



MICHIGAN ENGINEERING

NAVAL ARCHITECTURE & MARINE ENGINEERING  
UNIVERSITY OF MICHIGAN

# Dry Docking for Naval Architects

## Definitions and Methods for Analysis



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February 2026

This coursepack was made possible by the generous support and expert guidance from Douglas Pearlson and Pearlson Shiplift Corporation, whose knowledge was instrumental at every stage.

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## Section 1 - Importance and Evolution of Dry Docks

### 1.1 Importance of Dry Docking

Dry docks are an essential tool in all aspects of the maritime industry, playing a key role in both the launching and longevity of vessels. Because ships are, without exception, constructed on land within a shipyard, considerations must be made towards the method of launching the vessel into the water at some point along its range of completion. This may come in the form of a graving dock, in which the vessel's grand blocks may be joined to make a hull. In other instances, a shipyard may transfer the vessel into a floating dry dock or a shiplift system to be launched, typically prior to receiving final outfitting. Other ways of launching a vessel include side and marine railway launching. For side launching, a vessel is built on shore then launched on its side into the water using an inclined way with the vessel supported by a wedge shaped cradle. It then rights itself in the water. Marine railways can also be used to lower a vessel into the water. The cradle, in which the vessel sits, is rolled along an inclined track until the cradle is sufficiently submerged, and the vessel is floated.

Beyond launching a newly constructed vessel, a ship must also be removed from the water using a dry dock to undergo periodic out-of-water inspections, repairs, maintenance, and retrofits. A cargo ship, for example, is typically dry docked once every five years to undergo an out-of-water inspection of the hull, appendages, through-hull penetrations, rudders, propulsors, etc. Moreover, older vessels and passenger vessels may require more frequent dry dockings. Passenger vessels, for example, are required by regulation to dry dock for two hull inspections per five year period, without exceeding thirty-six months between inspections (SOLAS SOL004, Res. A.997). Scheduled maintenance, urgent repairs, or desired retrofits may require these vessels to be dry docked more frequently. Of course, these inspections, repairs, etc. typically require the vessel to be removed from the water entirely. This is typically performed at a repair yard with multiple dry docks. Based on the yard's resources, availability, and spatial or structural limitations of the available dry docks, the ship owner may be restricted in his or her selection of the repair yard.

Below is a list of potential maintenance or repair items that may be examined or undertaken while the vessel is in dry dock. Additionally, a number of items must be surveyed in order for the docking survey to be accredited by the classification society and regulatory authority.

- Condition of the hull is surveyed and new paint and anti-fouling is typically applied.
  - Prior to painting, fouling and oil spots are removed, usually with high pressure water jets and any rust is sand or shot blasted off.
  - Subsequently, the hull is examined by the classification surveyor and representative of the shipyard before painting commences.
- Condition of the rudder and propeller is closely examined, including dents, corrosion, fractures, and the condition of seals and bearings.
  - Examination of non-controllable pitch propeller (CPP) tail shafts require removal from the hull.
- Anchors and chain cables are inspected to monitor wear and corrosion.
- Limited engine maintenance is typically done while the vessel is at sea. However, large component removals or replacements are likely to require dry docking.
- Energy efficiency upgrades and installations or fuel conversions.

## 1.2 Evolution of Dry Docking

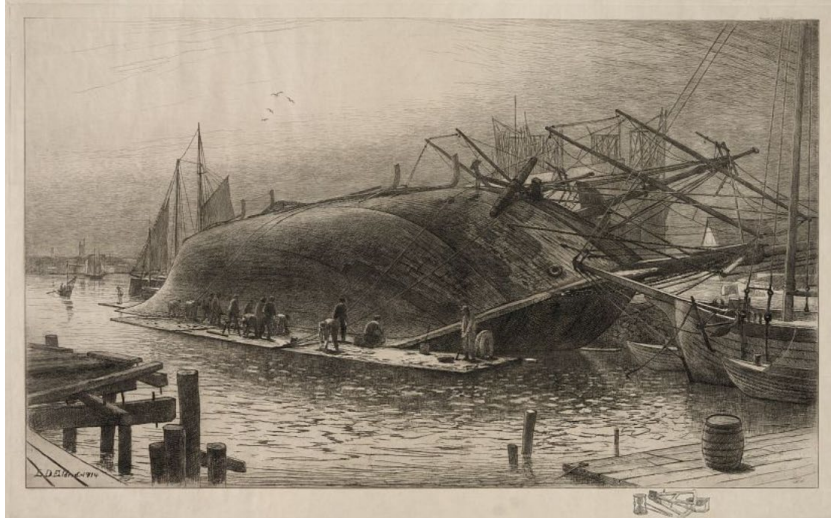
The creation of the first boats thousands of years ago marked the beginning of a long and evolving history of ship maintenance and launching techniques. Although early dry docking methods differed significantly from those used today, both have played crucial roles in the upkeep of vessels. Through utilizing their surroundings, nature, and early engineering, civilizations have been able to create unique dry docking methods. These methods have advanced as ship designs, technology, and materials have evolved. In this section you will see how grounding, transporting, careening, and dry docking have been used throughout history and evolved into what is used today.

In ancient times, many vessels remained smaller due to the difficulty of both construction and maintenance. The benefits of having these smaller vessels was that they could be pulled ashore for repair. Vessels that couldn't be pulled ashore were easily grounded. The grounding of a vessel is when it is taken to shallow water until the vessel no longer floats and lays on the ground instead. As the tide gets lower, the vessel's hull becomes exposed allowing for any necessary maintenance. However, this only gave crews a few hours to do necessary maintenance before the tide returned. It also put a high amount of stress on the grounded section of the hull. To combat this, ancient Egyptian and Phoenician ship builders would build shorter and thicker vessels that could withstand grounding (Morra, 2011).

During the 15th century, the most common method for the maintenance of large vessels was careening, also called heaving down. During high tide, vessels would be beached at docks or designated spots with soft sand. During low tide, the vessel would rotate and half of the hull would be exposed to allow for maintenance to be done. This was a very labor intensive process that would only allow crews to do maintenance on one side of the hull for as long as the tide was low. Before careening, the ship would need to be made as watertight and light as possible to prevent water from entering and damage to the hull. This method would still be used until the 20th century for larger vessels.



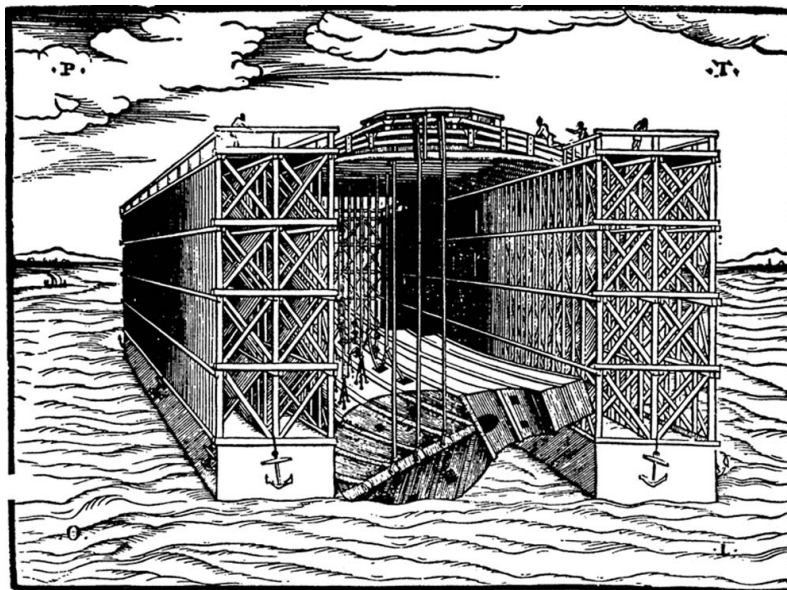
**Figure 1.2.1** Aft end of the Whaling Vessel, Sunbeam, while hove down by Joseph Tirrell, 1850.



**Figure 1.2.2** A wooden ship careened on its side for maintenance print done by L.D. Eldred, 1914.

The first ever recorded graving dock was the Portsmouth dry dock in the United Kingdom. It was built in 1495 to assist in the maintenance of British Royal Navy ships. As time progressed, the dry dock became more advanced through the addition of a stone basin and pumping technology. It was utilized until 1984.

The first floating drydock to have been recorded is shown in the image below. It shows a woodcut created in Venice in 1560. It portrays a ship that had been grounded for over a year being lifted by two connected floating structures. While it is unclear if the creator of the drawing ever used their design to lift the grounded ship, it shows that the concept of floating dry docks had been conceived.



**Figure 1.2.3** Woodcut of a Floating Dry Dock from *Descrittione dell'artifitiosa machina* (taken from *Floating Docks in the Sixteenth Century*).

The camel dock was first created in the Netherlands in the 17th century. They were primarily designed to aid in the repair and maintenance of vessels in harbors where the shallow water depth made dry docking difficult for larger vessels. The camel dock was a large rectangular box similar to a floating dry dock. These boxes were filled with water, and once positioned underneath the hull of the vessel, the water would be pumped out. This provided additional buoyancy to the ship so that it could navigate the shallower waters of the docks.

While similar ideas have existed previously, the first modern marine railway was created in 1818 by Thomas Morton. A vessel was floated onto a cradle with wheels on a rail. The vessel could then be pulled up the slope for drydocking. In the image below, a vessel can be seen in a cradle on rails.



16-A-3 (4) D Marine Railway - showing bow view of Tuna Clipper "SUN DAWN". Industrial Division, Cristobal, Canal Zone. 4/20/54

**Figure 1.2.4** Vessel, Sun Dawn, on a marine railway, 1954.



**Figure 1.2.5** John Blackwell's 210 ft long ScrewDock, 1892.

Although the concept of a shiplift dates back to the 1800s, the first modern shiplift design that overcame the limitations of the rigid lifting platform and the technology of the time was invented by Raymond Pearlson in 1957. His “Syncrolift” featured an articulated platform, allowing dockmasters to effectively monitor the longitudinal distribution of loads and addressed the leveling of the platform to easily facilitate transfer of the vessel. Over the years, the shiplift evolved on a larger scale, functioning like a vertical elevator to bring ships to land level, where they could then be moved through the dockyard on rails. As technology has advanced, the shiplift has become significantly easier for dockmasters to operate, incorporating strong back cradles which support the vessel that are transported by removable bogies or Self Propelled Modular Transporters (SPMTs). This innovation has reduced the need for rail wheels, as the modern shiplift and transfer systems can now more efficiently lift, transport, and store vessels today up to 40,000 tons docking displacement. In 2025, Pearlson Shiplift Corporation commissioned the largest shiplift and land level transfer system in the Western Hemisphere located in Jacksonville, Florida. The 500 by 110 foot wide shiplift platform has a maximum lifting capacity of 25,000 long tons, demonstrating that there is still innovation and progression being made in the dry docking industry.

It can be expected that the future of dry docking will include making efforts to minimize cost and risk while maximizing control of the vessel. For example, side launches of vessels could be phased out given safer alternatives exist today. This being said, the fundamental concept of supporting a vessel safely will not change.



**Figure 1.2.6** Rendering of a U.S. Navy destroyer sitting atop Pearlson’s 25,000 long ton capacity shiplift in Jacksonville, Florida.

## Section 2 - Types of Dry Docks

Although a naval architect may not be required to have an extensive engineering understanding of each electrical and mechanical system that goes into dry docking a vessel, they should have a strong understanding of the types of dry docks, their defining characteristics, and resulting advantages and disadvantages. Each type of dry dock shares similarities in the basic processes of supporting or launching a vessel from a series of blocks, but differences lie in the process and systems involved in isolating the vessel from the hydrostatic effects of the water. These defining characteristics provide insight into the limitations and applications of each dry dock, which builds an important intuition when performing calculations and feasibility assessments.

As mentioned in Section 1.2, modern dry docks employ the use of three primary dry docking methods. These methods are graving dry docks, floating dry docks, and shiplift systems, and are described in detail in the following subsections. Although less common at large shipyards, marine railways and mobile boat hoists systems are also relevant dry docking methods.

### 2.1 Graving Dry Docks

A graving dry dock, commonly referred to as a “basin” or “traditional” dry dock, is considered the oldest and simplest method of dry docking a ship. This method involves a fixed, reinforced basin constructed along the waterfront in an advantageous location within the shipyard based on workflow and geographical factors. The basin is created by removing or altering a large volume of land and reinforcing the floor, sidewalls, and headwall of the basin, typically with concrete. A dock gate is constructed to separate and seal the basin from the body of water, enabling it to be drained or flooded accordingly. The floor of the dock is lined with keel and side blocks according to the Blocking Plan (see Section 4.2), on which the keel of the vessel rests as the basin is drained. The engineering details of the dock gate, reinforced walls, and pump systems are out of the scope of this coursepack and typically not of concern for a naval architect; however, the arrangement, composition, and size of the keel blocks should be well understood. These attributes are dependent on the characteristics of the vessel being dry docked, but are largely universal between dry docking methods and thus will be discussed in later sections.

The graving dock is a suitable dry docking method for a wide range of ship sizes and tonnages. However, due to the large upfront construction costs and its immobility as a fixed structure, the investment of a graving dock is typically only justified in large shipyards constructing very large vessels. Additional benefits of the graving dock include its long life expectancy, low maintenance costs, and the static/highly stiff nature of the dock floor.



**Figure 2.1.1** Three Graving Dry Docks in Various Stages of Flooding. Nauta Ship Repair Yard, Gdynia, Poland. (<https://www.gac.com/poland/shipping/dry-docking-support>)



**Figure 2.1.2** Graving Dry Dock Lined with Keel and Side Blocks, including the Dock Gate at the far end of the basin. Dry Dock #1, Charleston Shipyard, constructed in 1833.

## 2.2 Floating Dry Docks

A floating dry dock is a large, buoyant platform, or pontoon, with vertical “wing walls” along symmetrical longitudinal outboards. The pontoon consists of an arrangement of ballast tanks used to submerge, float, trim, or heel the dry dock as necessary in the docking process. Most floating dry docks can be classified into three types: box, pontoon, or sectional:

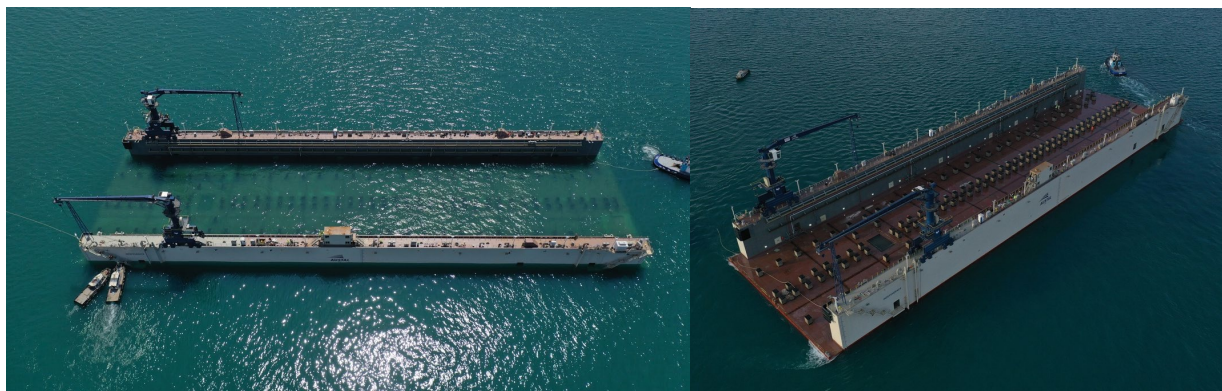
- A box type has pontoon and wing walls that are single, continuous structures. As a result, the box type floating dry dock may be lighter and more structurally rigid because forces and bending moments imposed by the vessel and hydrostatic forces can be transversely and longitudinally transferred.

- A pontoon type has continuous wing walls but disconnected, transverse sectional pontoons. Although this characteristic may ease the dry docks' transport over open water and enable modularity, the dry dock's structural stiffness must come solely from the wing walls, often resulting in increased overall weight.
- A sectional type has both noncontinuous pontoons and wing walls. The structure of this dock may be either loosely connected with “locking logs,” which can transfer small forces and moments, or hinge pins, which only allow shear force transfer.

Before the dry docking process commences for a vessel, the surface of the pontoon is lined in an arrangement of keel and side blocks according to the blocking plan (Section 4.2). The vessel being dry docked is floated above the partially submerged dry dock and held in place with a series of mooring lines. The dry dock is then procedurally deballasted, allowing buoyancy to slowly push the pontoon and keel blocks into the keel of the vessel, raising it out of the water. The vessel can then either undergo repairs and maintenance onboard the floating dry dock, or may be moved using a system of rails or transfer cars into the shipyard.

Extensive consideration for stability, local strength, and longitudinal and transverse strength of the floating dry dock must be made in its construction and within the docking plan (Section 4.1).

The floating dry dock comes with a number of advantages; its floating nature allows it to be towed both within the shipyard into desired placement, and from an external manufacturing yard after its initial construction. Additionally, the floating drydock does not occupy valuable waterfront property within the shipyard. It can accommodate a wide range of vessel lengths and vessel conditions, namely those under heel or trim. It also allows for translation from dock to shore if desired. With that being said, the floating dry dock will require extensive maintenance on the steel structure, and the pump and valve system. It may also be more susceptible to undesirable sea states or weather conditions during docking.



**Figure 2.2.1** Floating Dry Dock in Open Waters Lined with Keel and Side Blocks. Submerged/ballasted (left) and floated/deballasted (right). Sedef Shipyard, Turkey (<https://www.sedefshipyard.com/en/gemi.aspx?ID=37>)



**Figure 2.2.2** US Navy Submarine USS Scranton onboard a partially submerged floating dry dock, San Diego, CA. See link for timelapse of the submersion and floating process. (<https://www.youtube.com/watch?app=desktop&v=YX8h-bfrAr4>)

## 2.3 Vertical Shiplift Systems

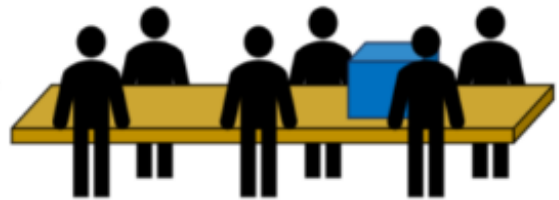
Although details vary between shiplift systems, the primary concept is the same: a large platform, on which the keel and side blocks are arranged, lifts or lowers a vessel from the water using a series of hoisting mechanisms. The blocks are typically mounted on a cradle to facilitate transfer ashore to a land level repair berth. Alternatively, the docking blocks can be secured directly on the platform. The platform does not necessarily need to satisfy the length overall of the vessel, but instead must span the maximum keel bearing length while allowing unsupported ship length to overhang the platform (ensuring of course that maximum loads and bending moments do not exceed capabilities of the hoist mechanisms or platform structure). The lifting system typically consists of a series of electro-mechanical hoists with synchronous motors in conjunction with multi-part steel wire rope along each side of the platform. The loading capacity along the length of the shiplift platform that these hoists must support is dependent on the capacity of each individual hoist and the longitudinal spacing between each “pair” of hoists. These hoists are connected via wire rope to the ends of the Main Transverse Lifting Beams (MTB), and therefore their lifting capacity must consider the weight of the platform associated with the MTB. This is the Maximum Design Load (MDL) capacity of the shiplift drydock, expressed in long tons per foot or metric tons per meter. Similar to the different types of the Floating Dry Dock’s Pontoon (Sec 2.2), transversal segments of the shiplift platform are either bolted or welded (creating a rigid connection) or pinned (effectively articulated):

- A rigid connection allows for the transfer of longitudinal forces and bending moments along the length of the platform, meaning for a perfectly rigid platform, each motor hoists an indeterminate percentage of the total weight of the platform, blocks, and docking vessel. Typically, the motors of each hoist along a “rigid” platform design are not synchronized to ensure that the vessel and hoists are not overloaded. As a result, the hoists will attempt to share any overload, but does not ensure that the platform is raised at the same speed and thus does not guarantee that it stays level. This is the case because, in practice, the platform will not be perfectly rigid and structural deflections and wire rope stretch will cause loads to be distributed to some extent near the location of the forces.

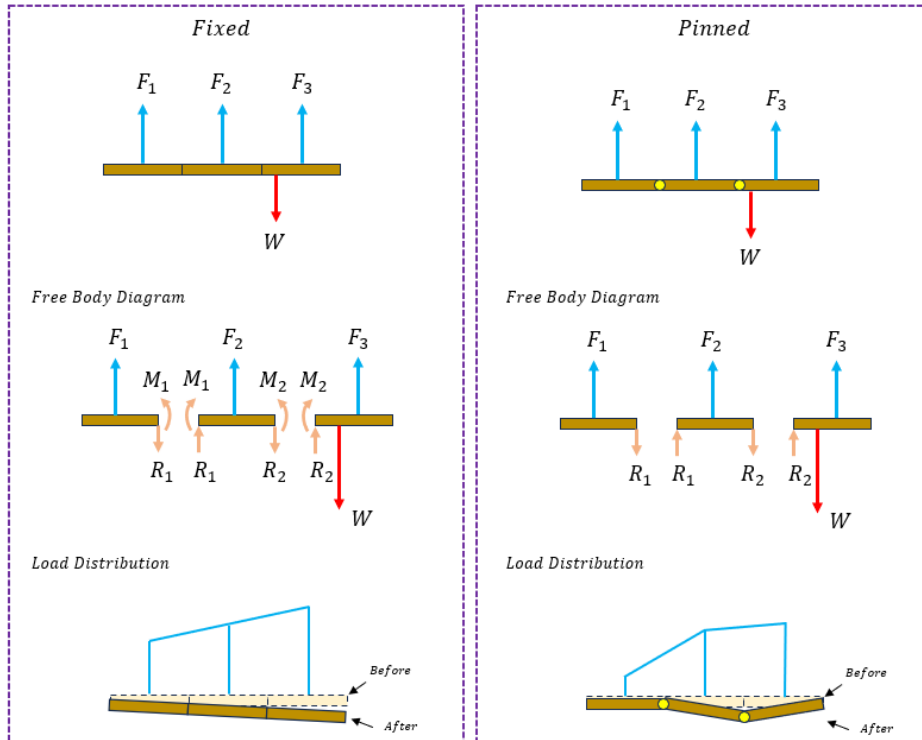
- An effectively articulated platform connects sections of the platform to one another via an articulated saddle or redundant pin, as the name suggests. While this connection transfers vertical forces, it does not allow the transfer of bending moments created by the weight on each section along the length of the platform. As a result, each hoist and motor along the length of the platform (symmetric about the centerline) only supports the local adjacent load to reduce the risk of any overloaded blocks from damaging the vessel. Hoists support different loads along the blocking length of the vessel. Therefore, each motor may require a different amount of power. To keep the platform level, the hoists are driven by synchronous AC motors that operate all the hoists at the same vertical speed, regardless of load on each hoist. This platform design is referred to as an “articulated shiplift,” and has a number of advantages (namely the ability to monitor loads supported by each hoist along the length of the platform, ensuring stress on the hull is within allowances).

The shiplift system sits along the waterfront, often protruding from the shipyard itself. Either rail mounted bogies, or system of rubber tired, towed or self-propelled modular transfer systems (SPMTs) may be used to translate the ship from the dock into the shipyard to undergo maintenance or repairs. When a docked vessel is transferred along the shore-facing, narrow end of the platform, this designates an “end transfer” shiplift and occupies the vast majority (~85%) of all active shiplift systems. Single and double sided “direct side transfer” shiplifts occupy the minority of shiplifts, but may still be ideal depending on shipyard layout design.

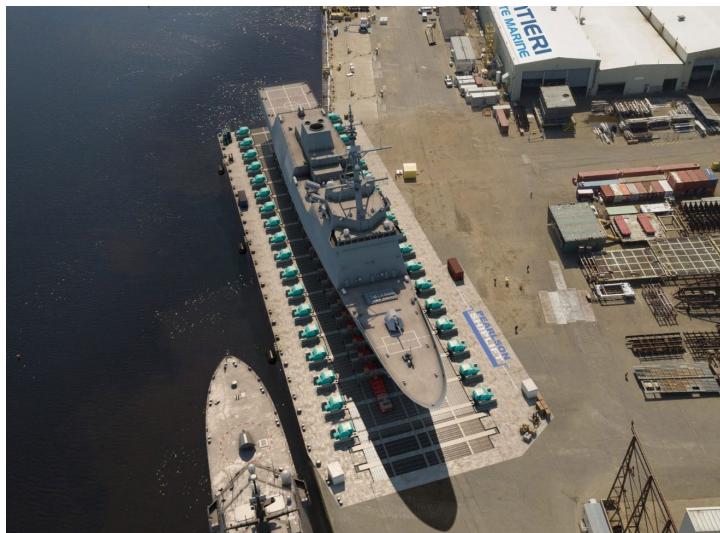
**Example:** An intuitive way to conceptualize the differences between rigid and pinned platforms is to imagine a long dining table with a very heavy item – representing an overloaded keel block – placed somewhere on its surface. The rigid table is then lifted by an even distribution of people along its longitudinal edges. As the group of people try to lift the table, they are given insight into the combined weight of the table and the item, but not the location or weight of the heavy item. Each person lifts the table without noticing the “local overload” because they are sharing the load. This is representative of the “rigid” shiplift design. Now consider a table that has been sectioned into a series of transverse segments (like the leaves of a banquet table) with one person assigned to the ends of each segment. Because the segments are not rigidly connected to one another, the amount of load felt by each person lifting will be different and dependent on whether or not the heavy item lies on their segment of the table. Therefore, each person would need to apply a different magnitude of power to lift their segment. The people lifting will be given insight into the distribution of load along the length of the table and, specifically, the location of the heavy item. They can stop lifting as soon as the local overload is noticed, before the vessel is damaged by the overloaded keel block.



See also Figure 2.3.2 below comparing simplified free body diagrams of both the rigid and pinned shiplifts.



**Figure 2.3.2** Free Body Diagrams of the Rigid and Pinned Shiplift Platforms, highlighting the Differences in Moment Transfer between Segments.



**Figure 2.3.1** Computer Rendering of a Constellation Class Frigate sitting atop blocks over a Pearlson Articulated Shiplift. Fincantieri Marinette Marine Shipyard, Marinette, WI. (<https://shiplift.com/>)

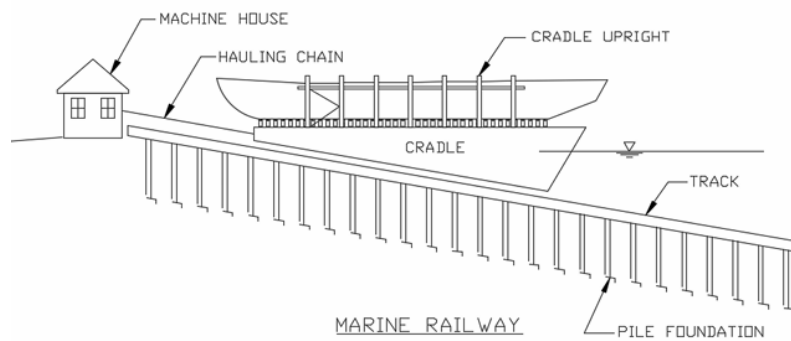
	Graving Dock	Floating Dock	Vertical Shiplift
Pro	<ul style="list-style-type: none"> <li>● Long life expectancy.</li> <li>● Unrestricted size limitations.</li> <li>● Simple docking operation.</li> <li>● Low maintenance costs.</li> </ul>	<ul style="list-style-type: none"> <li>● Dock can be constructed at an external build site.</li> <li>● Vessels can be transferred out of drydock.</li> <li>● Unrestricted size limitations.</li> </ul>	<ul style="list-style-type: none"> <li>● Articulated shiplift prevents excessive stresses on vessel hull.</li> <li>● Vessels can be transferred out of drydock for efficient use of labor.</li> <li>● Streamlines the vessel transfer process</li> <li>● Occupies a minimum of the valuable shipyard waterfront.</li> <li>● Fast operating speed.</li> </ul>
Con	<ul style="list-style-type: none"> <li>● Potential disrupts shipyard operation during construction.</li> <li>● Vessel must remain in basin while it undergoes repairs or maintenance.</li> <li>● High initial construction costs.</li> <li>● Occupies valuable waterfront. Restricted access and less efficient labor.</li> </ul>	<ul style="list-style-type: none"> <li>● Requires extensive structural and stability considerations.</li> <li>● Complex pump and valve systems require extensive maintenance.</li> <li>● Slow operating speed.</li> </ul>	<ul style="list-style-type: none"> <li>● Platform width and weight considerations for very wide vessels.</li> </ul>

**Table 1:** Comparison of the Graving, Floating, and Vertical Shiplift Dry Docking Methods.

## 2.4 Other Dry Docking Methods

### **Marine Railway:**

Although less common in shipyards today, a marine railway is a mechanical method of dry docking a ship that utilizes a large chain winch to pull a vessel longitudinally out of the water along a railed incline. Prior to dry docking, the cradle, which is lined with keel blocks and typically rolls on a rail track, is lowered into the water just below the vessel's draft. Then, by winching the cradle and vessel up the incline until the ship's keel rests on the keel blocks with partial support from hydrostatic forces. As the vessel and the cradle on which it sits are winched out of the water along the tracked incline, the hydrostatic forces decrease until the vessel is fully supported and completely out of the water. From there, the vessel can undergo any required maintenance, repairs, etc.



**Figure 2.4.1** Diagram of the Marine Railway Dry Docking Method, as discussed above. (Source from Heger’s Dockmaster Training Manual, 2022.)

Extensive consideration must be put into the materials and structural properties of the track, cradle, hauling winch mechanism, and various foundations. A simple calculation can be conducted to estimate the max load on the hauling chain with knowledge of the total weight ( $W$ ) of the ship, cradle, and chains by evaluating the slope of the track and estimating a coefficient of friction. The marine railway is a simple, cost effective, easily implemented and constructed, and fast operating method of dry docking a ship relative to a graving or floating dry dock. With that said, the method typically has a maximum lifting capacity of only 6,000 tons, and is a fixed structure requiring valuable real estate along the waterfront of a shipyard. This method also requires maintenance of the mechanical systems and the underwater structure.



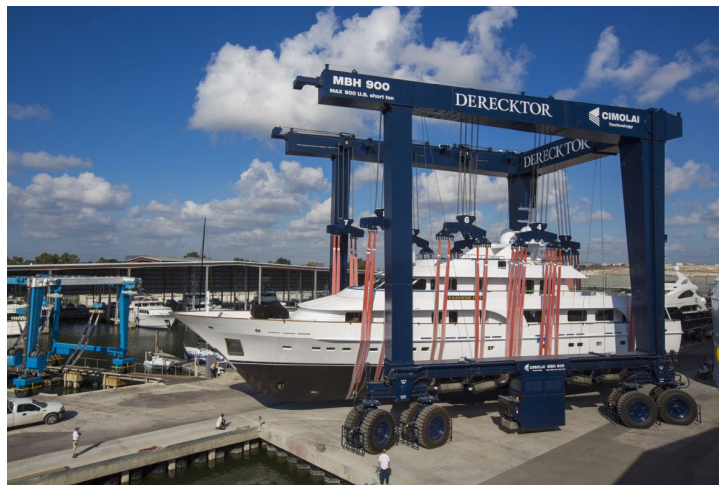
**Figure 2.4.2** Crandall Marine Railway Dry Dock at Poga Poga, American Samoa. Notice the large cradle and the keel and bilge blocks that the vessel sits on. Additionally, the rollers, rails, and hauling chains can be seen in the foreground.

([https://www.crandalldrydock.com/jobsite%20files/jobsite\\_americansamoa.html](https://www.crandalldrydock.com/jobsite%20files/jobsite_americansamoa.html))

### **Mobile Boat Hoist:**

The mobile boat hoist, often referred to as a Marine Travelift™, is a strap lift that is mounted on a structural frame with wheels that pivot to improve maneuverability. Instead of a structural platform on which the dry docked vessel is supported on keel and bilge blocks, the hull is typically supported by straps or slings. The slings rest in the water before the boat to be dry docked navigates above them. The slings and boat are then hoisted up and out of the water before being transported under the travel lift's power to the desired location within the yard or berth.

This method of dry docking is limited to vessels under ~1,500 tons. However, for vessels within this weight restriction, the mobile boat hoist has a number of advantages: it is very fast and easy to operate, it can be used to transport dry docked vessels anywhere within the yard, and requires minimal planning in typical use. With that said, the mobile boat hoist has large initial and maintenance costs, and the potentially excessive local loads from the straps can damage the vessel's hull. For larger units, the upland (transfer) requires foundations and a surface that can accommodate the concentrated wheel loads, especially when they are rotated.



**Figure 2.4.3:** 900 Ton Marine Boat Hoist Transporting a Personal Yacht in Florida, USA.  
(<https://www.cimolaitechnology.com/product/mobile-boat-hoist-mbh-900/>)

## Section 3 - Dry Docking Components

Although the components and respective complexities of each dry docking technique vary, there are a number of components that are both vital to the operation of each system and pertinent to a naval architect that deserve attention. While systems like dock gates, ballast pumps, and hoists are of the utmost importance for successful operation of their respective docking type, the engineering details are beyond the scope of this coursepack. Instead, keel and side blocks, their composition and structural characteristics, and strongback and other transport systems are covered in detail in the following sections due to their common usage for all drydocking methods.

### 3.1 Keel Blocks

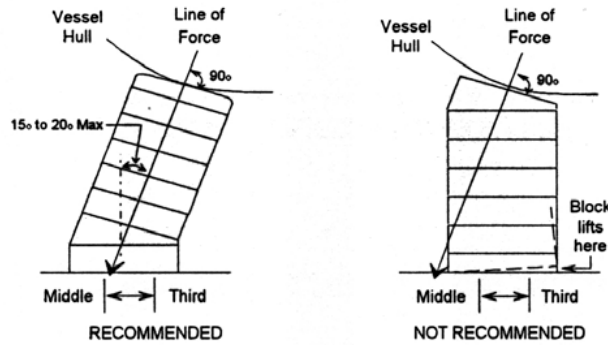
Keel blocks are rectangular, compound structures that play key roles in positioning, securing, and distributing loads on the hull of a dry docked vessel. The size, composition, positioning, and quantity of these blocks are dependent on the shape and weight distribution of the hull under which they support. As suggested by their name, keel blocks are positioned under the relatively flat, reinforced keel of the vessel. Because the rigidity of the vessel is highest along the bottom centerline of the vessel, most of the vessel's weight should rest on these keel blocks to minimize local and global hull deflection. Ideally, during the vessel's initial design, calculations are performed to determine the quantity and distribution of these blocks to ensure stresses do not exceed some amount dependent on the structure of the hull. More on this can be found in the blocking plan (Section 4.2) and methods of calculating these stresses can be found in Section 5.3. It should be noted that these calculation methods are approximate and cannot realistically consider the exact relationship between the deformity of the blocks or hull and the resulting loading on the blocks.

### 3.2 Side Blocks

Side blocks and bilge blocks also play important roles in stabilizing the docked vessel and distributing loads. Because these blocks are placed off the centerline, they support a smaller percentage of the overall load to prevent damage to the hull. To achieve this, side blocks may have a smaller surface area or lower effective stiffness (i.e. a smaller modulus of elasticity), allowing them to deform more easily than keel blocks and distribute loads to other blocks. The portions of these blocks that aid in allowing them to deform are the soft caps. The soft caps of the side blocks play an important role in ensuring the safety of the vessel. Side blocks and their composition are vital components of ensuring the stability of the vessel while it's being docked or, in extreme cases, through extreme events like hurricanes or earthquakes.

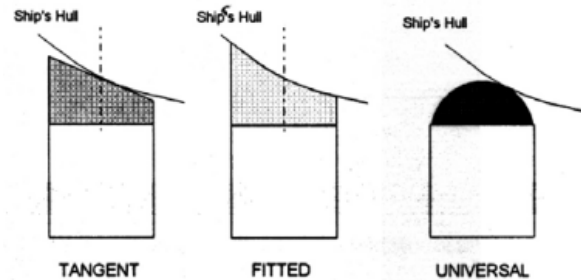
The geometry of side blocks may be more complex than that of the keel blocks in order to accommodate the shape of the dry docked vessel's hull. There are two aspects in the construction of side blocks in which this is most important: the foundation and orientation of the block, and the face of the soft cap. Ideally, the orientation of the side block should be such that the majority of the loading is axial (or normal to the plane of the block) to prevent the block from "kicking out" and becoming unstable. To achieve this, the load vector must be located within the center third of the base of the block, as shown in Figure 3.2.1. This can be seen where it is recommended that the

angle of the block does not exceed 20 degrees with the dry docking floor or platform.



**Figure 3.2.1:** Side Blocks along Bilge of Vessel Oriented to Maximize Component of Axial Forces (Heger Manual 2022).

The shape of the side block’s soft cap should also be taken into consideration. The low modulus of elasticity of the soft cap material allows the block to deform and reduces high point loads due to irregularities in the hull or hull shape. According to the Heger Manual, there are three primary side block soft cap shapes, varying on their specificity to the vessel, conformity to the hull, and manufacturing effort: tangential, fitted, and universal round cap. These can be found visually in the figure below:



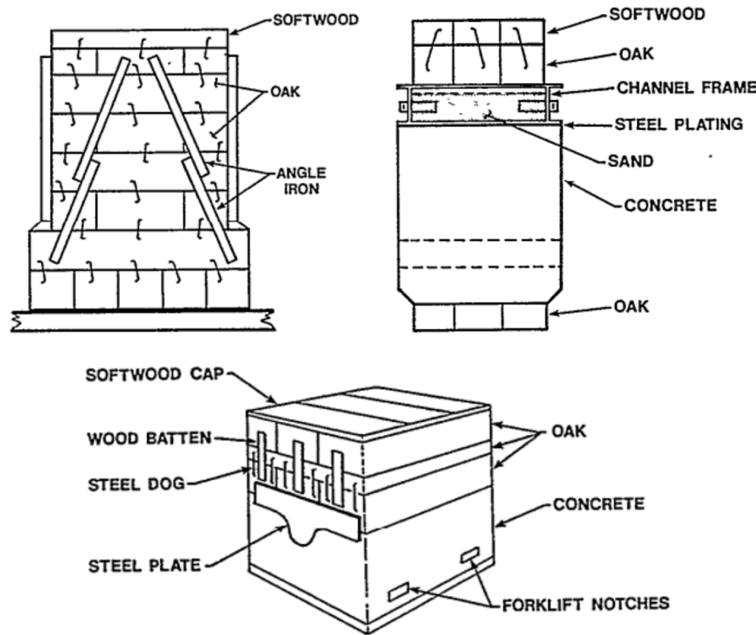
**Figure 3.2.2:** The Three Primary Side Block Soft Cap Shapes (Heger Manual 2022).

### 3.3 Block Composition and Construction

Block composition is dependent on the type of keel or side blocks being used in the dry dock. The most common type of block in a graving dock is a concrete/timber composite block; however, all-timber blocks, timber wedge release blocks, and elevated, steel structure supports are also common. Often keel blocks also feature a “sand pot,” which is an enclosed, steel box filled with sand (or some other incompressible material) that can be opened to relieve load on the block, allowing it to be lowered and removed.

Materials are layered within a block such that the structural behaviors of each material are exploited: a softwood is placed at the interface between the bulk of the block and the vessel’s hull to encourage the block to comply with the shape of the hull and deflect under load, subsequently spreading the responsive force along the hull more uniformly. Depending on the type of block, a concrete structure may be positioned below the hardwood portion of the block to create a highly rigid and secure base. Each component of the block is fastened to one another via steel “staples”,

and steel plates and bolts, referred to as “angle irons”. Three common types of dry dock blocks are visualized in the figures below:



**Figure 3.3.1** Visual Comparison of All-Timber (top left), Sand Pot (top right), and Composite Blocks (bottom) Keel Blocks. Sourced from “Strength Properties of Drydocking Timbers and Blocks,” US Department of the Navy (see appendix)

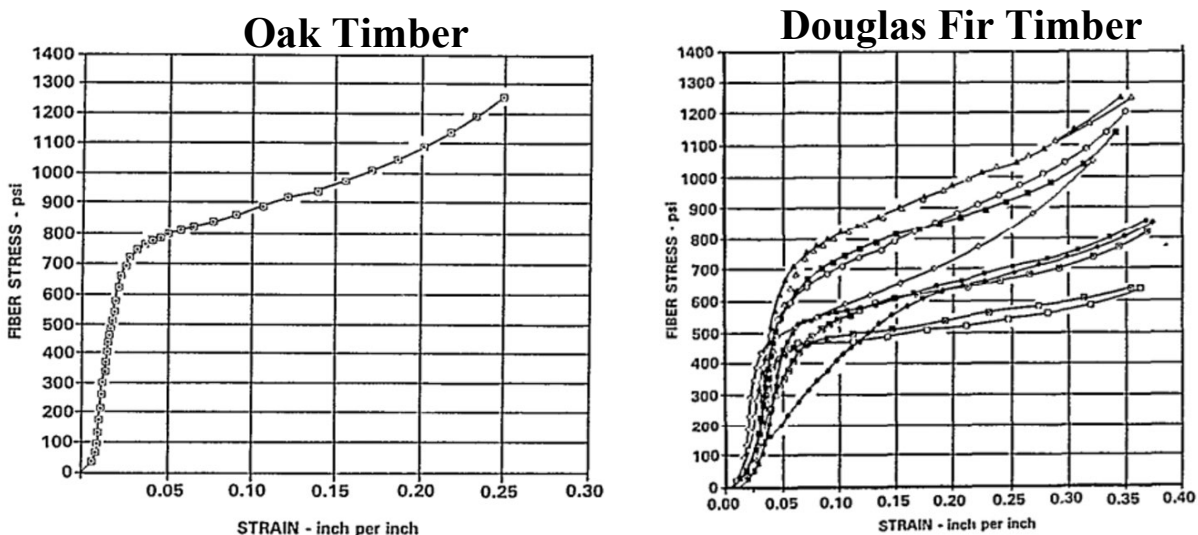
### 3.4 Structural Characteristics of Blocks and Materials

Although keel and side block types differ in material, shape, and application, a dry docked vessel should use an arrangement of blocks that share similar structural characteristics. These important structural characteristics include yield stress (applied stress, Force/Area, that a material may undergo before it experiences permanent deformation) and strain (nondimensionalized deflection), and should be considered to some extent in the construction of dry docking blocks and again when calculations are being performed to determine the loads on the hull during dry docking. As mentioned in the previous section, the structural components of blocks typically consist of timber, concrete, and steel. The structural properties for these materials are listed in Table 3.4.1.

Material	Yield Stress (psi)	Strain at Yield Stress (in/in)
Douglas Fir (Softwood)	250	0.025
Oak (Hardwood)	600	0.050
Concrete	435	0.00043

**Table 3.4.1** Structural Properties of Common Block Materials. Sourced from “Strength Properties of Drydocking Timbers and Blocks,” US Department of the Navy (see appendix)

It should be noted that each of the timber materials in Table 3.4.1 are representative of old, dry timber; the material characteristics may vary greatly based on the age and saturation of wood. Additionally, particularly for timbers and other materials that demonstrate significant strain under stress, the rate at which the material deflects under stress is not linear. This behavior is demonstrated in Figure 3.4.2 for Douglas Fir and Oak timber types.



**Figure 3.4.2** Experimental Stress vs. Strain Curves of Oak and Douglas Fir Timbers respectively. Notice the Departure from Linearity of each Material as well as the Inconsistency of the Douglas Fir between tests. Sourced from “Strength Properties of Drydocking Timbers and Blocks,” US Department of the Navy (see appendix)

The point at which the stress-strain curve departs from a semi-linear relationship is sometimes referred to as the fiber stress at proportional limit (FSPL), and corresponds approximately to the yield stress of the material. Fortunately, the behavior of the block beyond the FSPL is not necessary for calculations because these high stresses would cause damage to the vessel’s hull, which should be avoided.

### 3.5 Strongbacks and Transport Systems

Depending on the type of dry dock, it may be feasible to move the vessel out of the dry dock for maintenance, and subsequently enable access to other vessels. By nature, graving dry docks require the vessel to remain in the dock for the duration of its construction, maintenance, or repairs. Not only does this prohibit shipyards from reusing the dry dock for the duration of the vessel’s construction or repairs, but, for the case of the graving dry dock, it also may restrict accessibility to the vessel and hinder the transfer of materials or components. In contrast, the transport of the vessel out of floating dry docks, shiplifts, and marine railways is possible for these systems, enabling more frequent use and more efficient construction or repairs. Land level transfer from a shiplift is fundamentally easier than transfer from floating dock because of conjunction issues and has transformed the design of modern shipyards. To accomplish this, a shipyard may use a series

of railed or wheeled strongback cradles, hydraulic lift cars, self propelled modular transporters (SPMTs), or a number of other methods.

**Railed or Wheeled Cradles:**

A series of railed cradles are often placed transversely between the keel and side blocks of a new construction vessel, and the floor of the shipyard, especially in preparation for a floating dry dock launch. If strongback cradles are used they typically consist of structural steel girders with platforms to accommodate blocks, and rail wheels or rollers to allow the vessel to be moved either forwards or sideways via external push or tow. Wheeled strongbacks with tires are known as self-propelled modular transporters (SPMTs). Sand blocks allow the transfer of loads to remove or reorganize the blocks beneath the vessel.



**Figure 3.5.1:** US Navy LPD Undergoing New Construction atop Railed Strongbacks, Ingalls Shipyard (<https://www.seaforces.org/usnships/lpd/LPD-30-USS-Harrisburg.htm>)

**Hydraulic Lift Cars:**

Modular hydraulic lift cars may be used to transfer vessels onto or off of either floating dry docks or vertical shiplift systems and into the shipyard. Depending on the type of lift car and required lifting capacity, an arrangement of wheeled hydraulic jacks lift the vessel off of the dry dock’s blocks, transfer the vessel off of the platform or pontoon, and into the shipyard. These systems are typically modular and self propelled, allowing for quick transfer of vessels ranging in size and weight.



**Figure 3.5.2:** A Series of Hydraulic Lift Cars beneath Transverse Strongbacks supporting a

## Section 4 - Dry Docking Procedure

While the dockmaster is entirely responsible for the safe and effective dry docking of a vessel at a shipyard, a naval architect may be involved in creating or revising the docking plan and supporting the dockmaster during the dry docking of a vessel. Additionally, prior to the initial launch of a new or retrofitted vessel, a naval architect may play a large role in conducting calculations for the blocking plan based on as-designed weight curves, structural properties, and physical characteristics of the vessel. During construction or major modification when a vessel is launched or floated out from a drydock, a naval architect will need to provide in-progress estimates of the ship's properties including weights and centers.

### 4.1 Docking Plan

The docking plan is an extensive document that encompasses most of the information necessary to plan the dry docking of a specific vessel. It is an essential guide for dry docking a ship at a shipyard and should ideally be completed and associated with a new construction ship throughout its life. In most cases, the docking plan and the corresponding calculations and drawings are completed by the engineering firm that designed the vessel or the shipyard that constructed the vessel. Revisions to the docking plan may be necessary throughout the life of the vessel to accommodate changes in the weight distribution, trim, or other physical characteristics of the vessel. It is important that these revisions be recorded for major changes to prevent damage to the vessel's hull when being dry docked for maintenance or repair.

A complete docking plan for a vessel usually consists of the following information:

- **Title Block:** Ensure the most recent revision is being used.
- **References:** May provide sources or contacts for specific information regarding the vessel.
- **General Notes:** Provides crucial information regarding the draft marks, dimensions, painting procedure, appendages, blocking, trim and heel, and more.
- **Table of Displacements:** Quantitative information regarding the hydrostatic characteristics corresponding to the draft of the vessel. This includes displacement, added ton per unit of immersion, moment to change trim, LCB, metacenters, and more.
- **Vessel Profiles:** Engineering drawings of the profile view will give insight into measurement references, appendage locations, and block locations. Meanwhile, the plan view will show locations of the block distribution along the keel and bilge of the vessel. This will be discussed more in the following section regarding the blocking plan.
- **Hull Openings:** List of hull protrusions and penetrations below the waterline, and their corresponding locations along the hull. Necessary to ensure they do not conflict with or are damaged from block placement.
- **Keel Profile:** Engineering drawing of the vessel's keel showing exaggerated vertical variation from the expected hull shape. Usually these variations are only in the magnitude of about an inch, but are important to consider to prevent unexpected loads at or near these variations. Extreme variations of the keel may require modification of the block heights to ensure loading falls within allowable limits.
- **Table of Offsets:** This table provides additional quantitative information regarding the



10	NAVSEA TECHNICAL MANUAL FOR SONAR DOME RUBBER WINDOW			
9	STANDARD NAVY DOCKING DRAWING—SURFACE SHIPS			
8	NAVSEA TECHNICAL MANUAL (DOCKING INSTRUCTIONS)			
7	TEMPORARY HERCULITE SUN SCREEN FOR SONAR DOME			
6	SLING SUPPORT FOR SONAR DOME RUBBER WINDOW			
5	ARR OF ATTACH TO SUIT PROP SHAFT, SHIPPING & UPSHIPING			
4	LOCATION OF SEA CONNECTIONS			
3	CURVES OF FORM			
2	MASKER AIR HULL EMITTERS			
1	FAB & INSTL OF SHIPS NAME & DRAFT MARKINGS			
NO.	TITLE	CADE CODE	MFR OR CONTR NO.	NAVSEA NO.
REFERENCES				
4		3		

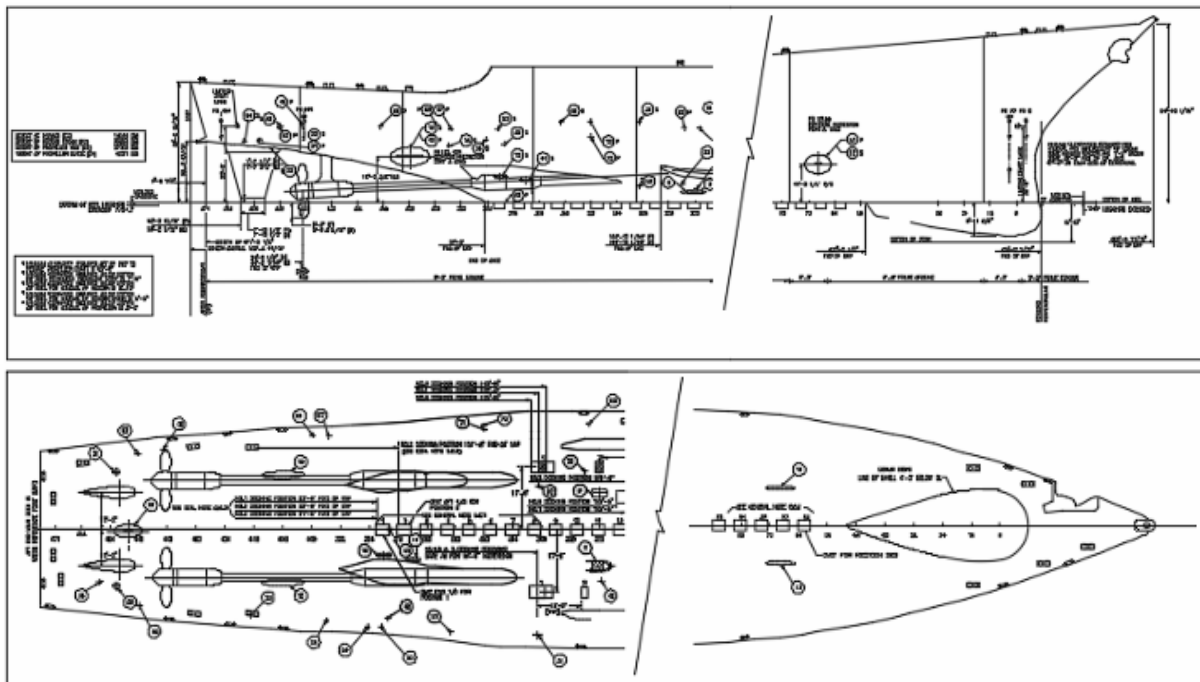
Figure 4.1.2 Reference (Heger's manual)

GENERAL NOTES	GENERAL NOTES CONTINUED															
<p>1. DRAFT MARKS</p> <p>A. ALL DRAFT MARKS ARE ARABIC NUMERALS. NAVIGATIONAL DRAFT MARKS ARE DESIGNATED BY "PROJ" SIX INCHES ABOVE UPPERMOST MARK.</p> <p>B. CORRECTIONS TO DRAFT READINGS FOR CALCULATIVE PURPOSES ARE FORWARD 0 INCHES, AMIDSHIPS 0 INCHES, AFT 0 INCHES.</p> <p>2. DIMENSIONS</p> <p>A. LONGITUDINAL LOCATIONS OF ALL ITEMS ARE GIVEN FROM THE STERN REFERENCE POINT (SRP), AFTER END OF MAIN DECK AT CL.</p> <p>B. HEIGHTS OF ALL ITEMS ARE GIVEN FROM THE BOTTOM OF THE KEEL AMIDSHIPS EXTENDED, EXCEPT AS NOTED.</p> <p>C. LONGITUDINAL LOCATIONS AND VERTICAL HEIGHTS OF SIDE BLOCKS ARE TAKEN TO THE AFTER SIDE OF BLOCKS.</p> <p>3. COMPLETE PAINTING OF HULL</p> <p>IN ORDER TO CLEAN AND PAINT THE ENTIRE BOTTOM OF THE VESSEL IN THREE SUCCESSIVE DOCKINGS, THE FOLLOWING POSITIONS OF THE VESSEL ARE NECESSARY:</p> <p>A. 8 FT - SPACED SIDE BEARERS</p> <ol style="list-style-type: none"> <li>POSITION NUMBER 1: AFTER END OF MAIN DECK AT CL (SRP) IS PLACED 162"-6" AFT OF AFTER SIDE OF NUMBER 4 SIDE BLOCK.</li> <li>POSITION NUMBER 2: AFTER END OF MAIN DECK AT CL (SRP) IS PLACED 164"-6" AFT OF AFTER SIDE OF NUMBER 4 SIDE BLOCK.</li> <li>POSITION NUMBER 3: AFTER END OF MAIN DECK AT CL (SRP) IS PLACED 160"-6" AFT OF AFTER SIDE OF NUMBER 4 SIDE BLOCK.</li> </ol> <p>B. 12 AND 18 FT - SPACED SIDE BEARERS</p> <ol style="list-style-type: none"> <li>POSITION NUMBER 1: AFTER END OF MAIN DECK AT CL (SRP) IS PLACED 138"-6" AFT OF AFTER SIDE OF NUMBER 1 SIDE BLOCK.</li> <li>POSITION NUMBER 2: AFTER END OF MAIN DECK AT CL (SRP) IS PLACED 140"-6" AFT OF AFTER SIDE OF NUMBER 1 SIDE BLOCK.</li> <li>POSITION NUMBER 3: AFTER END OF MAIN DECK AT CL (SRP) IS PLACED 136"-6" AFT OF AFTER SIDE OF NUMBER 1 SIDE BLOCK.</li> </ol> <p>C. REPEAT CYCLE OF POSITIONS, ASCERTAINING FROM VESSEL THE POSITION USED AT LAST DOCKING.</p> <p>4. PROPELLER AND OTHER APPENDAGES</p> <p>A. IN DETERMINING THE HEIGHT OF KEEL BLOCKS, CARE IS TO BE TAKEN THAT PROPELLER TIPS, SONAR DOME AND OTHER APPENDAGES CLEAR THE BOTTOM OF THE DOCK.</p> <p>B. MAXIMUM CLEARANCE IN WAY OF THE PROPELLERS IS OBTAINED BY POSITIONING THE SPINDLE AXIS OF THE NO.1 BLADE 21 DEGREES OUTBOARD OF TOP DEAD CENTER WITH BLADES AT 100% FORWARD PITCH.</p> <p>5. BLOCKING</p> <p>A. THE BLOCKING SHOWN ON THIS PLAN IS THAT REQUIRED FOR DOCKING IN SEISMIC REGIONS UNDER ORDINARY, UNDAMAGED CONDITIONS FOR 8'-0", 12'-0" AND 16'-0" SPACED SIDE BEARERS.</p> <p>B. THE KEEL HEIGHT SHOWN IS THAT REQUIRED FOR MINIMUM CLEARANCE UNDER SONAR DOME FOR DOCKS WITHOUT FITS. FOR DOCKS WITH FITS, THE KEEL HEIGHT MAY BE REDUCED PROVIDING MINIMUM REQUIRED CLEARANCES ARE MAINTAINED (INCLUDING ALLOWANCES FOR HANDLING EQUIPMENT REQUIRED FOR REMOVAL OF SONAR DOME, PROPELLERS OR RUDDERS).</p> <p>C. KEEL BLOCKS</p> <ol style="list-style-type: none"> <li>KEEL BLOCKS, 48" (FORE AND AFT) X 36" MIN (ATHWARTSHIP) SHALL BE BUILT UP AS INDICATED IN TYPICAL SECTIONS AND SHALL BE ARRANGED IN PIERS OF HARD WOOD OR COMPOSITE CONSTRUCTION (CONCRETE AND WOOD). ALL KEEL BLOCKS ABOVE 6'-6" IN HEIGHT (I.E. DOCKS WITHOUT FITS) SHALL BE CRIBBED. KEEL BLOCKS SHALL BE MOUNTED WITH 2" MINIMUM SOFTWOOD CAPS.</li> <li>LONGITUDINAL KEEL BLOCK SPACING SHALL BE 6'-0" CENTER TO CENTER WITH 30" CLEAR SPAN BETWEEN. NOTE THAT REGULAR KEEL BLOCK SPACING FOR POSITION NO.2 BEGINS WITH NO.2 KEEL BLOCK. THE NO.1 KEEL BLOCK FOR POSITION NO.2 IS LOCATED 3'-0" AFT OF WHERE 6'-0" SPACING WOULD DICTATE.</li> <li>KEEL BLOCKS SHALL BE IN ACCORDANCE WITH THE FOLLOWING DRAWINGS AS APPLICABLE, OR SHALL BE OF A CONSTRUCTION THAT WILL PROVIDE EQUIVALENT STABILITY:</li> </ol> <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th>DOCKING DWG. NO.</th> <th>TYPE DOCK</th> <th>TYPE DOCKING BLOCKS</th> </tr> </thead> <tbody> <tr> <td>823374</td> <td>GRAVING</td> <td>COMPOSITE PIER TYPE WOOD AND CONCRETE</td> </tr> <tr> <td>817336</td> <td>GRAVING</td> <td>TIMBER</td> </tr> <tr> <td>797762</td> <td>FLOATING</td> <td>TIMBER</td> </tr> <tr> <td>789241</td> <td>FLOATING</td> <td>FLOATING</td> </tr> </tbody> </table> <p>4. NO BLOCKS OR SHORTS ARE REQUIRED UNDER ORDINARY CONDITIONS OF DOCKING UNDER THE BOW FWD OF FRAME NO. 61 AND UNDER THE STERN AFT OF FRAME NO. 384.</p>	DOCKING DWG. NO.	TYPE DOCK	TYPE DOCKING BLOCKS	823374	GRAVING	COMPOSITE PIER TYPE WOOD AND CONCRETE	817336	GRAVING	TIMBER	797762	FLOATING	TIMBER	789241	FLOATING	FLOATING	<p>D. SIDE BLOCKS</p> <ol style="list-style-type: none"> <li>SIDE BLOCKS SHALL BE BUILT UP AS SHOWN IN TYPICAL SECTIONS OR IN A MANNER WHICH WILL PROVIDE EQUIVALENT TRANSVERSE STABILITY. IN ORDER TO PREVENT OVERTURNING, SIDE BLOCKS ABOVE 6'-0" IN HEIGHT (I.E. DOCKS WITHOUT FITS) SHALL BE TIED TOGETHER LONGITUDINALLY IN PAIRS BY MEANS OF STEEL TIE RODS, JOINED BY CRIBBING OR OTHER SUITABLE AND APPROVED MEANS. IF THE SIDE BLOCKS ARE HAUL BLOCKS, THEY MUST BE HAULED IN PAIRS.</li> <li>SIDE BLOCKS ARE NUMBERED FROM AFT TO FORWARD, WITH THE AFTMOST BLOCK FOR THE 12'-0" AND 16'-0" SPACING CONFIGURATION AS NO.1. TO MAINTAIN BLOCK NUMBERING CONSISTENCY BETWEEN THE 8'-0" AND 16'-0" SPACING ARRANGEMENTS, THE AFTMOST BLOCK FOR 8'-0" SPACING IS DESIGNATED AS NO.4 AND THE 16'-0" SPACED BLOCKS ARE DESIGNATED BY ODD NUMBERS ONLY.</li> <li>SIDE BLOCKS SPACED AT 8'-0" SHALL BE CENTERED AT 8'-0" AND 11'-3" OFF CENTERLINE. SIDE BLOCKS SPACED AT 12'-0" &amp; 14'-0" SHALL BE CENTERED AT 17'-3", 19'-11" &amp; 11'-3" OFF CENTERLINE. ALL SIDE BLOCKS SHALL BE 24" (FORE &amp; AFT) &amp; 30" (ATHWARTSHIP) AS INDICATED IN TABLE OF OFFSETS FOR SIDE BLOCKS AND BLADE KEEL.</li> <li>IF HAULED, SIDE BLOCKS LOCATED 19'-11" OFF CENTERLINE WILL NOT CLEAR THE BLADE KEEL UNLESS A WEDGE OR SIMILAR ARRANGEMENT IS UTILIZED.</li> <li>SIDE BLOCKS SHALL BE MOUNTED WITH 2" MINIMUM TO 6" MAXIMUM THICKNESS SOFT WOOD CAPS.</li> <li>VALUES FOR BEVEL IN 24" ARE TAKEN AT CENTER OF BLOCK (POINT "A") AND DIRECTION IS INDICATED AS "+" UP AND "-" DOWN FROM THE HEIGHT GIVEN AT AFTER SIDE OF THE BLOCK IN THE TABLE OF OFFSETS.</li> <li>BLOCKS WITH CROSS-HATCHING ARE USED FOR 16'-0" SPACING ONLY. BLOCKS WITH "+" ARE USED FOR 8'-0" SPACING AND 16'-0" SPACING.</li> <li>THE SIDE BLOCK ARRANGEMENTS SHOWN ARE DESIGNED TO RESIST SEISMIC LOADING IN ACCORDANCE WITH REFERENCE B. ANY ARRANGEMENT NOT SHOWN MUST BE CAREFULLY ASSESSED FOR COMPLIANCE WITH REFERENCE B AND FOR ADEQUACY OF SHIP STRUCTURE WHEN SUBJECTED TO THE LOADS DEFINED THEREIN.</li> </ol> <p>E. OMIT SIDE BLOCKS AS INDICATED IN TABLES OF OFFSETS AND KEEL BLOCKS AS INDICATED ON PLAN VIEW DUE TO INTERFERENCES WITH SHELL OPENINGS OR MASKER AIR EMITTER BELTS. THE REQUIREMENTS OF REFERENCE B MUST BE CONSIDERED IF ADDITIONAL BLOCKS ARE TO BE OMITTED.</p> <p>6. TRIM AND HEEL</p> <ol style="list-style-type: none"> <li>THE TRIM SHALL BE KEPT AT A MINIMUM (NONE IF PRACTICABLE) TO PREVENT EXCESSIVE KEEL BLOCK PRESSURE WHEN DOCKING (SEE REF B).</li> <li>THE SHIP SHALL NOT HAVE HEEL AND SHALL BE ACCURATELY PLACED IN THE DOCK.</li> </ol> <p>7. THE STRUCTURAL STRENGTH OF THE HULL IS ADEQUATE TO SUPPORT THE SHIP WITH SONAR DOME, COMPT. 6-0-0-0, FULL OF WATER WITHOUT ADDITIONAL BLOCKING; HOWEVER, IN ORDER TO PROTECT THE SONAR DOME RUBBER WINDOW (DOWN), THE FOLLOWING PROCEDURES SHALL BE FOLLOWED:</p> <p>A. DOCKING</p> <ol style="list-style-type: none"> <li>THE SONAR DOME SHALL BE COMPLETELY FILLED WITH WATER AND NORMALLY PRESSURIZED BY THE FRESHMAN. THE DOME SHALL REMAIN FULL UNTIL THE SHIP HAS LANDED ON THE BLOCKS. IF TRIM BY THE STERN IS REQUIRED, THE DOME MAY BE PARTIALLY OR COMPLETELY DEWATERED AND PRESSURIZED WITH AIR AT 15 (11) PSIG IN ACCORDANCE WITH REFERENCE 10.</li> <li>TO AVOID OVERSTRESSING THE RUBBER WINDOW, THE SONAR DOME SHALL BE COMPLETELY DEWATERED AND PRESSURIZED WITH AIR AT 15 (11) PSIG NO LATER THAN 3 HOURS AFTER THE RUBBER WINDOW HAS BEEN EXPOSED TO AIR.</li> <li>THE DOME SHOULD BE PRESSURIZED AT ALL TIMES WHILE THE SHIP IS IN THE DRYDOCK. IF THE DOME MUST BE DEPRESSURIZED FOR LONGER THAN 72 HOURS, THE DOME SHALL BE SUPPORTED IN ACCORDANCE WITH REFERENCES 8 &amp; 10.</li> </ol> <p>B. UNDOCKING</p> <ol style="list-style-type: none"> <li>THE SONAR DOME SHOULD BE COMPLETELY FILLED WITH FRESH WATER AND NORMALLY PRESSURIZED BY THE FRESHMAN. FLOODING SHOULD BE COMPLETED BEFORE THE WATER LEVEL REACHES THE BOTTOM OF THE DOME. BUT THE RUBBER WINDOW SHALL NOT BE EXPOSED TO AIR FOR MORE THAN 3 HOURS AFTER THE DOME HAS BEEN HAS BEEN FLOODED.</li> <li>IF TRIM BY THE STERN IS REQUIRED, THE SONAR DOME MAY BE EMPTY OR PARTIALLY FLOODED AND PRESSURIZED WITH AIR AT 15 TO 22 PSIG IN ACCORDANCE WITH REFERENCE 10.</li> </ol> <p>C. RUBBER WINDOWS OR DOMES COVERED WITH NO-FOUL RUBBER SHOULD PROTECTION FROM THE SUN, FOR PROTECTION SEE REFERENCE (7).</p> <p>D. CAUTION: TO AVOID COLLAPSING THE RUBBER WINDOW, MAINTAIN 15 TO 22 PSIG AIR PRESSURE AT ALL TIMES WHILE FLOODING OR DEWATERING THE SONAR DOME OR DURING SHIP DRY-DOCKING OPERATIONS.</p> <p>E. CAUTION: CERTIFIED SONAR DOME PRESSURIZATION SYSTEM OPERATOR MUST BE PRESENT AT THE PRESSURIZATION CONTROL STATION DURING ALL DOCKING AND UNDOCKING EVOLUTIONS.</p> <p>8. EXCEPT FOR DIMENSIONS CONTROLLING SIZE AND LOCATION OF BLOCKING, ALL DIMENSIONS ARE REFERENCE.</p> <p>9. ABBREVIATIONS ARE PER MIL STANDARD 12 (D) EXCEPT: SRP—STERN REFERENCE POINT.</p> <p>10. NUMBERS IN CIRCLES INDICATE ITEM NUMBERS IN "LIST OF SHELL OPENINGS BELOW 25 FT WL."</p> <p>11. WHEN THE SHIP IS LIGHTENED FOR DOCKING, STABILITY MUST BE ASSESSED.</p>
DOCKING DWG. NO.	TYPE DOCK	TYPE DOCKING BLOCKS														
823374	GRAVING	COMPOSITE PIER TYPE WOOD AND CONCRETE														
817336	GRAVING	TIMBER														
797762	FLOATING	TIMBER														
789241	FLOATING	FLOATING														

Figure 4.1.3 General Notes (Heger's manual)

## 4.2 Blocking Plan

The blocking plan is typically not a separate or independent document from the docking plan, but rather refers to the portion of the docking plan that outlines the blocking arrangements for a vessel in preparation for being dry docked. Ideally, the blocking plan consists of the elevation and plan docking drawings, keel profile drawing, the table of offsets, and the table of block pressures. From these documents, engineers at the shipyard know exactly where to place each block on the dry dock floor, as well as the corresponding height of each block based on the keel profile drawing. The images provided in Figure 4.2.1, taken from Heger's Manual, provide examples of what to expect from these drawings.



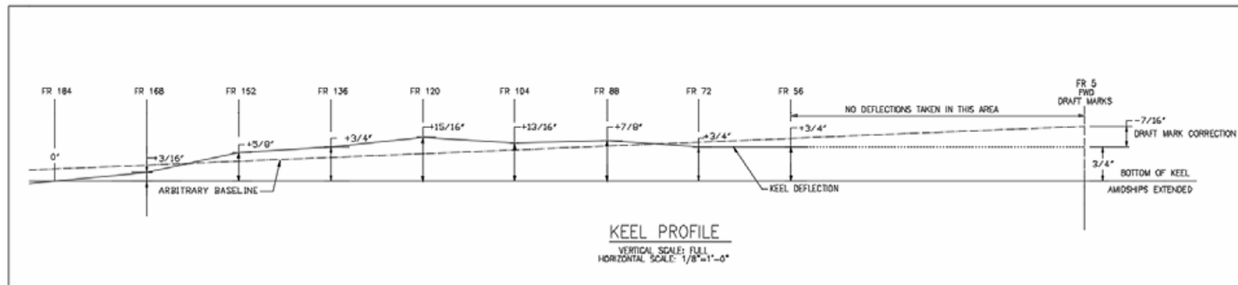
**Figure 4.2.1** Elevation and Plan, Respectively, Docking Drawings (Heger's Manual).

The elevation and plan drawings provide locations and arrangements of blocks near the bow and stern of the ship in relation to the aft and forward perpendiculars. The distance forward from the Stern Reference Point (SRP) is important to facilitate positioning the vessel relative to the location of the blocks when maneuvering into the drydock. The docking plan also shows how the blocks are arranged to accommodate appendages, hull openings, and the removal of the rudder and propeller. The docking plan may also include a drawing of alternative blocking positions, namely from the stern of the vessel or from other identifiable locations surrounding appendages. Alternative blocking positions may be necessary if extensive repair is required, such as damage to the hull causing structurally compromised regions of the hull or for planned equipment replacements.

In order to properly distribute weight along the vessel's keel and mitigate risk of damage, it is necessary that the keel blocks closely follow the shape of the keel. Discrepancies in block height (relative to the keel) will result in localized regions of high stresses on the hull. The keel profile

drawing (Figure 4.2.2) shows the keel measured deflection compared to its design drawing at each relevant frame number. From this drawing, a shipyard can ensure that the blocks are properly dimensioned.

The final piece of information necessary to support the vessel accurately and safely in dry docking is the table of offsets for side blocks. This table (see Figure 4.2.3) provides numerical data regarding the locations of the side/bilge blocks and the corresponding dimensional attributes of the hull at these locations.



**Figure 4.2.2** Keel Profile Drawing of Vessel showing Elevation Change Corresponding to Frame Numbers (Heger’s Manual).

TABLE OF OFFSETS FOR SIDE BLOCKS & BILGE KEEL FOR POSITION 1 INTERVALS GIVEN IN INCREMENTS OF 8'-0"																							
SIDE OF SHIP	BLOCK NO.	FWD OF SRP			POINT "A"			POINT "B"			POINT "C"			BEVEL IN 24" FOR ABC	BILGE KEEL								
		FT	IN	1/16	HEIGHT			HEIGHT			HEIGHT				DIM "D"			DIM "E"					
					HALF BR	FT	IN	1/16	HALF BR	FT	IN	1/16	HALF BR		FT	IN	1/16	FT	IN	1/16	FT	IN	1/16
P	4	162	6	0	9'-0"	1	11	2	7'-6"	1	5	12	10'-6"	2	5	1	-1 1/16	25	1	6	7	4	10
S		↓																-1 1/16	25	1	6	7	4
P	5	170	6	0		1	6	13		1	2	3		1	11	14	-7/8	25	2	13	6	9	4
S		↓																-7/8	25	2	13	6	9
P	6	178	6	0	11'-3"	1	10	3	9'-9"	1	5	8	12'-9"	2	3	12	-1	25	4	1	6	2	7
S		↓																-1	25	4	1	6	2
P	7	186	6	0		1	6	11		1	2	9		1	11	9	-13/16	25	5	4	5	8	6
S		↓																-13/16	25	5	4	5	8
P	8	194	6	0		1	3	11		1	0	1		1	8	0	-11/16	25	6	6	5	3	13
S		↓				OMIT	-	-		OMIT	-	-		OMIT	-	-		-	25	6	6	5	3
P	9	202	6	0		1	1	4		0	10	1		1	5	1	-9/16	25	7	7	5	0	7
S		↓																-9/16	25	7	7	5	0
P	10	210	6	0		0	11	10		0	8	12		1	3	2	-3/8	25	8	7	4	9	11
S		↓																-3/8	25	8	7	4	9

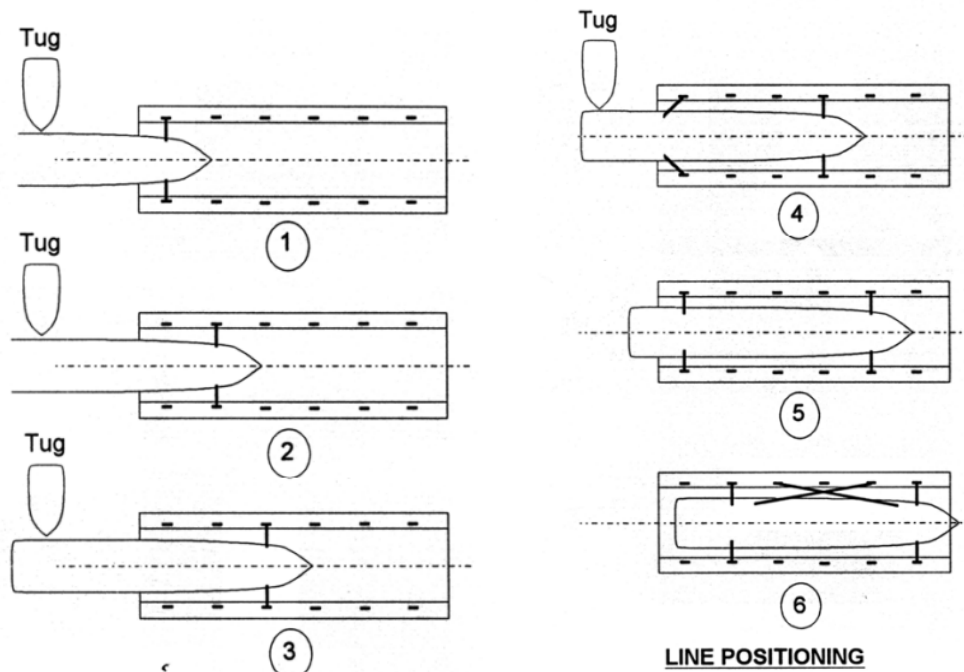
**Figure 4.2.3** Table of Offsets for Side Blocks provides Information regarding the Locations and Dimensions of the Side Blocks (Heger’s Manual).

### 4.3 Docking Operation

The operations, process, and safety checks of dry docking a vessel vary depending on the dry dock type. Dry docking operations follow an ordered process that includes advanced preparation, facility preparation, pre-docking checks, docking, and post-docking checks. Advanced preparation is the gathering of information regarding the vessel’s docking and maintenance plans and history. It allows for the facility and personnel to adequately prepare for the dry docking process. Items typically included in this stage are the place and date of the last dry docking, last docking position,

paint history, docking reports, and data for preparing block load and stability calculations. Next, the facility is prepared. This includes building the blocks per the proper docking plan, laying out lines for vessel handling, placing marks for positioning the vessel, and preparing centering devices. Pre-docking checks ensure that all physical aspects of the dry dock are prepared. Typically, water levels, block heights and layouts, clearances, centering devices, and line layouts are checked during the pre-docking period. The line handling team must be fully briefed before the docking evolution begins. This ensures that the facility is fully prepared for a safe docking.

Dry docking operations in a dry dock facility using a floating drydock follow the process shown in Figure 4.3.1. Vessels are typically maneuvered into the dry dock via a tug boat then transition to line handling. The responsibility of the ship is passed from the captain to the dockmaster as the vessel reaches the entrance of the drydock. Additionally, final checks on drafts, personnel stationing, communication, and procedures are done. After the vessel is fully secured inside the dock, the dockmaster must verify that the vessel reached the correct water level within the floating drydock. Line tensions are checked and divers may check the vessel under the waterline. If all is correct, fixtures such as gangways may be installed. If not, the dockmaster must investigate issues further. After the docking operation, the dockmaster will examine the blocks, check the dock freeboards, check dock ballast levels, make corrections to the docking plan, and monitor weight changes on the vessel.



**Figure 4.3.1** Line Positioning for Vessel Dry Docking (Heger’s Manual).

While the dry docking process for graving docks and floating docks are similar, floating docks also have a pumping plan. A pumping plan provides water levels in ballast tanks of the floating drydock for predetermined drafts of the entire dry dock. These drafts are determined by the vessel’s weight distribution in order to minimize bending stresses on the vessel and the floating drydock. Each compartment is meant to have a water level that provides enough buoyancy to equal the weight directly above the compartment. Figure 4.3.2 shows an example of a pumping plan for five stages of the pumping procedure. Fully submerged allows the floating drydock to match the trim

of the floating vessel while there is still clearance between the hull and blocks. Keel touchdown is when all blocks are barely touching the keel of the vessel. Half draft is when the vessel is lifted until it reaches half of its draft. Top of blocks means that the vessel's keel is at the waterline of the floating dock. Operational draft is the final draft where maintenance will take place on the vessel.

While the pumping plan is necessary, it does not need to be followed exactly and priority should be given to observations made. Deviations from the plan should be relatively small. If they are large, then the dry docking should be stopped so that further investigation can be done.

NOTES	DOCK DRAFT	TANK GROUP						SHIP DRAFT
		6	5	4	3	2	1	
Full Submerg.	47.7' 52.0'	39.16'	38.43'	37.70'	36.96'	36.25'	30.6' 35.5'	20.0' 24.0'
Keel Touch	43.8' 48.1'	35.13'	34.40'	33.67'	32.94'	32.20'	26.6' 31.5'	20.0' 24.0'
Half Draft	33.9' 36.0'	14.31'	13.19'	13.33'	13.48'	13.61'	14.5' 15.7'	10.0' 12.0'
Top of Blocks	24.0' 24.0'	6.34'	4.28'	4.75'	5.21'	5.67'	8.9' 10.1'	0.0' 0.0'
Operat. Draft	16.5' 16.5'	3.28'	1.22'	1.69'	2.16'	2.62'	5.8' 7.1'	0.0' 0.0'
							P S	

**Figure 4.3.2** Pumping Plan Example (Heger's Manual)

#### 4.4 Exceptional Docking Circumstances

Exceptional circumstances or factors pertaining to the vessel, dry dock, or other aspects of the dry docking operation can lead to additional calculations, measurements, or in extreme cases, may threaten the safety of the dry docking procedure. Although it would be difficult or impossible to create a comprehensive list of every factor that may alter the ideal dry docking process, several notable circumstances are explained below.

##### **Modification of the Blocking Arrangement:**

A number of circumstances may lead to the need to modify or make use of the alternative blocking arrangement in the blocking plan. This may be a result of a damaged region (further discussed below) or an area of the hull that must remain accessible for repair or maintenance (such as reapplying antifouling paint). Proper load distribution and block placement procedures should be followed when modifying the blocking arrangement beyond what is laid out in the blocking plan.

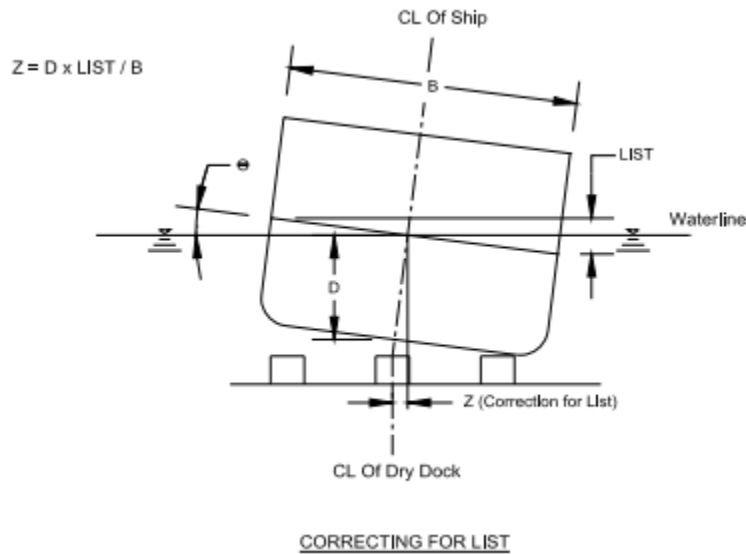
##### **Damaged Hull Section:**

The extent of modifications to the docking process as a result of damage to the vessel's hull is dependent on the location and severity. The location of the damage will dictate whether or not the

blocking arrangement must be modified to accommodate the damaged area. If the damaged area is below the waterline, a diver should be sent to survey the hull and the affected area. Damage near the bilge or keel may require that nearby blocks are removed to prevent further structural damage and ensure that unwanted protrusions do not affect the design block load distribution. Damage to the bow, stern, or any other large overhanging sections of the hull that will not be directly supported by the blocks, can compromise the structure of the region when hydrostatic forces are no longer applied and the vessel is in the dock. Depending on the severity of the damage, extensive engineering analysis may be required to ensure the structure of the hull can withstand the dry docking. Furthermore, severe damage below the waterline can cause flooding, changing the hydrostatic properties and weight distribution of the vessel. As the vessel is in the process of being dry docked, water may exit the vessel and further shift its weight distribution.

**Vessel Experiencing Considerable List or Trim:**

In the event that a vessel arrives at the shipyard with significant list, the condition needs to be corrected before the vessel can be placed on the blocks. The list is found by finding the difference in drafts on the port and starboard sides, typically by examining draft markings. As shown in Figure 4.4.1, the correction for list, Z, allows the dockmaster to place the vessel above the true vessel centerline. This may be done by adjusting ballast or adding, removing or shifting other weights as appropriate. While it is expected that the vessel will eventually correct its list as it rests more fully on the blocks, it will likely put exceptional loads on the listing side of the vessel’s keel or bilges which may damage the vessel’s hull or plastically deform the keel/side blocks, rendering those damaged blocks ineffective in distributing the resting vessel’s loads. In extreme list or floating dry dock operations, the stability of the vessel and the floating drydock may also be jeopardized.



**Figure 4.4.1** Visualization of the correction needed for a listing vessel (Heger’s Manual).

Similarly, in the case of significant trim, a thorough attempt at leveling the vessel’s trim should be made before it is dry docked to prevent local, elevated loads on the trimming portion of the vessel as it first makes contact and is righted by the blocks (referred to as a “knuckle reaction” or “sue load” if the stern or bow blocks, respectively, first make contact with the hull). A trim table or “moment to trim one inch” approximation may aid in determining the necessary weight addition

or ballast redistribution to flatten the vessel's trim. If the trim can not be removed, knuckle reactions or sue loads should be estimated to ensure that stress does not exceed the structural characteristics of the vessel or the local blocks.

In the case of a floating dry dock, the floating dry dock's trim may be ballasted to match the vessel's trim prior to docking the vessel. After the vessel is entirely resting on the blocks, the floating dry dock can then de-trim by redistributing or pumping out ballast to return both the dock and vessel to even keel.

**Incomplete Vessel Information or Docking Plans:**

The Heger Manual provides guidelines to approximate needed vessel characteristics if not provided to the docking yard before the docking operation. As discussed in Section 4.1, it may be possible to reach out to other sources to find information or previous docking logs pertaining to the vessel. If estimations must be conducted, large margins should be put on the quantity and size of the keel blocks to distribute load as evenly as possible. Methods of estimating block loads and floating dry dock stability are laid out in Section 5.

**Extraordinary Weather Conditions:**

Not ideal or elevated weather conditions may raise concern or halt the dry docking process. High abeam winds can cause large wind moments, jeopardizing the transverse stability of a vessel on blocks. As discussed in Section 3.2, side blocks aid in keeping a vessel upright and reducing the increased, asymmetrical local loads on the keel blocks from strong abeam winds. Wind overturning moments (loads) must be calculated based on the sail area of the vessel exposed to wind. The U.S. Coast Guard standard provides approximations and guidelines to conduct these calculations.

## Section 5 - Stability and loading during Dry Docking

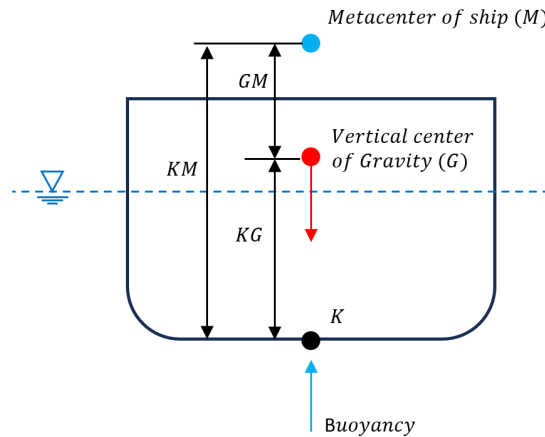
Docking is a controlled “grounding” operation. The purpose of dry docking is to maintain or repair vessels, but not to cause damage on them. Hence, it is imperative to assess the stability conditions during docking and undocking as well as how to estimate the loading conditions. In this section, we will first discuss the types of risks when docking a vessel. And moving on to discuss stability and loading estimation methods.

### 5.1 Stability

The worst scenario is to capsize the vessels either in docking or undocking phase. In this section, we will briefly review the key parameters for stability assessments and move on to discuss some factors that will affect the stability during docking and undocking. Although applied to dry docking, these are equivalent to the fundamental naval architectural principles of vessel stability.

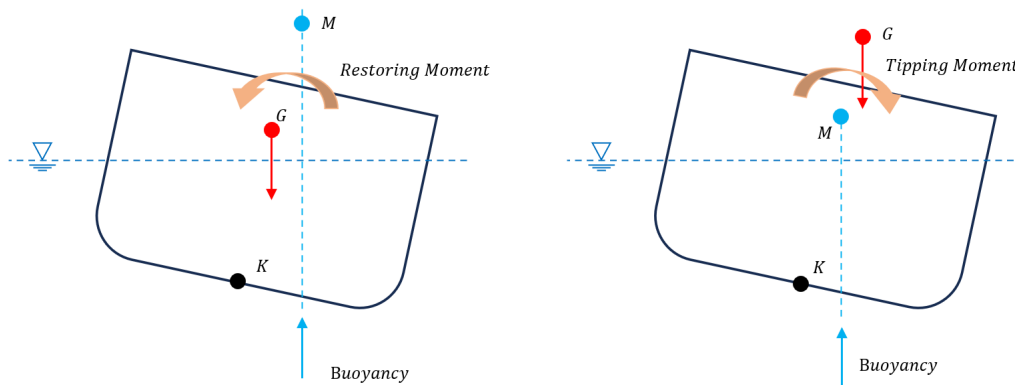
#### 5.1.1 Key Parameters for Stability Calculations

Considering a transverse cross section of a ship. The center of gravity is denoted as  $G$ . The metacenter, which is denoted as  $M$ , is the point in which a vertical line through the center of buoyancy will pass for any small angle of list (less than 7-10 degrees).



**Figure 5.1.1** Metacenter of ship ( $M$ ) and vertical center of gravity ( $G$ ).

The relative location of  $M$  and  $G$  will influence the stability condition of a ship. When the metacenter  $M$  is higher than the center of gravity  $G$ , there will be a restoring moment to help the vessel back to its original upright position. However, when the metacenter  $M$  is lower than the center of gravity  $G$ , it will create a tipping moment which will cause the vessel to capsize. Hence, knowing the position of the metacenter  $M$ , center of gravity  $G$ , and any factors that will influence the position is important to prevent the capsizing problem.



**Figure 5.1.2** The ship is stable when  $M$  is higher than  $G$  (left), while it is unstable when  $M$  is below the  $G$  (right).

### 5.1.2 Factors that Influence Vessel Stability

During the docking and undocking process, ensuring a complete understanding of the vessel's  $GM$  is critical to the stability of the docking vessel. Below is a list of factors that might influence stability conditions:

*Docking:*

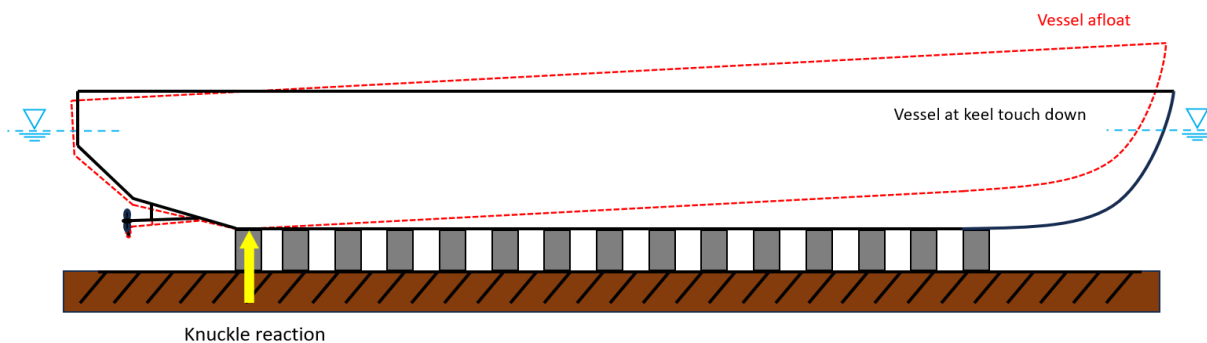
- Change of draft
- Contact between keel and docking blocks
- Free surface effect of liquid in tanks (e.g., ballast water)

*Undocking:*

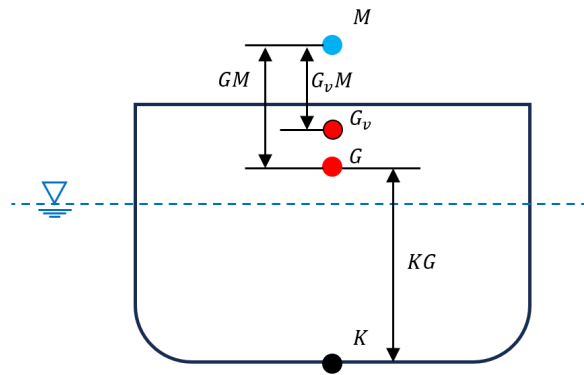
- Change of draft
- Vessel after modification or repairment

Here, we will use a simple example that demonstrates how the center of gravity changes at the moment that a trimming vessel first touches the keel blocks.

**Example:** Assuming a vessel has a total weight of 10,000 (LT) and  $KG$  of 10 (ft). At the time of keel contact, the knuckle reaction is 100 (LT). Estimate the new  $KG$  location.



**Figure 5.1.3** Knuckle Reaction at time of keel touch down.



**Figure 5.1.4** Knuckle Reaction at time of keel touch down.

The new position of the center of gravity is denoted as  $G_v$ . It is found by the following calculation:

Item	Weight (LT)	KG(ft)	Weight x KG
Ship Afloat	10,000	10	100,000
Knuckle Reaction	-100	0	0
Total	9,900		100,000

We can now estimate the new position of  $KG_v$ :

$$KG_v = \frac{100,000}{9,900} = 10.10 \text{ (ft)}$$

Hence, the new  $KG_v$  is higher than the original  $KG$ , which implies that as the relative distance of the  $GM$  decreases, so does the stability of the vessel. This is a simple example to show how the stability condition can be influenced throughout the docking process. For more details about vessel stability during dry docking, refer to the Heger's manual Section 5.2.

### 5.1.3 Stability of Floating Docks

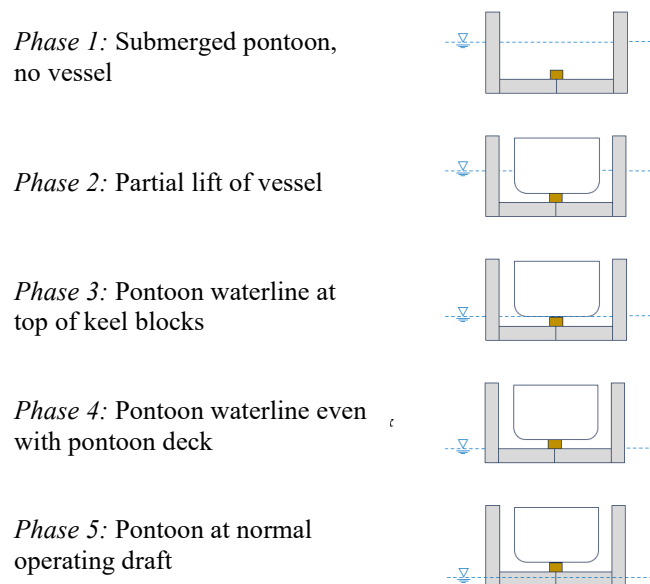
Stability for floating docks can be divided into two aspects: (1) docking phases, (2) size of the floating dock and free surface effect.

#### Docking Phases of a Floating Dry Dock

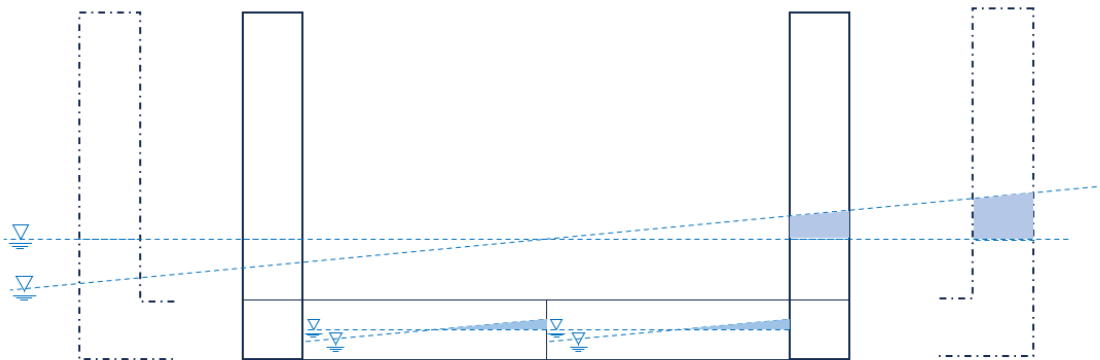
The dry docking process onboard a floating dry dock consists of five notable phases. According to Heger's manual, there is general guidance for determining the stability of floating docks: more waterplane area means more stability. Hence, the stability associated with phases three and four have the lowest stability levels.

### Size of the floating dock and free surface effect:

The size and free surface effect of the floating dock should also be considered. General guidance from Heger’s manual also claims that the wider the ballast tanks, the greater the transverse free surface effect, which results in a less stable dock.

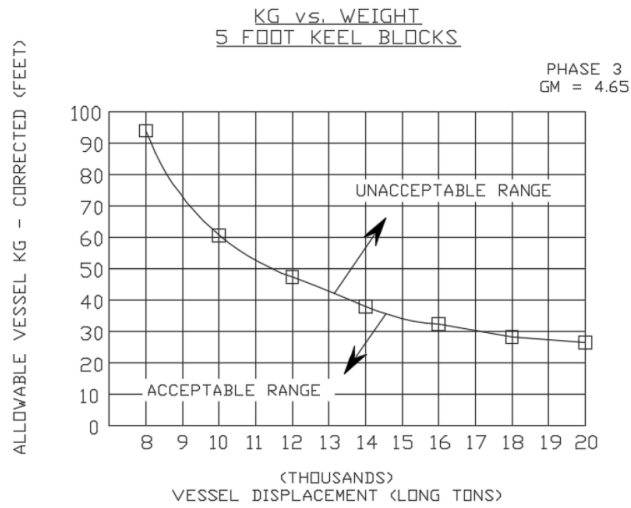


**Figure 5.1.5** Docking Phases of a Floating Dry Dock.



**Figure 5.1.6** Free Surface Effect in Ballast Tanks of Floating Dock.

To estimate the stability conditions, every floating docks should have a “KG vs Weight” plot as shown in Figure 5.1.7. When a ship is about to be docked on a floating dock, one can estimate the corrected KG (considering free surface effect) and see where the KG and weight are located on the plot. If the location is below the curve, the docking process should be stable. Otherwise, it is unstable and should not be docked.



KG vs. WEIGHT CURVE

**Figure 5.1.7** KG vs Weight for a Floating Dock at *Phase 3*.

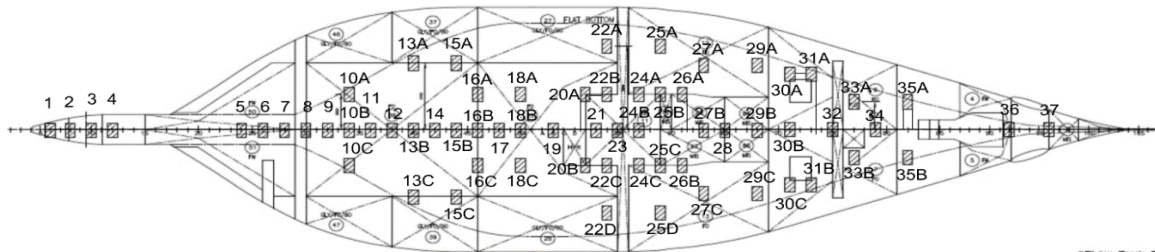
## 5.2 Loading

### 5.2.1 Parameters for Loading Calculations

The likelihood of damages can be greatly reduced if proper calculations are conducted before docking. In this section, some of the key parameters that are critical and necessary to estimate loads when docking a vessel are discussed.

#### Blocks: Number and Their Arrangement

The number of blocks directly influences how much load will be applied on each block. A quick estimation can be completed using the concept of averaged pressure. For example, if there is a vessel with a weight,  $W$ , and there is only a block with surface area of  $A$ . The pressure applied on the block is  $W/A$ . If there are 10 blocks with surface area  $A$ , each block will only take  $W/10A$ , which is 10 times less load than the previous example. More details and examples will be explained in the next section. It should also be noted that the arrangement of blocks will not only affect loading on blocks, but it will also affect overhang on the vessel. To prevent damage, the general guidance mentioned in the Heger's manual about knuckle force (Section 5.1) and overhang (Section 3.2) should be followed.

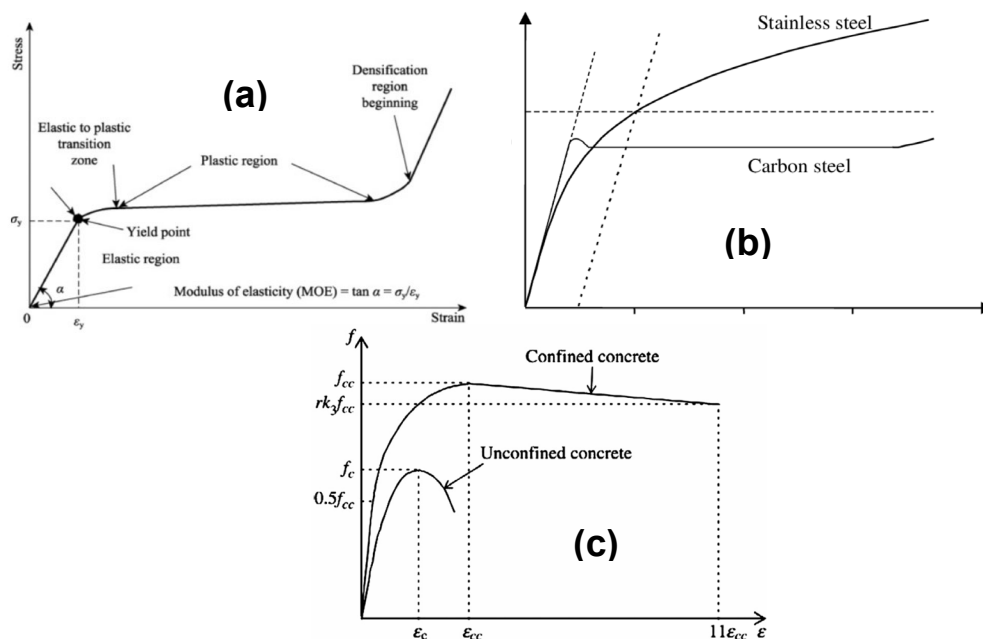


**Figure 5.2.1** Example block arrangement (top view)

## Blocks: Material Properties

Knowing the material properties of the block will help us estimate whether the load exceeds their limit or not. Typically, there are three common materials used for block construction: (1) wood, (2) steel, and (3) concrete. It is critical to know their Young's modulus ( $E$ ), Poisson's ratio ( $\nu$ ), and yield stress ( $\sigma_y$ ). The stress-strain relationships for these three materials are very different.

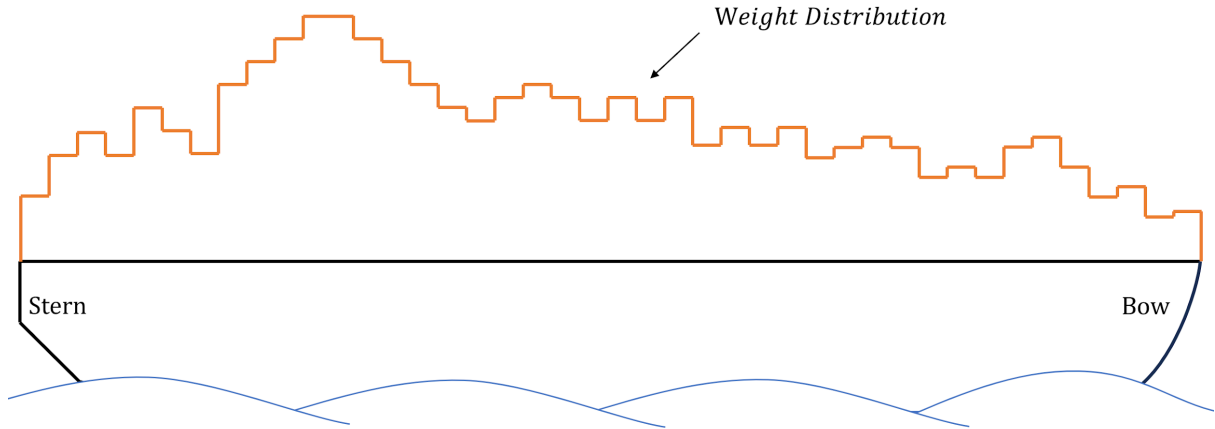
- *Wood*: After reaching its yielding point, the stress-strain relation is like elastic-perfectly-plastic material. However, at a certain point, the material gains its strength again.
- *Steel*: It is the most common material used for ship construction. It is a ductile material, which will have strain-hardening behavior after yielding.
- *Concrete*: It is a brittle material. Without lateral confinement, the material will soon crush after reaching its yielding strength.



**Figure 5.2.2** Typical Stress-Strain Relationships for (a)Wood , (b)Steel , and (c)Concrete.  
 Source: “Mechanical behaviour of wood compressed in radial direction-part I. New method of determining the yield stress of wood on the stress-strain curve”, “Numerical investigation of net section failure in stainless steel bolted connections”and “Finite element analysis on the capacity of circular concrete-filled double-skin steel tubular (CFDST) stub columns”

## Vessel: Weight Distribution

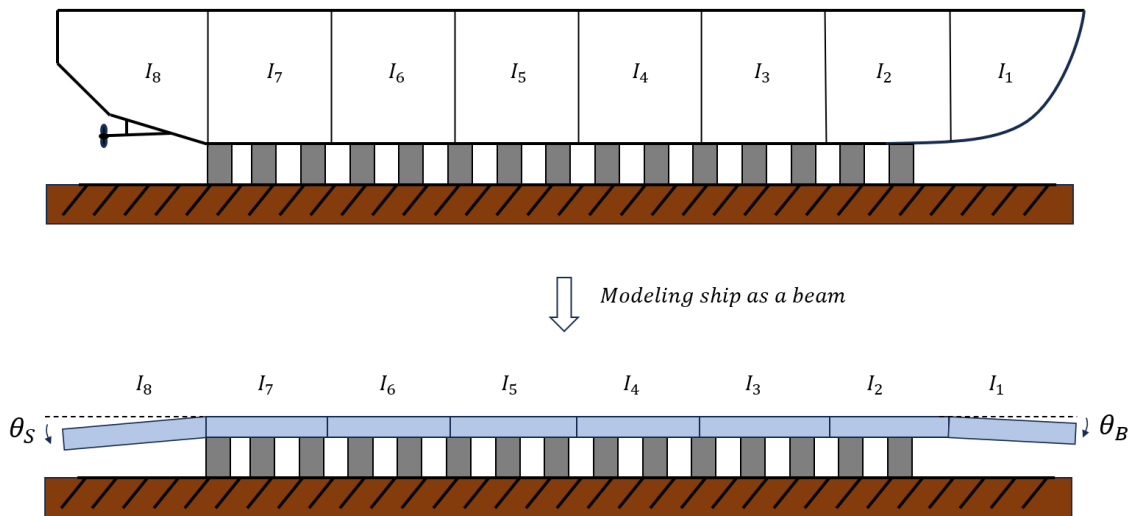
The weight of the vessel is not uniform. The distribution of equipment, cargo, and structures means the longitudinal center of gravity (LCG) is usually not located at half the length of the vessel. The eccentricity of the LCG will influence the loading condition. This will be further explained in the following section.



**Figure 5.2.3** Example Vessel Weight Distribution

### Vessel: Moment of Inertia

The rigidity of the vessel is related to the moment of inertia along the vessel. Knowing the moment of inertia can be used to model the vessel as a beam structure. With beam structure modeling, we are able to estimate the global deformation of the vessel, which helps estimate if any large deformations occur.



**Figure 5.2.4** Modeling Ship as a Beam.

### 5.2.2 Calculation Methods for Block Loading

In this section, we will introduce how to calculate loads on blocks in a graving dock (rigid foundation). As mentioned in the previous section, one potential cause of block damage and damage to the vessel, is overloading. Hence, it is critical to know how much load is being applied on the blocks. The most accurate estimation is direct measurement. Installation of strain gauges on the blocks would allow for direct measurement of applied loads, but this can be very time-consuming and expensive. A shiplift drydock with an articulated platform provides this

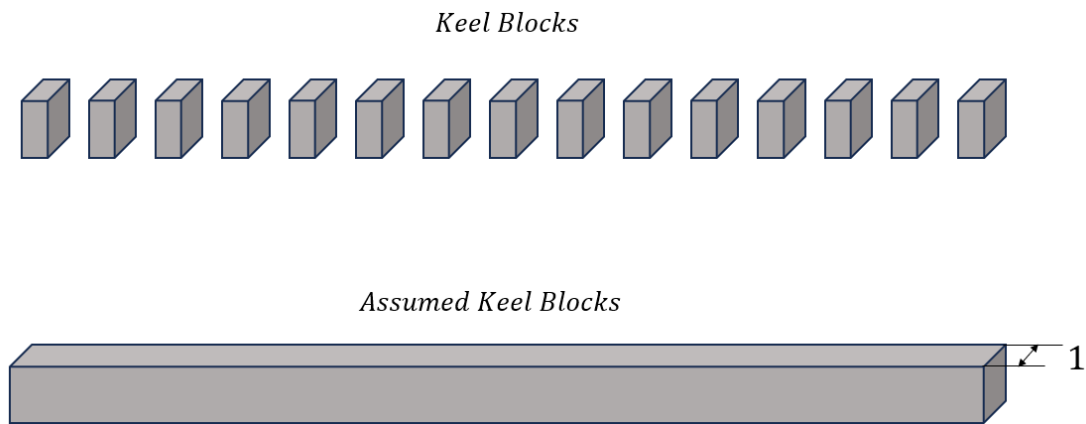
information to the dockmaster using the load cells at every hoist. Effectively the articulated platform is a determinate (simply supported) design.

Alternatively, for all other drydocks, analytical methods are used to estimate and determine the block loading. There are two common methods for block load estimation: (1) Trapezoidal Method; (2) Moment Area Method. These methods will be explained further in this section.

**Trapezoidal method:**

This method is composed of two parts: (1) average pressure and (2) flexural formula. The model assumptions include:

- The vessel is a continuous rigid body (no deformation).
- Only keel blocks are considered and modeled as one continuous rectangular cuboid with width of 1, as shown in the figure.



**Figure 5.2.5** Trapezoidal Modeling Assumption

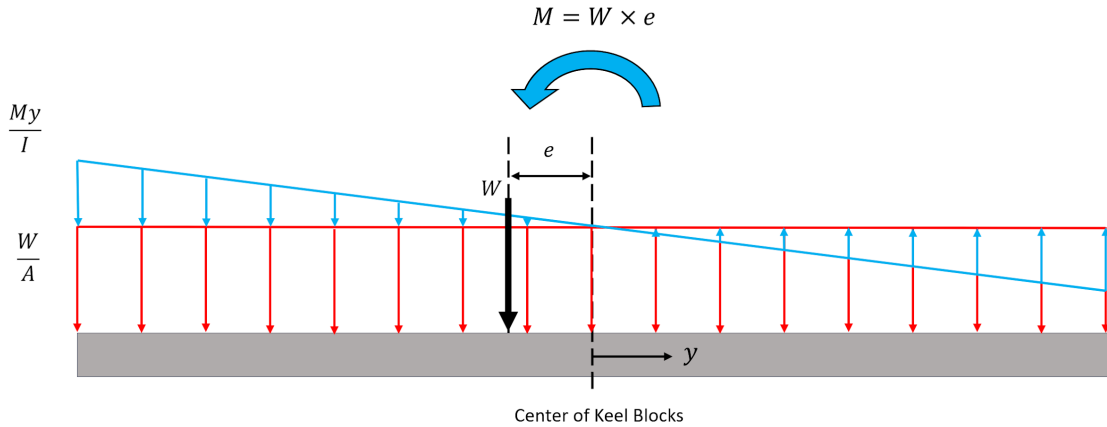
The equation for approximating pressure using trapezoidal method is:

$$Pressure \approx \frac{W}{A} \pm \frac{My}{I}$$

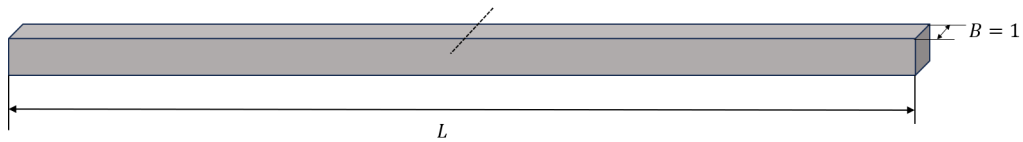
Where  $W$  is the total vessel weight,  $A$  is the total surface area of the blocks,  $M$  is the moment caused by eccentricity of the load,  $y$  is the coordinate location, and  $I$  is the block's area moment of inertia.

The equation to determine the moment of inertia of the block is:

$$I = \frac{BL^3}{12}$$

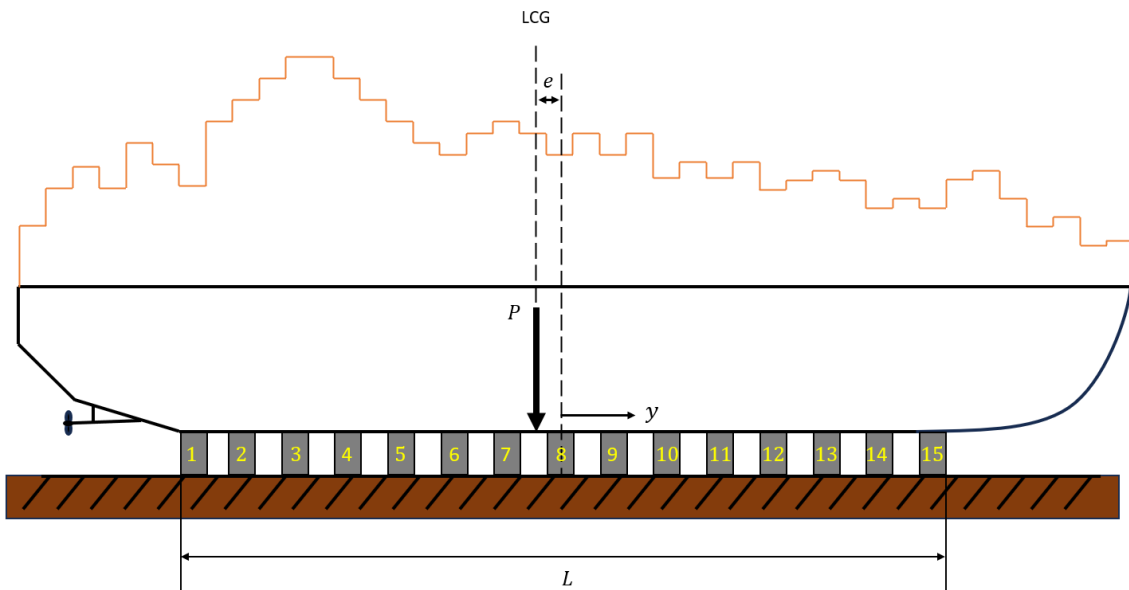


**Figure 5.2.6** Average Pressure (red) Flexural Formula (blue).



**Figure 5.2.7** Dimensions of the Block based on Trapezoidal Rule Assumptions.

**Example:** A vessel has total weight of  $W = 1000 \text{ kg}$ . The eccentricity is  $e = 2 \text{ meters}$ . The length and width of a single block are  $2 \text{ meters}$  and  $1 \text{ meter}$ , respectively. The gap between each block is  $1.5 \text{ meters}$ . Estimate the loads by using the trapezoidal method. It should be noted that the block spacing used in this example is simplified and assumed for the purpose of demonstrating the mathematical process of the trapezoidal method.



**Solution:**

The total block length:

$$L = 2 \times 15 + 1.5 \times 14 = 51m$$

The total surface area of the blocks:

$$A = L \times 1 = 51 m^2$$

Moment:

$$M = W \times e = (1000 \times 9.8) \times 2 = 19600 N \cdot m$$

Area Moment of Inertia:

$$I = \frac{BL^3}{12} = \frac{1 \times 51^3}{12} = 11054.25 m^4$$

Pressure on the blocks:

$$\frac{W}{A} \pm \frac{My}{I} = \frac{-(1000 \times 9.8)}{51} \pm \frac{19600}{11054.25} \times y$$

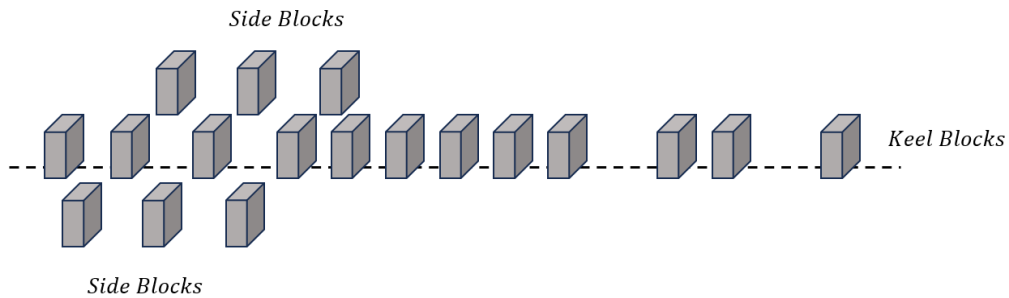
Block	y	Pressure (N/m <sup>2</sup> )	Load (N)
1	-24.5	-235.60	-471.19
2	-21	-229.39	-458.78
3	-17.5	-223.19	-446.37
4	-14	-216.98	-433.96
5	-10.5	-210.77	-421.55
6	-7	-204.57	-409.14
7	-3.5	-198.36	-396.73
8	0	-192.16	-384.31
9	3.5	-185.95	-371.90
10	7	-179.75	-359.49
11	10.5	-173.54	-347.08
12	14	-167.33	-334.67
13	17.5	-161.13	-322.26
14	21	-154.92	-309.84

15	24.5	-148.72	-297.43
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**Table 5.2.8** (Example) Pressure and Load on each Block.

**Moment Area Method:**

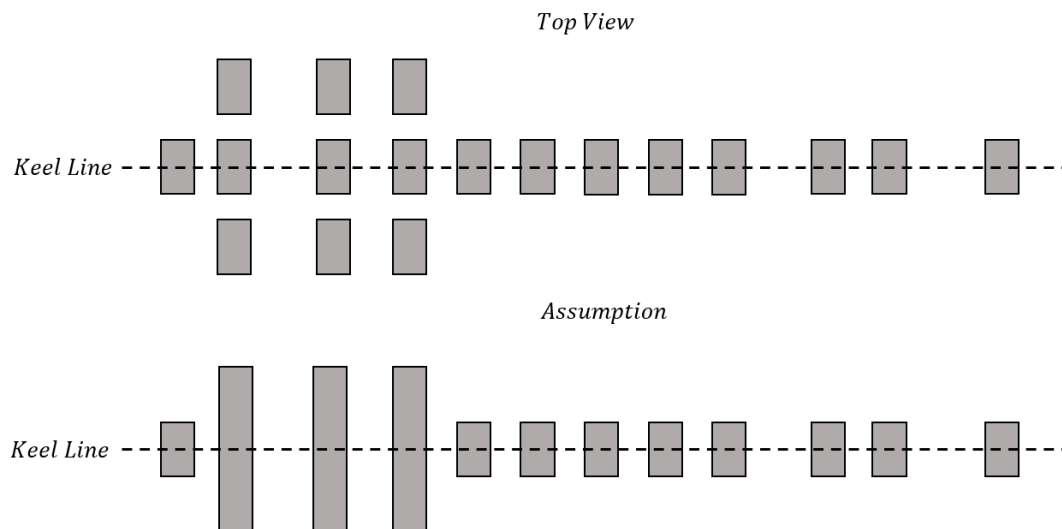
This method is also composed of (1) average pressure and (2) flexural formula, but the moment area method is more accurate than the trapezoidal method. Recall that the model used in the trapezoidal method assumes that keel blocks are evenly distributed, and they are taken as a single long block with width of one. We know, however, that block arrangements, including side blocks, are not uniformly distributed. They may have different sizes and are arranged in a way that aligns with the vessel's internal structures and weight distribution. Also, the blocks need to be placed away from parts that are going to be repaired. To estimate loads on blocks under such arrangements, the moment area method should be used.



**Figure 5.2.9** Example Block Arrangement.

Assumptions include:

- The vessel is a continuous rigid body (no deformation).
- Side blocks are under the same load as keel blocks.



**Figure 5.2.10** Block Width Assumption for Moment Area Method.

The equation for pressure, same as trapezoidal rule, is:

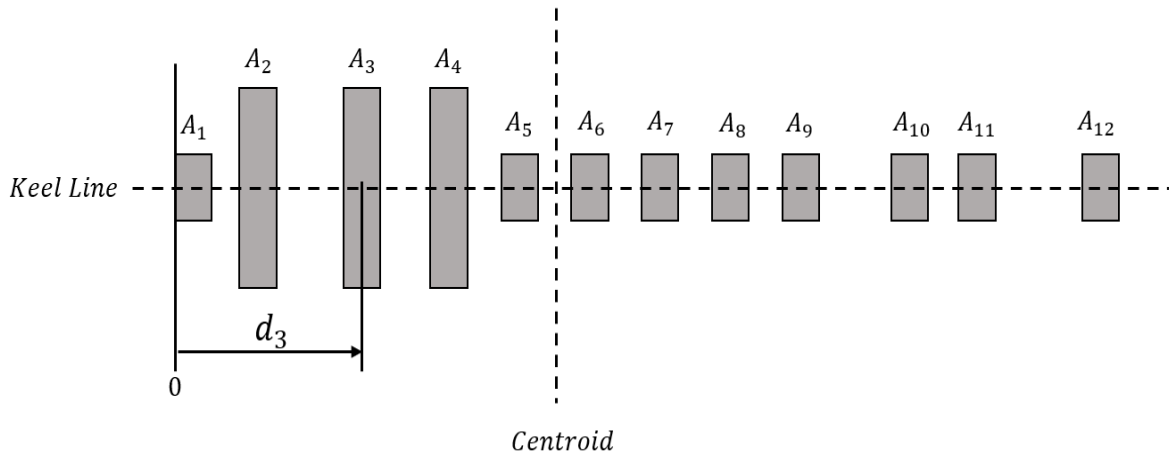
$$Pressure \approx \frac{W}{A} \pm \frac{My}{I}$$

Where  $W$  is the total vessel weight,  $A$  is the total surface area of the blocks,  $M$  is the moment caused by eccentricity of load,  $y$  is the coordinate location, and  $I$  is the block's area moment of inertia.

The formula is the same as the trapezoidal method, but we know that the centroid is no longer at the center of the keel block. In the trapezoidal method, the blocks are assumed to be a single continuous block, so the centroid is at the center. For realistic block arrangements, the centroid is not at the center because of the uniform arrangement of the blocks. Hence, we have to calculate the centroid first. After the centroid is located, this position will be used to calculate eccentricity ( $e = LCG - centroid$ ).

The equation to determine the centroid of the blocks is:

$$Centroid = \frac{\text{sum}(\text{area} \times \text{distance})}{\text{total area}} = \frac{(A_1 \times d_1 + A_2 \times d_2 + \dots + A_{12} \times d_{12})}{(A_1 + A_2 + \dots + A_{12})}$$

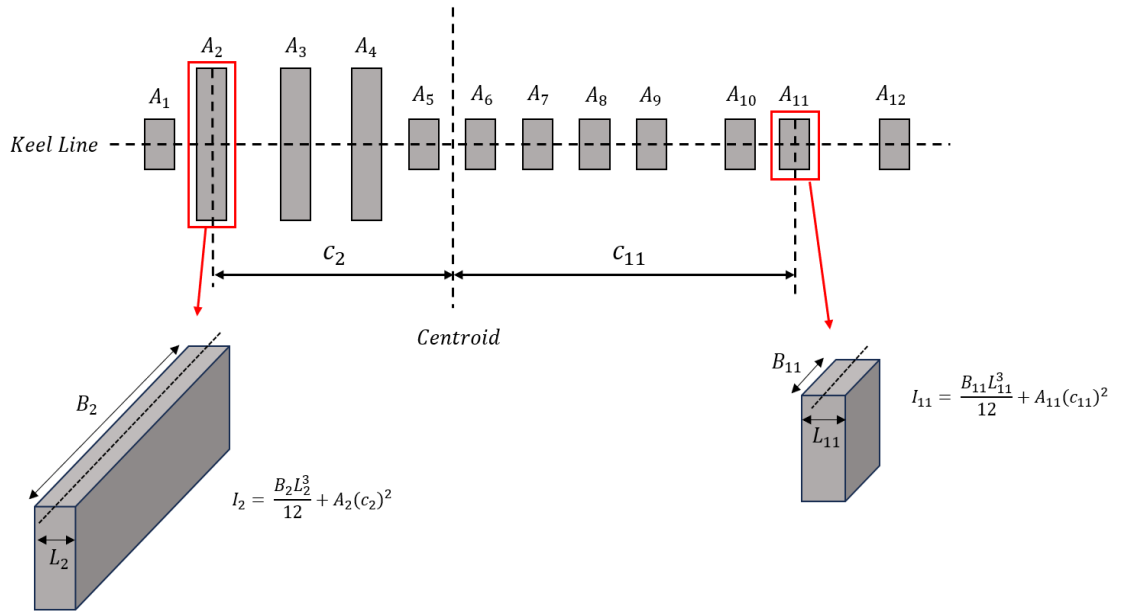


**Figure 5.2.11** Determining the Centroid of the Blocks.

In addition to finding the centroid, the area moment of inertia of each block also must be calculated and the total moment of inertia is the summation of all individual moments of inertia.

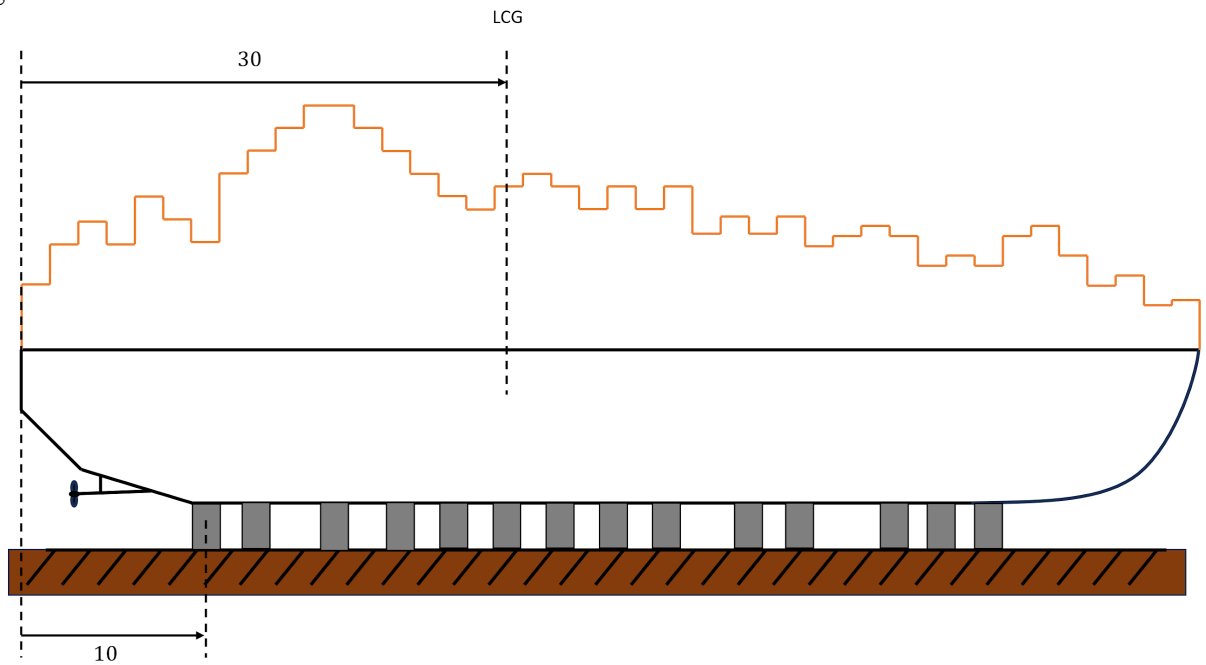
The equation to determine the total moment of inertia representing all of the blocks:

$$Total\ moment\ of\ inertia = I_1 + I_2 + \dots + I_{12}$$

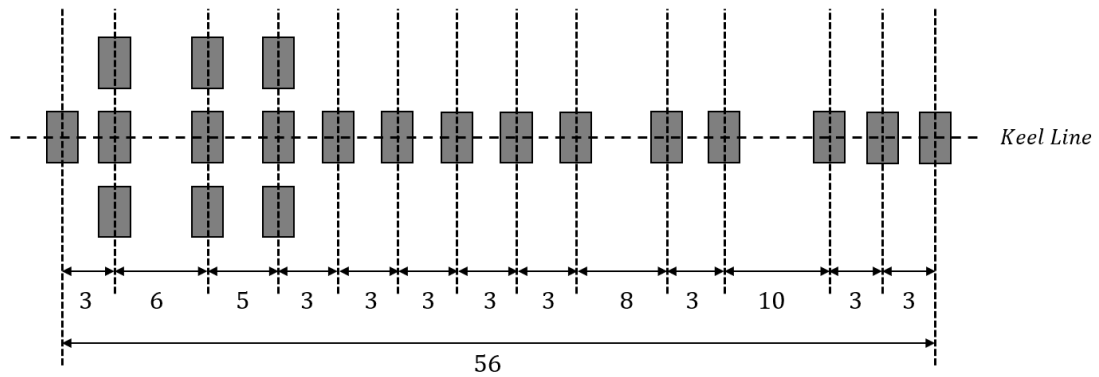


**Figure 5.2.12** Visual Demonstrating the individual Moment of Inertia of each Block.

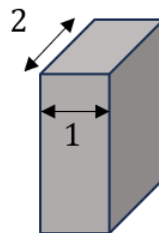
**Example:** A vessel has total weight of  $P = 1000 \text{ kg}$ . The LCG, block arrangement and dimensions are shown in Figures 5.2.13, 5.2.14, and 5.2.15 (unit: meter). Estimate the block loads by using the moment area method.



**Figure 5.2.13** (Example) Weight Distribution and Corresponding LCG of example vessel.



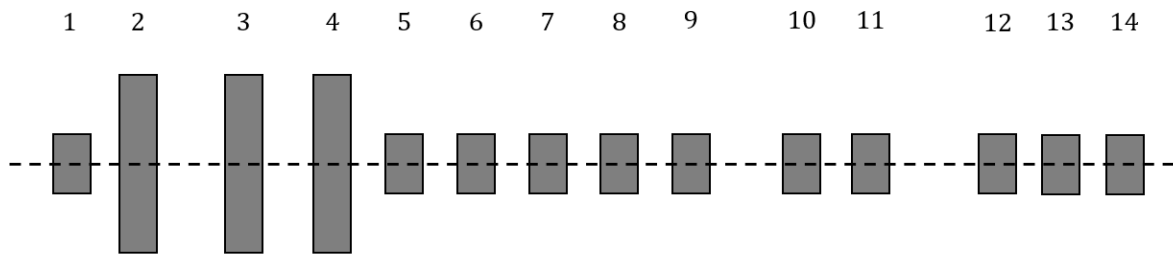
**Figure 5.2.14** (Example) Overhead view of Keel and Side Block Arrangement.



**Figure 5.2.15** (Example) Dimensions of Each Keel Block.

**Solution:**

Step 1: Assumed block arrangement:



Step 2: Calculate centroid:

Block	Distance*(d)	Area (A)	d*A
1	10	2	20
2	13	6	78
3	19	6	114
4	24	6	144
5	27	2	54
6	30	2	60
7	33	2	66
8	36	2	72
9	39	2	78
10	47	2	94
11	50	2	100
12	60	2	120
13	63	2	126
14	66	2	132

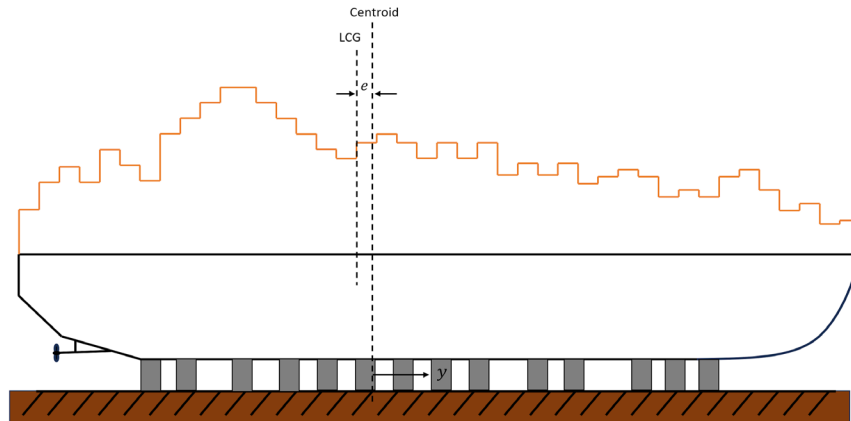
(distance (d) is measured from the reference line)

Total area =  $40 \text{ m}^2$

Summation of (d\*A) =  $1,258 \text{ m}^3$

Centroid:  $1258/40 = 31.45 \text{ m}$

Step 3: Calculate eccentricity and Moment:



$$\text{Eccentricity } (e) = 31.45 - 30 = 1.45 \text{ m}$$

$$\text{Moment } (M) = (1000 \times 9.8) \times 1.45 = 14,210$$

Step 4: Calculate Moment of Inertia:

Block	Distance* (c)	Area (A)	I*	I
1	21.45	2	0.1667	920.37
2	18.45	6	0.5000	2042.92
3	12.45	6	0.5000	930.52
4	7.45	6	0.5000	333.52
5	4.45	2	0.1667	39.77
6	1.45	2	0.1667	4.37
7	1.55	2	0.1667	4.97
8	4.55	2	0.1667	41.57
9	7.55	2	0.1667	114.17
10	15.55	2	0.1667	483.77
11	18.55	2	0.1667	688.37
12	28.55	2	0.1667	1630.37
13	31.55	2	0.1667	1990.97
14	34.55	2	0.1667	2387.57

distance (c): length from center of block to the centroid.

I\*: the moment of inertia with respect to its center axis.

$$\text{Total Area moment of inertia} = 11613.23 \text{ m}^4$$

Step 5: Pressure on blocks:

$$\frac{P}{A} \pm \frac{My}{I} = \frac{-(1000 \times 9.8)}{40} \pm \frac{14210}{11613.23} \times y$$

Block	Area (A)	y	Pressure (N/m <sup>2</sup> )	Load (N)
1	2	-21.45	-271.25	-542.49
2	6	-18.45	-267.58	-1605.45
3	6	-12.45	-260.23	-1561.40
4	6	-7.45	-254.12	-1524.70
5	2	-4.45	-250.45	-500.89
6	2	-1.45	-246.77	-493.55
7	2	1.55	-243.10	-486.21
8	2	4.55	-239.43	-478.87
9	2	7.55	-235.76	-471.52
10	2	15.55	-225.97	-451.95
11	2	18.55	-222.30	-444.60
12	2	28.55	-210.07	-420.13
13	2	31.55	-206.40	-412.79
14	2	34.55	-202.72	-405.45

**Table 5.2.16** (Example) Table of Block Loads corresponding to each Block.

## **Section 6 - Conclusions**

Dry docks and dry docking are a critical part of a vessel's lifetime, bridging the gap between a vessel's construction and its mission. Not only does a vessel start its life by way of dry dock, but it can be expected that it will return periodically to dry dock to undergo maintenance and repairs. Therefore, understanding the operation of the most common types of dry docks, as well as some of the advantages between types and calculation methods, is important for a naval architect to understand. Additionally, dry docking a ship requires a great deal of precautions and calculations to ensure that the process is carried out smoothly and safely – calculations that a naval architect may be responsible for. These simple calculations can be conducted to estimate the distribution of loads on each keel or side block as well as the stability conditions. These calculations reduce the risk of damage to the vessel, the dock, or the keel and side blocks during the docking process. For more information, refer to the reference appendix for some of the common manuals and guidances.

## Reference Appendix

These references provide insight into the docking requirements, operational process, and more details into calculations and block characteristics.

For general and in-depth information regarding dry docking:

- Dockmaster Training Manual – Heger Dry Dock Inc.

For information regarding dry docking standards and regulations:

- Naval Sea Systems Command (NAVSEA) – MIL-STD-1625D
- United States Coast Guard – SFLC 8634
- NAVSEA - NSTM Chapter 997 (Drydocking of Naval Vessels)
- Safe operation and maintenance of dry dock facilities / prepared by the Dry Dock Asset Management Task Committee of the Ports and Harbors Committee of the Coasts, Oceans, Ports, and Rivers Institute of the American Society of Civil Engineers; edited by Paul A. Harren.
- 77-22 ASCE Dry Dock Standard, American Society of Civil Engineers
- Criteria for Capacity Certification of Dry Docks and US Navy Standards, Paul S. Crandall

For additional examples and methods of calculating block loads, deflection, etc.:

- Calculating Block Load by the Moment Area Method, Robert Heger
- Accuracy Assessment of Methods for Predicting Dry Dock Block Reactions, Brandon M. Taravella

Other miscellaneous references containing useful dry docking related information:

- Strength Properties of Drydocking Timbers and Blocks, US Navy Carderock