Implementation of Circular Case 3
Railway applications
D5.3 - February (M33)

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0. Executive summary

The objective of Circular Case 3 – Railway application is to demonstrate the **use of this composite (paper deinking ash and paper deinking sludge), MUDIPEL, as a back-fill material set behind a retaining wall structure.**

In mountainous regions, landslides represent a threat to roads and railways, and need to be prevented by means of costly actions. Slovenian paper company VIPAP Videm Krško recycles around 600 Tons of paper per day to produce recycled pulp. The main waste streams coming from the production of recycled pulp are deinking paper sludge (DPS) and paper sludge ash (PSA). Annually, 25.000 tons of sludge ash are produced. Most of them are still dumped in landfills. For this Case, it is assumed that the new solution needs to be a performance/cost balanced technology for the Slovenian railway infrastructure, which consists of 1207 km of railway lines that need to undergo frequent maintenance labors in the unstable regions.

For Circular Case 3 - Railway application, a 50 m long retaining wall built and almost 100 Ton of the new composite MUDIPEL was used as a back-fill material set behind the retaining wall. The waste valorization process optimization, handling and providing was done by VIPAP Videm Krško, whereas the technical support and dosage optimization activities were performed by ZAG (Slovenian National Building and Civil Engineering Institute). Slovenian Railways, as the railway operator, supplied all the authorizations, and Dušan Holešek S.P. (SME) was in charge of the construction works. The location of the pilot project is in the south of Slovenia, 70 Km from the VIPAP facility in Krško, therefore being very convenient for the transport of MUDIPEL.

The composite MUDIPEL was firstly tested in ZAG's geomechanical laboratory, and the results were later verified through small field tests at VIPAP facilities. Based on the results measured at the small field tests, the technology for the installation of the material for construction sites was determined. It was established that no more than 4 hours may elapse between mixing the composite and its installation. At the construction site, the material was installed in 30 cm thick layers. Each layer was compacted and controlled to reach their optimal moisture and maximum density. Gabions were selected to execute the supportive construction. Before, during and after the construction, landslide stability and environmental monitoring tests were performed. Landslide and retaining wall structure has been stable until now . In the other hand, the performed chemical analyses showed that MUDIPEL doesn´t entail any negative environmental impact. Based on several laboratory and field tests, the STS (Slovenina Technical Approval) for MUDIPEL was granted, which allowed the use of this material as a back-fill material at the construction site.

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Keywords

Railways	Back-fill material	Deinking paper ash	Deinking paper sludge	Recycling material

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Abbreviations and acronyms:

DPA: Deinking paper ash

DPS: Deinking paper sludge

PPI: Pulp and Paper Industry

QA: Quality Assurance

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1. Introduction

ZAG and VIPAP Videm Krško have been cooperating for the last ten years to find an alternative and sustainable recycling solution for deinking paper sludge (DPS) and deinking paper fly ash/bottom ash (DPA). Several attempts have already been made to get a solution for using these two materials as components within a composite product, aiming to be used as a construction material.

The objectives of Circular Case 3 – Railway application is to demonstrate the **use of this composite (paper deinking ash and paper deinking sludge), MUDIPEL, as a back-fill material set behind a retaining wall structure.**

In mountainous regions, landslides represent a threat to roads and railways, which need to be prevented by means of expensive actions. Slovenian paper company VIPAP Videm Krško recycles around 600 Tons of paper per day to produce recycled pulp. Main waste streams from the production are deinking paper sludge (DPS) and paper sludge ash (PSA). Annually, 25.000 Tons of paper sludge ash are produced. Most of them are still dumped in landfills. For this Case, it is assumed that the solution needs to be a performance/cost balanced technology for the Slovenian railway infrastructure, which consists of 1207 Km of railway lines, which need to undergo frequent maintenance labors in the unstable regions.

For Circular Case 3 - Railway application, a 50 m long retaining wall was built and almost 100 Ton of the new composite MUDIPEL was used as a back-fill material behind the retaining wall. The waste valorization process optimization, handling and providing was done by VIPAP Videm Krško, while the technical support and the dosage optimization activities were performed by ZAG (Slovenian National Building and Civil Engineering Institute). Slovenian Railways, as the railway operator, awarded all the required authorizations, and Dušan Holešek S.P. (SME) was in charge of the construction works. The location of the pilot project is in the south of Slovenia (Figure 1), 70 km from the VIPAP facilities in Krško, which was very convenient for the transport of MUDIPEL.

According to the legislation in Slovenia, a recycled material not being covered by an already existing harmonized standard shouldn´t be used for buildings and infrastructures construction without an STS (Slovenian Technical Approval). For recycled materials, the appropriate chemical and mechanical tests need to be performed in order to prove that all the mechanical and environmental requirements of an equivalent natural or artificial material are fulfilled. Through the performance of the stablished laboratory and field tests, the STS for MUDIPEL was granted, which allowed its use as a back-fill material at the construction site.

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1.1. Objectives

The project PAPERCHAIN, Demo Case 3 aims to demonstrate the technical, environmental and economic feasibility of using DPA (deinking paper ash) and DPS (deinking paper sludge) as an alternative back-fill material, instead of the traditional use of virgin gravel or hydraulically bounded products, commonly used behind various retaining wall structures according to Slovenian regulations.

Civil engineering works normally use primary raw materials as aggregates/components within the construction products worldwide, such as natural aggregates and extracted soils. However, new ways to reduce or totally substitute their use by secondary aggregates have been discovered, through the valorisation of recycled and artificial aggregates, or valorising aggregates coming from the waste and sub-products processing from industrial activities.

The construction sector consumes a large amount of resources, and more than half of the greenhouse gases emissions worldwide are related to materials and resources management. Thus, the replacement of raw materials by secondary raw materials in civil engineering enables the reduction of environmental impacts considerably.

The traditional solution being used until now has been opening new quarries to extract materials over time. However, this activity entails high environmental impacts. Therefore, the valorisation of recycled aggregates is an alternative solution with much lower related environmental impacts.

However, the products containing recycled materials within its composition must be competitive in the market comparing to the traditional ones in terms of technical and economic performance (lower cost of production and transportation), since the quality of the final product depends on the properties of the used aggregates and all the processing phases until their final application.

Therefore, recycling presents interesting advantages over the traditional solutions, and enhances the protection of the environment, since it entails a lower extraction of granular materials in stone quarries or gravel pits, avoiding the related ecosystem destruction and landscape impacts as well.

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1.2. Pilot´s location

The Demo construction corresponding to this Circular Case was built in the Slovenian railway, and consisted on a 50 m length test section for landslide prevention. The waste valorization process optimization, handling and providing was done by VIPAP, while the technical support and dosage optimization activities were performed by ZAG (Slovenian National Building and Civil Engineering Institute). Slovenian Railways, as the railway operator, awarded all the authorizations, and Slovenian Railways – Infrastructure (SZ) is the railway operator, while Dušan Holešek S.P. (SME) was in charge of the construction works.

The location of the pilot project is in the south of Slovenia (Figure 1), 70 km from the VIPAP facility in Krško, thus being a very convenient distance for the transport of MUDIPEL. There is an unstable slope in that area near the railway line, which has to be stabilised with a retaining wall. Gabions conform the retaining structure, while MUDIPEL was set as back-fill material (Figure 2).

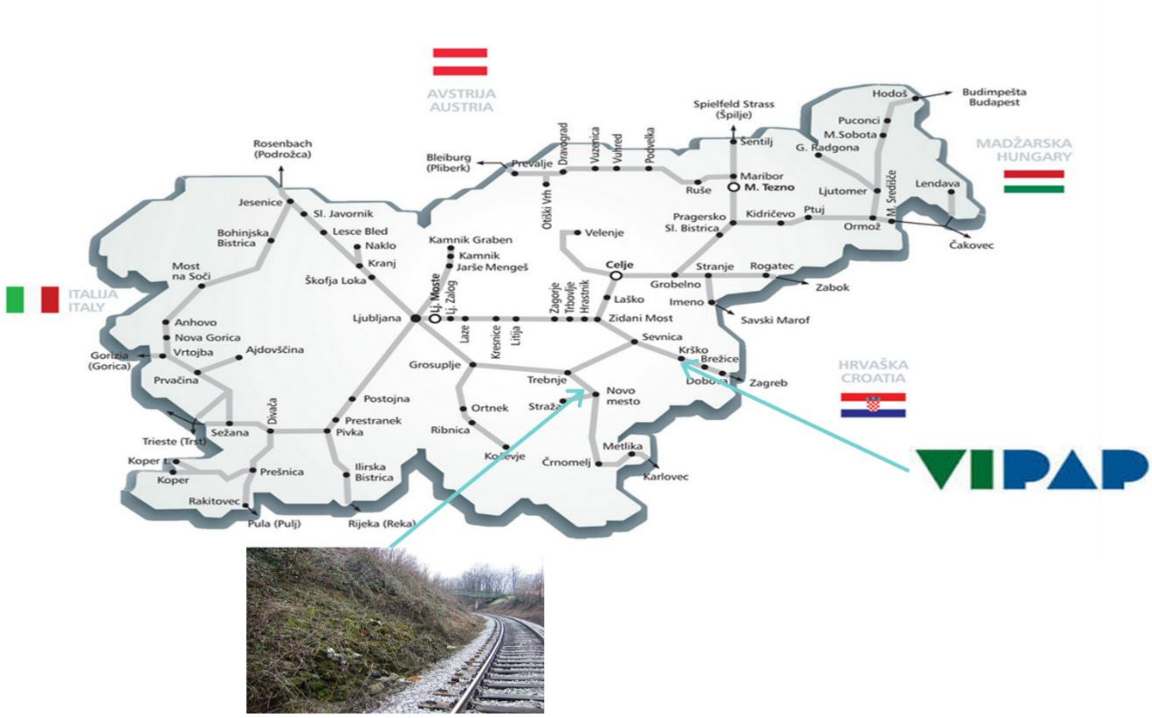

FIGURE 1 PILOT PROJECT'S LOCATION

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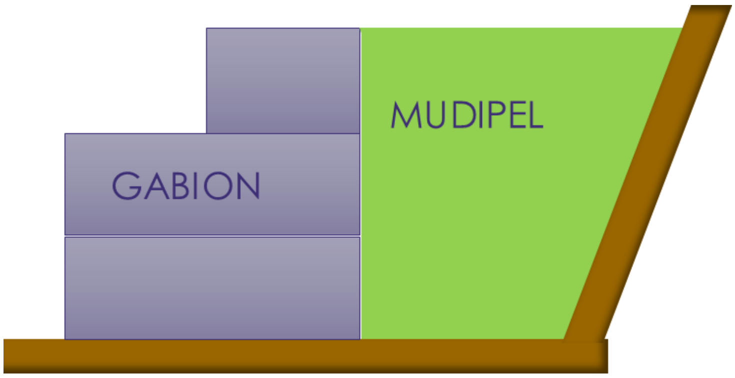

FIGURE 2 SKETCH OF THE RETAINING WALL STRUCTURE

1.3. Regulatory framework for Slovenian back-fill materials

For the Slovenian demo case a material named MUDIPEL, which includes recycled materials in its composition as mentioned before, was used as the back-fill material set between gabions and the rock/soil slope. The legal framework applying wastes in Slovenia is gathered below in Table 1.

TABLE 1 LEGISLATION ASSOCIATED TO WASTE AND BUILDING PRODUCTS IN SLOVENIA AND THE EUROPEAN UNION.

Country	Lesgilsation	Summary
Slovenia	Decree-Law n.º UL RS št.93/2013	In the article 9 of that directive it is stated that using other (recycled) material for railway construction stabilisation and soil/rock slope stabilisation near the railway line is possible. The same directive in the article 4 allows using the Technical Specification for Roads (TSC), where it´s reasonably appropriate.
	Decree-Law n.º UL RS, No. 61/11	Eluates must comply with the requirements foreseen in the Decree of the Landfill of Waste at Landfills (UL RS, No. 61/11) – "inert waste"
	Decree-Law n.º Construction Products Act - ZGPro-1	The Slovenian Law on the Construction Products.
	Ordinace n.º No. 3210-9 / 2002-23 of 20 December 2006	In accordance with Article 22 of ZGPro-1 (the Slovenian Law on the Construction Products), ZAG continues to be nominated as the Slovenian Technical Approval Authority

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According to the provisions of Article 5 of the Construction Products Act - ZGPro-1, in case that product isn´t covered by the existing harmonized technical specifications, the manufacturer must demonstrate the essential characteristics of the construction product on the basis of the Slovenian Technical Approval (STS) before placing it on the market. Issuing the Declaration of Conformity is also mandatory for the producer.

The Slovenian Technical Approval is a national technical specification, which needs to be complied when harmonized technical specifications (harmonized standard or European technical approval) aren´t available for a particular material or by-product.

As it was stated above, according to the legislation in Slovenia a recycled material not covered by the available harmonized standards, shouldn´t be used for building and infrastructure without an STS. For every recycled material an STS needs to be granted based on the required laboratory and field investigations. For recycled materials, appropriate chemical and mechanical tests need to be performed to prove their compliance with the applying mechanical and environmental requirements.

The Slovenian Ministry of Infrastructure is the responsible entity for the preparation and implementation of the government policy on transport infrastructures. There are several technical specifications that help to encourage the use of recycled materials. The most common applications of back-fill materials are presented in TABLE 2.

TABLE 2 SLOVENIAN TECHNICAL SPECIFICATIONS FOR BACK-FILL MATERIAL

Specification	Title
TSC 05.800:2001	For traffic infrastructures the Slovenian Technical Specification for roads (TSC) is used, which also includes technical requirements for the use of recycled material in the road construction
TSC 05.413	Requirements for back-fill material near structures and infrastructure.
TSC 06.740:2003	The properties of the recycled materials have to be proven with the demo field and for this procedure there is a technical specification.

The technical characteristics to be met by back-fill materials are determined in Technical specification TSC 05.413 - Construction of embankments, fillers and clay charges. Technical specifications also allow the use of fly ash as a filler material. For the utilisation of paper fly ash as filler material in the structure, the most important (critical) characteristics are the following:

- Optimal water content
- Maximum dry density by Standard Proctor test (TABLE 3)
- Modulus of deformation below the construction (TABLE 4)
- Environmental acceptability (TABLE 5)

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TABLE 3 OPTIMAL DENSITY REQUIREMENTS FOR BACK-FILL MATERIAL

Thickness of the layer	Required compression
Thickness up to 2 m	95 % $\rho_{d,max}$ SPP*
Thickness of more than 2 m	92 % $\rho_{d,max}$ SPP*

* Standard Proctor test

TABLE 4 IN-SITU TESTS FOR CONSTRUCTION MATERIAL

Material	Required modulus below the road		
	E_{v2} (MN/m²)	E_{v2}/ E_{v1} (MN/m²)	E_{vd} (MN/m²)
Stabilised soil or fly ash	≥ 30	≤ 2,2	≥ 15

Dynamic modulus of deformation (E_{vd}), Static modulus of deformation (E_{v1}, E_{v2})

Regarding the environmental aspects, the Decree-Law n.º UL RS, No. 61/11 states that the material needs to have eluates under the legally stablished leaching threshold values for their inert waste classification. Otherwise the waste should be dumped in landfill. TABLE 5 displays the limit values to classify the waste as inert. Before using the material, it´s necessary to perform a field test according to the TSC 06.740 rule (procedure for building field tests).

TABLE 5. LEACHING LIMIT VALUES FOR INERT WASTE

Component	Limit Inert waste mg/kg d.s.
As	0,5
Ba	20
Cd	0,04
Cr total	0,5
CU	2
Hg	0,01
Mo	0,5
Ni	0,4
Pb	0,5
Sb	0,06
Se	0,1
Zn	4
Chloride	800
Fluoride	10
Sulphate	1000

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2. Circular Case 3 –Railway applications

2.1. Detail location

In the region between Ljubljana and Novo Mesto, the unstable character of the slope endangers the safety of the railway line. The instability of the slope was already evident in the geological-geomechanical mapping of the site. The existing telephone poles along the railway layout are unstable (Figure 3), whilst the road above the slope is severely cracked (Figure 4) and individual stone blocks are frequently unstable and inclined towards the railway line.

Subsequently, after carrying out a detailed geomechanical investigation of the railway zone, the final pilot test location was selected, consisting on the execution of the 50 m gabion retaining wall pilot structure, in the exact place shown in Figure 5.

3 THE UNSTABLE SLOPE

4 DEFORMATION OF THE ROAD ABOVE THE UNSTABLE SLOPE

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FIGURE 5 EXACT LOCATION FOR THE PILOT

2.2. Pilot design

The pilot design was carried out included all the stages gathered in Figure 6:

FIGURE 6 PILOT DESIGN STAGES

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- Geomechanical investigation of the landslide
- Laboratory testing of the back-fill material MUDIPEL
- Building the small field demo
- STS documentation generation
- Design of the retaining wall construction

2.2.1. Geomechanical investigation of the landslide

The main purpose of the on-site investigation was to obtain reliable data regarding the physical characteristics of the soil at the selected site of the unstable landslide near the railway line, for which the geological, geomechanical and hydrogeological conditions for designing the retaining wall structure were provided. The geomechanical investigation needs to follow the rules of Eurocode 7 and EU standards for geotechnical drilling and boring, in-situ testing and laboratory testing.

2.2.1.1. Methods of testing

Geological mapping and borehole drilling

The geological mapping was done for the whole landslide zone and, in addition, a geological survey of the selected area will be carried out by Laser scanner and LIDAR aerial multitemporal images (from 2014 onwards), in order to provide a detailed geotechnical inspection over time.

The investigation program consisted on the drilling of 9 boreholes (Table 6), 5 - 15 m deep, with in-situ SPT tests (27 tests), pressuremeter tests (4 tests) and samples taken from the boreholes for laboratory tests, according to the programmed specifications.

TABLE 6 DATA ABOUT THE BOREHOLES AND THE TESTS INSIDE THE BOREHOLES

Borehole	Type	Coordinate			Depth (m)	In-situ test		Monitoring Inclinometer/ Piezometer
		X (m)	Y (m)	Z (m)		SPT	Pressuremeter	
P1	G	507812,4	78807,79	267,46	14,7	6		I/P
P2	G	507815,86	78827,52	268,13	14,7	7		P
P3	G	507832,15	78862,87	270,75	14,0	5		
P4	G	507838,79	78874,23	271,54	8,0	4		I
P5	G	507826,16	78886,49	260,07	3,2	1		P
P6	S	507859,39	78893	273,94	14,3		x	I/P
P7	G	507832,15	78862,87	270,75	12,0	5		
P8	G	507874,88	78930,78	268,8	8,0			I/P
P9	G	507889,82	78954,46	264,6	7,8	3		I/P
WMP-1	G	507445,11	79320,61	767,25	12,0			I/P

G - geomechanical borehole, S - structural borehole, I - inclinometer, P - piezometer

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FIGURE 7 GEOMECHANICAL DRILLING OF THE BOREHOLE P5

Pocket penetrometer tests

Pocket penetrometer tests are used to perform quick assessments of the unconfined compressive strength of cohesive soils in situ or in laboratory. These tests were performed on sample cores from all the boreholes in accordance with EC 7 standard, SIST EN 1997-2: 2007; Ground investigation and testing were carried out according to the manufacturer's instructions.

Standard penetration tests - SPT

The standard penetration test is used to estimate the strength and deformation characteristics of a particular soil. These tests were part of the on-site investigations according to the requirements of the SIST EN ISO 22476-3:2005 standard.

Pressuremeter tests

For the determination of the deformation characteristics of the rock, 4 pressuremeter tests were carried out, using an Oyo pressuremeter. These tests were performed according to the stablished requirements of the SIST EN 1997-2:2007 standard (Eurocode 7: Geotehnical design - part 2: Ground investigation and testing) and oSIST prEN ISO 22476-4:2008 (Geotechnical investigation and testing – Field investigation – Part 4: Menard pressuremeter test).

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Geomechanical laboratory tests

During the geotechnical drilling, 26 samples were taken according to the geotechnical drilling plan. The samples were delivered to ZAG's Geomechanical laboratory, assigned a laboratory identification number G 19/17, and then recorded in the book of samples. According to the testing program, and based on the inspection of the received samples, the following geomechanical laboratory tests were performed:

TABLE 7 GEOMECHANICAL LABORATORY TESTS

Test	Standard
Description and classification of the samples	USCS SIST EN ISO 14688-2:2004
Water content	SIST-TS CEN ISO/TS 17892-1
Atterberg limits	SIST-TS CEN ISO/TS 17892-12
Density determination	SIST-TS CEN ISO/TS 17892-2
Particle density determination	SIST-TS CEN ISO/TS 17892-3
Uniaxial compressive strength	SIST-TS CEN ISO/TS 17892-7:2004
Undrained shear strength with conus apparatus determination	SIST-TS CEN ISO/TS 17892-6:2004
Compressive strength	SIST-TS CEN ISO/TS 17892-7
Direct shear test	SIST-TS CEN ISO/TS 17892-10:2004
Particle size distribution	SIST-TS CEN ISO/TS 17892-10:2004 SIST EN 933-1:2012

2.2.1.2. Results of the geomechanical investigation

Geological mapping and borehole drilling

Based on the geological mapping and boreholes drilling, the geological maps with profiles were developed.

The LIDAR scan is shown in **¡Error! No se encuentra el origen de la referencia.**, the geological map in **¡Error! No se encuentra el origen de la referencia.** and characteristic profile near the borehole P6 in Figure 10.

As it can be observed in Figure 11, a layer of clay up to 11 meter thick lies above the shear plane in the assessed area.

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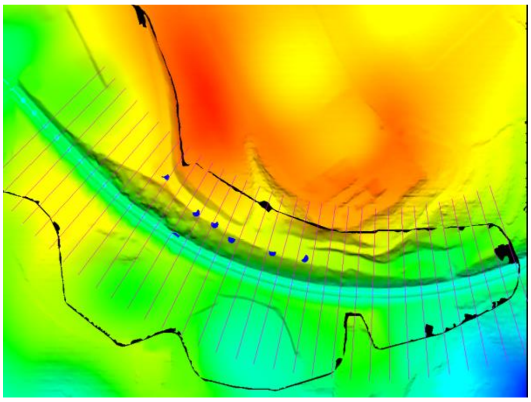

FIGURE 8 SCANNED REGION OF THE GEOTECHNICAL INVESTIGATION

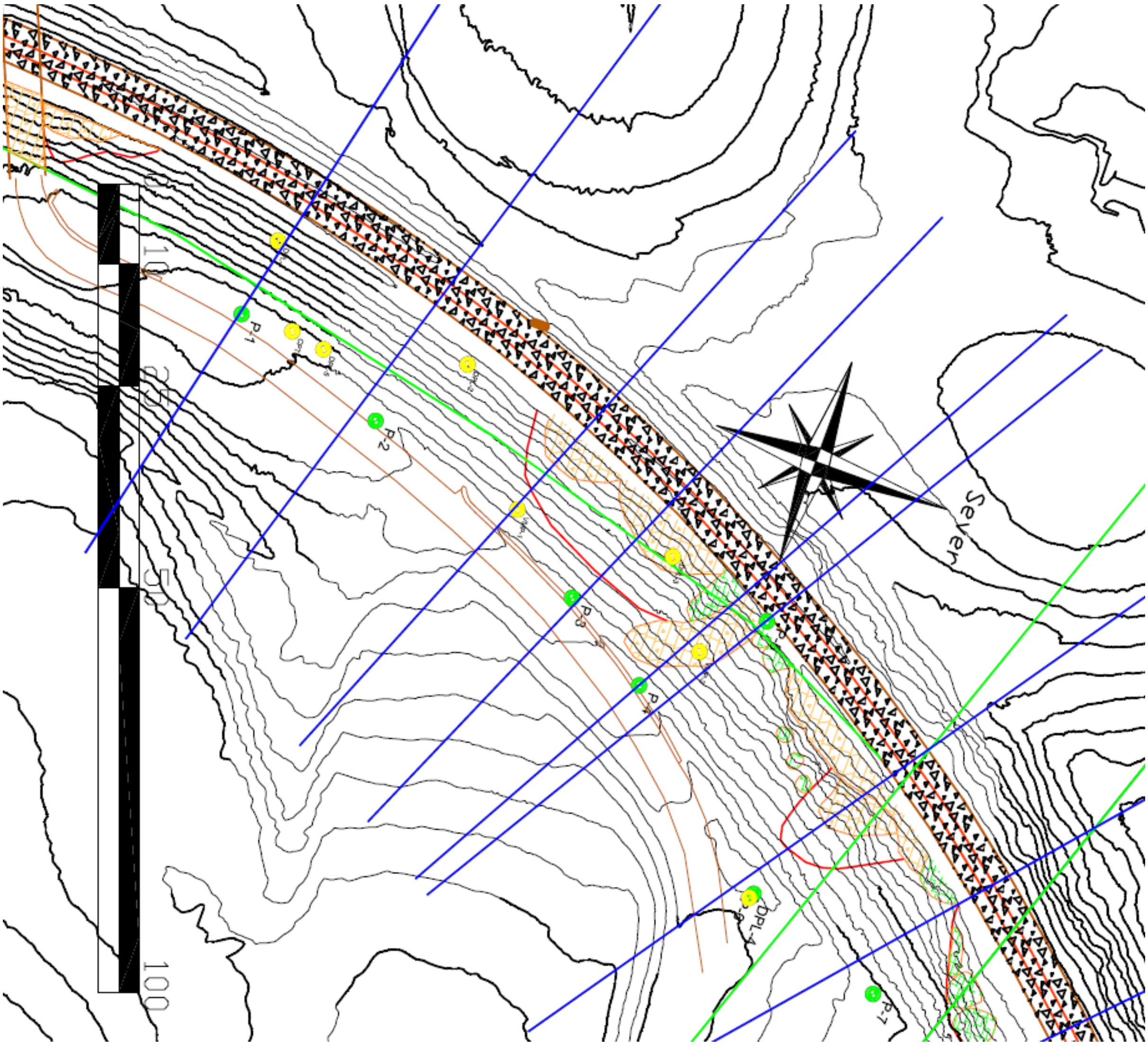

FIGURE 9 GEOLOGICAL MAP

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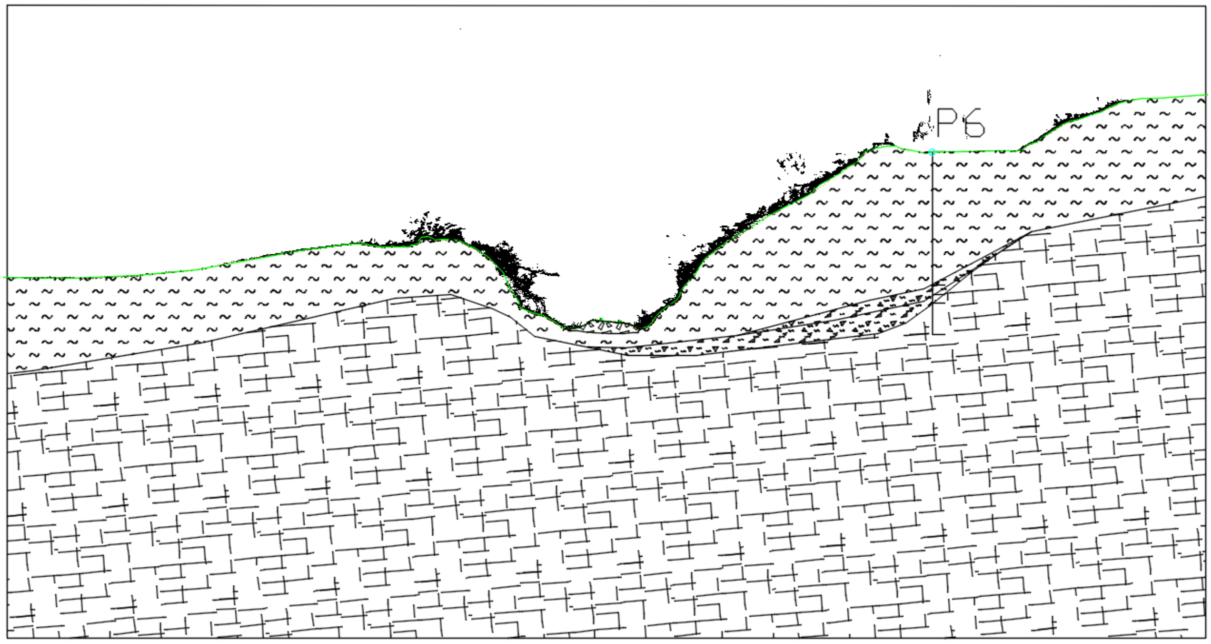

Figure 10 Characteristic geological profile near the borehole P6

Figure 11 The contact between the clay layer and limestone

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Pocket penetrometer tests

Pocket penetrometer tests were performed in boreholes P3, P6, P8 and P9. The measured values in boreholes P3 and P8 are between 35 and 70 kPa. In boreholes P6 and P9 lower values of 35 - 55 kPa were measured.

Pressuremeter tests

Pressuremeter measurements were performed in boreholes P3 and P6, in order to determine the rock strength. In the P3 borehole the measurements were made in limestone. These measurements showed high elastic modules, despite being carried out at a depth of 13 and 14 m in clayey limestone gravel. The modulus depends on the clay content in the limestone gravel and is in the range from 232 MPa to 898 MPa. Measurements made in the clay above the limestone showed much lower elastic modules; 12 MPa.

TABLE 8 RESULTS FROM THE PRESSUREMETER TESTS

Borehole	Depth (m)	Lithology	E_M (MPa)	E_{M1} (MPa)	P_{LM} (MPa)
P3	12,6	Limestone	12,1		
P3	13,2	Limestone	898	507,8	> 5,2
P3	14	Limestone	232		> 4,33
P6	2,5	Clay	6,6	32,6	0,7

E_M – load modulus, E_{M1} – load-reload modulus P_{LM} - plastic limit

Standard penetration tests - SPT

SPT tests were performed in all layers at different depths in the boreholes. The k_{60} measured for the hammer used is 1,281. The results of the measurements are gathered in Table 9 Results from the SPT tests". The results of the measurements were corrected according to the standard for field testing - standard penetration test SIST EN ISO 22476-3: 2005.

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Table 9 Results from the SPT tests

Bor-ehole	Depth	N_{60}	P_{60}	ρ	Modulus of compressibility Mv (MPa)	Description of layer	Density, consistency
	m	ud/30 cm	cm/60pu	°			
P1	2	19,2		30,3-36,2	7,5-15	humus	medium dense
	4	10,8		30,3-36,2	<7,5	red clay	medium dense
	6	10,7		30,3-36,2	>30	red clay	medium dense
	8	5,2		28,4-30,3	<7,5	red clay	loose
	10	8,4		28,4-30,3	<7,5	red clay	loose
	14	-	2,2	>40,9	>30	limestone	low penetrability
P2	2	11,9		30,3-36,2	<7,5	red brown clay	medium dense
	4	7,2		28,4-30,3	<7,5	red clay	loose
	6	3,5		28,4-30,3	<7,5	red clay	loose
	8	5,0		28,4-30,3	<7,5	red clay	loose
	10	3,4		<28,4		red brown clay	very loose
	12	-	2,0	>40,9	>30	limestone	low penetrability
	14	-	2,5	>40,9	>30	limestone	low penetrability
P3	2	6,8		28,4-30,3	<7,5	dark red clay with gravel	loose
	4	8,6		28,4-30,3	<7,5	dark red clay with gravel	loose
	6	10,9		30,3-36,2	<7,5	dark red clay with gravel	medium dense
	8	4,5		28,4-30,3	<7,5	light orange clay	loose
	10	4,9		28,4-30,3	<7,5	light orange clay	loose
P4	2	6,4		28,4-30,3	<7,5	red clay	loose
	4	7,9		28,4-30,3	<7,5	red clay	loose
	6	-	9,8	>40,9	>30	clayey gravel	high penetrability
	8	-	2,8	>40,9	>30	limestone	low penetrability
P5	2	3,0		28,4-30,3	<7,5	red clay	loose
P7	2	10,1		30,3-36,2	<7,5	dark red clay with gravel	medium dense
	4	5,6		28,4-30,3	<7,5	dark red clay	loose
	6	3,5		<28,4		dark red clay, greasy	very loose
	8	5,0		28,4-30,3	<7,5	dark red clay, greasy	loose
	10	-	2,9	>40,9	>30	limestone	low penetrability
P8	2	7,6		28,4-30,3	<7,5	red clay	loose
	4	7,2		28,4-30,3	<7,5	red brown clay	loose
	5,9	-	2,6	>40,9	>30	limestone	medium penetrability
P9	2	9,8		28,4-30,3	<7,5	pieces of limestone	loose
	4	-	5,9	>40,9	>30	fissured limestone with clay	
	6	17,0		30,3-36,2	<7,5	fissured limestone with clay	medium dense

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Piezometric measurements

Groundwater level measurements were taken in inclinometer wells; boreholes P1, P2, VMP1, P4, P5, P6, P7, P8, P9.

The VMP1, P5, P7, P8 and P9 holes are dry. The water level measured in the remaining wells is shown in Figure 12. The clay layers are quite impermeable, so the water is retained locally where the limestone is less cracked, and therefore water can´t flow through the cracks system. For the stability analysis, it was taken into account that in the event of heavy rainfall, the water level may rise almost to the surface.

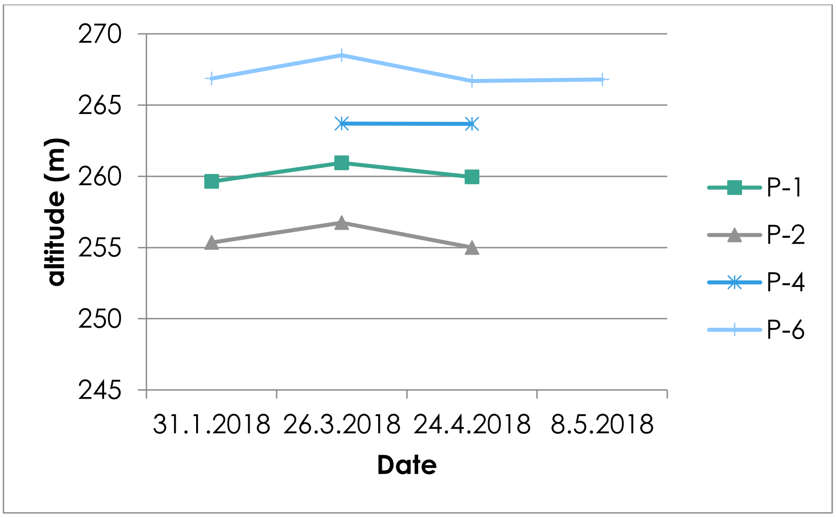

FIGURE 12 WATER LEVEL IN THE BOREHOLES

Inclinometer measurements

Water level measurements are made in inclinometer wells; boreholes P1, P2, WMP1, P4, P5, P6, P7, P8, P9.

The holes drilled near the road show no movement. In the VMP1 well, which was drilled in 2013, the first measurements showed that no major shifts occurred in the period until 2017. The larger displacement (2,5 cm) was measured between June 2017 and January 2018, and further measurements again show a comeback to stable values (Figure 13).

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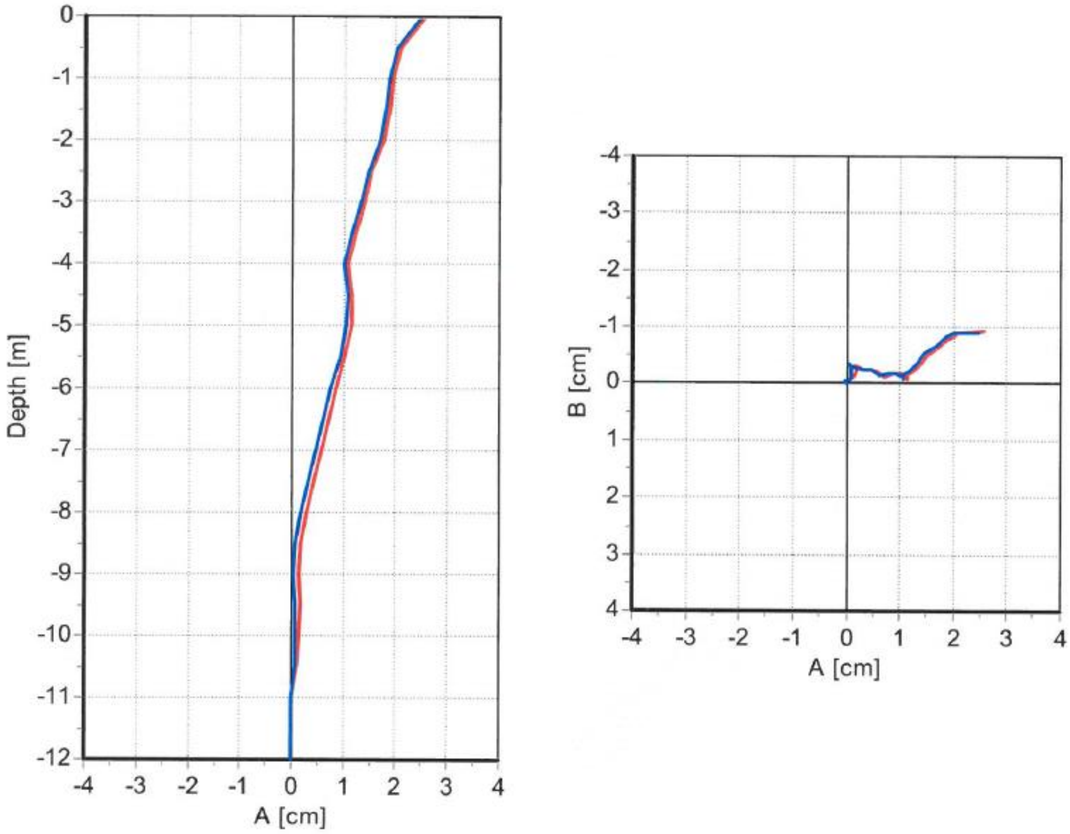

Curve	Measuring level	Measuring series	Date	Diff.days	Depth	Remark
(red)	WMP-01	01 - 00	31.1.2018 - 28.6.2017	217	12,0 m	12:58
(blue)	WMP-01	02 - 00	26.3.2018 - 28.6.2017	271	12,0 m	10:23

FIGURE 13 RESULTS ON INCLINOMETER MEASUREMENTS

Geomechanical laboratory tests

Laboratory tests have shown that the upper layers are mostly made of high plasticity clays, and sometimes with low plasticity clays. Individual ground layers are also present, but these occur only locally. The results of average geomechanical characteristics are given in the table below. For the shear characteristics the lowest results are presented.

TABLE 10 GEOMECHANICAL PROPERTIES OF THE LANDSLIDE REGION

Water content	Density wet	Density dry	Uniaxial strength	Modulus at 200 KPa	Permeability at 200 KPa	Shear angle (the lowest)	Cohesion (the lowest)
%	Mg/m^2	Mg/m^2	(kPa)	(MPa)	m/s	°	kPa
40	12,6	Limestone	277	11,561	5,7E-10	10	7

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Geomechanical characteristics of the clay and the silt layers range widely. The geomechanical characteristics are lower at the contact with the limestone (circled results), where precipitation is likely to flow. The shear characteristics (shear angle and cohesion) are presented given in Figure 14.

Clay layers present a low permeability coefficient (average 8,5 * 10^{-11}), therefore indicating that the precipitation water mostly flows on the surface.

The compressibility moduli are quite low (average of 2200 kPa at a load of 100 kPa), which confirms that the clays are of medium-stiff consistency.

Uniaxial compressive strengths average around 270 kPa, which is expected for medium to stiff clays.

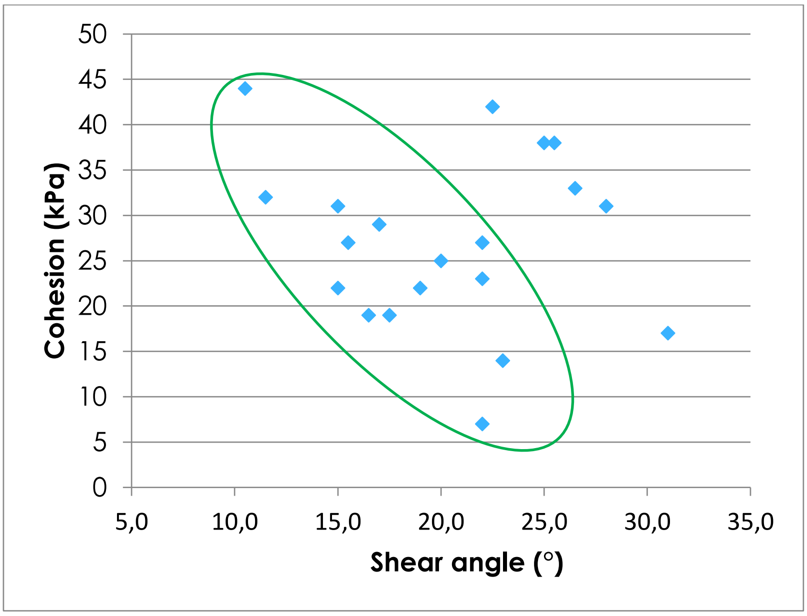

FIGURE 14 SHEAR CHARACTERISTICS OF CLAY LAYER

2.2.1.1. Engineering geological model

Engineering-geological conditions are given on the basis of a review of the existing documentation and the results of the field survey and borehole logging. The characteristic engineering-geological (IG) parameters are gathered in the table below. The units are presented in the order from the top to the lower layers.

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TABLE 11 ENGINEERING – GEOLOGICAL MODEL

Layer	Geological sign	Depth [m]	Description of the layer	USCS classification	Excavation category
IG 0		0,0 - 3,0	Artificial back-fill, upper layer of the railway, unbound layer		3
IG 1	PL, Q	0 - 13,58	Reddish brown clay to silty clay with high consistency (CH), with intermediate layers of clay of low plasticity and silt	CH, (CL)	4
IG 2	$J^{1}_{2,3}$	> 4,3 (13,58)	Fissured limestone, white to grey		4-5

All geomechanical assessment results for the landslide near the railway line were published in the Report No. 297/17-710-2, 18.7.2018, ZAG.

2.2.1. Laboratory testing of MUDIPEL

Deinking paper fly ash and bottom ash (DPA) and deinking paper sludge (DPS) are residues from deinking paper industry (DPI) VIPAP Videm, Krško. The composite from DPA and DPS was used in Demo case 3 as a back-fill material for the retaining structure made from gabions.

Deinking paper ash (DPA) is a burning residue generated in the boiler No. 5, where deinking paper sludge is burned. DPA consists of slags (approx. 90 % by weight) and fly ash (approx. 10 % by weight). The fly ash is a dust, with a particle size up to 1 mm, while the slag consist in grain agglomerates of ash of sizes up to 1 cm. Both chemical and mineralogical compositions are similar. Most of the components are in an amorphous phase. The main crystalline components consist on calcite, lime, portlandite and other minerals in minor quantities. A market name has already been assigned to the resultant product – MUDIPEL.

Deinking paper sludge (DPS) is generated by the processing of waste paper by the deinking process at the DIP (deinking paper industry) plant and the industrial waste water treatment plant from the production of paper and municipal waste water from VIPAP.

Based on several geomechanical and chemical analyses, the composition for MUDIPEL was set as 70 % of DPA and 30 % of DPS by dry mass (Figure 15).

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Further characteristics and details of MUDIPEL were presented in Deliverable D4.1, Report on solution feasibility and constraints, and in report **ZAG No. 296/17-710-4 Report about geomechanical laboratory investigation of the composite MUDIPEL**.

FIGURE 15 COMPONENT OF THE NEW COMPOSITE MUDIPEL

2.2.1. Small Demo fields at VIPAP's facility

In laboratory scale, the mixing of the different components of MUDIPEL didn´t represent any specific difficulties. At construction sites it often happens that mixing large quantities of materials in situ can cause unpredictable problems. With the aim to predict and avoid these problems, 10 small demo fields were built at VIPAP's facility (Figure 16), where the composite mixing and its installation was tested. The smaller test fields were made from various mixtures in order to determine the optimal composition of MUDIPEL and method of its installation. Field measurements of water content, density and load capacity at different periodic times were carried out there as well. Samples for laboratory tests of moisture, density and for chemical analyses were taken from the demo fields.

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FIGURE 16 SMALL DEMO FIELDS

The final decision for the composite to be used as a back-fill material was made based on the statistical results obtained from field and laboratory measurements, the experience using the composites for building small test fields and the chemical results of the leaching tests performed to check their environmental suitability. The composite of 30 % of DPS and 70 % of DPA happened to be the most appropriate mixture for the retaining wall structure.

The details about the testing methods and results for the Small demo fields are presented in deliverable D 4.1 Demonstration projects setup conditions, Paperchain and in **ZAG report No. 296/17-710-3 Report about results of the Small demo fields at VIPAP's facility, ZAG**.

2.2.1. Slovenian Technical Approval (STS)

Based on the results coming from the laboratory tests and small demo fields performed, Slovenian Technical approval was granted the 24. 8. 2018 with the number STS-09/0065, before the construction works for Demo Case 3 started. The notification was published on the internet site of the Technical approval department as shown in Figure 17, whereas the main characteristics are shown in Table 12.

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FIGURE 17 PUBLISHED STS FOR THE COMPOSITE MUDIPEL

TABLE 12 THE CHARACTERISTICS OF MUDIPEL

No.	Parameter	Method of proof (test, calculation)	Expression of a value level*	Required value level	Notes
1	2	3	4	5	6
Basic requirement 1: Mechanical resistance and stability					
1/1	Density	SIST EN ISO 17892-1:2015	Declarative value	Material has to be compacted at the optimal water content with tolerance margins of ± 2 %.	
1/2	Particle density	SIST EN 1097-7:2008	Limit value	2,27 Mg/m^3 ± 0,20 Mg/m^3	

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No.	Parameter	Method of proof (test, calculation)	Expression of a value level*	Required value level	Notes
1	2	3	4	5	6
1/3	Maximum dry density according to the Standard Proctor test	SIST EN 13286-2:2010/AC:2013	Limit value	0,95 Mg /m³ ± - 0,05 Mg/m³ %.	
1/4	Optimal water content according to the Standard Proctor test	SIST EN 13286-2:2010/AC:2013	Limit value	W_{opt}=49 % + 3 %.	
1/5	Uniaxial strength	SIST EN 13286-41:2004	Limit value	After 1 day: $q_u \geq 200$ kPa After 7 days: $q_u \geq 1000$ kPa	
1/6	Shear strength	SIST-TS CEN ISO/TS 17892-10:2004/AC:2010	Limit value	After 1 day: $\varphi' \geq 40°$ $c' \geq 30$ kPa; $\varphi'_{c=0} \geq 45°$	
1/7	Permeability coefficient	SIST-TS CEN ISO/TS 17892-11:2004/AC:2010	Limit value	After 7 days: At the load 100 kPa: $k \leq 10^{-8}$ m/s	
1/8	Compressive strength	SIST-TS CEN ISO/TS 17892-5:2004/AC:2010	Limit value	After 1 day at the load 100 kPa $E_{oed} \geq$ 5000 kPa After 7 days at the load 100 kPa $E_{oed} \geq$ 10000 kPa	
Basic requirement 2: Fire safety - not relevant					
Basic requirement 3: Hygiene, health and the environment					

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No.	Parameter	Method of proof (test, calculation)	Expression of a value level*	Required value level	Notes
1	2	3	4	5	6
3/1	The content of hazardous substances in the effluent Arsenic Bari Cadmium Whole chrome Baker Mercury Molybdenum Nickel Lead Antimony Selenium Zinc Chlorides Fluoride Sulphates	Acceptability of alternative materials in road or terrain construction, environmental impact assessment, Appendix 3 - Limit values according to Level 1 of Environmental Characterization, Table 1, column 1, Sétra, France, February 2012.	Limit values [mg/kg s. s.]	0,5 20 0,04 0,5 2 0,01 0,5 0,4 0,5 0,06 0,1 4 800 10 1000	
Basic requirement 4: Safety and accessibility in use					
Basic requirement 5: Noise protection - not relevant					
Basic requirement 6: Energy saving - not relevant					
Basic requirement 7: Sustainable use of natural resources - not specified					

2.2.1. Project design

An unstable zone near the regional Railway of Novo Mesto – Ljubljana section was chosen for building the Demo Object for the protection of an unstable slope. The request by Slovenian Railways - Infrastructure - Public Railway Infrastructure Manager (SZ) stated that the construction work needed to be carried out without interruptions of the traffic on the railway network. Due to this requests, it was necessary to choose an appropriate geotechnical solution, which could meet the requirements safely and permanently. The use of gabions for the retaining wall structure was another requirement set by the railway operator SZ.

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2.2.1.1. Laws, technical regulations, technical specifications, regulations for project design,

The relevant project directives about interoperability (TSI) and other European and national resultatives on shaping the development of public railways infrastructures were taken into account for this Circular Case 3 Demo:

- Building Act (GZ), adopted by the National Assembly of the Republic of Slovenia at its session on 24.10.2017, no. 003-02-9 / 2017-25 and entered into force 01.06.2018

- Railway Act / ZZelP-UPB6 / (Official Gazette of the RS, No. 11/11, 63/13, 99/15)

- Railway Safety Act ZVZelP-UPB3 / (Ur. L. RS, Nos. 56/13, 91/13, 82/15, 84/15 - ZzelP-J, 85/16, 41/17 and 30/18 - ZVZelP-1). Repealed with 6/16/2018 and partial extension of use (see Articles 109 and 113 of ZVZelP-1)

- Railway Safety Act / ZVZelP-1 / (Ur. L. RS, No. 30/18; 11, 56, 57, 58, 59, 60, Articles 61, 62, 68 apply from June 16, 2019)

- Slovenian Railway Infrastructure Development Program (NPRSZI)

- UPB-1 Environmental Protection Act (Official Gazette RS, No. 39/06, 49/06, 66/06, 33/07, 57/08, 70/08, 108/09, 48/12, 57/12, 92/13)

- Construction Products Act (Ur. L. RS, No. 82/13),

- Technical Requirements for Products and Conformity Assessment Act (ZTZPUS-1, Official Gazette of the RS, No. 17/11),

- Rules on project documentation (Official Gazette of the RS, No. 55/2008) and ISS Guidelines on Detailed Content project documentation

- Rules on the Design of Technical Guidelines for the Design, Construction and Maintenance of Facilities (Official Gazette of the RS no. 54/03),

- Rules on the protection of workers from the risks related to exposure to chemical substances at work (Official Gazette of the RS, No. 100/2001, Official Gazette of the RS, No. 39/2005, 53/2007, 102/2010, 43/2011 - ZVZD-1)

- Rules on Requirements for Ensuring the Safety and Health of Workers at Work (Official Gazette of the Republic of Slovenia, no. 89/1999, 39/2005, 43/11 ZVZD-1)

- National Program on the Development of the Slovenian Railway Infrastructure - NPRSZI

- The European Agreement on Major International Railways (AGC),

- Rules on the Upper Structure of Railways (Ur. L. RS 92/2010). Repealed with 6/16/2018 and prolongation of application until the enforcement of the regulation referred to in Article 113 of the ZVZelP-1 (see Article 109 of the ZVZelP-1).

- Traffic Regulations (Official Gazette RS 50/2011). Repealed with 6/16/2018 and extended to enforcement of the regulation referred to in Article 113 of the ZVZelP-1 (see Article 109 of the ZVZelP-1).

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- Rules on the Lower Structure of Railways (Official Gazette RS 93/2013). Repealed with 6/16/2018 and prolongation of application until entry into force of the regulation referred to in Article 113 of ZVZelP-1 (see Article 109 of ZVZelP-1).

- EU Commission Regulation, No. 1299/2014 of 18.11.2014 on technical specifications for interoperability with regard to the rail infrastructure subsystem in the European Union

- EU Commission Regulation, No. 1300/2014 of 18.11.2014 on the technical specifications for interoperability with regard to the accessibility of the Union rail system for disabled and disabled persons

2.2.1.2. Stability analyses

A numerical analysis of the stability of the retaining wall was performed using a finite element analysis under plain strain conditions, using DIANA software. The finite element mesh with the geological situation is presented in Figure 18. It was finally found out that the calculated displacements after the construction of the retaining wall are less than 0,6 mm (Figure 19), and therefore the slope is stable considering the supporting measures implemented (gabions and MUDIPEL backfill material).

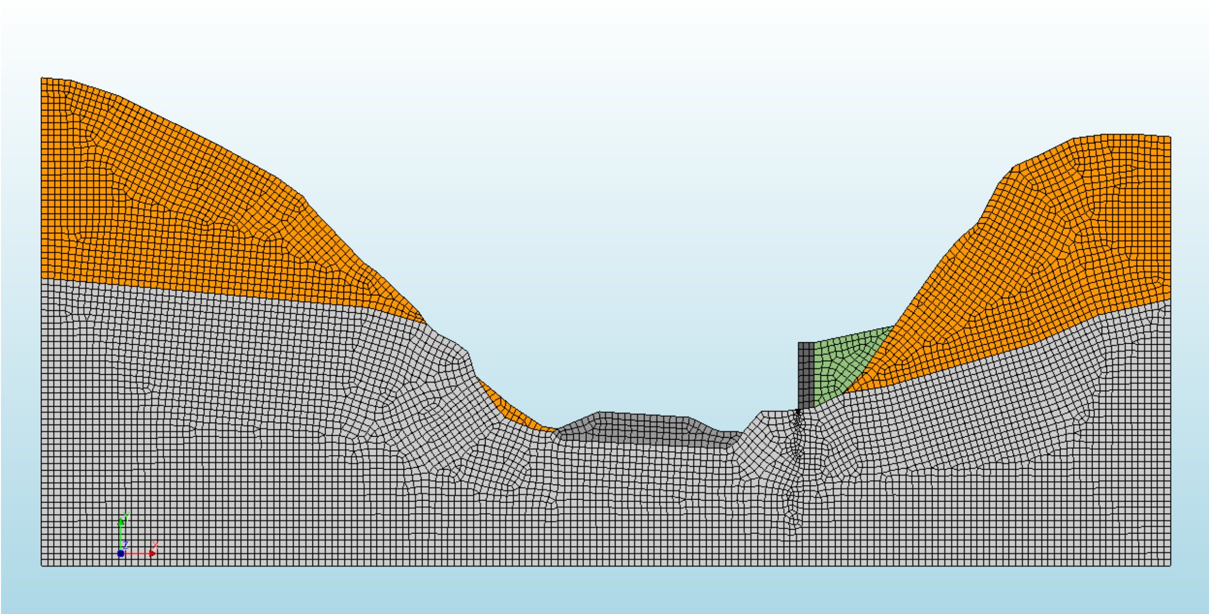

FIGURE 18 FINITE ELEMENT MESH FOR STABILITY ANALYSIS

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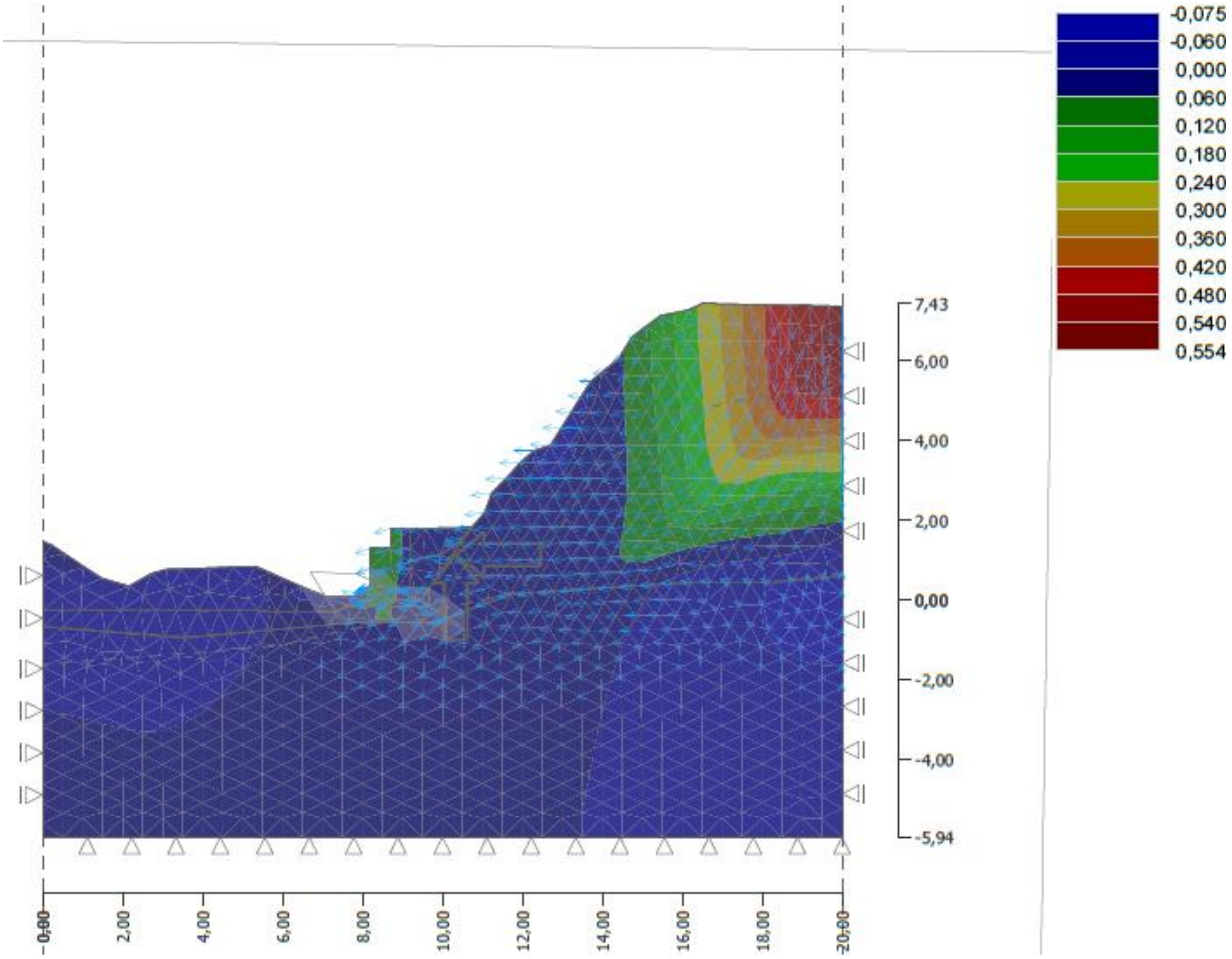

FIGURE 19 FINAL DISPLACEMENTS AFTER THE RETAINING WALL IS BUILT

The global stability was also verified by GEO5 - Gabion, following the theory of boundary states, using Bishop's circular-slip method. The slope was found to be globally stable (safety factor Fs = 3,33). The stability of the retaining wall structure under the stress conditions in the landslide region was calculated for the critical profile. The results showed that the structure is stable under the predicted vertical and horizontal loads (Figure 21).

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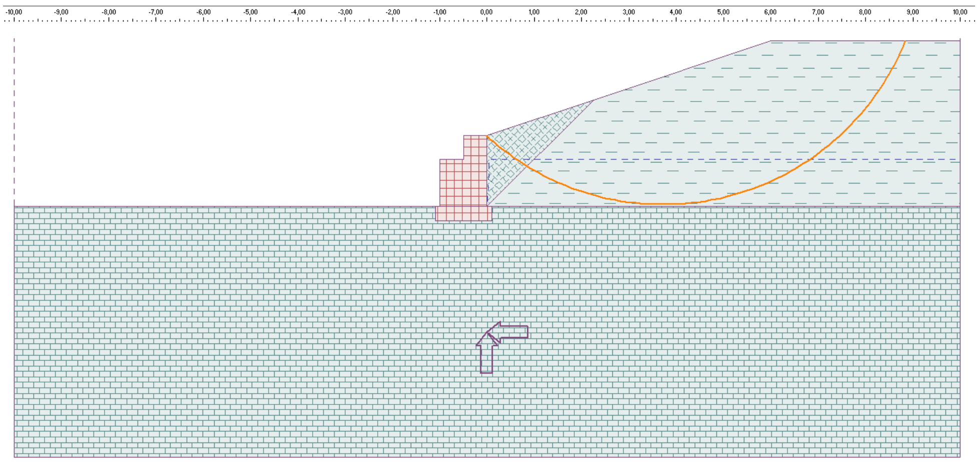

FIGURE 20 STABILITY ANALYSIS ACCORDING TO BISHOP'S CIRCULAR-SLIP METHOD

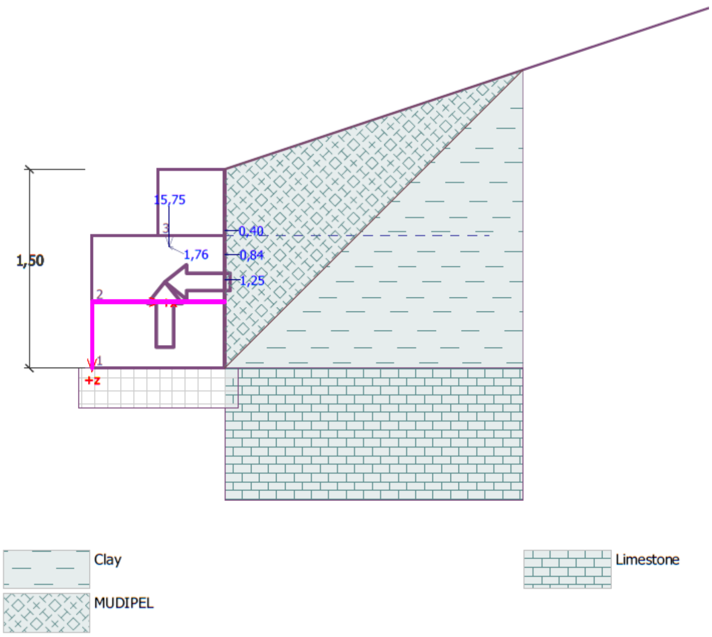

FIGURE 21 CALCULATION OF THE RETAINING WALL STABILITY

2.2.1.3. Design maps and profiles

According to the results of the stability analyses, the design details were set. The design maps (Figure 22), longitudinal profile (Figure 23) and transversal profiles (Figure 24) were drawn for the whole retaining wall structure. Further technical details were gathered in the **report No. 059-018-8 Design of the excavation and retaining wall structure, Arping.**

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TABLE 13 DESCRIPTION OF RETAINING WALL DESIGN

Material	Length (m)	Width (m)	High (m)	Description
Gabions	50	0,5 - 1,0	1,5	2 lower gabions: 1,0 m x 1,0 m x 0,5 m Upper gabion: 1,0 m x 0,5 m x 0,5 m
Back-fill material MUDIPEL	50	0,5 - 3,5	1,5	95 tons

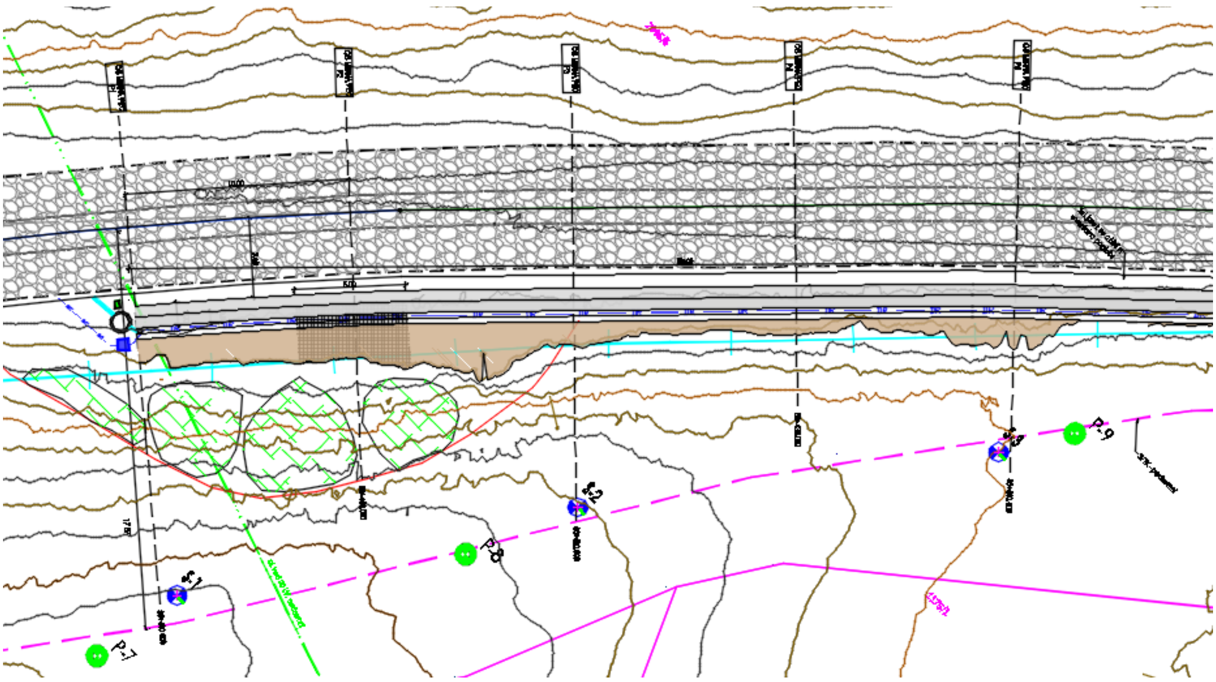

FIGURE 22 MAP OF THE RETAINING WALL

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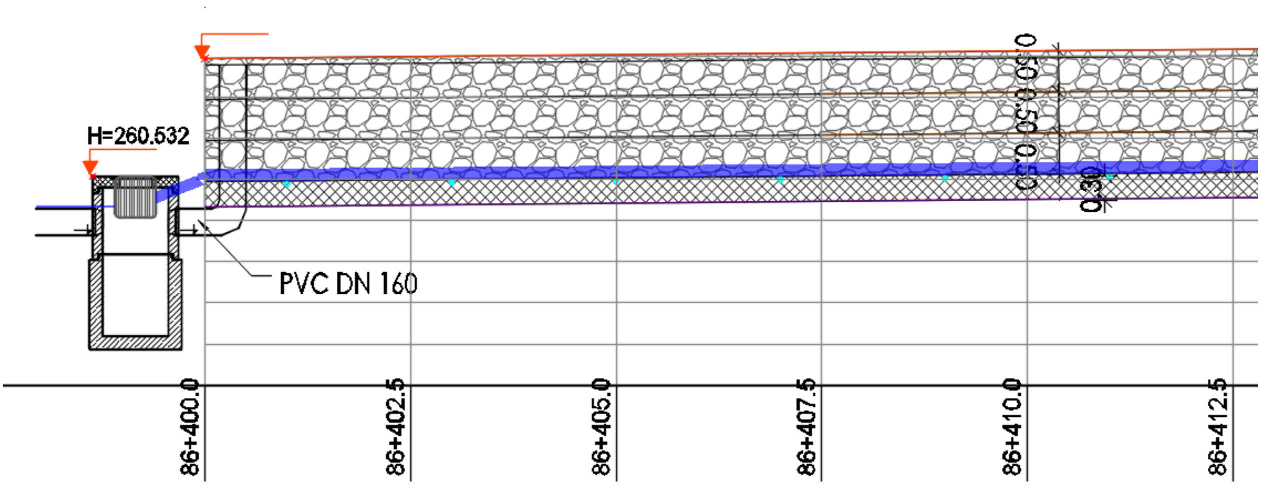

FIGURE 23 DETAIL OF THE LONGITUDINAL PROFILE OF THE RETAINING WALL STRUCTURE

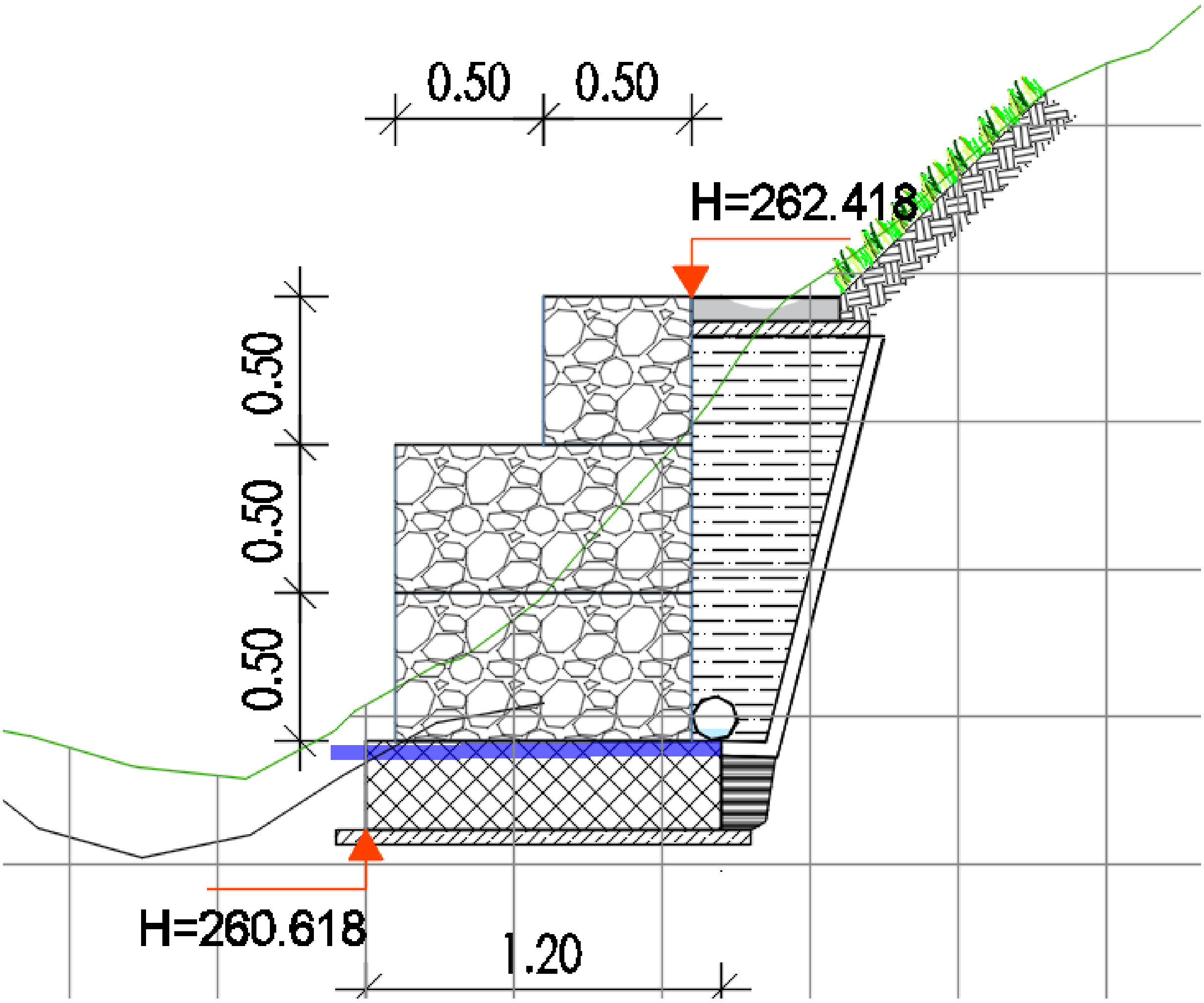

FIGURE 24 TRANSVERSAL PROFILE OF THE RETAINING WALL STRUCTURE NEAR THE BOREHOLE P6

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In the design phase, the monitoring of both the construction works and the structure performance after its construction is foreseen. For that purpose, both geotechnical and environmental parameters are being controlled according to Slovenian regulations.

2.3. Pilot execution

Pilot construction works started in August 2018. The works were divided into the following steps:

- Earth works
- Foundation of the retaining wall
- Building of the first layer of the gabions
- Installing MUDIPEL as the back-fill material
- Building of the second layer of the gabions
- Installing MUDIPEL as the back-fill material
- Installing the surface drainage system and other surface work (planning with humus and grass, e.g.)

A simplified procedure scheme is presented in Figure 25. The results of the in-situ and laboratory control tests are presented in report **No. P296/17-710-5 Results of laboratory and in-situ tests for the landslide Rogovila, ZAG.**

FIGURE 25 SIMPLIFIED PROCEDURE SCHEME FOR THE PILOT EXECUTION

All the work was carried out without disturbing or influencing the trains traffic, so a guard service was provided throughout all the time the construction works lasted.

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2.3.1.1. Earth works

Unstable limestone blocks and soil were removed from the zone with an excavator (Figure 26). Some large limestone blocks were crushed with the excavator tip (Figure 27). At the construction site it was discovered that the excavation needed to be larger, due to the presence of many unstable blocks, which had to be removed. This way, safe working conditions for the machines and workers were enabled.

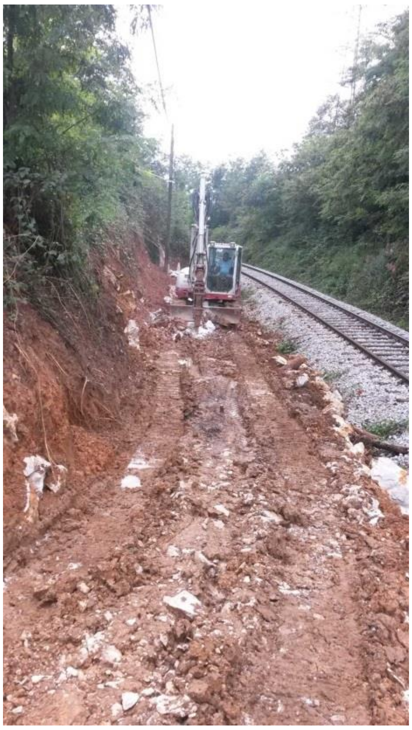

FIGURE 26 EARTH WORKS AT THE CONSTRUCTION SITE

FIGURE 27 CRUSHING BLOCKS OF LIMESTONE AT THE CONSTRUCTION SITE

2.3.1.1. Foundation work for the retaining wall

The unbound layer was compacted with a roller (Figure 28) over the prepared ground gravel material. The bearing capacity of the layer was measured with a plate bearing test apparatus (Figure 29).

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FIGURE 28 COMPACTION OF THE UNBOUND LAYER

FIGURE 29 MEASURING OF THE BEARING CAPACITY OF THE UNBOUND LAYER

Over the compacted layer a 30 cm thick, 50 m long and 1 m wide concrete slab was built (Figure 30). Pouring the concrete foundation was very difficult due to the inaccessibility of the construction site. A special pump lift had to be used (Figure 31).

FIGURE 30 THE CONCRETE FOUNDATION PLATE

FIGURE 31 POURING THE CONCRETE FOUNDATION PLATE

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2.3.1.2. Building the first layer of the gabions

The first layer of gabions was installed on the top of the concrete foundation plate (**¡Error! No se encuentra el origen de la referencia.**, **¡Error! No se encuentra el origen de la referencia.**). Drainage pipes were installed under the gabions to prevent the appearance of high water pressure behind the retaining wall. The draining concrete was installed behind the gabions (**¡Error! No se encuentra el origen de la referencia.**) and a geosynthetic and draining gravel material was installed on the top of it (**¡Error! No se encuentra el origen de la referencia.**).

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FIGURE 32 THE FIRST LAYER OF GABIONS

FIGURE 33 INSTALLING THE FIRST LAYER OF GABIONS

FIGURE 34 DRAINING CONCRETE BEHIND THE GABIONS

FIGURE 35 DRAINING LAYER

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2.3.1.3. Installing MUDIPEL as the back-fill material

By mid-October the back-fill material (MUDIPEL) was installed behind the gabions. The material was prepared at its optimal water content at the VIPAP facility from DPA (Figure 36) and DPS (Figure 37). The material was mixed at the dry mass ratio 70 % DPA and 30 % of DPS (Figure 38) and transported to the construction site located 70 km from VIPAP's facility (Figure 39).

FIGURE 36 DEINKING PAPER SLUDGE

FIGURE 37 DEINKING PAPER ASH

FIGURE 38 MIXING MUDIPEL

FIGURE 39 TRANSPORTING MUDIPEL

MUDIPEL was levelled at the construction site (Figure 40) and subsequently compacted to the required density (Figure 41) conforming a 30 cm thick layer. This procedure was used to install the rest of the layers of MUDIPEL as well (Figure 43, Figure 44). On the western side of the retaining wall geogrid layers were placed to locally strengthen MUDIPEL (Figure 45).

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FIGURE 40 LEVELLING MUDIPEL

FIGURE 41 COMPACTING MUDIPEL

FIGURE 42 INSTALLING THE SECOND LAYER OF MUDIPEL

FIGURE 43 SECOND LAYER OF MUDIPEL

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Figure 44 Installing the layer of geogrid

Figure 45 Geogrid in detail

2.3.1.4. The second level of gabions with the back- fill material

After all the initial layers of back-fill material were installed, the second level of gabions was constructed (Figure 46). At the beginning of the structure, probes for water content and temperature were installed into the back-fill material (Figure 47). Then the rest of the layers of the back-fill material were installed behind the gabions (Figure 48, Figure 49, Figure 50).

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FIGURE 46 INSTALLING THE SECOND LEVEL OF GABIONS

FIGURE 47 INSTALLING THE MEASURING PROBES

FIGURE 48 INSTALLING THE LAST LAYER OF MUDIPEL

FIGURE 49 LAST LAYER OF MUDIPEL COMPACTED

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FIGURE 50 COMPACTING THE LAST LAYER OF MUDIPEL

On the top of the last layer of MUDIPEL, a layer of humus was set to cover the structure, whereas a surface drainage system was built as shown in **¡Error! No se encuentra el origen de la referencia.**.

FIGURE 51 THE SURFACE DRAINAGE SYSTEM OF THE FINAL RETAINING WALL STRUCTURE

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2.3.2. Quality control of the construction work

All materials used in the structure have either an specific certificate according to an already existing technical rule, or have undergone standardization processes with the aim to obtain the required STS. The quality of the material and its compaction was also controlled at the construction site.

2.3.2.1. QA of unbound layer

Samples of the material were taken from the construction site and tested in the Geomechanical laboratory at ZAG. The material met all the required criteria according to the design project and Earth works and foundation, according to PTP(Slovenian technical requirements for earth works).

The dynamic elastic modulus has to be equal or higher than 20 - 25 MPa, and measurements confirmed that the required quality of the unbound layer had been met (displaying an average value of 24,1 MPa).

FIGURE 52 DYNAMIC PLATE TEST ON THE UNBOUND LAYER

2.3.2.2. Back-fill material – mechanical characteristics

The back-fill material properties tested were the following:

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- Dry density, water content by nuclear probe (Figure 53).
- Bearing capacity – dynamic modulus of deformation E_{vd} by Light mass deflectometer (Figure 54).
- Intact samples were taken for determining dry density, water content, shear strength parameters and environmental performance, (Figure 55, Figure 56).

FIGURE 53 MEASUREMENTS WITH THE NUCLEAR PROBE

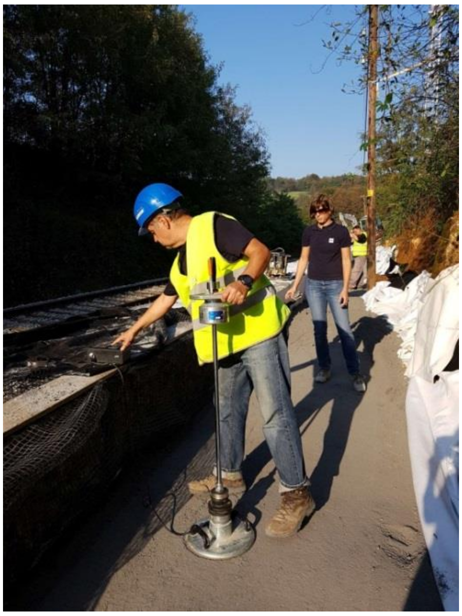

FIGURE 54 MEASUREMENTS WITH THE LIGHT MASS DEFLECTOMETER

FIGURE 55 TAKING SAMPLES FOR THE LABORATORY TESTING

FIGURE 56 PREPARING SAMPLES

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The results from the compaction tests showed that only the first three layers were compacted below 95 % $\rho_{d, max}$ (Figure 57). In the other layers, a higher compaction was detected. The reason for lower compactness in the first layers is the uncompacted drainage layer set under the MUDIPEL layers. The results of testing the back-fill material at the construction site and in the geomechanical laboratory are presented in Table 14. The most important are the shear strength properties, and the obtained results showed that the shear properties of the material taken from the construction site are higher than predicted in the design project. Shear characteristics values obtained of in-built MUDIPEL are gathered in Figure 57:

φ = 37°, c = 35 kPa (immediately)

φ = 45°, c = 200 kPa (after 28 days)

φ = 40°, c = 40 kPa (designed)

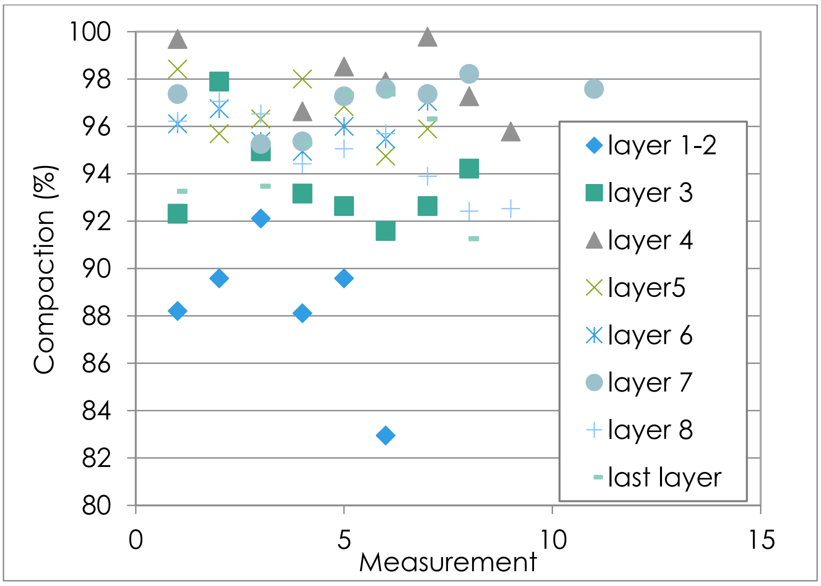

FIGURE 57 RESULTS OF THE MEASUREMENTS WITH THE NEUTRON PROBE

2.3.2.1. Back-fill material – chemical characteristics

The back-fill material was taken from the built structure after its adequate compaction. Chemical analyses showed that eluates didn´t exceed the threshold limits for the inert waste classification according to the UL RS, No. 10/14 date 22. 2. 2014 (Table 14):

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TABLE 14 RESULTS FROM THE LEACHING TESTS

Component	Limit (UL RS, No. 10/14 date 22. 2. 2014)	Sample G 38/18 after 2 days (2nd gabion)	Sample G 38/18 after 28 days (8th gabion)
	mg/l		
As	0,5	0,003	0,0033
Ba	20	16,04	8,82
Cd	0,04	< 0,002	< 0,002
Cr total	0,5	0,033	< 0,002
Cu	2	1,866	0,61
Hg	0,01	0,005	< 0,001
Mo	0,5	0,092	0,097
Ni	0,4	0,021	0,0064
Pb	0,5	0,005	< 0,005
Sb	0,06	< 0,001	< 0,001
Se	0,1	0,003	< 0,003
Zn	4	0,035	< 0,005
Chloride	800	29,1	13,5
Fluoride	10	4,01	3,6
Sulphates	1000	< 10	< 10

2.4. Efficiency parameters

The new material MUDIPEL has significantly higher shear characteristics compared to the natural gravel back-fill material. If the natural material had been used as a back-fill material for the retaining wall built in the Circular Case 3, higher structure would have been needed for the landslide stabilisation. This was mathematically proved by a numerical analysis, which showed that the 1,5 m high retaining wall with a natural backfill material isn´t high enough to stabilize the landslide, as shown in Figure 58 Unstable slope with a

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natural back-fill material". Another advantage displayed by MUDIPEL is that it´s a lightweight material. Compared to natural material (2,3 t/m3), it has a lower density (1 t/m3), being thus very suitable for soft grounds in which the load capacity is very poor. When a lightweight material is installed, the settlement of the soft ground should be significantly lower.

A more detailed comparison of costs and environmental impacts will be given in Report D6.1.

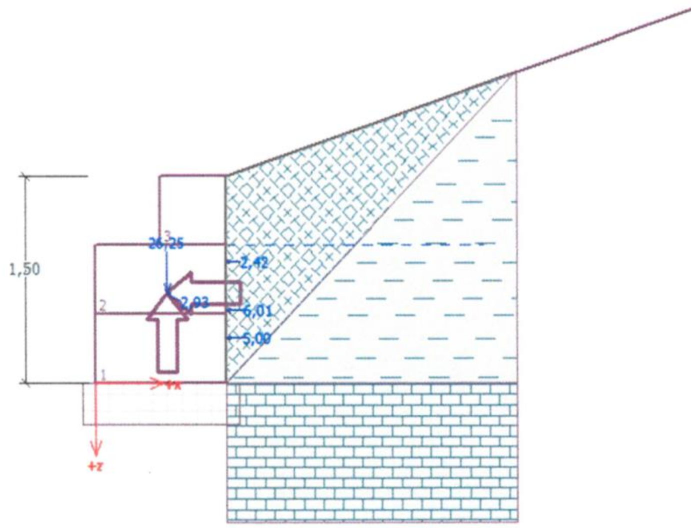
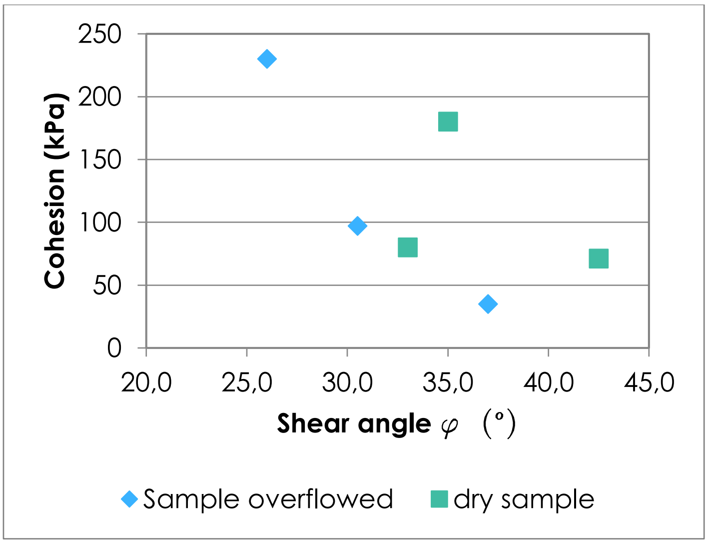


FIGURE 58 UNSTABLE SLOPE WITH A NATURAL BACK-FILL MATERIAL



59 SHEAR PARAMETERS OF IN-BUILT MUDIPEL IN NATURAL (DRY SAMPLE) AND SATURATED (INUNDATED) STATE

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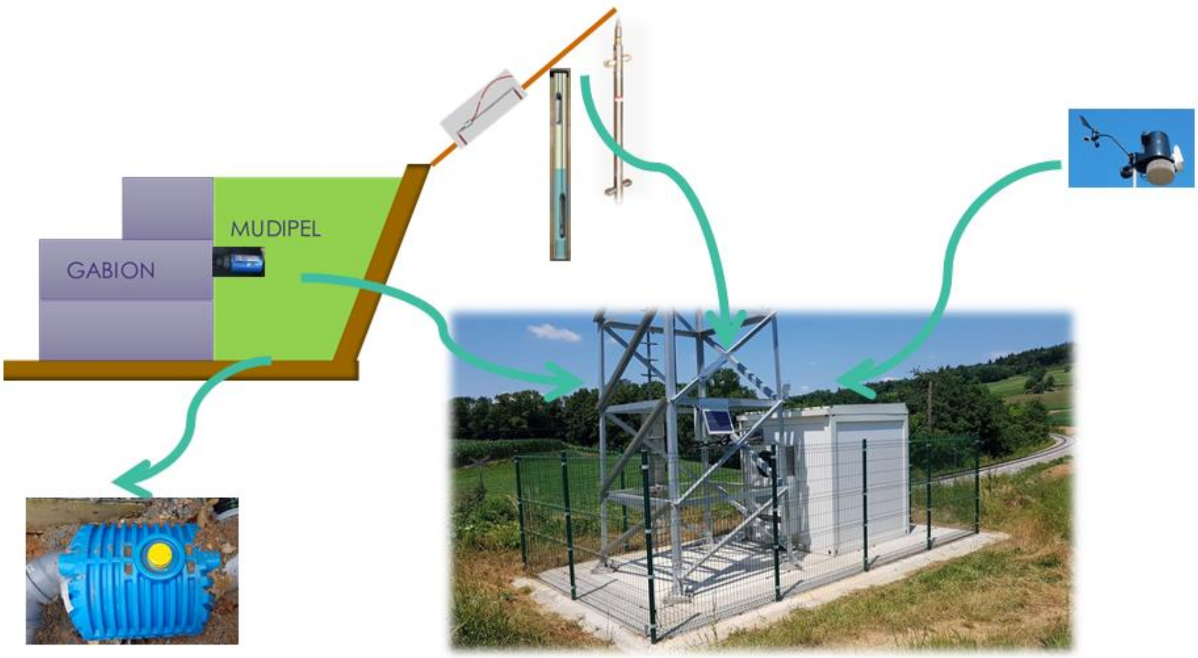
2.5. Monitoring

There is a monitoring station placed at the construction site (Figure 60). Most of the data is automatically recorded and sent to the ZAG's office, since an automated system was developed to obtain and monitor the following measurements:

- Weather station – precipitation, temperature
- Inclinometers - water level in the slope
- Probe for water content of back-fill material - MUDIPEL
- Probes for temperatures in backfill material – MUDIPEL.



60 MONITORING SYSTEM

2.5.1. Displacement monitoring

The displacements that may occure above the retaining wall structure are monitored with a manual inclinometer. Measurements in inclinometer P-6 which is outside the retaining wall structure showed that horizontal deformations continue (Figure 61). The depth of the shear plane is of 8 m. The inclinometers above the retaining wall (P7 and P8) showed that the slope above the retaining wall is stable (Figure 62, Figure 63).

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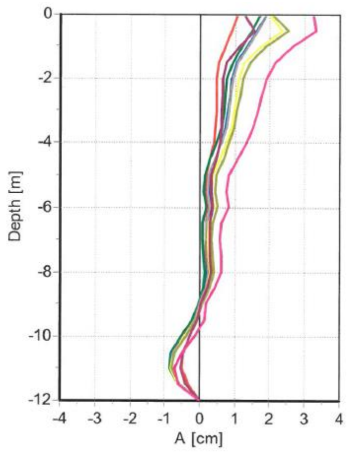

FIGURE 61 HORIZONTAL DISPLACEMENTS IN BOREHOLE P6

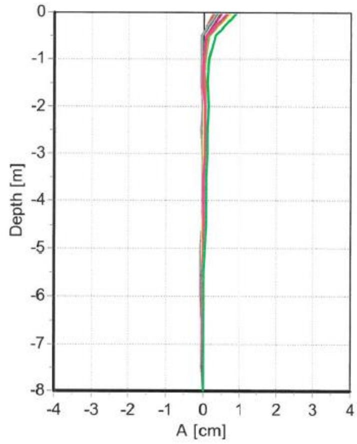

FIGURE 62 HORIZONTAL DISPLACEMENTS IN BOREHOLE P7

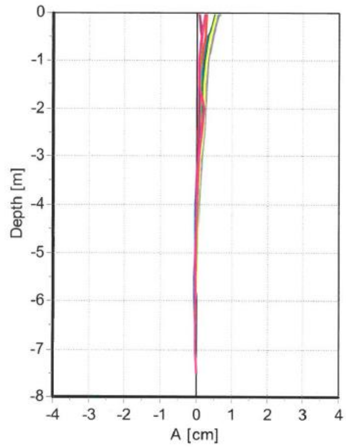

FIGURE 63 HORIZONTAL DISPLACEMENTS IN BOREHOLE P8

2.5.1. Water level

In piezometers P6, P7 and P8 ground water level is measured automatically. During the construction it was considered evident that in the region the water level is below the construction. The water in the boreholes comes from a local inflow into the boreholes and doesn´t seep through the soil (Figure 64).

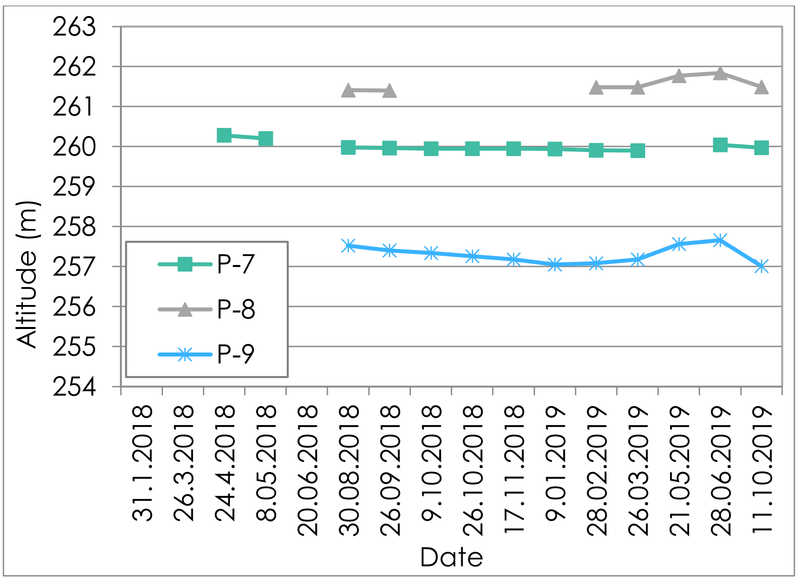

FIGURE 64 WATER LEVEL IN BOREHOLES

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2.5.1. Water content in MUDIPEL

A probe for measuring the moisture content and temperature of the back-fill material (MUDIPEL) automatically was installed below the surface (90 cm), as shown in Figure 65. The results are shown in Figure 66. Unfortunately the automated monitoring system for the water content measurements hadn´t started until 2019. The water content at the time of compacting the back-fill material was 57 % and now is around 47 %. The water content of MUDIPEL at compacting time was higher than optimum, but it was necessary because part of that water content was used in the chemical reaction. The comparison with the precipitation showed that the material is impermeable, because there is no correlation between the water content and precipitation (Figure 67, Figure 68, Figure 69).

FIGURE 65 PROBE IN MUDIPEL

FIGURE 66 THE LOCATION OF AUTOMATED SYSTEM FOR THE PROBE

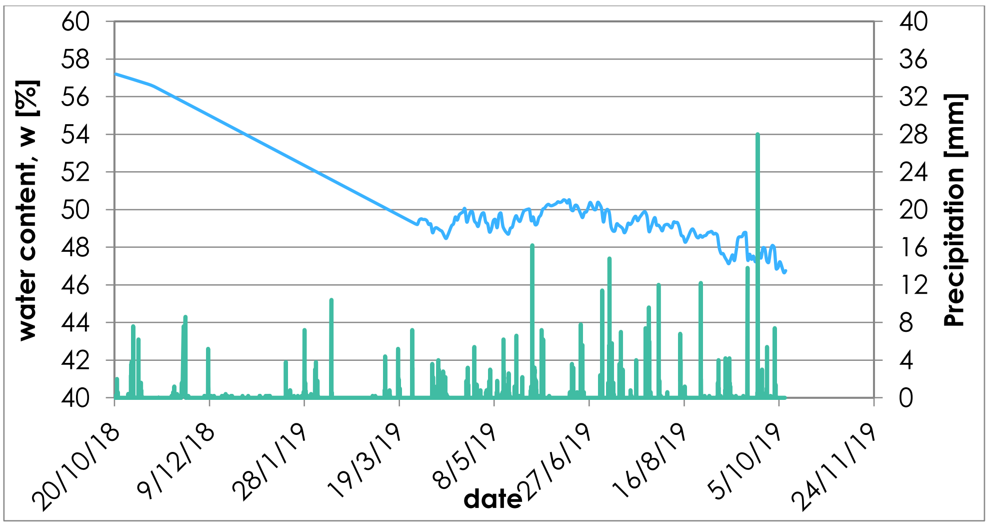

FIGURE 67 WATER CONTENT IN MUDIPEL VS PRECIPITATION

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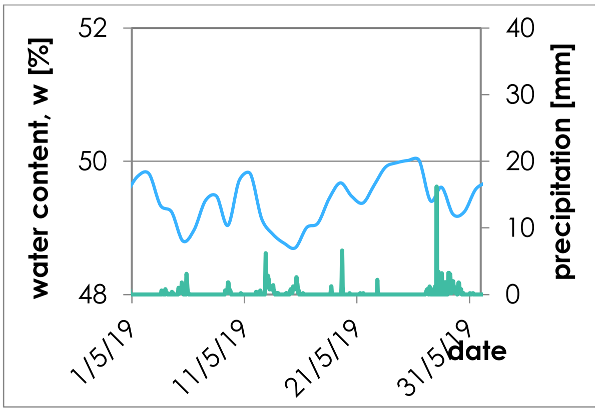

FIGURE 68 RESULTS FOR MAY 2019

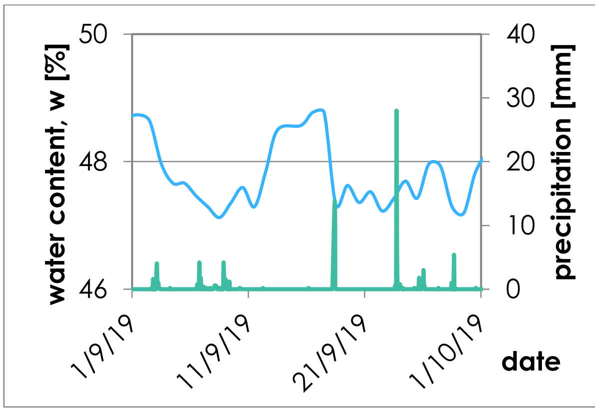

FIGURE 69 RESULTS FOR SEPTEMBER 2019

2.5.1.1. Temperature measurement

Temperature is another automatically measured parameter, and measurements are taken as different points and heights of the MUDIPEL back-fill material, as shown in Figure 70:

- T…at the weather station
- T1...50 cm under the surface of MUDIPEL
- T2…80 cm under the surface of MUDIPEL
- T3…110 cm under the surface of MUDIPEL

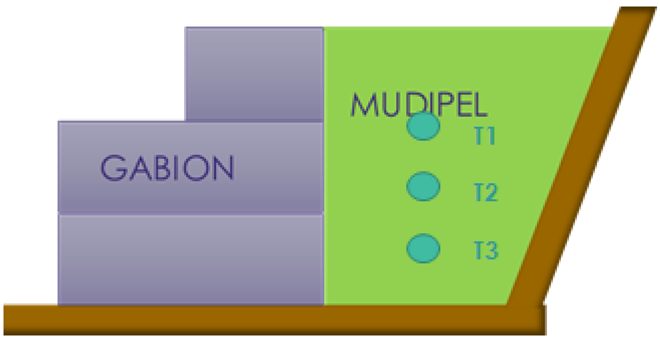

FIGURE 70 LOCATION OF THE TEMPERATURE PROBES IN BACK-FILL MATERIAL

The results of the measurements showed that a change in the outside temperature doesn´t influence the temperature inside the back-fill material significantly. Some correlation can

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be observed in T1 which is the highest sensor, while the temperatures in T2 and T3 remain quite stable, despite the fluctuation of the outside temperature (Figure 71, Figure 72).

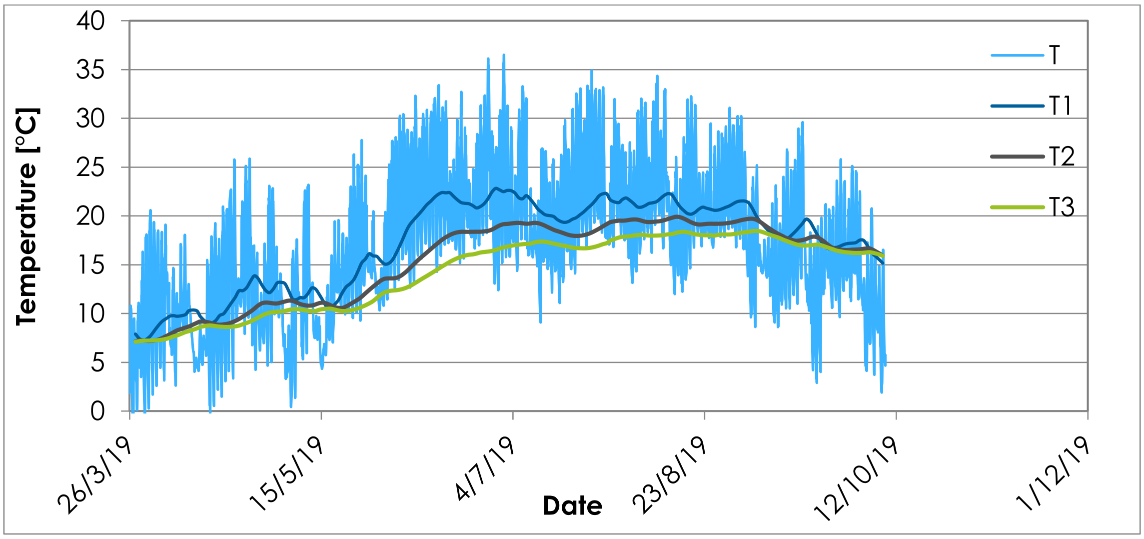

FIGURE 71 RESULTS OF THE TEMPERATURE OUTSIDE AND IN MUDIPEL

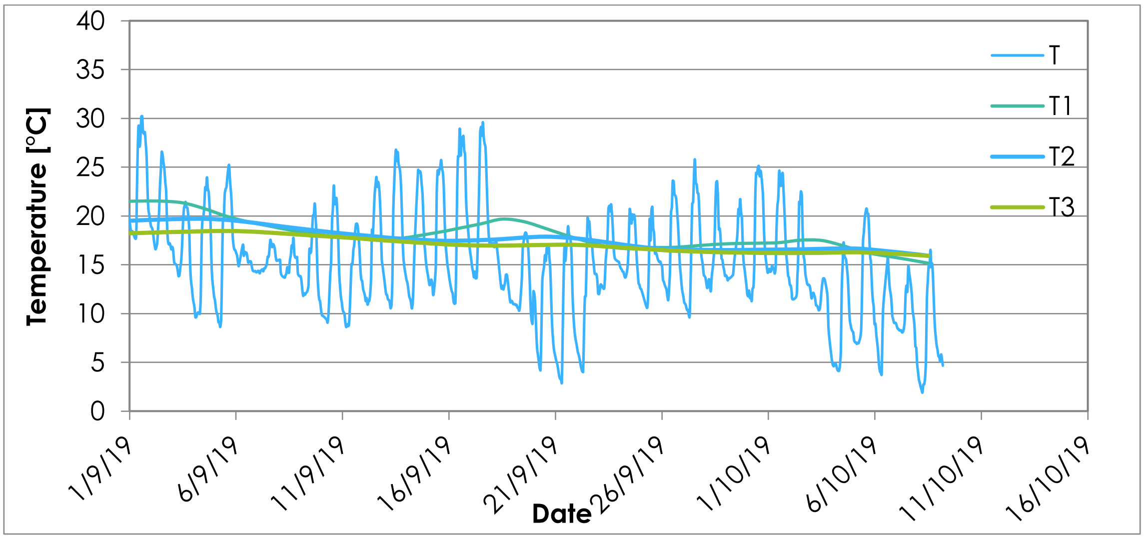

FIGURE 72 DETAIL RESULTS OF TEMPERATURE MEASUREMENTS FROM 1.9.2019 TO 16.10.2019

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2.5.2. Environmental monitoring

The water flowing from the drainage system between the gabions and the back-fill material was collected in a plastic tank (Figure 73) and was taken from the near borehole P6 for chemical analyses. These results show that the structure (back-fill material MUDIPEL) doesn´t have a significant influence on the water quality, since none of the tested parameters' concentration exceeds the limits set by Slovenian legislation (Table 15).

FIGURE 73 THE PLASTIC TANK

Samples of grass growing on the retaining wall surface (Figure 74, Figure 75) and its proximities were also taken to carry out a chemical analysis. The evaluation of the results is still ongoing.

FIGURE 74 SURFACE OF THE RETAINING WALL

FIGURE 75 SAMPLES OF THE GRASS

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TABLE 15 RESULTS OF THE CHEMICAL ANALYSIS OF THE WATER FROM THE DRAINAGE SYSTEM

Component	Limit (UR RS No. 98/15)	Surface water in piezometer 30. 8. 2018	Water sample 12. 4. 2019	Water sample 21. 5. 2019	Water sample 7. 10. 2019
	mg/l				
As	0,1	0,00074	0,0019	0,0006	0,0017
Ba	5	0,07	0,0080	0,0073	0,122
Cd	0,025	< 0,0002	< 0,0002	< 0,0002	< 0,0002
Cr total	0,5	0,0057	0,0031	0,0010	0,011
Cu	0,5	0,00098	0,042	0,011	0,013
Hg	0,005	< 0,0001	< 0,0001	< 0,0001	< 0,0001
Mo	1	0,0013	0,018	0,0024	0,0028
Ni	0,5	0,034	0,0011	0,0015	0,0024
Pb	0,5	0,00049	0,0005	0,0006	< 0,0005
Sb	0,3	0,00016	0,0039	0,0011	0,0017
Se	0,6	0,00035	0,0005	< 0,0003	0,0003
Zn	2	0,1	< 0,0005	0,0016	0,0005
Chloride	800*	-	5,17	1,52	2,19
Fluoride	10	< 0, 0001	0,264	< 0,10	0,204
Sulphates	1000*	< 0,00005	19	2	14

2.5.3. Geodetic monitoring

A laser scanner was used to perform the geodetic monitoring. Figure 76 shows a picture of the retaining wall and Figure 77 scanned situation. The following two figures serve as comparison between the scan of the landslide region before the retaining wall construction (Figure 78) and current situation (Figure 79). With the laser scanning measurements, the detailed deformation of the gabions and foundation is controlled (Figure 80). No displacements in the concrete plate below the gabions have been observed so far.

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FIGURE 76 THE PICTURE OF THE RETAINING WALL STRUCTURE

FIGURE 77 THE SCAN OF THE RETAINING WALL STRUCTURE

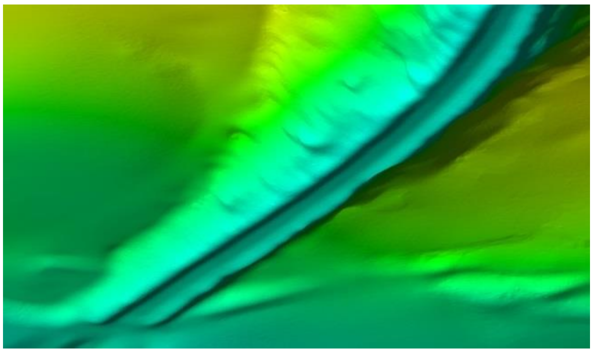

FIGURE 78 SITUATION BEFORE THE RETAINING WALL CONSTRUCTION

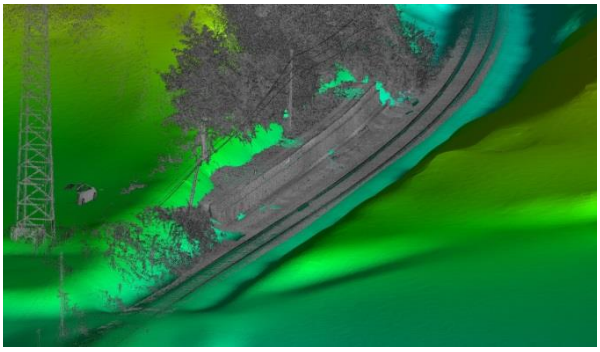

FIGURE 79 SITUATION WITH THE RETAINING WALL STRUCTURE

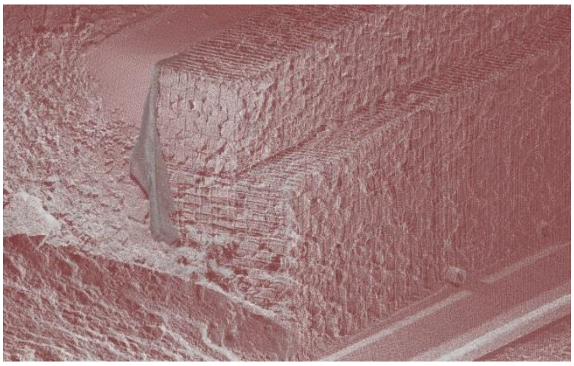

FIGURE 80 DETAIL OF THE RETAINING WALL

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3. Conclusions

The composite MUDIPEL was developed as a back-fill material for retaining wall structures. Preliminary tests were performed in ZAG's geomechanical laboratory and the results were later verified with small test fields at VIPAP facilities. Based on the results measured at the small test fields, the technology for the installation of the material at construction sites was determined. It was stated that no more than 4 hours should elapse between the composite mixing and its installation. At the construction site, the material was installed in 30 cm thick layers. Each layer was compacted and controlled to reach their optimal moisture and maximum density. Gabions were selected to conform the supportive construction. Before, during and after the construction, landslide stability and environmental monitoring are being performed. The following information was gathered:

- The technology for mixing and compacting MUDIPEL in layers/structures was improved.
- The use of MUDIPEL improved the stability of the slope.
- MUDIPEL is an impermeable material, property achieved through laboratory tests trials, and later confirmed with the monitoring system installed in the retaining wall.
- MUDIPEL is also a light-weight material with really high shear stregth parameters.
- No sub zero temperature have been observed during the first year. Colder winter in the next years could help to check the material behaviour at freezing temperatures.
- The influence of external temperature decreases with the depth of the material.
- Both MUDIPEL and water from drainage system comply with all the environmental requirements set by law.
- Continuous control during the production, mixing and installation stages of MUDIPEL is necessary in order to get high quality back-fill material.
- Rainwater doesn´t influence the water content of MUDIPEL, which indicates an adequate impermeability of the material.
- No displacements were measured after the construction work.

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4. References

Paperchain Deliverables:

1. Deliverable 2.1: Baseline Reporte – PPI waste streams valorisation potential.
2. Deliverable 8.1: Report on transition assessment for circular economy processes.
3. Deliverable 4.1: Report on solutions feasibility and constraints.
4. Deliverable 2.2: Quality assurance procedures for the circular model demos.
5. Deliverable D2.3: Raw materials supply scenario
6. Deliverable D4.2: Demonstration projects setup conditions

Internal sources

7. Report No. 297/17-710-2, about geomechanical investigations on landslide Rogovila, ZAG
8. Report No. 296/17-710-4 about geomechanical laboratory investigation of the composite MUDIPEL, ZAG
9. Report No. 296/17-710-3 Report about results of the Small demo fields at the VIPAP's facility, ZAG
10. Report No. P296/17-710-5 Results of laboratory and In-situ controling test for the landslide Rogovila, ZAG.
11. Report No. 059-018-8 Design of the excavation and retaining wall structure, Arping.

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