Coastal and Offshore Geotechnical Engineering

Part - 1

Important Notes

1. Introduction

Coastal and Offshore Geotechnical Engineering is a specialised field of geotechnical engineering focused on soil-structure interaction in marine and offshore environments. It supports the design and stability of structures such as ports, offshore platforms, wind turbines, pipelines, and coastal protection systems.

These projects face unique challenges, including wave, tide, and current conditions, scour, cyclic loading, corrosion, and complex seabed conditions. The discipline combines soil mechanics, marine loading, and advanced design methods to ensure safe, durable, and efficient infrastructure in harsh coastal and offshore settings.

Figure - Geotechnical Engineering, Source - SUBSEA

2. Scope and Importance of Coastal and Offshore Geotechnical Engineering

Coastal and offshore projects are vital for:

- Maritime transportation and ports
- Offshore oil and gas exploration
- Renewable energy (offshore wind, tidal energy)
- Coastal protection and climate resilience
- Subsea infrastructure and pipelines

Failures in offshore geotechnical design can lead to catastrophic environmental, economic, and human losses, making accurate soil characterization and robust design essential.

3. Marine and Coastal Soil Environment

3.1 Characteristics of Marine Soils

Marine soils are typically:

- Soft, normally consolidated clays
- Loose silts and sands
- Highly compressible with low shear strength
- Sensitive to cyclic and dynamic loading

Common types include:

- Marine clays (high water content, low permeability)
- Calcareous sands (crushable particles)
- Organic sediments

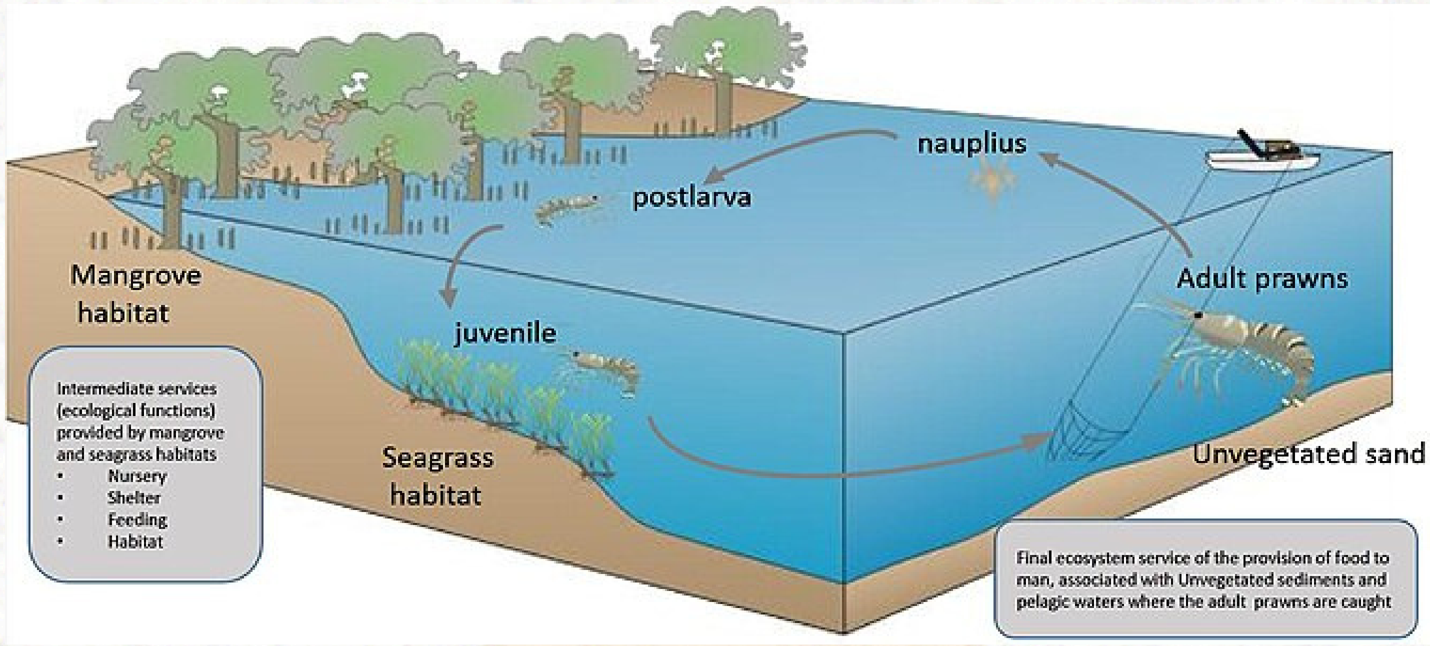

Figure - Marine coastal ecosystem, Source - WIKIPEDIA

3.2 Seabed Formation

Seabed soils are formed by sedimentation due to rivers, waves, and biological activity. Deposition occurs in layers, often resulting in highly stratified soil profiles.

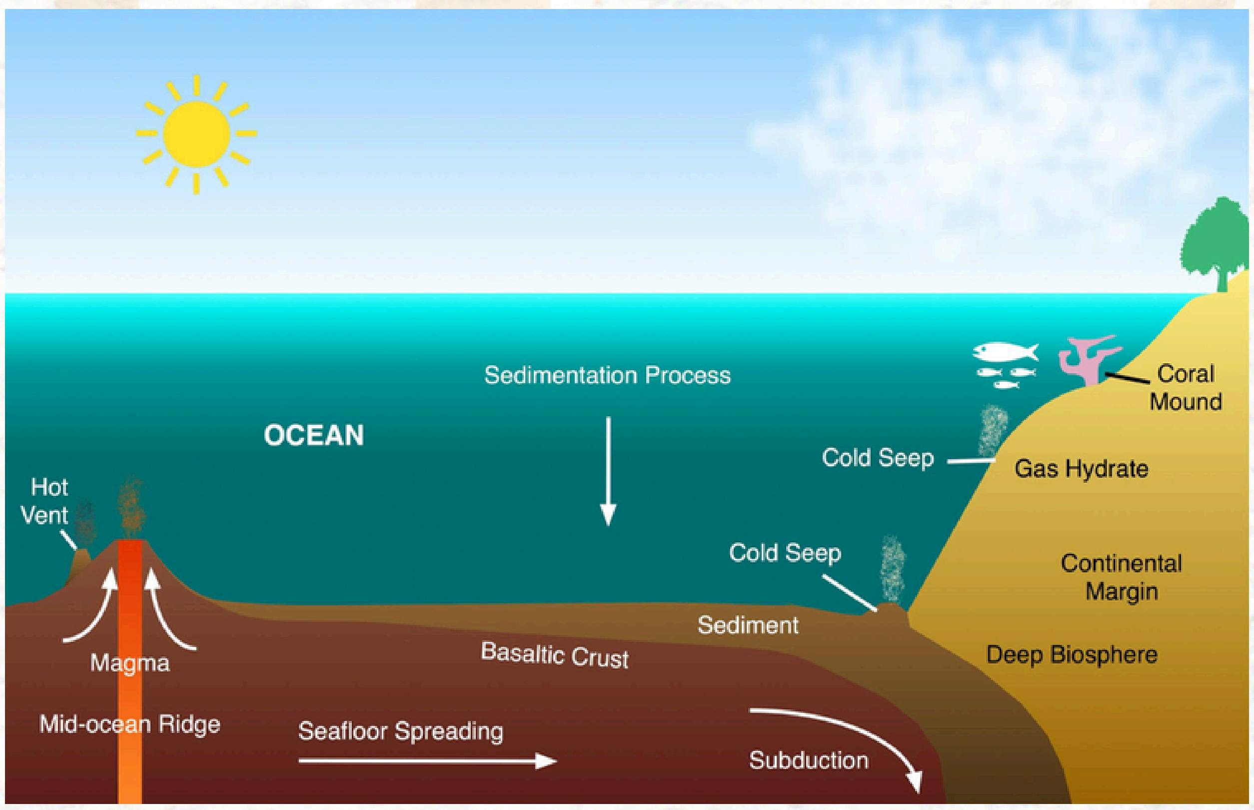

Figure - Seafloor and subseafloor sediments, Source - BOOKDOWN

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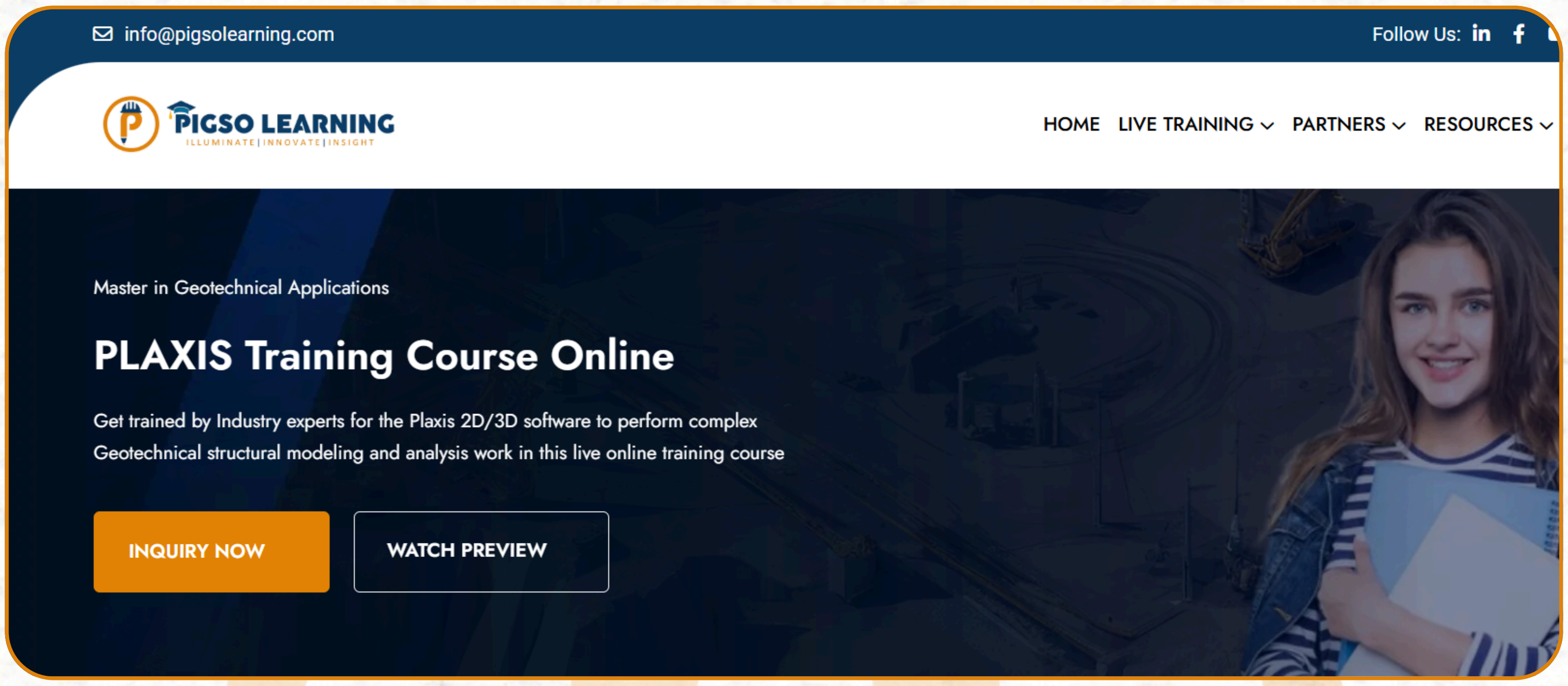

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4. Site Investigation for Coastal and Offshore Projects

Offshore site investigation is more complex and expensive than onshore investigation.

4.1 Geophysical Investigations

- Seismic reflection and refraction
- Side-scan sonar
- Multibeam echo sounding

4.2 Geotechnical Investigations

- Offshore boreholes
- Cone Penetration Test (CPTu)
- T-bar and ball penetrometer tests
- Sampling using piston samplers

4.3 In-Situ Testing Parameters

- Undrained shear strength (su)
- Pore pressure response
- Soil stiffness and strength anisotropy

5. Effective Stress in Marine Soils

The effective stress principle governs soil behaviour under submerged conditions.

Effective stress equation:

$$\sigma' = \sigma - u$$

Where:
- σ = total stress
- u = pore water pressure

Submerged unit weight: $\gamma' = \gamma sat - \gamma w$

Vertical effective stress at depth z: $\sigma' v = \gamma' z$

Effective stress controls shear strength, compressibility, and consolidation of marine soils.

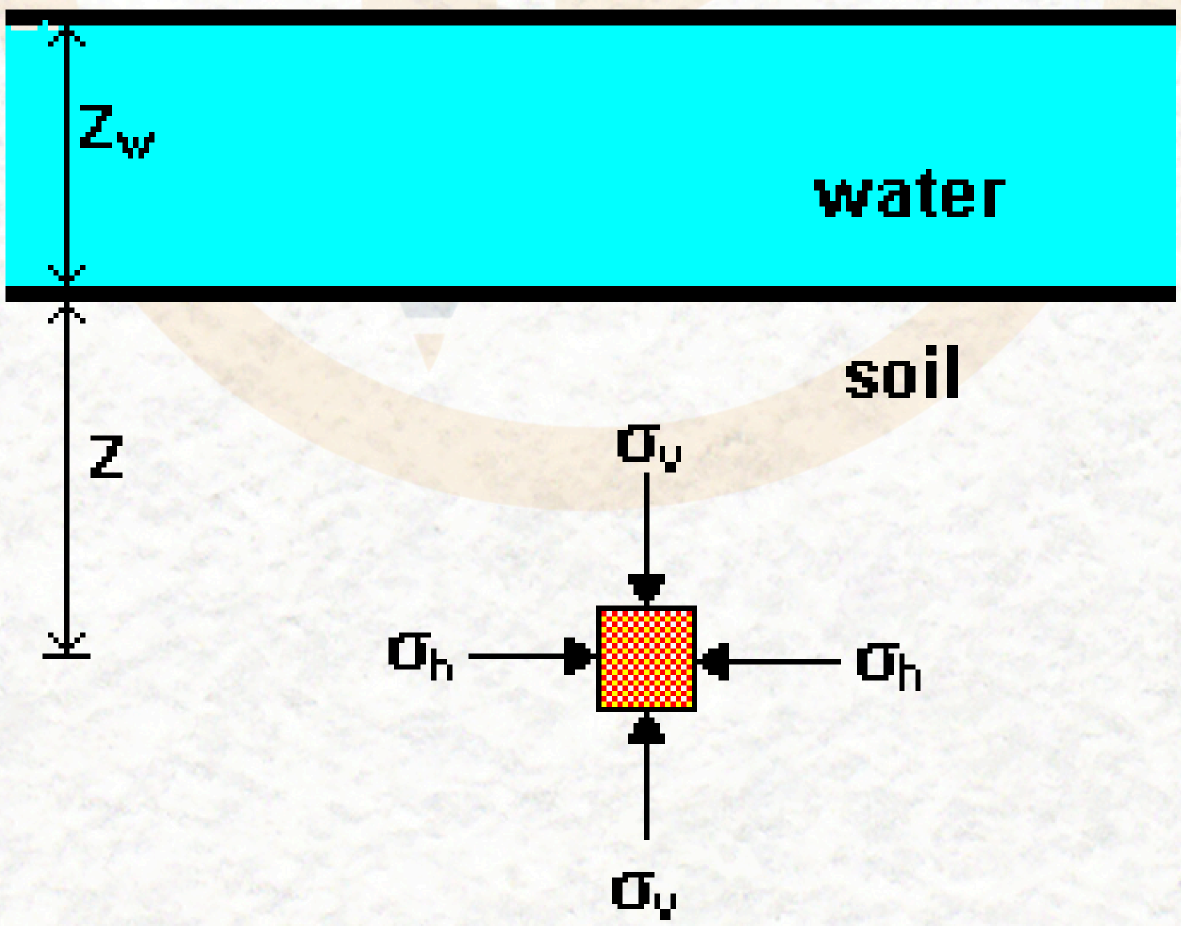

Figure - Effective Stress in Marine Soils, Source - Envroinment

6. Wave, Current, and Environmental Loading

6.1 Wave Loading

Waves induce cyclic and dynamic loads on offshore structures.

Key wave theories:

- Linear (Airy) wave theory
- Stokes wave theory
- Cnoidal wave theory

6.2 Hydrodynamic Forces (Morison's Equation)

For slender structures:

$$F = \rho\ CD\ D\ |u|u + \rho\ CM\ (\pi D^2/4)\ du/dt$$

Where:

- CD = drag coefficient
- CM = inertia coefficient
- u = water particle velocity

6.3 Current and Tidal Effects

Currents increase drag forces and influence scour around foundation

7. Soil Behavior Under Cyclic and Dynamic Loading

Marine soils are subjected to repetitive loading from waves and wind.

7.1 Cyclic Shear Strength

Cyclic loading may cause:

- Strength degradation
- Excess pore pressure generation
- Cyclic softening

7.2 Liquefaction Potential

Loose sands and silts may liquefy under cyclic loading.
Cyclic Stress Ratio (CSR):

$$CSR = \tau_{cyc} / \sigma'_v$$

Liquefaction resistance is assessed using cyclic triaxial and CPT-based methods.

8. Offshore Foundation Systems

8.1 Shallow Foundations

- Gravity-based structures (GBS)
- Mudmats

Bearing capacity (undrained clay): $q_u = N_c s_u$

Where $N_c \approx 5.14$ for strip footing

8.2 Pile Foundations

Widely used offshore due to deep, weak soils.

Axial capacity: $Q_{ult} = Q_s + Q_b$

Where:
- Q_s = shaft resistance
- Q_b = base resistance

Skin friction (clay): $f_s = \alpha s_u$

8.3 Suction Caissons

- Large-diameter steel cylinders
- Installed using suction pressure
- Widely used for offshore wind turbines

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