Projektantska skupina
2.TIR

Sofinancirano s pomočjo Instrumenta za povezovanje Evrope Evropske unije

IRGO CONSULTING d.o.o.

Technical Report

Second Track of Divača – Koper Railway Line, Lot 1

Study Title	**Technical Monitoring Plan for Tunnel T1**	
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1 GENERAL

According to SIST EN 1997-1: 2005, tunnels belong to the 3rd geotechnical category, which include unusually high risks or extremely demanding soil conditions or loads. Because, despite numerous investigations and complex analyzes, predicting the geotechnical behavior of such a facility is difficult, the standard allows the use of t.i. observation methods in which the project is checked during construction.

Before, during and after the construction of the tunnel, technical observation of the tunnel, the area above the tunnel and the structures on the surface or in the rock body in the vicinity of the future tunnel to determine the redistribution of stresses and strains and to control the stability of the tunnel and all existing structures at all stages of construction and during operation.

Technical observation of tunnel construction generally includes:

• Geodetic measurements of the displacements of the primary lining, the area above the tunnel and in the pre-excavations, and the infrastructure in the area of influence of the construction.

• Geotechnical measurements of deformations and stresses in the hilly rock and supporting elements, groundwater levels and vibrations caused by construction works.

• Geological monitoring by recording excavated areas and supplementing or. improving the geological model, monitoring pre-drilling, short-term forecasting of geological conditions in the advance of excavation faces and taking samples and their mineralogical, petrographic and geomechanical investigations.

• Hydrogeological monitoring with documentation of water sources in the area, identification of aquifers during construction, recording and measuring water inflows, monitoring of groundwater levels during construction, short-term forecasting of hydrogeological conditions in the advance of excavation faces and sampling and chemical investigations.

• Speleological monitoring with documentation of all karst phenomena in the limestone deposits of the Slovenian Karst.

• Visual inspection of the condition of the primary lining and the condition of the surface infrastructure.

• Multidisciplinary analysis and interpretation of all collected data to support the rational and safe progress of excavations.

Properly processed and interpreted technical observation data are used for:

• determination of the most appropriate support type according to the actual geological and geotechnical conditions,

• determining the length of the excavation step,

• checking the adequacy of the support measures used and the overall response of the hill support system - built-in support,

• checking the adequacy of project assumptions and optimizing construction, and

• data collection for rational and optimized design and implementation of the future parallel tunnel.

Technical observation data must be processed in real time and used in all construction decisions.

2 VALIDITY OF THE DOCUMENT

The submitted Technical Observation Plan provides only data and requirements concerning the specifics of the T1 tunnel, all other descriptions and technical details are given in the Technical Specifications (document 2TDK_LEA_PZI_TS_DOC_6: Technical Observation). The following specifications are given in the technical specifications:

- performance of individual measurements,
- necessary equipment for performing geodetic and geotechnical measurements,
- required area of operation of the equipment,
- frequency of measurements,
- accuracy of measurements,

the method of interpretation of the measurements, and

- required procedures in case of trigger values achieved.

In case of ambiguity or conflict between the provisions of the Technical Monitoring Plan and the Specifications in question, the provisions of the Plan shall prevail.

3 GEODETIC MEASUREMENTS

3.1 General

Geodetic measurements in the plan are divided into the following subgroups:

- MP-I-1 - geodetic measurements in the tunnel
- MP-I-2 - geodetic measurements on the surface (portal areas)
- MP-I-3 - geodetic measurements on infrastructure and other existing facilities
- MP-I-4 - leveling points on infrastructure facilities
- Surface scanning

3.2 Geodetic measurements in the tunnel

In tunnel T1, the measuring points in the primary lining must be installed in accordance with the following drawings:

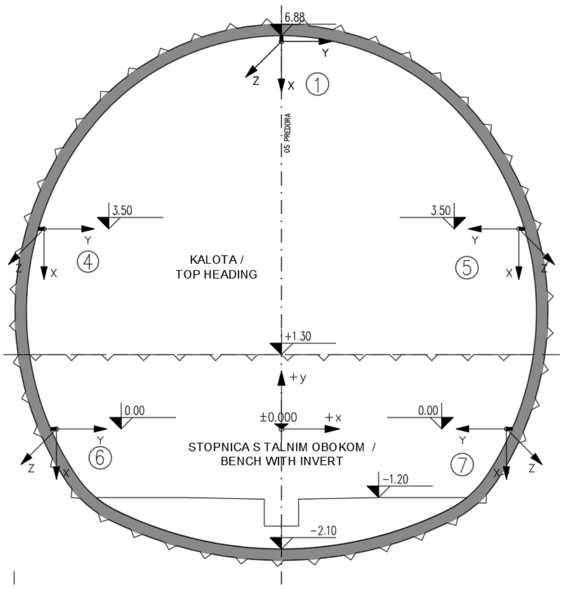


Figure 1: MP-I-1 - sketch of the positions of geodetic measuring points in the primary lining of the drained tunnel - 5 points

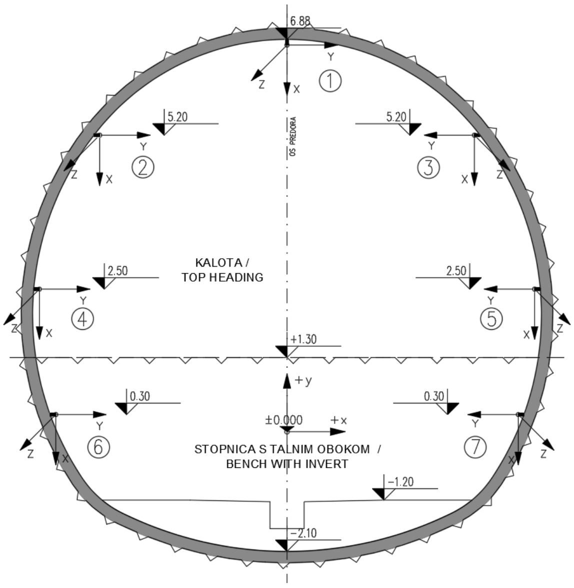


Figure 2: MP-I-1 - sketch of the positions of geodetic measuring points in the primary lining of the drained tunnel - 7 points

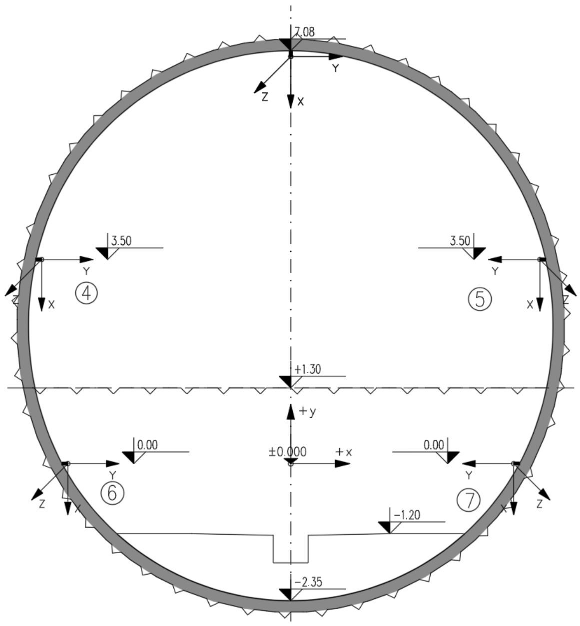


Figure 3: MP-I-1 - sketch of the positions of geodetic measuring points in the primary lining of an undrained tunnel - 5 points

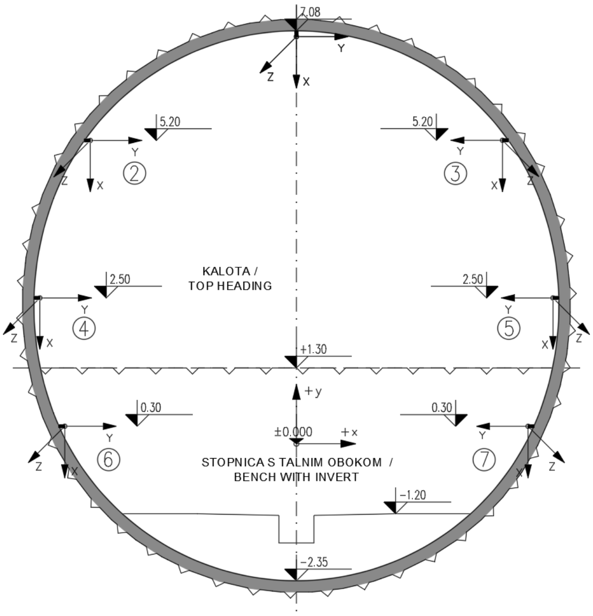


Figure 4: MP-I-1 - sketch of the positions of geodetic measuring points in the primary lining of an undrained tunnel - 7 points

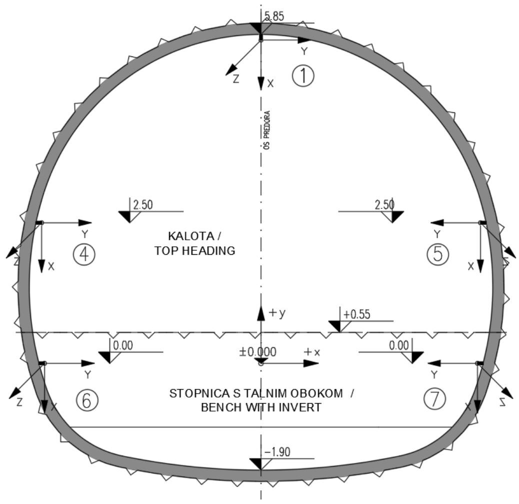


Figure 5: MP-I-1 - sketch of the positions of geodetic measuring points in the primary diameter lining - 5 points

According to the forecasted geological conditions, the installation of geodetic measuring profiles in drained and undrained tunnel profiles and in cross-sections is envisaged along the T1 tunnel. Installation is planned at the following stations:

Table 1: Predicted measurement profiles of geodetic measurement points in the primary lining in the area of tunnel T1 - main pipe

Estimated chainage from	Expected chainage until	Section length	Razmik med merskimi profili	Number of measuring points in the profile	Note
2.979,00	4.229,00	1.250,00	30 m	5	
4.229,00	4.254,00	25,00	10 m	7	break zone
4.254,00	4.624,00	370,00	30 m	5	
4.624,00	4.689,00	65,00	10 m	7	break zone
4.689,00	4.799,00	110,00	30 m	5	
4.799,00	4.824,00	25,00	10 m	7	break zone
4.824,00	5.624,00	800,00	30 m	5	
5.624,00	5.649,00	25,00	10 m	7	break zone
5.649,00	7.059,00	1.410,00	30 m	5	
7.059,00	7.084,00	25,00	10 m	7	break zone
7.084,00	7.294,00	210,00	30 m	5	
7.294,00	7.319,00	25,00	10 m	7	break zone
7.319,00	8.289,00	970,00	30 m	5	
8.289,00	8.314,00	25,00	10 m	7	break zone
8.314,00	8.434,00	120,00	30 m	5	
8.434,00	8.459,00	25,00	10 m	7	break zone
8.459,00	8.889,00	430,00	30 m	5	
8.889,00	8.939,00	50,00	10 m	7	transition to flysch
8.939,00	9.619,00	680,00	20 m	5	flysch
9.619,00	9.679,00	60,00	10 m	7	portal area

Table 2: Predicted measurement profiles of geodetic measurement points in the primary lining in the area of tunnel T1 - service pipe

Estimated chainage from	Expected chainage until	Section length	Razmik med merskimi profili	Number of measuring points in the profile	Note
2.966,89	4.276,89	1.310,00	30 m	5	
4.276,89	4.301,89	25,00	10 m	7	break zone
4.301,89	4.641,89	340,00	30 m	5	
4.641,89	4.706,89	65,00	10 m	7	break zone
4.706,89	4.891,89	185,00	30 m	5	
4.891,89	4.916,89	25,00	10 m	7	break zone
4.916,89	5.681,89	765,00	30 m	5	
5.681,89	5.706,89	25,00	10 m	7	break zone
5.706,89	7.086,89	1.380,00	30 m	5	
7.086,89	7.111,89	25,00	10 m	7	break zone
7.111,89	7.301,89	190,00	30 m	5	
7.301,89	7.326,89	25,00	10 m	7	break zone
7.326,89	8.281,89	955,00	30 m	5	
8.281,89	8.306,89	25,00	10 m	7	break zone

8.306,89	8.416,89	110,00	30 m	5	
8.416,89	8.441,89	25,00	10 m	7	break zone
8.441,89	8.881,89	440,00	30 m	5	
8.881,89	8.931,89	50,00	10 m	7	transition to flysch
8.931,89	9.581,89	650,00	20 m	5	flysch
9.581,89	9.650,00	68,11	10 m	7	portal area

Table 3: Predicted measurement profiles of geodetic measurement points in the primary lining in the area of the T1 tunnel - diameters

Crosspiece	Section length	Razmik med merskimi profili	Number of measuring points in the profile	Note
PR 1.1	20,0	10 m	5	/
PR 1.2	20,0	10 m	5	/
PR 1.3	20,0	10 m	5	/
PR 1.4	20,0	10 m	5	/
PR 1.5	20,0	10 m	5	/
PR 1.6	20,0	10 m	5	/
PR 1.7	20,0	10 m	5	/
PR 1.8	20,0	10 m	5	/
PR 1.9	20,0	10 m	5	/
PR 1.10	20,0	10 m	5	/
PR 1.11	20,0	10 m	5	/
PR 1.12	20,0	10 m	5	/
PR 1.13	20,0	10 m	5	/

The required regular frequency of geodetic measurements of the positions of measuring points in the primary lining is in accordance with the provisions of the Technical Specifications.According to the forecasted geological conditions, the following areas with the expected size of the measured displacements of the primary lining above 50 mm are envisaged.

Table 4: Predicted areas with measured displacements above 50 mm in the T1 tunnel area

Chainage	Calculated offset size	Note
Od 5+624,00 do 5+649,00	do 50 mm	break zone
Od 6+226,00 do 6+320,00	do *350 mm	Kaverna s sedimenti
Od 8+885,00 do 8+938,00	do 60 mm	Transition from limestone to flysch
Od 9+426,00 do 9+684,00	do 90 mm	South portal in flysch

* In the cavern with sediments, the calculated displacements were determined on the basis of a conservative estimate that the cavern is large and filled with clay sediments and crosses the tunnel perpendicular to the axis. Such a scenario is unlikely to be expected, so the measurement profiles at this point will be adapted to real

circumstances. In the remaining areas of the T1 tunnel, areas with the size of the measured displacements of the primary lining above 50 mm cannot be expected.

3.3 Surveying geodetic measurements - portal areas

Depending on the forecasted geological conditions and the presence of infrastructure, the following geodeticmeasurement points / profiles are envisaged in the impact area of the T1 tunnel:

Table 5: Predicted geodetic measurement points / profiles on the surface in the area of the T1 tunnel

Location	Number of measuring points	Note
North portal	11 point	portal area
South portal	20 point	portal area

The locations of geodetic measuring points for performing 3D measurements are shown in Figures 6, 7 and 8 and in the graphic appendices to the plan. The microlocation of an individual measuring point is adjusted accordingly to the situation on the ground.

The required regular frequency of geodetic measurements of the positions of measuring points on the surface is in accordance with the provisions of the Technical Specifications. The basic guide for the regular frequency of geodetic measurements of the positions of measuring points on the surface is:

- during the execution of works on the pre-excavation once a week or adapted to the progress of the works,
- for the time of underground excavation, in accordance with the requirements in the technical specifications,
- then once a month.

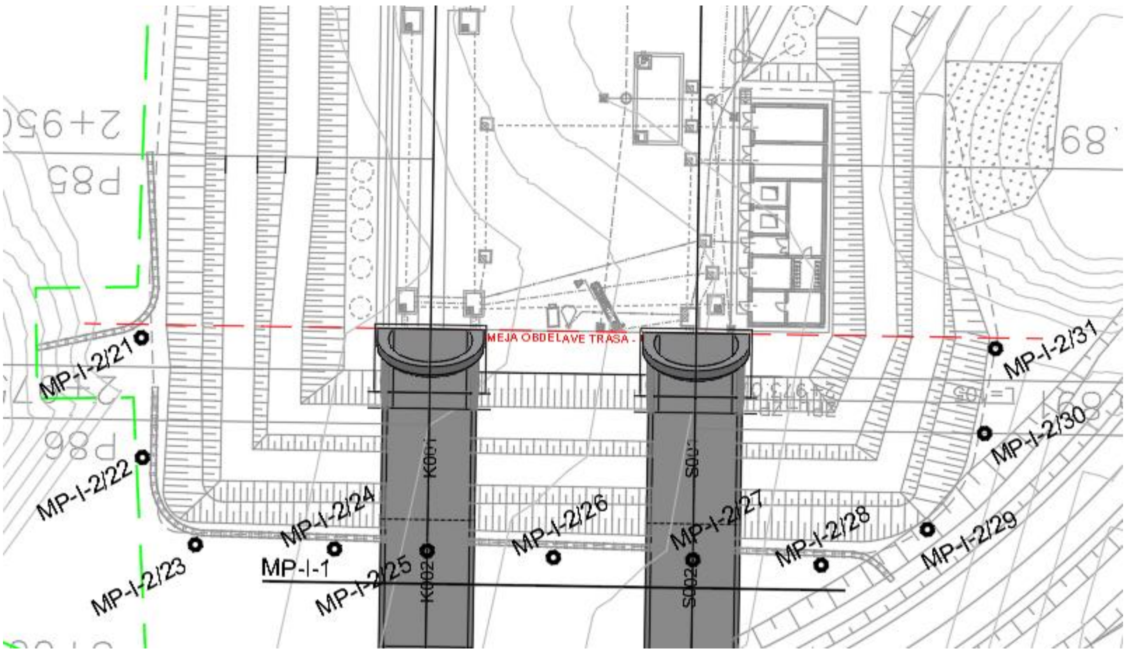


Figure 6: Locations of predicted geodetic measuring points on the surface in the area of tunnel T1 - portal Divača

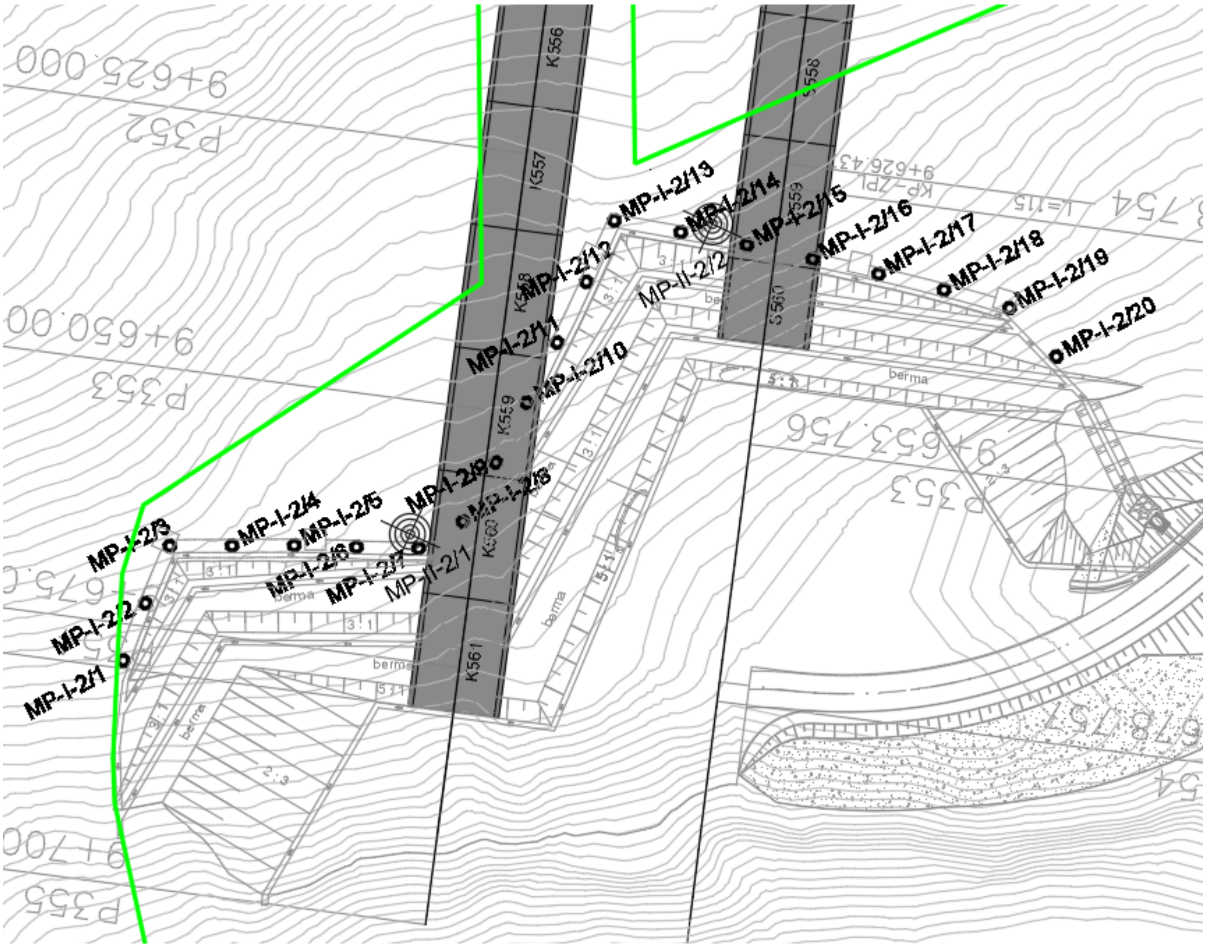


Figure 7: Locations of predicted geodetic measuring points on the surface in the area of tunnel T1 - portal Koper

3.4 Geodetic measurements on infrastructure and existing facilities

In the area of the T1 tunnel crossing under the local Lokev road, the installation of 2 measuring points is planned. The points are installed along the road, directly at the intersection of the road and each of the tunnel pipes.Above the tunnel there are one residential and one commercial building. It is planned to install 2 measuring points on a residential building directly above the axis of the service pipe and 2 measuring points on a commercial building directly above the axis of the main pipe. The locations of geodetic measuring points for performing 3D measurements are shown in Figure 8 and in the graphic appendices to the plan. The microlocation of an individual measuring point is adjusted accordingly to the situation on the ground.

Table 6: Predicted geodetic measurement points / profiles on the surface in the area of the T1 tunnel

Location	Number of measuring points	Note
Local road Lokev	2 points	the area of the tunnel crossing under the road
residential and commercial building	4 points	the area of the tunnel crossing under the existing facility

Figure 8: Locations of the planned geodetic measurement points on the surface in the area of the intersection of the T1 tunnel under the local road Lokev

3.5 Leveling points on infrastructure facilities

No leveling points are planned to be installed in the T1 tunnel area.

3.6 Scanning the surface

No surface scanning is planned in the T1 tunnel area.

4 GEOTECHNICAL MEASUREMENTS

4.1 Existing instruments in the pre - excavation and tunnel area

During the implementation of the program of basic and supplementary geological-geomechanical and hydrogeological research, the following instruments were installed in the area of the T1 tunnel:

Table 7: List of existing geotechnical instruments in the T1 tunnel area

Current mark	New instrument mark	Instrument type	Depth / dimensions	Current operator
T1-5	T1-MP-II-2_T1-5-I	Inclinometer	25 m	2TDK d.o.o.
T1-13	T1-MP-II-2_T1-13-I	Inclinometer	30 m	2TDK d.o.o.
T1-15	T1-MP-II-2_T1-15-I	Inclinometer	30 m	2TDK d.o.o.
T1A-2	T1-MP-II-2_T1A-2-I	Inclinometer	20 m	2TDK d.o.o.
T1A-3	T1-MP-II-2_T1A-3-I	Inclinometer	18 m	2TDK d.o.o.
T1-7	T1-MP-II-2_T1-7-P	Piezometer	250 m	2TDK d.o.o.
T1-8	T1-MP-II-2_T1-8-P	Piezometer	270 m	2TDK d.o.o.
T1-10	T1-MP-II-2_T1-10-P	Piezometer	160 m	2TDK d.o.o.
T1-12	T1-MP-II-2_T1-12-P	Piezometer	242 m	2TDK d.o.o.
T1-13	T1-MP-II-2_T1-13-P	Piezometer	347 m	2TDK d.o.o.
T1-14	T1-MP-II-2_T1-14-P	Piezometer	253 m	2TDK d.o.o.
T1-15	T1-MP-II-2_T1-15-P	Piezometer	135 m	2TDK d.o.o.

It is required that all working instruments listed in Table 7 be maintained during the construction works.

For piezometers in the T1 tunnel area, renaming according to the new nomenclature is foreseen. Piezometers that will be damaged during the underground excavation shall, as far as possible, be cemented above the top of the tunnel and observation shall continue.

4.2 New instruments in the pre-excavation and tunnel area

In the area of pre-excavations and tunnel T1, for the needs of construction monitoring, the installation of new geotechnical instruments is planned, namely

- MP-II-1 – extensometers in the well
- MP-II-2 – vertical inclinometers
- MP-II-3 – piezometers
- MP-II-4 - rock pressure cells
- MP-II-5 - pressure cells in the lining
- MP-II-6 - specific deformation meters
- MP-II-7 - measuring cells on radial anchors
- MP-II-8 - measuring cells on geotechnical anchors
- MP-II-9 - measuring radial anchorsMP-II-10 – laserski merilci pomikov v notranji oblogi

- MP-II-11 - expansion joints for measuring the displacement between the portal structure and the tunnel lining

The following geotechnical instruments must be installed in the area of the T1 tunnel during the construction works:

Table 8: List of new geotechnical instruments (MP-II-1 extensometers) in the T1 tunnel area

Measurement profile designation	Expected stationing	Location	Place of installation	Length	Permanent use (during operation)
MP-II-1/1	4.270,00	Main tube	From tunnel	2,4,6 m	NO
MP-II-1/2	4.680,00	Main tube	From tunnel	2,4,6 m	NO
MP-II-1/3	4.840,00	Main tube	From tunnel	2,4,6 m	NO
MP-II-1/4	5.650,00	Main tube	From tunnel	2,4,6 m	NO
MP-II-1/5	7.080,00	Main tube	From tunnel	2,4,6 m	NO
MP-II-1/6	7.310,00	Main tube	From tunnel	2,4,6 m	NO
MP-II-1/7	8.450,00	Main tube	From tunnel	2,4,6 m	NO
MP-II-1/8	8.920,00	Main tube	From tunnel	2,4,6 m	NO
MP-II-1/9	9.430,00	Main tube	From tunnel	2,4,6 m	NO
MP-II-1/10	4.280,00	Service tube	From tunnel	2,4,6 m	NO
MP-II-1/11	4.680,00	Service tube	From tunnel	2,4,6 m	NO
MP-II-1/12	4.900,00	Service tube	From tunnel	2,4,6 m	NO
MP-II-1/13	5.700,00	Service tube	From tunnel	2,4,6 m	NO
MP-II-1/14	7.100,00	Service tube	From tunnel	2,4,6 m	NO
MP-II-1/15	7.330,00	Service tube	From tunnel	2,4,6 m	NO
MP-II-1/16	8.450,00	Service tube	From tunnel	2,4,6 m	NO
MP-II-1/17	8.940,00	Service tube	From tunnel	2,4,6 m	NO
MP-II-1/18	9.450,00	Service tube	From tunnel	2,4,6 m	NO

Table 9: List of new geotechnical instruments (MP-II-2 inclinometers) in the T1 tunnel area

Measurement profile designation	Location	Place of installation	Length	Permanent use (during operation)
MP-II-2/1	Portal Koper	on the surface	16m	YES
MP-II-2/2	Portal Koper	on the surface	16m	YES

The locations of the new inclinometers on the pre-excavations are shown in the graphic appendices and Figure 7. It is planned to install inclinometers only on the Koper portal, while no inclinometers will be installed on the Divača portal of the T1 tunnel.

Table 10: List of new geotechnical instruments (MP-II-3 piezometers) in tunnel T1 (pair of piezometers in the measurement profile)

Measurement profile designation	Expected stationing	Location	Place of installation	Length	Permanent use (during operation)
MP-II-3/1	6.290,00	Main tube	from the tunnel	15 m	YES
MP-II-3/2	8.450,00	Main tube	from the tunnel	15 m	YES
MP-II-3/3	8.920,00	Main tube	from the tunnel	15 m	YES
MP-II-3/4	6.290,00	Service tube	from the tunnel	15 m	YES
MP-II-3/5	8.450,00	Service tube	from the tunnel	15 m	YES
MP-II-3/6	8.940,00	Service tube	from the tunnel	15 m	YES

Table 11: List of new geotechnical instruments (MP-II-6 specific strain gauges) in the T1 tunnel area

Measurement profile designation	Expected stationing	Location	Place of installation	Length	Permanent use (during operation)
MP-II-6/1	4.840,00	Main tube	from the tunnel	NO	broken zone
MP-II-6/2	6.290,00	Main tube	from the tunnel	YES	cavern with sediments
MP-II-6/3	8.450,00	Main tube	from the tunnel	YES	broken zone
MP-II-6/4	8.920,00	Main tube	from the tunnel	YES	flysch/limestone transition
MP-II-6/5	9.430,00	Main tube	from the tunnel	NO	flysch
MP-II-6/6	4.900,00	Service tube	from the tunnel	NO	broken zone
MP-II-6/7	6.290,00	Service tube	from the tunnel	YES	cavern with sediments
MP-II-6/8	8.450,00	Service tube	from the tunnel	YES	broken zone
MP-II-6/9	8.940,00	Service tube	from the tunnel	YES	flysch/limestone transition
MP-II-6/10	9.450,00	Service tube	from the tunnel	NO	flysch

Table 12: List of new geotechnical instruments (pressure cells on radial anchors MP-II-7) in the area of tunnel T1

Measurement profile designation	Expected stationing	Location	Place of installation	Length	Permanent use (during operation)
MP-II-7/1	4.270,00	Main tube	from the tunnel	6m	NO
MP-II-7/2	4.680,00	Main tube	from the tunnel	6m	NO
MP-II-7/3	4.840,00	Main tube	from the tunnel	6m	NO
MP-II-7/4	5.650,00	Main tube	from the tunnel	6m	NO
MP-II-7/5	7.080,00	Main tube	from the tunnel	6m	NO
MP-II-7/6	7.310,00	Main tube	from the tunnel	6m	NO
MP-II-7/7	8.450,00	Main tube	from the tunnel	6m	NO
MP-II-7/8	4.280,00	Service tube	from the tunnel	6m	NO
MP-II-7/9	4.680,00	Service tube	from the tunnel	6m	NO

MP-II-7/10	4.900,00	Service tube	from the tunnel	6m	NO
MP-II-7/11	5.700,00	Service tube	from the tunnel	6m	NO
MP-II-7/12	7.100,00	Service tube	from the tunnel	6m	NO
MP-II-7/13	7.330,00	Service tube	from the tunnel	6m	NO
MP-II-7/14	8.450,00	Service tube	from the tunnel	6m	NO

Table 13: List of new geotechnical instruments (radial measuring anchors MP-II-9) in the area of tunnel T1

Measurement profile designation	Expected stationing	Location	Place of installation	Length	Permanent use (during operation)
MP-II-9/1	8.920,00	Main tube	from the tunnel	6m	NO
MP-II-9/2	9.430,00	Main tube	from the tunnel	6m	NO
MP-II-9/3	8.940,00	Service tube	from the tunnel	6m	NO
MP-II-9/4	9.450,00	Service tube	from the tunnel	6m	NO

5 VIBRATION MEASUREMENTS

In the area of influence of the T1 tunnel, according to the forecasted geological conditions, vibration measurements are planned to be performed on the following existing facilities or infrastructure elements:

Table 14: Planned MP-III-1 vibration meters on facilities or infrastructure in the area of tunnel T1

Infrastructure element code	Number of mesurements	Horizontal distance at the beginning of regular measurements	Object category according to ÖNORM S 9012	Impact category according to ÖNORM S 9012	Object category by DIN 4150
residential buildings Lokev	2	150 m	2 (table 3)	Impulsive, often	L2
outbuildings Lokev	3	150 m	1 (table 3)	Impulsive, often	L2
transmission line poles (20kV)	3	150 m	2 (table 2)	Impulsive, often	L2
transmission line poles (HV)	4	150 m	2 (table 2)	Impulsive, often	L2
residential buildings Mihele	2	150 m	2 (table 3)	Impulsive, often	L2

The horizontal distance at the start of the regular measurements is given as the horizontal distance from the excavation face of the dome when the start of the regular vibration measurements is required. The requirement in the specifications is that the actual measurements must start at least 30 days in advance to determine what the ambient vibrations are without the impact of the construction works.

Table 13 shows the categories of objects, the category of vibration effects on objects according to the Austrian standard ÖNORM S 9012 and according to the German standard DIN 4150. The limit values for an individual object must be determined in accordance with the standard in diagrams.

6 GEOLOGICAL AND HYDROGEOLOGICAL MONITORING

6.1 Engineering-geological (IG) monitoring

Engineering-geological monitoring and inventory is carried out during excavations in portal areas and underground excavation and drilling. A detailed description of IG monitoring (method, technology, number of people, frequency, etc.…) is given in the Technical Specifications and will be specified in detail in the terms of reference for the implementation of GGHG monitoring.

6.2 Hydrogeological (HG) monitoring

Hydrogeological monitoring is carried out during excavations in portal areas and underground excavation and drilling. A detailed description of HG monitoring (method, technology, number of people, frequency, etc.…) is given in the Technical Specifications and will be specified in detail in the terms of reference for the implementation of GGHG monitoring.

The following describes the hydrogeological criteria (HGK), which are checked during construction.

Hydrogeological criteria (HGK1-5 and HGK permanent) for individual phenomena are related 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 a drained tunnel design on a given section. As a whole, they are used to submit a final proposal for the implementation of the internal lining (drained or undrained section), and in preliminary form also to support the decision regarding the implementation of the excavation of the dome. high-rise and floor vault. 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 status of groundwater (pre-injection, post-injection, construction of karst channel drains, etc.). Permitted groundwater abstractions, as given in the Figure, are defined on the basis of the amount of effluent from combined drained / undrained echoes in the tunnel, treated in the Groundwater Pollution Risk Analysis (Ratej and Prestor, 2011). 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).

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

Hydrogeological criteria are divided into five (5) segments according to the type of hydrogeological phenomenon and are presented in the table together with the time component, which is related to the dynamics of tunnel construction and the length of the measurement. The dynamics of 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 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 criteria do not affect the dynamics of construction. In these cases, the Contractor's activity will be required in terms of timely installation of drainage pipe or plug foil (criterion HGK 4), dams (criterion HGK 5) and ensuring the presence of a hydrogeologist who will perform regular measurements within the geological and geotechnical supervision. Details for the construction of dams required for the implementation of the hydrogeological criterion HGK5 are given in the project documentation.

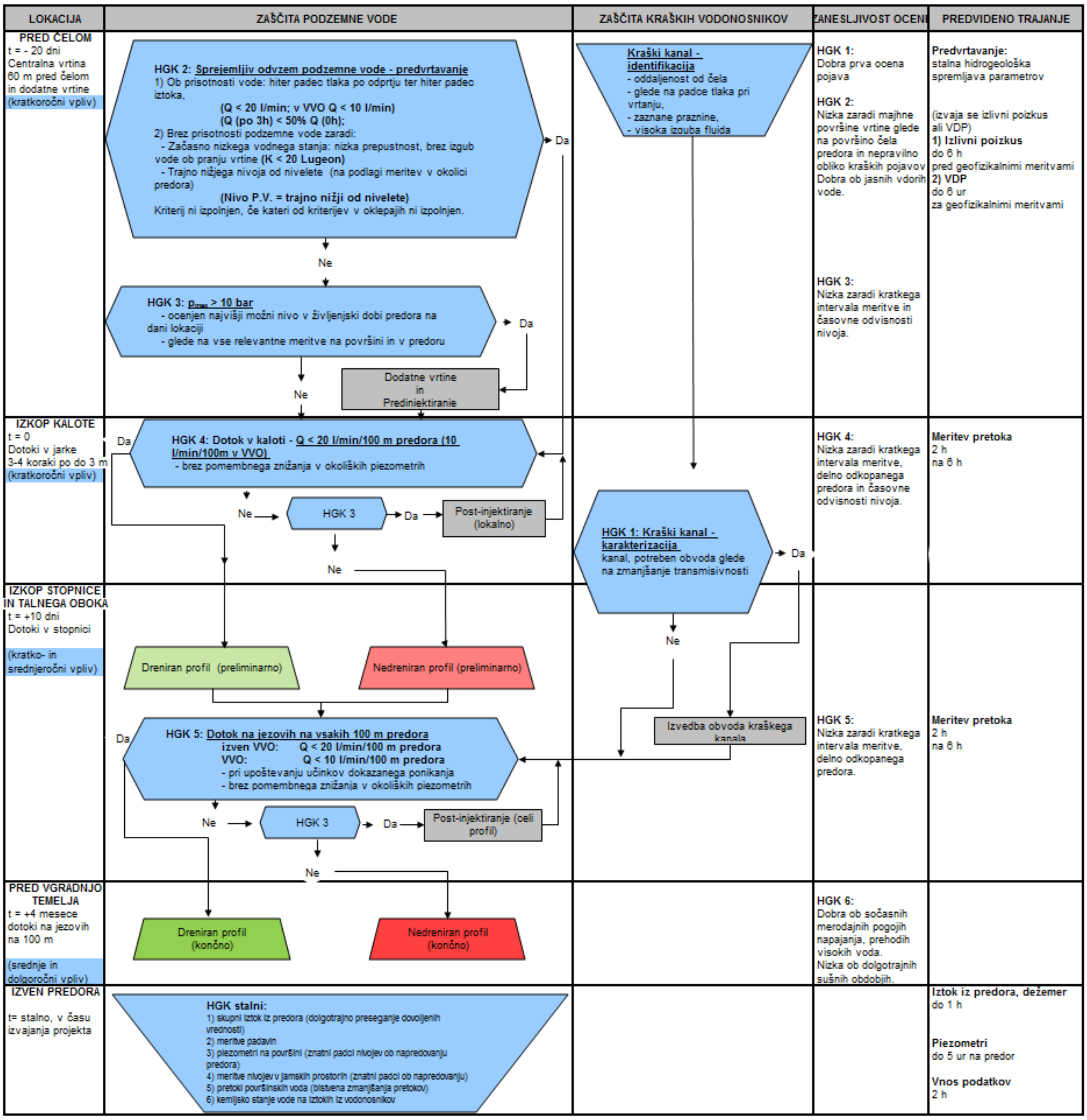


Figure 9: Scheme of hydrogeological monitoring of construction to determine compliance with the requirements of the Decree on the water protection area for the water body of Rižana aquifers (Official Gazette of the Republic of Slovenia, No. 49/08, 72/12 and 69/13)

The following are more detailed descriptions of individual hydrogeological criteria:

- HGK 1 is bound to karstic cracks or contacts, which represent a significant groundwater conductor. If the conductor is cut 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 drainage regime as before construction. HGK 1 can be determined in time during the excavation of the dome and stairs, indications (perceived gaps in drilling, their distance from the forehead, 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 drop at the measured flow, which must not exceed 20 l / min and within the water protection area, must not exceed 10 l / min, is determined through discharge tests. The flow rate should be faster than condition Q (after 3 h) <50% Q initial. If water is not present, but other indications suggest that it may occur at higher 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 still the smallest. It is necessary to ensure that protection against the leakage of groundwater from the well (by means of a packer or prevent-ory) is applied during the pre-drilling, so that the relevant groundwater pressures in front of the face can be measured. The measurement result is analyzed in the context of simultaneous measurements of levels in piezometers on the surrounding surface and cave spaces.
- 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 dome, namely at points of inflow along the wall) 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 the criterion, together with HGK 3, specifies the need for local injection or the basis for a preliminary decision drained / undrained section, for the excavation of stairs and floor arches.
- HGK 5 represents the longest available period of flow measurements on dams with standardized triangular overflows every 100 m of tunnel before closure with secondary lining. Approximately, the implementation period of HGK5 is estimated at 4 months, or longer, depending on the dynamics of the contractor in the implementation of the secondary coating. 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, and 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 the authoritative outflow of water from the aquifer during precipitation events, the measurement of flows at overflows is performed with a frequency between 6 and 12 hours. The strengthof proven effective downstream subsidence areas can be deducted from the measured upstream abstraction. At the same time, the groundwater levels in the surroundings are monitored, where there must be a drainage tunnel without a significant reduction in groundwater levels.
- HGK is a constant set of criteria that are constantly monitored outside the tunnel. Such criteria make an important contribution to the interpretations of hydrogeological measurements in the tunnel and to the final proposals made by the hydrogeologist. HGK constants are related to measurements of total outflows from tunnel pipes (to determine long-term exceedances of permissible values), precipitation measurements to determine the correlation with levels and inflows, measurements of levels in

piezometers on the surface and in cave spaces (significant declines as a direct impact on quantitative status of aquifers), surface water flows (significant reductions in flows as an indirect indicator of impact) and changes in the chemical status of groundwater at aquifer effluents.

6.3 Karstological accompaniment

Karst monitoring is carried out during excavations in portal areas and underground excavation and drilling in the area of medium and strongly karstic limestones. A detailed description of the karst monitoring (method, technology, number of people, frequency, etc.…) is given in the Technical Specifications and will be specified in detail in the terms of reference for the implementation of the GGHG monitoring.

6.4 Geophysical investigations

In the section of the tunnel where limestones occur, geophysical reflection and cross-hole investigations are planned in wells drilled from the front of the tunnel. A detailed description of the investigations and the scope of these are given in the Technical Specifications and will be specified in detail in the project order for the implementation of GGHG monitoring.

6.5 Rock samples for mineralogical, petrographic and geomechanical surveys

In the area of the T1 tunnel, sampling is planned for geomechanical mineralogical and petrographic investigations on the scale presented in Table 15.

Table 15: List of planned rock sampling in the T1 tunnel area.

Indicative Chainage / Location	Method of withdrawal	Intended types of investigations	Quantity	Note*
2+966 – 8+90	Samples from the forehead (limestone)	Uniaxial compressive strength with deformation measurements Built-in investigations	5 piece 3 piece	Limestone Limestone
8+900 – 9+650	Samples from the forehead (flysch)	Moisture and bulk density measurement Uniaxial compressive strength with deformation measurements Determining the point index Ultrasound examinations CAI abrasiveness Triassic investigation - Hoek cell / Brazilian test Robertson's direct shear investigation Sandstone roughness (JRC) and tilt test Swelling investigations Investigations of the occurrence of sulphate corrosion conditions Built-in investigations Execution of mineralogical-petrographic investigations	30 piece 10 piece 50 piece 5 piece 5 piece 3 piece 3 piece 10 piece 3 piece 3 piece 3 piece 10 piece	K, P in L K, P in L K, P in L K, P in L K, P in L K, P in L K, P in L K, P in L K, P in L K, P in L K, P in L K, P in L

* A… Limestone, P… Sandstone, L… .Lapor, K… .Calkarenite, PP… transition layers

6.6 Groundwater samples for chemical investigations

In the T1 tunnel area, sampling is planned for chemical investigations in the following areas:

In the T1 tunnel area, sampling is planned for chemical investigations in the following areas:

Stationary / location of collection	Withdrawal method (drilling / cutting pieces)	Intended types of investigations
4+250	Groundwater abstraction	Chemical analysis of groundwater
4+700	Groundwater abstraction	Chemical analysis of groundwater
4+820	Groundwater abstraction	Chemical analysis of groundwater
5+240	Groundwater abstraction	Chemical analysis of groundwater
5+650	Groundwater abstraction	Chemical analysis of groundwater
6+250	Groundwater abstraction	Chemical analysis of groundwater
6+770	Groundwater abstraction	Chemical analysis of groundwater
7+070	Groundwater abstraction	Chemical analysis of groundwater
7+300	Groundwater abstraction	Chemical analysis of groundwater
8+300	Groundwater abstraction	Chemical analysis of groundwater
8+450	Groundwater abstraction	Chemical analysis of groundwater
8+650	Groundwater abstraction	Chemical analysis of groundwater
8+850	Groundwater abstraction	Chemical analysis of groundwater

7 EXCHANGE VALUES

7.1 Geodetic measurements in the tunnel

Za predvidene podporne tipe na območju predora T1 veljajo naslednje sprožitvene vrednosti:

Table 17: Trigger values for geodetic measurements of measuring points in the primary lining in the area of tunnel T1 (applies to main and service pipe).

Support type	Primary lining thickness	Number of flexible compressible elements	Warning value offset (orange) *	Limit offset (red) *
D-K-3/0,73	5 cm	-	3 cm	6 cm
D-K-3/1,39	10 cm	-	3 cm	6 cm
D-K-4/1,77	15 cm	-	5 cm	10 cm
D-K-4/2,44	15 cm	-	5 cm	10 cm
D-K-4/3,54	15 cm	-	5 cm	10 cm
D-K-5/3,61	15 cm	-	5 cm	10 cm
D-K-5/5,20	20 cm	-	8 cm	15 cm
D-K-5/6,50	20 cm	-	8 cm	15 cm
D-K-6/8,68	25 cm	-	15 cm	20 cm
D-K-6/10,62	30 cm	-	15 cm	20 cm
D-K-6/12,40	30 cm	-	15 cm	20 cm
D-K-7/7,79	30 cm	-	5 cm	10 cm
D-K-7/9,82	30 cm	-	5 cm	10 cm
D-K-7/12,11	30 cm	-	5 cm	10 cm
D-K-7/13,96	30 cm	2	20 cm	30 cm
D-K-7/16,48	30 cm	2	20 cm	30 cm
D-K-7/19,03	35 cm	4	25 cm	35 cm
N-K-3/0,71	5 cm	-	3 cm	6 cm
N-K-3/1,35	10 cm	-	3 cm	6 cm
N-K-4/1,72	15 cm	-	5 cm	10 cm
N-K-4/2,37	15 cm	-	5 cm	10 cm
N-K-4/3,41	15 cm	-	5 cm	10 cm
N-K-5/3,49	15 cm	-	5 cm	10 cm
N-K-5/5,02	20 cm	-	8 cm	15 cm
N-K-5/6,25	20 cm	-	8 cm	15 cm
N-K-6/8,47	25 cm	-	15 cm	20 cm
N-K-6/10,32	30 cm	-	15 cm	20 cm
N-K-6/12,11	30 cm	-	15 cm	20 cm
N-K-7/13,38	30 cm	2	20 cm	30 cm
N-K-7/15,80	30 cm	2	20 cm	30 cm
N-K-7/18,22	35 cm	4	25 cm	35 cm

* serviceability limit state (radial displacement of the measuring point reaches 100% of the predicted deformation tolerance at the location of the installed measuring profile)

** limit state of bearing strength(90% of radial displacement at limit state of bearing strengthof primary lining)

Table 18: Trigger values for geodetic measurements of measuring points in the primary lining in the area of tunnel T1 (applies to cross-sections).

Support type	Primary lining thickness	Number of flexible compressible elements	Warning value offset (orange) *	Limit offset (red) *
K-4/0,91	5 cm	-	3 cm	6 cm
K-4/1,60	10 cm	-	3 cm	6 cm
K-5/2,51	15 cm	-	5 cm	10 cm
K-5/3,78	20 cm	-	5 cm	10 cm
K-6/6,60	25 cm	-	5 cm	10 cm
K-6/8,20	25 cm	-	5 cm	10 cm

* serviceability limit state (radial displacement of the measuring point reaches 100% of the predicted deformation tolerance at the location of the installed measuring profile)

** limit state of bearing strength(90% of radial displacement at limit state of bearing strengthof primary lining)

7.2 Geodetic measurements of infrastructure and existing facilities

In the area of the passage of the T1 tunnel under the local road Lokev, the installation of 2 measuring points is planned. The points are installed along the road, directly at the intersection of the road and each of the tunnel pipes. In addition, two points are installed on the commercial building, which will be located directly above the main pipe, and two more points on the residential building, which will be located directly above the service pipe. A total of 6 geodetic measuring points will be installed.

Preglednica 1: Sprožitvene vrednosti za geodetske meritve točk na lokaciji prečkanja predora T1 pod lokalno cesto Lokev

Point mark	Point location	Warning value offset (orange) *	Limit offset (red) **	Warning value rotation (orange) **	Rotation at limit value (red) **
MP-I-3/1	by the road	0,2 cm	0,5 cm	1/1000	1/500
MP-I-3/2	by the road	0,2 cm	0,5 cm	1/1000	1/500
MP-I-3/3	on the farm building, above the main pipe	0,2 cm	0,4 cm	1/1000	1/500
MP-I-3/4	on the farm building, above the main pipe	0,2 cm	0,4 cm	1/1000	1/500
MP-I-3/5	on a residential building, above the service pipe	0,2 cm	0,4 cm	1/1000	1/500
MP-I-3/6	on a residential building, above the service pipe	0,2 cm	0,4 cm	1/1000	1/500

* displacement calculated from 2D numerical analyzes at characteristic values of rock parameters

** shift or twist at which no damage to facilities or infrastructure is yet to be expected (Bjerrum, 1963) according to the table below:

$\frac{1}{1000}$	
$\frac{1}{900}$	
$\frac{1}{800}$	Meja, na kateri se lahko pričakujejo težave z občutljivimi napravami
$\frac{1}{700}$	
$\frac{1}{600}$	Meja nevarnosti za okvire z diagonalami
$\frac{1}{500}$	Varna meja za zgradbe, kjer razpoke niso dovoljene
$\frac{1}{400}$	Meja, pri kateri se pojavijo prve razpoke na panelnih ploščah Meja, pri kateri se lahko pojavijo težave na žerjavnih stezah
$\frac{1}{300}$	Meja, pri kateri postane vidno nagibanje visokih zgradb
$\frac{1}{200}$	Meja, pri kateri se pojavijo razpoke v panelnih ploščah ter opečnih zidovih Meja, pri kateri se pojavijo poškodbe nosilnih elementov konstrukcije
$\frac{1}{100}$	

7.3 Inclinometri

The following trigger values apply to inclinometer measurements in the T1 tunnel area:

Table 20: Trigger values for inclinometer measurements in the T1 tunnel area

Inclinometer mark	Pomik pri opozorilni vrednosti (oranžna)*	Limit offset (red) **
MP-II-2/1	0,3 cm	0,7 cm
MP-II-2/2	0,4 cm	0,7 cm

) * displacement calculated from 2D numerical analyzes and characteristic values of rock parameters (MSU)

** displacement calculated from 2D numerical analyzes at design values of rock parameters (MSN)

The required regular frequency of inclinometer measurements is:

- zero measurement after inclinometer installation;
- after the completion of the excavation of each floor;
- thereafter once a month during construction;
- after any emergency that could endanger safety on the construction site.

7.4 Radial pressure cells in the lining

No pressure cells are planned to be installed in the T1 tunnel area.

7.5 Pressure cells on measuring anchors

The following trigger values apply to the pressure cells at the measuring anchors in the area of tunnel T1:

Table 21: Trigger values for pressure cells on measuring anchors in the T1 tunnel area

Pressure cell designation	Anchor type	Axial force at anchor at warning value (orange) *	Axial force at anchor at limit value (red) *
T01_MP-II-7	CT-M22-250	210 kN	260 kN
	SN25-250	220 kN	235 kN
	IBO R32-250	170 kN	225kN
	IBO R32-360	270 kN	320 kN

* 90% of the force relative to the yield strength

** 90% of the force relative to the failure limit

7.6 Pressure cells on geotechnical anchors

In the area of the T1 tunnel, the installation of measuring cells on geotechnical anchors is not planned.

7.7 Intended set of measures

Intended set of measures to be applied in case of behavior outside acceptable limits:

- Increase the frequency of measurements.
- Identify the causes based on actual conditions and feedback analyzes.
- Additional passive or geotechnical anchors are installed on the pre-excavations.
- In the case of groundwater, drains are installed.
- The tunnel uses a support type with a shorter pitch and the installation of stronger support elements.
- In case of major deformations, the deformation tolerance is increased and, if necessary, ductile elements are installed.
- If necessary, the rock in front of the forehead is hardened by injection.
- In case of excessive landslides, partial excavation is carried out, rigid support is used and the floor vault is quickly closed.
- In case of excessive vibrations, the technology of work performance is adjusted.
- Inform the designer, who prescribes appropriate measures.

In the case of application of the above measures, it is also necessary to act in accordance with the provisions in the technical specifications:

- 2TDK_PZI_LEA_TS_DOC_3: Excavation and support of the tunnel
- 2TDK_PZI_LEA_TS_DOC_8: Other measures

8 DETECTION OF KARST PHENOMENA DURING CONSTRUCTION OF THE PENETRATION

8.1 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 pipes there is a high possibility of crossing karst phenomena, 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, with sediments (clay or coarse-grained materials such as sand or gravel), liquid soil and rock water, which can also be under relatively high pressure, possible.

For the purposes of this project, the term “karst phenomena” is used 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 phenomena, which, due to the fact that they are interconnected, can affect natural phenomena far from the route.

Due to the relatively limited capabilities of measures for the detection of karst phenomena, there is a high possibility that the karst phenomenon will be detected only when excavation occurs (in the case of karst phenomena in the tunnel profile), or subsequently with georadar or installation of support measures (anchors). the forehead of the excavation will already be away from the karst phenomenon, in the case of the karst phenomenon near the tunnel.

In any case, any detection of a karst phenomenon exceeding 2 m3 outside the contour of the tunnel, or is filled with poorly bearing material or water, or is connected to other underground spaces, must be entered in the construction log, and in the case of major remediation work , which are prescribed below.

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

8.2 Technological procedures for the detection of karst phenomena

The project envisages three procedures for the detection / detection of karst phenomena, taking into account the data obtained during the implementation of geological and geotechnical reports for the T1 tunnel. These procedures are:

- Horizontal borehole pre-drilling
- Bore on the forehead with a fan arrangement
- Geophysical measurements in wells

In order to ensure safety during the excavation of tunnel pipes, a system of prior detection of these phenomena should be provided for at the planning stage. The simplest and most effective system for detecting phenomena in front of the excavation face is pre-drilling with the help of a horizontal hole. Pre-drilling will be used to detect karst phenomena 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 phenomenon, one horizontal well in the front, 100 m long and 114 mm in diameter, will always be drilled along the entire length of the tunnel, 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 project for the T1 tunnel and in the technical specifications.

Georadar measurements (reflection method) will be used in parallel to detect possible karst phenomena and changes in the lithological structure in front of the forehead. The georadar image covers the transverse profile and the surroundings of the transverse profile of the tunnel at a distance of 0.5xD.

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

- Refleksijska merska tehnika
- Metoda cross-hole
- 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 acceptance of works. When carrying out procedures and measures for the remediation of karst phenomena, it is also necessary to take into account the provisions of technical specifications, document no. 8, Other measures.

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

In order to ensure safety during the excavation of tunnel pipes, a system of preliminary detection of karst phenomena should be envisaged in the planning 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 planning and primary substructure for stable rock materials.

Taking into account the density of karst phenomena, 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 acceptance. Scenarios are set for:

- low probability of karst phenomena - low level of karstification
- medium probability of occurrence of karst phenomena - medium degree of karstification
- high probability of karst phenomena - 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 phenomena (graphic appendices 3238 and 3239). Such preliminary information will be used for the basic categorization of phenomena, and only this will be finalized on the basis of geological-geotechnical monitoring, as explained below.

8.3.1 Low probability of occurrence of karst phenomena

In order to detect karst phenomena, even with a low probability of their occurrence, a horizontal hole in the forehead, 100 m long and 114 mm in diameter, is planned. The borehole is drilled by percussive rotary drilling with temporary pipework, if necessary. Drilling equipment must allow continuous measurement of drilling speed and pressure. The minimum switching of wells is 5 m.

If necessary, georadar (refractive method) and hydrogeological surveys are carried out in the well, as described in the geological-geotechnical observation project. In the zone of low probability of occurrence of karst phenomena, it is anticipated that a georadar refraction method will be performed at 20% of the length. No other georadar surveys are planned in this zone. In order to identify karst phenomena outside the range of the horizontal well, from the position of the dome to approximately 80% of the length of this zone, wells with a fan arrangement will be drilled. A total of 4 wells, 20m long with a diameter of 51 mm, will be drilled by percussive rotary drilling, with spatial placement as presented in graphic annex 8002. The estimated total length of the zone with a low probability of karst phenomena is approximately 1600m.

8.3.2 Medium probability of occurrence of karst phenomena

This scenario is an upgrade of the scenario for a low probability of occurrence of karst phenomena. 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 phenomena, four wells 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 switching of boreholes of 4 m in the longitudinal direction is envisaged. The total expected length of the zone with a medium probability of karst phenomena is approximately 2300 m.

8.3.3 High probability of occurrence of karst phenomena

This scenario is an upgrade of the scenario for the medium probability of occurrence of karst phenomena. In the existing horizontal well 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 phenomena, four wells 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.

Wells with a fan layout will be complemented by georadar surveys in the wells using the cross-hole and dawn-hole method. Two scenarios are foreseen here, with a total of 5 wells (graphic annex 8003) 28m long and 76 mm in diameter being drilled according to scenario 1. The wells will be drilled with impact rotary drilling, with PVC pipe and 60 mm. Refractive measurements are made in each of the five wells. In addition, cross-hole measurements are performed between individual wells, where basic and additional measurements are provided.

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

Georadar measurements enable the detection of karst phenomena larger than 1x1x1 m. In the zone of high probability of occurrence of karst phenomena, it is estimated that out of the total number of georadar measurements in wells, 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 phenomena is about 2300m.

8.4 Geophysical surveys in front of and behind the forehead - crosshole method

8.4.1 Basics

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

Strengthand resolution of georadar measurements in the well:

- detects and dates faults and karst phenomena the size of a meter upwards;
- gives a quantitative assessment of karst phenomena 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 research probe (sensor) and the investigated rock must be possible;
- the possibility of performing measurements in dry and wet wells.

Methods of georadar measurements in wells are:

- Reflective measurement technique
- Cross-hole method

8.4.2 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 research well. Measurements along the well 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 well. In the case of a karst phenomenon, we get information about the distance from the well, but without orientation.

8.4.3 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 wells. 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, we obtain data on the locations and depths of anomalies (karst phenomena), but it is not possible to identify the size and shape of the anomaly.

8.4.4 Georadar

The size and shape of karst phenomena 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 phenomenon is located under the floor vault. Georadar is based on the emission of its own electromagnetic field for the needs of research 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 suffocated (absorbed) within the karst phenomenon. When the transmitted electromagnetic signal traveling from the transmitting part of the antenna reaches the electromagnetic limit, 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 limit, 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 phenomena under the floor arch. 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 phenomenon up to a depth of approx. 4 m.

In accordance with Scenario 1, we do not investigate the area of the ground arch in georadar surveys in the wells, so it is necessary to subsequently check for the possibility of karst phenomena. Measurements with georadar can be performed after the floor arch has been made and before the installation of the secondary cladding. After the installation of the secondary 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 in the limestone geological sequence.

9 TRANSITION BETWEEN DRAINED AND UNDRAINED PART OF THE PENETRATION

9.1 General

For the needs of safe construction II. 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 December 2012, Geological Survey of Slovenia and the Institute of Mining, Geotechnology and the Environment, hereinafter referred to as risk analysis. It derives measures for the protection of water resources during the construction of facilities that have been used to develop several project solutions for the tunnel. The first project 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 abstraction of water from the environment will be negligible. 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, which includes a waterproofing layer (waterproof membrane and geotextile or plug foil) and longitudinal side drainage pipes as can be seen from the characteristic transverse profiles of the tunnel.

Another project solution is an 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 abstraction of water from the environment is not negligible. 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 undrained design, with the inner lining dimensioned so that it can withstand the hydrostatic pressures of the water. There were two reasons for this:

a) water under the given conditions karst flows through the network of connected containers, therefore, the fluctuations in the water level can be very fast, which makes the strengthof the drainage tunnel temporarily inadequate, and
b) if the drainage of the tunnel involves too much water, it can deplete water resources in the long run.

For the undrained section, the tunnel was designed to be almost circular in shape, and the cladding was appropriately dimensioned so that it could take up to 100 m of water column pressure. A sealing ring with an injection ring is provided between the drained and undrained tunnel profile. The rock mass at the passage is injected over a longer area if necessary to ensure virtually complete watertightness.

The need for a drained or undrained section of the tunnel will be preliminarily determined during the pre-drilling or. excavation of the calotte. The final decision on the type of section (drained or undrained 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:

c) the passage of a tunnel through or near a karst phenomenon,
d) the passage of the tunnel through a strongly cracked rock mass and
e) the passage of the tunnel through the intertwining of the presence of a karst phenomenon and strongly cracked hills.

The expected water pressure levels on an individual section play an important role in making a decision (drained vs. undrained). 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 with Appropriate injection measures to reduce the water permeability of the surrounding rock so that the permanent abstraction of water from the environment will be negligible or 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 diameters between pipes and also where niches are provided which cause the inner lining to deviate from the circular shape. To achieve the final decision, additional geological, hydrogeological and karst analyzes will be carried out if necessary.

9.2 Profile type selection method (drained vs. undrained)

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

Figure 10 shows a decision diagram that deals with individual cases, also taking into account the switches between different types of permeability. 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 undrained tunnel.

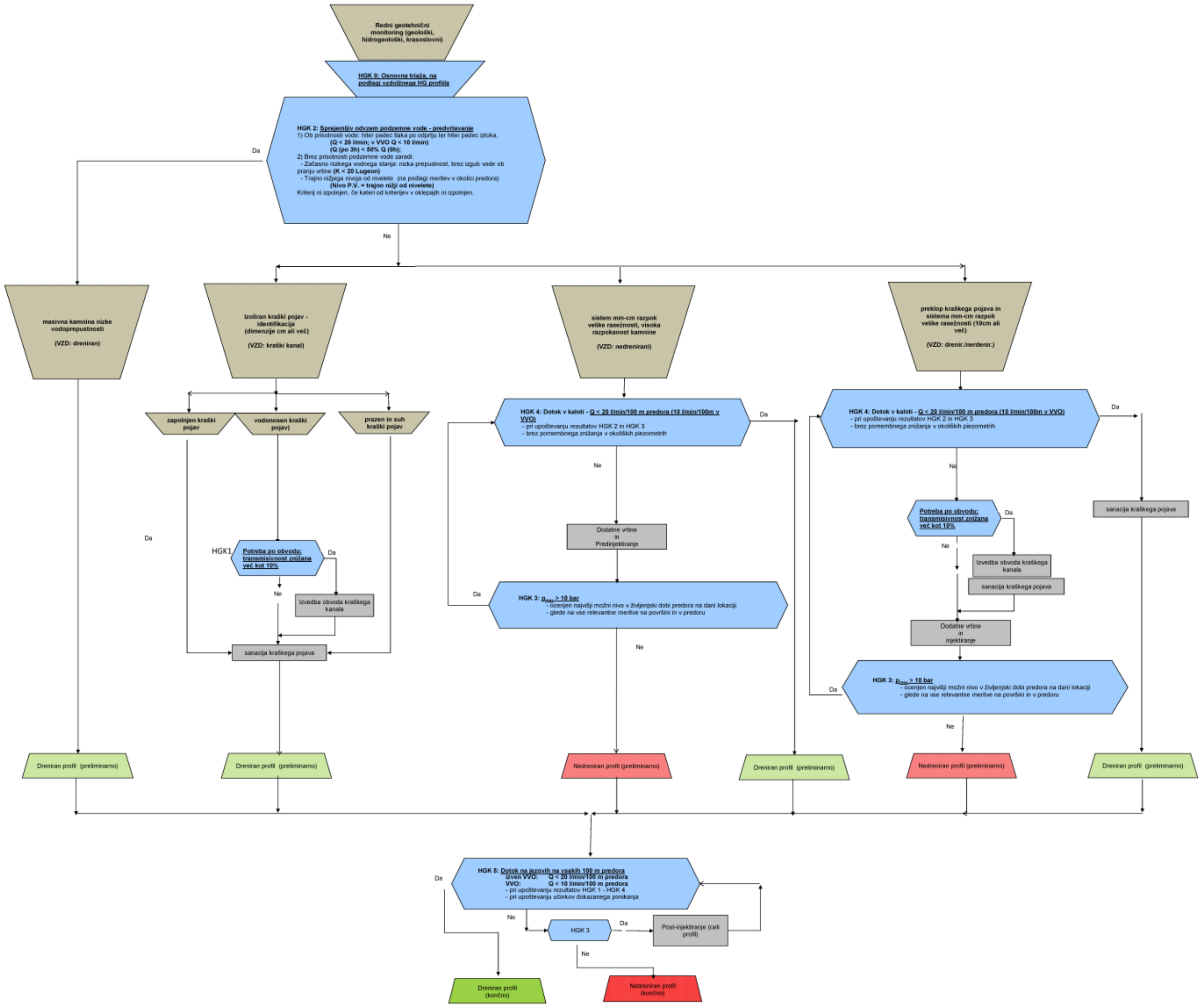
In case the abstraction of water quantities on an individual section is permissible, the tunnel will be built as drained. In case the water pressure is higher than 10 bar, the tunnel will also be built as a drain, and low abstraction of water from the aquifer will be ensured by pre-injection and post-injection measures of the surrounding rock. In all other cases, the tunnel will be built as undrained.

The longitudinal geological and hydrogeological profile (graph. Annex 3238) envisages the following hydrogeological areas in terms of abstraction of water from the aquifer:

- drained (free drainage for low flows),
- undrained (no water abstraction due to high flows, where water pressures are less than the limit pressure max p = 10 bar),
- karst channels (isolated karst phenomenon where both variants are possible or drained or undrained, according to the criteria given in the decision diagram) and
- undrained / drained (switching the presence of the karst channel and greater fracture porosity, where both variants are possible, in accordance with 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 skyscrapers and floor arches, 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 established that the phenomenon is incorrectly recognized due to the previous low reliability of the obtained data, the phenomenon must be reclassified and then treated through a new branch of



the diagram. decision-making, which is given in Figure 10.

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

Figure 9 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 10 so that the diagrams are perfectly aligned in this regard. The following is the concept of hydrogeological monitoring or. detailed explanation of hydrogeological criteria.

9.3 Influence of the choice of drained / undrained variant on tunnel construction and construction of passages

In order to ensure the smallest possible impact of decision-making on the dynamics of tunnel construction, excavation will take place in the dome in an undrained form. In the high-rise and floor vault, the excavation will take place on the basis of a preliminary decision, as shown in the decision diagrams or. 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 floor arch. This case is possible in that a undrained 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 reprofiling, which is thus minimized through the preliminary decision procedure. For the purposes of reprofiling the tunnel, a special item is specified in the inventory. The contractor will be given additional time if the reprofiling works are on a critical construction path.

One of the key technological procedures for successful tunnel construction in both variants is rock grouting. Injection reduces the permeability of the rock in the immediate vicinity of the tunnel to the extent that:

a) allow the reception of groundwater with a drained secondary coating, or
b) allow the reception of hydrostatic pressures of groundwater with undrained secondary lining.

We distinguish between the pre-injection process, which aims to limit water intrusions into the tunnel during construction and enable the construction of a drained variant. The second process is the post-injection process, the purpose of which is to reduce the water permeability after excavation of the tunnel. In both cases, injection is the only way to allow reduced abstraction of water from the aquifer at locations where water pressures are greater than the allowable maxP = 10 bar. Injection is similarly addressed in Chapter 7 of this report and in the technical specifications for special measures in tunnel construction.

The transition between the drained and undrained part must be sealed or. perform watertight. The measure is carried out in the middle of the border undrained camp, as shown in graphic annex 8015. It consists of an injection ring that fills the cracks around the tunnel and a bentonite strip that prevents the passage of water behind the waterproofing membrane. The injection ring is made after the excavation is completed and the entire cross-section is supported, i. domes and stairs with a floor vault, through the primary cladding. It runs along the entire circumference of the cross-section and consists of two injection planes, with an injection length of 4 m. Before installing the waterproofing membrane, the geotextile and plug film are cut at the injection site and a bentonite strip of min length is installed. 1.0 m 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 undrained cross-section, which bridges the karst phenomenon or passes through a strongly karstic area where the occurrence of groundwater is possible, is extended at least by the length of the camp on each side into compact limestone. Prior to the transition to the undrained part of the tunnel, inspection shafts are provided upstream in which the lateral drainage leads to the central collecting pipe.