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# GEOTECHNICAL STUDY FOR THE ARCHITA 2 TUNNEL – BEIA-SIDE PORTAL

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***Abstract***. *This paper presents a comparative analysis of the geotechnical investigations carried out for the Beia-side portal of the Archita 2 railway tunnel, which is part of the rehabilitation project for the Brașov–Sighișoara railway line, designed for speeds of up to 160 km/h. The research aims to define the geotechnical model, identify the factors contributing to slope instability, and provide the technical basis for the proposed construction solution.Data obtained from the initial investigation campaigns and from the supplementary investigation performed after the occurrence of the landslide were analysed. These data include boreholes, standard penetration tests (SPT), laboratory testing, piezometric observations, and inclinometer measurements. The results highlight three main geotechnical units, consisting of silty clays, transitional clays, and argillaceous marls, characterised by high plasticity, fissuring, and variable mechanical properties. At the contact between the superficial formation and the transitional unit, a residual shear zone was identified, which is relevant to the slope instability mechanism. The comparison between laboratory-derived parameters and those obtained from in-situ tests indicates significant differences, requiring a correlated interpretation of the results and an update of the geotechnical model. In order to mitigate the associated risks, the following measures are recommended: application of the cover-and-cut method, use of pile-supported retaining systems, minimisation of the exposure time of argillaceous materials, drainage of groundwater and surface water, and geotechnical monitoring throughout the construction period. The study demonstrates the importance of phased geotechnical investigations in the safe design of tunnels located in complex and actively deforming areas affected by extensive and deep-seated landslides.*

***Keywords***: *Archita 2 Tunnel, geotechnical investigations, Beia portal, slope instability, standard penetration tests, cover-and-cut method, geotechnical monitoring.*

## INTRODUCTION

This geotechnical study, based on the initial and supplementary investigation campaigns, addresses the entrance portal of the Archita 2 Tunnel on the Beia side. The project forms part of the contract for the rehabilitation of the Brașov–Simeria railway line, Section 1, Brașov–Sighișoara, subsections Brașov–Apața and Cața–Sighișoara. The contractor is the RailWorks Joint Venture, and the project beneficiary is C.F.R. S.A.

The Archita 2 Tunnel is designed to accommodate a double-track railway and comprises cut-and-cover sections at both ends and a central mined section. Its total length is approximately 221.56 m, extending from chainage km 253+657.89 to km 253+890.56. The mined section is 104.85 m long, extending from km 253+725.15 to km 253+830, and follows a straight alignment with an ascending gradient of 11‰ towards Archita and a maximum overburden of approximately 20 m. The end sections are to be constructed using the cut-and-cover method, while the central section will be excavated using conventional tunnelling methods. The diversion of a local road is also planned at the entrance on the Beia side.

The site is located near the village of Archita, in Vânători commune, Mureș County, in an area of hilly terrain near the watershed between the Olt and Târnava Mare river basins. The local drainage network belongs to the Târnava Mare basin, with the Archita and Scroafei streams as its main tributaries. Although no groundwater intersections are indicated along the

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alignment, the groundwater table may occur at depths of approximately 1–3 m in floodplain and terrace areas.

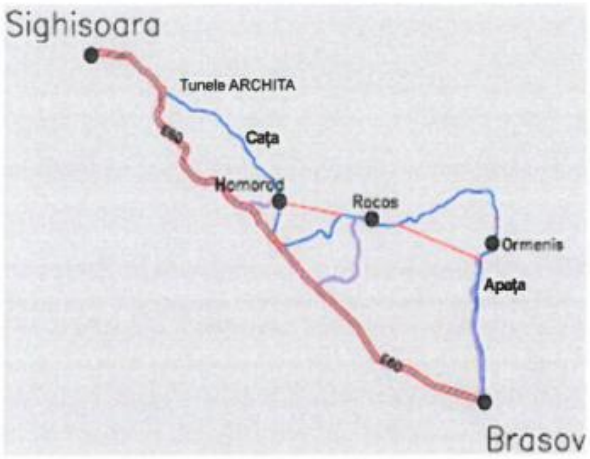



Figure 1. Location of Archita 2 Tunnel

Geologically and geomorphologically, the area is characterized by sedimentary formations and dissected slopes affected by erosion and instability processes. The Brașov–Sighișoara railway section is exposed to landslides, rockfalls, and flooding. The cohesive soils may be frost-susceptible. According to the seismic values specified in the reference documentation, the peak horizontal ground acceleration for the Augustin–Sighișoara section is $a_g = 0.12\ g$, and the corner period is $T_c = 0.7$ s.

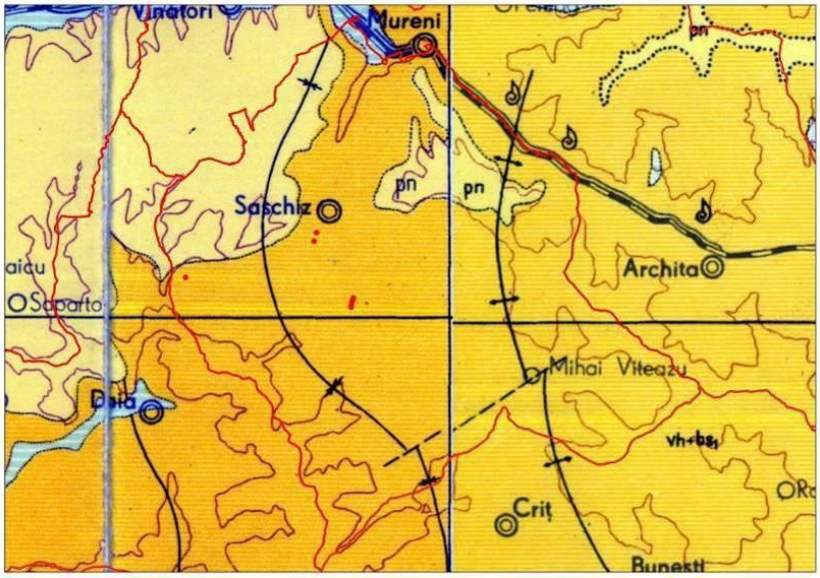



Figure 2. Geology of the Archita Commune
Geological Map 1:200,000, Târgu Mureș Sheet, IGR 1968

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## MATERIALS AND METHODS

### Materials analysed and study objectives

The study analyses the available geotechnical data for the entrance portal of the Archita 2 Tunnel on the Beia side. The materials reviewed include the geotechnical documentation from the initial and supplementary investigation campaigns, borehole logs, in-situ and laboratory test results, geotechnical profiles, and groundwater observations.

The analysis aims to identify the stratigraphic sequence, compare the results of the investigation campaigns, and summarize the geotechnical parameters used in the design. Results obtained directly from testing are distinguished from values estimated through The study was based on a comparative review of the available geotechnical documentation for the Archita 2 Tunnel, with particular emphasis on the Beia portal, using the borehole logs, geotechnical profiles, and field and laboratory test results presented in the diploma thesis. The review covered the investigations supporting the original design, the additional investigations undertaken by GEOLOGIC SITE S.R.L. and AGISFOR S.R.L., and the post-landslide investigation campaign carried out by AGISFOR in 2024.

The ground investigation programme comprised boreholes with disturbed and undisturbed sampling, Standard Penetration Tests (SPTs) and, during the original investigations, Ménard pressuremeter tests and Lefranc permeability tests. The main boreholes considered in the comparison of the investigation campaigns are listed in Table 1.

*Table 1*

Main boreholes considered in the geotechnical investigation campaigns

| **Investigation stage** | **Borehole IDs** | **Depths [m]** | **Investigation methods and instrumentation** |
|---|---|---|---|
| Investigations supporting the original design | ARCF36; ARCF37 | 15.00; 15.00 | Sampling, *in situ* testing, and piezometer installation.Cercel-Cristina-Madalina_proiect-diploma-final.docx |
| Initial stage – GEOLOGIC SITE | ARC2-TFN1; ARC2-TFN2 | 30.00; 28.00 | Continuous core drilling, sampling, and SPTs.Cercel-Cristina-Madalina_proiect-diploma-final.docx |
| Initial stage – AGISFOR | ARC2-TFN3; ARC2-TFN4 | 27.00; 30.00 | Continuous core drilling, sampling, and SPTs.Cercel-Cristina-Madalina_proiect-diploma-final.docx |
| Post-landslide stage – AGISFOR, 2024 | ARC2-TFN7; ARC2-TFN8; ARC2-TFN9 | 28.50; 33.00; 36.00 | SPTs and inclinometer installation in all three boreholes.Cercel-Cristina-Madalina_proiect-diploma-final.docx |

The borehole locations were examined in relation to the tunnel alignment, the portal area, and the reported ground instability to correlate the information obtained at the different investigation points. During the post-landslide campaign, borehole ARC2-TFN7 was specifically positioned to clarify the geometry of the transitional formation and provide additional information between boreholes ARC2-TFN1 and ARC2-TFN2.

*Table 2*

Layout of the geotechnical investigation points for the Archita 2 Tunnel

| ID | X | Y | Z | Depths [m] | Execution phase | Date of execution |
|---|---|---|---|---|---|---|
| ARC F36 | 286426.33 | 319269.29 | 510.52 | 15,0 | Bidding phase | 12.03.2011 |
| ARC DP19 | 286398.43 | 319272.93 | 506.78 | 23,4 | Bidding phase | 07.02.2011 |
| ARC2-TFN1 | 286531.45 | 286531.45 | 504.72 | 30,0 | Initial phase | 12.03.2020 |
| ARC2-TFN2 | 286489.00 | 319261.53 | 505.36 | 28,0 | Initial phase | 12.03.2020 |
| ARC2-TFN3 | 286451.40 | 319270.01 | 509.00 | 27,0 | Initial phase | 01.2021 |
| ARC2-TFN4 | 286410.33 | 319261.35 | 511.50 | 30,0 | Initial phase | 01.2021 |
| ARC2-TFN5 | 286381.13 | 319284.64 | 498.0 | 30,0 | Initial phase | 08.03.2021 |
| ARC2-TFN6 | 286351.77 | 319263.84 | 501.0 | 30,2 | Initial phase | 09.03.2021 |
| ARC2-TFN7 | 286508.48 | 319242.79 | 506.70 | 28,5 | Post-award phase | 12.03.2024 |
| ARC2-TFN8 | 286448.36 | 319227.52 | 511.30 | 33,0 | Post-award phase | 20.03.2024 |
| ARC2-TFN9 | 286395.65 | 319249.85 | 513.30 | 36,0 | Post-award phase | 23.03.2024 |

Laboratory testing included the determination of particle size distribution, natural water content, Atterberg limits, unit weight, and compressibility, together with tests to determine shear strength and unconfined compressive strength. In the reviewed documentation, soil identification and classification were carried out with reference to SR EN ISO 14688-1 and SR EN ISO 14688-2.

SPT results were interpreted to characterise the consistency of the investigated materials and indirectly estimate selected mechanical parameters using the correlations reported in the geotechnical studies. For the underlying weak rock formations, the post-landslide investigation report used the following empirical relationships, attributed in the reviewed documentation to CIRIA Report 143:

$$c_u = 5N_{60} \quad q_u = 2c_u \quad E = 0.6N_{\mathrm{SPT}}$$

In these relationships, $c_u$denotes the undrained shear strength, expressed in kPa; $q_u$is the unconfined compressive strength, expressed in kPa; and $E$is the deformation modulus, expressed in MPa. $N_{\mathrm{SPT}}$is the recorded blow count for the reference penetration of 300 mm, while $N_{60}$is the SPT blow count corrected to an energy ratio of 60%

Parameters estimated using empirical correlations were examined separately from laboratory-determined values to identify differences between the characterisation methods. Testing limitations were also considered: the documentation reports that splitting of some samples from the marly formations along sandy partings prevented certain triaxial tests from being performed.

The comparative analysis addressed the stratigraphic sequence and thickness of the formations, variations in strength and deformation parameters, and groundwater observations. The inclinometers installed in the 2024 boreholes were considered part of the monitoring programme described in the documentation; their installation alone was not regarded as evidence of slope stability.

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## RESULTS AND DISCUSSIONS

The comparative analysis of the geotechnical investigations for the Archita 2 Tunnel revealed differences between the initial ground characterisation, the findings of the supplementary investigation campaigns, and the geotechnical model adopted in the final synthesis. The main findings concern the delineation of the overburden and underlying formations, variations in mechanical parameters, and the identification of discontinuities relevant to the stability of the Beia portal.

Stratigraphic characterisation

The GEOLOGIC SITE investigations described the ground predominantly as high-plasticity silty clays, differentiated by colour, consistency, and physical and mechanical properties. The AGISFOR campaigns refined this interpretation by distinguishing the overburden from the underlying marly clays and marls, identifying the transition from cohesive soils to materials classified as weak rocks.

The 2024 post-landslide investigation campaign identified two main complexes, each subdivided into two subunits: overburden subunits C1.1 and C1.2, and underlying subunits C2.1 and C2.2. The characteristic values reported for these subunits are summarised in Table 2.

*Table 2*

Characteristics of the subunits identified during the post-landslide investigation campaign

| **Subunit** | **Lithological description** | **Average thickness [m]** | **N_{\mathrm{SPT}} [blows/300 mm]** | **\gamma [kN/m³]** | **c_u [kPa]** | **E [MPa]** |
|---|---|---|---|---|---|---|
| C1.1 | Stiff brown silty clays | 4.90 | 27 | 19.55 | 74 | 15.2 |
| C1.2 | Hard brownish-green sandy clayey silt | 4.95 | 64 | 19.85 | 108 | 29.4 |
| C2.1 | Hard grey marly clays | 4.00 | 93 | 20.30 | 320 | 39.0 |
| C2.2 | Hard grey marls | 15.00 | 154 | 20.35 | 554 | 62.8 |

The results indicate an increase in penetration resistance and stiffness from the near-surface materials to the underlying formations. However, the average thicknesses listed in the table refer to the investigation dataset as a whole and should not be confused with the local stratigraphic sequence at the Beia portal, where the documentation describes approximately 7.50 m of overburden, followed by marly clays extending to approximately 10.00 m depth and marls continuing to the investigated depth of 28.50 m.

Mechanical test results

The comparison between parameters estimated from SPT results and those determined in the laboratory revealed substantial differences, particularly for the marly formations. Table 3 presents the unconfined compressive strength values reported in the synthesis of the initial AGISFOR campaign, distinguishing between the results obtained using the two methods.

*Table 3*

Estimated and laboratory-determined unconfined compressive strengths

| Lithological complex | $N_{SPT}$/ 30cm | $N_{60}$ | CIRIA-derived values Rap. 143 | | Laboratory-determined values | |
|---|---|---|---|---|---|---|
| | | | $C_u$ (kPa) | $q_u$ (kPa) | $C_u$ (kPa) | $q_u$ (kPa) |
| 1<br>Silty clays | 23,00 | 20,70 | 84,87 | 169,74 | 61,65 | 123,65 |
| 2 | 57,00 | 58,00 | 290,00 | 580,00 | | |

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| | | | | | | |
|---|---|---|---|---|---|---|
| Green clays, classified as very weak rocks | | | | | | |
| 3 Marly clays, classified as weak rocks | 129,50 | 147,63 | 647,50 | 1.295,00 | 59,87 | 119,75 |
| 4 Clayey marls, classified as moderately weak rocks | 185,40 | 222,50 | 1.112,50 | 2.225,00 | 94,00 | 188,10 |

For the silty clays, the estimated and laboratory-determined strengths are of the same order of magnitude, whereas for the marly clays and clayey marls, the estimated values are approximately one order of magnitude higher. This difference indicates that SPT-based estimates and laboratory test results should not be treated as interchangeable without examining the testing conditions and the representativeness of the specimens.

Interpretation is also constrained by the behaviour of the recovered specimens: the documentation reports sandy partings that caused some samples from the marly formations to split into plates, preventing certain triaxial tests from being performed. Consequently, the mechanical characterisation of these materials must account for both specimen properties and the fracturing and bedding of the ground mass documented during the investigations.

Integrated geotechnical model

By correlating information from successive investigation campaigns, the final synthesis distinguished three geotechnical units: the superficial formation GU-I, the transitional formation GU-IIA, and the underlying formation GU-IIB. This subdivision constitutes the integrated ground model for the site and should be distinguished from the four-subunit classification used to present the findings of the 2024 campaign.

*Table 4*

Characteristic parameters of the integrated geotechnical model

| **Geotechnical unit** | **GU-I** | **GU-IIA** | **GU-IIB** |
|---|---|---|---|
| **$N_{SPT}$ [-]** | 7 - 45 | 39 - denial | 77 - denial |
| **y [kN/m$^3$]** | 20,0 | 20.0 | 20.5 |
| **c' [kPa]** | 30 - 50 | 50 - 60 | 60-80 |
| **cp' [°]** | 20 -24 | 20 - 24 | 24-27 |
| **$p_{rezidual}$ [°]** | 10 - 12 | 10 - 12 | 10 - 12 |
| **Cu [kPa]** | 50 - 70 | 70 - 90 | 90 -120 |
| **ko [-]** | 0,60 - 0,70 | 0,60 - 0,70 | 0,55- 0,65 |
| **Es[MPa]** | 5 - 10 | 10 - 20 | 30 - 60 |
| **V[-]** | 0,30 – 0,35 | 0,30 – 0,35 | 0,30 – 0,35 |

The integrated model indicates greater stiffness in the underlying formation, while retaining low residual friction angles of 10–12° for all three units. Furthermore, the documentation identifies a shear zone characterised by residual strength at the interface between GU-I and GU-IIA, associated with the landslides described at the site.

Therefore, high penetration resistance values at depth do not, by themselves, demonstrate slope stability, as the geotechnical synthesis also identifies low-strength surfaces, fracturing, and anisotropic ground behaviour. For the Beia portal, these findings support the assessment of stability at the scale of the entire slope rather than solely on the basis of the local strength of the excavated material.

**Hydrogeological conditions**

Groundwater observations differ between investigation stages: no groundwater was encountered during drilling in the GEOLOGIC SITE campaign, whereas the final synthesis reports piezometric levels at approximately 2.50 m depth in ARC-F36 and 6.00 m depth in ARC2-TFN1. Seepage was also reported at the interface between the overburden and underlying formations, together with the potential for the accumulation of precipitation-derived water during periods of heavy rainfall or snowmelt.

**Implications for construction**

The integrated interpretation of the results highlights the importance of limiting open excavations and the exposure of fissured clayey materials, as well as coordinating tunnel construction with stabilisation of the adjacent landslide. In this context, the documentation recommends considering the cover-and-cut construction method, together with retaining structures, drainage measures, and ground monitoring throughout construction.

The inclinometers installed in boreholes ARC2-TFN7, ARC2-TFN8, and ARC2-TFN9 enable horizontal ground displacements to be monitored and ground behaviour to be assessed in relation to the construction stages. However, in the absence of reported monitoring time series, the installation of instrumentation constitutes a monitoring measure rather than evidence confirming slope stabilisation.

## CONCLUSIONS

The comparative assessment of successive geotechnical investigation campaigns refined the ground model for the Archita 2 Tunnel and its Beia portal, distinguishing superficial, transitional, and underlying formations with different strength and deformation characteristics. The additional investigations provided a more detailed basis for interpreting the ground conditions than the limited investigations supporting the original design.

Although penetration resistance and stiffness generally increase with depth, these trends do not, by themselves, demonstrate overall slope stability. The identified shear zone at the interface between the superficial and transitional formations, together with fissuring, anisotropy, and low residual friction angles, highlights the importance of discontinuities in assessing potential instability.

The comparison of SPT-based estimates with laboratory-determined strengths revealed substantial discrepancies, particularly for the marly formations. Empirical correlations should therefore be interpreted cautiously and assessed alongside laboratory results, sample condition, and the structural characteristics of the ground mass. The inability to perform certain triaxial tests on specimens that split along sandy partings represents an additional limitation of the available mechanical characterisation.

Groundwater observations and reported seepage indicate that water management remains relevant despite the low hydraulic conductivity attributed to the fine-grained formations in the integrated model. Surface-water interception and subsurface drainage should be coordinated with the adjacent landslide stabilisation works to limit adverse effects on the slope and retaining structures.

The findings support an integrated approach in which tunnel and portal construction are coordinated with slope stabilisation rather than treated as independent works. The cover-and-cut method is recommended in the reviewed documentation to limit open excavation and the exposure of sensitive, fissured materials; however, its suitability and detailed configuration require project-specific design verification.

Geotechnical monitoring and confirmation of ground conditions during construction are essential components of the proposed risk-management strategy. The installed inclinometers provide the means to monitor horizontal displacements, but, without reported monitoring time series, neither slope stabilisation nor the effectiveness of the proposed measures can be confirmed from the available evidence.

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