MINING AND METALLURGY INSTITUTE BOR
UDK: 622

ISSN: 2334-8836 (Štampano izdanje)
ISSN: 2406-1395 (Online)

UDK: 621.311.243:622(045)=111
DOI: 10.5937/mmeb2401007S

Received: 08.05.2024.
Revised: 20.05.2024.
Accepted: 23.05.2024.

Original Scientific Paper
Mining

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MULTIDISCIPLINARY APPROACH TO THE ANALYSIS OF SUITABILITY THE LOCATION INTENDED FOR CONSTRUCTION THE SOLAR POWER PLANTS ON THE AREA OF A MINING WASTE DUMP[***]

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Abstract

By analyzing the world's best practices, the mining waste dumps can be turned into suitable land for location the renewable and clean energy power plants. There are several advantages that characterize these locations: they are characterized by the environmental conditions that are not acceptable for commercial or residential development. Generally, they are located near the existing roads and energy transmission or distribution infrastructure. They can be adequately zoned for renewable energy sources, provide the opportunity for employment in the urban communities and to promote cleaner and more cost-effective energy technologies, reduce the impact of energy systems on the environment (e.g. reduce the emission of harmful gases). As the solar power plants are usually built on large areas, which can lead to the changes in geological and geotechnical conditions along the project site, it is extremely important to design the appropriate geotechnical investigations to reduce or limit the geological uncertainty and determine the suitability of site for construction. In these cases, the geotechnical studies are very complex, striving for a multidisciplinary approach in analyzing the site in question for construction a solar power plant, respecting the current legislation, regulations, norms and standards.

Keywords: *solar power plants, renewable energy, geotechnics, mining waste dump*

1 INTRODUCTION

Using the publicly available information [1], the US Environmental Protection Agency (EPA) monitored the completed renewable energy projects on previously contaminated land, landfills, and mine dumps in order to identify the trends, educate stakeholders, and encourage the future development and site reconstruction. Solar power plants on landfills were a particularly attractive option for reconstruction and over time represented an increasing share in all locations intended for conversion of space (Figure 1).

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[***] *This work was financially supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, Contract on realization and financing of the scientific research work of the Mining and Metallurgy Institute Bor in 2024, Contract No.: 451-03-66/2024-03/ 200052*

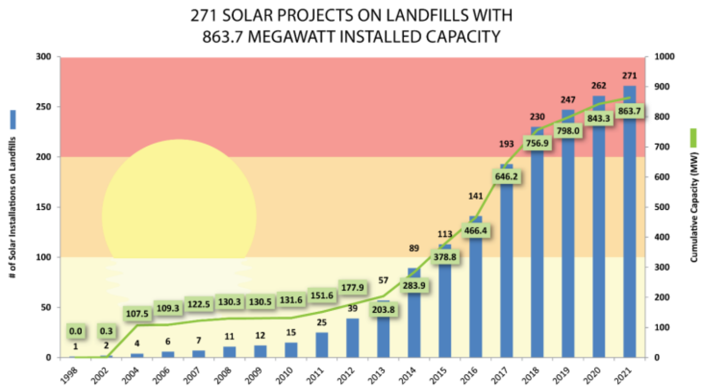


Figure 1 *Annual growth of solar installations on landfills (Source EPA) [1]*

In 2012, the solar power plants on landfills, intended for construction the renewable energy sources accounted for 39% of the total number of locations, while in 2018 that percentage was significantly higher (81%).

Regarding the potential of locations for construction the solar power plants on landfills and dumps, the ETA created a map of potential locations for their construction, available to the future Investors (RE-Powering Mapper), Figure 2 [1].

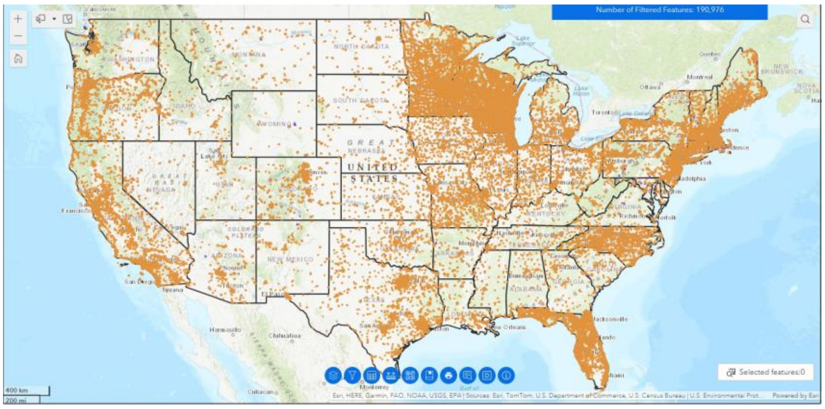


Figure 2 *RE-Powering Mapper application [1]*

The RE - Powering Mapper application enables searching:

- For multiple types of solar, wind, biomass and geothermal energy locations;
- According to several attributes including country, area, renewable energy capacity, distance to the nearest urban centers and more;
- Site Specific Screening Reports with Geotechnical Studies;
- Liaison with the EPA or state program that governs the land repurposing.

Geotechnical studies are necessary to analyze the site suitability for construction the renewable and clean energy power plants. This paper presents the recommendations for design the exploration and laboratory works, based on the latest world experience [2] (appropriate and optimal scope of geological and geotechnical explorations for the new solar power plants).

2 COMPLEXITY OF THE GEOTECHNICAL STUDY

For the new solar power installations, a good geotechnical study must bring together a range of multidisciplinary data and provide the following information:

- Geomorphological characteristics of the location, with an analysis of threats from external high water;
- Effect of high water on erosion, i.e. washing of material;
- Defining the relevant precipitation intensities for different probabilities of occurrence;
- Defining the relevant high water of torrential watercourses for occurrence probabilities of 1% and 2%;
- Defining the common meteorological parameters such as relative humidity, precipitation, temperatures, air pressure, sunshine, wind direction and intensity, wind rose, etc.;
- Defining the characteristic snow load, in accordance with the valid regulations and standards;
- Carrying out a precise zoning of the soil according to its geological and geotechnical characteristics with the delimitation of areas where photo power panels cannot be installed;
- Defining the panel funding methods: type, feasibility, limitations;
- Analyzing the aggressiveness of soil and groundwater, with an assessment the corrosiveness of foundation soil and groundwater on concrete structure, reinforcement in the reinforced concrete structure and steel structure;
- Providing data on electrical resistance of different grounding levels for appropriate designed groundings;
- Defining the geotechnical parameters of the represented soil lithotypes (soil classification, shear strength, deformability...) in which the foundations of panels will be founded;
- According to the Eurocode EC8-1, determining the type of soil at location;
- Assessment the possibility of earth excavating for the recommended type of machine for earthworks and digging trenches (providing data on depth and angle of temporary excavations);
- Determining the calculated bearing capacity and settlement for shallow foundations (foundation strips and foundation soles);
- Assessment the strength of deep foundations on piles, which is confirmed by the pull-out tests;
- Detecting and quantifying the geological hazards (risks) such as: earthquakes, watersheds, collapses, erosions, landslides;
- Defining the groundwater levels and main hydrogeological characteristics of different represented soil lithotypes;
- Determining the thermal resistance of natural soil and disposed material necessary to design the electrical trenches.

3 TYPES AND SCOPE OF MULTIDISCIPLINARY RESEARCH AND TESTS FOR GEOTECHNICAL STUDY

Research and testing methods must be carried out in accordance with the modern world trends, valid legal regulations on the type, scope and density of exploratory works and laboratory tests, providing the guidelines that can be used by the planners and designers of solar power plants, through the following stages:

3.1 Field exploratory works

- *Engineering geological mapping of the field* where the solar power plant zone should be registered and adequately displayed on the map and geotechnical sections of the following data on the field: lithological composition of the terrain and genesis, structural and textural characteristics of the field, hydrogeological phenomena, active geological processes and phenomena created in the field;
- Instrumental locating of exploratory wells, *execution of exploratory drill holes*, engineering geological mapping of the core of exploratory drill holes with sampling for laboratory-geomechanical tests, performing the standard penetration test in wells *(SPT);*
- *Performing a dynamic penetration test (DPT)* in order to obtain the soil compaction and dynamic soil resistance, through which the compressibility modules, bulk weights, undrained cohesion in clay soil and angles of internal friction in sand, gravel and clayey sand are determined by the correlation links. The dynamic penetration test is the most suitable test for evaluation the soil strength, feasibility of piling and precise zoning of the field, due to its ease of use, portability and lower cost of execution compared to the other techniques, Figure 3. The results of these tests can be correlated with the SPT test values in exploratory drill holes;

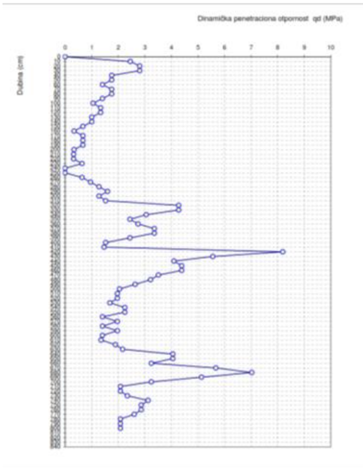


Figure 3 *Dynamic penetrometer Pagani DPM 30/20 with dynamic penetration resistance curve qd (MPa)*

- *Measuring the electrical resistance of the soil.* The most widespread and convenient technique for an electrical resistance analysis is the electrical tomography using a Venner array with 21 to 42 electrodes placed along the line [3]. With these configurations, the electrical resistivity of the soil laterally and in depth can be determined. The interpretation of these results makes it possible to create a representation of different geological units in a crosssection. Alternatively, the VES (Vertical Electrical Soundings) tests can be used, which determine the electrical resistance at a single point at various depths. This technique has been surpassed by the electrical tomography because, as stated earlier, it has the advantage of being able to make a geological interpretation over a larger area;

- *Measuring the thermal conductivity of the soil.* Thermal conductivity is the ability of soil to conduct or dissipate heat. It depends on the type of soil, humidity and temperature. In the case of electrical trenches, it is important to determine the thermal properties of the natural soil or thermal properties of the deposited material. Thermal resistance tests are carried out on the floors of the open pits, in the exploratory drill holes or exploratory excavations. This allows the thermal conductivity measurements to be performed in situ at the desired depth or at different depths. The undisturbed samples can be used for further testing in the laboratory with a range of moisture content (drying curve) or even with different temperatures [4]. The results of thermal conductivity must be followed by data for the density and moisture of sample, since these parameters largely determine the thermal properties of the soil, Figure 4.

(a) (b)

Figure 4 *Manual petrol drill Villager with power 2.2 kW (a) and heating and cooling curves on a representative sample (b)*

- *Conducting the exploratory excavations*, if it is necessary to classify the base for construction the paths/roads or to determine in detail the deformability of shallow foundations, using a dynamic plate, or an "in situ" CBR test.

The overview table 1 presents the minimum field explorations that must be carried out, depending on the size of the landfill, that is, the space intended for construction the solar power plant. The number of exploratory works should be increased or decreased depending on the local conditions (shape, slope, geology of the narrower exploration area, accessibility, existing facilities, etc.).

Any field exploratory work must be continuously controlled by a geotechnical engineer focused on the project needs and its details.

Table 1 *Recommended number of field explorations depending on the project area*

Surface (ha)	Number of exploratory excavations	Number of dynamic penetrometer test points	Number of electrical resistance test points	Number of conductivity temperature test points
<2	3-5	3-5	1-2	1-2
2-5	5-7	5-7	2-3	2-3
5-10	7-12	7-12	3-5	3-5
10-30	12-22	12-22	5-9	5-9
30-100	22-40	22-40	9-11	9-11
100-300	40-60	40-60	11-15	11-15
> 300	1 for every 5 ha	1 for every 5 ha	1 for every 20 ha	1 for every 20 ha

3.2 Laboratory testing

Laboratory tests can be divided into several groups. The purpose of testing the physical and mechanical properties of rocks and soil in the field is to obtain the physical and mechanical strength parameters, as well as deformability parameters required for the geostatic calculations.

The overview Table 2 presents the recommended number of laboratory analyses according to the number of samples:

Table 2 *Recommended number of laboratory analyses*

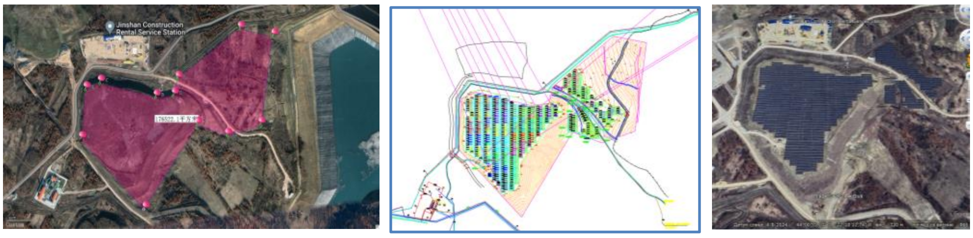
Test name	**Every 5 samples**
IDENTIFICATION TESTS	
Humidity, w (%)	5
Specific gravity, γs (kN/m^3)	5
Volumetric weight, γz (kN/m^3)	5
Granulometric composition of soil	5
Soil consistency limits - Atterberg limits	5
TEST FOR STRDENGTH DETERMINING	
Parameters of direct shear resistance - soil	0.5
MATERIAL USABILITY	
Modified proctor test	0.25
CBR index	0.25
ROCKS	
Density	0.75
Point Load Test	0.75
CHEMICAL ANALYSIS	
Content of organic and combustible matters	1
Sulfate content	1
Water aggressiveness on concrete	1
pH	1
Chloride content	1
Alkalinity/acidity determination	1
Content of soluble sulfates (in water and acid)	1
Determination of acidity according to Baumann-Gully	1

3.3 Cabinet works

Geological-geotechnical reports are directly related and can be divided into: Reports on Work Performed, Preliminary Reports and Final Reports.

4 CONSIDERATIONS AND RECOMMENDATIONS FOR THE CONSTRUCTION OF A SOLAR POWER PLANT IN THE SURROUNDINGS OF BOR

Based on the latest world experience, looking at and evaluating the hydrological, engineering geological, hydrogeological, geotechnical and chemical properties of the field, position and purpose of the solar power plant itself (Figure 5) [5], the following is significant:



(a) (b) (c)

Figure 5 *Solar power plant project from location to the construction (a, b, c)*

- Morphological characteristics of a wider site planned for construction are the result of geological processes in geological history, out o0f which the most significant are the intense tectonic effects and exogenous processes. The field on which the site in question is located is mostly flat, or with a slight slope. The absolute elevations of the field are between 342.05-345.98 meters above sea level (difference around 4.0 m);
- The field is located on the watershed of the Grčava basin, outside the effect of existing watercourses. The location is not threatened by the external high water, only by precipitation that falls on the location itself and which should be evacuated in an appropriate manner;
- According to the A. Casagrande criteria, the soil on the site is dangerous to the effects of frost;
- Adopt a minimum of 1 m for the depth of soil freezing;
- The value of snow load on the ground for location is: Sk = 2 kN/m^2;
- Dominant wind direction is from southwest to the northeast;
- Regarding the soil corrosivity, only one sample showed a high level of sulfate > 200 mg/kg, which places a field part in the middle with the medium corrosive potential;

- Relative air humidity ranges from 70%-86%, the mean value is 78%, which according to the degree of corrosiveness to steel, according to this parameter, places the location in the C4 category;
- It is recommended that the average thickness of a galvanized layer on the surface of a spiral steel pile should not be less than 80 μm, and the local minimum thickness should not be less than 60 μm;
- The field, up to the test depth (8.00 m), is built of sediments of the anthropogenic origin and Quaternary age, except for the area for construction of connection-distribution facility where the Miocene sandstones are represented;
- According to the GN-200, the sediments of anthropogenic origin and Quaternary age belong to the category III, while the Miocene sandstones belong to the category IV-V;
- On the basis of performed geophysical measurements, it can be said that the humidity at the location in question ranges from 13.5% to 31.8% to a depth of 1 m, or from 20.1% to 40% to a depth of 2 m. On the basis of performed analysis, it can be stated that the thermal conductivity values for humidity of samples from 13.5% to 22.8% range from 0.709 W/mK to 0.864 W/mK with the heating temperature range from 23.5°C to 28,7°C. Thermal conductivity values for humidity samples from 25% to 40% range from 0.894 W/mK to 1.049 W/mK with an average heating temperature range of 23.2°C to 25.6°C. The average values of electrical conductivity parameter (σ) to a depth of 1 m are about 221 ms^{-1} and 208 ms^{-1} to a depth of 2 m. Based on all the measurements, performed at location 01, the mean values of measured parameters are shown, Table 3.

Table 3 *Mean values of measured parameters*

Mean parameter values at location 01		
Parameter	Depth 1.0 m	Depth 2.0 m
Heating temperature range (°C)	23.5 – 28.7	23.2 – 25.6
Thermal conductivity range	0.759—0.969	0.821 – 1.049
Thermal conductivity	0.846	0.915
Humidityω_{mean}(%)	22.6	27.4

- On a total of 2 engineering geological profiles, the conditions prevailing in the field were interpreted;
- By analyzing and synthesizing the results from the field explorations and laboratory tests, it can be said that there are 2 quasi-homogeneous environments on tested field, separated by their genetic type (anthropogenic sediments and Quaternary deposits), more important engineering-geological properties and physical-mechanical characteristics;
- During the performing of exploratory drilling in the drill holes, no underground water was found in the field;

- Design the object at 8^o MCS. According to the Eurocode EC8-1, the site belongs to the soil type D;
- The expert survey of the field did not reveal the morphological forms that would indicate the movement of earth masses, at the location and its immediate surroundings. The general conclusion is that the field in natural conditions is stable, and as such suitable for any type of urbanization with respect to the recommendations;
- In an interactive sense, by analyzing the engineering geological sections of the field, on one side, and the object on the other, the quasi-homogeneous zones were distinguished, which differ from each other in geotechnical characteristics, and the geotechnical models of the field were adopted accordingly;
- According to the calculations, for the foundation depth D_f = 1.30 m and D_f = 1.50 m and different dimensions of the foundation plates (4.05 x 5.55 m, 12.50 x 3.50 m, 10.80 x 3.50 m and 6.00 x 2.50 m), the calculated values of the bearing capacity of the foundation soil (with a buffer layer d = 10 cm) are higher than the designed loads;
- Calculation of the settlement size obtained for foundation singles is for the central point s = 0.00-4.69 cm;
- The calculated bearing capacity and settlement of the spiral steel pile is determined for different lengths and diameters of the pile. Values of the safety factor (Fs) that do not meet the stability condition are marked;
- The results of geostatic calculations of the landfill slope stability showed that the stability in relation to the shearing is ensured. The stability analysis was performed for the case of calm loading (without an earthquake) and for the case of an earthquake, where the impact of earthquake was simulated by adding the horizontal forces whose values were adopted for a specific location;
- Based on the new knowledge gained about the field, the recommendations for designers during construction and exploitation are listed, what will ensure the safety, durability and full operational usability of the solar power plant facility.

5 CONCLUSION

Evaluation the location suitability of the mining waste dump in terms of sustainability is a difficult task and should be solved comprehensively [6]. A good geological-geotechnical study is always necessary in evaluation the suitability for construction a solar power plant, providing the valid data for design, reducing risks and long-term problems during the facility exploitation. In addition to the above, it must not be forgotten the administrative needs arising from guarantees during the financing or purchase-sale process.

REFERENCES

[1] Best Practices for Siting Solar Photovoltaics on Municipal Solid Waste Landfills, EPA (2022), https://www.epa.gov/re-powering/

[2] Marín F.P., Chinarro J.A.L., Technical Specifications of Geological – Geotechnical Requests for Photovoltaic Plants, Orbis Terrarum, 2021.

[3] Standard Test Method for Measurement of Soil Resistivity Using the Wenner Four - Electrode Method (ASTM G57-20). ASTM International 2020, https://www.astm.org/

[4] Dorronsoro J., Merino C., Technical Specifications on Electrical Methods for the Request of a Geophysical Study for New Photovoltaic Plants, Orbis Terrarum, 2022.

[5] Savić D., Project Study on Geotechnical Conditions for Construction of a 9.99 MW Solar Power Plant (2# Mining Waste Landfill) in Bor - Location 1, Geoing Group, 2023. (In Serbian)

[6] Sivakumar Babu G.L., Lakshmikanthan P., Santhosh L.G., Assessment of Landfill Sustainability, https://www.researchgate.net/publication/310740034.