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Study and geotechnical improvement of soft soils for the New Port development in Porto Romano, Albania

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ABSTRACT: The relocation of commercial port activities from the Port of Durrës to Porto Romano, Albania, has required extensive onshore and offshore geotechnical investigations due to the presence of thick deposits of soft, compressible, and seismically vulnerable soils. This study presents the results of three major site investigation campaigns comprising drilling, SPT, CPTU, downhole seismic testing, sampling, and comprehensive laboratory testing. The subsurface conditions are dominated by Holocene marine, lagoonal, and alluvial deposits characterized by low shear strength, high compressibility, and low permeability. Four principal soil units were identified offshore: soft silty sand–silty clay, loose to medium dense sand, weathered weak mudstone–sandstone, and moderately weak bedrock. Liquefaction assessments based on CPT data indicate that loose silty sands between depths of approximately 4–15 m are highly susceptible under the design earthquake with PGA = 0.317g. Appropriate ground improvement techniques, including stone columns, soil replacement, and drainage measures, were selected to mitigate settlement and liquefaction risks. The study provides a comprehensive basis for foundation design and long-term performance of the new Porto Romano Port infrastructure.

KEYWORDS: ground characterization, soft soil, liquefaction, settlements, monitoring.

1 INTRODUCTION

Following Decision No.1 dated 14.10.2020 of the Albanian Council of Ministers, the relocation of commercial maritime activities from the Port of Durrës to Porto Romano has necessitated detailed geotechnical evaluation.

The work plan for the above investigations was divided into three campaigns and respective reporting:

- Campaign 1 – Onshore Surveys Phase I
- Campaign 2 – Onshore Surveys Phase II
- Campaign 3 – Offshore Surveys

The new port platform extends along a low-lying coastal plain dominated by soft, compressible soils.

This paper presents the results of the onshore and offshore soil investigations and outlines the selected ground improvement approach to ensure stability and serviceability.

2 PROJECT AREA AND GEOLOGICAL CONTEXT

2.1 *Project area*

The Porto Romano site is located approximately 10 km north of the current Port of Durrës.

The project zone features a flat, coastal terrain bounded by weathered sandstone and mudstone hills, as seen in Figure 1.

Figure 1. The investigation site, comprising onshore and offshore survey phases.

2.2 *Geological context*

The subsurface is dominated by Holocene marine, lagoonal, and alluvial deposits underlain by weathered Pliocene mudstone and sandstone.

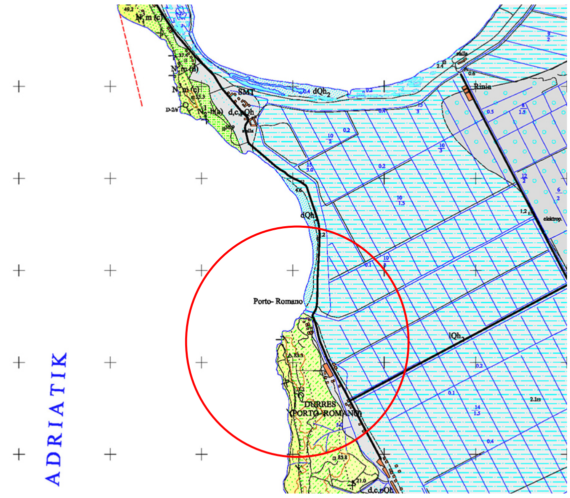

Figure 2. Geological map of the area under study.

Based on offshore and nearshore data, the typical generalized stratigraphy consists of four main soil units.

Table 1. Main layers encountered at investigation site and their geotechnical characteristics

Layer	Depth Range (m)	Dominant Soil Type	Key Properties	Engineering Behavior
1	0–4	Soft silty sand / silty clay	Cu = 12–20 kPa, w > 40%	Highly compressible, liquefiable
2	4–15	Loose to medium dense sand	qc = 3–6 MPa, Dr < 45%	Main liquefiable layer
3	15–35	Weathered mudstone–sandstone	UCS ≈ 1.5–3.5 MPa	“Hard soil” behavior
4	>35	Moderately weak mudstone	Increasing stiffness with depth	Bearing stratum

Figure 3 illustrates a geological cross-section through the back-thrust zone, revealing the stratigraphy and tectonic influences in the area.

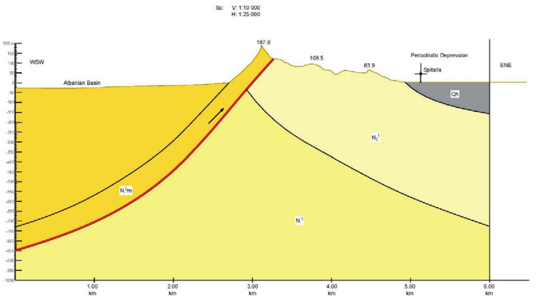

Figure 3. Geological cross section through back thrust.

The thrust faulting and associated structural deformation have contributed to the heterogeneous nature of the subsurface profile, creating lateral and vertical variations in density and strength-especially within the younger, alluvial and marine deposits.

These features further exacerbate the seismic vulnerability of the site, particularly in areas underlain by compressible, liquefiable materials.

Further CPTU profiling and borehole correlation were essential to refine the boundaries between these soils and to assess their geotechnical behavior under cyclic loading and foundation demands.

3 GEOTECHNICAL INVESTIGATION AND LABORATORY TESTING

3.1 *Site Investigation Program*

The geotechnical investigation of the Porto Romano New Port development was conducted through three major campaigns between 2021 and 2022, comprising two onshore phases and one offshore phase. The objective was to fully characterize the stratigraphy, mechanical behavior, and consolidation properties of the foundation soils under both static and seismic loading conditions.

3.1.1 *Onshore Investigations*

The onshore investigation program included:

- 54 CPTu tests (8 in Phase I and 46 in Phase II),
- 60 boreholes with depths up to 70 m (7 in Phase I and 53 in Phase II),
- Standard Penetration Tests (SPT) at 1.5 m intervals,
- Undisturbed and disturbed sampling,
- Downhole seismic tests,
- Laboratory testing: grain size distribution, Atterberg limits, triaxial (UU and CU), and oedometer tests.

3.1.2 *Offshore Investigations*

The offshore investigation program included:

- 51 offshore boreholes with sampling,
- SPT at 1.5 m intervals,
- Downhole seismic testing,
- Laboratory testing: classification, triaxial, and oedometer tests

Due to the required investigation depth exceeding 5 m below seabed level, vibro-coring was not feasible, and therefore all offshore data were obtained using rotary drilling with casing. Rock samples recovered from deeper levels were tested for uniaxial compressive strength.

3.2 *Difficulties Encountered During Onshore and Offshore Investigations*

The investigation works were affected by significant site-specific constraints.

3.2.1 *Onshore Difficulties*

- The groundwater table lies between 0.3 m and 1.0 m below ground level, causing continuous borehole instability in soft clayey and silty soils.
- Collapse of borehole walls was frequent in organic and highly plastic clay layers.
- Access limitations due to marshy terrain and very soft ground conditions restricted the movement of heavy drilling rigs.
- Obtaining undisturbed samples in very soft clays required repeated attempts and special thin-walled samplers.

3.2.2 *Offshore Difficulties*

- Offshore drilling was affected by wave action, strong currents, and narrow weather windows, limiting effective working time.
- Maintaining borehole verticality and consistent SPT energy transfer under marine conditions was challenging.
- Sample recovery from highly sensitive marine clays was often disturbed.
- Continuous casing and controlled rotary methods were necessary to ensure borehole stability and data reliability.

Despite these difficulties, a comprehensive and reliable dataset was acquired for geological and geotechnical interpretation.

3.3 *Laboratory testing results*

Laboratory testing was conducted on representative samples from both onshore and offshore boreholes. The test program included:

- Grain size distribution
- Atterberg limits
- Oedometer consolidation tests
- Triaxial compression tests (UU and CU)
- Uniaxial compression tests on rock samples

The investigations revealed:

- Low undrained shear strength: Cu = 12–25 kPa in marine clays,
- High compressibility: Cc = 0.20–0.38,
- Low coefficient of consolidation: cv = (1–5) × 10^{-8} m²/s,
- Weak rock strength: UCS = 1.5–3.5 MPa, representative of heavily weathered rock.

Based on these values, the deeper mudstone and sandstone are more appropriately classified as hard soils rather than competent rock for geotechnical design.

3.3.1 *Soil Classification*

The classification of soil samples based on Atterberg limits plotted on the Casagrande Plasticity Chart indicates that:

- Nearshore silty clays fall mainly within CL–ML zones,
- Deeper marine clays trend toward medium plastic clays (CL),
- Sands classify predominantly as SM–SP.

The distribution confirms the dominance of low- to medium-plasticity fine-grained soils within the upper 20–25 m.

3.3.2 *Compressibility and Consolidation Behavior*

The soil compressibility was evaluated by oedometer testing on representative clay and silty clay samples from depths between 4 m and 28 m.

From the e–log σ′ consolidation curves, the following parameters were derived:

- Pre-consolidation stress (σ′c)
- Compression index (Cc)
- Recompression index (Cr)
- Coefficient of consolidation (cv)

Table 2. Summary of consolidation parameters

Soil Type	Depth Range (m)	Cc	Cr	cv (m^2/s)
Marine silty clay	6–12	0.30–0.38	0.05–0.07	$(1–2)\times10^{-8}$
Lagoonal clay	12–20	0.25–0.32	0.04–0.06	$(2–3)\times10^{-8}$
Clayey silt	20–28	0.20–0.26	0.04–0.05	$(3–5)\times10^{-8}$

The values in Table 2 confirm the high consolidation settlement potential and slow dissipation of excess pore water pressures under loading.

3.4 *Comparison of Consolidation Parameters from Laboratory and In-Situ Tests*

To verify the reliability of the consolidation parameters used for settlement and time-rate analyses, a comparison was performed between the coefficients of consolidation (cv) obtained from laboratory oedometer tests and those derived from CPTU pore pressure dissipation tests.

The CPT-based cv values were back-calculated from excess pore pressure decay curves using standard semi-log interpretation techniques.

The CPT-derived cv values are consistently slightly higher than laboratory values, which is attributed to:

- Sample disturbance during extraction and trimming for oedometer testing
- Differences in stress level and drainage conditions between field and laboratory.

Table 3. Comparison of "cv" from oedometer and in-situ tests

Soil Type	Depth Range (m)	cv from Oedometer (m^2/s)	cv from CPTU (m^2/s)
Marine silty clay	6–10	1.5×10^{-8}	2.2×10^{-8}
Marine silty clay	10–14	2.0×10^{-8}	2.8×10^{-8}
Lagoonal clay	14–18	2.5×10^{-8}	3.6×10^{-8}
Clayey silt	18–24	3.5×10^{-8}	4.8×10^{-8}

Both datasets confirmed the consistency of laboratory and in-situ assessments as indicated in Table 3.

3.4.1 *Shear Strength Behavior from Triaxial Testing*

Both Unconsolidated–Undrained (UU) and Consolidated–Undrained (CU) triaxial tests were performed on:

- Marine silty clay (depths 6–14 m),
- Lagoonal clay (depths 14–24 m),
- Weathered mudstone from deeper layers.

Typical Strength Ranges:

- Undrained shear strength (Cu): 12–25 kPa for soft clays,
- Effective friction angle (φ′): 24°–30° for silty sands,
- Peak axial stress in soft rock: 1.5–3.5 MPa.

The results show strain-softening behavior, particularly in weathered rock and sensitive marine clays.

3.4.2 *Swelling and Collapse Potential*

Swell–collapse tests were performed on selected silty clay and clayey silt samples from depths between 3.5 m and 9.0 m, where partial saturation was observed.

The results indicate that:

- Samples subjected to low vertical stress (< 150–180 kPa) exhibit positive swelling upon wetting.
- At higher stress (> 180 kPa), collapse settlement dominates after saturation.

These behaviors are critical for:

- Lightly loaded slabs, Pavements,
- Shallow foundations without ground improvement.

For zones exhibiting swell/collapse behavior, ground replacement, preloading, or deep foundations are required to prevent serviceability damage.

4 SEISMIC AND LIQUEFACTION CONSIDERATIONS

The Porto Romano project area is located within one of the most seismically active zones of Albania.

The national seismic micro-zonation study carried out by the Institute of Geo-Sciences, Energy, Water and Environment (IGJEUM, 2020) defines the seismic input parameters for engineering design in this region. Based on this reference, a design Peak Ground Acceleration (PGA) of 0.317g was adopted for the Ultimate Limit State (ULS) conditions at the site. This value corresponds to a 475-year return period and is consistent with the requirements of:

- Eurocode 8 (EN 1998) for seismic design, and
- National Seismic Hazard Zoning Regulations

4.1 *Methods Used for Liquefaction Assessment*

Liquefaction potential was evaluated primarily using in-situ CPTU data, supplemented by laboratory classification and strength tests.

The following internationally recognized CPT-based methods were applied:

- Boulanger & Idriss (2014) updated stress-based CPT procedure,
- Cross-checking with Eurocode 8 – Annex E recommendations

4.2 *Identification of Liquefiable Soil Layers*

The CPT and borehole data indicate that the primary liquefiable unit is a loose silty sand to fine sand layer encountered between depths of approximately 4 m and 15 m below ground or seabed level.

This layer is characterized by:

- Low to moderate cone resistance (qc),
- Low effective vertical stress due to shallow groundwater, and
- Contractive behavior under cyclic loading.

Deeper silty clays (below 15–18 m) generally exhibited non-liquefiable behavior due to:

- higher plasticity,
- lower permeability,
- cohesive soil structure.

These soils exhibited low cone resistance (qc), elevated pore pressure response, and friction ratios consistent with loose, contractive behavior under dynamic loading.

Table 4. CPT Summary table for liquefiable layers

Depth (m)	qc (MPa)	fs (%)	Soil Type	FSliq
4–6	2.5–3.2	1.1–1.4	Silty sand (SM)	0.73
6–9	3.0–4.2	0.9–1.2	Fine sand (SP–SM)	0.75
9–12	3.8–5.0	0.7–1.0	Silty sand	0.91
12–15	4.5–6.0	0.6–0.9	Fine sand	1.14

The results in Table 4 clearly indicated that the soil layers between 4 m and 12 m depth are highly susceptible to liquefaction, with FSliq consistently below 1.0 under ULS seismic loading.

4.3 *Foundations design considerations*

Based on the liquefaction results, we recommend:

1. Shallow foundations without ground improvement are not acceptable in zones where FSliq < 1.0.

2. Deep foundations (piles) must be used for:
- quay walls,
- heavy port structures,
- breakwater foundations.

For backland zones, ground improvement is mandatory prior to the use of shallow foundations.

5 GROUND IMPROVEMENT

5.1 *Objectives of Ground Improvement*

The ground improvement program for the Porto Romano New Port was developed to mitigate the following critical geotechnical hazards identified during the investigation and analysis phases:
- Liquefaction of loose silty sand layers between 4–12 m depth,
- Excessive primary and secondary consolidation settlement of soft marine clays,
- Low bearing capacity of near-surface soils,
- High post-earthquake deformation risk for quay walls and backland structures.

Each zone requires different improvement intensities and foundation solutions.

Based on geological, geotechnical, and seismic conditions, the following improvement methods were recommended as engineering design solutions:
1. Stone Columns (Vibro-Replacement)

Stone columns are adopted where thick, soft clay and liquefiable sand layers are present.

2. Soil Replacement (Excavation and Granular Refill)

In near-surface zones where very soft soils extend to shallow depths (< 4–5 m).

3. Pile foundations remain essential for waterfront and heavy marine structures.

In zones with very weak or organic clays, the following alternatives may be locally applied:
- Prefabricated Vertical Drains (PVDs) + Preloading,
- Deep Soil Mixing (DSM) for localized stability improvements.

The selected ground improvement works are part of the final design solution for the project and are treated in another article.

6 RESULTS AND OBSERVATIONS

Based on the results of the geotechnical investigation, in-situ testing, laboratory analyses, and site-specific seismic considerations, the following conclusions are drawn regarding the foundation design and ground improvement strategies for port development:
1. The subsurface conditions across the port area exhibit significant variability, with weak marine and alluvial deposits underlain by stiffer layers interpreted as hard soil or soft rocks. Layers characterized by relatively high stiffness and strength, are deemed suitable as bearing strata for heavy marine structures.
2. The upper 15–20 m consists of very soft, highly compressible and seismically vulnerable soils.
3. Consolidation settlements are expected to be large in magnitude and slow in time rate.
4. Swell/collapse behavior represents an additional serviceability hazard.
5. Weathered mudstone and sandstone provide a competent bearing stratum only at significant depth.
6. The Porto Romano site is exposed to strong seismic shaking with PGA = 0.317g.
7. Loose silty sands at 4–12 m depth are highly liquefiable.
8. Post-liquefaction settlements and loss of bearing capacity pose a major design risk.
9. Laboratory and CPT-derived consolidation parameters show good agreement, confirming the reliability of both testing approaches.
10. Primary consolidation dominates settlement
11. Layers with low permeability and high void ratios exhibit slower consolidation, whereas sandy silt and silty sand layers consolidate faster.
12. CPT-based in-situ measurements effectively complement laboratory data, enhancing confidence in foundation design and settlement predictions.
13. Monitoring and staged loading strategies are recommended for sites with soft clay deposits to ensure settlements remain within acceptable limits
14. Ground improvement is mandatory for all zones affected by liquefaction and soft clay deposits.
15. Stone columns + shallow foundations are suitable for backland development.
16. Pile foundations remain essential for waterfront and heavy marine structures.
17. The approved improvement strategy ensures:
    Seismic safety,
    Acceptable settlements,
    Long-term performance and durability

This geotechnical design strategy addressed both seismic and static load demands, while ensuring the long-term functionality and safety of port operations.

7 CONCLUSIONS

The Porto Romano site presented significant geotechnical challenges including low-strength, compressible, and organic-rich soils within a seismically active region.

The combined investigation and improvement techniques proved effective in mitigating settlement and liquefaction risks, setting a robust foundation for this critical port infrastructure.

8 ACKNOWLEDGEMENTS

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