Proceedings of the 7th International Conference on Geotechnical and Geophysical Site Characterization
Barcelona, 18 - 21 June 2024

Uniaxial compressive strength versus shear seismic wave velocity

Marc Cabrera[1], *Miguel* Combarros[1]

[1]*Ingérop, Geotechnical & Tunnels Department, Avd. Diagonal 534 -Barcelona, Spain*
marc.cabrera@ingerop.es

ABSTRACT

Worldwide, geotechnical engineers frequently use the Uniaxial compression test for soils and rocks as a basis for determining the strength of the materials, despite the fact that test results are subject to a wide range of uncertainties (drilling technique, care during transport and stockage, sample preparation, and sample representativity of the soil or rock layer). The process of geophysical site research uses Refraction Seismic Survey and Passive Tomography to determine the shear and compression seismic wave velocities for various rock and soil layers under the surface. The study examines the correlation between the outcomes of the Uniaxial Compression Tests and the shear seismic wave velocity measured at a 400 ha location in the Atacama Desert (Chile), which was intended to host 84 km of linear solar panels. A robust survey of the axial compression value was determined at a vast site spanning 400 hectares by integrating Uniaxial compression tests, Brazilian test, Shear, and Compression seismic wave velocity.

Keywords: Uniaxial Compression Test, Brazilian Test, Passive Tomography, Refraction Seismic Survey, reliable strength.

1. Introduction

Solar energy projects with large-scale solar panel installations and, among many other features, an enormous expanse of land where these solar panels can be installed are determined by renewable power sources like solar energy.

At 2,000 metres above sea level and covering an area of around 100,000 square kilometres, the Atacama Desert is a flat, raised volcanic desert situated at the foot of the Andes mountain range.

As the most irradiated area on Earth, the Atacama Desert also generates one of the world's highest amounts of renewable solar energy due to its characteristic daily climate, which can occur with or without clouds and relatively low concentrations of ozone, aerosols, and humidity.

A 400Ha region was chosen to be the solar field's implementation site on a 1.600Ha flat zone in the Atacama Desert. This area will be divided into 12 solar subfields, each of which will consist of 30 loops (alignments) of 300m long.

In addition to the huge surface to be investigated, the location of this zone, far from inhabited areas, meant that the site investigation aimed to define the best location and distribution of panel loops and power unit, to obtain the strength characteristics of underground soil layers. Other relevant characteristics of soil layers were decided to be investigated in the future phases of the project development.

The comprehensive findings of the various site investigation methods and the analysis's conclusions regarding the strength characteristics to be used to the 18,000 solar panel foundations' preliminary design and cost estimate are presented in this article.

2. Site investigation

Site investigation of the 400Ha area for a feasibility study of a solar energy project in a flat zone of the Atacama Desert was carried out according to the research methodologies available in the region. The site investigation works conducted were:

1. 48 shallow trenches
2. 13 boreholes, with cores ranging from 10 to 22m depth, and following samples and in situ tests:
   - 36 Standard Penetration Test
   - 7 Menard Presurometer Test
   - 6 Intact Samples
   - 31 Samples
3. Laboratory tests:
   - 41 particle size distribution, Atterberg Limits
   - 10 particle size analysis by sedimentation
   - 33 Uniaxial Compression Test
   - 16 Brazilian Test (indirect tensile strength)
   - 50 natural and dry bulk density
   - 22 Proctor Test
   - 85 soluble salts content
4. 13 Passive MASW Test (Multichannel Analysis of Surface Waves), conformed by two orthogonal profiles of 48m length each one.
5. 68 Refraction Seismic profiles of 72m length each one.

While the site investigation methodologies defined are conventional (i.e., those that are accessible in the area), each test was designed to yield timely and dependable data that could be extended to the vast 400Ha zone through regular and scientific analysis.

As a result, 13 of the 68 refraction seismic profiles were positioned to cross the positions of the 13 boreholes, and 13 passive seismic tests (two series of independent measurements perpendicular to each other) were installed in the positions of the 13 boreholes.

A sedimentary breccia with varied depths of cementation and loose granular material on the surface (1 m thick) were identified thanks to the thorough description of the boreholes' 140 m core samples.

Because of the various cementation levels found in the sedimentary breccia, selecting samples for the Brazilian and uniaxial compression tests was found to be a major element in producing accurate test results. To accurately describe the various cementation levels of the sedimentary breccia for all laboratory tests, a thorough inspection and description of the materials was required.

3. Geotechnical analysis

Cores description showed the different underground soil layers:

Table 1. General soil profile

Geotechnical Level	Description
H0	Granular loose material
H1	Compacted sedimentary breccia
H2	Cemented sedimentary breccia
H3	Poorly Cemented sedimentary breccia
H4	Volcanic Substratum

All these layers were identified in all boreholes with different thickness.

A volcanic substratum was found between 12 and 16 metres below the surface. The distinct behaviour of sedimentary breccia in this research leads to the disregard of data from this geotechnical level.

The compression seismic velocities (Vp) of each borehole sample used for the laboratory test were determined at the same depth using the data from the 13 refraction seismic profiles that were implanted across each borehole (Figure 1).

Seismic shear velocities (Vs) were determined at the same depth of each drill sample utilised for laboratory testing, taking into account the findings of the 13 passive seismic stations inserted above each borehole (Figure 2).

For every geotechnical level that was discovered, an examination of the seismic compression and shear wave velocities was conducted, leading to the following conclusions:

- Different depths of geotechnical levels could be identified considering core description or geophysical techniques results, but the depth differences were identified in all cases below 3m.
- A compression wave velocity of around 1000m/s has been identified at the top of the compacted sedimentary breccia.
- A compression wave velocity of around 1800m/s has been identified at the top of the cemented sedimentary breccia.
- Shear wave velocities limits of Compacted and Cemented sedimentary breccia have not been clearly identified considering the core description.

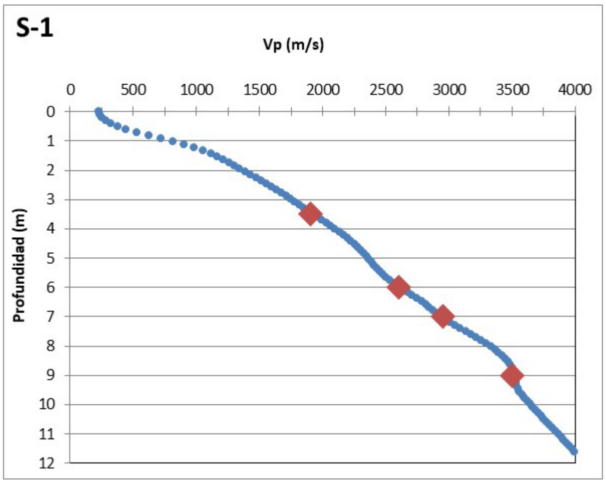

Figure 1. Seismic compression velocities at borehole S-1 position and samples depth of laboratory tests.

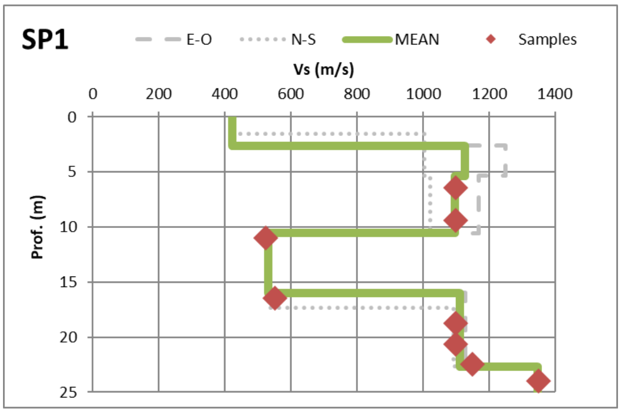

Figure 2. Seismic shear wave velocities at borehole SP-1 position (results of two orthogonal profiles and mean result) and samples depth of laboratory tests.

Based on the description of the cores, which showed varying degrees of cementation of sedimentary breccia, and the results of the passive seismic survey, the analysis of the 33 Uniaxial Compression Test, conducted in samples from the 13 boreholes, did not demonstrate a direct relationship with depth.

After a review of the test findings, which took into consideration the general correlation between the Uniaxial Compression Test and the Brazilian Test, which ranges from 6 to 8, about 10% of unusual test results were found. In the general analysis, the correction of the abnormal test result was taken into account (Figure 3).

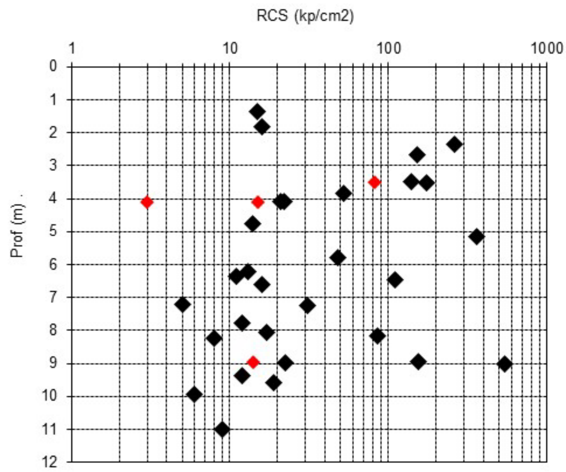

Figure 3. Uniaxial Compression Test results (in red the abnormal results).

4. Uniaxial Compressive Strength and Shear Seismic Wave Velocity relationship

The following direct relationship was determined by taking into account the corrected findings of the 33 Uniaxial Compression Tests that were performed as well as the shear wave velocity value from the passive seismic stations at the same depth:

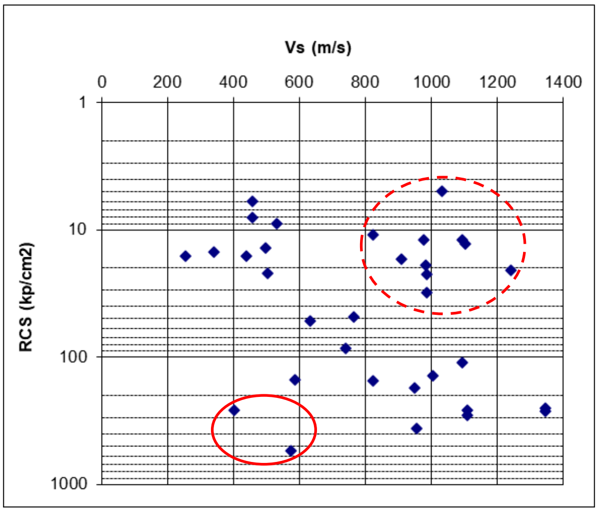

Figure 4. Results of Uniaxial Compression Tests and Passive Seismic Test.

A general relationship between the Uniaxial Compressive Strength Shear Seismic wave velocities was identified, but a specific review of some results was conducted:

- 2 results of 33 Uniaxial Compression Tests conducted showed higher results than predicted by the general relationship. Additional revisions to the core and sample description showed that Uniaxial Compression Test has been conducted on a thin, well-cemented zone embedded at the top of compacted sedimentary breccia (at 2.35m depth) or at the top of poorly cemented sedimentary breccia (at 9.0m depth). Since the height of the sample is just a few decimetres, the results of the Uniaxial Compression Test results were considered not representative of the general behaviour of the underground soil layers.
- 10 results of 33 Uniaxial Compression Tests conducted showed lower results than predicted by the general relationship. All samples were placed from 6 to 9m deep, corresponding in all cases to the Compacted or Cemented Sedimentary Breccia Layer. Additional revisions to the core and sample descriptions led us to consider, that the Cemented Sedimentary Breccia Geotechnical Level was formed by an interbedded layer of Compacted and Cemented Sedimentary Breccia.

A general relationship between Uniaxial Compressive Strength and Shear Seismic Wave Velocity was defined for Compacted and Cemented Sedimentary Breccia:

$$RCS\ (kp/cm2)=3.74\cdot EXP\ (0.0036\cdot V_S)$$

$$300<Vs(m/s)<1400$$

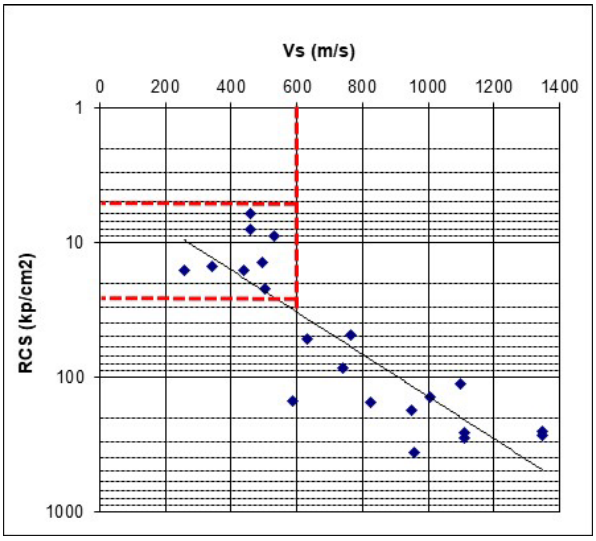

Figure 5. The general relationship between Uniaxial Compressive Strength and Shear Seismic Wave Velocity for Compacted and Cemented Sedimentary Breccia.

It was observed that shear seismic wave velocity measured directly into breccia core samples (Kahraman et al and Majstorović et al) were higher (from 2.000 to 3.500m/s) than "on site" measures (from 300 to 1.400m/s). Since the Uniaxial Compressive Strength of breccia core samples were also much higher (from 200 to 800kp/cm2), it was concluded the general relationship could be representative for soils (sedimentary breccia soils, ranging from compacted to cemented soils).

Shear wave velocities limits of Compacted and Cemented sedimentary breccia were finally identified in relation to the results of the Uniaxial Compression Test:

- Geotechnical Level H1 (Compacted sedimentary breccia)
  - Vs(m/s)<600
  - 5 <RCS(kp/cm2)<25

- Geotechnical Level H2 (Cemented sedimentary breccia)
    - Vs(m/s)>600
    - 25 <RCS(kp/cm2)<250

5. Conclusions

A site investigation is conducted to determine the basic hypotheses of the project, adapted at the phase of the project (the stage of development), and the typology of the geotechnical works to be designed.

The most relevant geotechnical work identified in the feasibility project of renewable solar energy in a 400Ha flat region plain in the Atacama Desert was the foundation of the 18,000 solar panels planned in the first stage of the development. The cost and reliable budget deviations of the foundations for 18,000 solar panels were identified as the most important risks of the feasibility study.

Taking into account the identified risk, the site investigation was planned to obtain the most reliable strength characteristics of the underground layers, and the characteristics of the underground layers were only lightly investigated (future phases of the project development will focus on less relevant characteristics).

Every site investigation methodology has some technological constraints by nature, but it also has limitations based on the types of soil strata that need to be examined. Additionally, but no less significant, conditions include the extension that needs to be looked into (related to cost), the zone's location (in the middle of a desert, far from populated areas), the common site investigation techniques that are available, and—above all—the expertise and calibre of local specialist companies.

Different site investigation techniques were defined, considering cost, availability, and limitations. These techniques combined geophysical methods (passive tomography and refraction seismic survey) with traditional laboratory tests, such as axial compression tests and the Brazilian test, and conventional boreholes with the goal of obtaining a representative and reliable value of the axial compression strength of underground layers in order to determine the viability and cost of the 18,000 solar panel foundations.

A representative and trustworthy distribution of uniaxial compression strength could be obtained by analysing 33 uniaxial compression tests, correcting them by comparison with 16 Brazilian experiments, and generalising the results as characteristic values by comparison with 13 passive seismic profiles.

Using Uniaxial Compressive Strength, and spatial distribution and thickness of geotechnical level H1 and H2, 5 zones with different pile length (ranging from 12m for Zone 1a to 5m for Zone 3), were defined for the 18,000 solar panel.

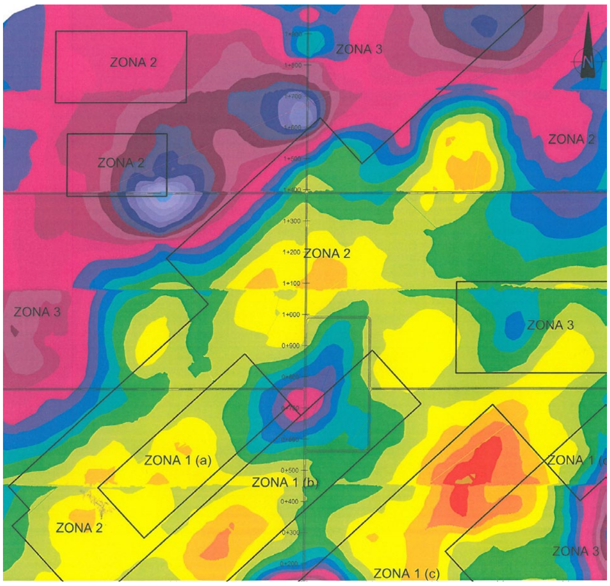

Figure 6. Foundation typology distribution in 400Ha zone in the Atacama Desert, according with the depth contact of Level H1 and Level H2.

Reliability in terms of cost and schedule, was analysed, and specifications for foundation works cost estimation were established for the feasibility study.

References

Kahraman, S. A. İ. R., Alber, M., Fener, M. U. S. T. A. F. A., & Gunaydin, O. (2008). “Evaluating the geomechanical properties of Misis fault breccia (Turkey)”. *International Journal of Rock Mechanics and Mining Sciences*, 45(8), 1469-1479.

Majstorović, J., Gligorić, M., Lutovac, S., Negovanović, M., & Crnogorac, L. (2019). “Correlation of uniaxial compressive strength with the dynamic elastic modulus, P-wave velocity and S-wave velocity of different rock types”. *Podzemni radovi*, (34), 11-25.