TECHNICAL SPECIFICATIONS OF GEOLOGICAL – GEOTECHNICAL REQUESTS FOR PHOTOVOLTAIC PLANTS

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Abstract: Photovoltaic plants are usually executed over large areas. This can result in changes of the geological and geotechnical conditions along the project site. Due to previous issue, it is extremely important to design an appropriate geotechnical survey which reduces or delimits geological uncertainty. For reducing these geological uncertainties is extremely important to design a correct geotechnical campaign. 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.

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 450 PV plants in different countries, which involves more than 35 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, at least, the following information:

- Accurate ground zonation (mapping) according to its geological and geotechnical features
- Delimitation of the areas where PV modules cannot be installed.
- Definition of the module foundations: type, driving feasibility, limitations…
- Analyse the ground aggressiveness for concrete and steel (corrosion potential).
- Provide electrical resistivity data of the different ground levels for an appropriate earthing system design.
- Provide geotechnical parameters of the different ground strata (classification, strength, deformability…) that will be used for foundation design.
- Evaluate ground excavability and the recommended machinery type for earthworks and trenching.

- Recommended excavation slopes.
- Define the bearing capacity for shallow foundations.
- Evaluate the pile foundation strength, which will be confirmed with pull out tests.
- Detect and quantify geological hazards 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.
- Determination of 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 providing 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 for any local code or standard.

2. GROUND INVESTIGATION

2.1. Geological mapping

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

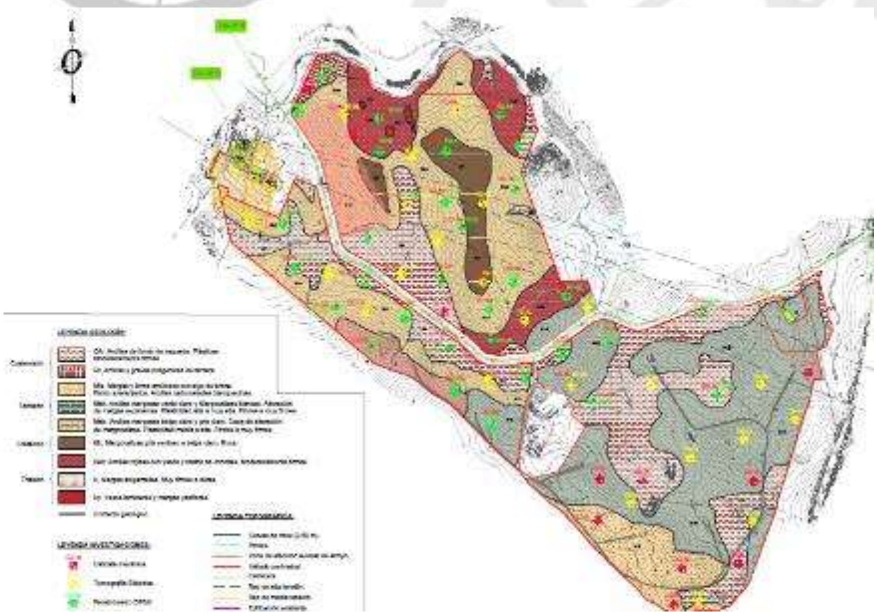

Fig. 1: Geological mapping drawing developed by ORBIS TERRARUM

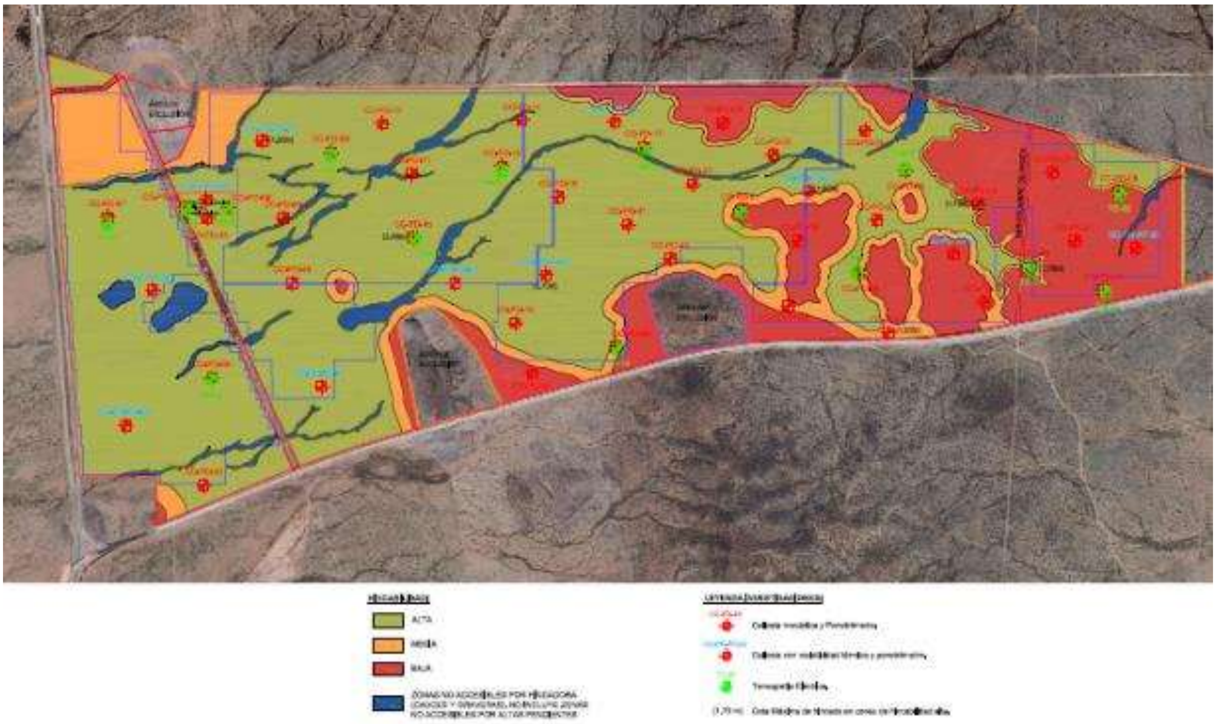

Fig. 2: Technical feasibility of driven piles drawing, developed by ORBIS TERRARUM

2.2. Trial pits

Direct data are collected generally by mechanical trial pits up to 3,5 m depth, which is slightly higher than the usual length of the driven metallic piles for the module foundations. Additionally, 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 specialized technician (geologist or similar) will make a geological-geotechnical description of the different strata, collecting also representative samples (of soil, rock and water). Any remarkable aspect as the presence of man-made fills, or contamination evidence will be also marked. Once a trial pit is finished it will be closed by filling it with the excavated material to avoid any hazard to people or cattle.

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

Even it is not usual, trial pits campaign 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 seismic hazard zones, or even the use of georadar (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 known previously.

2.3. Dynamic penetration tests

Dynamic penetration test is the most suitable test for estimating the ground strength, pile driving feasibility and for making an accurate zonation, due to its easy use, transportability, and so its reduced prices 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. Both results of these tests can be correlated with the value of the SPT test.

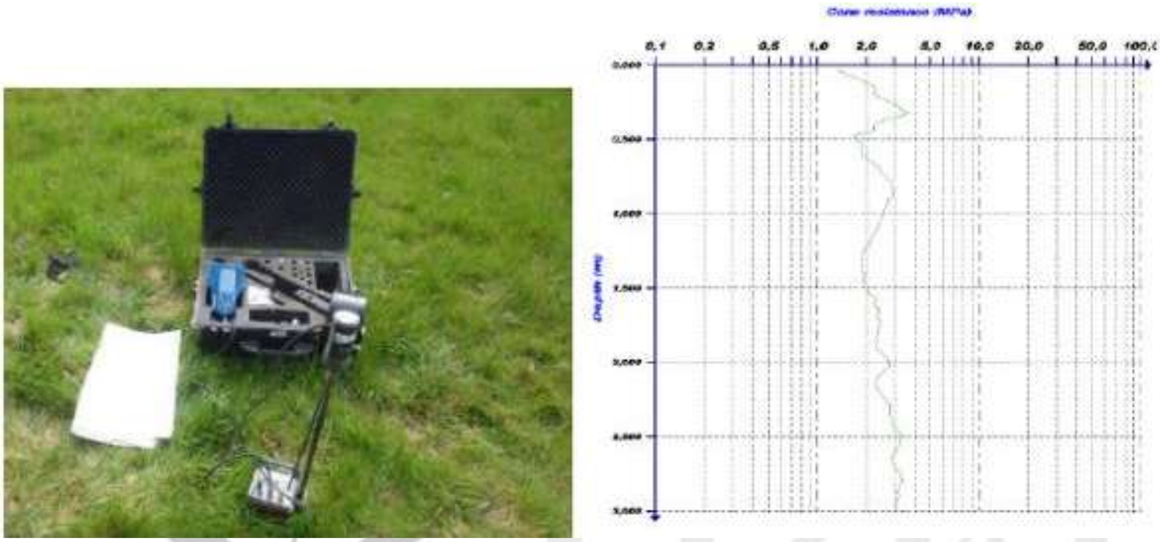

Fig. 4: Panda2 penetrometers and real penetrometer log

Penetrometer tests allow to 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).

Related to previous fact, 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 it can be determined the electrical resistivity of the ground along the line and also in depth. The interpretation of this results allows to make a representation of the different geological units in a cross-section.

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

A less accurate alternative is to determine the electrical resistivity of the ground by means of a Vertical Electrical Sounding using a Wenner or Schlumberger quadruple pole.

The determination of the electrical resistivity is very important for estimating the corrosion potential of the soils and is also very useful for the design of the earthing system.

Picture 1: Geophysical test by electrical tomography

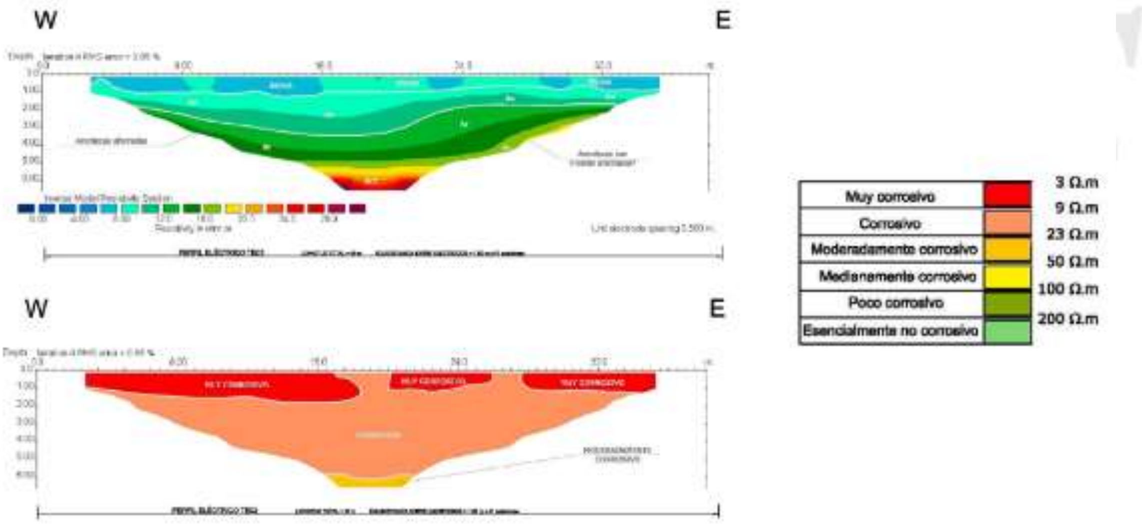

Fig. 5: Electrical Tomography sections. Up: with geological interpretation. Down: with corrosion potential

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 but also the thermal properties of the backfill material.

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

Picture 3: Thermal resistivity device

In the case of backfill material, a compaction degree (based in proctor test) and moisture content similar to that used during the backfill works on site must be used.

2.6. Seismic Characterization

In those 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

(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.

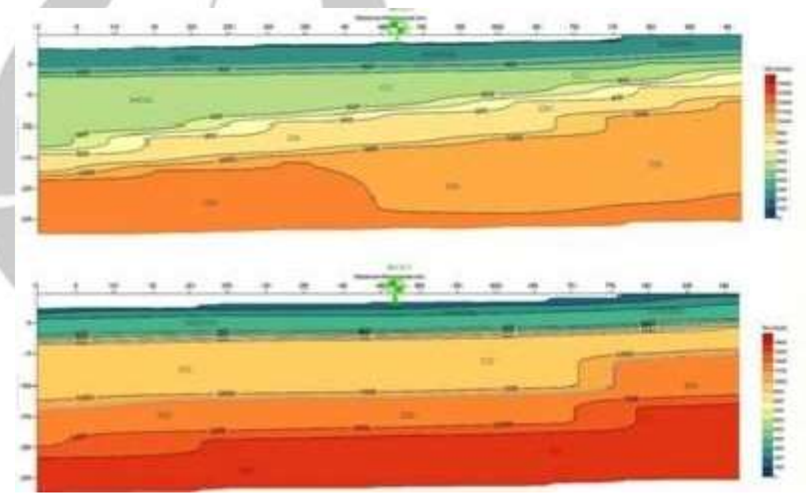

Fig. 6: Sections of stiffness and Vs30

2.7. Ground deformability

If it is necessary to classify the subbase category of soils for path/road construction or to determine in detail the deformability of shallow foundations, devices as the German dynamic plate, or the in-situ CBR test are available. Both let to perform several tests 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 much 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, (a non-very common situation in PV projects), it would be necessary to perform oedometric tests on undisturbed samples to evaluate long term consolidation.

3. GUIDELINES FOR GEOTECHNICAL SURVEY DESIGN

Next chart provides the minimum field investigations which must be carried out depending on the plot size. The investigation numbers should be increased or reduced depending also of 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 needs and details.

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 are a basis on which the geotechnical company can propose to be complemented 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.

4. LABORATORY TESTS

Laboratory tests can be divided into several groups. The first group corresponds to the identification and state tests that allows to know the type of soil. The second group includes mechanical tests to know the strength and deformability of soils or rocks. There would be a third group referring to the reuse of materials when this item is necessary in the project. Finally, the fourth group would be that of chemical tests to evaluate the aggressiveness of soil and water to concrete and steel (corrosion). Testing request must be always made by the technician responsible of the study depending on the nature of the materials found (soil, rock, cohesive, non-cohesive…).

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

Chart 1. 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
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
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

TEST	EVERY 5 SAMPLES
Sulfide content	1
Water aggressiveness to concrete	1

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

5. REPORT

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

- Work done reports
- Feasibility or preliminary reports
- Factual reports
- Final reports

The different types of report are described below.

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

Feasibility or preliminary reports. This report includes the minimum and necessary data to define the site geology, geological risks, the driving feasibility and optimal areas and basic recommendations. In this case, the number of investigations and laboratory tests is lower than in a final study as the scope is only to provide main recommendations to the client for preparing a basic project. The results of this report are not used for the plant design.

Factual report previous to the final study. Unlike the previous, this study consists in an advance of the main conclusions based in the field investigations. Factual reports contain a minimum part of the field investigation results. The total field and laboratory data will be part of the final report. This report is requested when the plant design is made at the same time than the geotechnical study.

Final report. This report includes all the relevant information and analyses made based in the geotechnical survey and laboratory tests 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, all the field works carried out and a summary of laboratory tests results.
- Geology: Regional and local geology, hydrogeology, geomorphology…
- Seismic analysis: seismic characterization of the site based in 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.
- Module foundations design: the typology and zoning for the foundations will be defined; In the event that the pile driving is not possible as a first option, other possibilities will be explored, such as the execution of a predrilling, the use of screws, or direct foundations. In the case of rocky terrain, micropiles or direct foundations will be used.
- Shallow foundations design: Typology and calculation of the superficial foundations for inverter cabins and light elements
- Electrical resistivity data for the earthing system design.

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 mapping that allows to design the subsequent pile-driving and pull-out tests 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 contemplated in this type of studies, although it varies with the 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 more week for the drafting of the final geological - geotechnical report.