TECHNICAL SPECIFICATIONS OF GEOLOGICAL – GEOTECHNICAL REQUESTS FOR PHOTOVOLTAIC PLANTS

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Key words: Photovoltaic plants, Renewable Energy, Geotechnics, in-situ tests, Electric Tomography, Corrosivity, Expansive Clays.

Abstract: Photovoltaic plants are usually constructed over large areas of land. This leads to changes in geological and geotechnical conditions along the project site. To reduce these geological uncertainties, it is extremely important to design an appropriate geotechnical survey. This article contains and provides the technical recommendations and scope for requests, based on the wide background of ORBIS TERRARUM in geological and geotechnical studies all over the world, see the countries on the world map at www.orbisterrarum.es

1. INTRODUCTION

This document includes the design recommendations for an appropriate and optimum geological and geotechnical survey for new PV plants, based on ORBIS TERRARUM experience, studying more than 620 PV plants in different countries, which involves more than 50 GW installed.

The cost and deadlines optimization is present in the type of investigations proposed. A good geological and geotechnical study is always necessary in the project of a photovoltaic plant to provide valid data for the design and to avoid risks and long-term problems during the plant operation. In addition, we must not forget the administrative needs derived from the guarantees during the financing or purchase-sale processes.

A good geotechnical report should include the following information:

- Accurate ground zoning (mapping) according to geological and geotechnical features
- Delimitation of the areas where PV modules cannot be installed.
- Definition of the module foundations: type, driving feasibility, limitations…
- Analysis of the ground aggressiveness for concrete and steel (corrosion potential).
- Electrical resistivity data of the different ground levels for an appropriate earthing system design.
- Geotechnical parameters of the different ground strata (classification, strength, deformability…) that will be used for foundation design.
- Ground excavatability and the recommended machinery for earthworks and trenching.
- Recommended excavation slopes.

- The bearing capacity for shallow foundations.
- The pile foundation strength, which will be confirmed with later pull out tests that also provide deformability data.
- Geological hazards such as earthquakes, swelling, collapse, erosion, landslide occurrence, karst…
- Identification of man-made fills and/or ground contamination
- Groundwater level detection and main hydrogeological features of the different strata.
- The thermal resistivity of the natural ground and the fill material (with different moisture content) for the design of electrical trenches.

The following chapters describe the different site investigations, laboratory tests, and report content that provide a guideline that can be used by the promoters and designers of photovoltaic plants as a first approach for geotechnical study requests.

Sometimes, these geotechnical studies must be completed with specific studies for electrical lines, electrical substations and/or roads or paths which are generally regulated by local codes or standards.

2. GROUND INVESTIGATION

2.1. Geological mapping

A surficial geological mapping of the site will be needed. This mapping is generally based on direct observations (geotechnical investigations, geological materials, outcrops, geomorphology…), geological bibliography, and the interpretation of indirect data from geophysical techniques, such as electrical tomography. Geomechanical stations will be made in rock outcrops to determine the weathering degree, fracturing and rock mass structure.

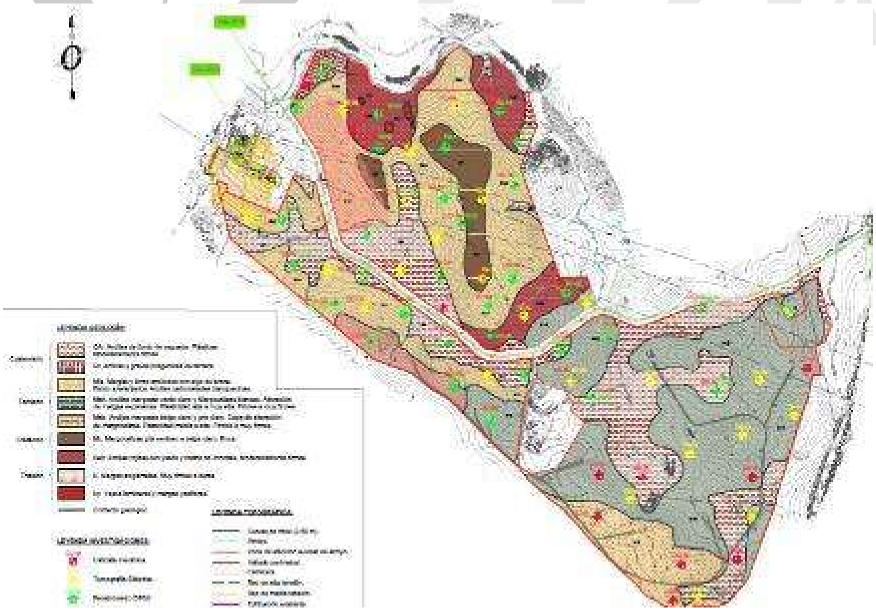

Fig. 1: Geological mapping drawing developed by ORBIS TERRARUM

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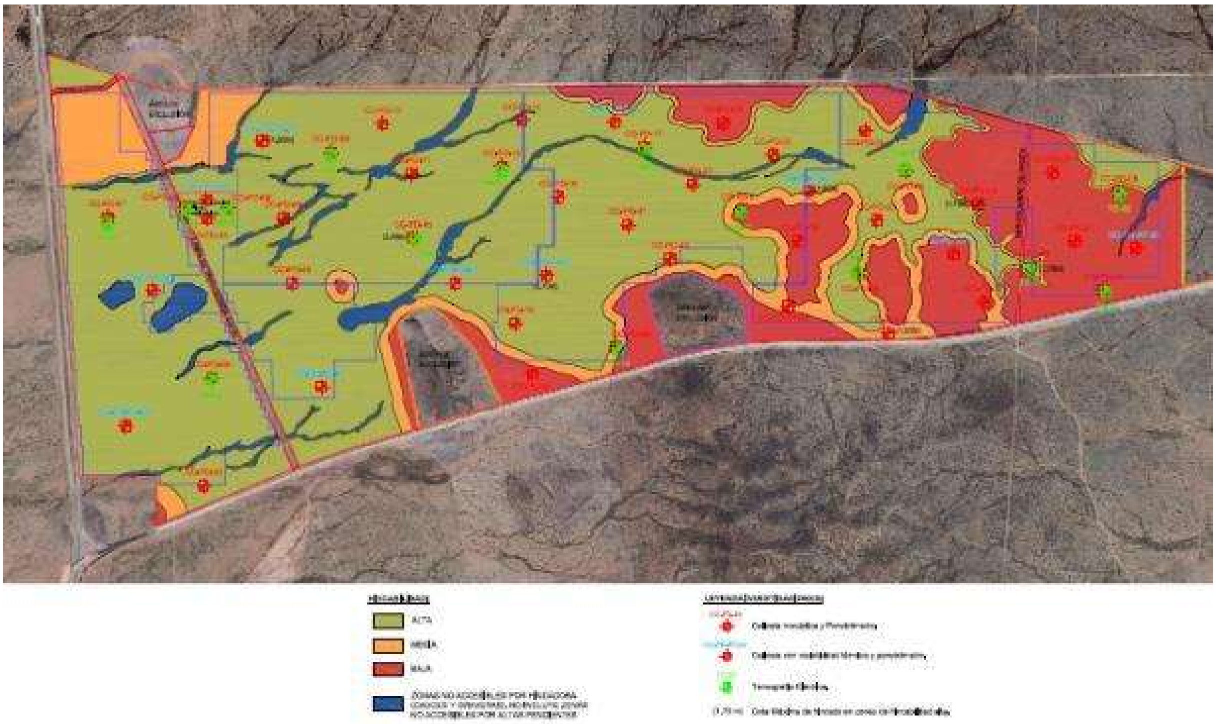

Fig. 2: Technical feasibility of driven piles drawing, developed by ORBIS TERRARUM

2.2. Trial pits

Direct data is generally collected by mechanical trial pits up to 3,5 m depth, slightly longer than the usual length of the driven metallic piles for the module foundations. These investigations are useful to study the ground under other facilities (as inverters, lightweight buildings...) for the geotechnical foundation design. During the excavation of the trial pits, a specialised technician (geologist or similar) will make a geological-geotechnical description of the different strata, and collect representative samples (of soil, rock and water). Any remarkable aspect as the presence of man-made fills, or contamination evidence will also be marked. Once a trial pit is finished it is closed by filling it with the excavated soil properly compacted to avoid any hazard to people or cattle.

Fig. 3: Trial pit detail for geological log and sampling

Trial pit campaigns could be complemented with other investigations as boreholes with sample recovery, in-situ infiltration/permeability tests, refraction seismic tests and passive seismic as ReMi for

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seismic hazard zones, or even Orbis' geophysics department uses the ground penetration radar (GPR) for detection of archaeological finds and/or underground services.

For the design of the geotechnical campaign the presence and location of underground services must be previously known.

2.3. Dynamic penetration tests

Dynamic penetration tests are the most suitable for estimating ground strength, pile driving feasibility, and accurate zonation, due to their easy use, transportability, and reduced price in comparison with other techniques. It is very common to use light penetrometers type Panda2, especially in soft soils and in difficult-to-access areas. Other heavy penetrometers as DPSH type are commonly used on harder soils. Both results of these tests can be correlated with the value of the SPT test.

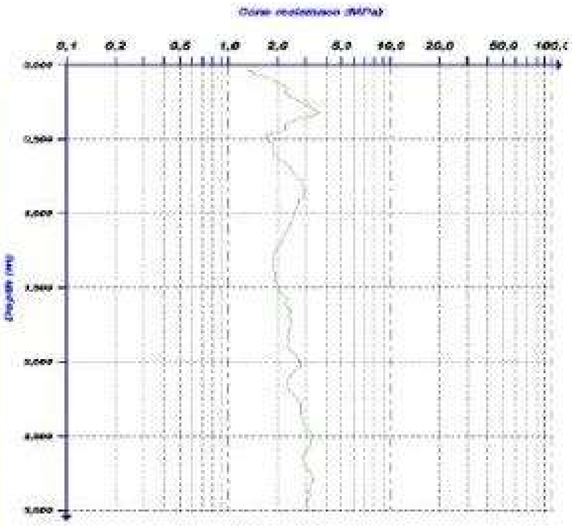

Fig. 4: Lightweight penetrometers and real penetrometer log

Penetrometer tests estimate the penetration strength of the different geotechnical strata observed into the trial pits.

In countries where these penetrometers are not well known, it is possible to replace them with SPT type boreholes, performing SPT tests continuously up to the stated depth (usually 3,0 or 4,0 m).

It is very important to determine the topsoil thickness. Topsoil usually has low strength and a variable content of organic matter. As this soil is rarely removed, especially in horizontally-and-flat sites, it is highly recommended to not consider its thickness a strength in the design of the pile foundation length.

2.4. Electrical resistivity

The most extended and suitable technique for the electrical resistivity analysis is the electrical tomography using a Wenner array with 21 to 42 electrodes placed along a line. With this configuration the electrical resistivity of the ground can be determined along the line and also in depth. The interpretation of these results allows us to make a representation of the different geological units in a cross-section.

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Alternatively, VES (Vertical Electrical Soundings) tests can be used, which determine the electrical resistivity of a single point at different depths. This technique has been surpassed by electrical tomography since it is able to make a geological interpretation of a larger surface area.

Determining the electrical resistivity is important to estimate the corrosion potential of soil and design the earthing system.

Picture 1: Geophysical test by electrical tomography

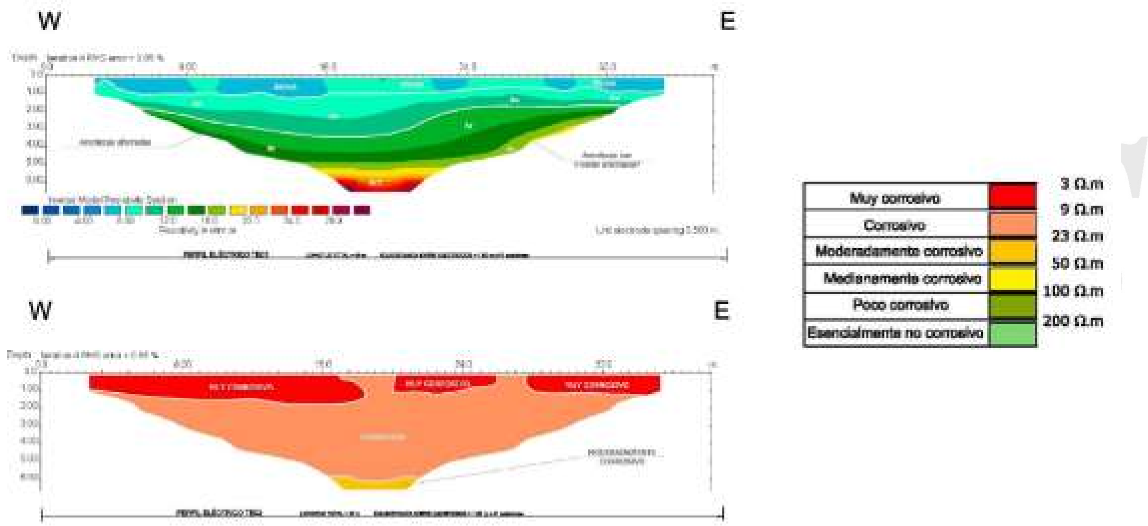

Fig. 5: Electrical Tomography sections. Up: with geological interpretation. Down: with corrosion potential

The measurement of electrical resistivity can also be carried out in the laboratory using the Soil-Box device. In this case, the measurement is carried out on compacted samples subsequently saturated with distilled water. This parameter is recommended for the definition of the corrosion potential according to American codes.

Picture 2: Soil-Box device for measurement of electrical resistivity in laboratory

2.5. Thermal resistivity

Soil thermal resistivity is the measure of the capacity of the ground to conduct or dissipate heat from the source (generally, power or electrical cables). In the case of electrical trenches, it is important to determine the thermal properties of the natural soil and the backfill material.

Thermal Resistivity tests are carried out inside open pits or other excavations. This allows to perform in-situ resistivity measures at any desired depth or at different depths. Collection of undisturbed samples can be taken to the laboratory for further testing with a range of moisture contents (Dry-Out curve) or even different temperatures.

Thermal resistivity results must be accompanied by the value of the soil density and moisture content of the sample (or natural state), since these factors greatly affect the thermal properties of the soils.

Picture 3: Thermal resistivity device

In the case of backfill material, a compaction degree (based on proctor test) and moisture content similar to that used during the backfill works on site, must be used. These tests are usually postponed to the construction phase once the soil with which the trench will be filled is known with certainty.

2.6. Seismic Characterization

In the projects located in areas with seismic hazard, it is necessary to determine, according to the seismic regulations of each country, the calculation parameters corresponding to the terrain present in the study area and the possible implications in the projected structures.

V_{S30}, defined as the average seismic shear-wave velocity from the surface to a depth of 30 meters constitutes an internationally accepted parameter for the classification of site according to the IBC

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(International Building Code), for the estimation of site coefficients (Eurocode) or for liquefaction analysis.

Picture 4: Passive Seismic test

The Passive Seismic or ReMi (Refraction Microtremor) method allows to determine the Vs30 parameter of the site quickly and reliably. It is also useful for obtaining the geological model and the distribution of stiffness in depth in order to characterize the ground response to seismic or cyclical movements.

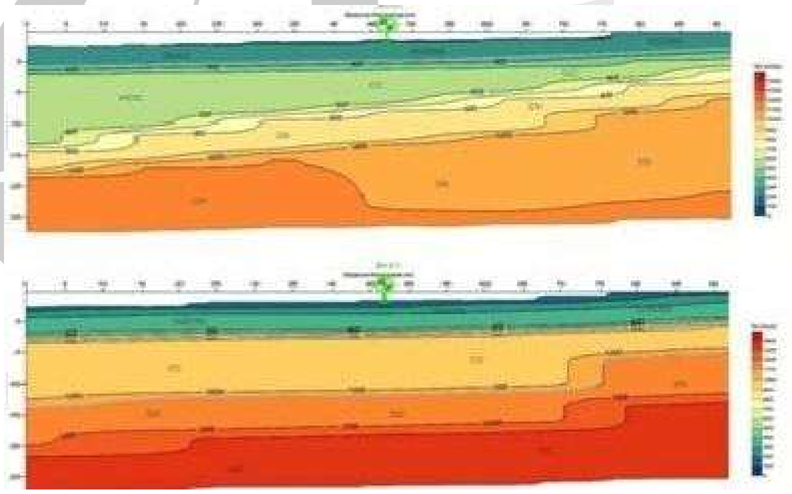

Fig. 6: Sections of stiffness and Vs30

In some countries it is mandatory to know the frequency and fundamental period of natural ground vibrations, for which the HVSR test is usually used.

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Picture 5:: HVSR test

2.7. Ground deformability

If it is necessary to classify the subbase category of soils for path/road construction or to determine the vertical deformability of shallow foundations. In order to do this, devices as the German dynamic plate, or the in-situ CBR test are available. Both allow several tests to be performed in a single day quickly and efficiently, especially in the case of unsaturated soils.

Fig. 7: Dynamic load plate, Zorn

If the ground near the surface is saturated, it will be necessary to carry out static plate load tests, although they take more time than the dynamic plate tests. They also need to have a reaction element such as a sand-loaded truck.

In the case of saturated clay soils and high surface loads, (not a common situation in PV projects), it would be necessary to perform oedometric tests on undisturbed samples to evaluate long term consolidation settlement.

2.8. Road testing

The main roads within the photovoltaic plant will have a little ADT traffic but will require sizing to ensure durability, especially when passing through soft or expansive soils in which part of the soil must be cleaned, isolated, or reinforced before construction. It is necessary to characterize the nature and deformability of the natural roadside esplanade during the geotechnical investigation if its layout is

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known. To do this, the in situ CBR test, dynamic penetrometers and dynamic or static load plate tests can be used. The load-bearing capacity of the soils used in the different layers that will make up the path are usually postponed to a phase prior to construction, once the materials that will be used are known.

2.9. Expansive clays and collapsible soils

It is common to find clays susceptible to shrinking and cracking during the dry season and swelling during the wet season. This will be especially problematic in dry and arid regions. Once potentially expansive clays have been detected, for example, based on their high plasticity, their swelling and their ability to crack must be quantified. This can be done through free swelling tests or alternatively swelling pressure tests with different humidity, and linear retraction limits tests. Depending on the intensity of the expansive potential, preventive measures will have to be designed to minimize the risk on the foundations.

If you have time, it is useful to measure the thickness of the active layer to evaluate the variation in humidity at different depths over a full year. Otherwise it will be estimated from the bibliography and climatology. Swelling will be greatest near the surface and practically non-existent at the bottom of the layer. Only a part of this active layer will suffer shrinkage cracks, whose depth will be visible during the summer season. It is highly advisable to measure the cracks on the excavation wall.

Collapsible soils are fine soils, without plasticity, with or without the presence of sulfates that can collapse due to changes in tension or humidity. In the presence of these soils it will be necessary to carry out specific tests such as the collapse test in an oedometer.

2.10. Soil corrosion

The possible corrosion induced by the chemical and electrochemical reaction between the soils and buried metals, generally steel and galvanised steel, is of utmost importance in photovoltaic plants where foundations using driven piles are used intensively.

The corrosive potential will be evaluated using Standard DIN 50929 part 3 2023, in our opinion the most complete, which analyses different parameters of the ground and electrical resistivity, or if they exist, through local regulations.

DIN 50929 standard evaluates the corrosion resistance of steel coatings through hot galvanising but does not quantify the thickness of galvanising necessary for the project, which must be quantified by a specialist or by galvanising companies and not within a geotechnical study.

Evidently, corrosion produced by atmospheric agents to the part of the metal profile outside the ground is beyond the scope of a geotechnical study.

3. GUIDELINES FOR GEOTECHNICAL SURVEY DESIGN

The chart provides the minimum field investigations that must be carried out depending on the plot size. The number of investigations should be altered depending on the difficulties of the plot (shape, slopes, local geology, access, facilities...). Every investigation must be supervised continuously by a specialized technician (Geologist or similar) focused on the project´s needs and details.

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Chart 1. Recommended number of field investigations according to plot size

SURFACE (Ha)	TRIAL PITS	PENETROMETERS	ELECTRICAL RESISTIVITY	THERMAL RESISTIVITY
<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 each 5 Ha	1 for each 5 Ha	1 for each 20 Ha	1 for each 20 Ha

The investigations proposed here by ORBIS TERRARUM serves as a guideline for the geotechnical company to propose to complement with another type of investigation, such as: core recovery boreholes, infiltration/permeability tests, dynamic plate tests, or seismic refraction/passive tests in the case of sites with seismic hazard.

In the case of corrosion, these projects can be completed with specific atmospheric corrosion studies (bibliographic and Wire-On-Bolt Tests) or with soil corrosion modelization tests in the case of soils that can be made in the phase of geotechnical study.

To extend the study of soil corrosion these projects can be completed with specific soil corrosion modelling tests.

4. LABORATORY TESTS

Laboratory tests can be divided into several groups. The first group corresponds to the identification and state tests that allow us to know the type of soil. The second group includes mechanical tests that allow us to test the strength and deformability of soils and rocks, and aspects such as potential expansiveness and risk of collapse. The third group refers to the reuse of materials necessary in the project. Finally, the fourth group of tests includes chemical tests to evaluate the aggressiveness of soil and water to concrete and steel (corrosion). Testing requests must always be made by the technician responsible for the study depending on the nature of the materials found (soil, rock, cohesive, non-cohesive…).

As a first approach, the next chart establishes a recommendation for laboratory tests measurement:

Chart 2. Laboratory tests for every 5 samples

TEST	EVERY 5 SAMPLES
IDENTIFICATION AND STATE	
Grain-size distribution by sieve	5
Atterberg Limits	5
Natural moisture content	5

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TEST	EVERY 5 SAMPLES
Dry and bulk density	3
STRENGTH	
Direct shear test	0,50
REUSE OF MATERIALS	
Modified Proctor (máximum density and optimum moisture)	0,25
CBR Index	0,25
SWELLING AND SHRINKAGE	
Free Swell Index	0,20
Swelling Pressure	0,20
Shrinkage Index	0,20
Retraction Index	0,20
ROCKS	
Rock density	0,75
Point Load Test (PLT)	0,75
CHEMICAL	
Soluble sulfates content (in water and in acid)	1
Baumann-Gully Acidity	1
Organic matter content	1
pH	1
Alkalinity/Acidity determination	1
Chloride content	1
Sulfide content	1
Water aggressiveness to concrete	1

In addition to the tests summarized above, other tests can determine the electrical and thermal properties of soils in the laboratory.

5. REPORT

Geological-geotechnical reports are directly related with the scope of the geotechnical survey and can be divided into:

- Work completed or factual reports
- Feasibility or preliminary reports
- Final reports or design reports

The different types of report are described below.

Work completed report: This report is a summary of the field investigations. No conclusions or recommendations are given.

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Feasibility or preliminary reports: This report includes the minimum and necessary data to define the site´s geology, geological risks, driving feasibility, optimal areas, and basic recommendations that allow for pre-sizing and estimating associated costs. These reports include less investigations and laboratory tests than in a final study, as the scope is only to provide main recommendations to the client for preparing a basic or preliminary project. The results of this report are not used for the plant design. It is recommended that this report number additional geotechnical investigations are necessary to complete future data for the geotechnical design study.

Final report: This report includes all the relevant information and the analysis made based on the geotechnical survey and laboratory test results. The results of this report are used for the plant design. This report contains, at least:

- Basic information: description of the main features of the project.
- Work done: description of the bibliographic information consulted, the field works carried out, and a summary of laboratory tests results.
- Geology: regional and local geology, hydrogeology, geomorphology, etc.
- Seismic analysis: seismic characterization of the site based on national or international codes.
- Geological and natural risks: description of the main risks and estimation of its hazard.
- Geotechnical characterization: description of the geotechnical units identified with summary of its geotechnical parameters.
- Aggressivity to concrete and steel (corrosion).
- Thermal resistivity: thermal properties of the different geotechnical units
- Excavability and slope design: Recommendations for excavability of the different geotechnical units and recommendations for permanent or temporary slopes.
- Reuse of materials: reuse of the geotechnical units that can be excavated during the plant construction.
- Determine the esplanade for main pathways if its location is known before the beginning of the geotechnical study.
- Module foundations design: the typology and zoning for the foundations will be defined.
- When direct driving is not possible as a first option, other possibilities will be explored, such as: the execution of pre-drilling, the use of screws, or direct foundations. In the case of rocky terrain, micropiles or direct foundations will be used.
- Shallow foundation design: typology and calculation of the superficial foundations for inverter cabins and light elements
- Electrical resistivity data for the earthing system design.

It is good professional practice to first carry out the geotechnical study and then study the strength and deformation of the foundation with full-scale tests, once the section and inertia of the metal piles and required loads are known. These static load studies are called ramming and pull out tests. The detailed analysis of the results will allow defining the optimal embedment length and validating the deformations obtained.

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Designs and cross-sections

It is important that the report provides representative geological columns of the different areas identified.

Similarly, it is important to provide a detailed surficial geological mapping and a pile driving feasibility map that allows to design the subsequent pile-driving and pull-out test campaign according to the ground expected, (although this design may need to be modified after the pull out tests campaign).

Annexes

All field investigations will be collected in the corresponding annex to the Geotechnical Report with the detailed description of each of the investigations (georeferenced position, machinery, date, geological-geotechnical description by a specialist technician, samples collected and other observations) with an extensive photographic report of the activities and the general conditions of the site.

Deadlines

The usual deadlines that are considered in this type of studies, although it varies with the plot size, are 1 or 2 weeks for field works depending on the magnitude of the project, 2 weeks for laboratory tests and interpretation of the geophysical data, and 1 or 2 more week for the drafting of the final geological - geotechnical report.

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