GEOTECHNICAL OPINION AND DOCUMENTATION OF SUBSOIL INVESTIGATION as part of the investment project of construction of device for Vacuum Degassing of Steel for Melt Shop

Place: ***Cracow, April 2018***
Municipality: ***Cracow municipality***
County: ***County of Cracow***
Province: ***Lesser Poland***

1. General information

Geotechnical Opinion together with Documentation of Subsoil Investigation has been prepared for the area of investigation as part of the investment project of construction of device for Vacuum Degassing of Steel for the Melt Shop.

The purpose of this study is to recognize the soil and water conditions at the premises of the Steel Melt Shop at ArcelorMittal S.A. in Cracow and to determine the geotechnical category of the planned building structures.

The following were applied to recognise the conditions in question:

- Regulation of the Minister of Transport, Construction and Maritime Economy of April 25th, 2012 on determination of geotechnical conditions for foundations of building structures (Journal of Laws No. 2012, item 463).
- “Geografia Fizyczna Polski” [Physical Geography of Poland] – J. Kondracki;
- “Zarys geotechniki” [An Outline of Geotechnics] – Z. Wiłun;
- “Hydrogeologia Ogólna” [General Hydrogeology] – Z. Pazdro;
- Archival documents;
- Literature;
- Visual inspection of the site;
- Performed works.

The results of works that have been performed and information gathered while performing them have been presented in this opinion and documentation.

2. Geographical Location

2.1 Location of the area and how it is used

The area of works that have been performed is located in the Lesser Poland Province [Małopolska], County of Cracow, Cracow Municipality, Nowa Huta District.

In the area of the planned project there are the devices and machines necessary in the process of transforming crude iron and scrap into liquid steel.

A general location of the area of works is shown on the topographic map at a scale of 1:10000 in Appendix 1, and a detailed one - on the map in Appendix 2.

2.2 Morphology and hydrography

According to the physical-geographical regionalization by Jerzy Kondracki, the project site belongs to the Sandomierz Basin macro-region (512.4-5) within which the Nadwiślańska Plain mesoregion is distinguished (512.41).

The area of investigations is located at the higher terrace of the Vistula River, on its left bank.

The floodplain terrace is located about 20 m above the Vistula valley and is composed of sandy-gravel and silt formations.

There are no natural lentic or lotic waters in the investigated area.

At a distance of approximately 1.4 km to the south-west, the Dłubnia river flows, which enters the Vistula River located approximately 2.0 km to the south from the area of investigations. The project site is located outside the area at risk of ground surface inundation.
Morphologically, the surface of the investigated area of ArcelorMittal plant, is very little varied. The site elevation in the area of the investigation is 218.6 m asl.

3. Description of performed works

3.1 Drilling

3 geotechnical boreholes have been made and marked as O-1, O-2 and O-3.
The O-1 and O-2 boreholes were 1.70 m deep, while the O-3 borehole - 20 m bgl, resulting in the total length of all boreholes of 54.0 meters. All the boreholes were made inside the Melt Shop hall in accordance with instructions of the customer.
On the map received from the customer, the area of the hall was divided into axes.
The boreholes O-1 and O-3 have been drilled between axes 46 and 47, while O-2 between axes 51 and 52. Location of the boreholes is shown on the documentary map at a scale of 1:200, Appendix 2.
The drillings were made by rotary drilling method, using the Æ100 mm. diameter spiral hollow stem auger.

During the drilling, a detailed macroscopic description of the drilled soil was carried out, attention being paid to the type of soil, its colour, moisture content, liquidity index and content of organic matter. Attention was also given to the occurrence of interbedding, lamination, admixtures etc. Also during the drilling representative samples were taken from the core run for laboratory analysis. Macroscopic description, collection and storage of all samples were carried out according to PN-EN 1997 - 2, Eurocode 7 "Geotechnical Design, Identification and Testing of the Subsoil".
After profiling and sampling, the boreholes were backfilled with excavated material (cuttings) compacted in layers, the lithologic and stratigraphic succession of drilled strata being observed.
The geotechnical borehole logs, containing the drilling results, are presented in Appendices 3.1-3.3.

3.2 Laboratory tests

The samples taken during drilling were submitted to the Soil Mechanics Laboratory of the Geological Company S.A., where macroscopic examination was performed. Then, in order to determine physical and mechanical properties of the soils, representative samples were selected from each lithologically varying layer for laboratory tests. These tests were conducted in accordance with Eurocode 7
Geotechnical Design, Part 2: Ground Investigation and Testing.
The conducted laboratory tests included identification of the basic physical characteristics of soil, such as grain-size analysis, natural moisture content, bulk density, Atterberg limits and determination of soil strength characteristics, including: the internal angle of friction and cohesion in the triaxial apparatus.
Tabulated results of the laboratory tests for individual soil samples are given in Appendix 6, while the grain size distribution graphs of the tested soil – in Appendix 7.

4. Geological structure

The general information about geological structure of the subsoil comes from geological, hydrogeological and economic maps of the region and explanations to them, as well as from archival studies, whereas the detailed information was obtained from geotechnical drillings, laboratory tests and observation of the area.

Geologically, the area of Krakow is located on the border of the Silesian-Cracow Monocline, Miechów Trough and Carpathian Foredeep. It is a heavily tectonically disturbed region, mainly due to the Neogene tectonics.

The area in question is located within the Carpathian Foredeep, filled with autochthonous Miocene formations and molasse. Flysch formations of the Outer Carpathians and folded allochthonous Miocene series moved over the Miocene deposits from the south. The Miocene substratum is made up of Upper Jurassic limestones. The entire surface of the area of investigations is covered by Quaternary formations, filling the proglacial stream valley of the Vistula River and forming a series of floodplain terraces. These are usually sandy-gravel deposits of fluvioglacial and fluvial origin. The loose formations have probably accumulated in the period of northern Poland glaciations, but a part of this series may be the sediments of the Vistula River.

In the subsoil of the documented site, Tertiary (Miocene) and Quaternary formations occur. However, Quaternary soils were found down to the depth of the borings drilled, because the analysis of archival material shows that the Miocene soils occur at the terrain elevations below 190 m asl, i.e. more than 25 meters below ground level.

Both cohesive and loose Quaternary formations occur in the area of investigations. Cohesive deposits are mainly formed as: silts with clay, silts, locally silts with clay and inserts of sand, with consistence ranging from solid to plastic. Cohesive formations make a complex with significant thickness, located directly under the anthropogenic soils and over loose formations. At the area of investigations in question, the cohesive formations have been drilled in all three boreholes at the depth from 0.8 to1.5 m bgl, and their thickness is 12.3 to 13.2 m. Loose formation were encountered in all boreholes that were made. These are the medium sands in a semi-dense state, locally with a clay or with inserts of silts with clay. They are located below the cohesive formations, at the depths of 13.8-14.3 m bgl. They were not drilled through and reached to the depth of the borings made.

The boreholes have been made inside the Melt Shop hall, therefore over the entire surface of the invested area there are the anthropogenic formations with a thickness from 0.8 to 1.5 m bgl. Locally, the thickness between the boreholes may be greater due to the presence of foundations under the machinery in the area of the hall and as a result of previous, numerous redevelopments of the plant area.

5. Hydrogeological conditions

The general information about hydrogeological conditions come from a hydrogeological map and archival studies.

The area discussed is located in the catchment area of the Vistula River (first order river), between its left-bank tributary Dłubnia river (second order river).

Groundwater is present here in the Quaternary sand and gravel formations and forms a continuous water-bearing horizon (aquifer) of free-flow or slightly confined type. A periodic seepage in the cohesive Quaternary formations may also occur. The ground level waters are supplied by infiltration of rainwater and snowmelt water. The water level periodically and

significantly fluctuates (during a drought, increased precipitation, spring thaw, floods and flood conditions).
The area of investigations is located close to the boundary of a Quaternary major groundwater reservoir (GZWP 450) of the Vistula River valley.
It is a porous medium reservoir, located in the Holocene sandy and sandy-gravelly formations, locally clayey, showing a diverse natural resistance to contamination. The reservoir is connected with the system of fossil river valleys only slightly coinciding with the contemporary hydrographic system. The water-bearing deposits of GZWP 450 have a thickness of 3-6 m, occasionally reaching even 10-12 m, at a capacity from a single well above 2 m3/h. The average filtration rate for the aquiferous layer determined based on the trial pumpings from the wells in the neighbouring areas is k=6.08*10-4 m/s.
During the research works a free surface of water has been drilled in the O-3 borehole at a depth of 18.0 m bgl, corresponding to a level of 200.6 m asl.

6. Geological model with determination of derived geotechnical data

The subgrade soils have been classified and characterized based on the field work, laboratory tests of soil samples, analysis of archival materials as well as engineering analyses and calculations. The subsoil has been identified to a maximum depth of 20.0 m bgl.

Three geotechnical strata have been distinguished, the distinguishing criteria being: strength parameters, origin, type of soil as well as states of consistency and density. These are:
Stratum I – anthropogenic formations;
Stratum IIa – cohesive soils in semi-solid and hard plastic state;
Stratum IIb – cohesive soils in plastic state;
Stratum III – loose formations.
The values of liquidity index I_L were determined using laboratory method and field method based on the results of conducted field investigations.
The values of internal angle of friction and cohesion of soil were determined in the triaxial apparatus.
Interpretation of the spatial pattern of geotechnical layers is illustrated by the geotechnical cross-sections, presented in Appendices 5.1-5.3. However, another pattern of the boundaries of strata, their depth and thickness, may locally exist, especially within the anthropogenic soils. Because this area was previously built-up, foundations or the old buildings are likely to occur.
Summary results of laboratory tests are presented in Appendix 6.
Below is a description of individual distinguished strata:

Stratum I – encountered in all geotechnical boreholes. Because the drillings were carried out inside the melt shop hall, at the initial section of the borehole profiles there were the anthropogenic soils. In the area of the O-1 borehole there is a 0.2 m thick concrete topping on a fill of rubble with silt and clay. In the O-2 borehole there is a fill made of grit, rubble and silt with clay up to a depth of 1.3 m bgl, and in the O-3 borehole there is a flooring of clinker brick, on a fill made of aggregate, grit and stones. The total thickness of anthropogenic formations is 0.8-1.5 m, but locally it may be thicker due to the previous, numerous redevelopments of the plant area and the presence of foundations under the machinery within the area of the hall.

Stratum II **–** encountered in all geotechnical boreholes, formed by cohesive Quaternary soils. It is mainly formed as silt with clay, silt, sporadically with sand inserts, in solid, hard plastic and plastic state. These formations are present directly below the strata of anthropogenic soils at the depth from 0.8 to 1.5 m bgl.
The cohesive soils are sensitive to water because of a high content of the silt and clay fractions, therefore their parameters may deteriorate at contact with waters, for example with groundwater seepage. According to the state of soils, the II geotechnical stratum was divided into the soils of solid and hard plastic state - IIa and plastic state - IIb.

Stratum IIa – it was drilled in all boreholes that have been made just below the anthropogenic formations of the stratum I, i.e. at a depth of 0.8-1.5 m and it reaches up to the depth of 7.5 m in O-1 boreholes and 14.3 m bgl. Its thickness ranges from 6.0 m in borehole O-1 to 11.0 m in borehole O-3. The Stratum IIa is formed as silt with clay in solid and hard plastic state. These formations are wet and moist, light-brown. Soils of the stratum IIa are characterized by the following parameters:
- natural moisture content w_n = 18.7 %
- bulk density r = 2.100 g/cm^3
- degree of plasticity I_L = 0.00
- internal angle of friction f_u = 21^o
- cohesion C_u = 28 kPa

Stratum IIb – it was drilled in all boreholes that have been made, just below the stratum IIa, and above the stratum III, i.e. at the depths of 7.5-11.0 m bgl and reaches to the depth of 13.8-14.3 m. Its thickness ranges from 3.0 m in borehole O-3 to 6.3 m in borehole O-1. The stratum IIb is formed as silt with clay, in plastic state, sporadically with sand inserts. These soils are wet and light brown. Stratum IIb is characterised by the following parameters:
- natural moisture content w_n = 22.4 %
- bulk density r = 2.025 g/cm3
- degree of plasticity I_L = 0.40
- internal angle of friction f_u = 13o
- cohesion C_u = 18 kPa

Stratum III – encountered in all geotechnical boreholes. Stratum III is formed as Quaternary non-cohesive soils, represented by medium sand, sand with clay, locally medium sand with inserts of silt with clay, at semi-dense state, moist, saturated, bright brown and brown. The roof of these formations is located below the soils of stratum II at the depth of 13.8-14.3 m. Thickness of this stratum is not known, as it has not been drilled through. Stratum III formations are characterised by the following parameters:
- bulk density r = 1.850 g/cm3
- degree of density I_D = 0.50
- internal angle of friction f_u = 30.0^o

7. Assessment of the suitability of the area for the designed objects

A cover of Quaternary formations was found in the subsoil, in the roof covered by 0.8-1.5 m thick anthropogenic formations.
They are built of clinker floor or concrete slab placed on a substructure made of silt with clay and sand, mixed with concrete rubble or aggregate.
Due to the fact that the area was redeveloped several times, there is a possibility of encountering remains of the foundations of old buildings and an increased thickness of anthropogenic formations at some places when earthworks are conducted between the drilled boreholes.
Below the anthropogenic formations there are Quaternary cohesive formations in the form of silt with clay and, sporadically, silt with clay and inserts of sand in the states from solid to plastic. At the same time, solid and hard-plastic formations form a significant part of the substrate. Together with anthropogenic formations they reach the depth of 7.5-11.0 m bgl. The plastic formations are located below and reach the depth of 13.8-14.3 m bgl. Thickness of plastic soils at the places of drillings was 3.0-6.3 m. Below there is a roof of loose formations (13.8-14.3 m), developed as medium sands at semi-dense state, locally sand with clay and medium sand with the inserts of silt with clay. Sandy formations were not drilled through and reached the depth of the drillings that have been made, and their minimum thickness was 3.2 m.
In the investigated area, in a borehole O-3 a water table was found at the depth of 18.0 m bgl. Groundwater seepage may occur within the area of cohesive formations, whose amount and intensity varies depending on weather conditions, such as draughts, precipitation, floods, snow melt. Cohesive soils are very sensitive to changes in volume associate with the change in amount and state of water, hence they may be subject to shrinking, swelling and heaving, the plastic and soft plastic soils being most vulnerable.
According to the Regulation of the Minister of Transport, Building and Maritime Economy of 25 April 2012. (Journal of Laws 2012, item 463) on determination of geotechnical conditions for foundations of building structures, the area being concerned is subject to simple soil conditions and it is proposed to assign the II geotechnical category, but it will finally be determined by the designer in the building design after determining the size of loads from the designed objects and the depth of foundations.

8. Conclusions and recommendations

1. This study was ordered by ArcelorMittal Poland S.A., 41-308 Dąbrowa Górnicza, al. Piłsudskiego 92.
2. This documentation presents the results of the works carried out as part of the investment task consisting of constructing a Vacuum Degassing Device for the Melt Shop.
3. As part of the works carried out inside the Melt Shop Plant, 3 geotechnical boreholes were drilled: O-1 and O-2 boreholes to the depth of 17.0 m and O-3 borehole to the depth of 18.0 m bgl. In addition, the samples of soil taken from the boreholes were subject to laboratory tests, allowing determination of the basic physical and strength properties of the soils. Location of the drillings is shown on a documentary map at a scale of 1: 200, Appendix 2.
4. Description of geological structure of the area in questions has been presented in section 4, and the hydrogeological conditions in section 5.
5. For detailed description of the distinguished geotechnical strata, see Section 6.
6. If piles are to be used, it is necessary, when making the piles, to perform acceptance of the subgrade for one pile in the group of piles forming a separate foundation for compliance of the subgrade soil parameters with the documentation.

7. When planning deeper excavations, secure the walls of the excavations to ensure the stability of their walls, by formworking or shaping the walls at an appropriate slope and by preventing any possible inflow of ground water.
8. During the periods of increased precipitation and spring snowmelt, seepage may occur in cohesive soils, the number and intensity of which may increase.
9. Where cohesive soils are exposed to water, which severely affects their physical and mechanical parameters, it is advisable to limit the use of vibration technology in the works associated with foundation of the building, because of the potential occurrence of thixotropy phenomenon.
10. The area of the performed works is developed, therefore, before any groundwork is commenced a detailed inventory should be made of the underground infrastructure and other underground objects which may affect the foundation of the designed structures.
11. According to the Regulation of the Minister of Transport, Building and Maritime Economy of 25 April 2012. (Journal of Laws 2012, item 463) on determination of geotechnical conditions for foundations of building structures, the area is subject to simple soil conditions and I propose to assign the II geotechnical category for the structures to be designed.