Geological & geotechnical study of a construction site in Porto Romano area, Albania

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ABSTRACT

Porto Romano port complex new facilities are part of the expansion plans of Durres port and its modernisation. However, the relocation site presented many significant spatial and geotechnical challenges to be considered and mitigated.
Soil conditions and the country's high seismic activity meant the project required extensive feasibility and technical studies to find a safe and sustainable approach. For a detailed geological and geotechnical investigation of the area, various geotechnical, geophysical tests were carried out such as: borings, SPT test, CPTU test, Seismic refraction, MASW, Downhole and HVSR allowing to obtain the fundamental resonance frequency of the ground. Field recordings per each layer were than compared and calibrated to the results and tests performed in the laboratory. The construction site displayed a variety of soils from soft to firm silty Clays, to loose to medium dense silty Sands and layers with high organic content. During execution of SPT tests, sandy layers gave more satisfactory results, meanwhile, for silty CLAY layers, the results of CPTU testing were considered in analysis.
This detailed soil investigation and characterization served to properly design the new port facilities, identify, and protect from the liquefaction phenomena at this specific site.

Keywords: in-situ testing; laboratory testing; geophysical methods; geotechnical engineering.

1. Project and Site information

1.1. List of symbols and abbreviations

CPTU -Cone Penetration Test with pore pressure measurement (U2)
SPT -Standard Penetration Test
BH -Borehole
(G)SI-(Geotechnical) Site Investigation
qc-cone tip resistance
fs-side friction resistance
C-cohesion
Φ-internal friction angle
Su-vane shear strength, undrained cohesion
ASTM-American Society for Testing and Materials
MASW- Multichannel analysis of surface waves
HSVR-Horizontal to vertical spectral ratio analysis
UCSS- uniaxial compressive strength on soil samples
Vs-shear wave velocity
Vp-primary wave velocity
UU- Unconsolidated undrained (Triaxial test)
G-shear modulus (derived parameters from downhole test)
Ed-average oedometric modulus (derived parameters from downhole test)
E-average Young's modulus (derived parameters from downhole test)
Ev-average bulk modulus (derived parameters from downhole test)

1.2. General data about the project

This paper provides a comprehensive set of experimental data on subsoils where the new integrated port of Porto Romano will be built.

The area where the project is developed lays in the soft soils of the north-eastern part of Albania, with difficult geological conditions and requires a detailed study with different field, laboratory testing and geophysical investigation.

The investigation for this project was divided into onshore and offshore parts of the project and the

a) In-situ testing geological testing comprised:
   - Mapping
   - Desk study
   - 111 Drillings (varying depth of 20.00-70.00m)
   - Sampling (soil, rock, water)
   - Piezometer (installation and measurements)
   - 1400 SPT tests (every 1.50m)
   - 54 CPTU tests
   - Vane shear test
b) Laboratory testing comprising:
   - physical characterization like bulk density, specific weight, grain size distribution analysis, determination of plasticity limits etc…
   - mechanical tests form direct shear tests, oedometer tests, triaxial testing, unconfined compressive strengths of soils, swelling, and more tests following the technical

specifications to define the deformation and strength parameters.
- chemical analysis on soils and water samples; and

c) Geophysical measurements like:
- Seismic refraction,
- MASW,
- Downhole test
- Horizontal to vertical spectral ratio analysis, also referred to as simply HVSR analysis as a method for estimating the natural resonant frequency (and thereby the fundamental site period) of the ground using a measurement of passive microtremors. All the geophysical methods were part of field testing and accurate techniques for determining physical-mechanical and dynamic properties of soils.

d) Geotechnical engineering report as a final step of the overall investigation work also including a seismic evaluation of the area under study.

The marine and land works are presented in the general layout below, also indicating the objects per each area as seen in Fig.1.

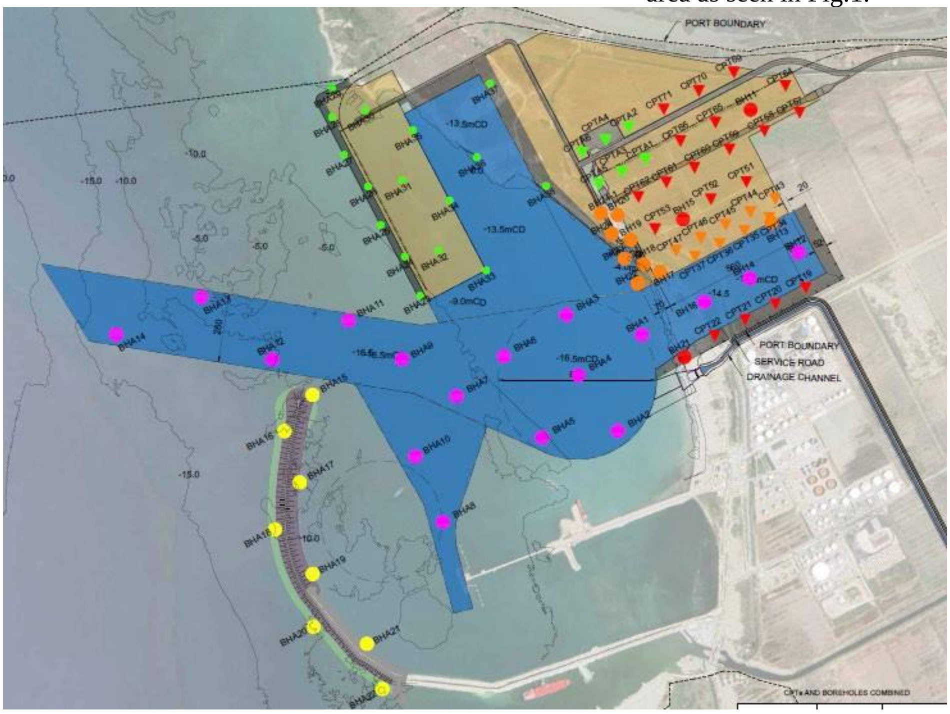

Figure 1. Overview of soil investigation, locations of BH's and/or CPTUs.

2. Geological and hydrogeological structure

Porto Romano is part of the zone of the western depression of Albania, but in the studied site, we have tried to summarise the encountered deposits, referring the new study and consulting also other projects and studies made in the zone. In the specific site where will be constructed the new port are present the following deposits illustrated in "Table 1" and Fig.2 below.

Regarding the hydrogeological aspect of the site, the underground water level is very close to the ground surface, and it is encountered from (-0.50 m) down to (-1.50 m) depth.

Table 1. Geological structure

	Description	Composition	Strength
Holocene deposits (d,c,pQh)	deluvial deposits and the weathered part of bedrock	sand, silty sand, silty clay, clay strata	Very soft to soft
Holocene deposits (dQh2)	maritime deposit	fine gravels, sand, silty sand, silty clay and clay strata	Very soft
Holocene deposits (lQh2)	marsh deposits	fine to medium sand, silty sand, silty clay, clay layer and clayey peat layer	Very soft to soft
Deposits of Pliocene N_2^1h	constitute the foundation of new Holocene deposits	Sandstone, Mudstone, rare conglomerates and in some cases carbonates interlayer	Very weak (Hard clays)
Deposits of Mesimian $N_1$3m	the foundation of new maritime deposits	Sandstone, Mudstone, conglomerates	Very weak (Hard clays)

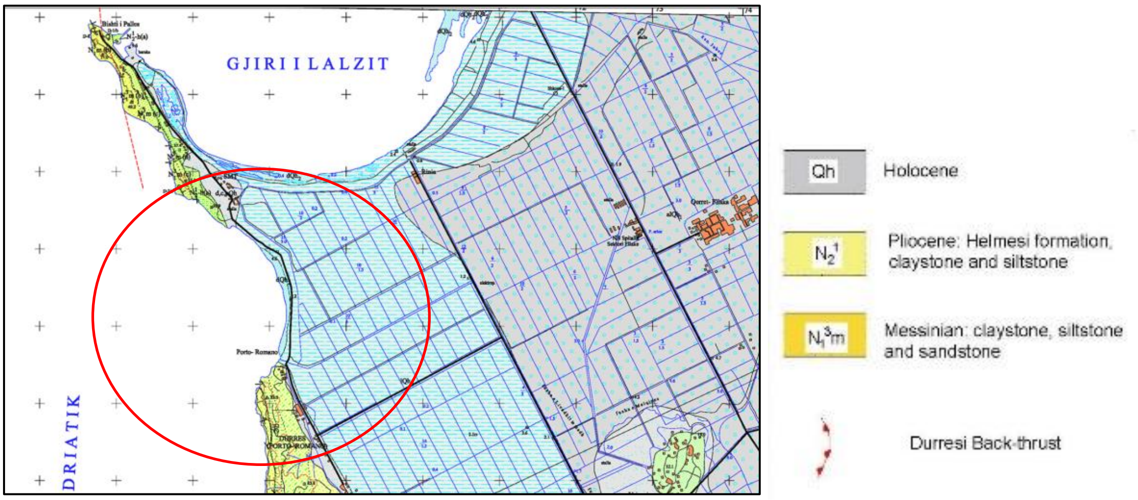

Figure 2. Geological map, indicated inside the red circle Porto Romano Port area.

3. Tectonic activity

The Albanides are divided into two active tectonic domains:

- an "external" domain in compression characterized by the reverse faulting, and
- an "internal" domain in extension characterized by the normal faulting.

The convergent boundary between the Albanides and Adria Microplate, based on the oil and gas seismic exploration carried out by foreign companies, is now well constrained to be located along the Adriatic and Ionian coasts (Aliaj et al., 1996, Aliaj, 2006).

From Dhermi-Othoni Island strike-slip to Vlora city it follows the contact between Sazani and Ionian tectonic units and then from Panaja through Frakulla to Durresi anticlinal line of quasi-northern extension it is deeply buried under Middle Miocene-Pliocene molasses of the Periadriatic Foredeep Basin.

In the figure segments of Albanides collision zone are noted by capital letters: LC- Lefkas-Corfu, and DD- Dhermi-Durres. LU- Lezha-Ulqini segment belongs to the Dinarides.

For more details, please refer to Fig.3 below.

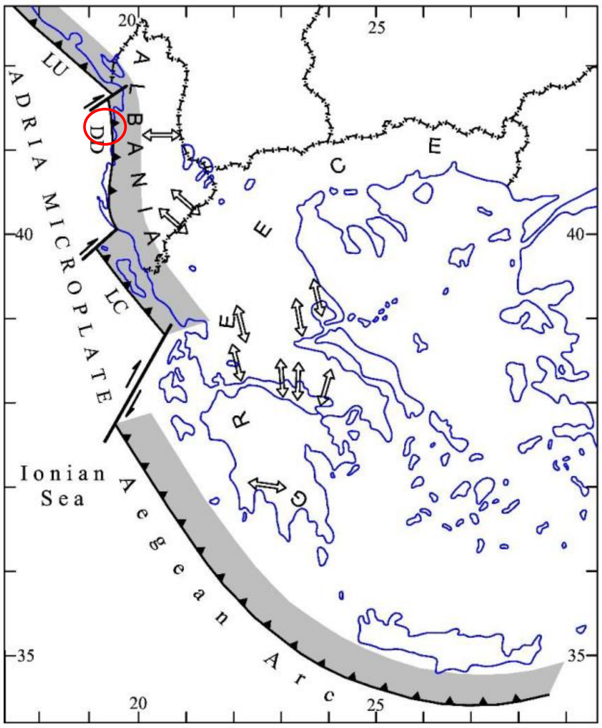

Figure 3. "Southern convergent margin of Eurasia Plate: Adriatic collision and Aegean Arc (modified by Aliaj 2006 with separation of two segments in the Albanides collision zone). Indicated inside the red circle the area.

4. Field investigations

Taking into account the relatively large number of tests for the project under study, we aimed to prove if the combination of different field and laboratory tests gives good, compatible, or reliable results. Refer to chapter 1, in the paper.

Or, in case there were any discrepancies, when did that happen and why.

These results would help the engineers to design different objects part of the project, including the improvement of the foundation's basement, but furthermore would extend their knowledge for future projects in the area, or on these types of soils.

4.1. Results of SPT & Undrained shear strength and their variability along the geological cross section

In all the boreholes carried out in this project, SPT tests were performed every 1.50m and the results are recorded in the borehole logs. Based on these results, the features of layers that have been met have been distinguished. Refer to Fig.4 and "Table 2" below:

Figure 4. Sample of a “Cross-section”, drawing conducted for the project.

Table 2. SPT & Undrained shear strength variability along the geological cross section

	Layers Strength & Description	Thickness (m)	SPT (NSPT)	Hand Torvane su (kPa)
1	**Very soft silty clay**	1-2	0-2	20-25
2	**Soft, silty clay**	1-2	2-4	22-42
3	**Loose to Medium dense silty sand to sandy silt**	2.5-10	3-15	-
4	**Stiff silty clay**	8-11	20-25	130-160
5	**Firm to stiff, silty clay**	20-25	7-11	75-120
6	**Weak to moderately weak, very fractured mudstone, & sandstone**	>50	>50	>500

The classification of the above layers is made according to ASTM standard about soil classification.

We would like to notice that in total we have encountered fourteen different layers, but to make it simpler for this paper purposes we merged some layers with similar features and resulted in total six layers as presented in “Table 2” above.

In some cases, throughout the project there have been anomalies in the SPT reading results.

During the field testing, we have verified that sandy layers due to the presence of salt gave higher results than expected, when in fact they are slightly compacted layers.

Chemical analyses have shown that the percentage of salt in the marsh area was several times higher than that of sea water.

These reading have been correlated because of that information.

4.2. Results of CPTU tests

In this project, a significant amount of CPTU tests have been performed.

The results of them were consistent with the SPT tests and the laboratory analysis.

As mentioned above, also in the CPTU tests, there were seen higher values of measured parametrs due to the presence of salt in the sandy layers. In these layers the CPT cone penetrated with difficulty.

These results have been correlated with other tests and the report has provided the interpreted data.

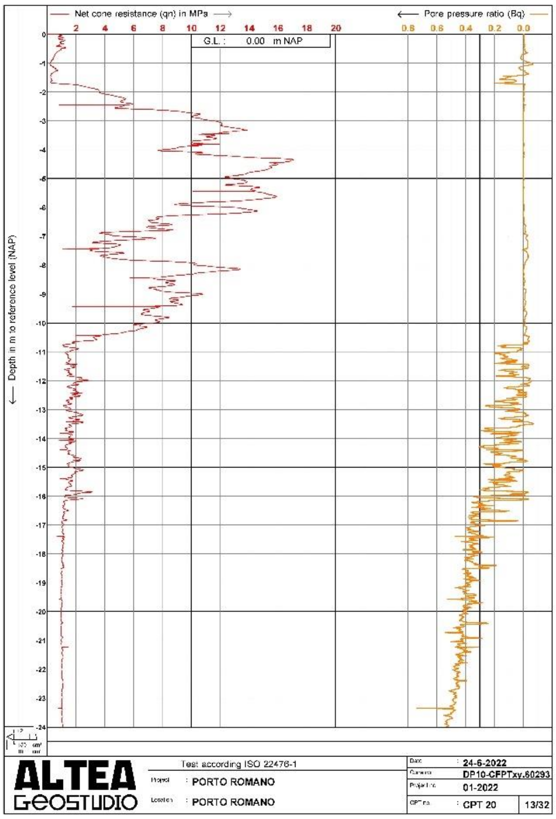

Figure 5. Sample of a “CPTu” test reading conducted for the project.

The graph above gives the results of cone resistance and pore pressure ratio towards depth.

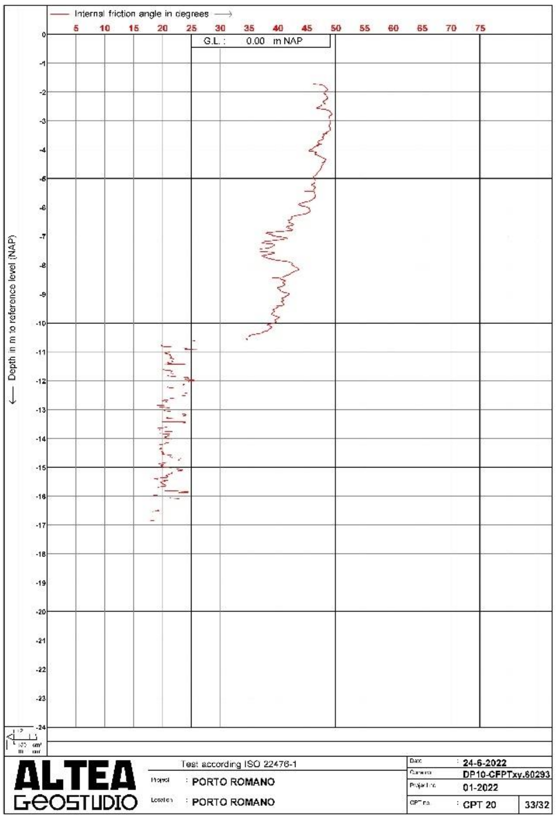

Figure 6. Sample of a "CPTu" test reading conducted for the project.

The graph above gives the results of internal friction angle versus depth.

4.3. Results of geophysical survey

For the study of the geological and geotechnical conditions of the port area in Porto Romano, we have performed geophysical surveys. We have measurements of refracted waves, MASW method, Downhole testing and horizontal to vertical spectral ratio surveys.

The results of these measurements have helped to evaluate the dynamic parameters of this area. As we mentioned above, this is an area with deposits with weak characteristics and high seismic intensity.

These various tests have provided sufficient data to identify layers and assess the seismic risk for the new structures of the new integrated port. In the paragraph below are given graphs and summary of the measured and derived data (see "Table 3", "Table 4" and Fig.7, 8.

4.4. MASW and Downhole seismic test results

Downhole seismic testing was used to gather and measure shear and compression wave velocities of soils and rock.

The P-wave and S-wave velocities are directly related to the important geotechnical elastic constants of Poisson's ratio, shear modulus, bulk modulus, and Young's modulus.

It was performed both on the offshore part and onshore part of the project.

Meanwhile, the multichannel analysis of surface waves, aka MASW it is a seismic exploration technique which evaluates ground stiffness by measuring shear-wave velocity (Vs) of subsurface in 1-D, 2-D, and 3-D.

The most common depth range of measurements goes from 0-30 meters.

Table 3. MASW measurements and MASW measurements and coherence with other geotechnical parameters derived from in situ tests.

	Depth [m]	Thickness [m]	Vs [m/s]	Vp [m/s]	NSPT	Qc [kPa]
1	4.82	4.82	118.3	193.1	9	54.22
2	10.41	5.59	162.7	265.7	16	269.62
3	17.05	6.64	164.3	268.3	9	283.00
4	24.23	7.18	173.2	282.8	7	368.55
5	32.69	8.46	192.7	314.7	10	631.18
6	oo	oo	248.4	405.7	0	2260.83

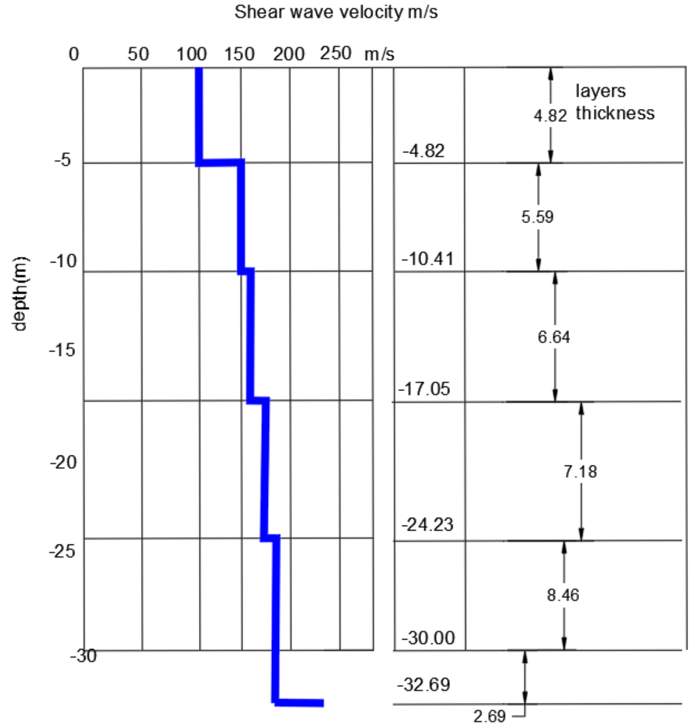

Figure 7. "MASW measurements" conducted for the project identifying the sub-layers.

After the MASW test interpretations it was concluded that the soil type falls under "D" category, which indicates deposits of poor consistency, coarse grain soils or poor consistency fine grain soils, with thickness superior to 30 m, characterized by gradual improvement of the mechanical properties with depth and Vs,30 inferior to 180 m/s (or NSPT,30 < 15 in coarse grain soils and cu,30 < 70 kPa in fine grain soils).

In the offshore borehole, the depth of investigation was 50.0 m and started from 10.0m because of casing tubes. This study also revealed that the P-wave and S-wave velocities can be used to determine the geotechnical parameters of a site that can be used to easily characterize its subsurface condition. We have calculated the density, Poisson's ratio, the shear deformation modulus, the oedometric modulus, Young's modulus, the bulk modulus for each interval and VS30.

"Table 4" presents the results of downhole direct method up to depth of 45m.

Table 4. Geotechnical parameters derived from downhole test results.

Depth [m]	Vs [m/s]	ni	G [MPa]	Ed [MPa]	E [MPa]	Ev [MPa]
1.08	77.29	0.35	10.2	44.65	27.59	31.05
8.17	353.25		257.94	455.07		111.16
15.32	165.11	0.49	47.88	2464.06	142.7	2400.21
24.19	140.85	0.49	32.82	1918.02	97.89	1874.26
35.08	186.00	0.49	61.41	4350.04	183.34	4268.17
40.00	282.09	0.47	160.72	2462.9	470.94	2248.61
45.00	196.35	0.49	71.85	6408.65	214.73	6312.86

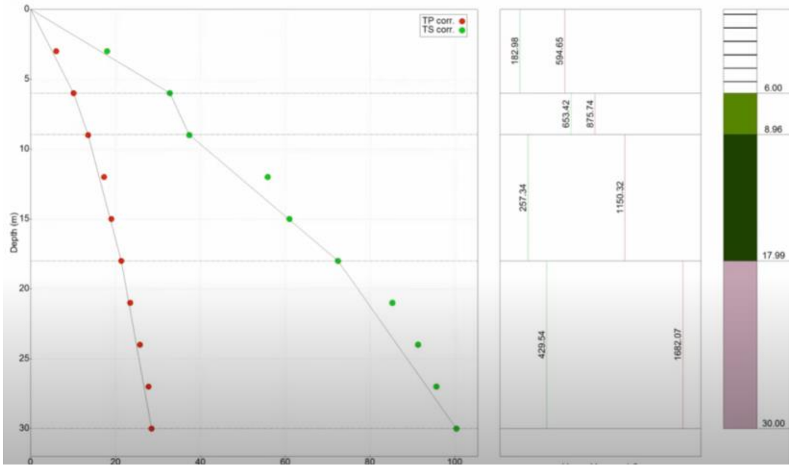

Figure 8. “Travel time graphs” with corrected travel times of “p” and “s” waves identifying the sub-layers versus depth.

The downhole seismic method (DH) measures the time taken for the P and S waves to move between a seismic source located on the surface of the ground, and the receivers, placed inside a borehole. Once entered the information for the project, the depth reached and the travel times, we got:

- the distances from source to receiver;
- corrected travel times;
- speeds of P and S waves;
- some important geotechnical parameters;
- the travel time graph with seismic layers from which can be determined the average velocity in each layer, some average geotechnical parameters and VS30.
- the graph of P and S waves interval velocity and definition of seismic layer;
- graphics relating to geotechnical parameters, derived for each interval;
- the stratigraphy of the borehole;
- the final report

5. Laboratory analysis

Laboratory testing is an integral part of geotechnical engineering design.

A well planned and properly executed laboratory testing program following the request of the clients provided soil and/or rock properties needed to perform geotechnical analyses and develop geotechnical models for the project facilities.

Most test procedures were based on specific international standards, but a proper interpretation of test results was essential to estimate the engineering characteristics of soil and rock materials to accurately predict their behaviour.

A large set of tests are executed on soils such as classification and index properties tests, strength and deformation tests, permeability testing, and a numerous index properties or strength parameters on rock samples mostly found on the offshore part of the project.

Sample	σv kPa	H mm	dt h	tf kPa	Sh mm	V micron/min		
1	200.00	29.21	1.31	98.00	3.41	102		
2	400.00	28.93	1.83	173.00	3.20	73		
3	800.00	28.54	2.59	309.00	3.14	51		

C' = 36.30 (kPa)
φ' = 18.60 °

Exploratory number: **BH-21**
Sample : **Undisturbed Structure**
Depth : **36.30-37.00m**

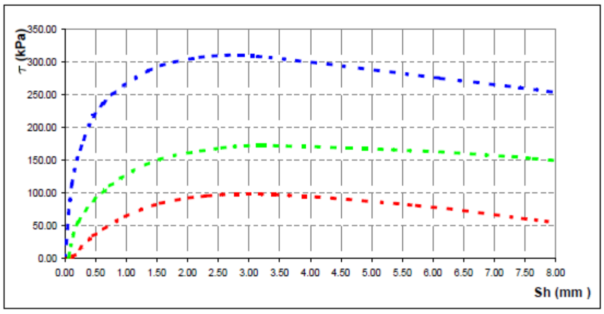

Figure 9. Example of results of “Direct shear test” on firm to stiff silty clays, undisturbed sample at 36.30 m.

Some of the mechanical parameter ranges are summarised in “Table 5” below.

Table 5. Geotechnical parameters measured in laboratory.

Samples tested for	ϕ [º]	C [kPa]	UU [kPa]	Ed [MPa]	UCSS [kPa]
very soft layers	12-17	19-28	34-42	2-5	40-45
Soft layers	14-20	25-32	38-50	4-7	50-70

loose to medium layers	30-36	5-12	30-35	6-9	50-65
Stiff layers	19-25	30-60	110-170	10-13	250-300
firm to stiff layers	18-23	27-50	65-120	9-12	200-250
Weak rocks	28-30	200-350	-	-	800-2000

A crucial part of the geotechnical investigation study was the comparison and interpretation of laboratory tests results with the data of the field tests.

The geotechnical and seismological engineering report was the final step of the overall investigation work.

6. Conclusions

The main objective of this paper is to emphasise that the application of different methods for the study of weak soils in high seismicity areas is very important.

Results presented in "Table 1" and "Table 2" are compatible, since in the first table they give a more generic view of the geological situation of the area, and the second one gives the exact results after performing the geological works and laboratory testing.

Correlation between these methods gives reliable results.

SPT test is a good way to evaluate the characteristics of sands (non-cohesive soils).

CPTU test is a very good method for evaluating cohesive and less cohesive soils such as soft soil and loose fine sand.

The comparison between predicted and measured features with different tests indicates good consistency and low scatter for the results obtained from the proposed methods.

Geophysical measurements give very good results, especially when they are correlated with each other for the evaluation of the dynamic parameters of geological layers in this area.

Geophysical method has the potential to reduce the cost of geotechnical investigations. This approach will help to reduce the cost of geotechnical investigations and also protect the environment from destruction caused by the invasive nature of geotechnical equipment

From the many tests performed on these rocks, it turns out that the resistance in uniaxial compression strength ranges between 0.80-2.00 MPa.

These values show that these soils can be modelled as soft rocks or hard clays.

Always recommended a good collaboration between local geologist, seismologist, and geotechnical design team to collect the right amount of data needed for the foundation system to be used per each facility/object to be design.

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Continental Oil & Gas; Stream Oil & Gas Ltd; Transatlantic Petroleum Ltd as some of the companies which have done research for oil and gas reserves in Albani.