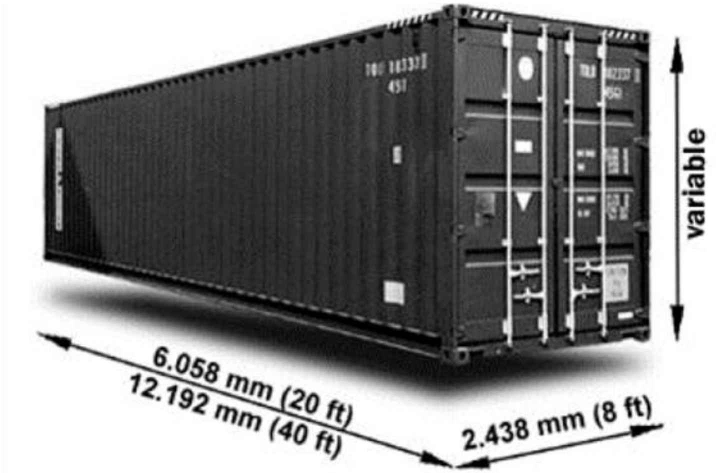
Geotechnics Seminar

25 September 2025

Teble of Contents

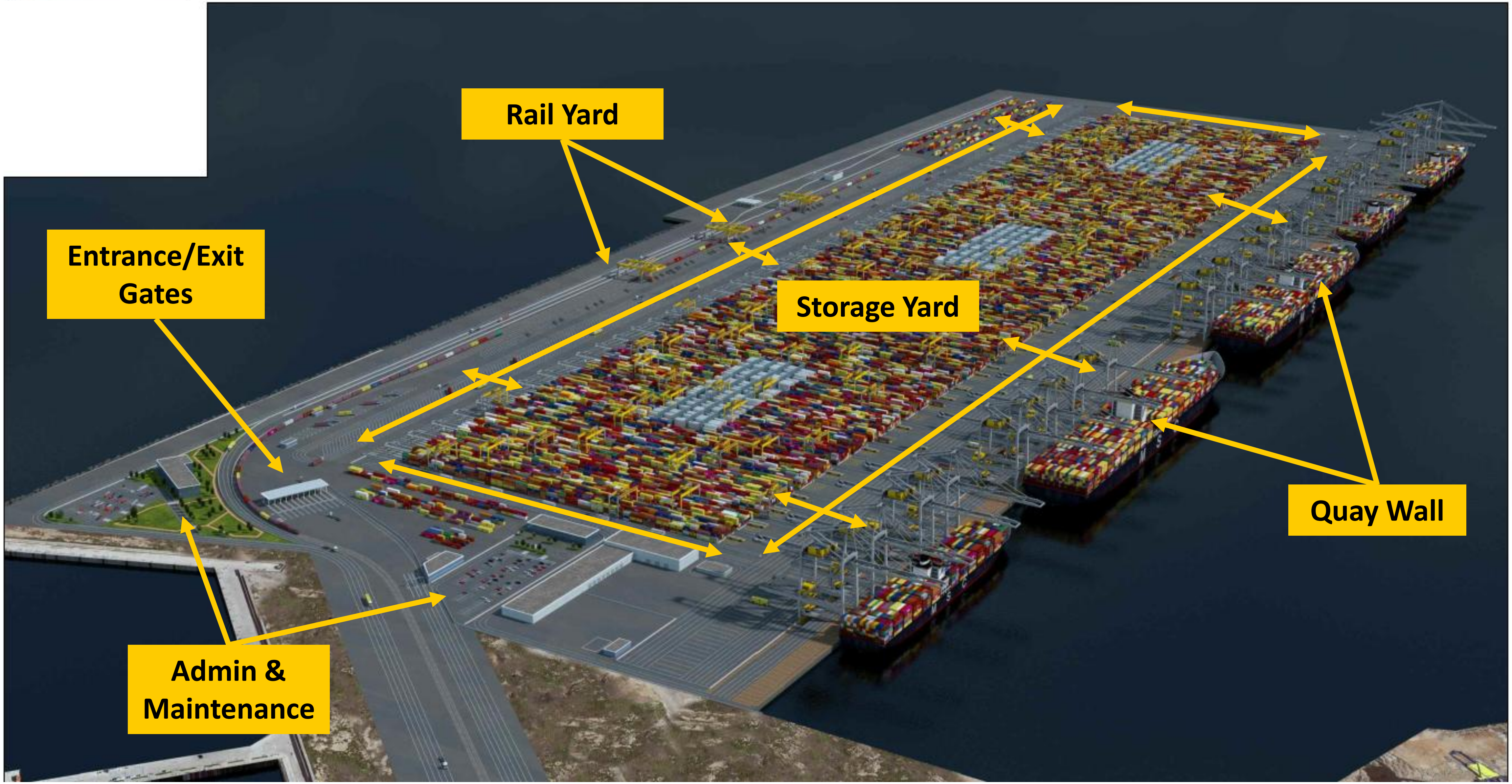
TiL Presentation

Marine Container Terminals
The Container



- **Revolutionized Global Trade**
  - Standardized containers allowed goods to be moved seamlessly between ships, trains, and trucks, drastically reducing handling time and costs
- **Boosted Economic Growth**
  - Shipping cost are cut by 90% compared to handling cargo as "break-bulk"
  - Shipping becomes just a fraction of the final price of the product
- **Enabled Globalization and Supply Chains**
  - Products can be manufactured where it is most cost-effective and then transported and sold world-wide, powering global supply chains and making markets accessible to businesses world-wide
- **Transformed Ports, Cities, and Infrastructure**
  - Ports became larger, as the demand for more land and deeper quay walls increased, reshaping urban development
  - As ports grew bigger, the economy of "port cities" benefited (more jobs, revenue, etc.)
- **TEU – T**wenty-foot **E**quivalent **U**nit
  - Universal unit of measurement for capacity in container logistics business
  - Max. allowable weight of 20/40ft container ≈ 30T

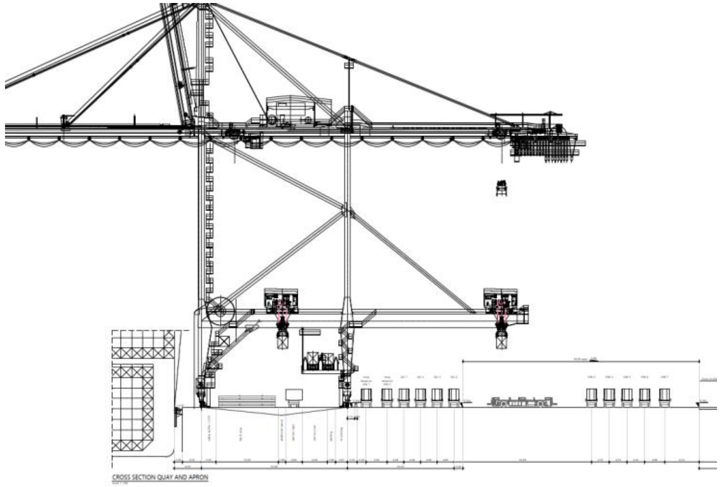
Marine Container Terminals
The Terminal



Marine Container Terminals
Quay Wall

Critical marine structure that:

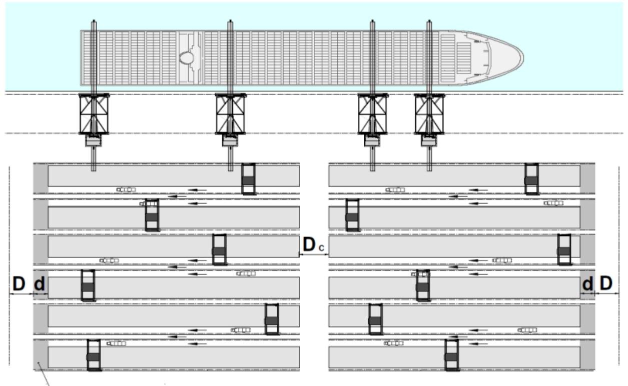
- Facilitates the safe mooring of vessels
- Supports and powers the Ship to Shore Cranes that load/unload containers from/to ships/horizontal transport vehicles
- Ensures the provision of services to the ships such as connection to shore power, water bunkering, etc.
- Supports auxiliary activities



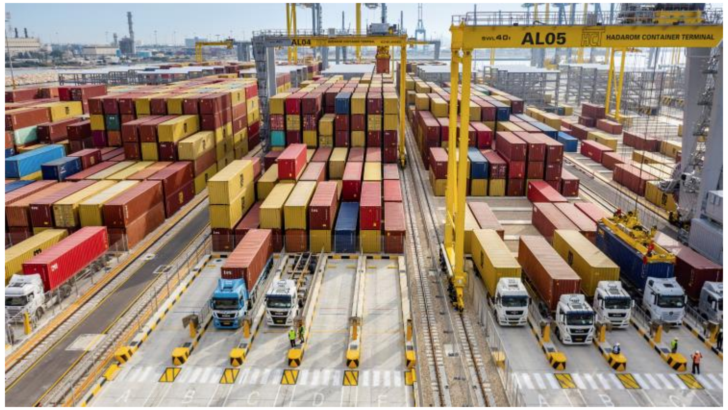
Marine Container Terminals
Storage Yard

Typical container yard configurations based on the type of equipment and cargo

PARALLEL RTG:
A combination of Rubber-Tired Gantry cranes (RTGs) with Terminal Tractors (TTs) with container stacks oriented parallel to the quay. Typical for transhipment terminals.



PERPENDICULAR (AE)RMG:
A combination of (Electrified/Automated) RMG (Rail-Mounted Gantry) and perpendicular configuration is typical for terminals with predominantly local (import/export) cargo



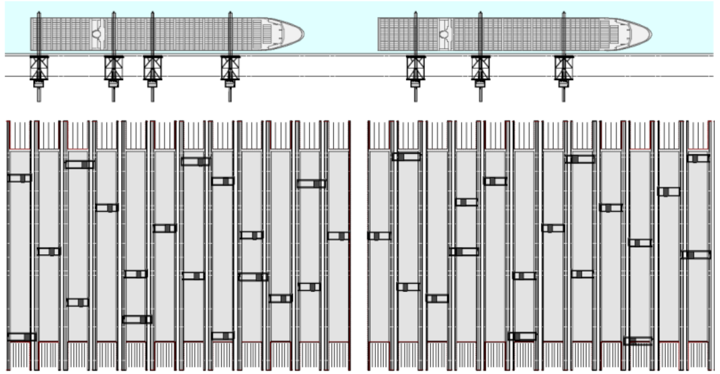
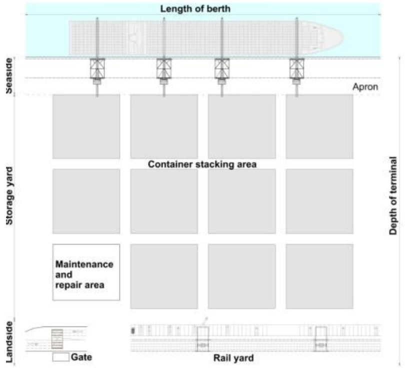
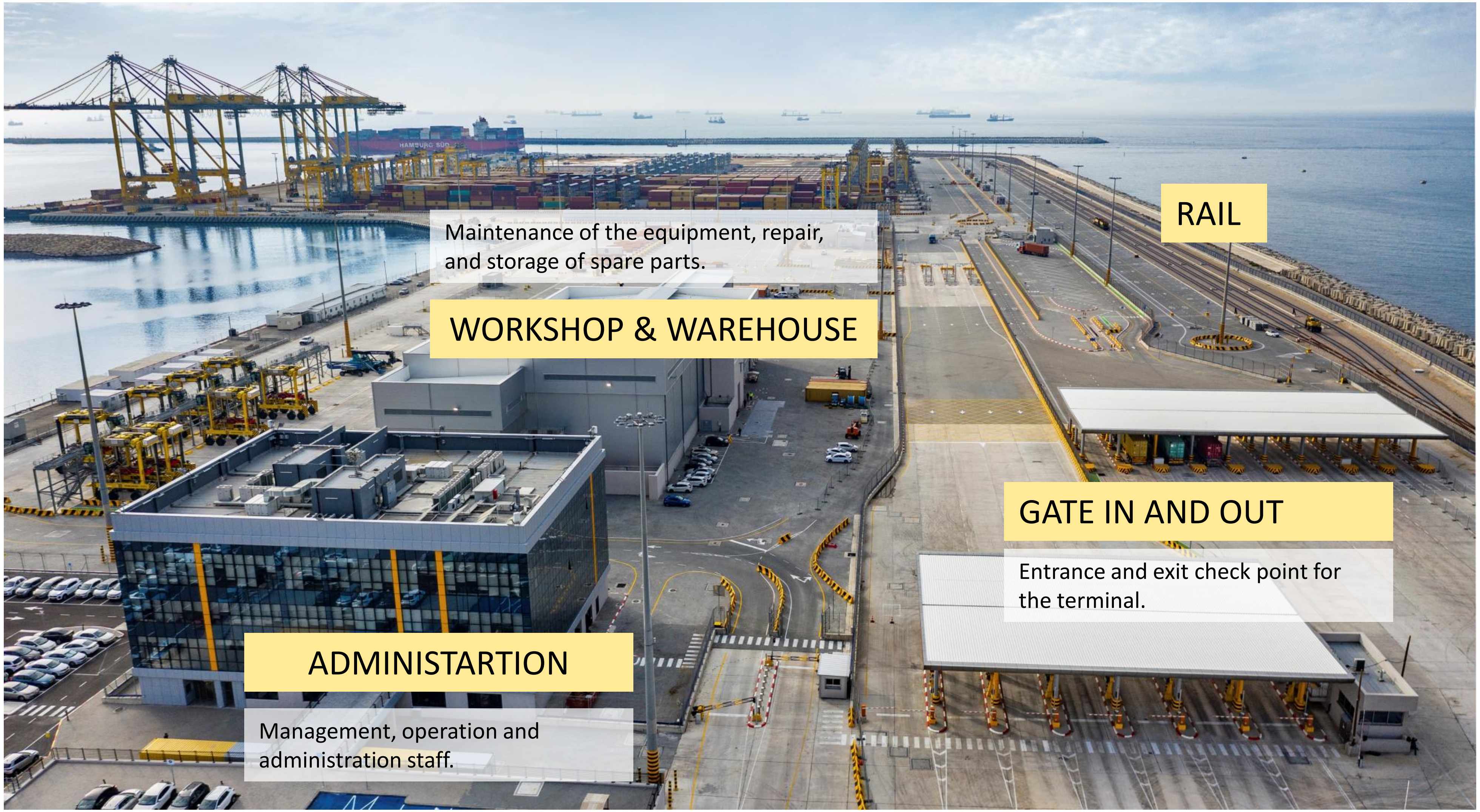


Figure 3.24: End-loaded perpendicular RMG layout

STRADDLE CARRIER:
A Straddle Carrier is advantageous because it performs both horizontal transportation and handling of containers at the storage yard. However, the storage capacity per m^2 is less



Marine Container Terminals
Facilites



Design Criteria

- Quay Wall
  Design vessel, design crane, services, etc.
- Storage Yard
  Storage height, modality, circulation, etc.

Environmental Conditions

- **Geotechnical Conditions**, Geophysical Conditions, Climate (wind, waves, corrosion), Pollutants, Bathymetry, Topography, etc.

Cost

- Very high infrastructure development cost (CAPEX) ≈ 60% of the overall investment (the remaining 40% corresponds to the cost of equipment, systems and technology)
- Quay Walls: 100-200 kUSD/m
- Yard & Facilities: 500-1000 USD/m^2

Geotechnical Challenges
Soil Geotechnical Conditions

Land Availability

- We don’t get to choose the port sites, so we have to “deal” with the existing soil conditions.
- Often container terminals are developed close to river mouths where poor quality fluvial deposits accumulate

Availability of Quality Soils

- Vast quantities of quality material is required for fill, replacement and reclamation
- Sources of fill materials are limited and dredging material is often of poor quality

Uncertainties

- One of the greatest risk associated with port project is uncertainty related to soil conditions
- Mitigation is challenging and strategies include proper risk allocation between Employer/Contractor
- Strong engineering teams are required to maintain awareness
- The insufficient mitigation of the risk associated to soil conditions is the most common reason for project cost overruns

Geotechnical Challenges
Performance Requirements

Displacement Criteria

- Due to very high service loads (Ship to Shore Cranes of weight ≈ 2000T; modern container vessels of DWT > 200kT) it becomes challenging to maintain quay wall displacement within acceptable limits
- Acceptable quay wall displacement is governed by structural criteria, as well as the operational tolerances of the STS cranes which are usually defined based on ISO 12488-1

Settlement Criteria

- The introduction of Automation (Automated Staking Cranes, Automated Horizontal Transportation Vehicles) resulted in high requirements (very small margin) for absolute and (most importantly) differential settlement of the operational areas
- Typical allowable settlement criteria ≈ no more than 20cm in 25 years

Geotechnical Challenges
Execution Challenges

- Availability of experienced labor
- Availability of specialized equipment
- Misalignment between Local Regulations, International Standards and Project Specifications
- International setting (language barriers, cultural differences, calendar differences, etc.)
- Simultaneous operations (brownfield projects)
- Risk of budget and schedule overruns
- …

Geotechnical Solutions
Process Flow

Investigation

- Specify and implement a geotechnical soil investigation campaign to characterize the existing soils at the site location

Interpretation

- Collection (*factual reports*) and interpretation (*interpretative reports*) of the data collected in the investigation stage.
- Specify and design the engineering internation required to improve the soil conditions in accordance with the performance requirements

Intervention

- On-site implementation of the soil improvement wors specified during interpretation

Verification and monitoring

- Testing of the “improved” soils to verify that the performance requirements are met
- Return to previous stages if needed
- Monitor settlements and displacements throughout the lifetime of the asset to ensure they remain within limits

Geotechnical Solutions
Investigation Technques

In-situ Testing

- Land and Marine Exploratory boreholes with sample extraction
- Standard Penetration Tests (SPT)
- Cone Penetration Tests with pore pressure measurement (CPTu)
- Test pits
- Field vane
- …

Laboratory testing

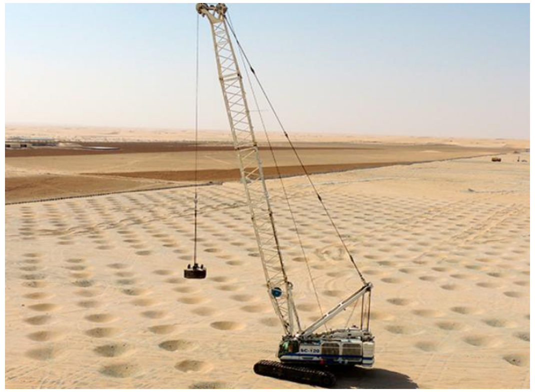
- Visual Identification
- Particle size distribution
- Plasticity Index
- Moisture content
- Consolidation tests
- Strength testing (triaxial, direct simple shear, etc.)
- California Bearing Ratio (CBR)
- …

Typical Soil Investigation Equipment

Geotechnical Solutions
Intervention Techniques

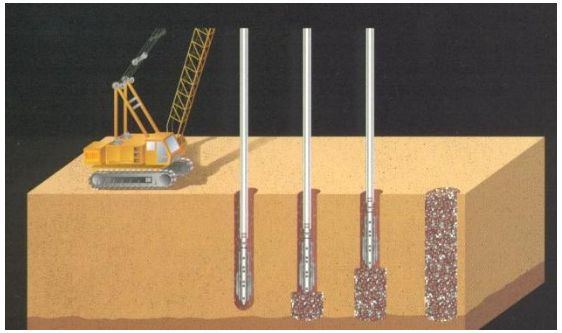
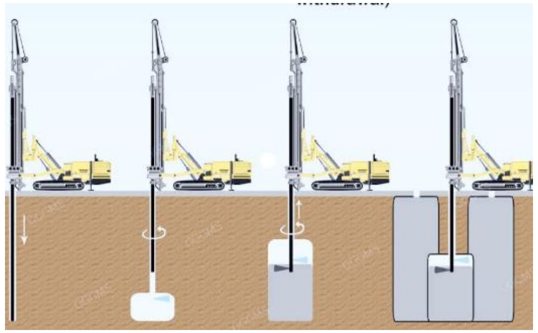
Common Soil Compaction Methods in Port Developments

- Vibro-flotation
- Dynamic compaction
- Surcharge with wick drains (cohesive soils)
- …

Common Soil Improvement Methods in Port Developments

- Stone Columns
- Jet grouting
- Soil replacement
- Rigid inclusions
- Compaction grouting
- Soil mix
- …

Geotechnical Solution
Verification and Monitoring

Common Verification Methods

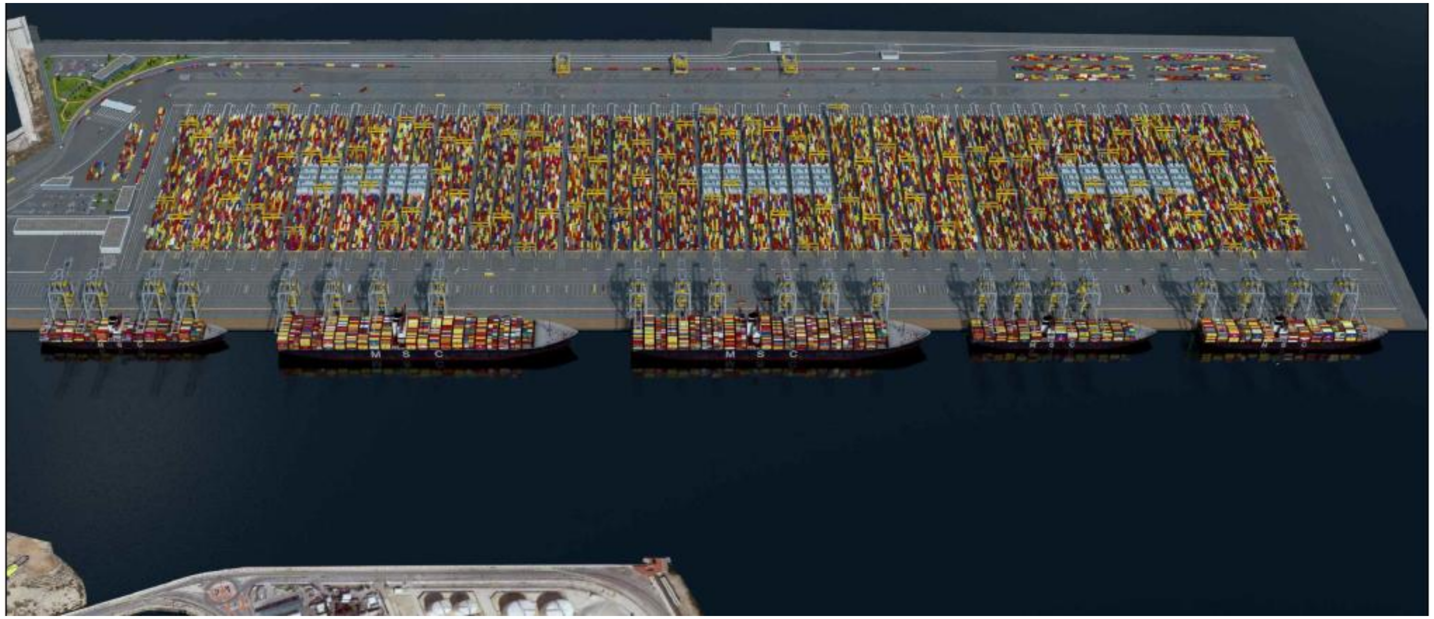
- Post-treatment in-situ testing (SPT, CPT)
- Plate load & Zone load tests
- Sacrificial Test Piles (o-cells, load bridge)
- Non-destructive Pile Tests
- …

Common Monitoring Methods

- Settlement points
- Heave gauges
- Inclinometers
- Piezometers
- Observation wells
- …

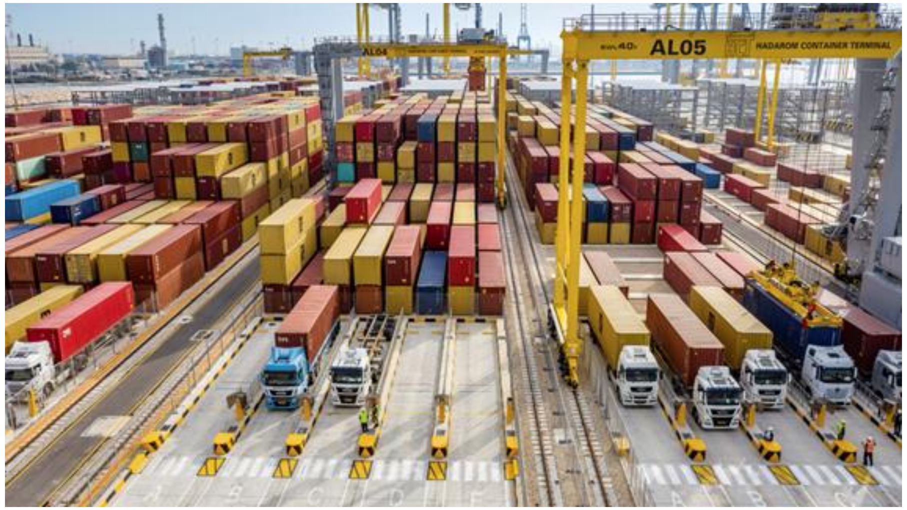
Case Study
Greenfield Automated Container Terminal

- Development of a new greenfield state of the art Fully Automated Container Terminal facility in Europe
- The new container terminal will be developed together with the local Port Authority and TiL who will be the Operator
- The development comprise a 2km long quay wall and an operational area of 136ha (1ha=10,000m^2)
- Total project investment CAPEX > 2 BN EUR
- Port Authority: Dredging, Reclamation, Compaction, Quay Wall
- Operator: Pavements, Foundations, Utilities, Buildings, Equipment
- Utilization of Rail Mounted Automated Stacking Cranes for handling the containers at the storage yard (**more that 20,000m of rail**) and Automated Guided Vehicles (AGVs) for the horizontal transportation



Case Study
Greenfield Automated Container Terminal

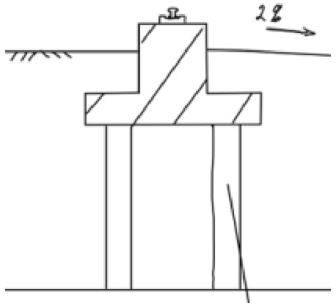
ASC Foundation



EPFL + TiL Multicriteria evaluation of ASC foundation options

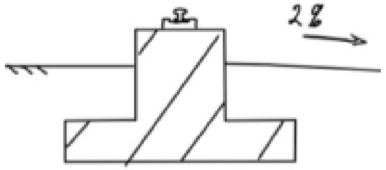
- Due to presence of Automation, engineers tend to be conservative
- Study the available options for ASC foundation design
- Evaluate each option against the performance requirements, cost (initial investment + maintenance cost) and disruption of operations
- Propose a recommendation specifically for the new North Container Terminal considering the local geotechnical conditions
- Develop a decision tree for selection of the appropriate foundation design considering the location particulars

Concrete beam on piles



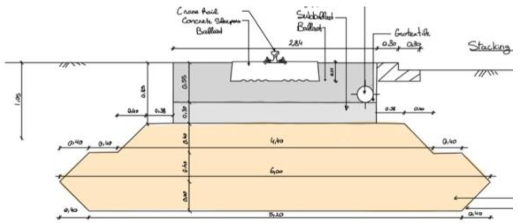
- Very rigid element; almost 0 displacements
- High implementation cost (CAPEX)
- Low maintenance cost (OPEX)
- Low operational disruption

Concrete beam on grade



- Rigid element but vertical displacement (settlements) can occur
- Moderate implementation cost
- Low maintenance cost
- Moderate operational disruption

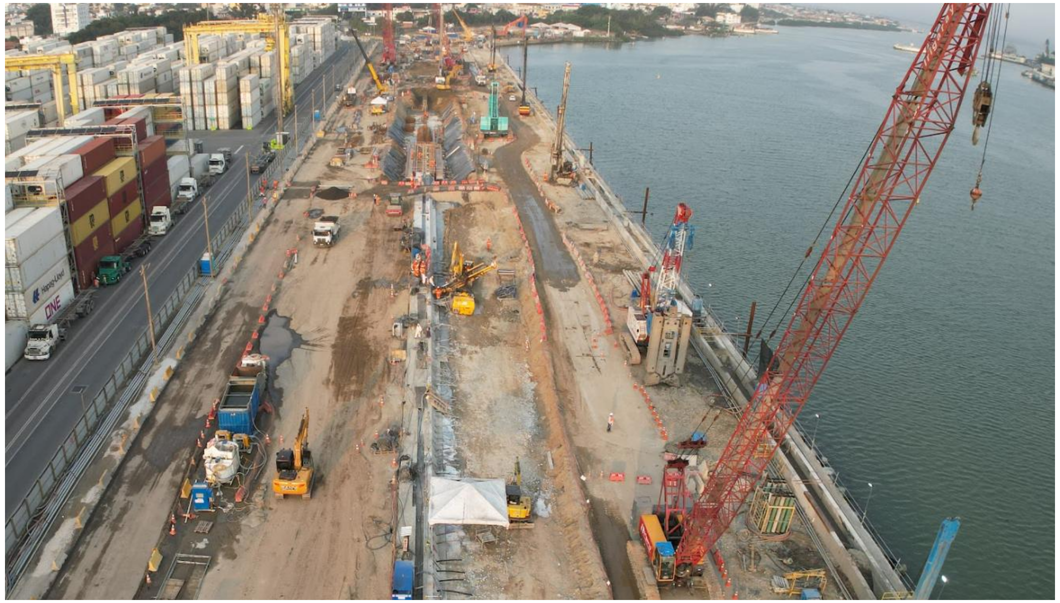
Sleeper on ballast foundation

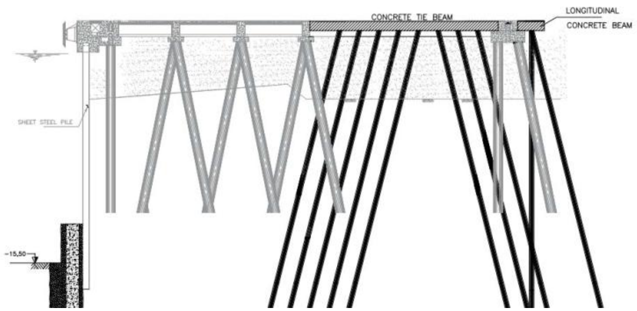


- Flexible element vertical displacement (settlements) occur
- Low implementation cost
- High maintenance cost
- High operational disruption

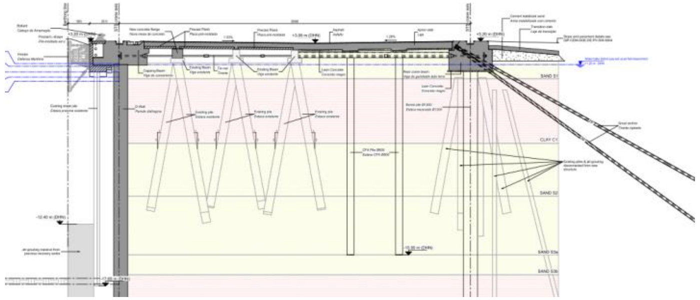
Case Study

Quay Wall Improvement Project



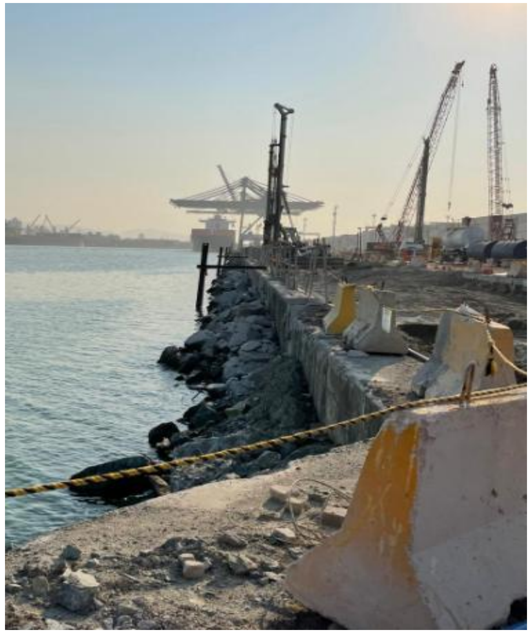


Typical cross section of the existing (old) quay wall

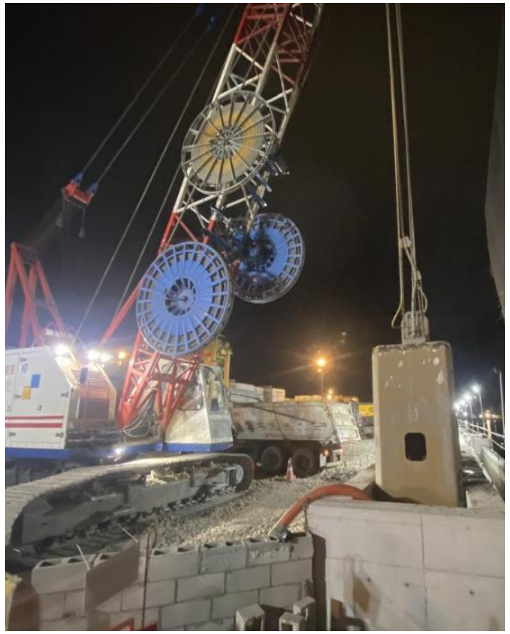


Typical cross section of the new quay wall

- TiL commissioned the design and execution of a major quay improvement project at one of its terminals in South America
- The objective of the project is to increase capacity of the 900m quay wall to allow for greater water depth in front of the quay wall, the installation of larges STS cranes, and the berthing of larger container ships
- Extensive soil and structural investigations were carried out in advance to determine the residual capacity of the existing structure and to facilitate the development of the project specifications
- After reviewing various possibilities, the final solution comprises the construction of a new diaphragm wall quay with ties and grout anchors replacing the existing wall
- Unique project features: the installation of a temporary rock bund Infront of the quay to ensure stability during construction**; 70m deep** D-wall panels
- Complicated execution methodology in an already “congested” brownfield site

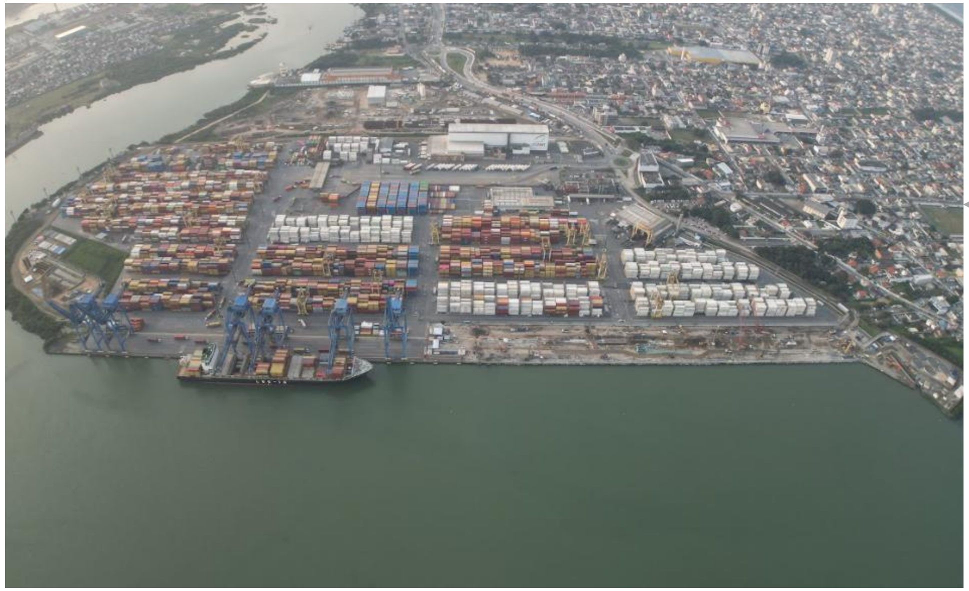


Temporary rock bund



D-wall excavation

Case Study
Quay Wall Improvement Project



Overall project view

Laydown area

De-sanding tanks

Drying pits

Geotechnics Seminar
Key takeaways

- **Ports are Complex Systems**
  Geotechnical engineering plays a critical role in ensuring structural integrity, safety, and performance of port infrastructure
- **Challenges Are Site-Specific**
  Soil conditions, land availability, and performance requirements drive design decisions and cost
- **Uncertainty is a Major Risk**
  Inadequate soil characterization is a leading cause of cost overruns and delays
- **Solutions Exist But Require a Process**
  Investigation → Interpretation → Intervention → Verification → Monitoring
- **Performance Criteria Are Tight**
  Automation and heavy loads demand strict settlement and displacement limits
- **Innovation & Collaboration Matter**
  Advanced soil improvement techniques and strong engineering teams are key to success

Terminal Investment Limited