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# LABORATORY TESTING OF SAMPLES AT THE LOCATION OF THE THERMAL POWER PLANT - UGLJEVIK 3

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ABSTRACT

Field research for the purpose of the construction of the Thermal Power Plant Ugljevik 3 wasconducted in two phases. In the first phase for the smaller scope of the fieldworks, more laboratory analyses were performed. In the second phase, fieldworks were conducted in a larger scaleand laboratory analyses were considerably smaller.Designers dictated different volume of laboratory tests. In the first phase local legislation was respected while in the second phase Chinese planners considered that there was no need for larger volume of laboratory tests thereby giving more importance to the field study of drilling cores, SPT experiments and chemical analyses of the soil.

Key words: *soil and rock samples, laboratory testing, geological environment*

## INTRODUCTION

Geological and geotechnical studies at the location of the Thermal Power Plant Ugljevik 3 were conducted in two phases - the first stage for the purpose of conceptual design and the second one for detailed design. Within the first phase of the research, a smaller volume of exploratory wells was carried out with accompanying laboratory tests. In the second phase significantly lower number of sampleswas prepared compared to the number of exploratory wells.

Depending on the characteristics of the rocks in a vertical profile, to a depth of about 30.0 m, disturbed and undisturbed soil and rock samples were taken. Samples were processed in the laboratory of the Technical Institute in Bijeljina.

Various volumes of sampling in the first and the second phase of the researchwere dependent on designers. In the first stage of the research, samples were taken in accordance with our local legislative on data requirements for sufficient exploration of geological environment. Designers who came from Chinese school that minimizethe significanceof laboratory tests in comparison to the fieldworks, especially SPR experiments and geophysics, were replaced in the second phase.

Sufficient volume of data from the first phase with data from the second phase anyhow provided basic knowledge of geological environment, that is about layers in a vertical section. This paper will present overall volume of laboratory analyses and methods applied as well as parameters for isolated areas.

## SAMPLES OVERVIEW

During the exploratory drilling and preparation of exploratory wells, more samples were taken than it was delivered into the laboratory. Some samples were damaged during the removal or packagingand transport to the laboratory. Also, when selecting samples in the field and sending them to the laboratory, a selection is made if multiple samples from the same geological environment occur. After sampling has been completed selected sample iscovered with paraffin depending on whether it wastaken into cylinder or the cores, and transported to the laboratory on a daily basis.

Selection of samples for the laboratory undertakes the following:

- A description of the sample with certain data on:
  - number of the well
  - depth of sampling
  - lithological description
  - date of shipment to the laboratory

During the first phase of the research, from 35 wells, in the laboratory were taken:

- 194 samples, out of which:
  - 42 disturbed and undisturbed samples of the soil
  - 152 samples of the rocks

In the second phase field research is considerably wider. It has been made 100 wells wherefrom significantly fewer samples were taken compared to the scope of the research:

- 130 samples, out of which:
  - 13 disturbed and 98 undisturbed soil samples
  - 16 rock samples

- 3 samples of water

After sampling has been completed selected sample is covered with paraffin depending on whether it was taken into cylinder or the cores, and transported to the laboratory on a daily basis.

## RESULTS OF LABORATORY ANALYSES

Laboratory testing of samples wereperformed in order toenable a proper way to receive all the samples that came in the laboratory of a specific institute, including the following:

- A list of all samples with specified data on:
  - number of the well
  - depth of sampling
  - lithological description
  - date of receipt of the samples in the laboratory

- Selection of the samples by type of
  - the soil – disturbed and undisturbed
  - rocks
  - water

- Selection of the samples according to the schedule of laboratory tests

- Conditional storage of all samples, including proper storage area where there will be no violation of the basic characteristics of the samples such as natural humidity, structure and shape.

In the first stage of the research, out of samples taken from 35 wells, in the laboratory were processed:

- 183 samples, out of which:
  - 34 disturbed and undisturbed soil samples
  - 149 rock samples

In the second stage of the field research, smaller number of samples was processed in the laboratory:

- 121 sample, out of which
  - 10 disturbed and 95 undisturbed soil samples
  - 16 rock samples

- 3 samples of water

All the samples of the first phase were processed in the laboratory of the Technical Institute in Bijeljina while the samples of the second stage were analyzed in three laboratories:

- Laboratory of the Technical Institute in Bijeljina – 103 samples of soil and rocks
- MOL from Belgrade – 18 samples of soil for chemical analyses
- The Institute for Water from Bijeljina **-** 3 samples

Samples selected for laboratory analyses preserved almost all of their natural featuresfrom the place and time of their sampling until thearrival in the laboratory.

On the basis of previously made programme of laboratory analyses, they were conducted in accordance with applicable standards in Bosnia and Herzegovina. The sequence of testing of samples in the laboratory of the Technical Institute in Bijeljina is shown in Figure 1.

In situ investigations defined geological environments in vertical profiles, and laboratory analyses determined their geomechanical properties.

**Geological environment 1,** belongs to Quaternary sediments of alluvial sediments and deluvial – proluvial formations. A complex of alluvial sediments is made of gravels, sands and clays, of thickness up to 4,0 m. Deluvial **-** proluvial sediments consist of clays and rarely clayey debris. They do not spread over the entire site and have maximum thickness up to 7.0 m. Complex of these sediments is characterized by plastic environments that behave plastically and rarely as a liquid.

**Geological environment 2,** belongs to a complex of rock substrates that is built ofmarly sediments such as marly clay, clay marl and clay marl with interbeds of marly clays with thickness from mm to dm. Transitional sediments from substrates towards Quaternary sediments are sediments of substrate weathering crustand sandstone blocks immersed into clayey ground. Substrate weathering crust sediments are not widely distributed while sandstone blocks immersed into clayey mass can be of larger dimensions. They have no larger distribution.

**Geological environment 3,** is built of marls with interbeds of sandstonesandof thickness from mm up to dm.Frequent alterations are presentand they are manifestedin certain intervals in the form of bright banded sandstones and dark bands ofmarls.In addition, the environment is characterized by the presence of marls alternating with clayey marl. Part of the marly rock complex is characterized by more expressed fractures, where the cracks are smooth and compressed. Softer marly rocks are typical of quasi-plastic medium.

**Geological environment 4,** is built of marly rocks with a small presence of sandstone. There can be found marls with interbeds and lenses of sandstone, sandy marl and marl with sandstone, which often alternates with clayey marl of thickness from cm to dm. Harder rocks are characterized by the presence of fractures usually at an angle of $45^0$ while greater presence of softer rocks givesquasi-plastic properties to the environment.

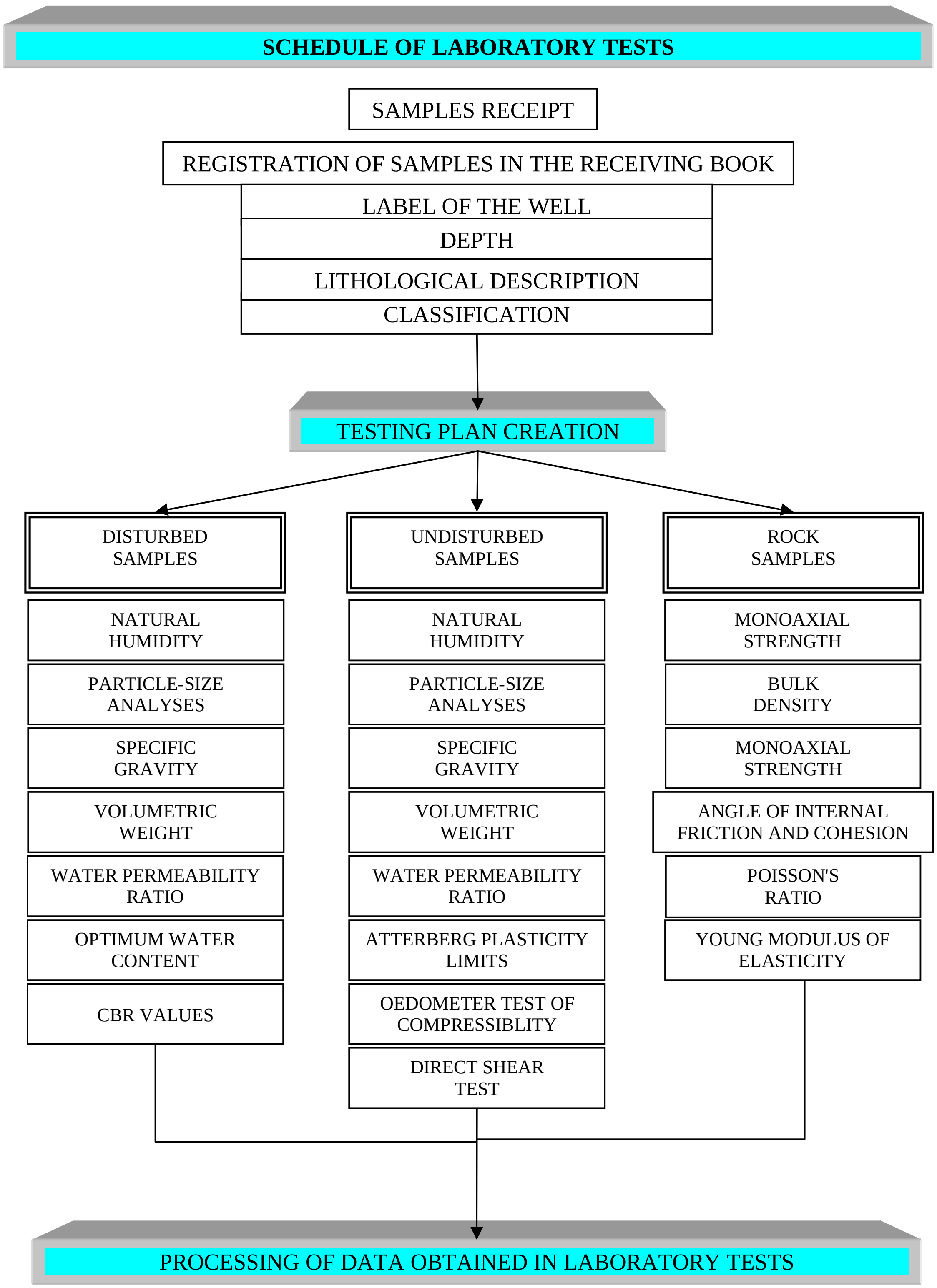


Figure 1.Sequence diagram of testing of samples in the laboratory of the Technical Institute

**Geological environment 5,** is made of sandstone that is characterized by alternations of sandstones and interbeds of marl, then sandstones and interbeds of marl and clayey marl. At the location it extends at a depth of 26.0 m. Rocks belonging to this region are very cracked and fractures are mostly rough and filled with clayey matter. Certain parts, containing mostly sandstone, are characterized by brittle areas and in the places of local character, quasi-plastic medium can be separated.

Laboratory tests were conducted in accordance with following applicable standards in the field of testing of soil, rock and water, Table 1.

Table 1. Types and methods of laboratory testing of soil, rock and water

| **Laboratory tests on soil samples** | |
|---|---|
| **TYPE OF TEST** | **STANDARDS** |
| Grain-size distribution | BAS CEN ISO/TS 17892-4:2009 |
| Consistencylimits– Atterberg limits | BAS CEN ISO/TS 17892-12:2009 |
| Specific gravity of soil | BAS CEN ISO/TS 17892-3:2009 |
| Volumetric weight of soil | BAS CEN ISO/TS 17892-2:2009 |
| Soil humidity | BAS CEN ISO/TS 17892-1:2009 |
| Water permeability ratio | BAS CEN ISO/TS 17892-11:2009 |
| Direct shear test | BAS CEN ISO/TS 17892-10:2009 |
| Soil compressibility test | BAS CEN ISO/TS 17892-5:2009 |
| Optimum water content – Modified Proctor's experiment | BAS EN 13286-2:2011 |
| Determination of California bearing ratio – CBR test | JUS U.B1.042 |
| **Chemical analyses of the soil** | |
| Sulphates, $SO_4^{2-}$ | Standard method 4110 B |
| Chlorides, $Cl^-$ | Standard method 4110 B |
| Calcium dissolved in water, $Ca^{2+}$ | SRPS H .Z.181 |
| Magnesiumdissolved in water, $Mg^{2+}$ | SRPS H .Z.181 |
| Bicarbonates, $HCO_3$ | Internal method |
| Carbonates $CO_3^{2-}$ | Internal method |
| Gypsum | Internal method |
| Total dissolved salts | Standard method 2540 B |
| pH | EPA M 9045 D |
| **Laboratory testing of rock samples** | |
| Ratio of density and porosity | BAS EN 1936:2009 |
| Uniaxial compressive strength | JUS B.B7.126 |
| **Laboratory testing of water samples** | |
| Total alkalinity | BAS EN ISO 9963-1:2000 |
| Carbonates | Calculated by the method BAS EN ISO 9963-1:2000 |
| Bicarbonates | Calculated by the method BAS EN ISO 9963-1:2000 |
| Sum Ca and Mg | BAS ISO 6059:2000 |
| $NH_3$ – N | BAS EN ISO 7150-1:2002 |
| $NO_3$ . N | BAS EN ISO 10304-1:2002 |
| Chlorides | BAS EN ISO 10304-1:2002 |
| Sulphates | BAS EN ISO 10304-1:2002 |
| Total of solids | Standard methods 2540 (C)APHA-AWWA-WEF 2005 |
| Total of soluble matter | Standard methods 2540 (C)APHA-AWWA-WEF 2005 |
| Free $CO_2$ | Calculated by the method BAS EN ISO 9963-1:2000 |
| $Calcium_{2+}$ | Standard methods 3500 (B)APHA-AWWA-WEF 2005 |
| $Magnesium_{2+}$ | Computationally |

Results of laboratory analyses for selected geological environments are presented in Table 2, which shows the limit values from minimum to maximum [1, 2, 3, 4, 5]. These parameters cannot be used for geostatic analyses since they refer to the entire site where the research was conducted.

## COMMENT ON THE RESULTS

Soil samples refer to geological environment 1 and rock samples to other geological medium. Due to the presence of faults in the research area, depths of individual mediums are different. In addition, there are frequent alternations of mediums in the vertical profile.

Values of parameters for all environments are moving in a slightly wider range and data that can be reliably used for geostatic analyses, necessary for design of buildings, are obtainedby their correlation and translation into parameters of rock mass.

Facilities located in the complex of future thermal power plant are of different importance, both in size and content of the plants that require completely stable structure to be installed on. For these reasons, all necessary parameters were analyzed as well as conditions prevailing in geological environments, especially in the area of present faults.

Chemical analyses of the soil related to geological environment 1 showed the presence of various concentrations of individual elements. Concentrations are generally increased due to the presence of the Thermal power plant Ugljevik 1. Most of the particles of certain elements are transferred to the soil to a certain depth by means of surface water that infiltrates into the soil.

Various concentrations of particular elements in water samples are characterized by their movement through different geological environments at various depths affectedbythe fault area. In some places there is a direct connection of surface water with the fault zone, that is water from geological environment 1 interferes with water from the fault zone. In other parts of the field, the fault zone intersects individual geological environments in greater depth, aggravating the connection with surface waters.

The presence of the Thermal power plant Ugljevik 1 provides increased concentrations of certain particles in the air and on the ground and surface waters. To which extent are particles reflected into the surface water and further ontransferred towards underground water should be the subject of special research.

For a more detailed study of various concentrations of certain elements in underground water it is necessary to establish an observation network of piezometers and determine the sampling frequency.Filter construction should be installed on piezometers, in the media which the underground water is coming from and being affected by the faults.

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Tabel 2. Results of laboratory testing of soil, ground and water

| **Laboratory tests** | **REZULTS** | | | | |
|---|---|---|---|---|---|
| | **Geological environment 1** | **Geological environment 2** | **Geological environment 3** | **Geological environment 4** | **Geological environment 5** |
| **SOIL** | 1 | 2 | 3 | 4 | 5 |
| Grain-size distribution | | | | | |
| gravel | 0,00 % | | | | |
| sand | 7,15 – 38,45 % | | | | |
| dust | 41,79 – 74,65 % | | | | |
| clay | 10,59 – 16,55 % | | | | |
| Consistency limits – Atterbeg limits | | | | | |
| Yield point $W_L$ | 28,91 – 51,33 % | | | | |
| Plastic limit Wp | 13,36 – 21,20 % | | | | |
| Plasticity index Ip | 15,58 – 34,40 % | | | | |
| Consistency index c | 0,582 – 1,323 | | | | |
| Liquidity Index $I_L$ | 0,113 – 0,373 | | | | |
| Specific gravity | 25,61 – 27,06 kN/$m^3$ | | | | |
| Volumetric weight of soil | 17,25 – 20,35 kN/$m^3$ | | | | |
| Porosity | 30,94 – 40,62 % | | | | |
| Soil humidity | 9,68 – 24,87 % | | | | |
| Water permeability ratio | $1,16x10^{-6}$ -$7,06x10^{-9}$ cm/s | | | | |
| Direct shear test | | | | | |
| Cohesion (c) CD and R | c=14-28 / 12-25 kN/$m^2$ | | | | |
| Angle of internal friction (φ) CD and R | φ=10-20 / 9-$18^0$ | | | | |
| Soil compressibility test | | | | | |
| Modulus of compressibility $Mv_{100-200}$ | 1721 – 10363 kN/$m^2$ | | | | |
| Modulus of elasticity $E_{200-100}$ | 44444 – 12654 kN/$m^2$ | | | | |
| Porosity ratio $e_{100-200/200-100}$ | 0,412-0,599/0,552-0,363 | | | | |
| Coefficient of consolidation $Cv_{100-200}$ | $2,47x10^{-3}$- $7,21x10^{-4}$ $cm^2$/s | | | | |
| Compressibility index Cc | 0,104 – 0,202 | | | | |
| Water permeability ratio | $1,23x10^{-10}$ -$7,37x10^{-11}$ m/s | | | | |
| Optimum water content – Modified Proctor's experiment | 12,22 – 16,37 % | | | | |
| Determination of California bearing ratio – CBR test | 3,3 – 4,4 % | | | | |

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Chemical analyses of the soil | | | | | |
| Sulphates, $SO_4^{2-}$ | 7,85 – 134,15 mg/kg | | | | |
| Chlorides, $Cl^-$ | 21,29 – 128,89 mg/kg | | | | |
| Calcium dissolved in water, $Ca^{2+}$ | 28,60 – 67,50 mg/kg | | | | |
| Magnesium dissolved in water, $Mg^{2+}$ | 21,10 – 32,20 mg/kg | | | | |
| Bicarbonates, $HCO_3$ | 160,30 – 288,40 mg/kg | | | | |
| Carbonates $CO_3^{2-}$ | < 0,5 mg/kg | | | | |
| Gypsum | < 0,5 mg/kg | | | | |
| Total dissolved salts | 1360,0 – 5360,0 mg/kg | | | | |
| pH | 6,04 – 7,47 | | | | |
| **ROCKS** | | | | | |
| Density | | 2346 – 2482 kg/m$^3$ | 2354 – 2558 kg/m$^3$ | 2491 – 2568 kg/m$^3$ | 2498 – 2651 kg/m$^3$ |
| Porosity | | 0,875 – 2,541 % | 0,269 – 2,148 % | 0,463 – 1,283 % | 0,165 – 0,743 % |
| Humidity | | 1,11 – 8,65 % | 1,72 – 5,79 % | 0,71 – 5,42 % | 0,64 – 3,84 % |
| Monoaxial strength | | 2,39 – 6,94 MPa | 2,49 – 16,82 MPa | 4,68 – 14,96 MPa | 12,02 – 49,55 MPa |
| Angle of internal friction | | 13,13 – 25,07 | 13,80 – 31,88 | 16,49 – 33,56 | 27,27 – 40,25 |
| Cohesion | | 0,44 – 1,48 MPa | 0,84 – 1,92 MPa | 1,28 – 3,42 MPa | 1,65 – 6,37 MPa |
| Poisson's ratio | | 0.111 – 0,306 | 0,115 – 0,309 | 0,109 – 0,271 | 0,112 – 0,345 |
| Modulus of deformation | | 148 – 778 MPa | 140 – 1319 MPa | 292 – 1494 MPa | 1316 – 10478 MPa |
| Youngmodulus of elasticity | | 210 – 798 MPa | 269 – 1369 MPa | 398 – 1976 MPa | 1447 – 13032 MPa |
| **WATER** | | | | | |
| Total alkalinity | | | | | 202,0 – 1054,0 g/m$^3$ |
| Carbonates | | **Faultzone – passing through geological environments 2,3,4,5** | | | < 10,0 – 24,1 g/m$^3$ |
| Bicarbonates | | | | | 248,0 – 665,5 g/m$^3$ |
| Sum Ca and Mg | | | | 28,0 – 536,0 g/m$^3$ | |
| $NH_3$ – N | | | | 0,07 – 0,75 g/m$^3$ | |
| $NO_3$ – N | | | | <0,02 – 1,58 g/m$^3$ | |
| Chlorides | | | 27,74 – 51,55 g/m$^3$ | | |
| Sulphates | | | 0,56 – 109,2 g/m$^3$ | | |
| Total of solids | | | 500,0 – 1427,0 g/m$^3$ | | |
| Total of soluble matter | | 421,0 – 1178 g/m$^3$ | | | |
| Free $CO_2$ | | 217,0 – 928,0 g/m$^3$ | | | |
| $Calcium_{2+}$ | | 8,7 – 155,8 g/m$^3$ | | | |
| $Magnesium_{2+}$ | | 1,6 – 35,9 g/m$^3$ | | | |

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