of further excavation to the karst formations is determined by entering it in the diary. The rehabilitation is then carried out according to the class of the karst feature.

6.2.2 Karst formations, previously detected in the direction of the tunnel as a space filled with poorly load-bearing material, water or both

In this case, the excavation is temporarily stopped and an inspection by a designer, geologist, hydrogeologist and engineer is carried out, where it is necessary to envisage investigation works by entering in the construction diary, which will help determine the extent and shape of the underground opening. The existing borehole must be temporarily sealed to prevent water from entering the site. Investigation work must be carried out as soon as possible. When they are completed, the inspection is carried out again by the designer, geologist, hydrogeologist and engineer, where the method and pace of further excavation to the karst formations is determined by entering it in the diary. The rehabilitation is then carried out according to the class of the karst feature.

6.2.3 Karst formations, previously detected, laterally near the tunnel as an empty underground space

In this case, the excavation continues, but the inspection is carried out by a designer, geologist, hydrogeologist and engineer, where it is necessary to provide investigation work by entering in the construction log, which will help determine the extent and shape of the underground opening. Investigation work must be carried out as soon as possible. When they are completed, the inspection is carried out again by the designer, geologist, hydrogeologist and engineer, where the method and pace of further excavation to the karst formations is determined by entering it in the diary. The rehabilitation is then carried out according to the class of the karst feature.

6.2.4 Karst formations, previously detected, laterally near the tunnel as a space filled with poorly bearing material, water or both

In this case, the excavation is temporarily stopped and an inspection by a designer, geologist, hydrogeologist and engineer is carried out, where it is necessary to envisage investigation works by entering in the construction diary, which will help determine the extent and shape of the underground opening. The existing borehole must be temporarily sealed to prevent water from entering the site. Investigation work must be carried out as soon as possible. When they are completed, the inspection is carried out again by the designer, geologist, hydrogeologist and engineer, where the method and pace of further excavation to the karst formations is determined by entering it in the diary. The rehabilitation is then carried out according to the class of the karst feature.

6.2.5 Karst formations previously not detected

There is a high probability that the excavation of tunnels will lead to the occurrence of karst formations that will not be detected in advance, so there may be unforeseen events that pose a danger to workers and can cause economic damage to machinery. Possible dangers are:

- inflow of large amounts of water into the excavation space.
- a rock-fall of poorly bearing material.
- opening of karst channels, caves and abysses.

These events and their consequences cannot be fully predicted in advance, so the procedures and safety protocols that need to be implemented when excavating tunnels are presented below.

6.3 Construction through a karstified rock mass

The following procedures and safety protocols need to be taken into account in a karstified area.

6.3.1 Informing workers about possible hazards at the construction site

Informing workers about possible hazards at the construction site. Workers must be informed about the dangers inherent to the excavation of a tunnel in the karst underground, and they must also be informed about the possibilities of rescue. Rescue exercises should be performed at least once a month in case of water ingress.

6.3.2 Free, clearly marked evacuation route in the tunnel, along which it is possible to escape to the outside

The evacuation route must be wide enough for people to pass, and the direction of rescue must be marked with illuminated arrows.

6.3.3 A functioning information system in the tunnel

It is necessary to implement such an information system that immediate notification is possible, preferably by performing wireless transmission of a telephone signal in the tunnel.

6.3.4 Accessible rescue equipment near the work site

At least minimal rescue equipment must be available near the work site.

6.3.5 Other measures, such as closing water gates in areas where strong intrusions of large amounts of water are possible

The design and use of water doors are specifically addressed in this technical documentation. The conditions of use of water doors are specifically discussed below. In the event that the karst formation is not detected and water or poorly bearing material enters the tunnel after excavation, workers must evacuate to a safe place as soon as possible. This is followed by an inspection of the site by the designer, geologist, hydrogeologist and engineer, and if necessary and if it is safe, protection of machinery at the site or removal of machinery to a safe place. Further work is carried out with instructions, depending on the extent of karstic formations.
In addition to the procedures listed above, the legislation dealing with work in tunnels and the safety requirements given in accordance with the safety design must be observed at work at all times.

6.4 Tunnel construction and measures in case of karst formations

The general characteristic of karst formations is that they require individual treatment, so precise design solutions cannot be given in advance. Only the procedures by which individual cases are resolved and the basic technical solutions for individual cases can be determined in the design.

Basically, according to the method of treatment, we distinguish four types of karst formations, namely:

- Karst formations that do not pose a threat to safety and enable the smooth continuation of work
- Karst formations, which require temporary suspension of works, but with relatively simple measures enable the continuation of works and subsequent rehabilitation if necessary
- Karst formations that require immediate shutdown of works and rehabilitation of minor conditions before the continuation of works
- Karst formations that require immediate shutdown of works and extensive rehabilitation before the continuation of works

6.4.1 Karst formations that do not pose a threat to safety and enable the smooth continuation of work

This group includes smaller karst caves on the perimeter of the tunnel, which reach between 2 and 10 m3 of volume outside the tunnel profile, through with no water flows, does not contain poorly bearing material and there is no danger of falling or crumbling rocks.

Openings smaller than 2 m3 must be considered in the same group as the rock-falls, which must be removed by the contractor in accordance with the specifications in the technical specifications.

For karst formations with a size of 2-10 m3, it is necessary to carry out an inspection by a designer, geologist, hydrogeologist and engineer, and then it is necessary to confirm the smooth execution of works or confirm minor measures in the event that safety at work at the site in question is endangered.

6.4.2 Karst formations, which require temporary suspension of works, but with relatively simple measures enable the continuation of works and subsequent remediation if necessary

This group includes unfilled karst channels crossing the tunnel route, as filled or unfilled funnels and caverns larger than 10 m3 located near the tunnel. This group also includes karst formations with dimensions of less than 10 m3 in the event that their unfavourable position or spatial position is such that it threatens the stability of the tunnel.

The following immediate measures are needed to address such karst formations:

- Temporary suspension of works during tunnel excavation
- Securing the part of the tunnel where the karst formations is located or detected
- Drainage arrangements, if necessary

This is followed by a tour of the formations by a designer, geologist, hydrogeologist and engineer, where it is necessary to provide measures to enable the re-start of excavation works, such as:

- Drainage arrangement that does not impede further excavation work
- Additional reinforcement with shotcrete or anchoring
- Grouting to block or restrict the flow of water into the tunnel
- Other measures to allow safe further excavation at the head of the tunnel

After the measures have been taken, the excavation of the tunnel continues.

Once the area is protected and the necessary protection measures are implemented, it is necessary to prepare a program for investigation into the karst formations, which must be approved by an engineer. The investigation program is prepared by a geologist, hydrogeologist and designer. Investigation work may include:

- Exploratory drilling
- Georadar
- Cave exploration
- Other procedures by which relevant data can be obtained

As a result of investigation work, it is necessary to prepare a short report, which must contain all the results of investigation, all the necessary calculations and explanations, from which it is necessary to uniformly draw the following conclusions or answer the following questions:

- Whether the existing channel can damage the tunnel structure, either in the excavation phase or in the final design?
- What are the possible negative effects in the event that there is no rehabilitation of the karst feature?
- What are the possible negative effects on the hydrogeological conditions in the aquifer in case of remediation?

In case it turns out that additional measures are necessary, it is necessary to make a rehabilitation design or provide design solutions with an entry in the construction logbook. To enable the appropriate rehabilitation of the tunnel, the following procedures can be used:

- Reinforcement of the final coating
- Drainage
- Grouting
- Bypass arrangement
- Tunnel sealing
- Other measures that will prove to be suitable for the remediation of the tunnel and the karst formations in the affected area

This is followed by the implementation of rehabilitation works in accordance to the design solutions, while it is necessary to ensure the smooth implementation of works in the tunnel.

6.4.3 Karst formations that require immediate shutdown of works and rehabilitation of minor scope before the continuation of works

This group includes unfilled channels of large dimensions that cross the route of the tunnel, and filled or unfilled funnels and caverns up to 50 m3 in size, located near the tunnel. This group also includes karst formations with dimensions of less than 50 m3 in the event that their unfavourable position or spatial position is such that it threatens the stability of the tunnel.

For such karst formations it is necessary to proceed as follows:

- Immediate shutdown of tunnel excavation works
- Securing the part of the tunnel where the karst formations is located or detected
- Drainage arrangements, if necessary

This is followed by a tour by a designer, geologist, hydrogeologist and engineer. Based on the inspection, the designer prepares the design documentation in which he envisages measures that enable the restart of excavation works such as:

- Drainage arrangement that does not impede further excavation work.
- Additional reinforcement with shotcrete or anchoring.
- Grouting to block or restrict the flow of water into the tunnel.
- Other measures to allow safe further excavation at the head of the tunnel.

Once the area is protected and the necessary protective measures have been taken, an investigation program must be drawn up during the interruption of work, which must be approved by the engineer. The investigation program is prepared by a geologist, hydrogeologist and designer. Investigation work may include:

- Exploratory drilling
- Georadar
- Cave exploration
- Other procedures by which relevant data can be obtained

As a result of investigation work, it is necessary to prepare a design for the permanent remediation of the karst formations. The design documentation must contain all the results of the investigation, all the necessary calculations and explanations, from which the following conclusions must be drawn uniformly or the following questions must be answered:

- Whether the existing channel can damage the tunnel structure, either in the excavation phase or in the final design?
- What are the possible negative effects in the event that there is no rehabilitation of the canal?
- What are the possible negative effects on the hydrogeological conditions in the aquifer in case of remediation?

The remediation design must include all design solutions that allow for the appropriate remediation of the tunnel, most likely using the following procedures:

- Reinforcement of the final coating
- Drainage
- Grouting

- Bypass arrangement
- Tunnel sealing
- Other measures that will prove to be suitable for the remediation of the tunnel and the karst formations in the affected area.

This is followed by the implementation of rehabilitation works in accordance with the design solutions. After the rehabilitation works have been carried out, the excavation of the tunnel continues.

6.4.4 Karst formations that require immediate shutdown of works and extensive rehabilitation before the continuation of works.

This group includes filled channels and caverns up to 100 m3 in size and larger that cross the tunnel route. In such cases, water and poor load-bearing material may enter the excavation area, which can pose a danger to workers and cause significant damage to machinery. In any case, such karst formations cause work to stop at the construction site. This group also includes karst formations with dimensions of less than 100 m3 in the event that their unfavourable position or spatial position is such that it threatens the stability of the tunnel.

For such karst formations it is necessary to proceed as follows:

- Immediate shutdown of tunnel excavation works
- Securing part of the tunnel, and removing people and machinery located in the area of the karst formations, or moving it to another construction site.
- Implementation of immediate measures to limit damage (drainage, removal of material)

This is followed by a tour by a designer, geologist, hydrogeologist and engineer in safe conditions. Based on the inspection, the designer prepares design documentation in which it envisages all procedures of temporary arrangement on the construction site and the procedure of remediation of the karst formations, including the implementation of investigation works and preparation of design documentation for permanent remediation of the karst formations.

Once the area is protected and the necessary protective measures are implemented, an investigation program must be developed, which must be approved by the engineer. The investigation program is prepared by a geologist, hydrogeologist and designer. Investigation work may include:

- Exploratory drilling
- Georadar
- Cave exploration
- Other procedures by which relevant data can be obtained

As a result of investigation work, it is necessary to prepare a report, which must contain all the results of investigation. On the basis of the report, it is necessary to prepare design documentation for rehabilitation or bridging of the karst formations. The design documentation must include special conditions for the arrangement of the construction site in the phase of rehabilitation, the location of construction machinery and workers, and a dynamic work schedule plan. All design solutions must be approved by an engineer.

Design solutions that enable the appropriate remediation of the karst formations will most likely follow the following procedures:

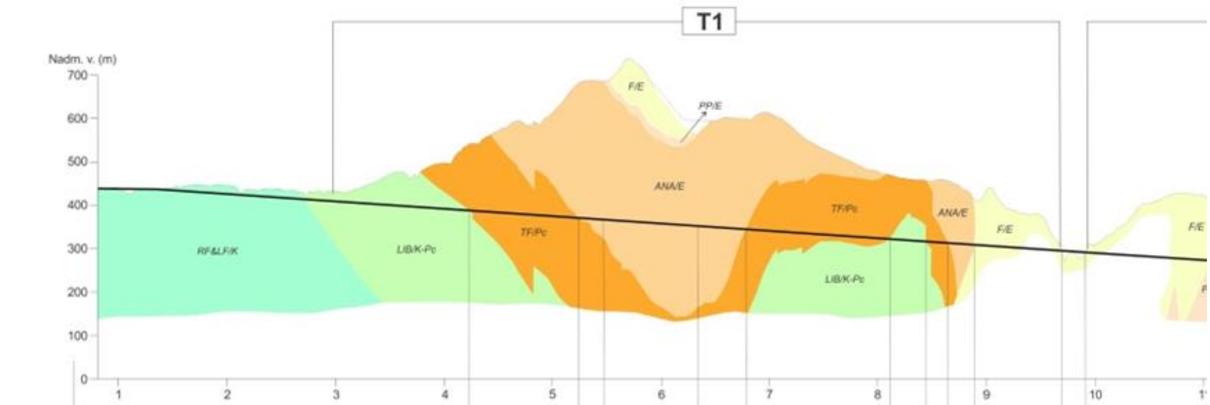
- Removal of karstified rock
- Execution of the bridging structure
- Reinforcement of the primary lining

- Reinforcement of the inner lining
- Drainage
- Grouting
- Bypass arrangement
- Tunnel sealing
- Other measures that will prove to be suitable for the remediation of the tunnel and the karst formations in the affected area.

This is followed by the implementation of rehabilitation works in accordance with the design solutions, which are conceptually given in the graphic annexes 8009-8014. After the rehabilitation works have been carried out, the excavation of the tunnel continues.

6.5 Estimation of the number of karst formations in tunnels T1 and T2

The estimate of the number of karst formations in the tunnel is summarized according to the Interpretation of karst conditions for the construction of tunnels T1 and T2 [6]. Figure 6.1 shows the sections with the predicted density and diameter of the pits.



Odsek	A	B	C	D	E	F	G	H	I	J1	J2
Gostota jam [jam/km]	5-10	<5	<10	<5	<10	<5	<10	<5	<10	<1	
Premer jam [m]	>10	<5	<5	<5	<5	<5	<10	<5	<5	<1	

Figure 6.1: Predicted karstification / permeability along tunnels T1 and T2 [6]

6.5.1 Section A

Section A runs along the Cretaceous limestones and limestones of the Liburnian formation. In the cave cadastre, 11 caves were recorded in a two-kilometer strip along the route of the railway line, and 15 caves were discovered nearby in the same rocks during the construction of motorways.

It is expected that 5 to 10 caves/km will be opened on this section. Tunnels (dry old ones, formed due to the former flow of water flows in a predominantly flooded zone; example: Divaška jama) may be larger in diameter (even over 10 m), and larger predominantly horizontal epiphreatic channels may also occur. We anticipate that 50-66% of the tunnels will be filled with fine-grained sediments and gravel (just below the surface), and deeper also with residual coating. In the meantime, (sub) recent vadose abysses may appear, up to 5 m in diameter. Their cross-sections will be round or slit with pronounced cracks. The caves will be above the regional height of the karst groundwater, and we can expect more pronounced jets and locally trapped water in some places.

Greater permeability is expected at the Cretaceous-Paleocene boundary at the transition of Section A to Section B.

5 to 10 caves/km are expected, some can be over 10 m in diameter.

6.5.2 Section B

Section B runs through Paleocene limestones. Knowledge of lithology and borehole data indicate a lower frequency of caves in the limestones of Dani and Thanetium.

No caves were recorded in the cadastre of caves in the two-kilometer strip along the route, and several smaller caves were discovered on the motorway section, most of which were filled with sediment.

Most channels are expected to be up to a few meters in diameter and filled with fine-grained sediments. We also expect vadose abysses up to a few meters in diameter and a few tens of meters deep.

The possibility of trapped water is small, but greater than in the previous section.

Greater karstification is expected on the fault zone at the chainage km 4,840.

Up to 5 caves/km up to 5 m in diameter are expected.

6.5.3 Section C

Section C passes through Eocene limestones, which are not covered with impermeable rocks on the surface. Alveolinic-numulite limestones are generally more karstic, as shown by data from the Črni Kal area. Nevertheless, there are no recorded caves in the cave cadastre in this area.

The concentration of vertical abysses will decrease towards the end of the section, as the vadose speleo-genesis becomes shorter and shorter due to the synclinal geological structure.

Up to 10 caves / km with a diameter of up to 5 m are expected.

6.5.4 Section D

Section D runs in Eocene limestones, which, however, are covered with impermeable Eocene marls and flysch. Since carbonate rocks are covered with flysch, vadose abysses are not expected. There is a greater possibility of locally trapped water in this area. We expect channels of diameters of the order of a few meters, exceptionally up to 10 m, in the case of less expected remains of old now fossil caves.

Given the shorter time of speleo-genesis, lower permeability is expected, higher permeability is possible only on locally severely limited inflows of surface water from the flysch roof.

Up to 5 caves / km are expected, which will have a diameter of up to 5 m.

6.5.5 Section E

Section E is identical to section C in terms of geological structure. We expect caves formed in the phreatic or epiphreatic hydrological zone, whose channels are (sub) horizontal, and vadose abysses. The density of the abysses should increase from the beginning of the section to the end due to the length of the speleo-genesis.

Given the high permeability of this type of limestone on the karst edge, we can expect a higher permeability of this area than shown by the condition of the recorded caves near the section. Namely, the Karst Edge was much more studied due to numerous interventions in it (quarry, construction of the motorway).

Up to 10 pits / km with a diameter of up to 5 m are expected.

6.5.6 Section F

Section F runs in Paleocene limestones. Lithological data and data obtained from drilling indicate a lower frequency of caves in Dani and Thanetium. No caves have been recorded in the cave cadastre on this section, and several caves have been discovered on the motorway section, which have been partially filled with sediments.

Most of the channels are expected to be a few meters in diameter. Some caves may also be filled with sediments. A vadose abyss up to a few meters in diameter is expected.

According to the geological profile, higher turbidity is expected at the fault zones at the stationing of km 7,100 and km 7,300 m.

Up to 5 pits / km with a diameter of up to 5 m are expected.

6.5.7 Section G

A short section G runs through the Cretaceous limestones of the Liburnian formation. In the cave cadastre, one cave is recorded directly along the route. In this section, sections of larger (sb) horizontal phreatic and epiphreatic caves are expected, the diameters of which can reach up to 5 meters. We also expect vadose abysses with a break of a few meters.

A higher density of channels is expected at the stationing of km 8,300 and km 8,440, as strong fault zones are expressed here.

In general, up to 10 caves / km with a diameter of up to 10 m are expected.

6.5.8 Section H

Section H runs through Paleocene limestones. No caves were recorded in the cave cadastre on this section, and individual caves were discovered on the motorway section, most of which were filled with sediments.

Most of the channels are expected to be a few meters in diameter. Some caves may also be filled with sediments. A vadose abyss up to a few meters in diameter is expected, as borehole as upright, narrow and long crevice caves, formed by pronounced faults and cracks in the SE-NW. They can be up to 2 m wide and 10 and more meters long.

Greater density of karst features is expected at the chainage km 8,500, where the route crosses strong fault zones.

Up to 5 caves / km are expected, which can have a diameter of up to 5 m.

6.5.9 Section I

Section I runs through Eocene limestones. In the cave cadastre, one cave is recorded along the route. We expect vadose abysses of a few meters in diameter. Greater permeability is expected at the contact of alveolar-numulite limestone and transition layers and flysch at the stationing km 8,930.

In general, up to 10 caves / km with a diameter of up to 5 m are expected.

6.5.10 Section J2 (km 9,929-11,280)

The characteristics of section J2 are the same as section J1 (Section J1 runs through impermeable Eocene flysch rocks and transition layers. Despite the significant carbonate binder in the flysch rocks, no greater permeability is expected.). There is a greater possibility of conductive channels at the stationing km 10,830, as lateral phreatic water flows independent of the locally impermeable flysch roof can occur along the folds, which are inclined in the longitudinal direction.

In general, up to 1 cave / km up to 1 m in diameter is expected.

6.6 Estimation of the number of karst formations in the T1 tunnel

Based on the sections of different levels of karstification obtained from the karst report [6], shown on the longitudinal geological-geomechanical profile of the T1 tunnel (graphic annexes 3238 and 3239), an analysis of the number of karst formations, their size, occupancy status and probability of crossing the tunnel route was carried out. Based on the density of karst formations, 6 sections A-F are separated along the tunnel, as shown in Table 5.1.

			features that clash with tunnel route (No.)				features that are less than 5m afar from tunnel route (No.)			
section	**No. caves <2m**	**No. caves >2m**	<2 m empty	<2 m filled	>2 m empty	>2 m filled	<2 m empty	<2 m filled	>2 m empty	>2 m filled
A	**0**	**10**	0	0	3	12	0	0	2	8
B	**3**	**7**	2	6	3	9	1	3	2	6
C	**2**	**3**	2	4	1,5	4,5	1	2	1	3
D	**4**	**6**	2	8	3	7,5	1	4	2	5
E	**1**	**8**	2	2	3	10,5	1	1	2	7
F	**1**	**1**	2	2	1,5	1,5	1	1	1	1

Table 5.1: Estimation of the number of karst formations in the T1 tunnel.

Table 5.1 shows that the estimate number of karst formations that cross the route of the tunnel is about 90, with about 45 of them larger than 2m, which means that there will be a high probability for their remediation. Estimation of the number of karst formations that do not cross the route of the tunnel but are in the area of influence or at a distance of up to 5m is about 60. The total estimated number of karst formations with the the influence zone along the entire length of the tunnel is about 150.

7 Grouting

7.1 General

Grouting is the injection of cement or chemical grouts into a surrounding rock to reduce the permeability of the rock, without significantly increasing the volume of the rock, nor significantly changing its strength or stiffness characteristics. Exceptionally, in the remediation of karst formations, grouting can be used to consolidate karstic rocks by injecting cement or chemical grouting masses into the surrounding rock to consolidate strongly fractured rocks and karst formations filled with liquid sediments. In this case, the volume of the rock increases and its strength and stiffness characteristics improve.

For the needs of remediation of karst formations, grouting will also be used to fill empty karst formations of smaller dimensions in the impact area of the tunnel or right next to it with pumped concrete or. cement or chemical grouts. Only those karst formations can be filled in, for which, due to their smaller dimensions, it can be reasonably assumed that due to the expected smaller impact on the general permeability of the rock, it is not necessary to perform construction of a bypass around the tunnel.

Grouting of the rock is envisaged as one of the necessary measures to reduce water permeability in the vicinity of the tunnel, as explained in Chapter 4. In the rehabilitation of karst formations, grouting is planned as one of the auxiliary technological procedures improving the properties of sediments trapped in karst formations. In this case, however, the grouting task can also be switched in order to reduce the water permeability of the rock. The grouting of the rock is performed with an injection mass of different composition (cement mortar, microcement cement mortar, polymer injection mass, etc.) under a suitable pressure in a predetermined zone in the vicinity of the tunnel.

Grouting is performed in accordance with applicable standards, namely: Slovenian standard SIST EN 12715: 2002, Execution of special geotechnical works – Grouting. Also the Contractor is obliged to use the instructions given in the document: Expert Comments to EN 12715 - Grouting (OGG, Slazburg, 2017) issued by the Austrian Society for Geomechanics.

When performing grouting, the Contractor must fully comply with the instructions, recommendations and conditions given in the Technical Specifications for Special measures tunnel construction [13].

The following is a brief summary of the provisions given in the Technical Specifications regarding grouting. Given that the implementation of grouting directly depends on the local hydrogeological conditions in each section, the Contractor is obliged to prepare a Technological Grouting Study (Method Statement) for each grouting process, which is adapted to micro-local geological and hydrogeological conditions. The technological study must contain:

- description of grouting equipment (drilling sets, mixers and grouting pumps, packers, measuring instruments),
- the method of drilling by ensuring the exact position of the boreholes,
- the method and frequency of measuring the course of drilled boreholes,
- the choice of the type of grout (cement or chemical and the use of additives) with the reasons for the choice,

- selection of injection parameters (pressure, viscosity of injection mass) with justification of the reasons for selection,
- a detailed description of the grouting preparation and injection process (preparation of the mass, a description of all grouting stages, including the choice of packer type and position, and borehole and packer cleaning procedures),
- a detailed description of all other related activities.

When performing grouting, the Contractor must regularly and continuously document the grouting process to a minimum extent, which for each of the drilled boreholes includes:

- borehole mark,
- number of grouting injection stages,
- the type of injection mass used,
- recording the grouting injection duration, pressures and injection volume in each of the stages, and recording other relevant information during execution such as e.g. communication between boreholes, etc.

The efficiency of the grouting must be checked by carrying out control boreholes and performing the Lugeon test in the improved rock to determine the degree of reduction of the rock permeability in the area of the performed grouting. Based on the obtained results, a decision is made on the possible continuation of the grouting procedure. The decision on the further stages of grouting is made by the Engineer and the Geotechnical Engineer within the framework of geotechnical supervision. Basic instructions on the implementation of pre-grouting and post-grouting are given in the drawings as part of the detection and remediation of karst formations.

The following are descriptions of individual procedures in which grouting can be used in the remediation of karst formations.

7.2 Grouting to fill cavities

Grouting is performed mostly with a single packer to seal the borehole head and inject the injection mass under pressure through the packer. For the remediation of karst formations, such as e.g. in the case of crossing isolated smaller channels and fractures of larger dimensions, which on the basis of geophysical measurements are reasonably assumed to (1) extend significantly away from the tunnel and are part of a larger system of karst formations and (2) that for them due to smaller dimensions and expected minor impact on the general permeability of the rock is not necessary to perform a bypass around the tunnel, the use of double packers is envisaged. In this case, the use of a double packer is envisaged to limit the length of the borehole where the injection mass is injected (in case of higher water flows polyurethane with expansion additives). The grouting will be carried out in several steps to ensure the primary sealing. After completion of the primary sealing, grouting with a single packer is performed according to the procedures described in the technical specifications.

7.3 Pre-grouting to prevent inflow of water in front of the tunnel front during construction

This type of grouting can be used to protect the area from the excavation face by using pre-grouting in fractured rock aquifers or. for the case in which the tunnel passes through a fault zone of limestone, and in the case of further excavation such inflows of water into the tunnel are expected to obstruct the excavation works and cause instabilities in places. In this case, the normal drainage of water by drainage boreholes would not be successful due to excessive amounts of water and new inflows.

Pre-grouting is used to reduce the permeability of the rock-mass around the entire profile of the future tunnel, which is carried out from purpose-built fan-shaped boreholes in the area in front of the top heading. Pre-grouting of the entire ring around the future tunnel is performed at the front of the top heading with a fan-shaped arrangement of boreholes 21 m to 22 m long and a slope of 13 ° from the horizontal at the top of the tunnel to a slope of 22 ° from the horizontal at the bottom of the tunnel. In each phase of grouting, 27 boreholes by means of impact rotary drilling with a diameter of 51 mm, 22 m long are drilled. Based on experience in the construction of tunnels in jointed rock with similar hydrostatic pressures, it is anticipated that a pre-grouting step to ensure adequate rock thickness with reduced permeability will need to be carried out every 4 m. The described layout, length and switching of the boreholes ensure, in the case of a properly performed pre-grouting, a ring of rock at least 4 m thick with reduced permeability around the entire cross section of the future tunnel. The grouting is carried out in phases (odd and even boreholes) and begins in the invert and continues towards the top of the tunnel. Pre-grouting is carried out from the top heading plateau by the procedures defined in the technical specifications and in accordance with the instructions given in graphic annex drawing 8005.

7.4 Post-grouting to prevent water inflow into the tunnel (grouting behind the top heading)

Post-grouting is performed as a measure to reduce the permeability of rock mass, which is carried out from purpose-built radial boreholes from an already built tunnel, if the pre-grouting was not fully successful and the permeability of the rock was not reduced accordingly. Post-grouting of the entire cross-section is carried out after the completion of the excavation of the entire cross-section of the tunnel and the installation of all required elements of the primary support from the invert level with radial boreholes at least 4 m long. In each phase of grouting, 23 boreholes with a diameter of 51 mm are to be drilled by means of impact rotary drilling. Based on experience in the construction of tunnels in jointed rock with similar hydrostatic pressures, it is assumed that it will be necessary to carry out a radial distance of boreholes for post-grouting every 1.5 m. The described layout and length of the boreholes ensures, in the case of a properly performed post-grouting, at least 4 m thick ring of rock with reduced permeability around the entire cross section of the future tunnel. Post-grouting is carried out from the invert plateau after all parts of the excavation and support of the entire cross-section of the tunnel have been completed by the procedures defined in the technical specifications and in accordance with the instructions given in graphic annex drawing 8006.

7.5 Grouting for various purposes in the remediation of karst formations

Given that the spatial orientation of karst formations is completely random, it will be necessary to use grouting for various purposes in the remediation of karst formations, where the purpose and quantity of grouting boreholes must be adapted to local geological and hydrogeological conditions. The following are the most likely scenarios for this type of grouting use with brief descriptions. In similar cases not described in this technical report, the instructions given below should be used as described or changes within the rational scope.

7.5.1 Sealing of local cracked zones, after excavation

This measure prevents the lateral inflow of water into the tunnel, in case it is necessary to rehabilitate the local aquifer karst zone that intersects the tunnel. The purpose of such sealing is to prevent the inflow of water into the tunnel during construction or to prevent additional loading of the tunnel during operation. The measure involves drilling a series of boreholes in suitable places, and grouting using double packers to perform the appropriate effect.

7.5.2 Sealing of local cracked zones, during excavation, construction from an adjacent tunnel tube

This measure prevents the inflow of water into the tunnel by grouting from an adjacent tunnel tube. The position, yield and shape of the weathered zone must be known. From the front of the tunnel, grouting boreholes are made in an appropriate place, crossing the broken zone in front of the front of the tunnel near the contour of the tunnel.

7.5.3 Grouting to divert water near the tunnel tube

The grouting involves blocking the water flowing from the karst channel in a certain direction, and diverting the water in another direction in a way that is useful for the construction of the tunnel.

7.5.4 Grouting to increase the load-bearing capacity of the tunnel structure

The process encompasses improved rock properties by fabricating a reinforced tunnel support layer in places where higher pressures of water pressures through caverns are expected. The procedure involves the construction of a tunnel lining, and grouting behind the lining to fill joints.

7.6 Reinforcement of larger karst caverns filled with filling material (Jet grouting)

Jet grouting is a widespread soil consolidation process that can be used in tunnel construction to strengthen the tunnel perimeter in front of the excavation face or for improved sediments within the karst formations. In this case, this procedure is only possible in a material that is suitable for jet grouting (deposited material in larger caverns). The purpose of jet-grouting is to fill cavities and to reduce the inflow of water into the tunnel during excavation.

The jet grouting process comprises drilling a borehole and then pressing the suspension under high pressure to create a composite of the base material and the grouting material of approximately circular profile. The jet-grouting process for the needs of remediation of karst formations must be carried out in accordance with the valid standard SIST EN 12716: 2019 or to ensure its meaningful use in underground construction conditions.

8 REHABILITATION OF KARST FORMATIONS

The remediation of karst formations includes all processes that ensure a safe and permanent bridging of karstic formations.

8.1 Description of remediation processes based on the size and location of the karst formation

Remediation processes differ according to the location and size of the karst formation. The description of the criteria, the summary of safety and construction continuation impact and measures are summarized in drawing 8100.

8.1.1 Remediation of karst formations crossing the tunnel route

The first large group includes the remediation of karst formations that cross the tunnel. As each phenomenon requires a different treatment, the group is divided according to two criteria, space size and size of fill, into the following groups:

• Karst channels and funnels, less than 2 m in diameter, which are not filled.

• Karst channels and funnels, caverns, less than 2 m in diameter, filled with water and / or poorly bearing material.

• Karst channels and funnels, more than 2 m in diameter, which are not filled.

• Karst channels and funnels, caverns, more than 2 m in diameter, filled with water or poorly bearing material.

Methods of remediation of karst formations and the descriptions of the implementation procedures are given in the following subchapters.

8.1.1.1 Karst channels and funnels, less than 2 m in diameter, which are not filled

Karst formations belong to this subgroup if they meet the following conditions:

• they cross the tunnel route,

• the diameter of the channel is less than 2 m,

• the channel or funnel is empty,

• water never flows through the channel or funnel,

• the channel or funnel does not endanger the tunnel structure itself, but there is a possibility of ravelling in the roof or sides or of penetration in the ground.

Figure 8106 shows a possible implementation of the remediation of the karst channel. The general procedure for dealing with such karst formations is given in the previous sections; recommendations or specifics for this case are as follows:

• stop excavation progress at the face,

• securing the part of the tunnel where the karst formation is located or detected.

It is necessary to place a protective fence around the place where the funnel passes into the roof or an area where there is a possibility of rock block fall of the karstic material. It is also necessary to make a protective fence around the place where the funnel passes into the invert. All places must be lighted and properly marked as hazardous.

Once the hazardous areas have been adequately secured, excavation works can continue.

This is followed by additional research, which in this or a similar case includes:

• If necessary, additional exploratory drilling.

• Cave exploration in the area a few meters away from the tunnel.

• Georadar measurements in the vicinity of the openings, in order to detect the orientation and size of the karst formation in the area located a few meters away from the tunnel.

In the event that it is established that there is no material or water in the funnel, at least in the vicinity of the tunnel, which could in any way affect the tunnel structure, and that tunnel construction will not adversely affect the surroundings, remediation should be carried out as follows:

• backfill with excavated material;

• installation of Q189 steel mesh attached to steel segments or otherwise. Behind the mesh, if necessary, pre-installation of formwork or separation geotextile layer;

• this is followed by shotcreting C 25/30 up to 30 cm thick, leaving holes for subsequent injection on the structure;

• when the concrete acquires adequate strength (at least 75%), grouting is performed behind this lining;

• implementation of drained cross section.

A similar procedure is carried out in the ground, with a preliminary barrier at a suitable depth to prevent the injection mass from escaping.

If this is possible and represents a suitable solution, shotcrete can also be used to fill the holes instead of grout.

8.1.1.2 Karst channels and funnels, caverns, less than 2 m in diameter, filled with water and / or poorly bearing material

Karst formations belong to this subgroup if they meet the following conditions:

- they cross the tunnel route,
- the diameter of the channel is less than 2 m,
- the channel or funnel is filled with water or poorly bearing material,
- the channel or funnel does not endanger the primary tunnel structure,
- possible water ingress; in case of liquid material there is a probable inflow of deposit material into the tunnel.

Drawing 8106 gives one of the possible implementations of the remediation of the karst channel. The general procedure for dealing with such karst formations is given in the previous sections. Recommendations or specifics for this case are as follows:

• Stopping the advance at the face and, if necessary / possible, moving to another point (remediation of the karst formation is not on the critical path of construction)

• Securing the part of the tunnel where the karst formation is located or detected

It is necessary to place a protective fence around the place where the funnel passes into the roof or an area where there is a possibility of rock block fall of the karstic material. It is also necessary to make a protective fence around the place where the funnel passes into the invert. All places must be lighted and properly marked as hazardous.

• Measurements / assessment of water pressure and flows.

• Drainage arrangements and removal of poorly bearing material

It is necessary to remove all water from the site, and it is also necessary to arrange the drainage of water that could still flow from the karst formation. It is also necessary to remove poorly bearing material from the site.

Once the hazardous areas have been adequately secured, drainage has been arranged and emergency work has been carried out, excavation work can continue.

This is followed by additional research, which in this or a similar case includes:

• If necessary, additional exploratory drilling.

• Georadar measurements in the vicinity of the openings, in order to detect the orientation and size of the karst formation in the area located a few meters away from the tunnel.

• Cave exploration in the area a few meters away from the tunnel.

Remediation works in the case of an aquifer include at least:

• Making a bypass of equivalent cross section as channel flow

• Installation of cast concrete or shotcrete outside the tunnel excavation cross-section

• Implementation of remediation according to the procedures described in point 6.1.1.1

In the event that the bypass and remediation prevent the action of water pressures on the lining of the tunnel, the tunnel can be made in a drained concept.

In cases where the channel is filled with liquid material, it is generally necessary to follow the procedures described in point 6.1.1.1 during remediation. Before deciding on the type of cross section, it is necessary to determine the permeability of the material or possible water inflows and the water pressures.

On the basis of geotechnical research, it is necessary to predict what the behaviour of the karst formation will be after the remediation, where it is also necessary to adjust the construction of the tunnel in the area of the karst formation.

Construction adjustments may include:

• Increasing the thickness of the inner lining

• Reinforcement of the inner lining

• Adjustment of the drainage system at the affected section.

8.1.1.3 Underground space or karst cave, more than 2 m in diameter, not filled

Karst formations belong to this subgroup if they meet the following conditions:

• they cross the tunnel route,

• the diameter of the channel is more than 2 m,

• the underground space is not filled,

• water never flows through the underground space.

This category mainly includes larger karst caves and caverns. The method of remediation can vary significantly depending on the size of the cavern and especially its position relative to the tunnel tube. If the underground structure is located entirely within the contour of the tunnel, remediation is not necessary, and in case the underground structures intersect the contour of the tunnel, the methods of remediation in such a case refer to:

• Remediation in the crown (possible design given in drawing no. 8105) and sides of the tunnel (one of the possible designs given in drawing no. 8101)

In this case, the karst cavern intersects the contour of the tunnel in the roof. The remediation process must be carried out by an artificial wall, behind which grouting is executed.

• Remediation in the ground of the tunnel (one of the possible designs given in drawing no. 8103)

It is necessary to implement a bridging structure that first allows the passage during the excavation of the tunnel, and then it must have such properties that it allows the proper installation of the track.

• The karst formation is larger than the contour of the tunnel in all directions

It is necessary to carry out backfilling or a bridging structure, which first allows the passage at the time of excavation of the tunnel, and then it must have such properties as to allow proper installation of the track. The final structure can be closed, but it is also possible to place the route outside the tunnel through the underground cave.

The general procedure for dealing with such karst formations is given in the previous sections. The following are recommendations or specifics for this case:

• Suspension of works during tunnel excavation

• Securing the part of the tunnel where the karst formation is located or detected

• In case of stopping the work, move to another point (bench, …). in this way, the remediation of the karst formation is not on the critical path of construction.

The place around where the cavern is located must be secured. All places must be lighted and properly marked as hazardous. Once the hazardous areas have been adequately secured, excavation work can continue.

This is followed by additional research, which in this or a similar case includes:

• if necessary, additional exploratory drilling;

• hydrogeological research;

• georadar measurements in the vicinity of openings, in order to detect the orientation and size of the karst formation;

• cave exploration.

If it is established that there is no material or water in the cavern, at least in the vicinity of the tunnel, which could in any way affect the tunnel structure, and that the cavern is not connected to other underground spaces, the remediation should be approached with the following measures and materials:

• limiting the remediation area with formwork, reinforcing mesh and shotcrete, backfill, etc.;

• backfill with excavated material;

• installation of a separation layer and installation of cast concrete or shotcrete in layers, leaving holes for subsequent grouting on the structure beforehand;

• when the concrete has acquired adequate strength (at least 75% compressive strength), grouting is carried out if necessary.

A similar procedure is carried out in the ground, with a preliminary barrier at a suitable depth to prevent the injection mass from escaping. If necessary, a reinforced concrete floor slab is made, and in special cases also a bridging structure.

8.1.1.4 Karst channels and funnels, caverns, more than 2 m in diameter, filled with water or poorly bearing material

This category mainly includes larger karst caves and caverns. The method of remediation can differ significantly depending on the size of the cavern and especially its position in relation to the tunnel tube, the content of material and water, water pressure and the amount of inflowing water.

Karst formations belong to this subgroup if they meet the following conditions:

• they cross the tunnel route,

• the diameter of the channel is more than 2 m,

• the channel or funnel is filled with water or poorly bearing material.

Figures 8101 and 8105 show the possible implementation of the remediation of the karst cavern. The general procedure for dealing with such karst formations is given in the previous section. Here are the recommendations or special features for this case:

• immediate shutdown of tunnel excavation works,

• securing the part of the tunnel and performing emergency works.

Emergency works include the protection of workers and machinery and the implementation of other measures to limit damage. Move the team to another construction site as needed and able.

It is necessary to remove all water from the work site, and it is also necessary to arrange the drainage of water that could still flow from the karst formation. It is also necessary to remove poorly bearing material from the site. If the karst formation has been detected in advance, drainage is carried out in a controlled manner through a system of drainage pipes, and the improvement of rock mass properties is carried out by grouting.

If safety is ensured by emergency and quick measures (stability of the tunnel, protection against falling pieces of rock on the site, drainage, additional water inflows are not possible, etc.), the excavation work can continue, otherwise the team will be moved to another site in a manner so that research and remediation of the karst formation is not on the critical path of construction.

This is followed by additional research, which in this or a similar case includes:

• georadar measurements in the vicinity of the openings, in order to detect the orientation and size of the karst formation in the area located a few meters away from the tunnel;

• cave exploration in the area a few meters away from the tunnel;

• if necessary, additional exploratory drilling;

• measurements of water pressure and flows.

Remediation works should be carried out in accordance with the project design, which is prepared for each similar case separately.

On the basis of geotechnical research, it is necessary to predict what the behaviour of the karst formation will be after the remediation, where it is also necessary to adjust the construction of the tunnel in the area of the karst formation.

Construction adjustments may include:

• increasing the thickness of the inner lining;

• reinforcement of the inner lining;

• adjustment of the drainage and drainage system at the affected section.

8.1.2 Remediation of karst formations that do not cross the tunnel route

The second large group includes the remediation of karst formations that do not cross the tunnel. As each formation requires a different treatment, the group is divided according to two criteria, space size and density of fill, into the following groups:

• Karst canals and funnels, less than 2 m in diameter, which are not filled and are less than 2 m away from the tunnel in the top heading or 4 m in the bench

• Karst canals and funnels, caverns, less than 2 m in diameter, which are filled with water or poorly bearing material and are less than 2 meters away from the tunnel in the top heading or 4 m in the bench.

• Karst canals and funnels, more than 2 m in diameter, which are not filled, are less than 5 meters away from the tunnel in the top heading and bench, or 10 m in the invert.

• Karst canals and funnels, caverns, more than 2 m in diameter, which are filled with water or poorly bearing material and are less than 5 meters from the tunnel in the top heading and bench, or 10 m in the invert.

8.1.2.1 Karst canals and funnels, less than 2 m in diameter, which are not filled and are less than 2 m away from the tunnel in the top heading or 4 m in the bench

This category includes karst formations that fill the following conditions:

• they are less than 2 meters away from the tunnel in the top heading and the bench or 4 m in the invert,

• the diameter of the channel is less than 2 m,

• the channel is empty,

• the channel is in a position which can endanger the tunnel structure, either in the tunnel excavation phase or the final tunnel structure, due to the possibility of water or poorly load-bearing material entering the tunnel or due to falling material and increased loads in the future.

Because the karst channel does not intersect the tunnel and is relatively small in size, it is unlikely to be detected before the tunnel reaches an underground structure. It will then be detected either by measurements (georadar) or by exploratory boreholes, which is less likely. It is much more likely that the karst channel will be detected during working operations during excavation and tunnel support, such as drilling anchors.

As the funnel does not hinder the progress of the works, it is not necessary to stop the excavation works, so a visit by a designer, geologist, hydrogeologist and engineer follows, where it is necessary to provide research to determine the location and extent of the karst phenomenon.

In order to obtain data on the dimensions, size and filling of the channel, it is necessary to carry out additional research work, which includes:

• exploratory drilling;

• georadar;

• cave exploration;

• other procedures by which relevant data can be obtained;

• breakthrough to the karst formation and visual inspection.

Before starting the research work, it is necessary to prepare a research program, which must be approved by the Monitoring. The research program is made by a Geotechnical Engineer and Designer.

As a result of research work, it is necessary to prepare a report, which must contain all the results of research, all the necessary calculations and explanations, from which it is necessary to uniformly draw the following conclusions or answer the following questions:

• Can an untreated channel damage the tunnel structure, either in the excavation phase or in the final design;

• What are the possible negative effects in the event that there is no remediation of the channel;

• What are the possible negative effects on the hydrogeological conditions in the aquifer in case of remediation.

In the event that remediation is necessary, the report should include all design solutions that allow for the appropriate remediation of the channel, with the following procedures most likely to be used:

• additional excavation / reprofiling if necessary,

• reinforcement of the final lining,

• grouting,

• tunnel sealing,

• other measures that will prove to be suitable for the remediation of the tunnel and the karst formation in the affected area.

8.1.2.2 Karst canals and funnels, caverns, less than 2 m in diameter, which are filled with water or poorly bearing material and are less than 2 meters away from the tunnel in the top heading or 4 m in the bench

If karst formations meet the following conditions:

• they are less than 2 meters away from the tunnel at the top heading or side or 4 m in the invert,

• the diameter of the channel is less than 2 m,

• the channel is filled with water or low-bearing (liquid) material,

• The channel is in a position which can endanger the tunnel structure, either in the tunnel excavation phase or the final structure of the tunnel, due to the possibility of water or poorly-bearing material entering the tunnel or due to increased loads in the future.

Because the karst channel does not intersect the tunnel and is relatively small in size, it is unlikely to be detected before the tunnel reaches an underground structure. It will then be detected either by measurements (georadar) or by exploratory wells, which is less likely. It is much more likely that the karst channel will be detected during excavation operations and tunnel support, such as drilling anchors, or that water or poorly bearing material may enter the tunnel due to the small thickness and cracking of the load-bearing wall between the tunnel and the channel.

In the event of the intrusion of water or poorly bearing material, it is necessary to immediately carry out urgent protective work, which includes:

• temporary suspension of works during tunnel excavation,

• securing the work where the ingress occurs,

• drainage arrangements.

This is followed by an inspection by the designer, geotechnical engineer and monitoring, where it is necessary to envisage measures by enabling the re-start of excavation works, such as:

• drainage arrangements that do not hinder further excavation works;

• execution of additional reinforcement with shotcrete or anchoring;

• grouting to block inflow into the tunnel;

• other measures to allow safe excavation at the face of the tunnel.

In order to obtain data on the dimensions, size and filling of the channel, it is necessary to carry out additional research work, which includes:

• exploratory drilling;

• georadar;

• cave exploration;

• other procedures by which relevant data can be obtained.

Before starting the research work, it is necessary to create a research program, which must be approved by the engineer. The research program is developed by the Geotechnical Engineer and Designer.

As a result of research work, it is necessary to prepare a report, which must contain all the results of research, all the necessary calculations and explanations, from which it is necessary to uniformly draw the following conclusions or answer the following questions:

• Whether the unrepaired channel can damage the tunnel structure, either in the excavation phase or in the final design.

• What are the possible negative effects in the event that there is no remediation of the channel.

• What are the possible negative effects on the hydrogeological conditions in the aquifer in case of remediation.

In the event that remediation is necessary, the report should include all design solutions that allow for the appropriate remediation of the channel, with the following procedures most likely to be used:

• reinforcement of the final lining;

• drainage;

• injection;

• bypass arrangement;

• tunnel sealing;

• other measures that will prove to be suitable for the remediation of the tunnel and the karst formation in the affected area.

Remediation procedures can vary greatly from case to case, but nonetheless, the following are basic guidelines:

• In case the remediation envisages filling the karst channel with grout, it is first necessary to prevent the inflow of water and new intact material into the tunnel area, which is done by shut-off grouting in suitable places, which prevents new inflows from above and below. This is followed by the implementation of water drainage through drainage boreholes and the injection of the replacement mass with one of the procedures that are most suitable for individual cases.

• It is necessary to take into account that the closures of karst channels can have unpredictable consequences, so it is necessary to envisage measures that compensate for any changes in the vicinity of the tunnel that may adversely affect the tunnel structure. This includes measures that enable the tunnel structure to withstand possible water pressures in the vicinity of the tunnel, as well as the arrangement of appropriate drainage.

First, shut-off injection is carried out, at a suitable place where the channel is already moving away from the tunnel at the crown, and on the side of the tunnel. Compaction is used to displace the base material, and additional inflows of water from the area above the barrier at the crown and the area below the barrier on the side of the tunnel are prevented. This is followed by drainage of the karst channel between the two barriers and then grouting through drainage pipes when the water inflow is reduced.

8.1.2.3 Underground spaces, more than 2 m in diameter, which are not filled and are less than 5 meters away from the tunnel in the top heading and bench, or 10 m in the invert.

The following are recommendations or guidelines for the remediation of underground spaces that meet the following conditions:

• they are less than 5 meters from the tunnel in the top heading and/or bench or 10 m in the invert,

• the diameter of the channel is between 2 and 10 m,

• the channel is empty,

• the channel is located in such a position that it can endanger the tunnel structure, either in the tunnel excavation phase or the final structure of the tunnel, due to the possibility of water or poorly bearing material entering the tunnel, falling material and thus increased loads in the future.

Because the karst channel does not intersect the tunnel, it is less likely to be detected before the tunnel reaches an underground structure. It will then be detected either by measurements (georadar) or by exploration wells. It is more likely that the karst channel will be detected during work operations during excavation and tunnel support, such as anchor drilling.

As the phenomenon does not hinder the progress of the works, it is not necessary to stop the excavation works. This is followed by an inspection by the Geotechnical Engineer and the Monitoring, where it is necessary to provide research in the construction log to determine the location and extent of the karst formation.

In order to obtain data on the dimensions, size and filling of the channel, it is necessary to carry out additional research work, which includes:

• exploratory drilling,

• georadar,

• cave exploration,

• other procedures by which relevant data can be obtained,

• breakthrough to the karst formation and visual inspection.

Before starting the research work, it is necessary to prepare a research program, which must be approved by the Monitoring. The research program is made by a Geotechnical Engineer.

As a result of research work, it is necessary to prepare a report, which must contain all the results of research, all the necessary calculations and explanations, from which it is necessary to uniformly draw the following conclusions or answer the following questions:

• Whether an unrepaired channel can damage the tunnel structure, either in the excavation phase or in the final design.

• What are the possible negative effects in the event that there is no rehabilitation of the channel.

• What are the possible negative effects on the hydrogeological conditions in the aquifer in case of remediation.

In the event that remediation is necessary, the report should include all design solutions that allow for the appropriate remediation of the channel, with the following procedures most likely to be used:

• reinforcement of the final lining,

• concreting,

• grouting,

• tunnel sealing,

• other measures that will prove to be suitable for the remediation of the tunnel and the karst formation in the affected area.

8.1.2.4 Karst canals and funnels, caverns, more than 2 m in diameter, which are filled with water or poorly bearing material and are less than 5 meters from the tunnel in the top heading and bench, or 10 m in the invert

The following are recommendations or guidelines for the remediation of karst channels that meet the following conditions:

• they are less than 5 meters away from the tunnel in the top heading and bench or 10 m in the invert,

• the channel diameter is greater than 2 m and less than 10 m,

• the channel is filled with water or poorly bearing (liquid) material,

• the canal is in a position which can endanger the tunnel structure, either in the tunnel excavation phase or the final structure of the tunnel, due to the possibility of water or poorly bearing material entering the tunnel or due to increased loads in the future.

Since the karst channel does not intersect the tunnel, it is unlikely that it will be detected before the tunnel reaches the underground space. At that time, it will be detected either by measurements (georadar) or by exploratory wells. due to the small thickness and cracking of the load-bearing wall between the tunnel and the channel. In the latter case, it is necessary to suspend or stop the work and start carrying out research work.

In the event of the intrusion of water or poorly bearing material, it is necessary to immediately carry out emergency protective work, which includes:

• suspension of works during tunnel excavation,

• securing the work where the ingress occurs,

• drainage arrangements.

This is followed by an inspection by the Designer, Geotechnical Engineer and Monitoring, where it is necessary to envisage measures to enable the re-start of excavation works, such as:

• drainage arrangements that do not hinder further excavation works;

• execution of additional reinforcement with shotcrete or anchoring;

• grouting to block inflow into the tunnel;

• other measures to enable safe further excavation at the tunnel face.

In order to obtain data on the dimensions, size and filling of the channel, it is necessary to carry out additional research work, which includes:

• exploratory drilling,

• georadar,

• cave exploration,

• other procedures by which relevant data can be obtained.

Before starting the research work, it is necessary to prepare a research program, which must be approved by the Monitoring. The research program is made by a Geotechnical Engineer.

As a result of research work, it is necessary to prepare a report, which must contain all the results of research, all the necessary calculations and explanations, from which it is necessary to uniformly draw the following conclusions or answer the following questions:

• Whether the unrepaired channel can damage the tunnel structure, either in the excavation phase or in the final design.

• What are the possible negative effects in the event that there is no remediation of the channel.

• What are the possible negative effects on the hydrogeological conditions in the aquifer in case of remediation.

In the event that remediation is necessary, the report should include all design solutions that allow for the appropriate remediation of the channel, with the following procedures most likely to be used:

• reinforcement of the final lining,

• drainage,

• grouting,

• bypass arrangement,

• tunnel sealing,

• other measures that will prove to be suitable for the remediation of the tunnel and the karst formation in the affected area.

8.2 Bypass arrangement

In places where the tunnel crosses a permanent or temporary aquifer, it is necessary to make a bypass (see [6] and **Error! Reference source not found.**). A bypass must ensure water flow equal to the original, with a maximum reduction of transmissibility of 10%. A bypass can be made of PE100 pipes. If there is a need for a larger bypass, the construction of an underground "outlet" may be envisaged.

8.3 Bridging structures

In the event that the tunnel route is during the excavation of the tunnel clashes with a major karst formation, there may be a need to build a bridging structure for the tunnel tube. Such karst formation can be an abyss or individual corridors of karst caves or parts of larger karst systems. This type of karst formations can be permanently or temporarily exposed to the water regime. In this case, it is also necessary to take into account the buoyancy force resulting from the hydrostatic pressures to which the bridging structure could be exposed during the construction or operation phase.

As part of possible solutions for the bridging structure, the construction of a reinforced concrete U-shaped footbridge is envisaged, as shown in graphic annex drawing 8007. As can be seen from the annex, the footbridge is integrated into the tunnel shape so as to cover all the elements of characteristic cross-section including drainage system.

When designing the footbridge, it was verified that such a solution can withstand spans of up to 6m, with the further planning stage having to be adapted to local geological, karst and hydrogeological conditions. When building a footbridge, special attention must be paid to the foundation supports, which must be integrated into a competent rock mass that is not karstified. In the event that this cannot be achieved at a given location, the rock mass must be consolidated or improved for the needs of the footbridge foundation. This can be achieved by grouting or other technological processes such as filling cavities with concrete or reinforced concrete.

Each bridging structure must be considered as an individual structure, taking into account the following loads:

- Constant load (own weight of tunnel lining and equipment)
- Useful load (weight of train or locomotive and/or freight wagons)
- Buoyancy force (in case there is a possibility of water action of bridging structure)
- Dynamic load (train braking force)
- Seismic load (earthquake load)

In the event that the construction of the bridging structure will be demanding and time consuming, it is necessary to make a by-pass tunnel in the excavation of the tunnel so that the excavation of the tunnel can take place unhindered during the construction of the bridging structure.

9 WATER GATE

9.1 Introduction

When building tunnels in rock mass where sudden water ingress can occur, water gates can be used to limit damage in the event of water ingress or for safety reasons. Use is recommended in the case of a downwards excavation, where the water level can rise upwards, all the way to the portal. In the case of an upward excavation, the water is expected to flow towards the portal.

The following are the basics for the use of water gates in the construction of tunnel T2, in excavation downwards, i.e. direction Divača towards Koper. In the simultaneous construction of the tunnel from both portals, a maximum water column of 42.5 m is envisaged. In the event that the water column rises to the mentioned height, water would flow through the Divača portal.

9.2 Basics

In tunnels T1 and T2, which will be constructed from both sides, there is a possibility of water ingress into the tunnel. The greatest possibility of water ingress is at the excavation face, and the quantities can also be so large that they can endanger workers and make it impossible to work in the tunnel for a long time.

If water enters the tunnel, it can endanger workers and machinery, depending on the amount. In this case, it is necessary to go to a safe place as soon as possible, which can be quite far from the excavation face. Therefore, there is a need for pre-installation of a barrier, which during the normal operation of the construction site allows the passage of people and machinery, and in case of sudden water ingress or rising groundwater in karst canals, it closes and prevents water spillage behind the barrier.

For this purpose, we propose the implementation of steel water gate, which must have the following characteristics:

• it must cover the entire profile of the tunnel,

• they must allow the passage of people and machinery during the execution of works,

• it must allow ventilation, supply of compressed air and electricity,

• they must withstand water pressure that reaches values of a few bar,

• they enable controlled release of water through the water gate,

• they can be operated,

• they can be prepared for operation within a few minutes (from normal mode to emergency mode).

The water gate is installed according to needs. We suggest that the water gate be made on the side of the excavation in front of each constructed cross passage, at a distance behind the face between 300-500 m. They need to be made as movable so that they can follow the excavation.

Water gates are needed especially when excavating downwards (direction Divača towards Koper), because water can fill or flood the tunnel. When digging upwards, the water can drain towards the portal, but it is necessary to expect for the drainage of a larger amount of water with drained channels or pipes of suitable size.

Water gates must be installed so that they can withstand the pressure of the water column up to the Divača portal (approx. 4.25 bar), which means that the water gate structure must be installed in the tunnel walls via the AB structure and, either through the anchor system or by constructing a slot, on which the door leans. Water gates are schematically shown in graphic appendix 8161.

9.3 Construction of the water gate

Anti-flood gates are generally made of a single door leaf, which prevents the intrusion of flood water after closing. In addition, a round opening is provided above the door, which allows the passage of ventilation pipes. In addition, two DN400 water outlets are provided. The wing and the closure of the ventilation opening as well as the AB structure have a sealing tape inserted in the circumferential slot, which must withstand the expected water column. The force of the flood water is transmitted to the concrete installation frame via the gate and cover. Anti-flood gates of this type carry the load of flood water only from the side as intended, so that the force of the flood water presses the door structure on the load-bearing elements of the concrete structure. The gates must be made in accordance with the design requirements and the technology of the contractor, which mainly affects the sealing (four-sided) and the method of closing and installation.

The gate is installed for the time of the construction of the tunnel. The purpose of the gate is to protect the workforce and equipment from a sudden water ingress, and to enable safe withdrawal. In the design documentation, the designer envisages the installation of the gate and the necessary construction work for the installation of the gate in accordance with the requirements of the anti-flood gate manufacturer. When preparing the project documentation, special attention must be paid to the manipulation space required for the installation of the gate.

In this particular case, anti-flood gates with four-sided sealing are provided. The sealing below is expected to be executed with a low threshold.

The gate construction consists of built-in and movable parts. The movable parts (door wings) can be dismantled and used on another part of the tunnel tube during the construction phase. Care must be taken to ensure that all load-bearing elements of the structure (concrete supports and elements mounted on concrete supports) are built identically, so that the gate can be installed.

Closing the gate must be simple, taking into account the requirement of minimal maintenance and easy closing in case of danger of water ingress. Despite the anticipated high water pressures (approx. 42.5 m of water column), the installation of a gate without a closing mechanism is envisaged. Due to its heavy weight, the gate is closed with a working machine, secured against opening and pressure of the seals is provided by means of two screw elements. Closing, however, should not take more than just a few minutes.

In the next stage, ventilation pipe should be closed with a frog flap. Through the two water outlets DN400 the water can then be drained in a controlled way to the Divača portal area. Water is also expected to contain particles (e.g. sand), so the pump used must be capable of operating in the presence of particles. In case the water is completely retained, the openings remain closed.

Anti-corrosion protection is not required in this case, as the time of use is limited to the construction of tunnel tubes, so the gate is not protected. The intended gate material (minimum requirement) is black steel S235, which is the cheapest possible design, and at the same time allows the simplest installation on site.

Such gates are not exactly in everyday use, but are made individually, according to the project and are dimensioned based on specific project requirements. Due to this fact, it is necessary to develop a gate that will meet the requirements of the project and will be adapted to the project conditions. The basis for determining the dimensions and design of the gate and the load-bearing structure of the gate are static calculations based on the predicted loads.

Due to the above, the contractor must already think carefully at the time of the offer about their technology and method of approach, as well as the associated costs and installation time. After signing the contract, the contractor must immediately start preparing the water gate proposal, which is approved by the client. The contractor must have a contractual number of tested flood gates before the start of the underground excavation at the construction site.

The gate has been statically checked (Appendix 11.1), with a wall thickness of 1.0 m with a basic reinforcement of ϕ20 / 15 and reinforcements around the gate and other penetrations.

10 WATER OUTLET

The tunnel runs through the karst world, which is at the same time rich in groundwater. To reduce the cost of constructing the tunnel, groundwater around the tunnel tube is drained and discharged into a collection drainage pipe running along the tunnel. The latter is located at the bottom of the tunnel tube. The aquiferous karst world is a source of drinking water for the Trieste area. Therefore, it is not allowed to drain the drained water to the surface, but it will need to be drained back underground.

The route of the tunnel intersects karst caves at several points, which form the system of the karst groundwater aquifer. Drained water can be discharged into the latter through pipe outlets. In this way, the aquifer's water balance remains virtually unchanged. During precipitation, water accumulates in underground karst caves, which could flood the tunnel. Therefore, it is necessary to discharge drained water in a way that prevents the intrusion of water from karst caves into the tunnel pipe.

Along the entire length of the tunnel, two discharge shafts are planned. Suitable locations will be determined during the implementation phase by the relevant services.

The discharge is shown graphically in Figures 8301 - 8312.

10.1 System design

The basic problem of discharging drained water into the subsoil occurs during heavy rainfall, when karst caves are flooded. In some places, the groundwater pressure on the tunnel tube lining can grow up to (according to estimates) 8 - 10 bar. After additional investigations, local extreme values are up to 14 bar, but discharges are projected in the water pressure range up to 10 bar. The latter is, of course, also transferred to the discharge pipelines and indirectly (if the discharges were not adequately protected) into the interior of the tunnel. The basic safety device against tunnel flooding is a non-return valve with a ball, which prevents backflow through the discharge pipeline. The latter is very reliable as it is used to prevent backflow in pipelines in which fecal and sludge storm water flows. In the event that the non-return valve does not seal completely (by which we mean countercurrent sealing), the filtered water is drained to the surface through a central drainage pipe. As an additional safeguard, measurements of water levels (continuous) is provided in the central drainage pipe. In the event that a critical level is detected for any reason, the valve on the discharge pipeline is automatically closed by means of an electric motor drive. The probe for water levels measurements and the electric motor drive of the valve will be connected to the backup power supply in addition to the main one.

10.2 Facilities with equipment

The central drainage pipe Ø 400 mm runs along the entire tunnel. In the sections where the tunnel intersects the karst caves, reinforced concrete shafts are constructed in front of the latter, through which discharge pipelines run. In addition to the pipes, all elements (shut-off and non-return valves, cleaning pieces, …) necessary for the smooth operation of the outlet under all operating conditions are also installed in the shafts. The discharge pipe runs through a shaft in a closed system so that the latter is not flooded.

The shaft can be entered by a standard stainless steel ladder, e.g. Huber type SiS 2 DIN ISO 2768-m with trap guide against falling into the depth (or equivalent), through the inlet opening 100 x 80 cm (the latter also serves to replace individual discharge elements), which is covered with a non-typical cover made of stainless steel with the load-bearing capacity of 50 kN.

Drained water discharge includes the following basic elements:

• fittings (transitional, branches, knees, assembly-disassembly),

• gate valves,

• non-return valve,

• cleaning piece,

• pipelines,

which can be seen from the bill of materials - see graphic appendices. The latter enable the correct operation of the outlet and the replacement of individual, most loaded fittings.

10.3 Maintenance

The outlet is designed so that it is possible to replace individual elements. In the event of a minor leak, a portable drainage pump is installed in the deepened part of the shaft, with which (until the problematic element is replaced) the water is pumped through a flexible pipe into the central drainage system.

For regular maintenance of the outlet, a special cleaning piece is provided, which has a dual function:

• inspection and cleaning of the discharge pipeline between the non-return valve and the outlet into the cave,

• checking the tightness of the non-return valve.

When checking the tightness of the non-return valve, the end valve (shut-off valve) is closed and a pressure hose is connected to the fire coupling welded to the cleaning piece. A pressure test is then carried out to check the tightness of the non-return valve.

The status of the outlet must be checked regularly, namely:

• Once a week, or after each rain, check the general condition of the outlet (especially the tightness of the pipeline and fittings) and, if necessary, clean or replace leaky elements.

• Open and close the valves once a month to prevent them from rusting. If necessary, clean the bed and lubricate the movable parts. It is also necessary to check the operation of the electric motor drive on the inlet valve and the operation of the probe for measuring the level in the central drainage.

• 1 x every 6 months or after each major rainfall, check the tightness of the non-return valve,

• check the tightness of the valves once a year.

Valves and non-return valves must be replaced after the end of their service life, regardless of their condition.

Both valves must be closed when replacing the non-return valve. Cleaning the outlet is only possible at low water levels in the cave. For other maintenance work, the end valve must be closed (to prevent groundwater from entering the shaft).

More specifically, the requirements for the maintenance of the drained water drainage system will be defined in the POV technical documentation (operation and maintenance project), which is prepared after the completion of the tunnel construction. The shaft and the discharge pipeline are only a part of the entire tunnel maintenance system.

10.4 Pressure test

The pressure test shall be performed in accordance with PSIST EN 805, Chapter 10, and the internal rules of the manager. The pipes are tested at a pressure of 16 bar. The test is performed after the pipeline installation is completed. Before filling the pipeline with water, both ends of the test section as well as all branches and curves must be sealed, clamped and anchored to prevent movement of the pipeline during the test. Support at the ends of the pipeline must be installed for as long as the test pressure in the pipeline lasts. Fill the test section with clean water and air it. We mount two manometers on the pipeline to read the pressure. One manometer must be located at the lowest point of the test section. The amount of water required to reach the test pressure is read on the pressure pump vessel. Measurement of water consumption must be accurate. The test must be attended by a professionally qualified person conducting the test; on the part of the investor, the supervisory body. Until the pre-test is performed, the pipeline must be filled with water and under a pressure of 9 bar, continuously for 24 hours.

The pressure test is performed according to the internal instructions of the operator, namely the parameters of the main test are as follows (extract from DD SVVO TP NL 01; pressure test of drinking water pipelines, ductile iron pipes and steel pipes):

MAIN TEST

If a pre-test is performed, the latter should be run for 24 hours at a maximum operating pressure of 9 bar.

The pre-test is followed by the main test according to DIN 4279, part 1. The duration of the main test depends on the nominal diameter of the pipeline, namely for DN 250 - 400: test duration 6 h.

The test pressure of the system should be in accordance with the design. The following applies to ductile iron and steel pipelines:

STP = MDPa + 500kPa = (900kPa + 200kPa) + 500kFa = 1600kPa = 16 bar,

MDPa = operating system pressure - a certain value of pressure in case of water hammer, which must not be less than 200 kPa.

The test conditions are met if no greater pressure drop than 0.2 bar is found at the end of the test.

The test must be carried out in accordance with the provisions cited above. If the pressure test shows leaks at the joints, the test must be stopped, the pipeline emptied and the fault rectified, and the test repeated. A record of the pressure test shall be kept in accordance with the form adapted to DIN 4279, Part 9, signed by the operator's supervisory body, the pressure test contractor and a representative of the contractor who builds the pipeline. The record of successful pressure tests is an integral part of the PID.

We would like to point out that when performing the test, it is especially important to pay attention to the correct execution of the sealing points at the end of the test part of the pipeline, because large forces act at these places and the structure must safely take them over. In these works, special attention must be paid to safe execution (observe the work safety regulations).

10.5 General demands

All proposed equipment for which the manufacturer is listed (covers, ladders, reinforcements, ...) can be replaced with equipment from other manufacturers, but with the same characteristics as proposed.

Fittings, pressure pipes and ladders inside the building, and covers are made of AISI 304 stainless steel (V.N.r. 1.4301). Gate valves and non-return valves installed in the pressure line must be suitable (corrosion and operating) for storm wastewater (standard EN 598).

All elements installed in the discharge pipeline must withstand an operating pressure of 10 bar.

All reinforcements and fittings installed in the outlet are made of standard elements, manufactured and tested according to the applicable standards and must have the appropriate certificate.

11 Appendices

11.1 Water gate – static analysis

2TDK
Vodna vrata - Water doors
Definition von Material und Querschnitten

Default design code is EuroNorm EN 1992 (2004) Concrete Structures (Slowenija) V 27.0
Structure and Tab.7.1N: AN (Buildings)
Snow load zone : 1

No. 1 C 35/45 (EN 1992) (mod) C35

```
--------------------------------------------------------------------------------
Youngs-modulus   E        34077 [N/mm2]    Safetyfactor             1.50 [-]
Poisson-Ratio    mu        0.20 [-]        Strength        fc       35.00 [MPa]
Shear-modulus    G        14199 [N/mm2]    Nomin. strength  fck     35.00 [MPa]
Compression modulus       18932 [N/mm2]    Tens. strength   fctm     3.21 [MPa]
Weight                     25.0 [kN/m3]     5 % t.strength  fctk     2.25 [MPa]
Density          rho       2350 [kg/m3]    95 % t.strength  fctk     4.17 [MPa]
Temp.elongat.coeff.    1.00E-05 [1/°K]     Bond strength    fbd      2.86 [MPa]
                                           Service strength         43.00 [MPa]
                                           Fatigue strength         20.07 [MPa]
                                           Ten.strngth fctd          1.27 [MPa]
Stress-Strain for serviceability         eps[o/oo]  sig-m[MPa]  E-t[N/mm2]
Is only valid within the defined            0.000       0.00       35781
stress range                               -1.123     -31.50       19765
                                           -2.246     -43.00           0
                                           -3.500     -26.18      -28065
                                         Safetyfactor               1.50
Stress-Strain for ultimate load          eps[o/oo]  sig-u[MPa]  E-t[N/mm2]
Is only valid within the defined            0.000       0.00       35000
stress range                               -2.000     -35.00           0
                                           -3.500     -35.00           0
                                         Safetyfactor               1.50
Stress-Strain of calc. mean values       eps[o/oo]  sig-r[MPa]  E-t[N/mm2]
Is only valid within the defined            0.000       0.00       29818
stress range                               -1.123     -19.27        8335
                                           -2.246     -23.33           0
                                           -3.500     -20.25       -4413
                                         Safetyfactor             ( 1.50)
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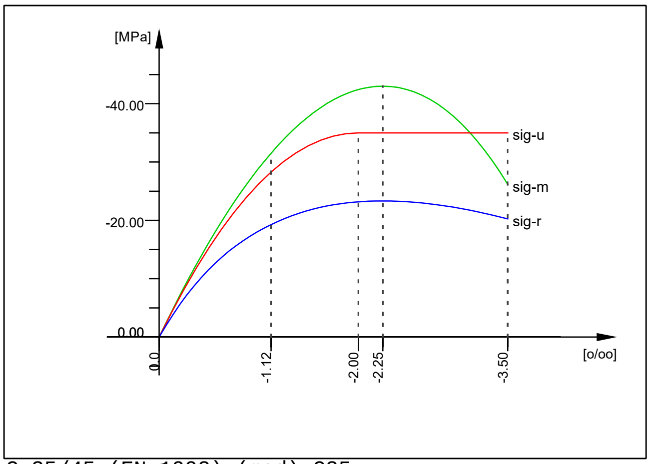

C 35/45 (EN 1992) (mod) C35

No. 2 C 35/45 (EN 1992) (mod) C35_a

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--------------------------------------------------------------------------------
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Poisson-Ratio    mu        0.20 [-]        Strength        fc       35.00 [MPa]
Shear-modulus    G        14199 [N/mm2]    Nomin. strength  fck     35.00 [MPa]
Compression modulus       18932 [N/mm2]    Tens. strength   fctm     3.21 [MPa]
Weight                     25.0 [kN/m3]     5 % t.strength  fctk     2.25 [MPa]
Density          rho       2350 [kg/m3]    95 % t.strength  fctk     4.17 [MPa]
Temp.elongat.coeff.    1.00E-05 [1/°K]     Bond strength    fbd      2.86 [MPa]
                                           Service strength         43.00 [MPa]
                                           Fatigue strength         20.07 [MPa]
                                           Ten.strngth fctd          1.27 [MPa]
Stress-Strain for serviceability         eps[o/oo]  sig-m[MPa]  E-t[N/mm2]
Is only valid within the defined            0.000       0.00       35781
stress range                               -1.123     -31.50       19765
                                           -2.246     -43.00           0
                                           -3.500     -26.18      -28065
                                         Safetyfactor               1.50
Stress-Strain for ultimate load          eps[o/oo]  sig-u[MPa]  E-t[N/mm2]
Is only valid within the defined            0.000       0.00       35000
stress range                               -2.000     -35.00           0
                                           -3.500     -35.00           0
                                         Safetyfactor               1.50
Stress-Strain of calc. mean values       eps[o/oo]  sig-r[MPa]  E-t[N/mm2]
Is only valid within the defined            0.000       0.00       29818
stress range                               -1.123     -19.27        8335
```

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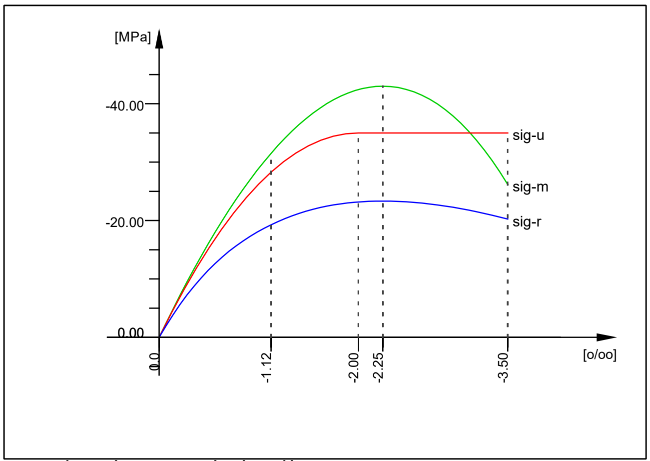
Vodna vrata - Water doors
Definition von Material und Querschnitten

No. 2 C 35/45 (EN 1992) (mod) C35_a

-2.246	-23.33	0
-3.500	-20.25	-4413
Safetyfactor		(1.50)



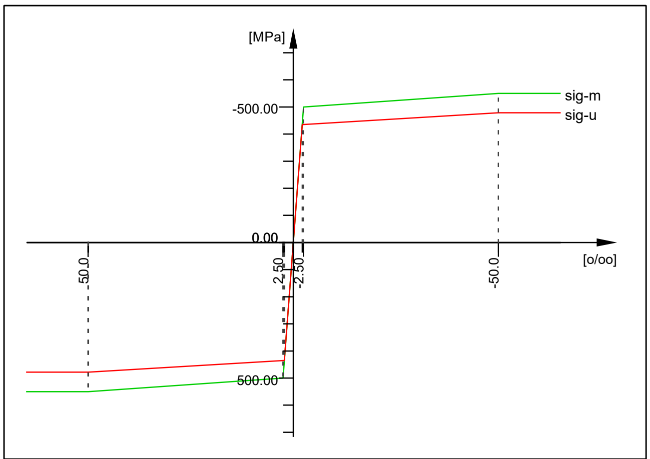
C 35/45 (EN 1992) (mod) C35_a

No. 5 B 500 B (EN 1992) B500

Youngs-modulus	E	200000 [N/mm2]	Safetyfactor		1.15	[-]
Poisson-Ratio	mu	0.30 [-]	Yield stress	fy	500.00	[MPa]
Shear-modulus	G	76923 [N/mm2]	Compr.yield val.	fyc	500.00	[MPa]
Compression modulus		166667 [N/mm2]	Tens. strength	ft	550.00	[MPa]
Weight		78.5 [kN/m3]	Compr. strength	fc	550.00	[MPa]
Density	rho	7850 [kg/m3]	Ultim. plast. strain		50.00	[o/oo]
Temp.elongat.coeff.		1.20E-05 [1/°K]	relative bond coeff.		1.00	[-]
max. thickness		32.00 [mm]	EC2 bondcoeff. K1		0.80	[-]
			Hardening modulus		0.00	[MPa]
			Proportional limit		500.00	[MPa]
			Dynamic stress range		152.17	[MPa]

	eps[o/oo]	sig-m[MPa]	E-t[N/mm2]
Stress-Strain for serviceability Is also extended beyond the defined stress range	1000.000	550.00	0
	50.000	550.00	0
	2.500	500.00	1053
	0.000	0.00	200000
	-2.500	-500.00	1053
	-50.000	-550.00	0
	-1000.000	-550.00	0
	Safetyfactor		1.15

	eps[o/oo]	sig-u[MPa]	E-t[N/mm2]
Stress-Strain for ultimate load Is also extended beyond the defined stress range	1000.000	478.26	0
	50.000	478.26	0
	2.174	434.78	909
	0.000	0.00	200000
	-2.174	-434.78	909
	-50.000	-478.26	0
	-1000.000	-478.26	0
	Safetyfactor		(1.15)



B 500 B (EN 1992) B500

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Vodna vrata - Water doors
Definition von Material und Querschnitten

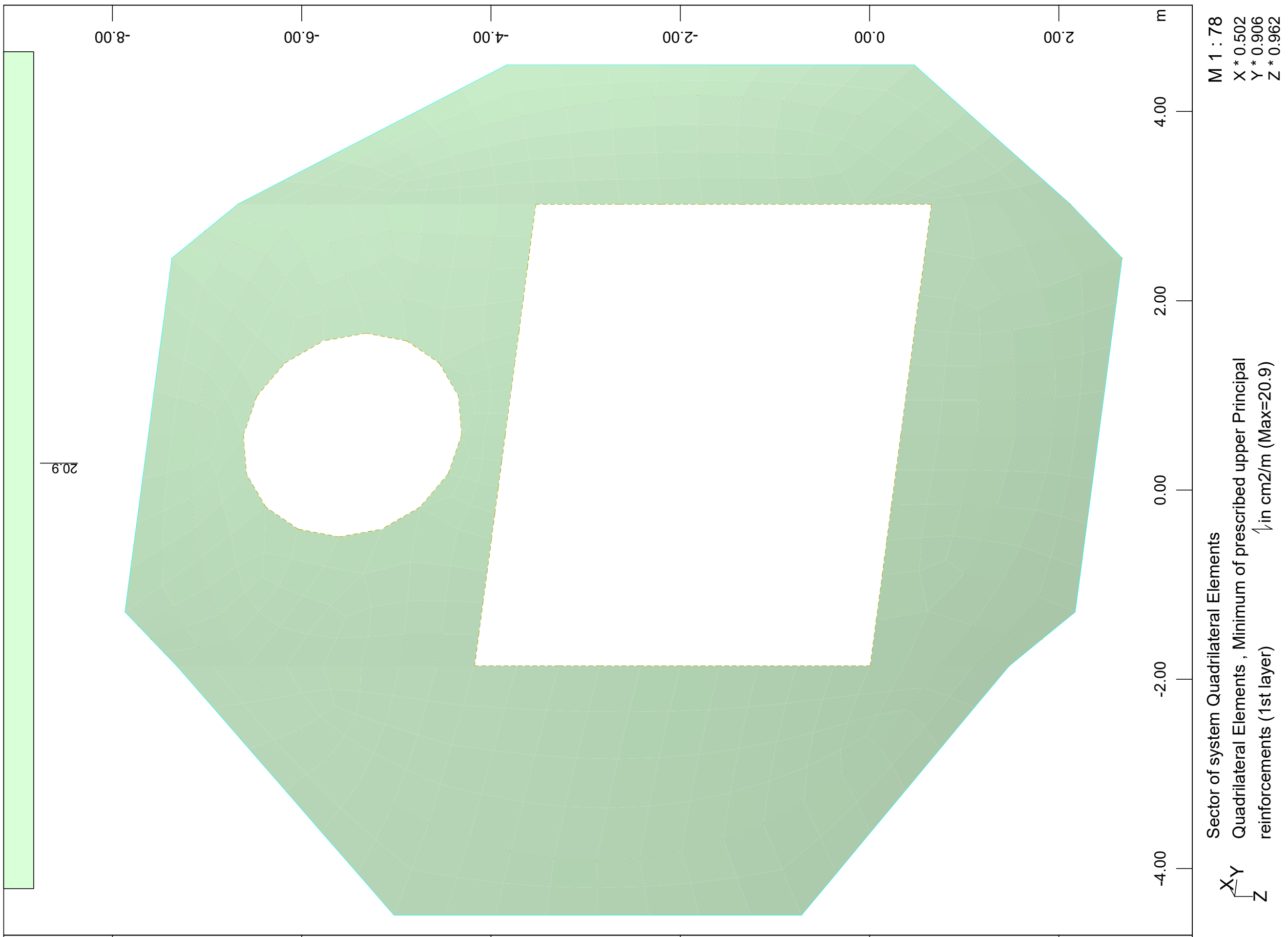
Elastic bedding

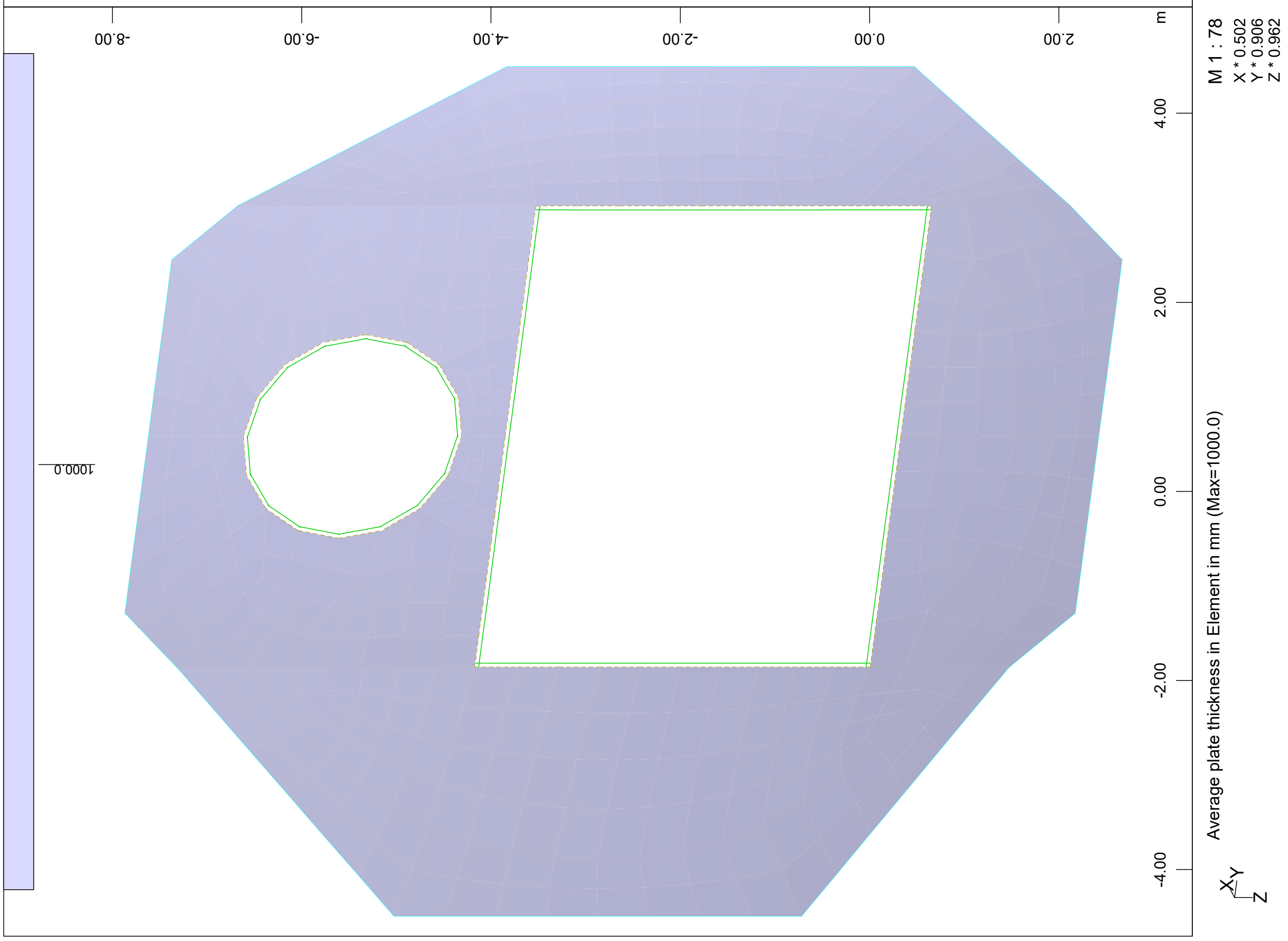
No.	Cs[kN/m3]	Ct[kN/m3]	ft[MPa]	fy[MPa]	tan[-]	c[MPa]	dil[-]	w[kN/m3]
2	1.1200E+06	5.6000E+05	0.00	0.00	0.20	0.00	0.00	0.0

Cs = Elastic bedding
Ct = Elastic bedding
ft = Tens. strength ft
fy = Yield stress fy
tan = Friction coefficient
c = Cohesion
dil = Dilatancy coefficient
w = Mass density

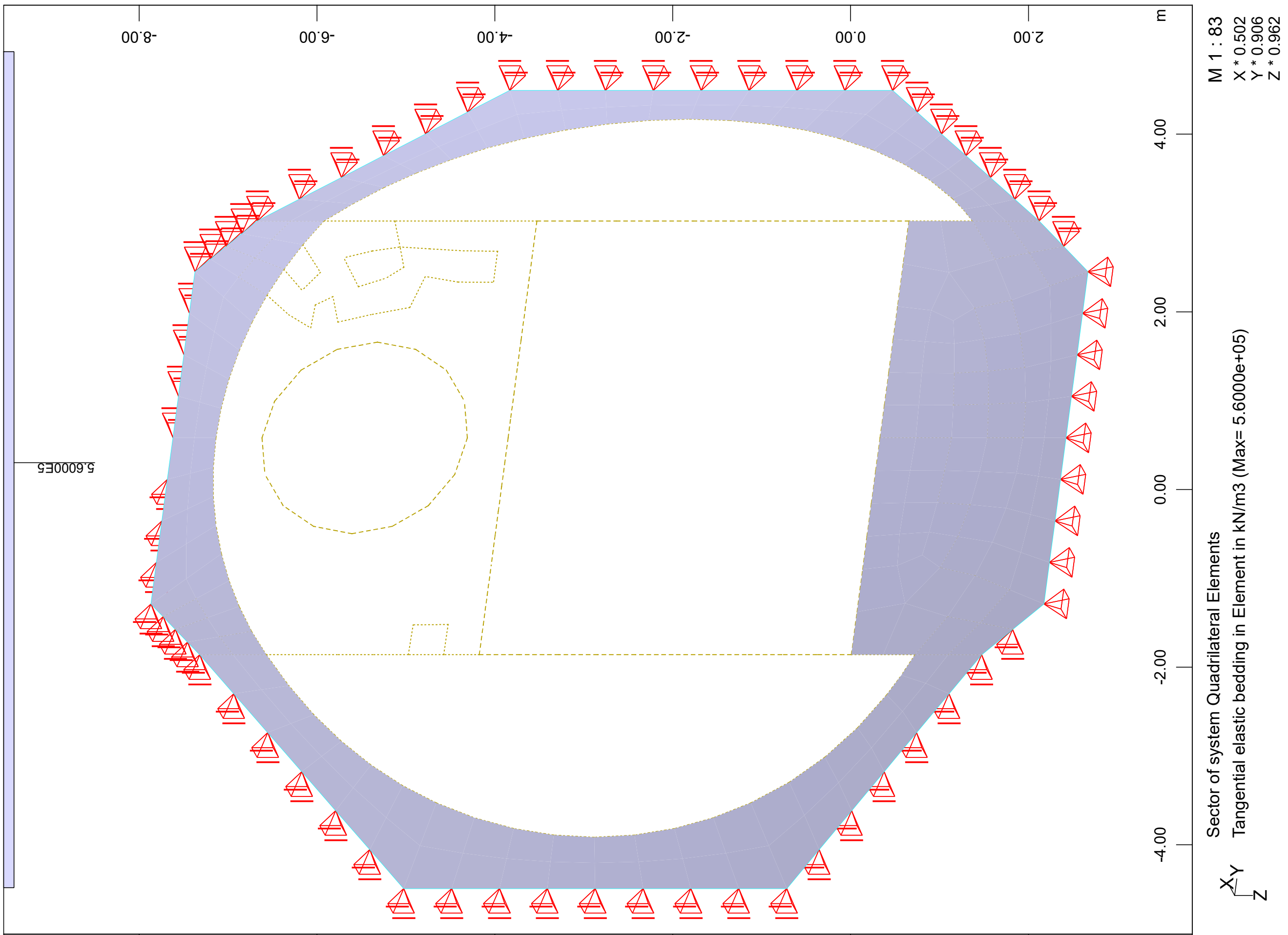
2TDK

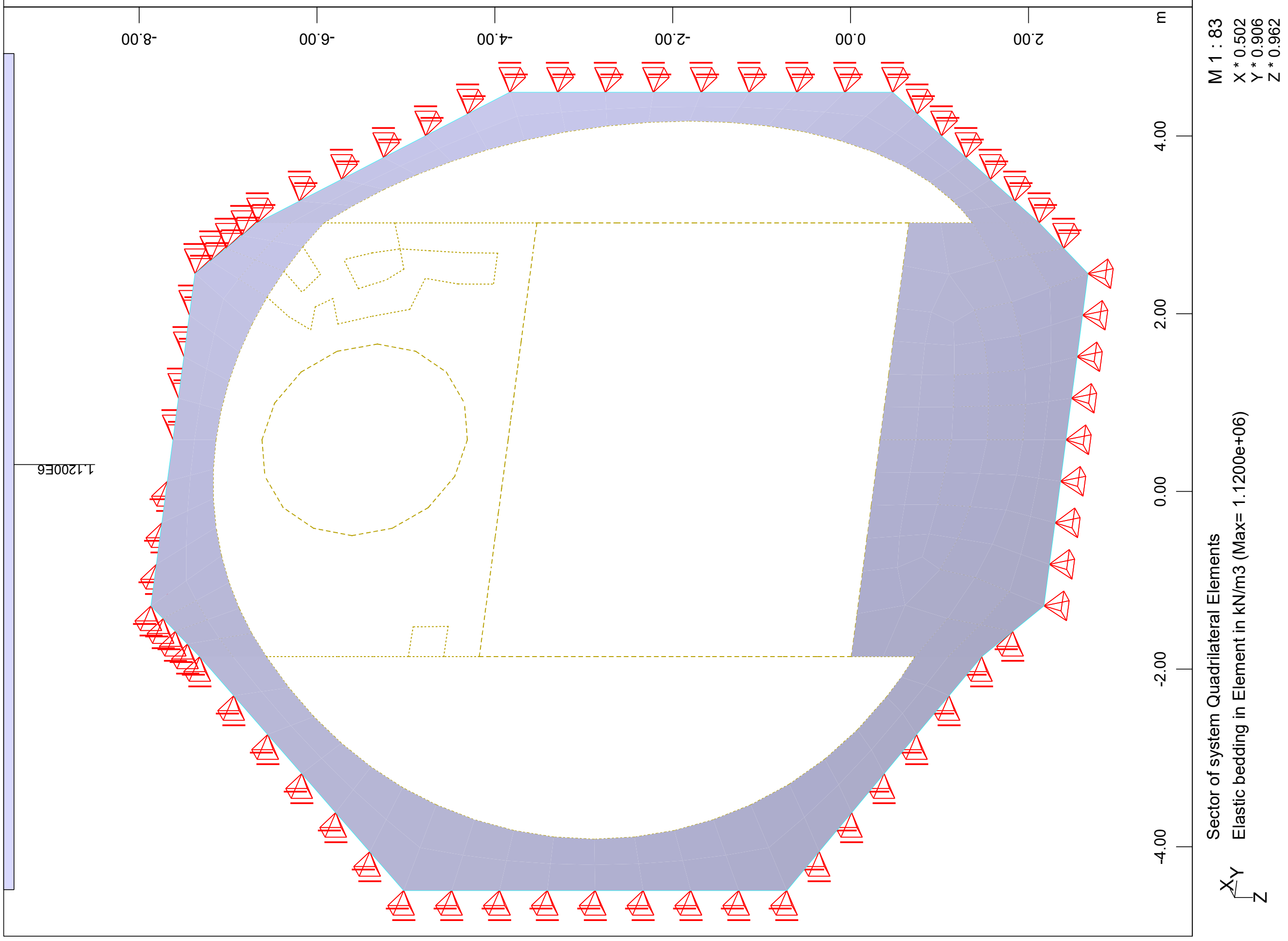
Vodna vrata - Water doors



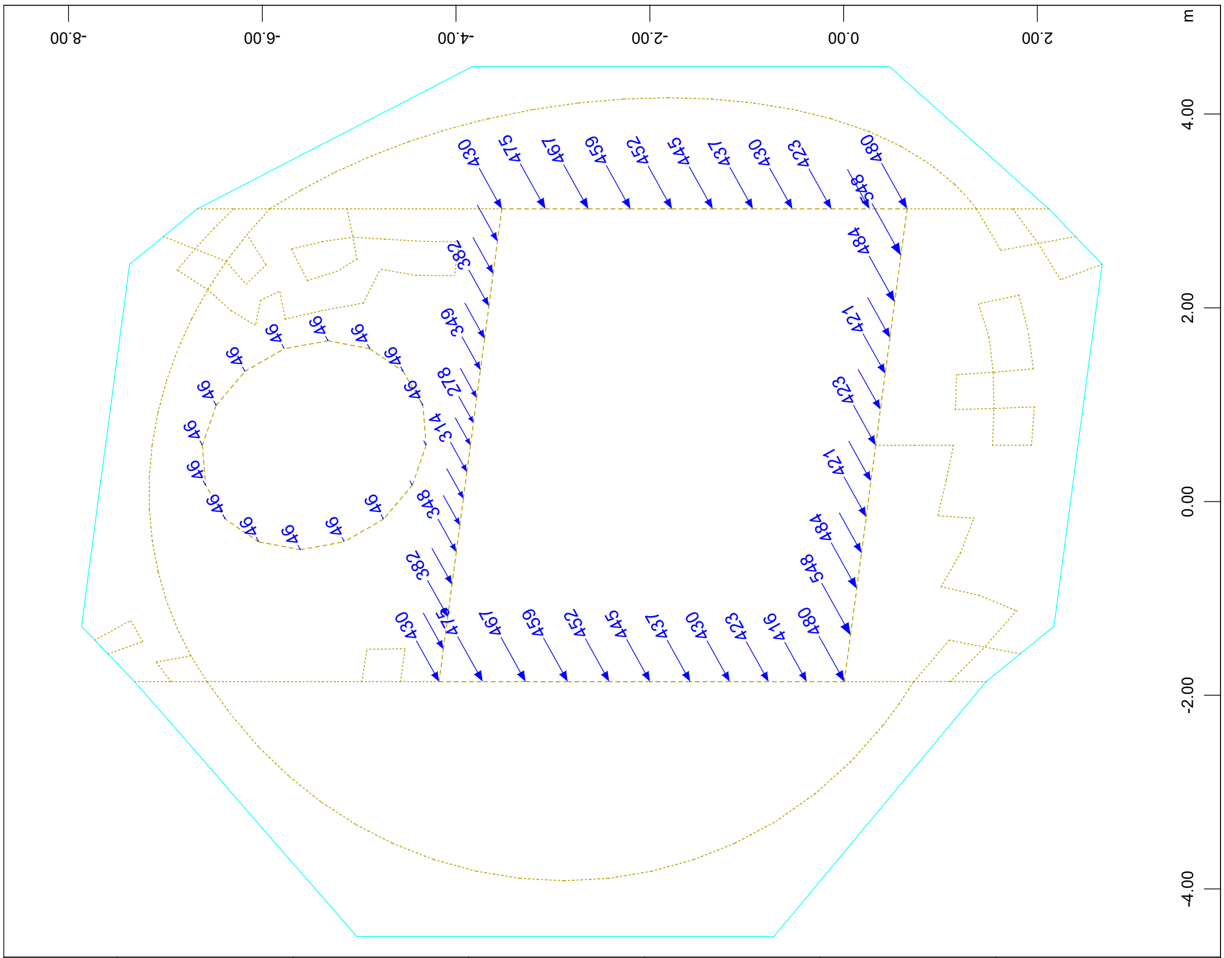


2TDK
Vodna vrata - Water doors



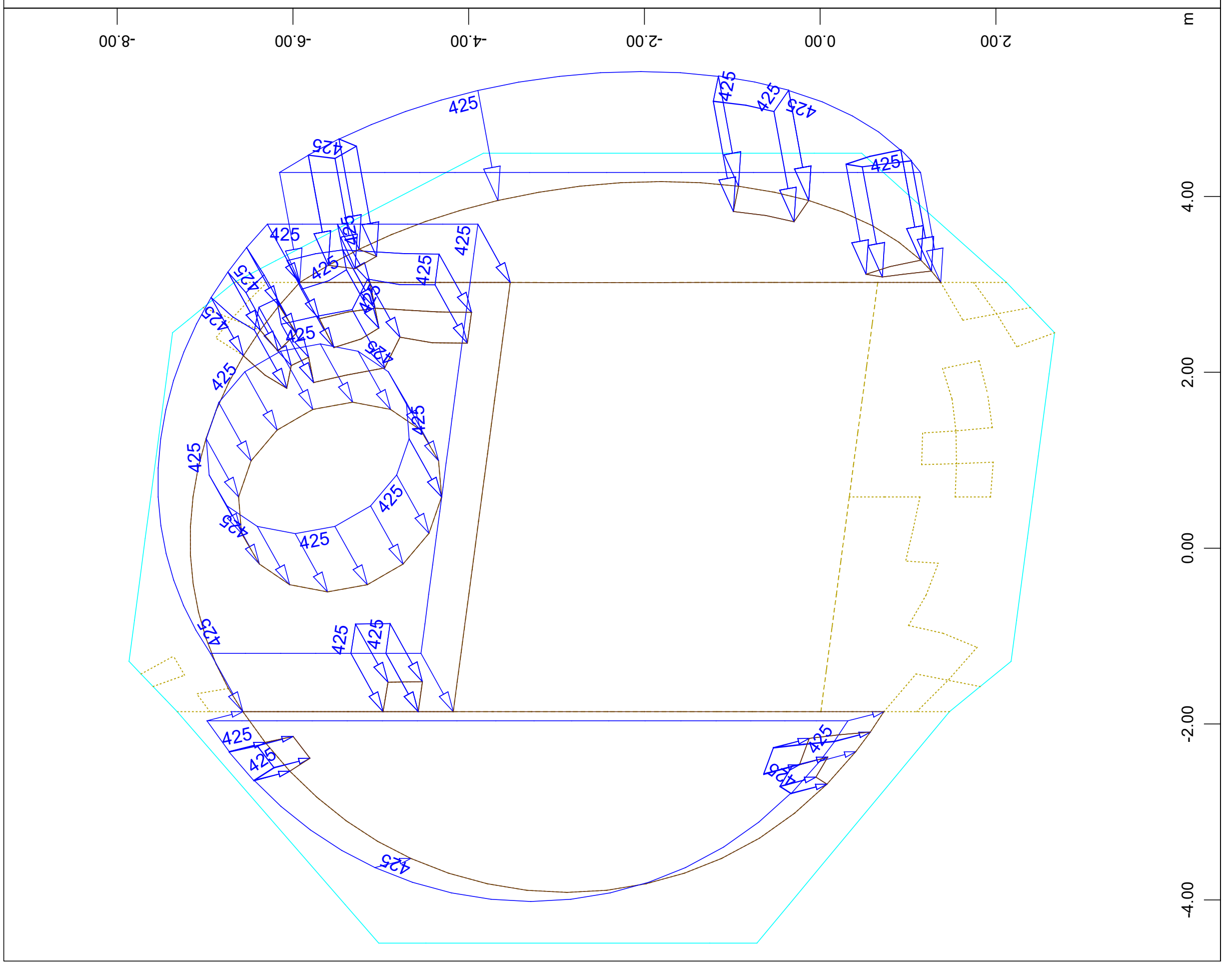


2TDK
Vodna vrata - Water doors



M 1 : 78
X * 0.502
Y * 0.906
Z * 0.962

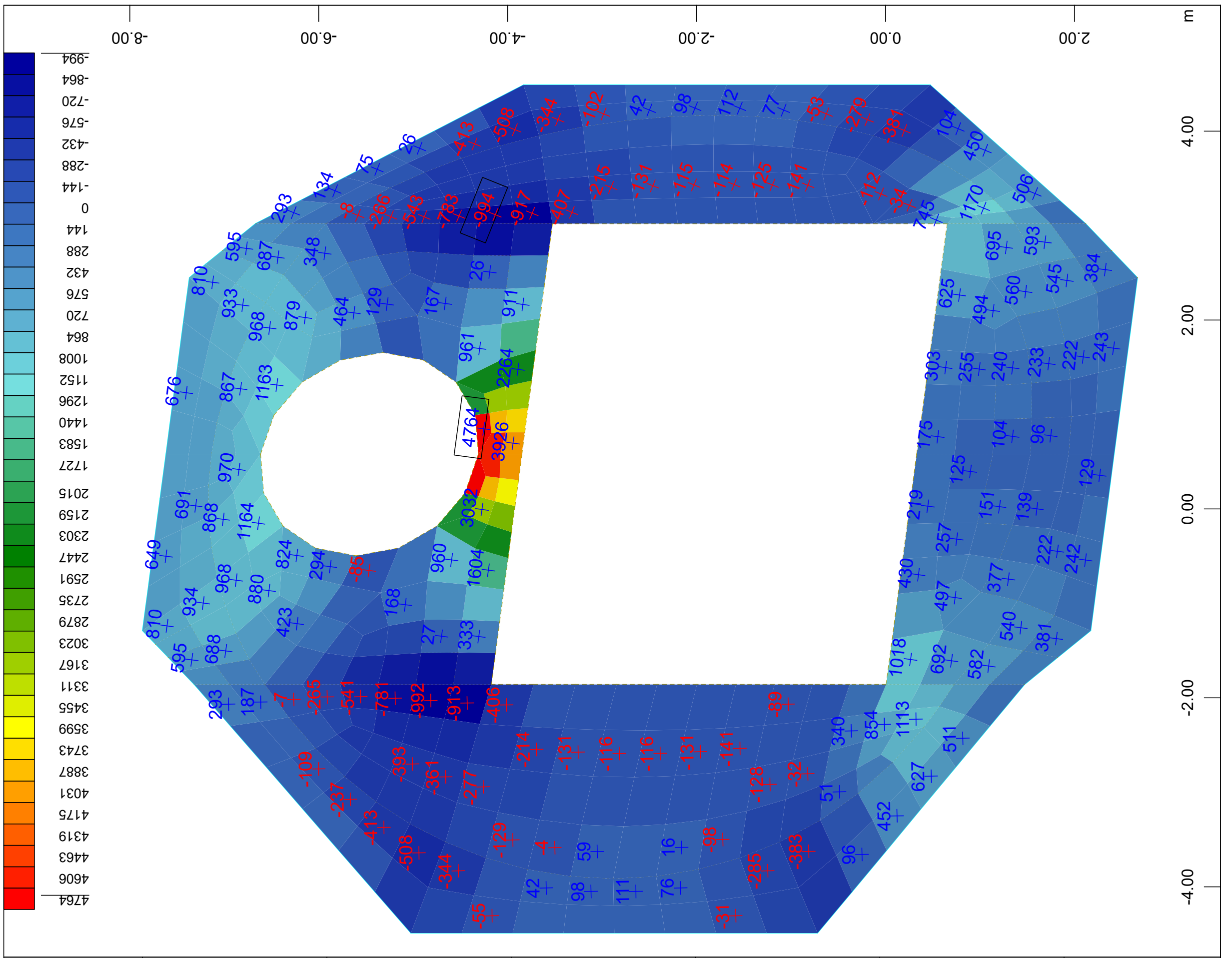
Sector of system Quadrilateral Elements
Single load, Loadcase 1001 vodni_pritisk , (1 cm 3D = unit)
Nodal load (force) vector (Unit=351.6 kN) (Max=547.9)



M 1 : 86
X * 0.502
Y * 0.906
Z * 0.962

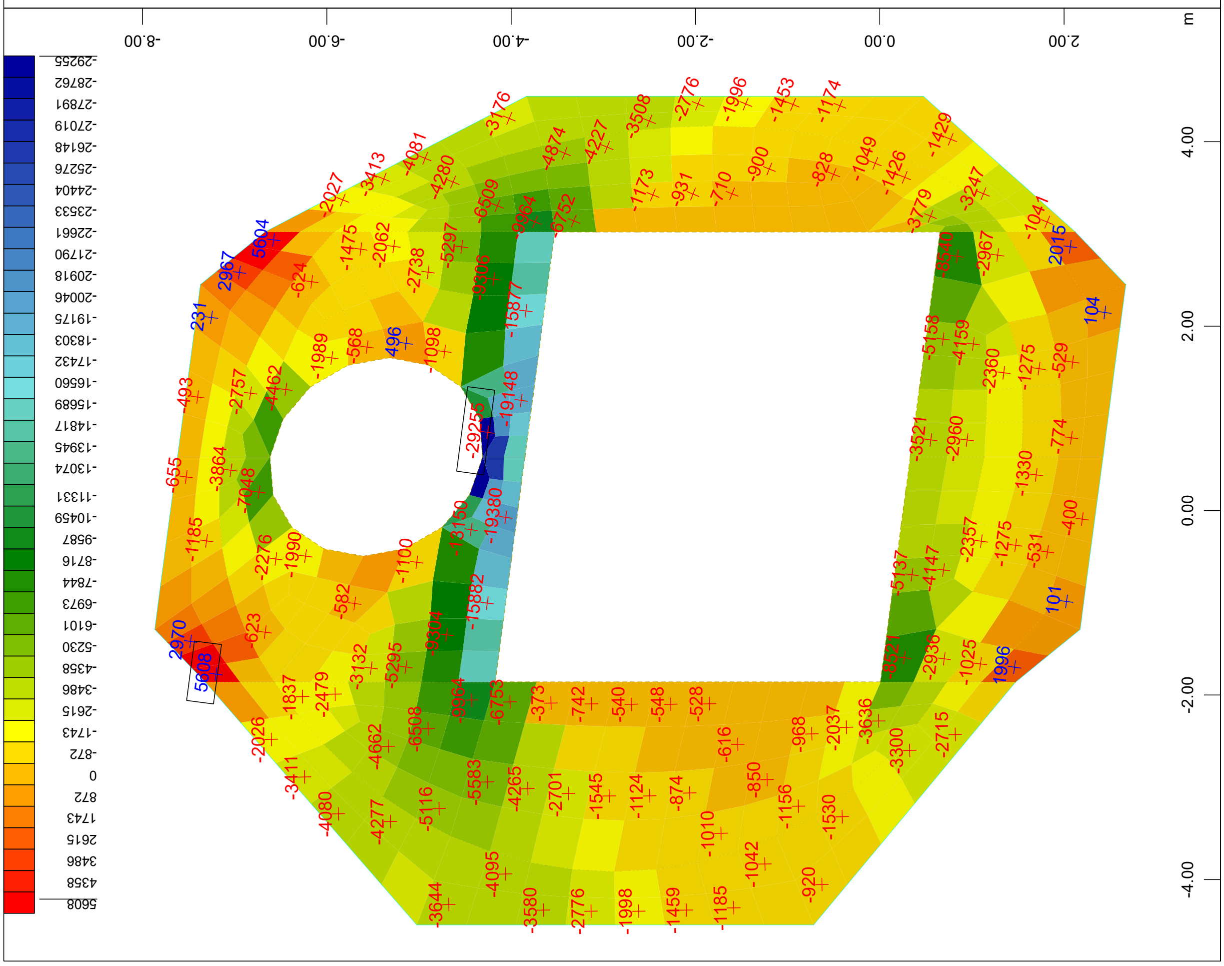
Sector of system Quadrilateral Elements
Area load, Loadcase 1001 vodni_pritisk , (1 cm 3D = unit)
Area element load (force) in local z (Unit=242.2 kN/m2)

2TDK
Vodna vrata - Water doors



M 1 : 80
X * 0.502
Y * 0.906
Z * 0.962

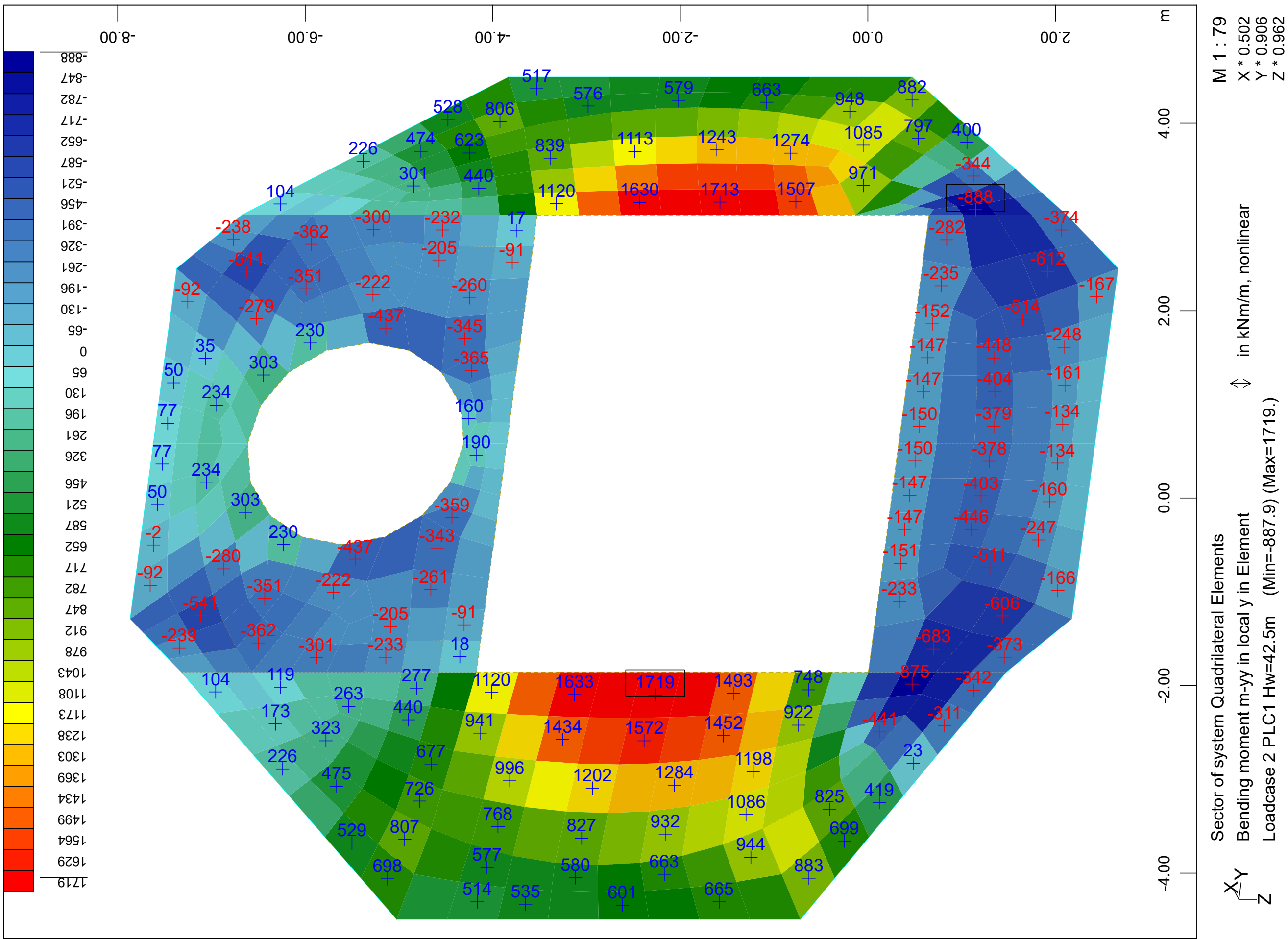
Sector of system Quadrilateral Elements
Bending moment m-xx in local x in Element in kNm/m, nonlinear
Loadcase 2 PLC1 Hw=42.5m (Min=-994.1) (Max=4764.)

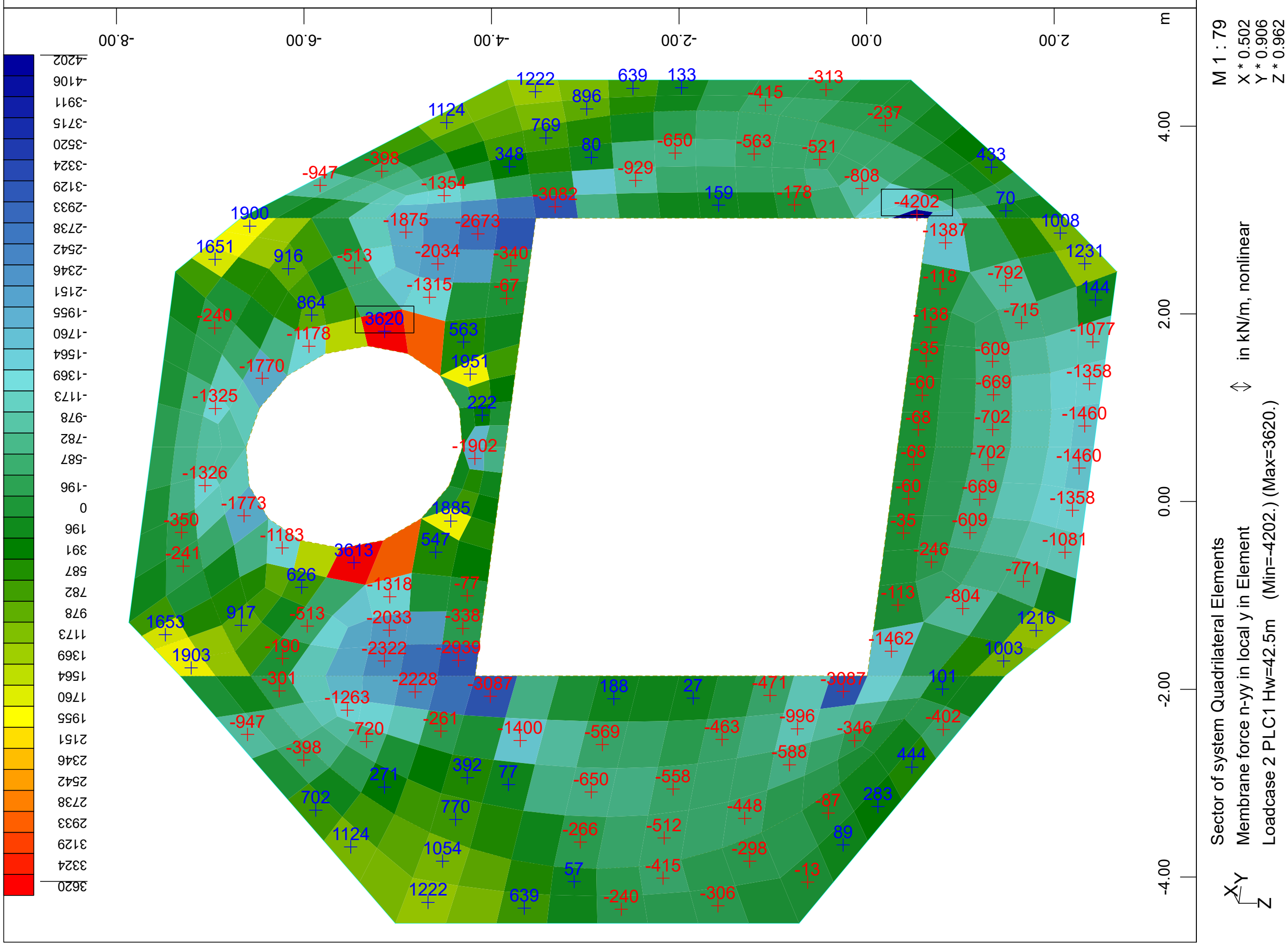


M 1 : 82
X * 0.502
Y * 0.906
Z * 0.962

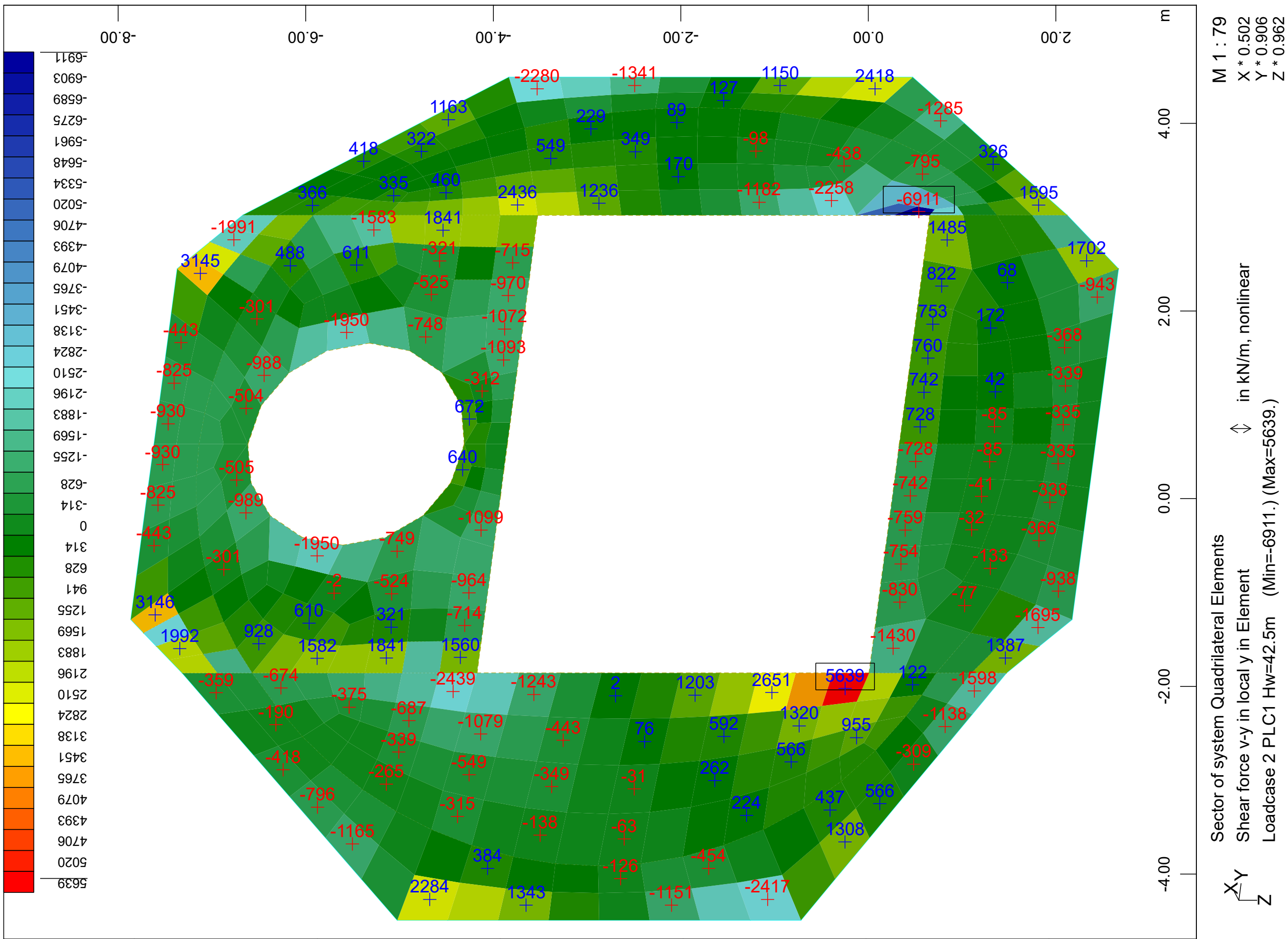
Sector of system Quadrilateral Elements
Membrane force n-xx in local x in Element in kN/m, nonlinear
Loadcase 2 PLC1 Hw=42.5m (Min=-29255.) (Max=5608.)

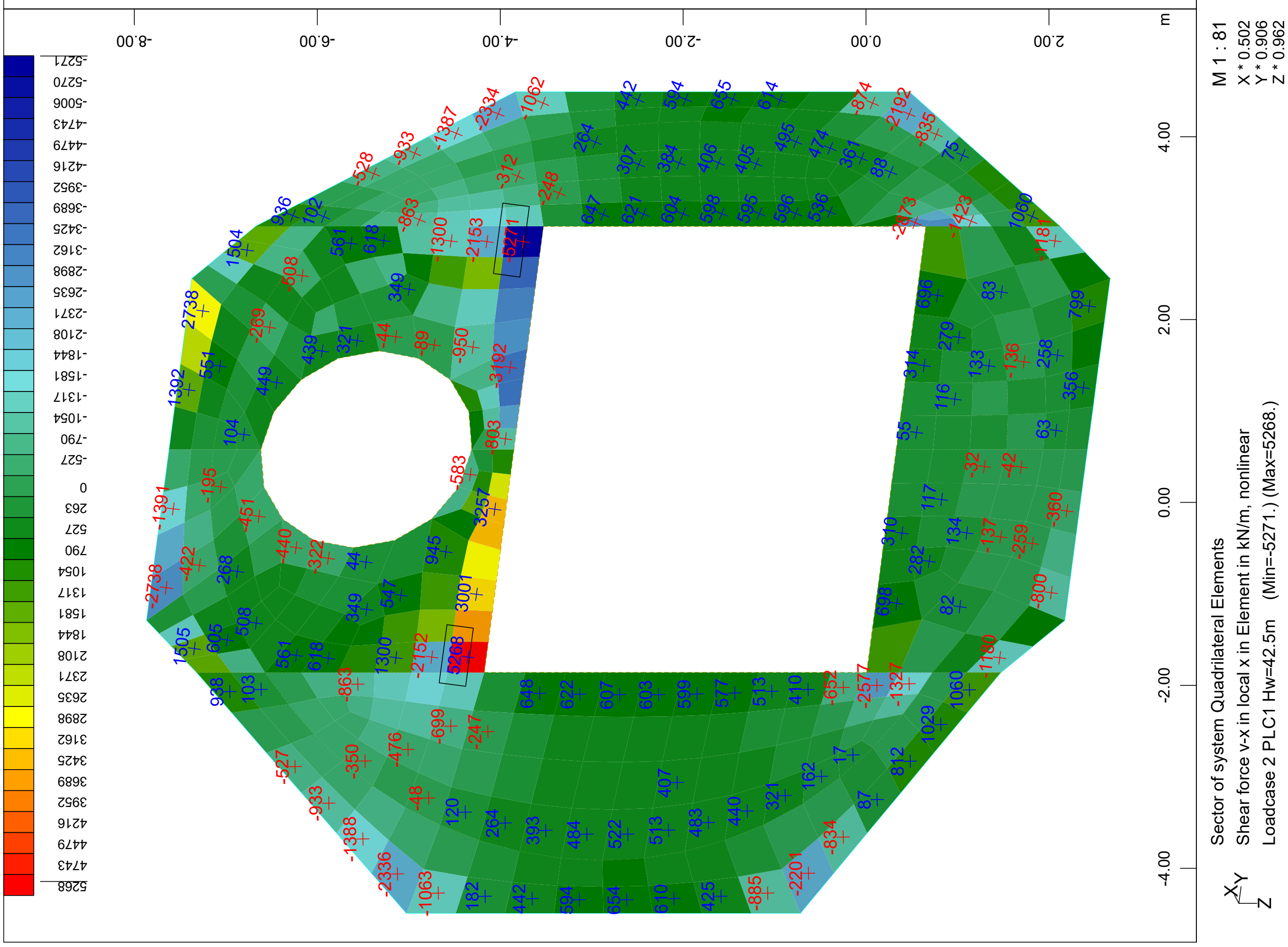
2TDK
Vodna vrata - Water doors



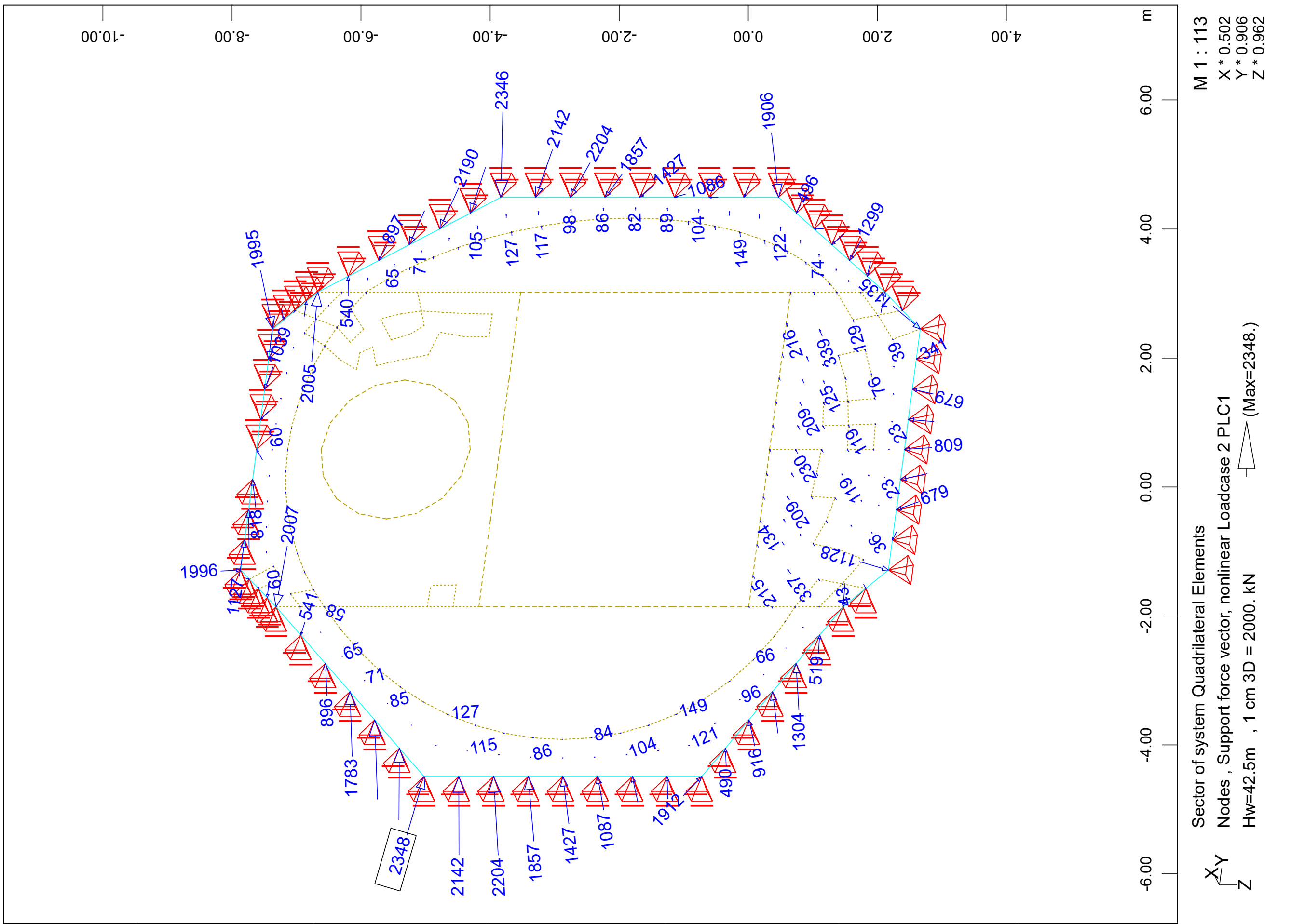


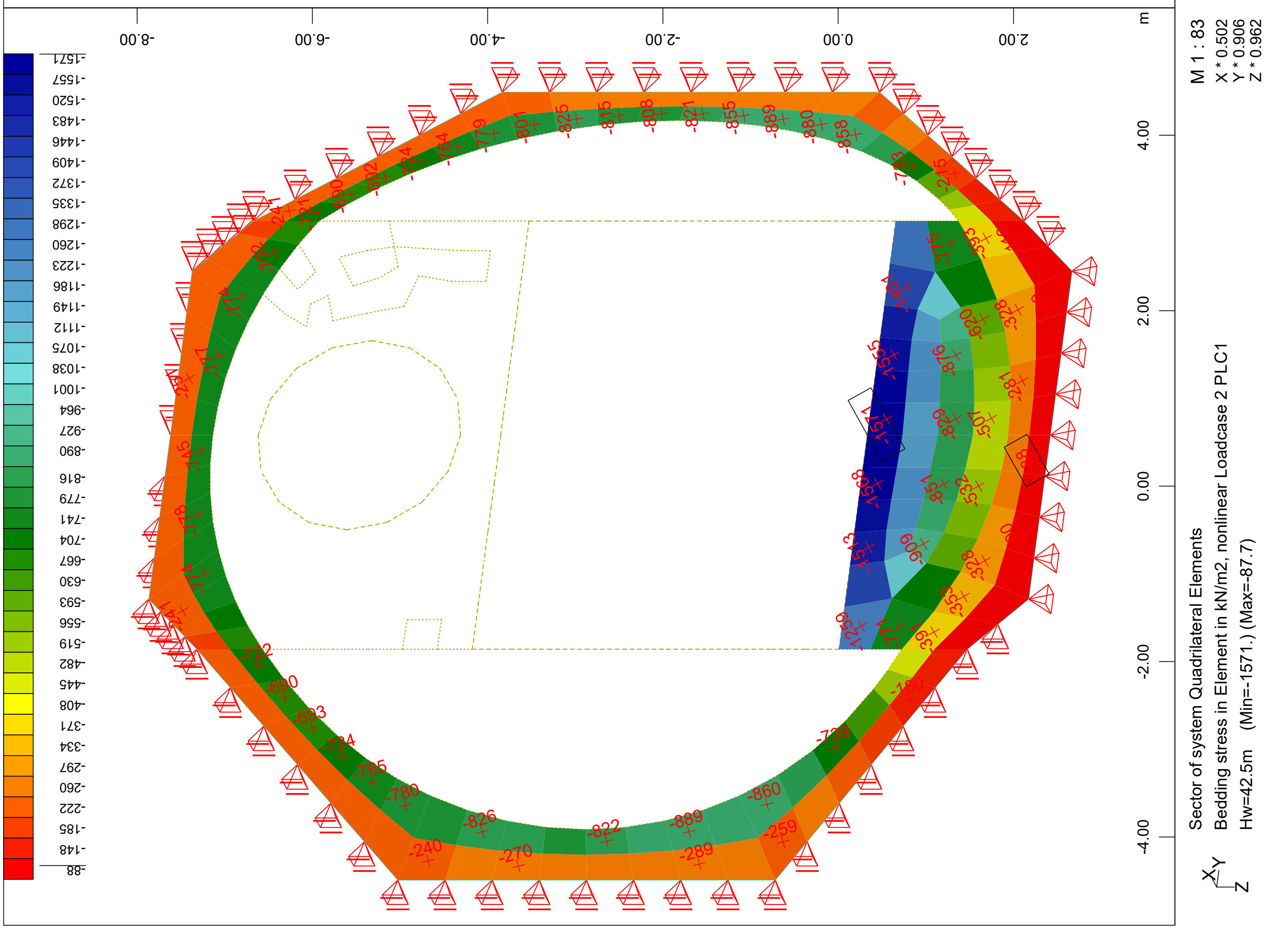
2TDK
Vodna vrata - Water doors



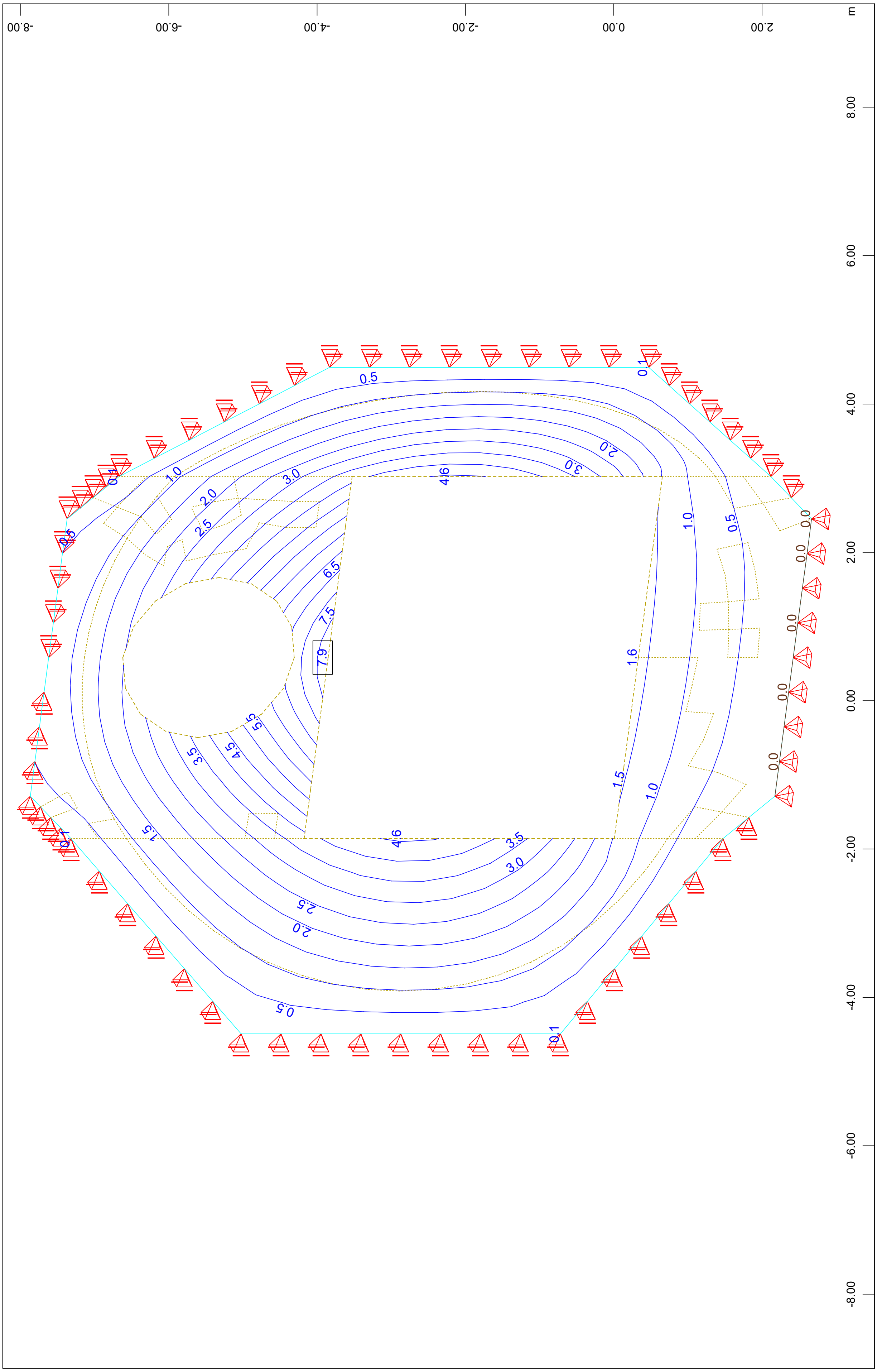


2TDK
Vodna vrata - Water doors





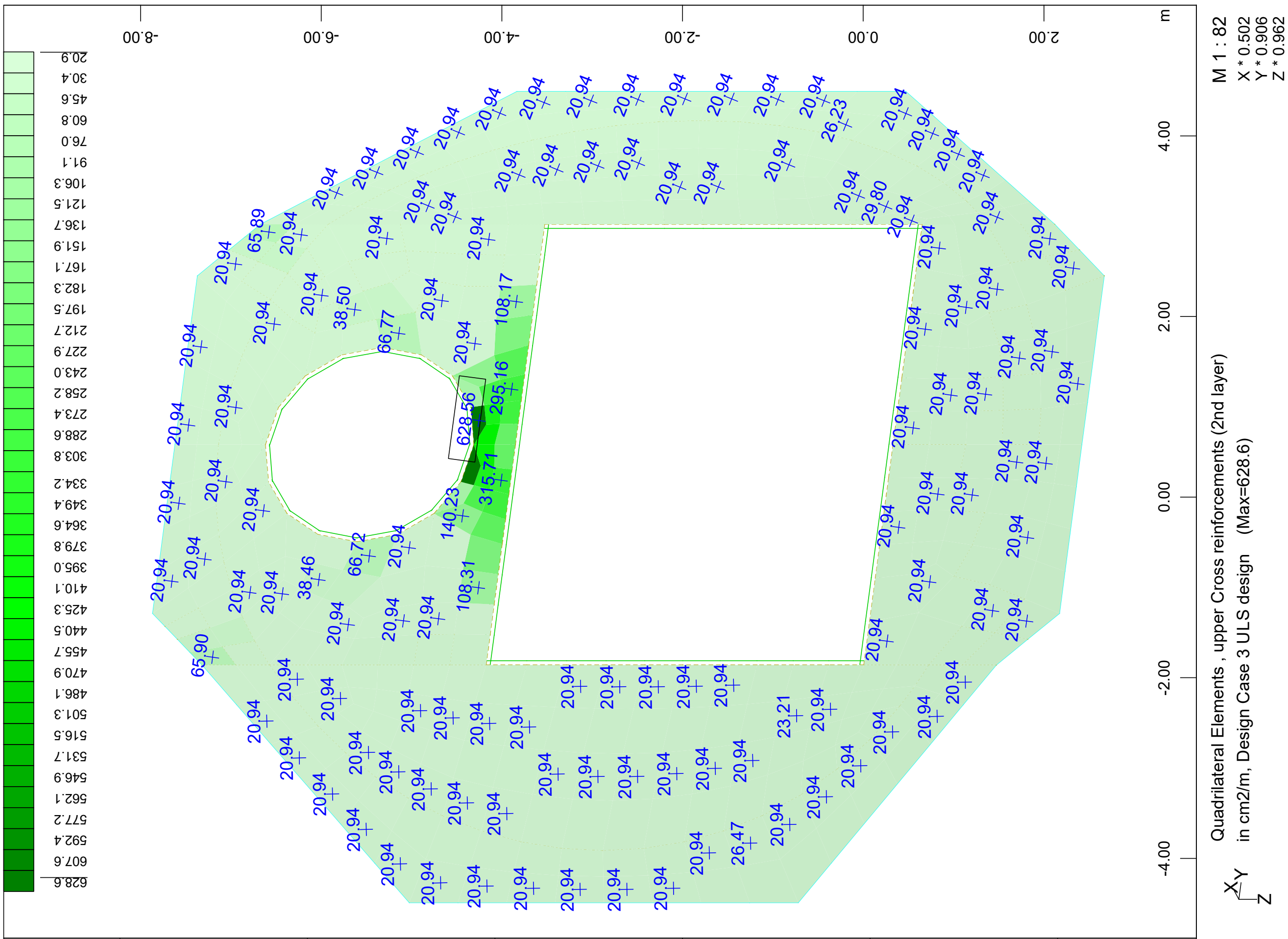
2TDK
Vodna vrata - Water doors

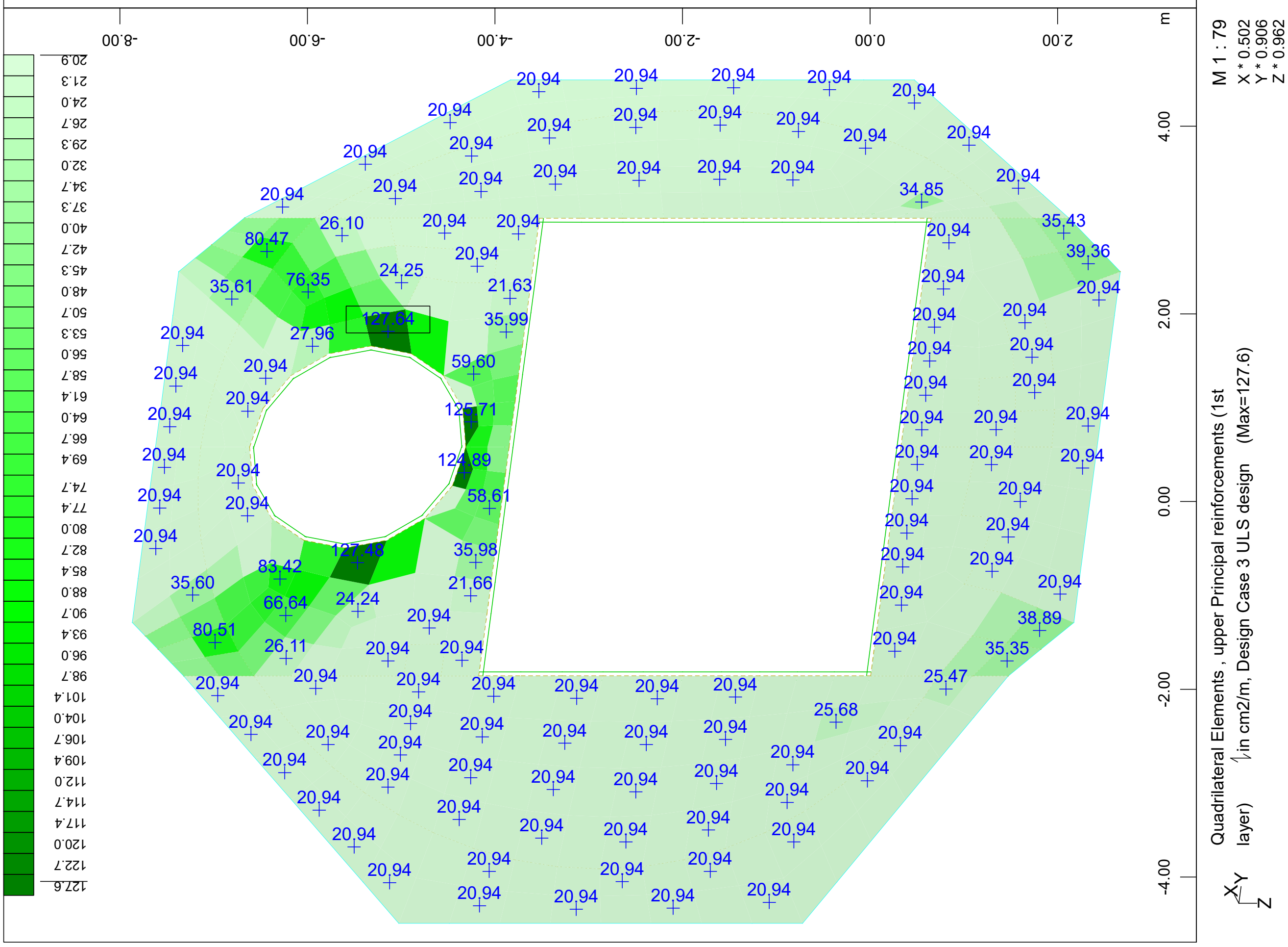


M 1 : 73
X * 0.502
Y * 0.906
Z * 0.962

Sector of system Quadrilateral Elements
Nodal displacement vector in Node, nonlinear Loadcase 2 PLC1 Hw=42.5m , from 0 to 7.85 step 0.500 mm

2TDK
Vodna vrata - Water doors





2TDK
Vodna vrata - Water doors