TEXAS A&M UNIVERSITY
GALVESTON CAMPUS

MANAGEMENT OF PORT FACILITIES AND INFRASTRUCTURE

2. Harbor Facilities and Infrastructures

MARA 616

Professor: Dr. Jean-Paul Rodrigue

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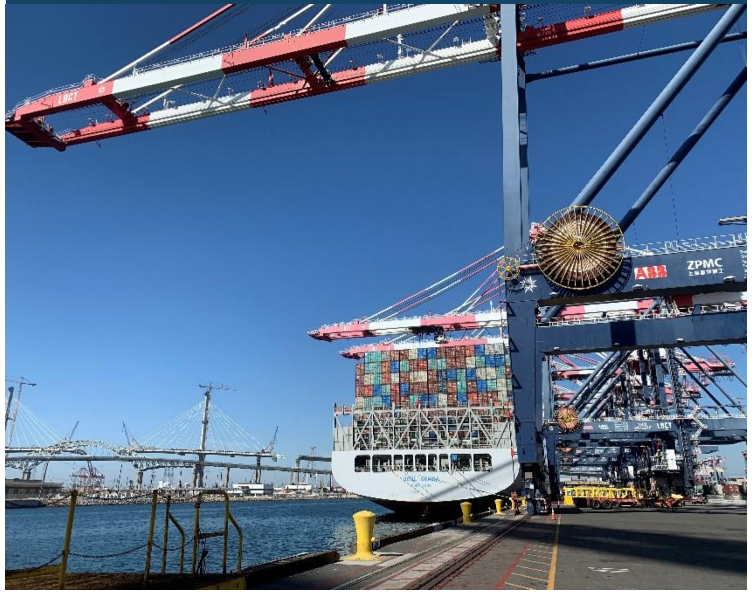


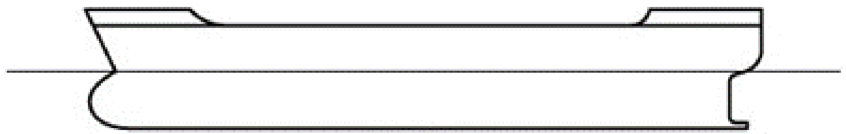
A. Ship Design Characteristics and Ports

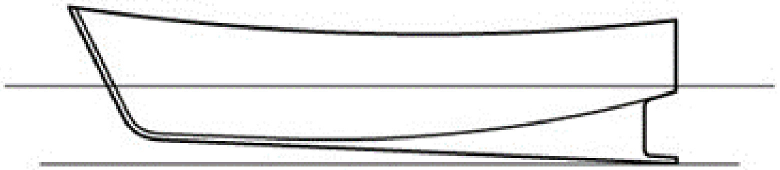
Do We Design Ports Around Ships of Ships Around Ports?

- The importance of standards (e.g. Panamax)
- Pull effect
  - Panamax, has substantially influenced terminal design in the 20th century.
  - Provided a set of technical characteristics, particularly draft and length, around which port infrastructure was built.
- Push effect
  - Growth of ship size began in the 1970s.
  - Prevalent for container shipping in the early 2000s.
  - Push considerations in terminal design and equipment for new terminals.
  - Incentives for existing terminals to expand their technical capabilities with dredging and new equipment.

Vessel Measurements

- Baseline
  - A line in the longitudinal plane of symmetry of the ship's hull parallel to the designed summer load waterline.
- Summer load line
  - The waterline up to which the ship can be loaded, in sea water, during summer when waves are lower than in winter.
  - Usually marked by a different paint color (red) below the load line.
  - Red because the paint contains copper, an anti-biofouling component.





Common Ship Hull Markings

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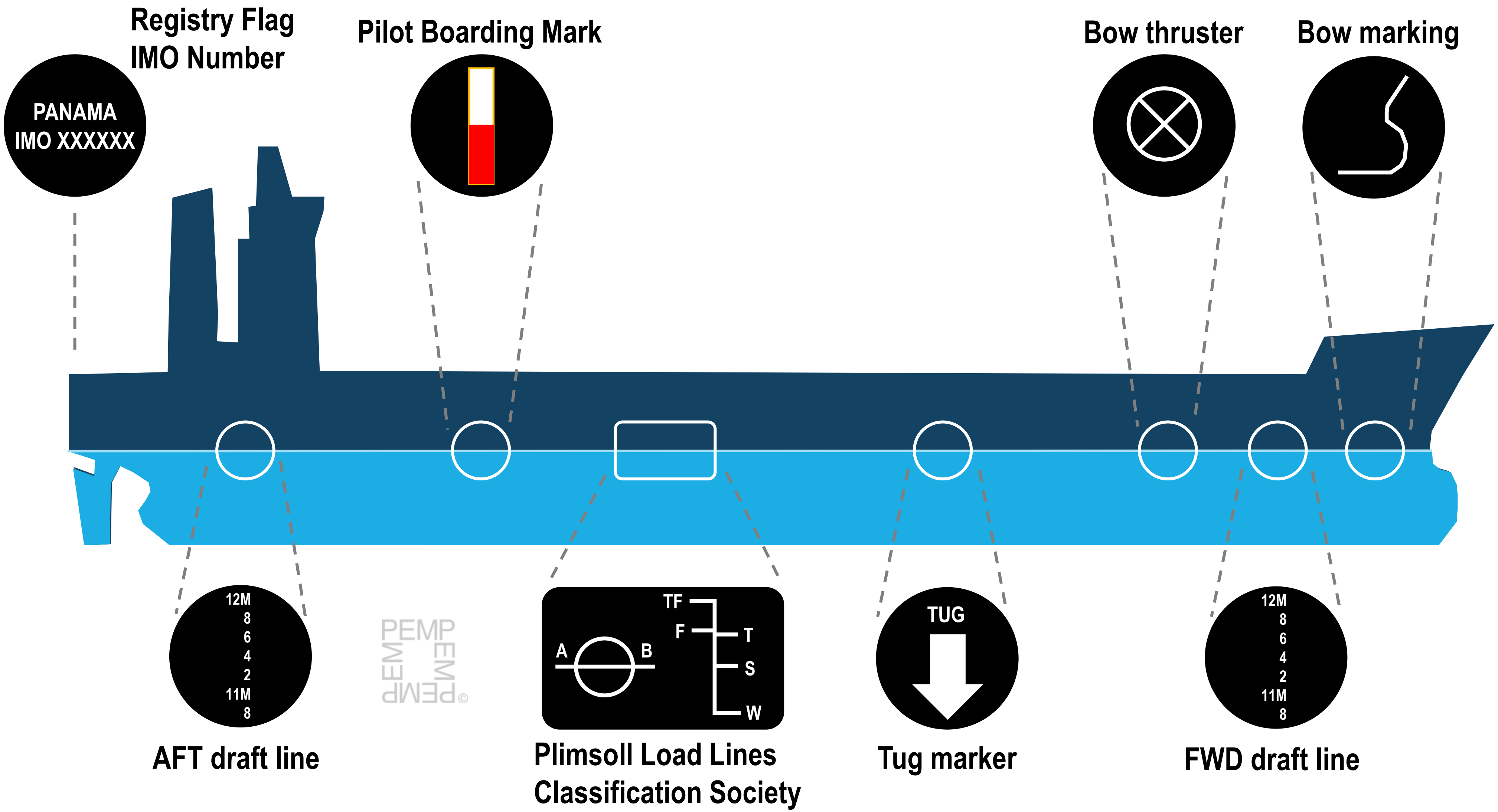
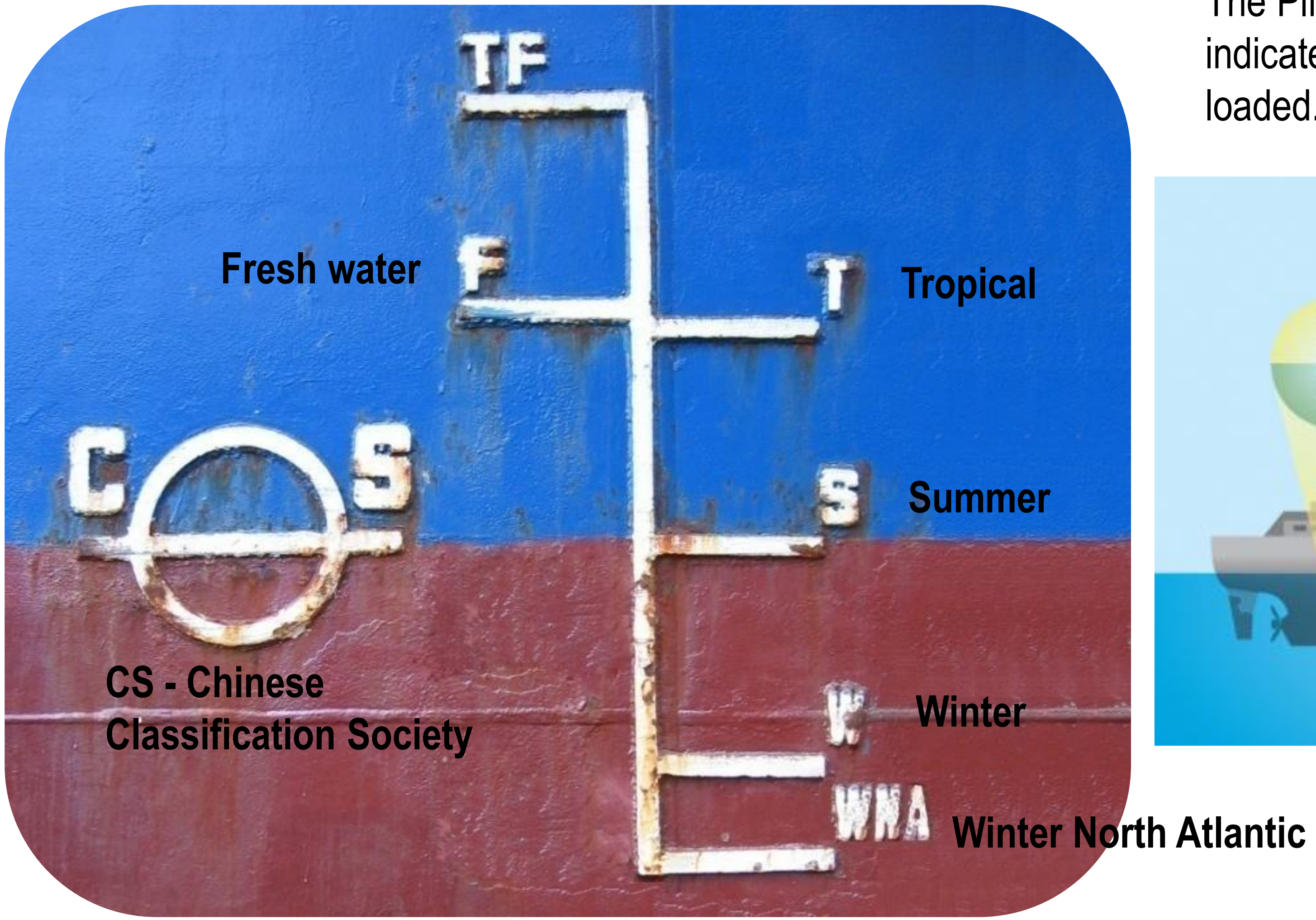
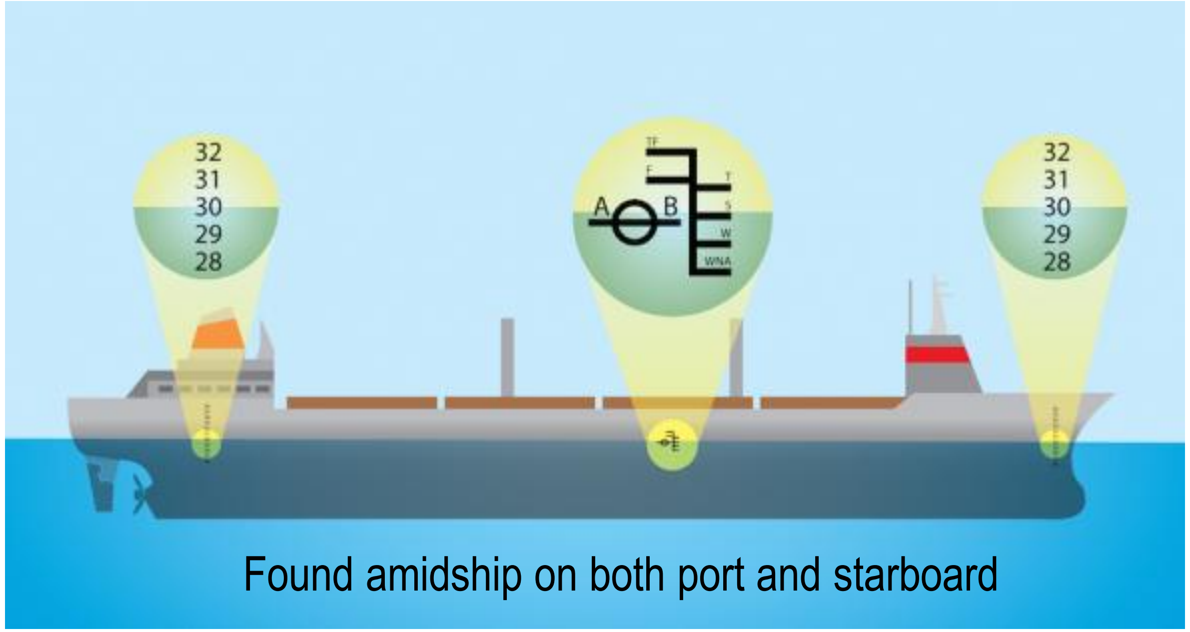


Plimsoll Mark - Load Lines

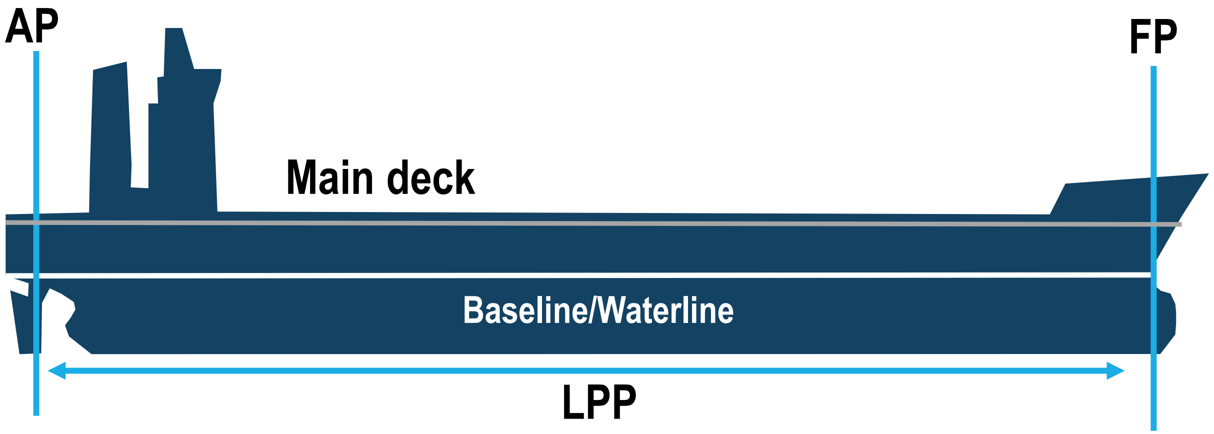


The Plimsoll Mark and Load Lines indicate how heavily a ship can be loaded.



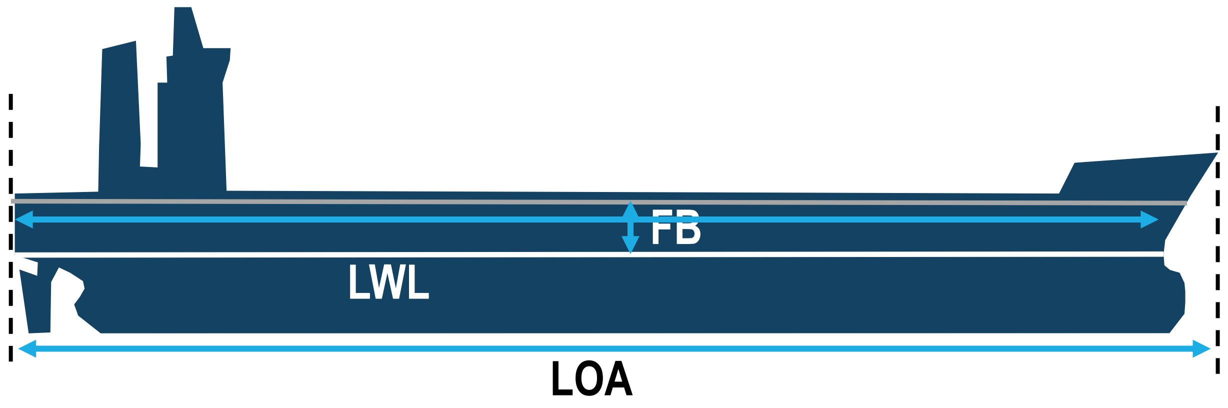
Vessel Measurements

- Forward Perpendicular (FP)
  - The perpendicular drawn at the point where the bow of the ship meets the waterline while it floats at design draft.
- Aft perpendicular (AP)
  - The perpendicular drawn through the rudder stock (shaft).
- Length between Perpendiculars (LPP or LBP):
  - The longitudinal distance between the forward and aft perpendiculars.
  - Measured for steering capability.



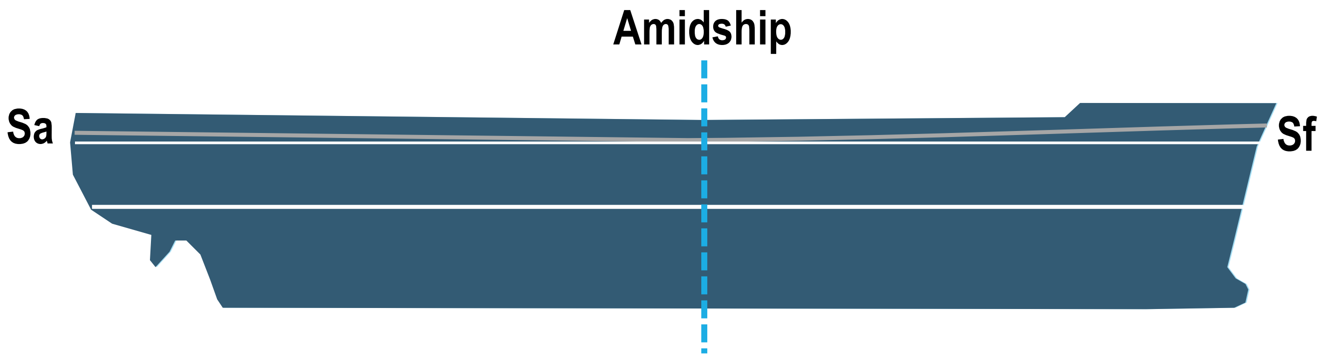
Vessel Measurements

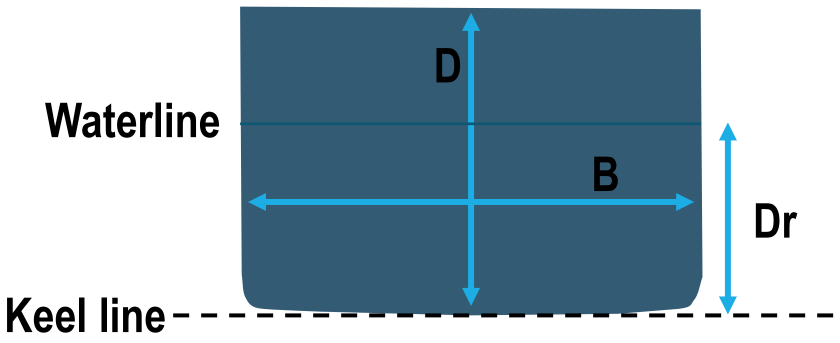
- Length of Waterline (LWL)
  - The length of the ship's hull intersecting the surface of the water.
  - Related to the water displacement.
- Length Overall (LOA)
  - The maximum length from the forwardmost point of the ship's hull to the aft-most point.
  - To fit locks and docking areas.
- Freeboard (FB)
  - The distance between the waterline and the main deck or weather deck of a ship.
  - Must be high enough to avoid potential deck flooding during rough sea conditions.



Vessel Measurements

- Sheer (Sf & Sa)
  - A measure of main deck curvature.
  - Sheer forward and aft build volume into the hull and increase its buoyancy.
  - Keeping the ends from diving into an oncoming wave and slowing the ship.
  - Long ships tend not to have sheer.
- Beam (B)
  - The distance between the two sides of the ship at its greatest width (amidship).
- Depth (D)
  - Middle of length from the top of keel to the uppermost continuous deck at side.
- Draft (Dr)
  - Length from the top of keel to the waterline.
  - Important measure to access ports and canals.





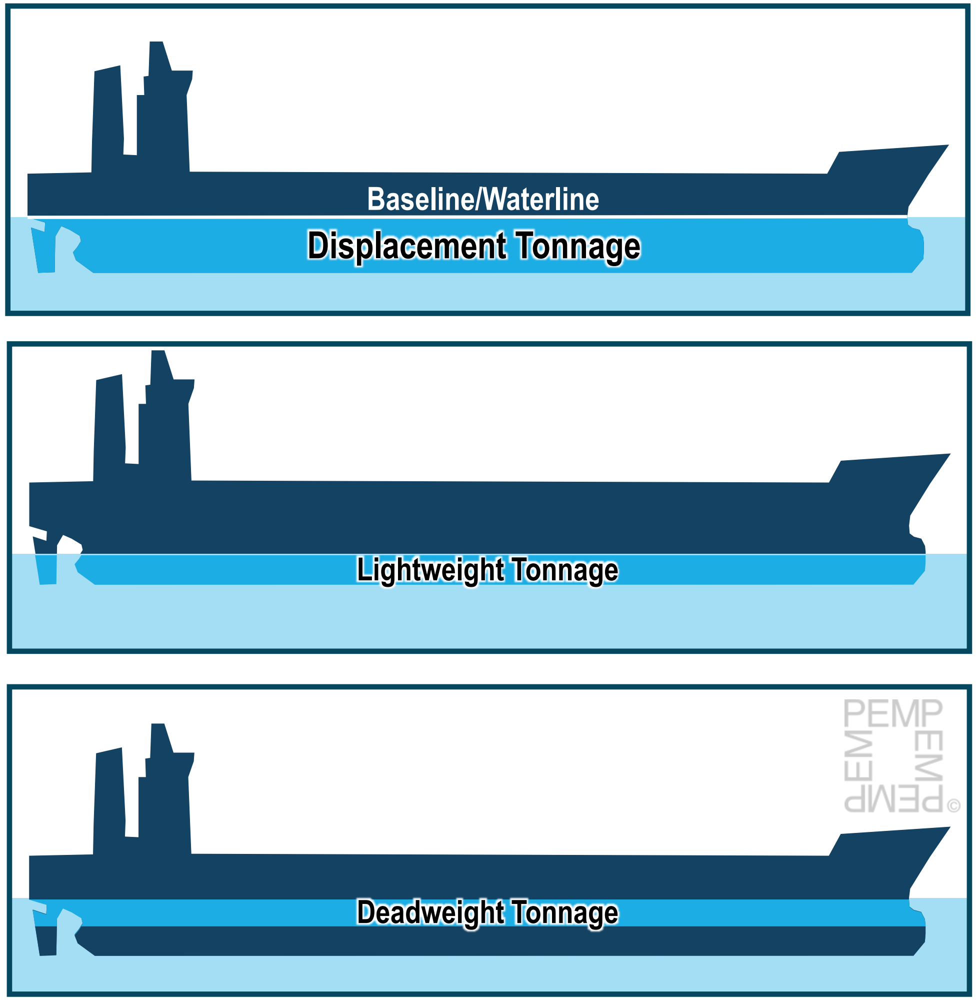
MV Dali (Measurements)

Length (LOA)	299.92 m (984 ft)
Beam	48.2 m (158 ft 2 in)
Draft	15.03 m (49 ft 4 in)
Depth	24.8 m (81 ft 4 in)
Freeboard	9.77 m (32 ft 1 in)

Displacement and Tonnage

Read this content

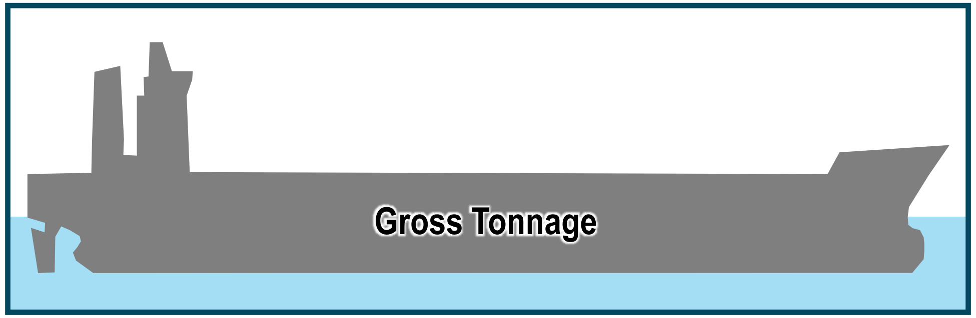
- Displacement tonnage (D)
  - Total weight of the ship when fully loaded.
  - Measured by using the weight of the water being displaced, expressed in metric tons.
- Lightweight tonnage (L)
  - The total weight of the ship when empty.
  - Measured by using the weight of the water being displaced, expressed in metric tons.
- Deadweight tonnage (DWT)
  - Maximum weight that a ship can carry.
  - DWT=D-L.
  - Expressed in metric tons and includes bunker and stores.

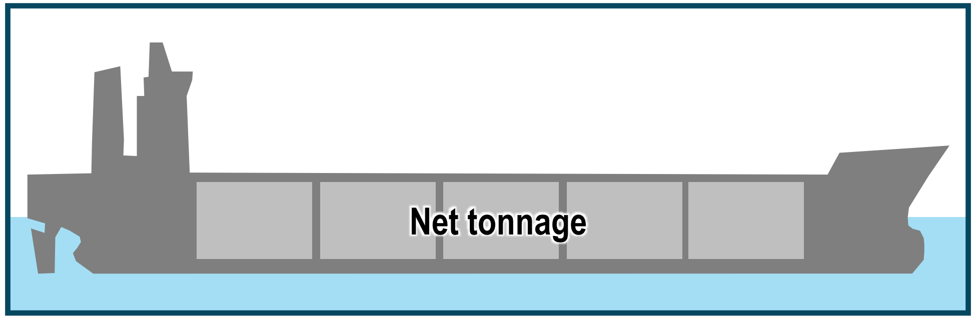


Displacement and Tonnage

Read this content

- Gross tonnage (GT)
  - Total volume of a ship converted into tonnage.
  - Measured as volumes of all enclosed spaces and expressed in cubic meters.
- Net tonnage (NT)
  - Subtracting the volume occupied by the engine room and the space necessary for the operation of the ship (crew quarters, bridge, etc.) from the gross tonnage.
- Gross register tonnage (GRT)
  - Calculated in a specific way according to the country of registry.
  - To determine the fees that a ship will pay to use a canal (Panama GRT, or Suez GRT) or a port.





Displacement and Tonnage

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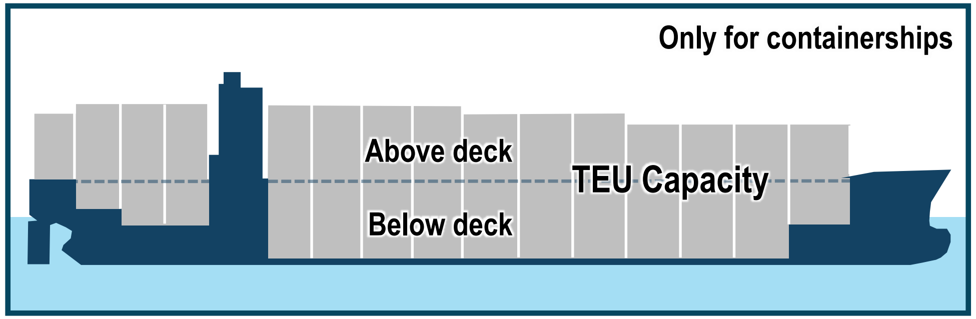
- TEU Capacity
  - Only for containerships or ships able to carry containers.
  - Estimate of the volume in Twenty-Foot Equivalent Units that can be carried without impairing visibility or exceeding the baseline (waterline).
  - Slot capacity (fixed): Total number of containers that can be put in the carried slots.
  - Loadable capacity (variable): Total number of containers that can be loaded on a ship, based on its weight and stability limits.

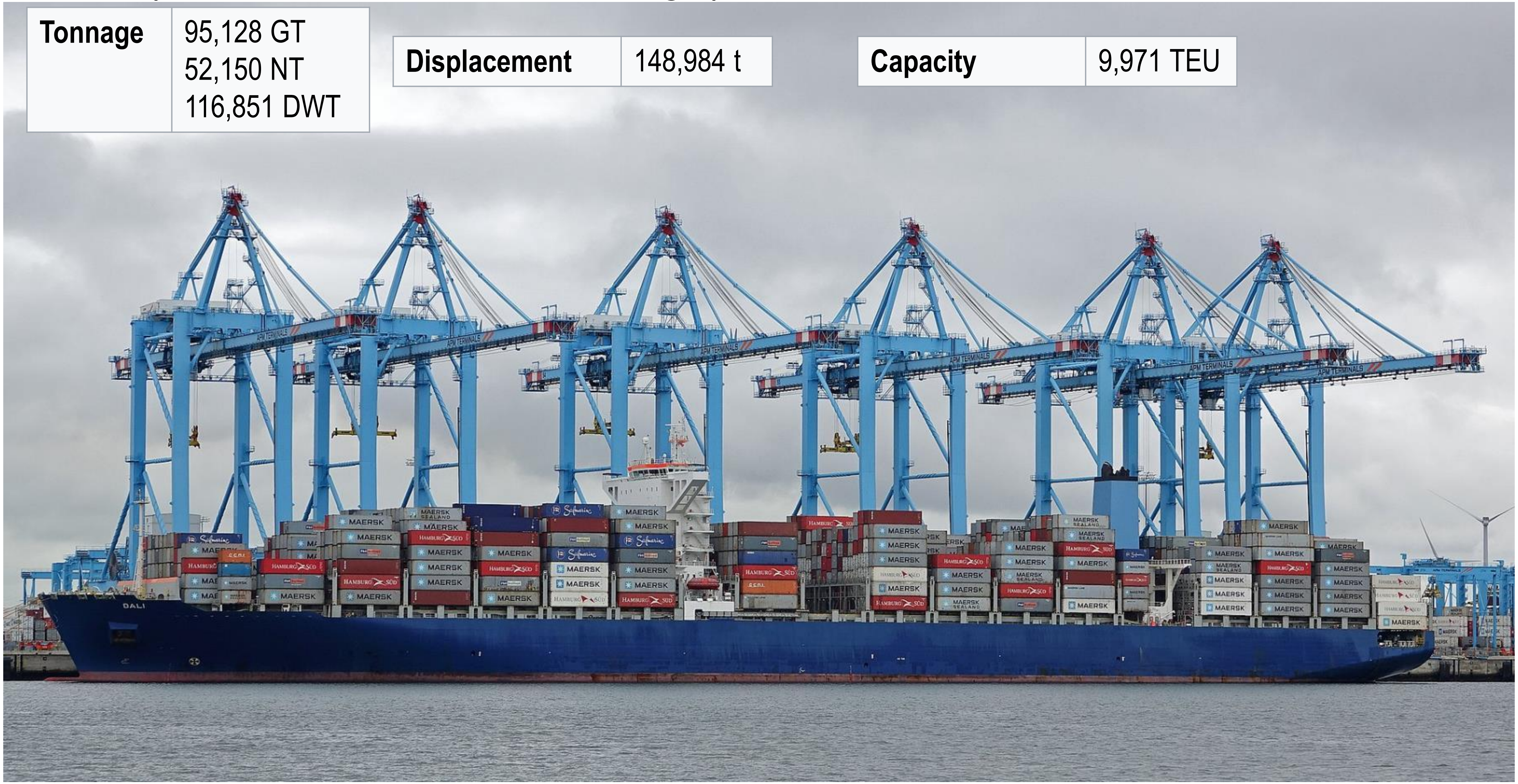


MV Dali (Displacement and Tonnage)

Tonnage	95,128 GT 52,150 NT 116,851 DWT

Displacement	148,984 t

Capacity	9,971 TEU



Bulk Ship Classes

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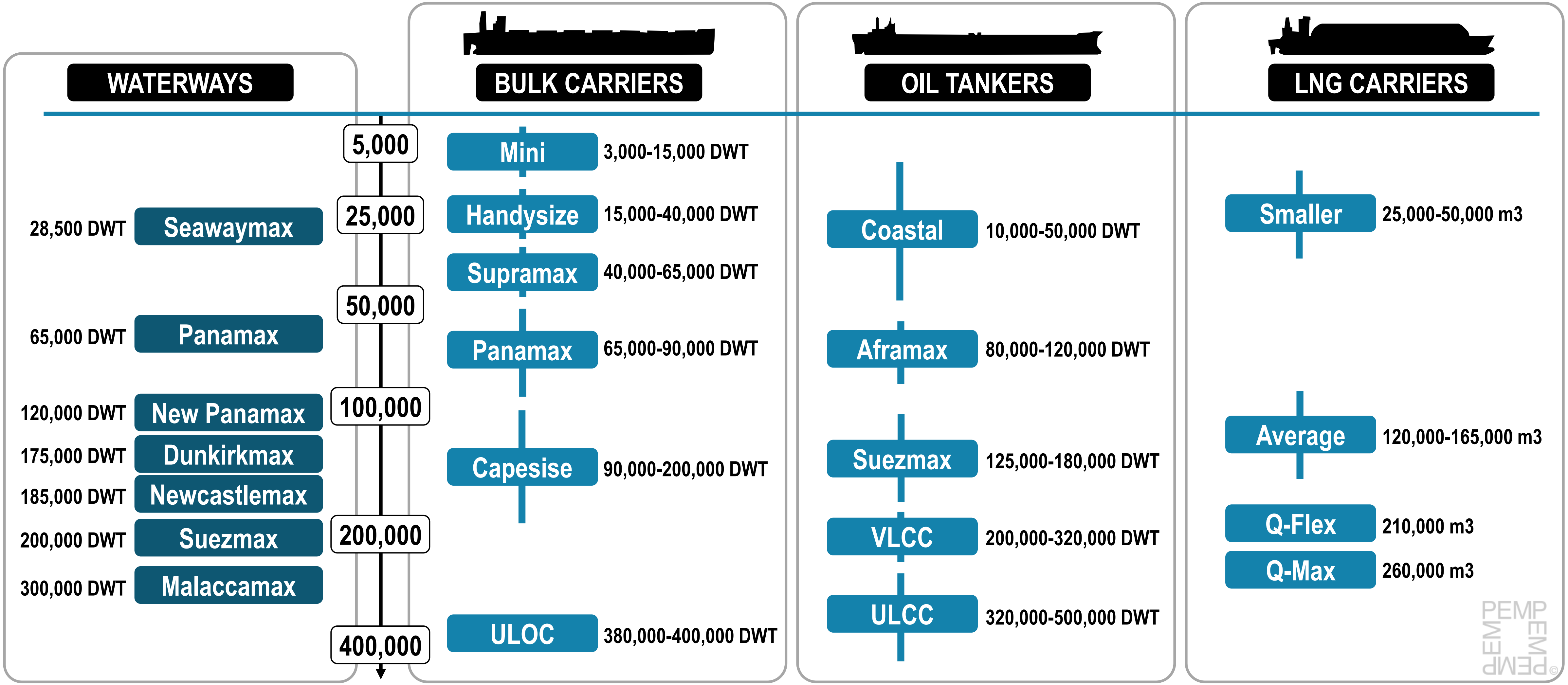

Most Commonly Used Vessel Categories

PANAMAX	A ship of the maximum size that can enter the old locks of the Panama Canal. The locks are 110 feet wide, 1000 feet long.
AFRAMAX	A ship of 80,000-120,000 dwt, which is the AFRA standard (Average Freight Rate Assessment). Established to standardize contract terms with well-defined tanker ship capacity.
POST-PANAMAX	A ship too large to enter the old locks of the Panama Canal. The expansion of the Panama Canal allowed to accommodate many post-Panamax ships.
HANDYSIZE	A ship in the 10,000 to 50,000 dead-weight ton range. Common in small regional markets as they can operate in many ports.
SUEZMAX	A ship roughly 200,000 dead-weight tons, the maximum size that can fit through the Suez Canal.
CAPESIZE	Large dry-bulk carriers of a capacity greater than 80,000 dead-weight tons. Relates to the ships that originally could not fit through the Suez Canal and had to go around Africa by way of the Cape of Good Hope.

Vessel Size Groups

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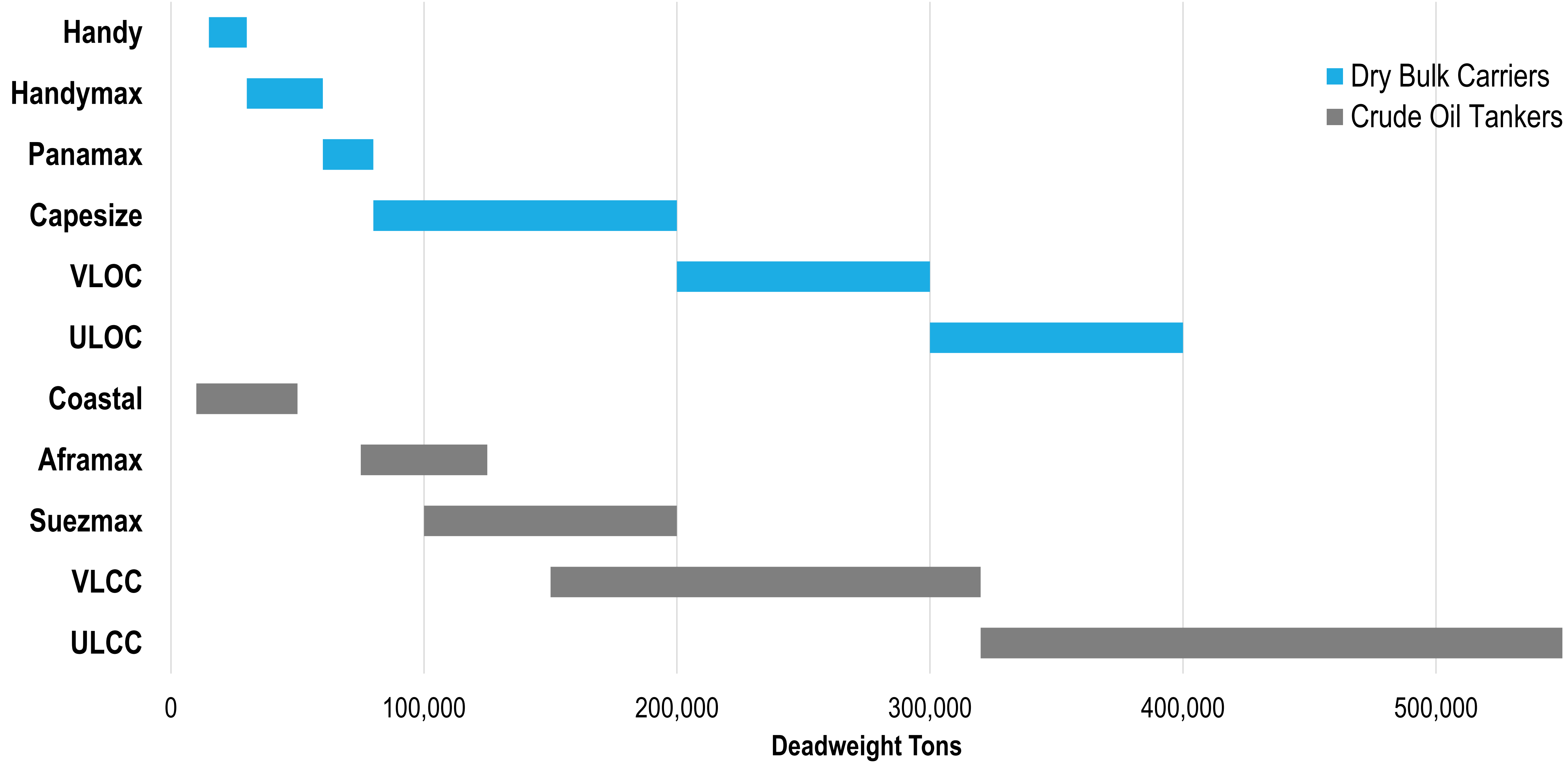

Evolution of Containerships

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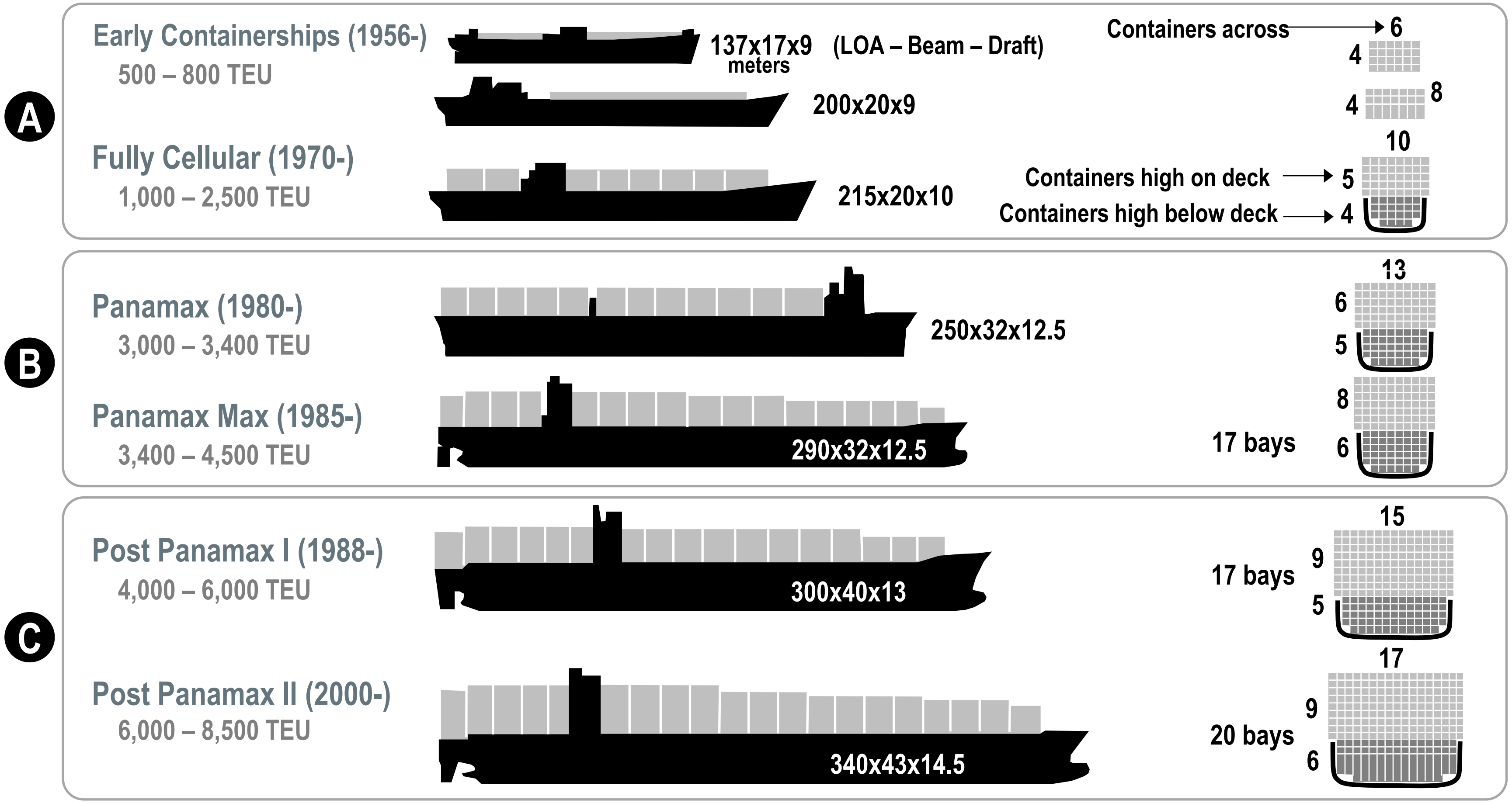
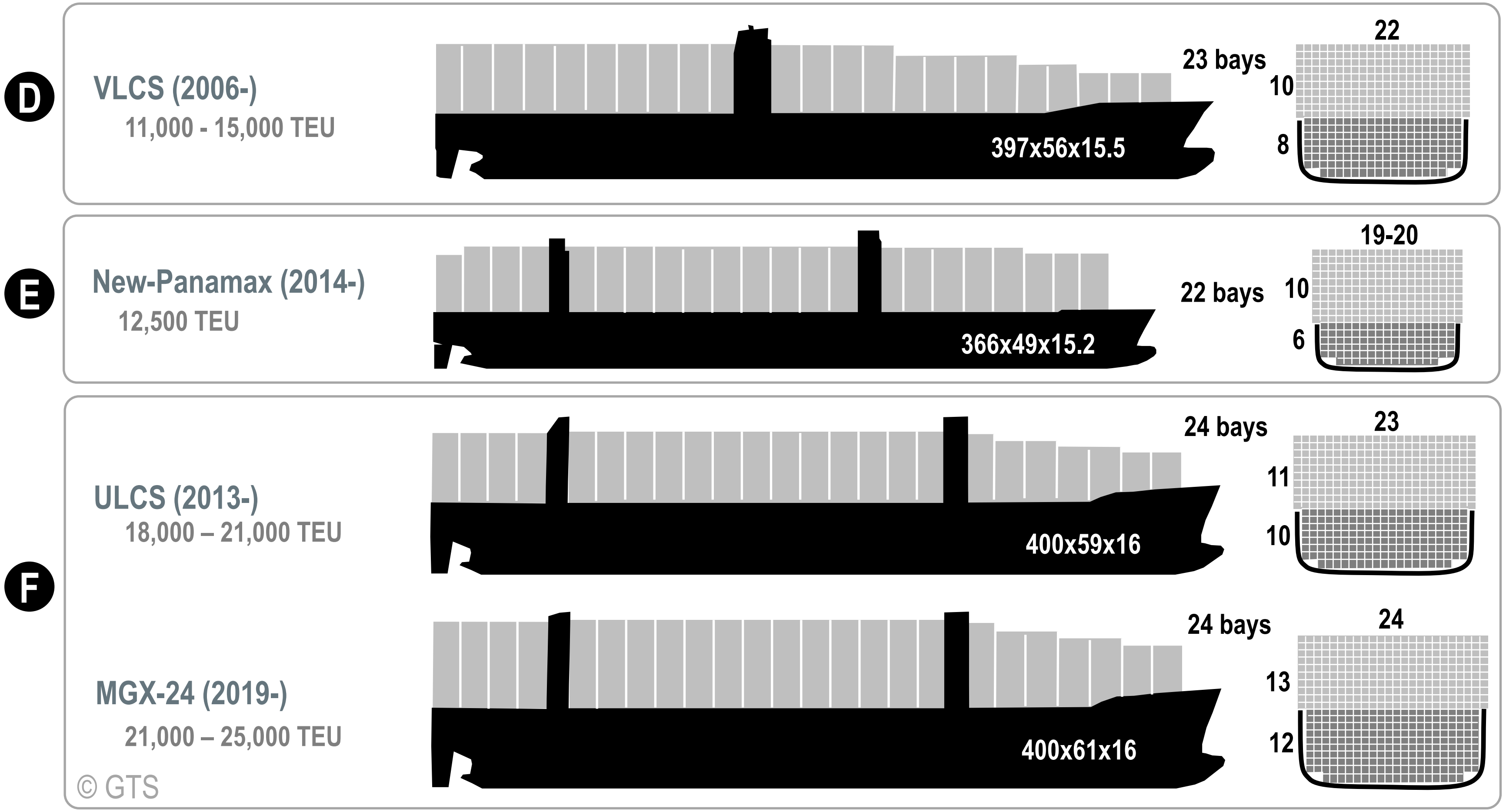


Evolution of Containerships



The Largest Available Containership, 1970-2023

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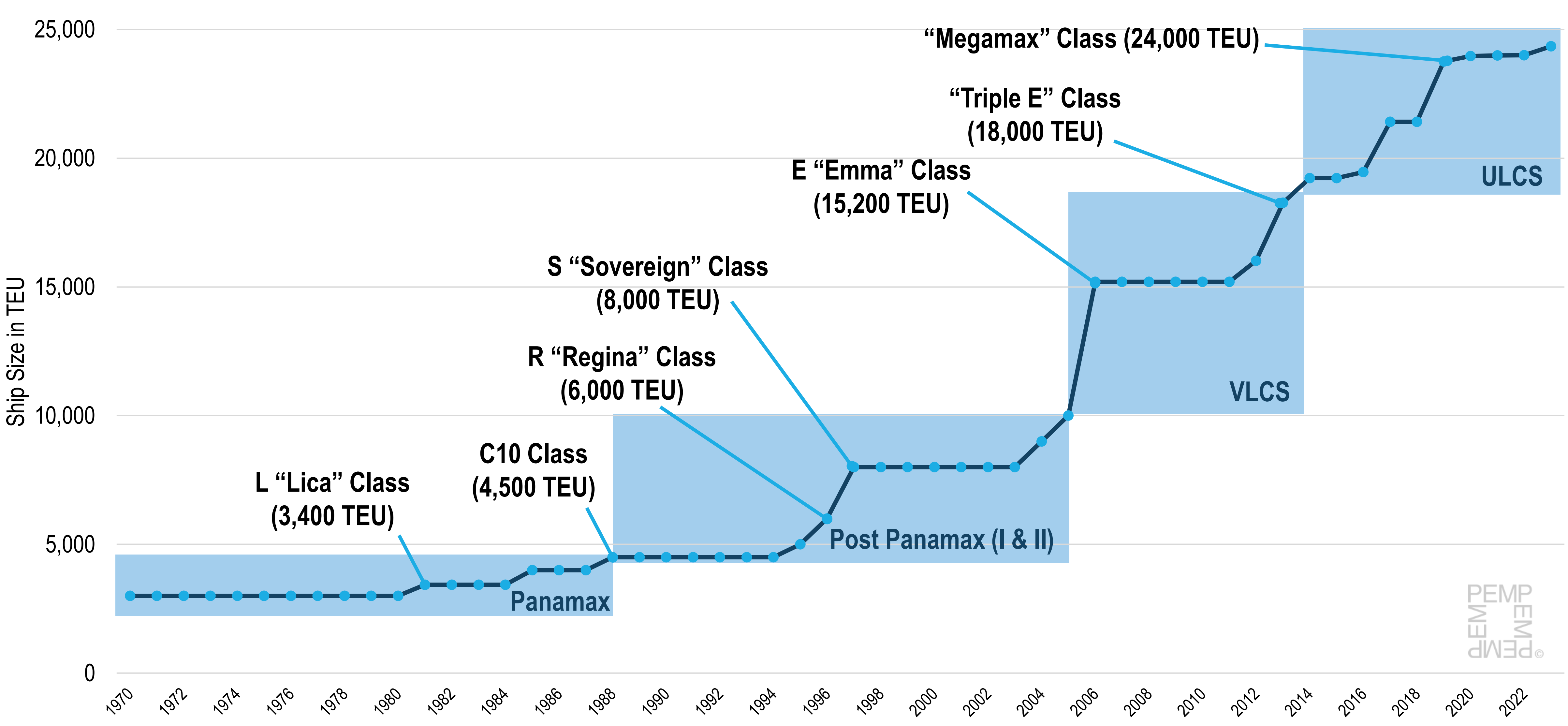

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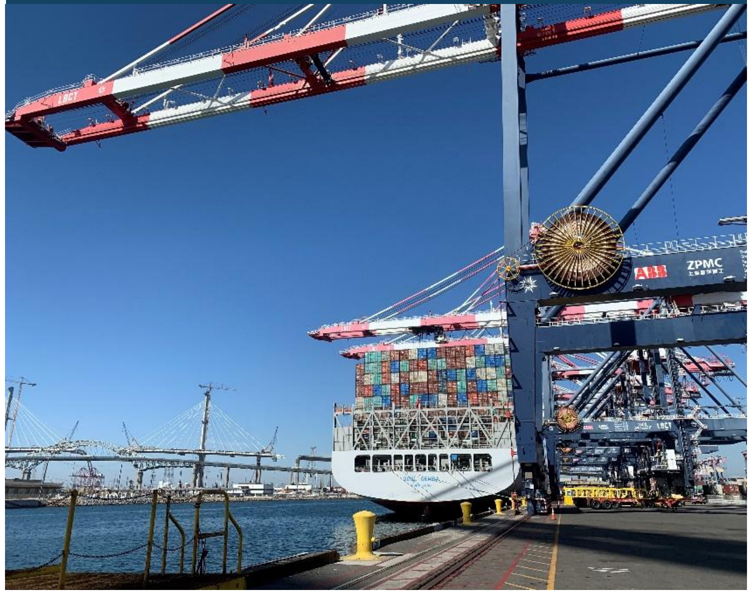


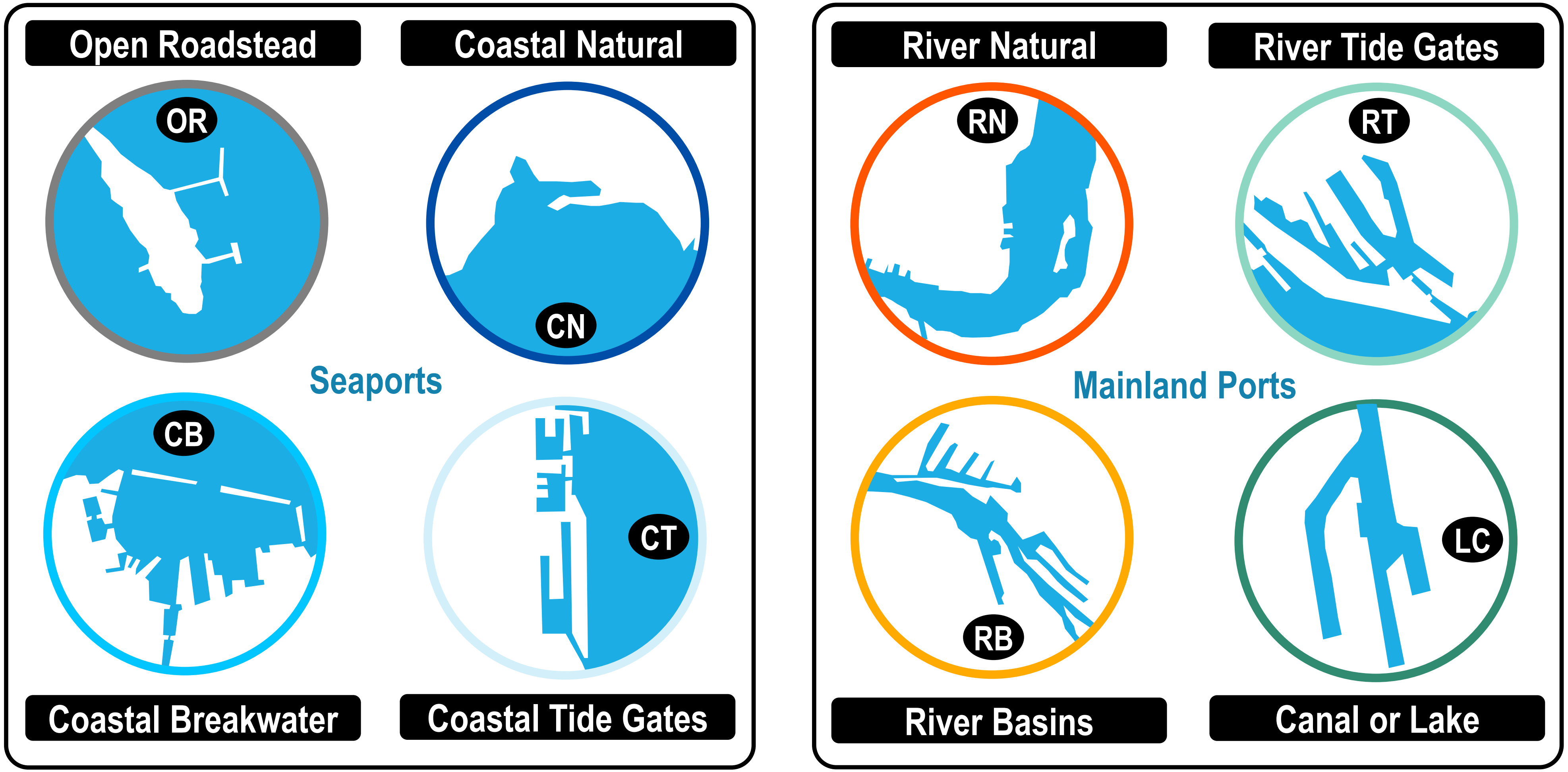
B. Physical Site Characteristics

Read PW Section II-2.4

Port Site Selection

- Construction aspects
  - Complexity and costs of dredging.
  - Complexity and costs of construction.
- Environmental and social impacts
  - Protected zones.
  - Compliance with environmental rules and regulations.
  - Special interest groups.
- Port planning aspects
  - Nautical accessibility.
  - Availability of land.
  - Hinterland accessibility.

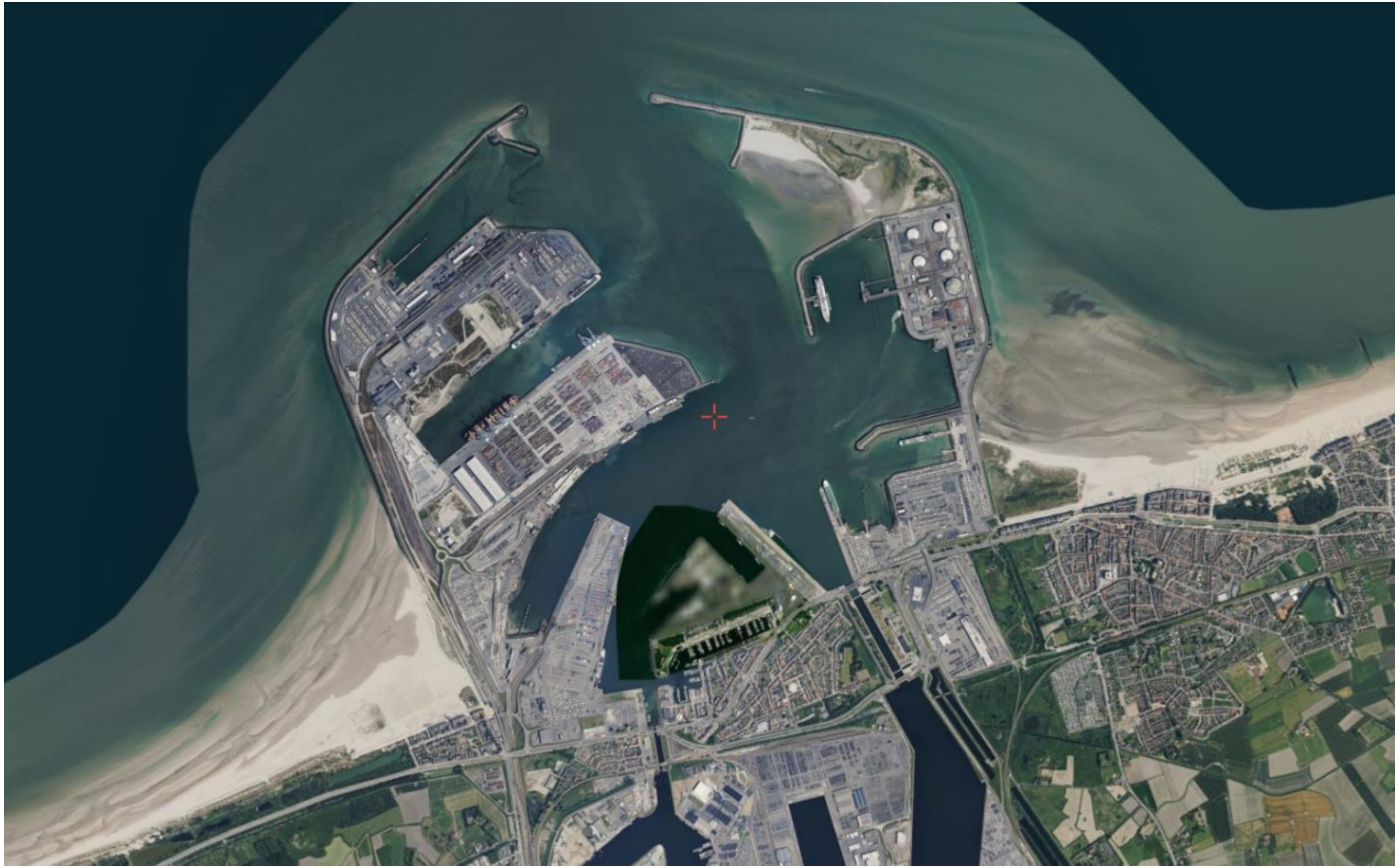
Harbor Types



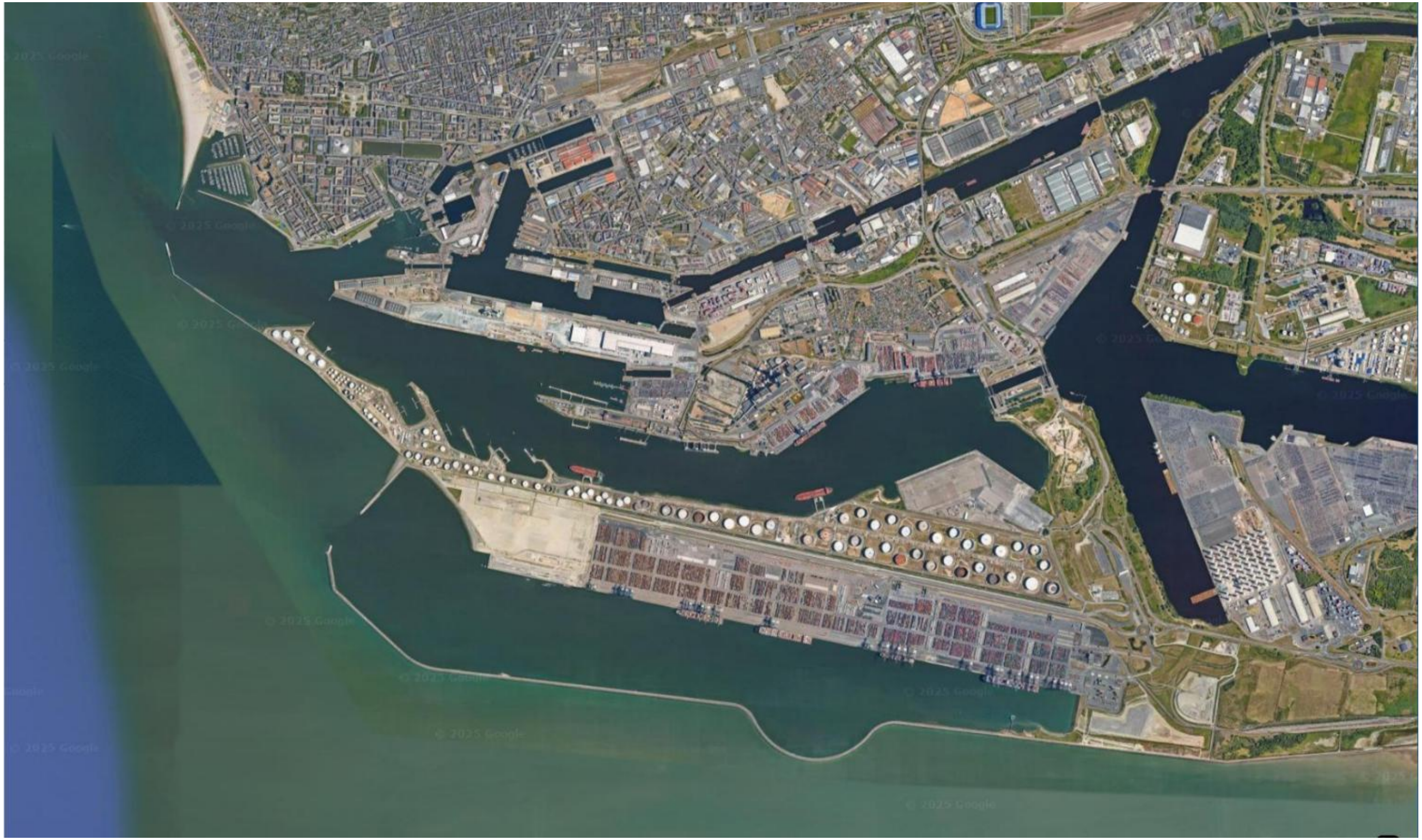
Open Roadstead (OR): Ras Tanura, Saudi Arabia

Coastal Natural (CN): Cartagena, Colombia

Coastal Breakwater (CB): Zeebrugge, Belgium



Coastal Tide Gates (CT): Le Havre, France



Topography and Bathymetry

- Land based restrictions
  - Availability of flat land.
  - Neighboring urban activities.
  - Land reclamation can be expensive.
- Water depth
  - Function of the types of vessels allowed to call.
  - Chart datum: The sea level of reference.
  - Lowest Astronomical Tide (LAT).
    - Lowest common water depth, taking into consideration tides.
    - Mean Sea Level in areas of limited tide.
  - Bathymetry is morphodynamical.
    - Sedimentation.

Tuas Container Terminal Megaproject, Singapore

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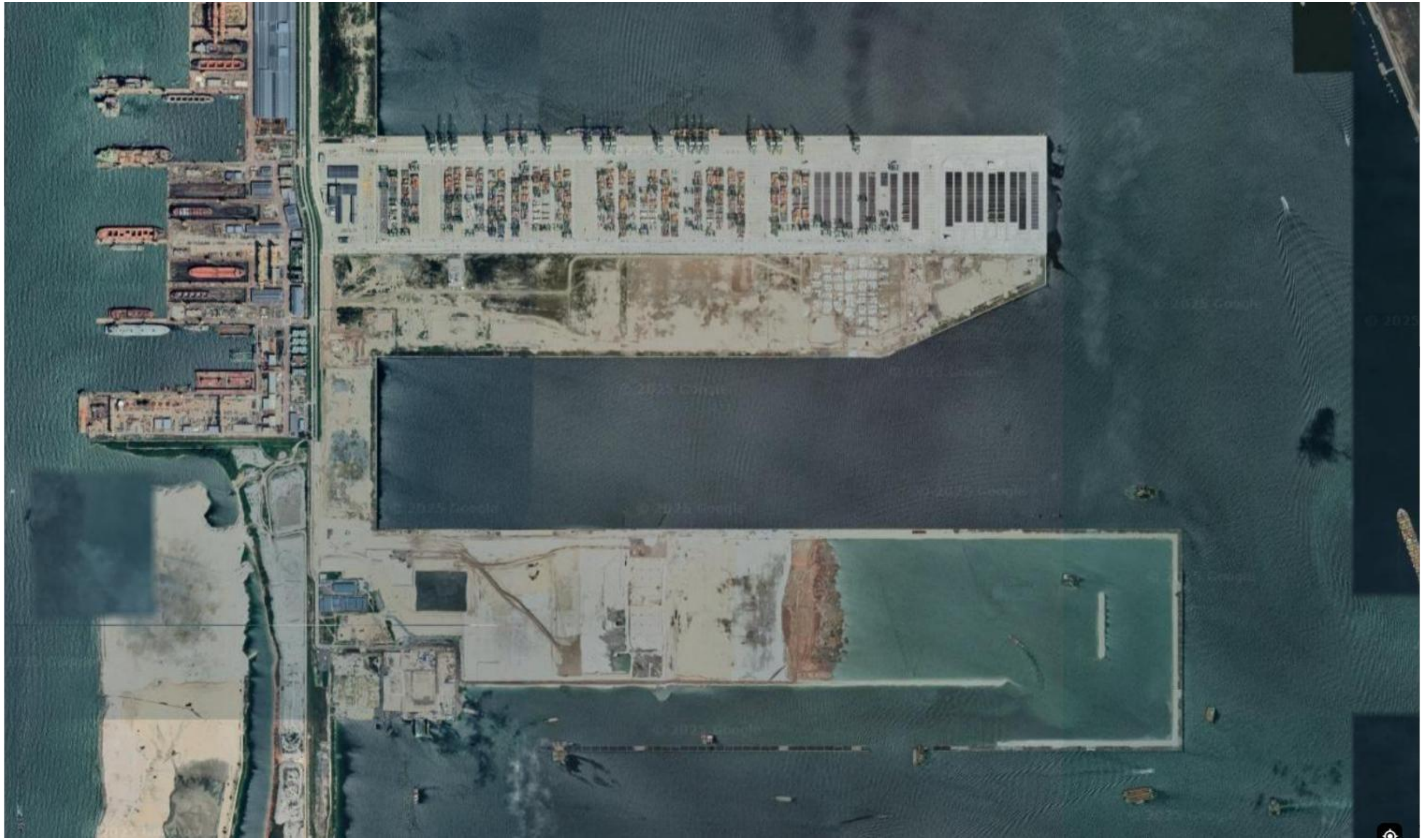
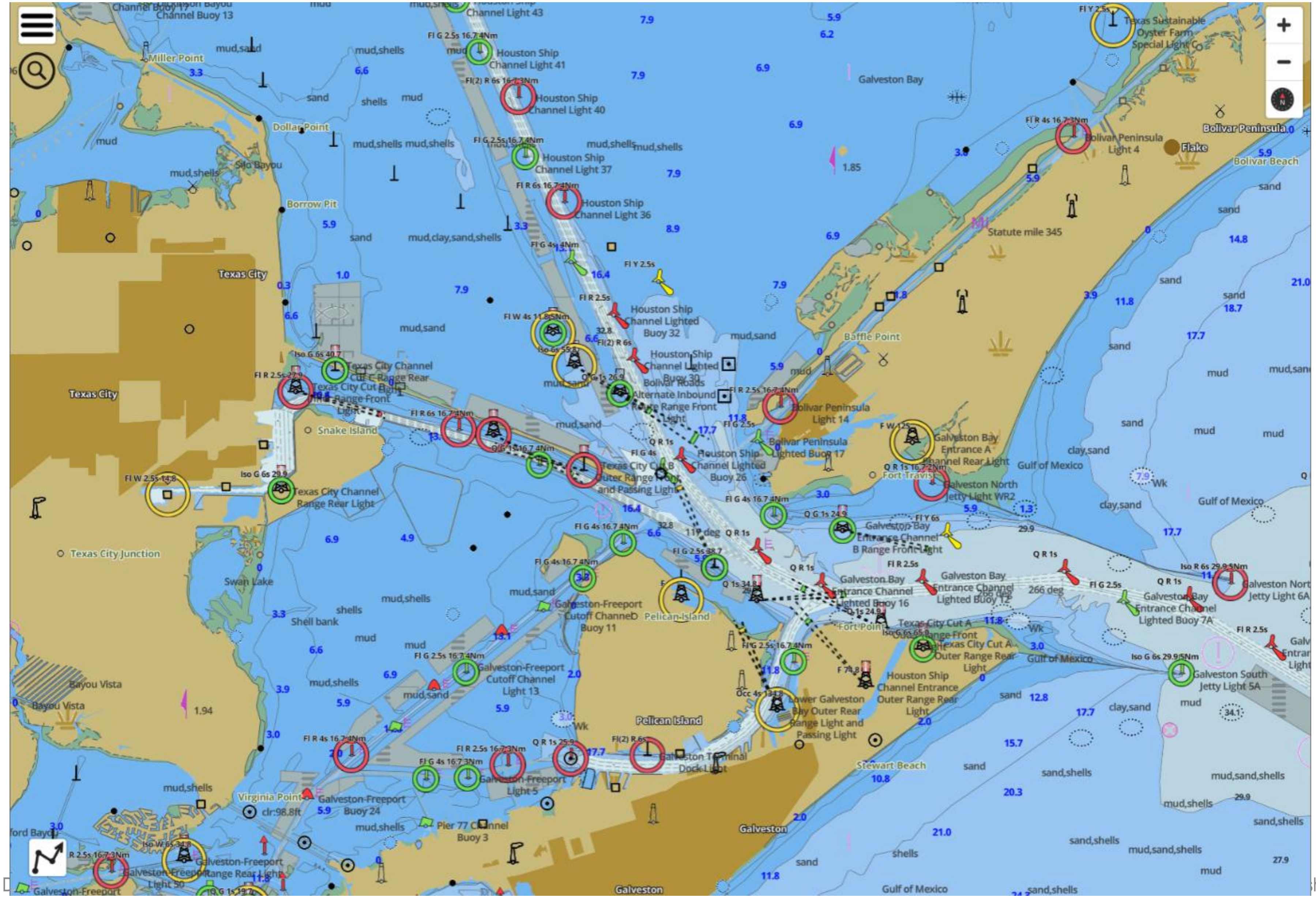


Bathymetry of Galveston Bay



The Evolution of a Port

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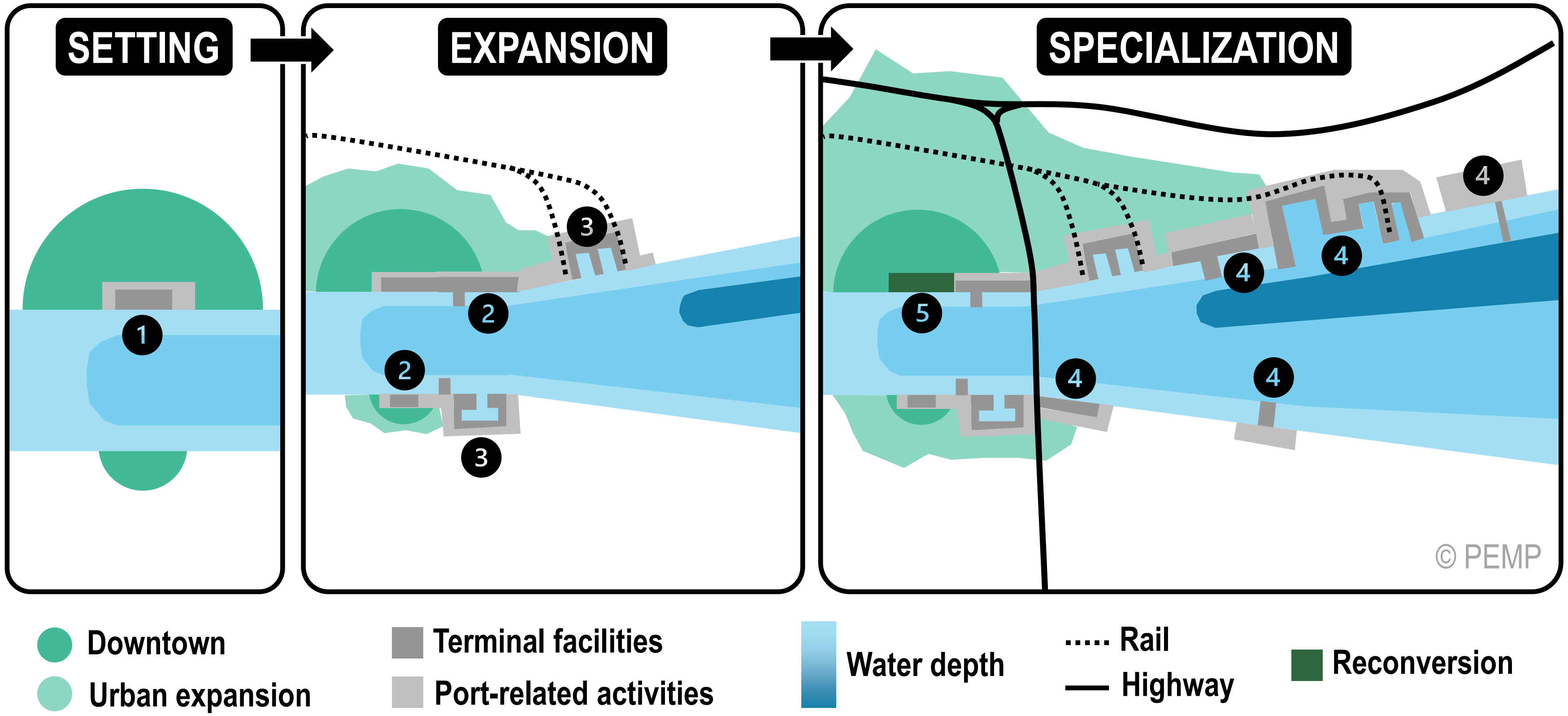

Evolution of the Port of Rotterdam

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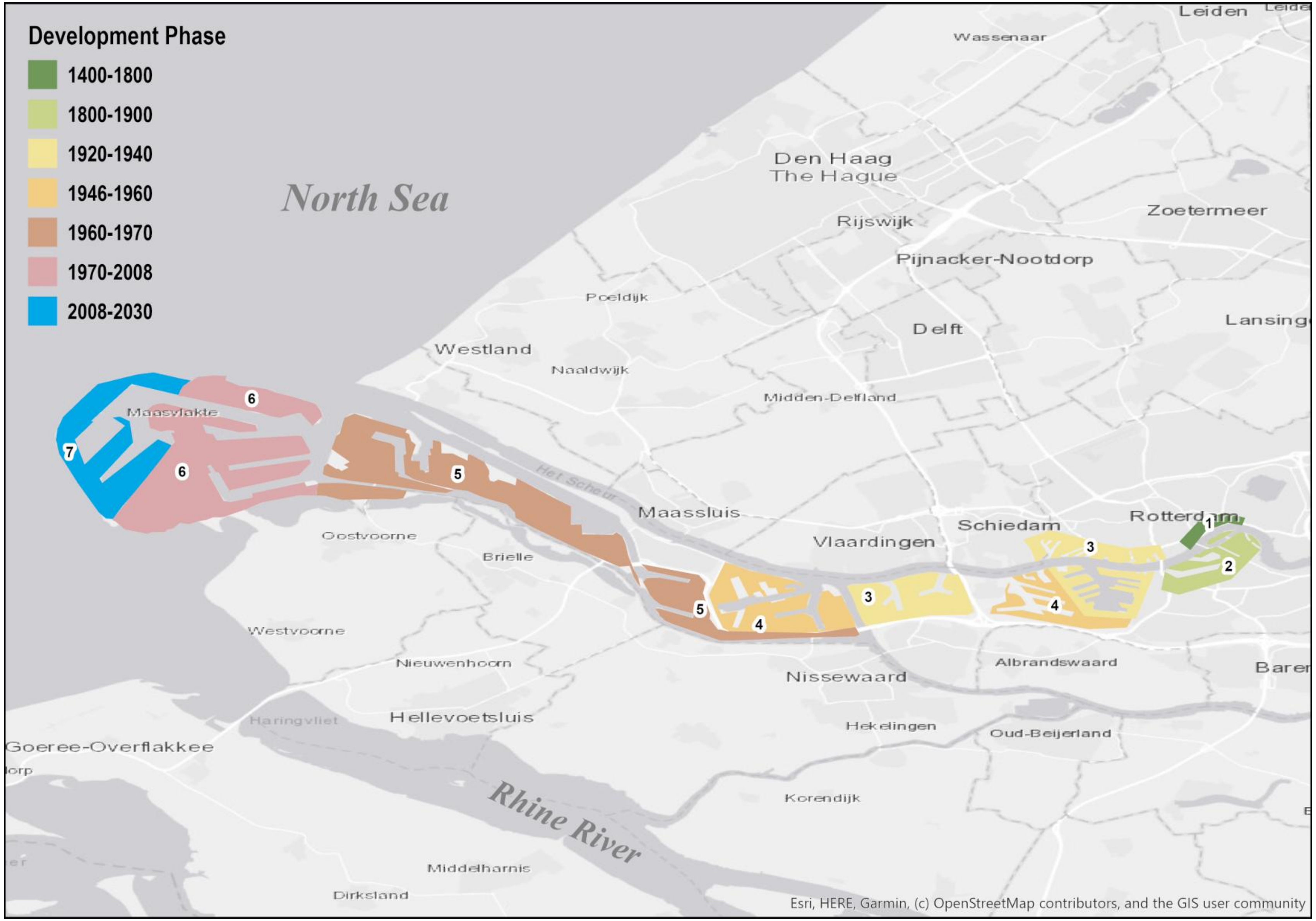

Topography and Bathymetry

- Water levels
  - Tides.
  - Storm surges.
  - Low barometric pressure (hurricanes).
  - Large scale meteorological effects (El Nino).
  - Tsunamis.
  - Potential sea level rise.
- Wind
  - Access channel orientation and width.
  - Mooring forces and vessel motions at berth.
  - Zoning of adjacent land (dust and pollutant emissions).

Risk of Hurricanes for Global Container Ports, 2019

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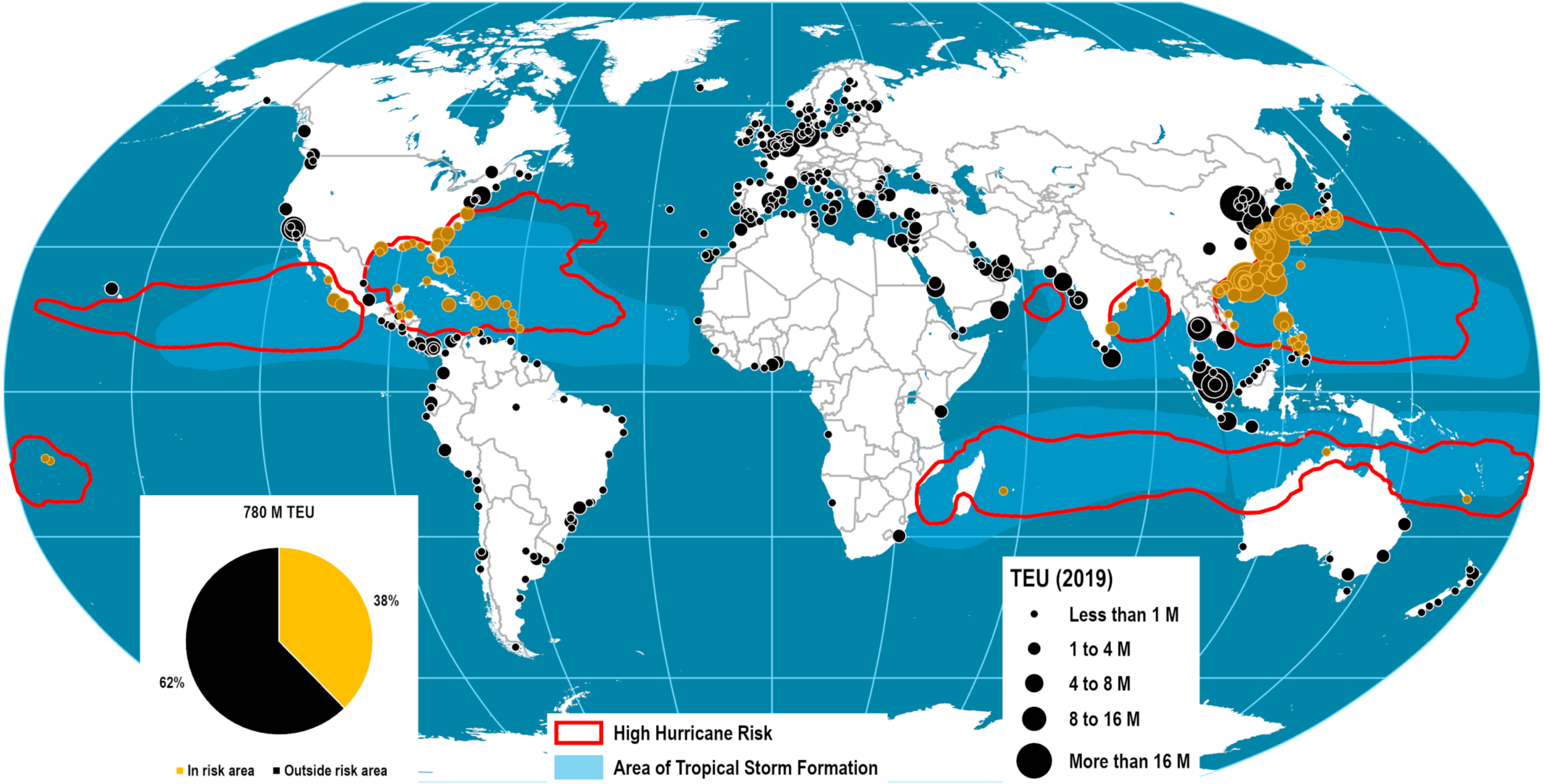
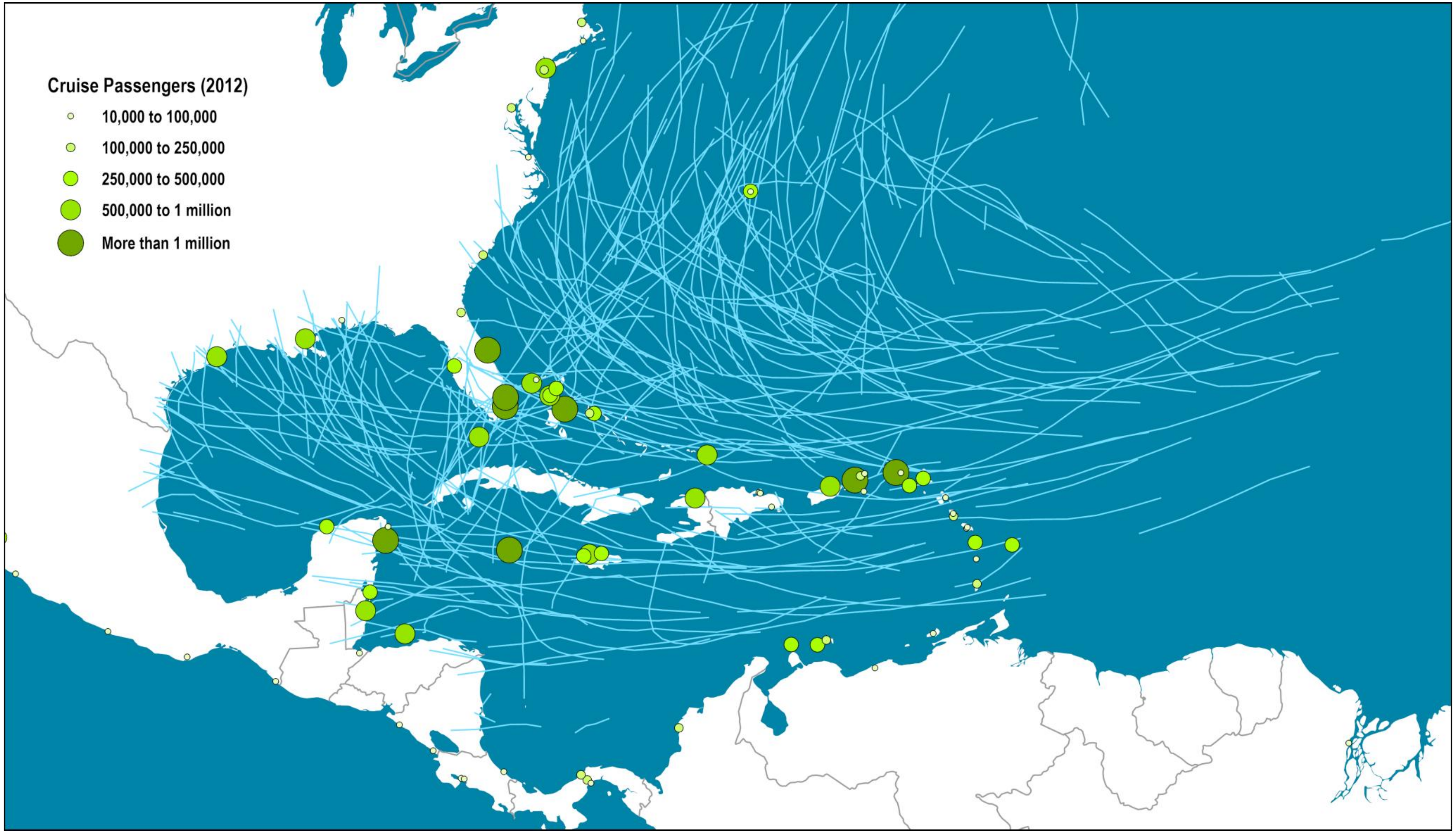


Cruise Passengers Handled at Caribbean Ports (2012) and Path of Atlantic Hurricanes Above Category 3 (1900-2009)



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Topography and Bathymetry

- Geotechnical conditions
  - Subsoil conditions
    - Increase dredging costs.
    - Higher risk of infrastructure failure.
  - Seismic conditions
    - Frequency and scale of earthquakes.
    - Risk of liquefaction.
  - Sedimentation and erosion
    - Dredging expenses.

Risk of Earthquake for Global Container Ports

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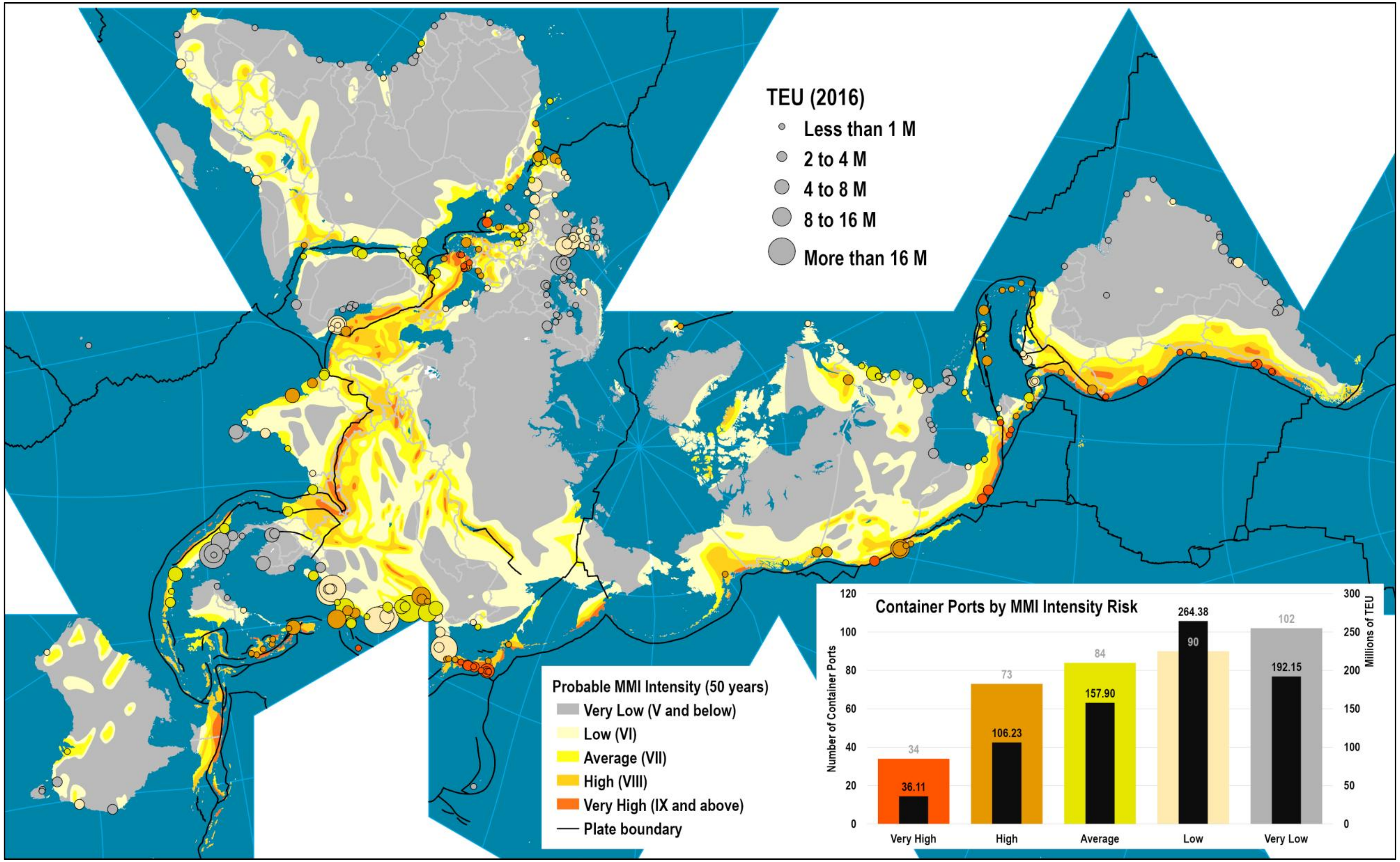

Cubic Yards Dredged by the US Army Corp of Engineers at Selected Port Districts, 2014-2018

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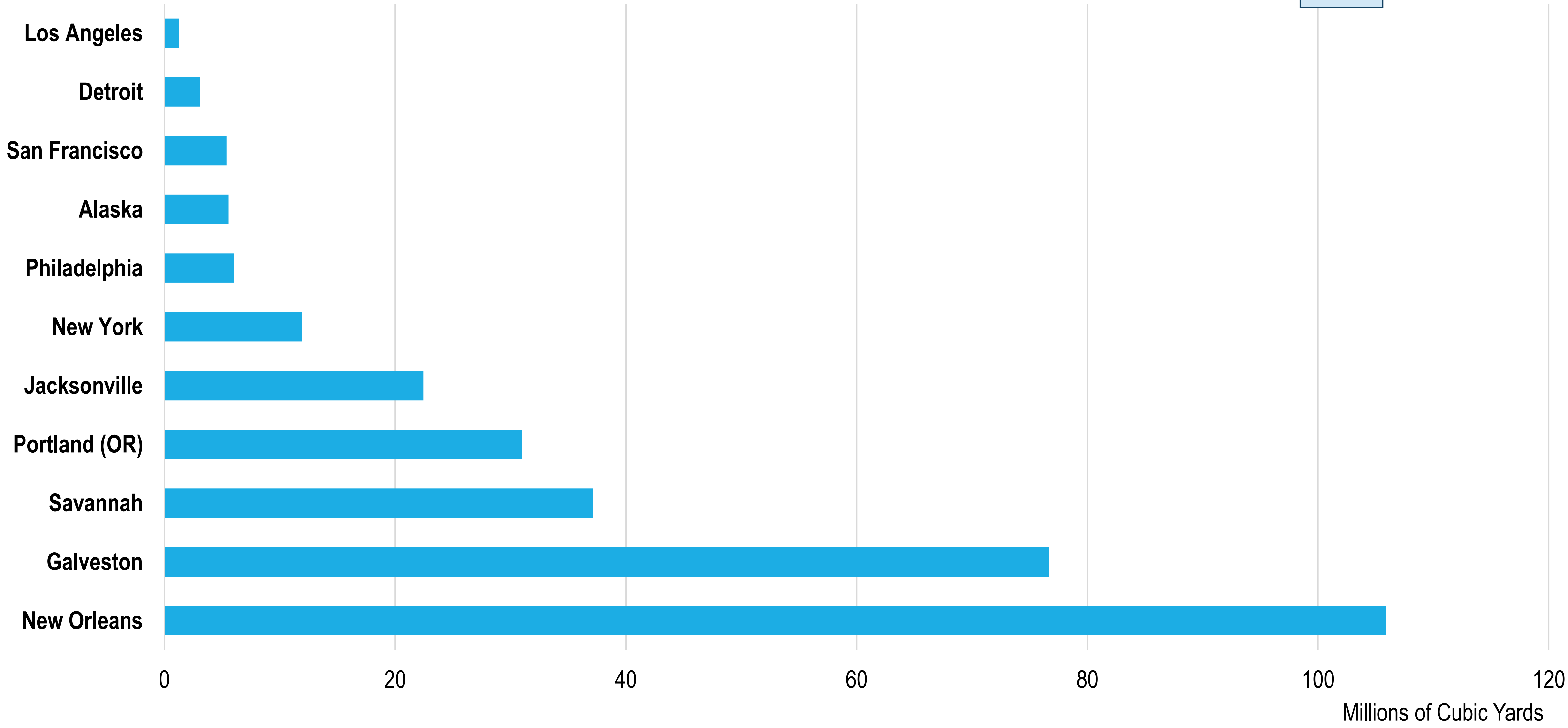

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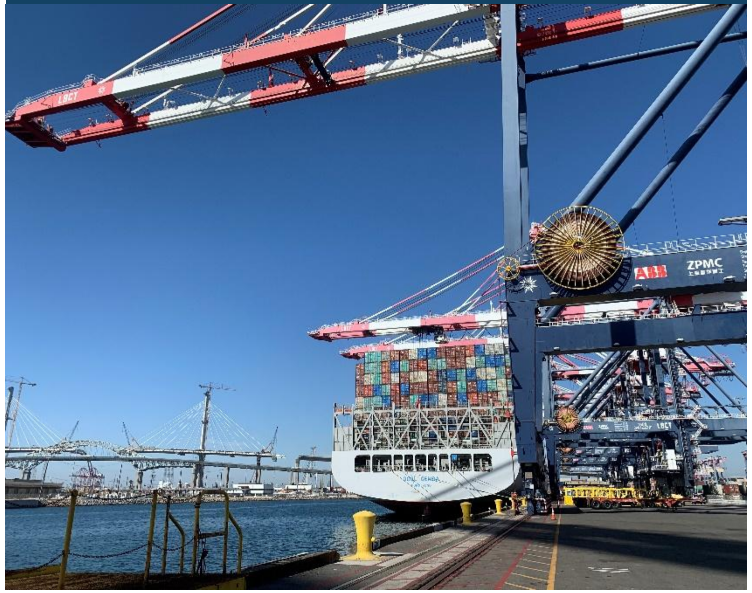


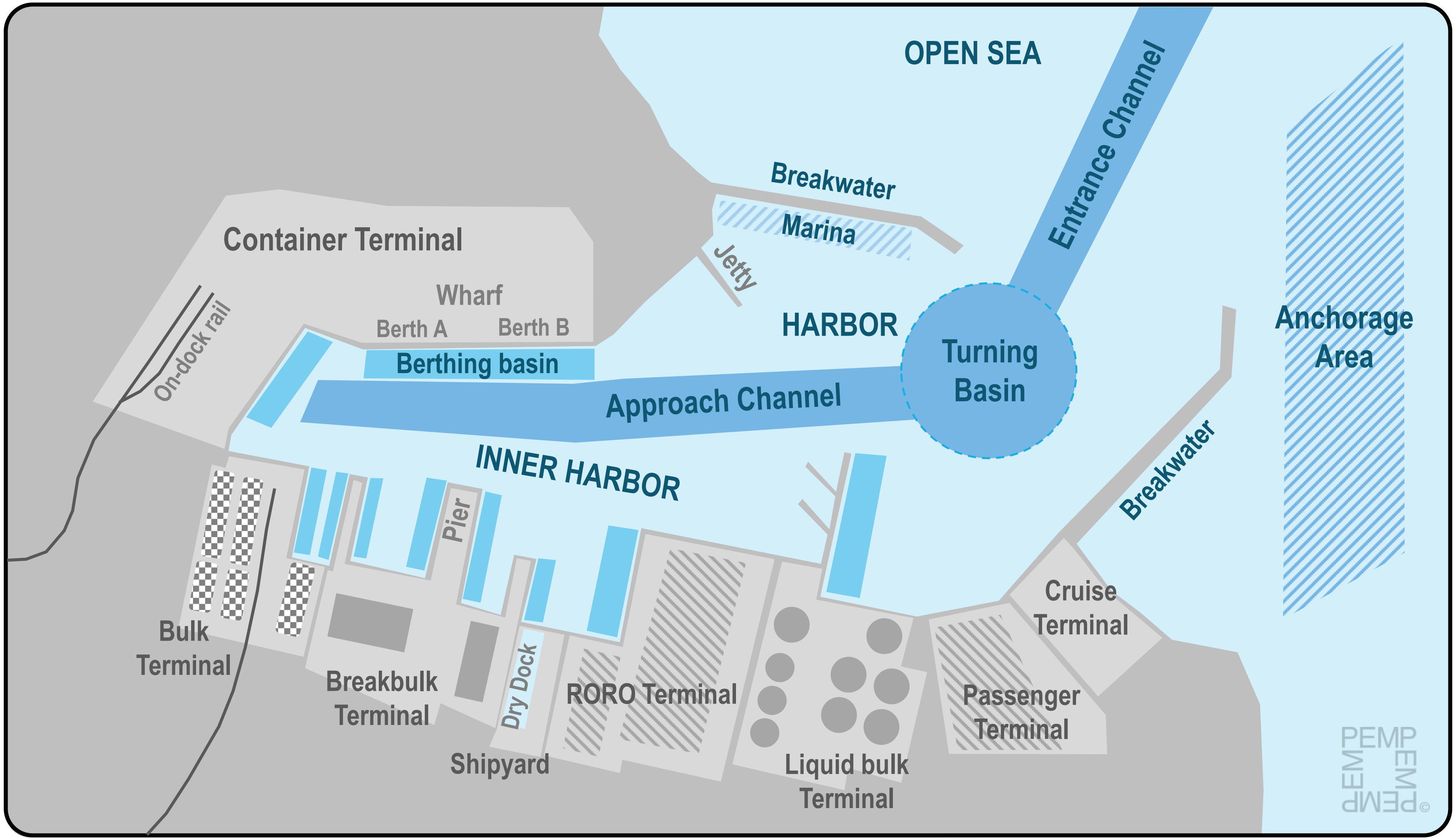
C. Types of Port Infrastructure

Read PW Sections II-3.1, II-3.2

Port Infrastructure

- Support for maritime operations
- A form of coastal resilience engineering
  - Protecting coastal areas from erosion and storm surges.
- Includes various elements
  - Navigation infrastructure.
  - Vessel berthing.
  - Cargo handling.
  - Hinterland access.

Main Physical Elements of a Port



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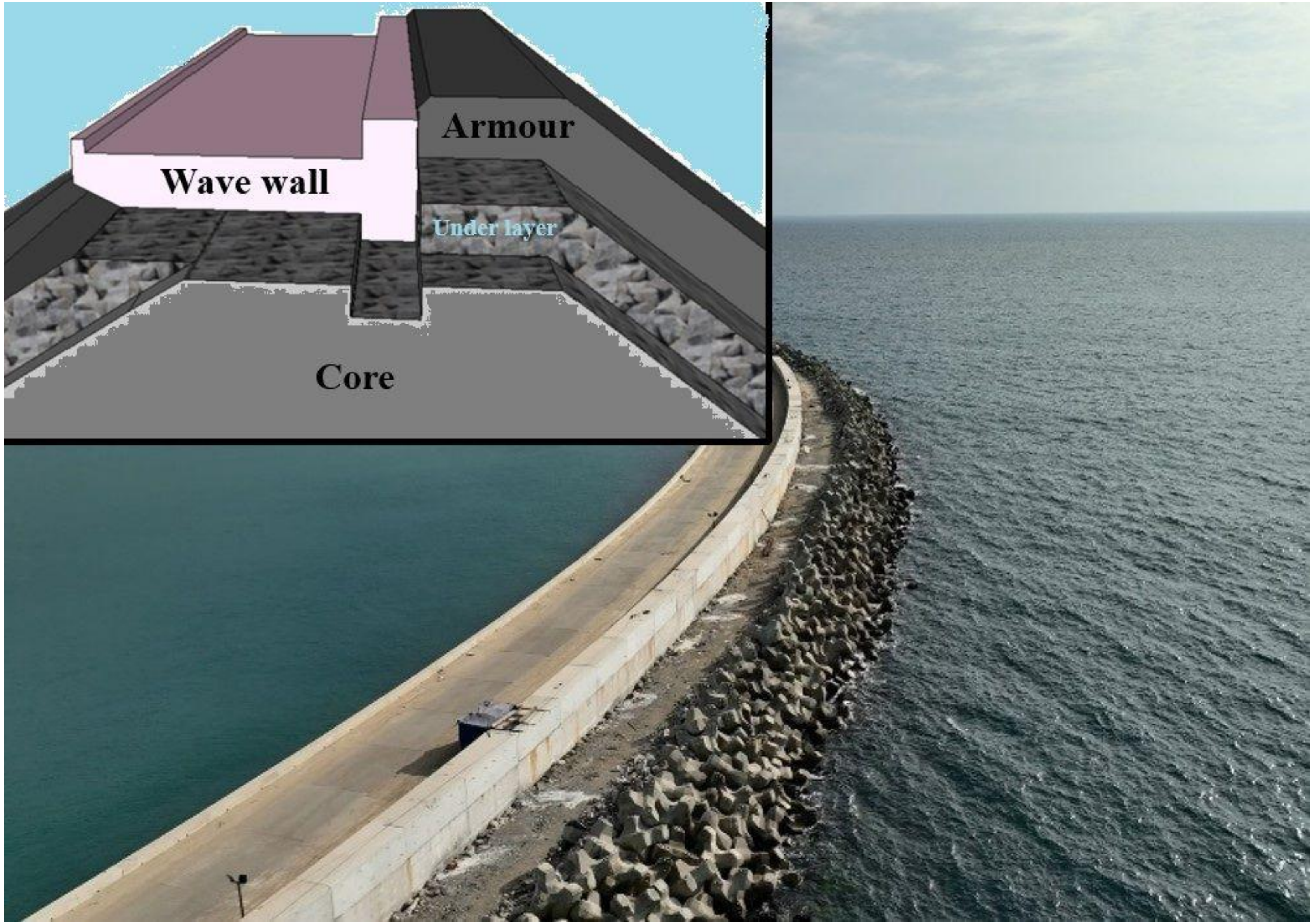
Breakwaters and Jetties

- Breakwaters
  - Protect harbors from wave action.
  - Reduce sediment buildup in harbor.
  - Influence sediment transport patterns along adjacent shores.
  - Constructed using large concrete blocks, rubble mounds, or caissons.
  - Can be detached (offshore) or shore-connected depending on coastal conditions.
- Jetties
  - Extend perpendicular from shore.
  - Stabilize inlet channels and prevent shoaling (increase in wave height as it enters in shallow water).
  - Some are used as offshore docking facilities for ships.

Rubble Mound Breakwater, Al-Faw, Iraq (14.5 km in length)

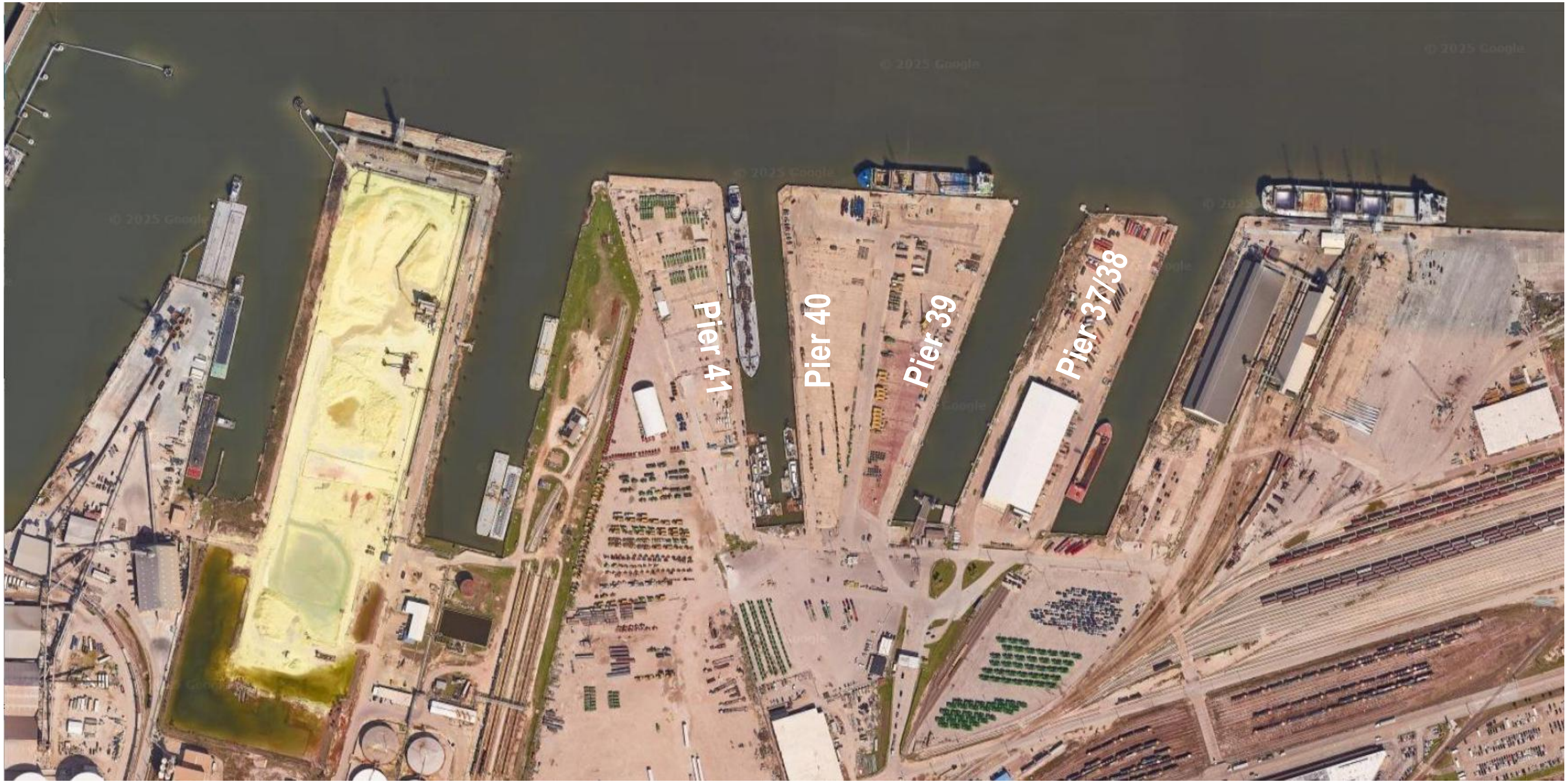

Armour
Wave wall
Under layer
Core

Breakwater at the Port of Zeebrugge, Belgium

Quays, Wharves and Piers

- Quays
  - The physical docking structure.
  - Vertical walls for ships to berth alongside and unload cargo.
  - Constructed using reinforced concrete, steel sheet piles, or gravity structures.
  - Designed to withstand lateral earth and sea pressures and ship impact forces.
- Wharves
  - A lateral structure composed of continuous quays.
  - Extend from shore into deeper water.
  - Equipped with bollards, fenders, and mooring systems for secure vessel docking.
- Piers (or finger pier)
  - Docking structures (quays and wharves) extending into the harbor.
  - Extensions of the terminal facility.
  - A pier can hold facilities such as storage sheds and warehouses.

Finger Piers at the Port of Galveston



Docks and Berths

- Docks
  - Water area where ships are loaded and unloaded.
  - Dry docks allow ship maintenance and repair by pumping out water.
- Berths
  - Specific locations along quays or wharves for vessel mooring.
  - They have a numbering system.
  - A terminal is composed of one or more berths.
  - Specialized berths cater to different vessel types (container, bulk, tanker).

Harbor Layout and Design

- Harbor design integrates natural coastal features with engineered structures
- Aims to optimize vessel traffic flow, cargo handling efficiency, and environmental protection
- Considers long-term coastal processes and potential climate change impacts

Natural vs Artificial Harbors

- Natural harbors
  - Present in protected coastal areas (bays, estuaries, deltas).
  - Offer inherent shelter from waves and storms, reducing infrastructure needs.
  - Most natural harbors have been settled.
- Artificial harbors
  - Created through extensive engineering and construction.
  - Require breakwater systems to provide protection.
- Natural harbors often have depth limitations, while artificial harbors were built to escape depth constraints

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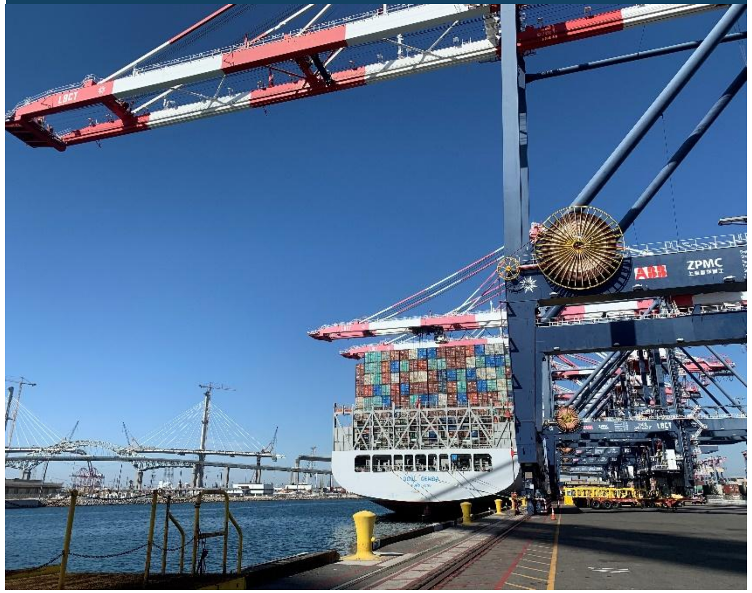

D. Port Water Areas

Read PW Sections II-3.1, II-3.2

Operational Steps in a Commercial Port Call

High seas
- Vessel calls at the port 24 hours in advance

Pilot boarding areas
- A pilot comes aboard and assist maneuvering

Harbor
- Vessel enters harbor and reduces speed
- Tugs assist vessel to approach designated berth

Berth
- Berthing, connecting lines.
- Cargo transfer
- De-berthing

Harbor
- Tugs assist vessel to the access channel for departure

Pilot boarding areas
- Vessel leaves harbor
- Pilot disembarks

Anchorages and Pilot Boarding Areas

- Anchorages
  - Temporary holding areas for ships awaiting berth availability.
  - Holding area for ships waiting a new assignment.
  - Can restock, change crews and bunker.
  - Located in areas with suitable water depths and bottom conditions for anchoring.
  - Proximity to navigation channels and potential impacts on other port operations.
- Pilot boarding areas
  - Usually outside harbor limits (5 km from entrance channel).
  - Leave ample time for pilot to board and go to the bridge.
  - Usually by pilot ships (helicopters if conditions are difficult).

Entrance Channel

- Outer access channel
  - Outside breakwater or protected area.
  - Width a function of vessel beam, traffic density, and environmental conditions.
  - Depth accounts for vessel draft, squat effect, and under-keel clearance.
- Alignment minimizes cross-currents and provides smooth transitions for ships
- Entrance location balances wave exposure, sediment transport, and navigational safety
- May incorporate protective structures (breakwaters, jetties) to maintain channel stability

Turning Basins

- Turning basins allow large vessels to rotate and change direction within the harbor
- Sized based on the length overall (LOA) of the design vessel plus maneuvering clearance:
  - 2 LOA is the standard clearance.
  - 1.5 LOA for a ship with bow thrusters.
  - 1.2 LOA for a ship with tug assistance.

Tug Assisted Turning Bassin, Port of Wilmington, North Carolina