TECHNICAL SPECIFICATIONS ON ELECTRICAL METHODS FOR THE REQUEST OF A GEOPHYSICAL STUDY FOR NEW PHOTOVOLTAIC PLANTS

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ABSTRACT

Photovoltaic plants are facilities that typically occupy a large area of land. This can result in geological and geotechnical conditions changing within the same plant. For this reason, a correct design of the geophysical campaign is necessary to reduce geological uncertainties. Thus, it is intended to detail the applications of electrical methods and other geophysical methodologies with the intention of standardising the number of investigations to be carried out within a geophysical survey. In this sense, without these methodologies, the number of direct investigations would be higher and, consequently, there would be an additional cost overrun in the campaign. This article provides recommendations based on the extensive experience of the Applied Geophysics Department of Orbis Terrarum in geophysical studies for photovoltaic plants on all continents.

Keywords: Photovoltaic plants, renewable energy, geophysics, electrical methods, electrical resistivity tomography, corrosivity.

RESUMEN

Las plantas fotovoltaicas son instalaciones que normalmente ocupan una gran superficie de terreno. Esto puede dar lugar a que las condiciones geológicas y geotécnicas cambien dentro de una misma planta. Por este motivo es necesario un correcto diseño de la campaña geofísica que reduzca las incertidumbres geológicas. Por esta razón se pretenden detallar las aplicaciones de los métodos eléctricos y otras metodologías geofísicas con la intención estandarizar el número de ensayos a ejecutar dentro de una campaña de reconocimiento. Sin estas metodologías, el número de investigaciones directas sería mayor y por tanto se evidenciaría un sobrecoste en la campaña. En este artículo se aportan recomendaciones que se basan en la amplia experiencia del Departamento de Geofísica Aplicada de Orbis Terrarum en estudios geofísicos para plantas fotovoltaicas en los 5 continentes.

Palabras clave: Plantas fotovoltaicas, energías renovables, geofísica, métodos eléctricos, tomografía de resistividad eléctrica, corrosividad.

1 INTRODUCTION

This document is written with the purpose of providing and standardizing the correct methodology for the design of a geophysical investigation campaign for new photovoltaic plants. These recommendations are based on: (1) the experience of the Applied Geophysics Department of Orbis Terrarum (www.geophysicsapplications.com), (2) on the technical specifications published by Puell y López (2021) for the request of a geological-geotechnical study in photovoltaic plants (www.orbisterrarum.es) and, (3) on the research record of more than 500 solar plants in several regions of the world and more than 50 GW completed.

Cost and time optimization is a key factor in the type of investigations that are proposed. A good geophysical study is always necessary to support the project of a solar photovoltaic plant in order to provide valid data for the design and avoid risks and problems in the long term during the operation of the facilities Puell y López (2021).

Applications of electrical methods for a geophysical survey complementary to the geotechnical study must focus on the following aspects:

(i) Characterize the terrain through geoelectric models.
(ii) Analyze the corrosion potential of soil to steels.
(iii) Provide electrical resistivity data for the design of the grounding network.
(iv) Investigate, if it is detected, the behavior and position of the groundwater levels.
(v) Identify anthropic fills, cavities and/or possible contamination of the terrain.

Sometimes these studies must be supplemented with additional geophysical surveys to characterize other physical properties or with specific investigations as transmission lines, electrical substations or access roads to the plant. All of these are generally subject to local standars.

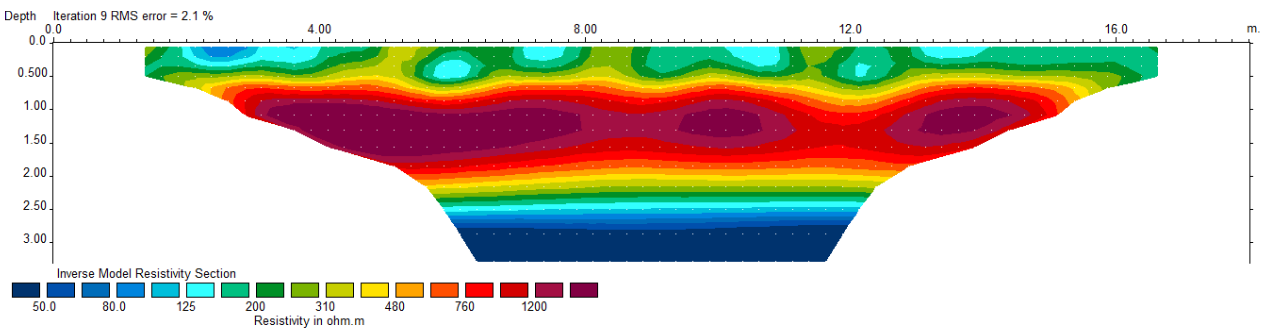
2 ELECTRICAL CHARACTERIZATION OF THE TERRAIN

2.1 ELECTRICAL RESISTIVITY TOMOGRAPHY

This method stand out as the most common and complete investigation, it applies a Wenner or Schlumberger device with 21 or 42 equidistant electrodes along a line to determine the electrical resistivity of the ground in two dimensions. The interpretation of these results allows to visualize a representation of each geological unit in a two-dimensional section, also allows the identification of groundwater levels, the delimitation of pollutants, cavities and/or anthropic fills and the classification of the penalty parameter Z_2 to configure the corrosivity of the soil (DIN 50 929-3).

(a) Field arrangement

(b) Field arrangement



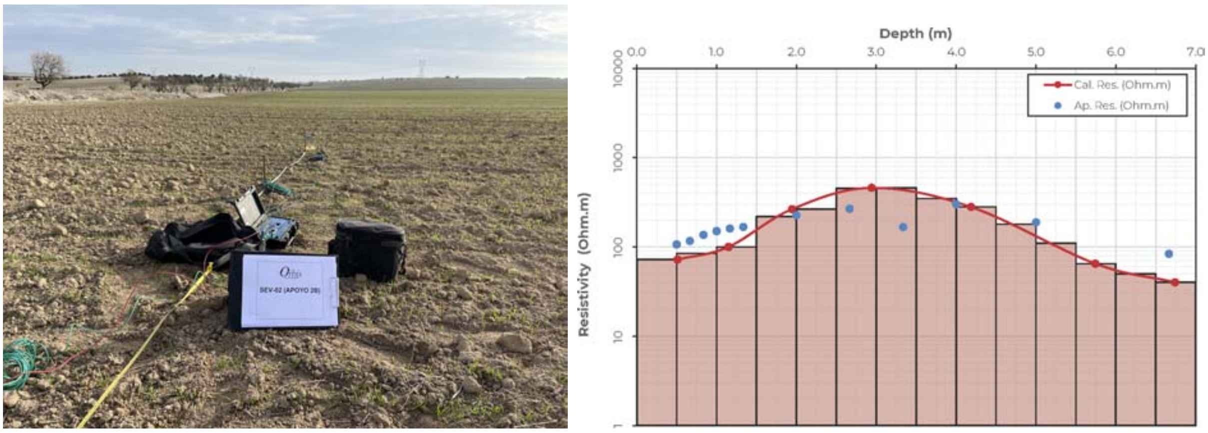
(c) Processed electrical resistivity section

Figure 1: *Geoelectrical characterization through electrical tomography resistivity method.*

2.2 VERTICAL ELECTRICAL SOUNDING

Another option to perform a geoelectric characterization is through VES (Vertical Electrical Sounding) tests by designing tetraelectrodic devices with different openings, this allows to determine the electrical resistivity in a single point at different depths, commonly Wenner (ASTM G57-20) or Schlumberger type devices are used due to their fast design. For processing, the resistivity values measured in the field (apparent) are inverted and then transformed into one-dimensional curves with the calculated resistivity parameters.

This technique has been replaced by electrical resistivity tomography since the latter has the advantage of being able to perform a geological interpretation in 2 dimensions which implies larger volumes of data.



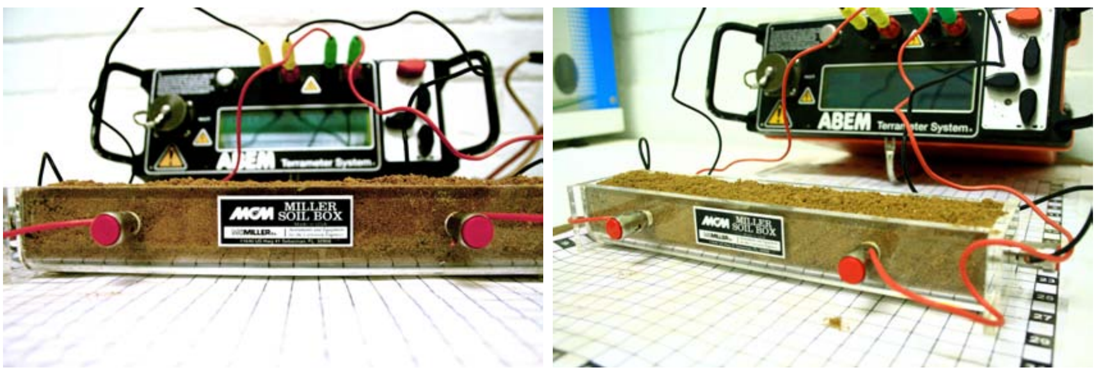
(a) Field arrangement

(b) ρ_a y ρ_v vs depth

Figure 2: *Geoelectrical characterization by vertical electrical sounding test.*

2.3 SOIL-BOX

Electrical resistivity can also be estimated in the laboratory using the two-electrode method known as Soil-Box. The measurement is performed on compacted samples that are saturated with distilled water, the results are shown in curves in which the calculated resistivity is exposed at different percentages of moisture. This method is the recommended for the classification of corrosion potential according to US guideline (ASTM G187-18) and is also applicable for plants that need to complement the DIN 50 929 (2018) standard in later stages (Pull Out Test, trench backfilling,...).



(a)

(b)

Figure 3: *Geoelectrical characterization through Soil-Box method.*

3 DESIGN GUIDE

The equation (1) determines the minimum behavior of the electrical resistivity investigations to be performed based on the Orbis Terrarum experience. This family of curves is explained as a function of the area to be studied and the average slope of the terrain as expressed in figure 4.

The influence of topography on the acquired model is highlighted and the susceptibility that the latter brings to a geophysical campaign can be pointed out as its direct proportionality on changes in the terrain is demonstrated (erosion, preferential flow zones, vegetation distribution, lateral and vertical changes of facies,...).

$$N = \sqrt{S \cdot P_m} \quad ; \quad N(S, P_m) : \left\{ N(S, P_m) \in \mathbb{N} \ \wedge \ (S, P_m) \in \mathbb{R}^+ | \, (S \cdot P_m) > 0 \right\} \tag{1}$$

Where:

N = Number of test.
S = Area (Ha).
P_m = Average slope.

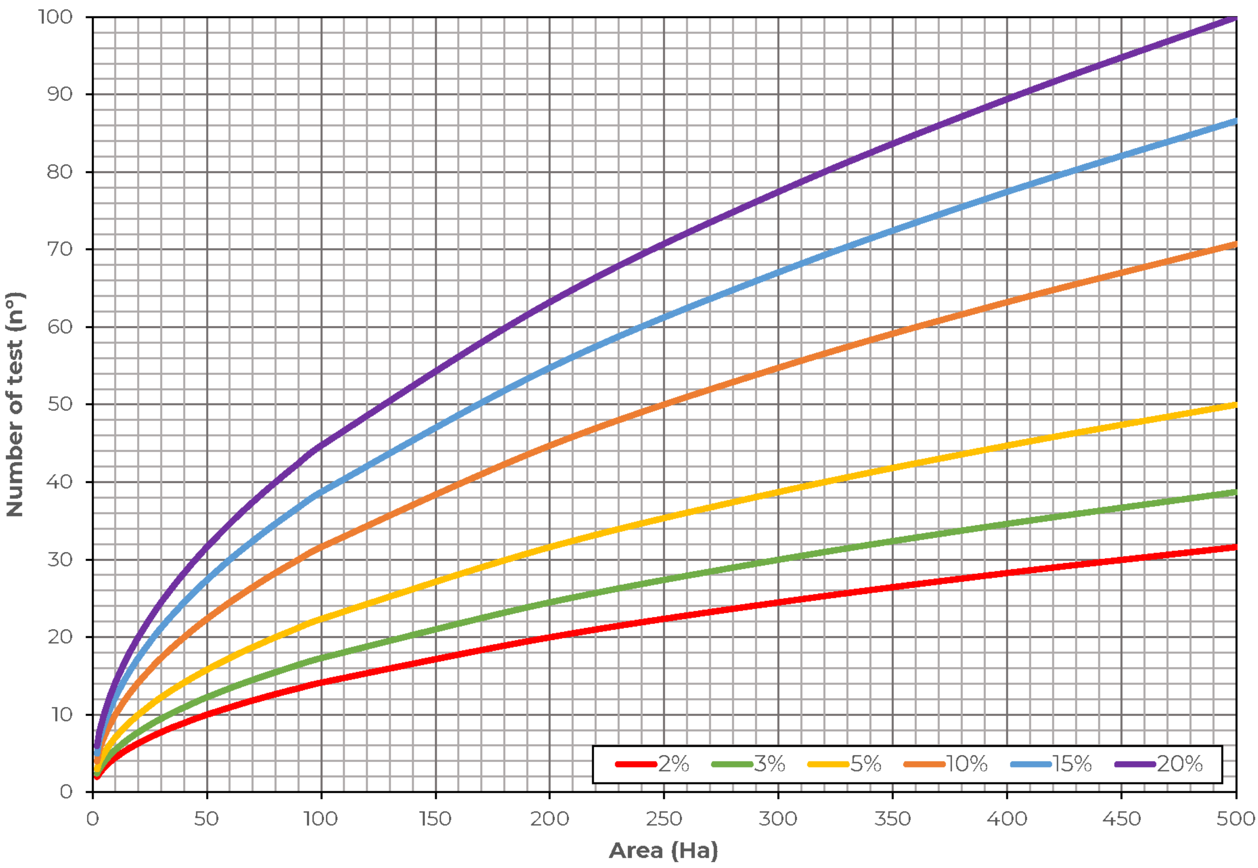


Figure 4: *Number of test depending on the area to be investigated and its average slope.*

The table 1 shows the number of tests to be performed (N) for average slopes of 2%, 3%, 5%, 10%, 15% and 20% showing, for example, how a 2% is considered as a isotropic terrain and a 20% results in a higher number of investigations as an effect of the irregularity of the area.

Table 1: *Recommended number of investigations according to the size and the average slope of the plant.*

Area (Ha)	Average slope (%)					
	≤2	≤3	≤5	≤10	≤15	≤20
2	2	**2**	3	4	5	6
5	3	**4**	5	7	9	10
10	4	**5**	7	10	12	14
30	8	**9**	12	17	21	24
50	10	**12**	16	22	27	32
100	14	**17**	22	32	39	45
300	24	**30**	39	55	67	77
400	28	**35**	45	63	77	89
500	32	**39**	50	71	87	100

As a reference, when estimating the investigations in a plot where slopes have not been analyzed, it is recommended to adopt a value of 3%, although, depending on the heterogeneity of the area (local geology, pollutants, presence of the groundwater, cavities and/or anthropic fillings, accesses, facilities...) the number of investigations should be increased to the next level of the table 1, in this case 5%.

All surveys must be continuously supervised by a specialized technician (Geophysicist/ Geologist or similar with experience) with knowledge of the client's needs and project details.

4 REPORTS

The purpose of the report results focuses on the processing and interpretation of the selected electrical method in order to establish the soil resistivity values. This allows, on one hand, to confirm the geological model of the area and, on the other hand, to evaluate the soil resistivity values for the correct design of the grounding network. In addition, the corrosion potential of the soil is identified to determine its aggressiveness towards buried metallic materials.

The minimum data to be provided to the client is as follows:

(i) Location plan of the geophysical investigations.
(ii) Processed geoelectrical profiles (electrical tomography) or 1D curves of the calculated resistivity (SEV).
(iii) Distribution of the factor Z_2 as a function of soil resistivity according to DIN 50 929-3 (2018).
(iv) Catalog of the calculated resistivity according to the depth and opening of the electrodes for the correct design of the grounding network (minimum 6.50 m of investigation).
(v) Resistivity distribution maps in the area where the new PVP and the electrical substation will be built at four different depths: 0.5 m, 1.0 m, 1.5 m and 2.0 m (see figure 5).
This product can also be built by implementing electromagnetic techniques in the frequency domain, with the advantage that the latter are characterized by their fast execution and can easily detect lateral resistivity variations and delimitation of anthropic fills and/or pollutants.
(vi) Depending on the area where the future PFV will be located and according to the client's specifications, other geophysical methodologies must be executed for the determination of the different parameters explained in the section 5.

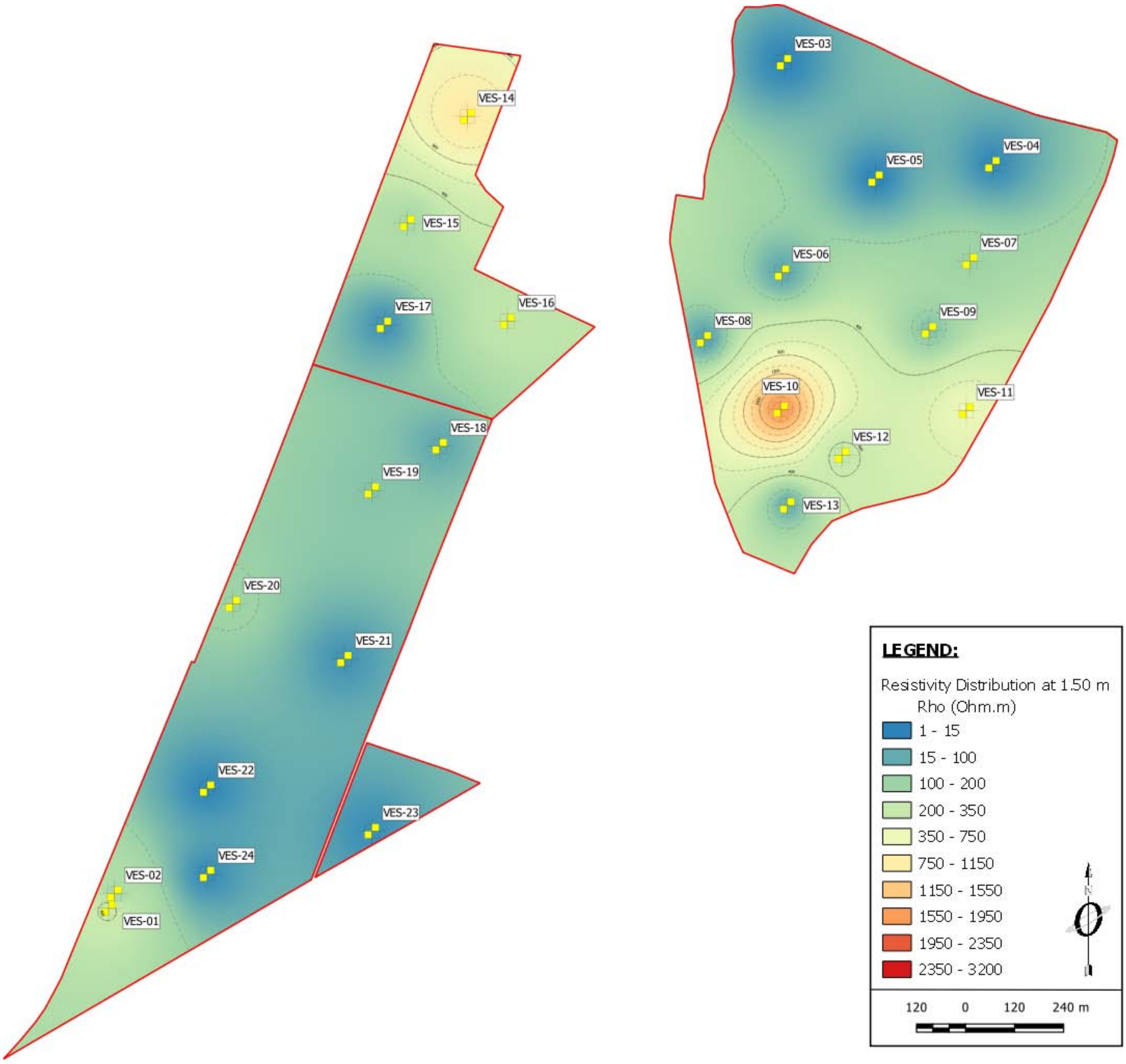


Figure 5: *Distribution of electrical resistivity measured at a specific depth.*

DEADLINES

The usual deadline for this type of study, although they vary depending on the methods applied and the size of the area to be investigated, usually is 1 week for field survey and another 1 week for the drafting and processing of the final report for a plant of about 100 MW.

5 OTHER GEOPHYSICAL TECHNIQUES TO BE USED

Depending on the geographical location of the new Photovoltaic Plant and according to local regulations, client specifications, project difficulty and seismic hazard, the following geophysical techniques should be taken into account:

(i) Seismic refraction to model the terrain as a function of P-wave velocity (V_P) and thus characterize the excavability or mechanical properties of the bedrock.

This technique stands out for its fast execution and depth of investigation to estimate geological models that allow the delimitation of excavable, ripable and flyable zones (see figure 6).

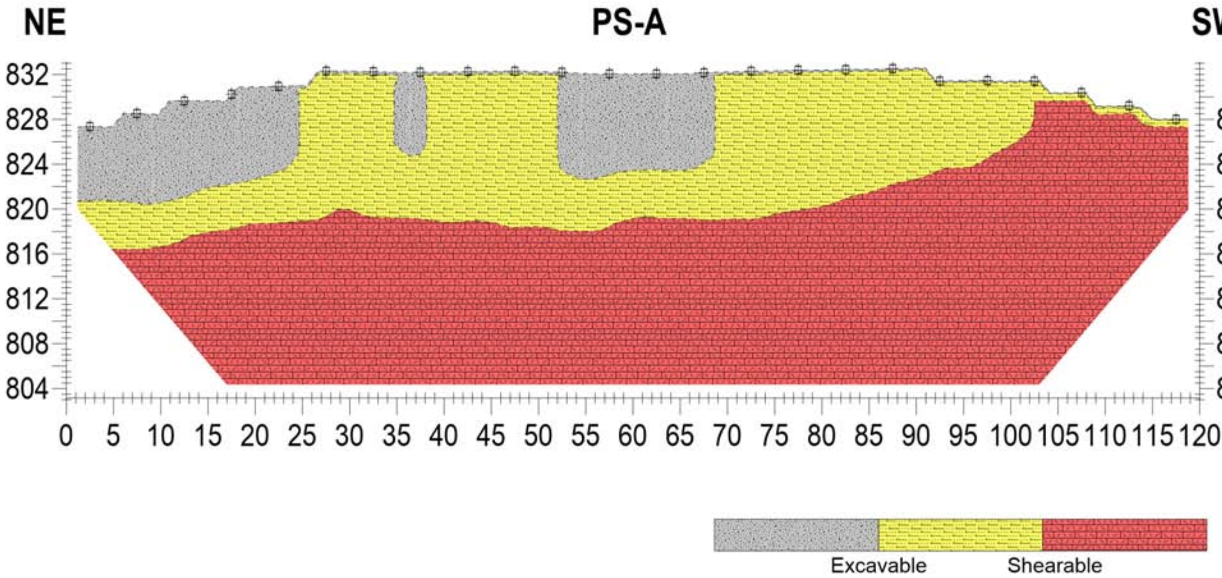


Figure 6: *Distribution of excavable, shearable and flyable areas of a P-wave velocity section.*

(ii) Multichannel analysis of surface waves (MASW) or microtremor refraction (ReMi) for the calculation of the S-wave velocity (V_S), characterization of the V_{S30} and its consequent classification according to the international standards of the area to be investigated (local seismic standards, Eurocode, IBC, ...).
In addition, techniques that study surface waves and their subsequent spectral analysis stand out as effective tools for the determination of soil-rock interface at different depth ranges.

(iii) Calculation of dynamic elastic deformation moduli for very low deformability ranges (E_0, G_0, K_0 and K_0) using combined V_P and V_S techniques such as seismic refraction and MASW or ReMi, crosshole (Dorronsoro y Merino, 2019) and downhole.

(iv) Application of the HVSR spectral ratio method or Nakamura technique for the calculation of the fundamental frequency of the ground in active seismogenic zones (site effect).

(v) Vibration recording for the calculation of response spectra.

(vi) Use of georadar for the detection of buried services.

(vii) Execution of electromagnetic methods in the frequency domain as a fast, reliable and efficient response for the calculation of electrical resistivity in specific cases where electrodes cannot be driven into the ground, in areas where the bedrock substrates are outcropping or those where there is not an optimal contact between the pins and the ground (wind sands).
Likewise, this technique is shown to be one of the most effective for distinguishing lateral resistivity variations and delimiting anthropic fills, karstic cavities and/or pollutant plumes.

The importance of knowing the local regulations and evaluating the seismic hazard of the study area where the new photovoltaic plant is going to be built must be taken into account in order to use multiple geophysical techniques that provide greater support to the geotechnical study and thus characterize the terrain in terms of acoustic properties, resistive properties or vibration records.

For further information please visit `www.geophysicsapplications.com`

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