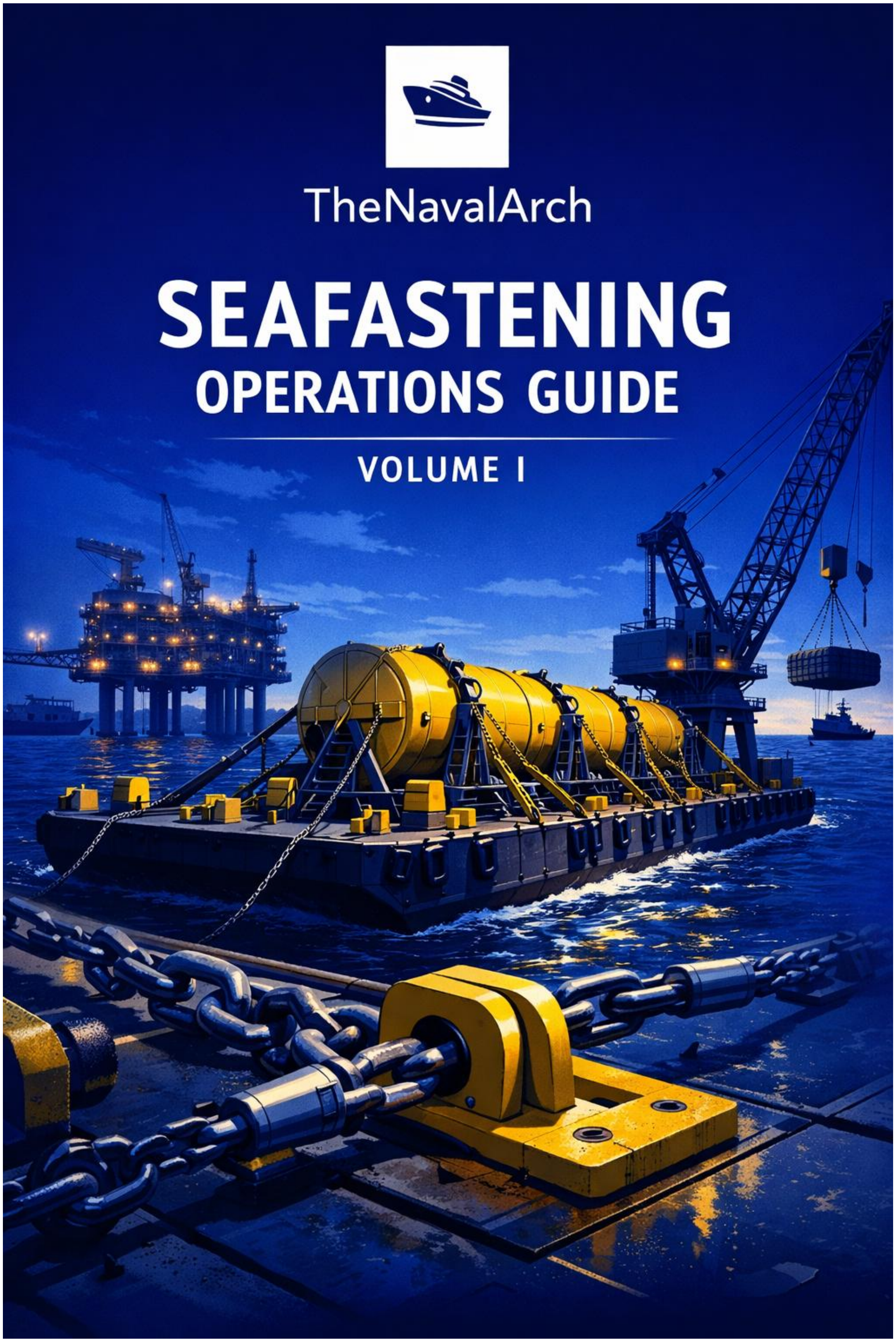

TheNavalArch
SEAFASTENING
OPERATIONS GUIDE
VOLUME I

TheNavalArch's
Seafastening Design Guide
Volume I

Marine transportation and installation operations require careful engineering to ensure the safety of vessels, cargo, and personnel. Activities such as towing, mooring, seafastening, lifting, and loadout expose structures to complex combinations of environmental, inertial, and structural loads, where even small errors in design or planning can have significant consequences.

Seafastening design is a critical element of these operations. It involves the proper restraint of cargo against sliding, tipping, and uplift under vessel motions and environmental forces, while ensuring compatibility with vessel structure and industry standards. Effective seafastening requires a clear understanding of load paths, force distribution, and structural behaviour.

This **Seafastening Operations Guide – Volume I** compiles a selection of TheNavalArch's technical articles into a single reference document. The guide focuses on practical engineering principles and commonly applied methodologies used in marine operations, with coverage extending beyond seafastening to include towing, mooring, anchoring, lifting, and loadout.

The content is intended to support engineers, surveyors, and marine professionals involved in the planning, design, and review of marine operations, serving as a technical reference rather than a substitute for project-specific engineering or class approval.

Table of Contents

ARTICLE 1: Transportation Analysis for deck cargo – complete breakdown

A project cargo being loaded onto a vessel's deck (Source: torontodrydock.com)

Introduction

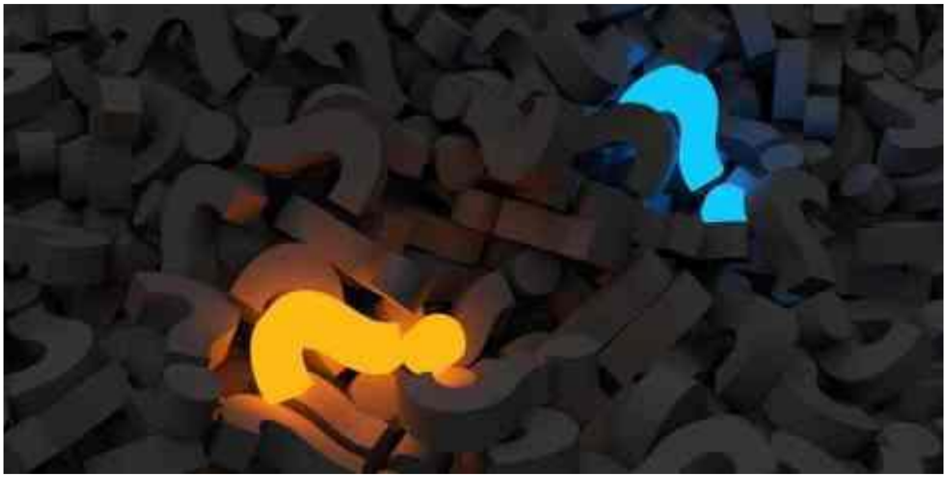
In the simplest terms, Transportation Analysis is the complete design and engineering which goes behind making a transportation operation successful. In this post we'll talk about transportation of project cargo over deck. Such cargo can be equipment, modules or other heavy structure (like a jacket or a crane being transported). A visualization of the entire operation appears quite simple – place the item on the deck of the vessel, move the vessel to its destination, and unload the item. However, depending on the size and geometry of the cargo, the whole operation can involve deeper intricacies which require careful engineering calculations and analyses. In this article we breakdown the steps involved in doing a complete transportation analysis. This may or may not be applicable to all vessels or cargo, but it can give a fair idea to avoid common pitfalls of engineering during marine transportation.

Steps of Transportation

In general, the following steps are followed for any deck cargo transport:

1. The Cargo is lying on quay side and is loaded to the vessel. This step is called 'loadout'
2. After loading on the vessel, the cargo has to be secured to the vessel. This step is called 'Seafastening'
3. The vessel motions and stability during the voyage have to be pre-assessed
4. Upon reaching the destination, it has to be loaded in from the vessel to the quay/port. This step is called 'load-in'

Digging deeper



If we dig deeper and think more analytically, following are the questions which may become relevant for each step

During Loadout/Load-in

- Is the vessel big enough to accommodate the cargo?
- Even if the vessel if big enough, is it strong enough? Will its deck be able to withstand the load of the cargo?
- How will the transfer from quay to vessel be done? Will the cargo be lifted, will it be skidded or transferred using a SPMT trailer?
- Will the vessel stay stable during the loadout/load-in? How will we ensure it is at even keel during the process?

After Loadout from Quay to vessel

- How will the cargo be secured to the deck? Will it be lashed using ropes, or will it be welded to the deck?
- How many lashings to be used? How strong should the lashings be?
- How to spread out the cargo load on the deck? What should be the ideal location where the cargo legs should sit?

During the transportation

- How to maintain the stability of the vessel during the transport?
- How will the cargo be affected by environmental forces of wind, wave and current? How to estimate how much load will come on to the cargo from these forces? How will they impact the design of the seafastening?

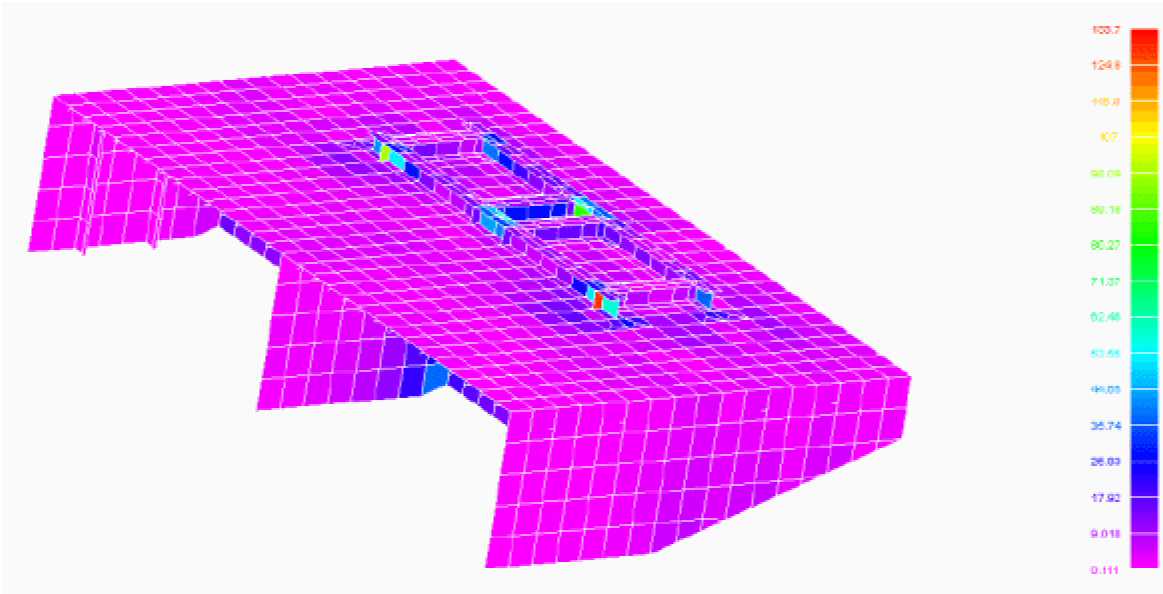
- How will the vessel move? Will it use its own propulsion, or will it be towed? How to select the right tug, if it is to be towed?

Breaking it down

Here we break down the steps of engineering which are performed for a successful transportation operation. Again, not all of them may be applicable to all operations, and we can pick and choose depending on the complexity of the operation.

Additionally, it should be noted that all these analyses and calculations must be performed much prior to the actual operation and passed on to the operations team and approving authority (generally Marine Warranty Surveyor).

- **Ship or tug-barge?** Whether to use a self-propelled ship or a tug-barge combination is generally a commercial decision and taken at the very initial stage
- **Space check** – The vessel must have clear deck space to accommodate cargo. However, that's not enough – the deck space should be sufficient to add lashings to the cargo on the sides and ends. An initial look on the locations of lashing points on the cargo can give a good idea of the space needed for lashings
- **Deck strength** – A quick check to see if the deck of the vessel is strong enough can be made by looking at the vessel's specification sheet. The deck strength is specified in units of tons/m^2. Given the weight of the cargo and its footprint on the deck, we can calculate the deck load due to the cargo. This deck load should be within the deck strength limit of the vessel. While this may not be a very good parameter to judge any point loads the vessel may experience, it is still a good parameter to gauge the vessel's strength sufficiency in vessel selection stage. For the final transportation analysis, a thorough assessment of the deck strength (beam analysis or FEA if needed) must be carried out

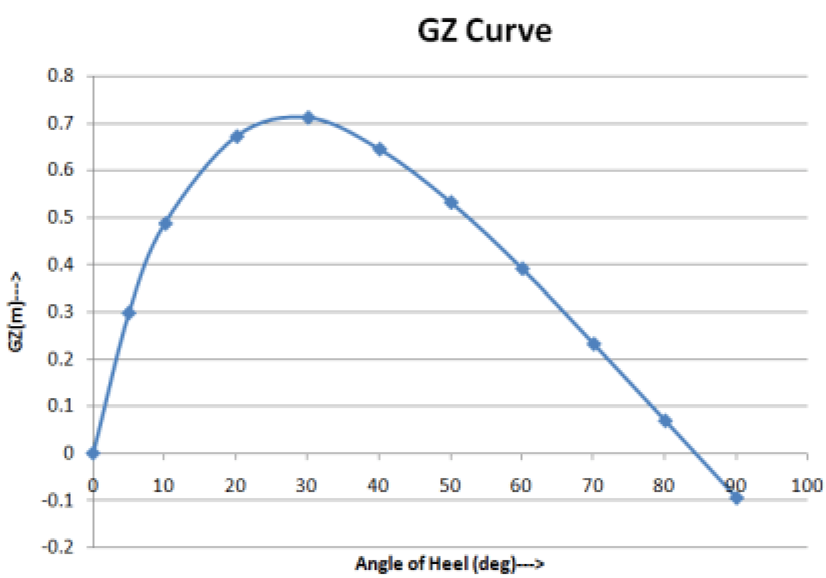


FE Analysis of a deck structure

- **Loadout capability and strength**: If the loadout is a lifted loadout, then the loadout operation is simple and doesn't require a detailed ballasting operation. For SPMT or skidded loadouts, the vessel must have enough ballast capability to go through the critical stages of loadout. Generally, the most critical stage is when the whole cargo has just lifted on to the vessel and is lying on the end where it has been loaded from. The tanks at the other end of the vessel must have enough ballast capacity to keep the vessel on even keel. Also, the longitudinal strength of the vessel must stay within the limits. Generally, a spreadsheet solution for preliminary checks of vessel ballast capability can be developed for preliminary assessment. However, for heavier cargo, a software solution for hydrostatics and stability (like GHS/MOSES) must be used. For heavier Cargo, it should also be noted that the foot of the cargo should sit on strong points like bulkheads to avoid any strength issues. Once the vessel has been selected, a thorough assessment of its ballasting capability, stability and strength must be performed for each stage of loadout. However, generally Loadout is a separate operation in itself and a separate loadout report is prepared. It is not generally included in the Transportation Analysis document. Design of loadout accessories like the loadout ramp also forms part of this stage

A loadout using SPMT trailer

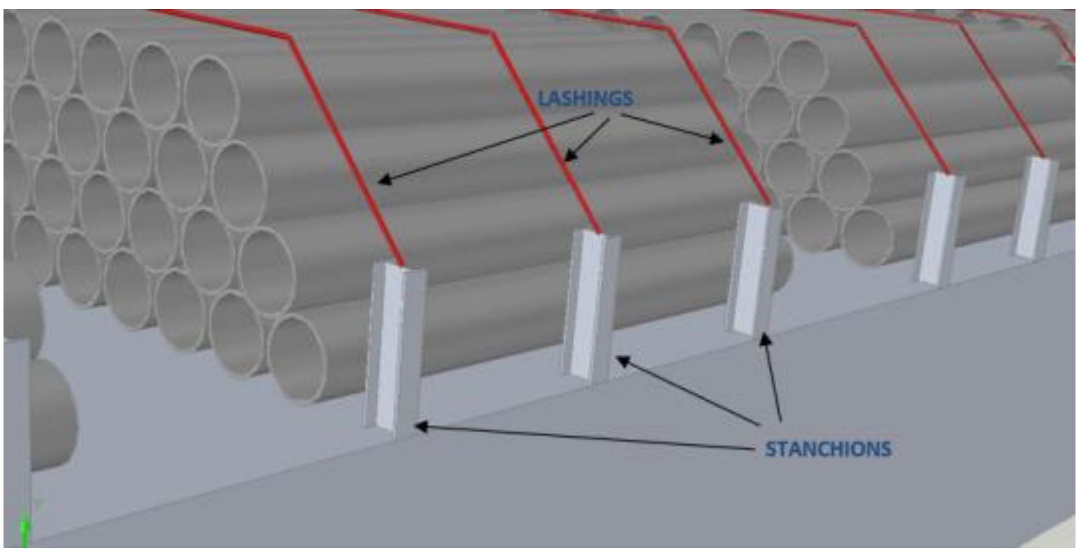
- **Transportation Stability:** a check of the intact and damaged stability of the vessel during the transportation stage too needs to be performed. This may involve creating a 3D model of the vessel, performing detailed stability calculations using standard software and checking them against applicable Class rules

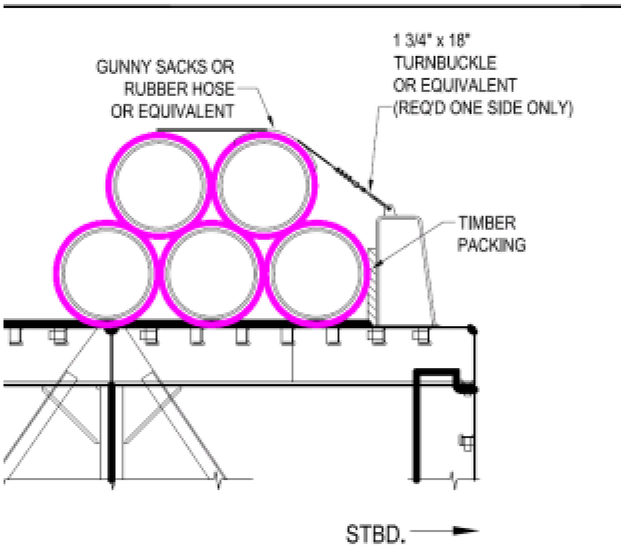


A typical Ship Stability Curve (a.k.a. GZ Curve or righting arm curve)

- **Seakeeping/Motions analysis:** To determine what kind of forces the cargo may experience during the transport (wind, wave, current), we may need to perform a complete seakeeping analysis, keeping in mind the worst sea state which the cargo may experience along the route. The environment data can be obtained from nautical charts or metocean data. However, during the design or vessel selection stage, a conservative estimate can be made using a simple spreadsheet application following standard guidelines like DNV-ST-N-001.

- **Seafastening Design:** a detailed design of lashings may not be required at the vessel selection stage, but it will be a part of the transportation analysis. The lashing design will involve design and specification of multiple lashing items:
    - **Lashing ropes or wires:** As applicable, enough lashing ropes should be provided on sides and end of the cargo to restrain the cargo against the forces obtained from seakeeping analysis. The complete specification of ropes/wires must be provided – length, size, type, end type, material etc.
    - **Stoppers/clips/dog-plates:** Stoppers are used to restrain the translational movement of cargo. Clips/dog-plates are used to restrain the tipping of cargo. At times they my be used in conjunction with lashings
    - **Shackles and pad-eyes** – Shackles must be of sufficient strength to support the lashings. Pad-eyes must be designed to be installed on deck and should be checked against any out-of-plane loads.
    - **Stanchions**: If the cargo needs to be supported by stanchions on the side, the stanchions shall be of sufficient strength. At times, a FE Analysis may be needed to affirm the suitability of stanchion.
    - **Dunnage**: For cargo with small footprint, dunnages should be used to spread the load on the deck. Detailed check of dunnage strength should be performed to ascertain their size and suitability
    - **Wegdes, turnbuckles, rubber hoses** – these are accessories of lashing ropes and should be provided in sufficient numbers.
    - **Lashing Plan:** A complete lashing plan drawing showing all lashing items must be prepared and included in the Transportation Analysis document





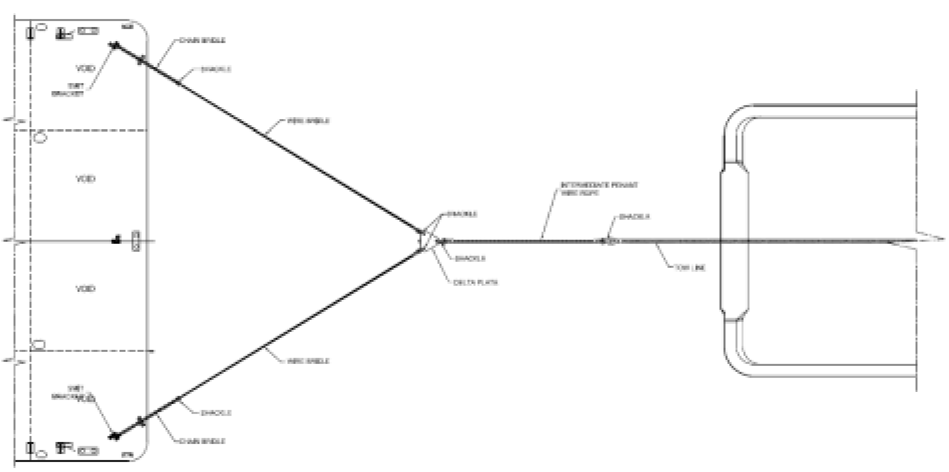
LASHING REQUIREMENTS

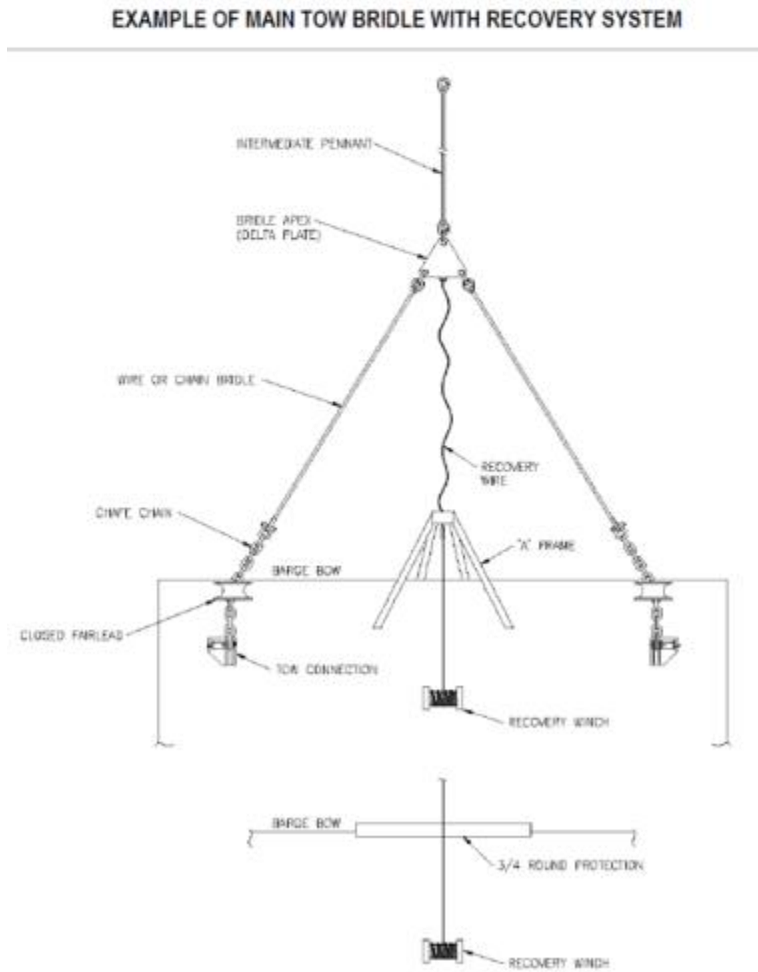
ITEM	DESCRIPTION	LENGHT (m)	QTY	MASS (kg)
4	1 3/4" x 18" TURNBUCKLE OR EQUIVALENT (REQ'D ONE SIDE ONLY)	-	42	-
5	Ø24mm WIRE GR. 1770, SOFT EYE BOTH END	27	10	-
6	Ø24mm WIRE GR. 1770, SOFT EYE BOTH END	29	32	-
7	GUNNY SACKS OR RUBBER HOSE OR EQUIVALENT	-	100	-
8	TIMBER DUNNAGE 50 THICK. x 150 WD. x (25.00m) 7 PLACES @ EACH LOWER BAY	-	42	-
9	12 TON SHACKLE	-	42	-
10	WIRE ROPE CLIP FOR 24mmØ WIRE	-	350	-
11	PADEYE (250x220x30mm THK)	-	84	-
12	PADEYE CHK. PL. (150mmØ x10mm THK)	-	168	-
13	PADEYE BASE PL. (300x250x20mm THK)	-	30	-

Typical lashing for transporting pipes

- **Towing/Emergency towing arrangement:** If the vessel is being towed, a suitable tug has to be selected for it. This will involve carrying out bollard pull calculations to select the tug. Also, a towing arrangement plan may be needed detailing the complete towing bridle and its specifications required as per standard guidelines (DNV-ST-N-001). If the vessel is a Barge, an emergency towing arrangement may also have to be prepared and submitted as part of the Transportation Analysis document.

TOWING ARRANGEMENT





Typical Towing/Emergency Towing Arrangement (source: GL ND-0030 Rev 5)

Thus, we can see that a complete Transportation Analysis involves multiple engineering calculations and analyses which have to be performed diligently to ensure success of the operation.

Now we list down the typical contents table of a Transportation Analysis below. Please note that loadout is not included, as it is generally considered a separate operation with an independent analysis report. For each analysis performed, detailed results from software can be included in the Appendix of the report.

Transportation analysis: typical table of contents

- Introduction: project details and what cargo is being carried
- Vessel and cargo particulars
- Tow route particulars and environment data
- Stability analysis during transport
  - Intact and damaged stability
  - Longitudinal strength check
- Motion/Seakeeping analysis
- Deck Strength check
- Seafastening design
  - Lashing design based on seakeeping results
  - Lashing plan (drawing)
  - Stanchion design/check
  - Pad-eye check
- Towing Arrangement design (if applicable)
  - Bollard Pull calculation
  - Towing bridle design
  - Towing and emergency towing arrangement plan (drawing)

A thorough Transportation Analysis (TA) performed on time for an operation is a great asset to the operations team in planning and execution. While surprises are almost always guaranteed during operations, a comprehensive TA serves as a solid reference to manage them effectively.

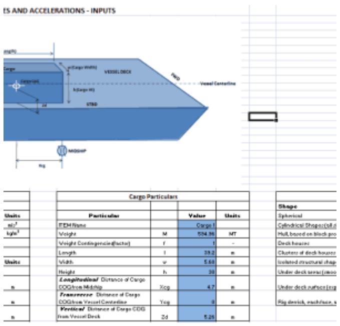
Disclaimer:

This post is not meant to be an authoritative writing on the topic presented. thenavalarch bears no responsibility for the accuracy of this article, or for any incidents/losses arising due to the use of the information in this article in any operation. It is recommended to seek professional advice before executing any activity which draws on information mentioned in this post. All the figures, drawings and pictures are property of thenavalarch except where indicated, and may not be copied or distributed without permission.


ENGINEERING SERVICES
Seafastening Design & Marine T&I Expertise
Specializing in deck cargo seafastening design.
MWS-approved engineering for Marine T&I operations.
Loadout, sea transport & installation engineering.
Rigging design and lifting calculations.
Offshore structural design & analysis.
Learn more online
https://thenavalarch.com/engineering-service-thenavalarch/
TheNavalArch Pty Ltd
Suite 405, Level 2,
66 Victor Cres
Narre Warren VIC,
Australia 3805
Ph/WhatsApp: +61432185746
info@thenavalarch.com
TheNavalArch

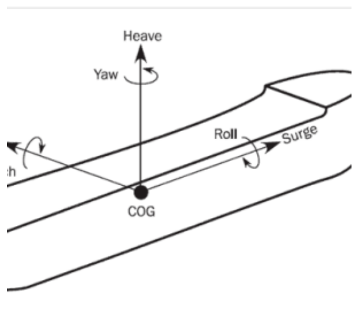
TheNavalArch's Apps for Seafastening Design

TheNavalArch has its own apps to help in various aspects of transportation analysis. Do check them out below:



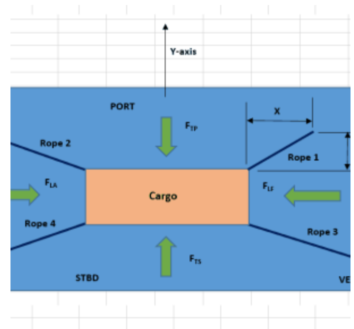
Cargo Forces & Accelerations

Rated**3.00**out of 5

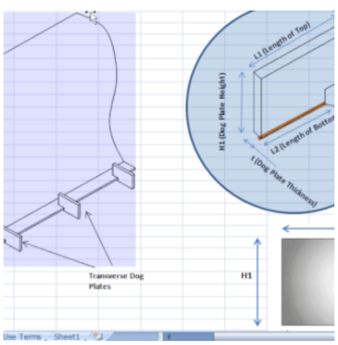


DNV Ship Motion Calculator

Rated**4.00**out of 5

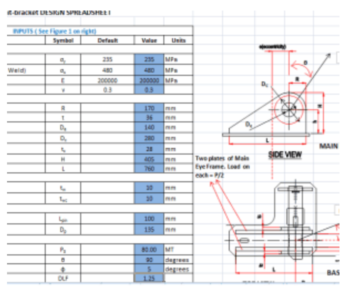


Lashing Design (4 Point Lashing, IMO CSS)



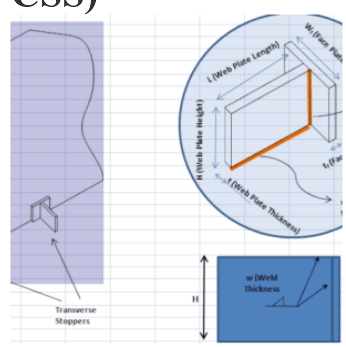
Dog Plate Design Spreadsheet

Rated**4.00**out of 5

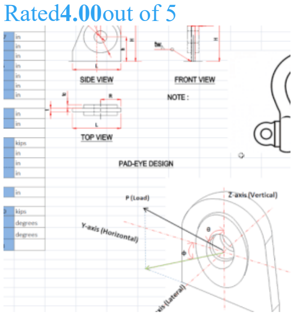


Smit Bracket Design Spreadsheet

Rated**5.00**out of 5

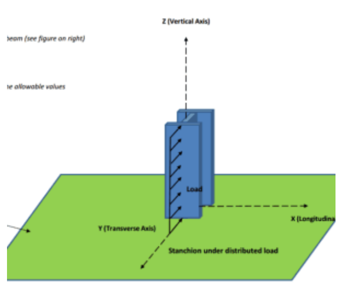


Stopper Design Spreadsheet

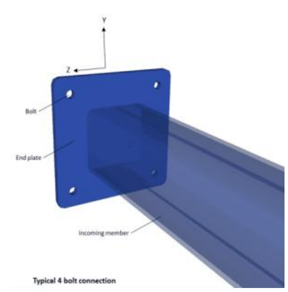


Pad-Eye Design Spreadsheet

Rated**5.00**out of 5



Stanchion Design Spreadsheet



Bolt Check Spreadsheet (based on Eurocode 3)

ARTICLE 2: Designing a simple 4-point lashing system for a Deck Cargo

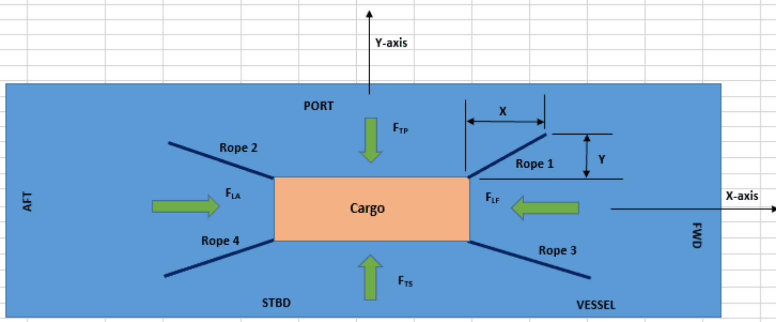


Figure 1 - 4-point Lashing of Cargo onboard Ship (Plan view)

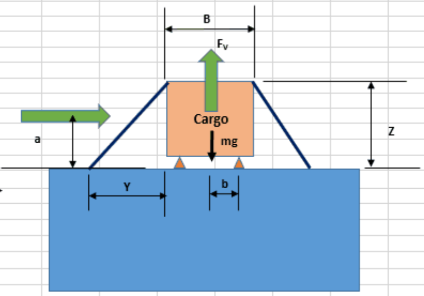


Figure 2 - Sectional View (looking Aft)

Introduction

Lashing of a deck cargo on a ship involves different means and mechanisms to secure the cargo to the deck of the ship. This 'securing' is important to contain the movement of the cargo in view of the ship motions during the transportation.

The simplest 'system' which comes to the mind is to take a few ropes and tie one end of each rope to some point on the cargo, and tie the other end to some point on the ship's deck. The ropes can be evenly distributed so that the securing in all the directions is ensured.

In this article we'll discuss the basics of cargo lashing and will also take a look at a simple 4-point lashing system design for a rectangular shaped cargo.

Designing the right lashing for a cargo depends on multiple factors

- ***Size and weight of cargo*** – a bigger, heavier cargo requires stronger lashings. Also, the available space for lashing is an important factor in deciding the lashing configuration
- ***Forces on the cargo*** – depending on the size of the vessel and the environment of the tow route, the cargo experiences forces of surge, sway and heave which lead to pitch, roll and heave forces which need to be overcome by the lashings
- ***Force distribution*** – another very important factor is the distribution of forces among the lashings used. The forces should be evenly distributed among lashings, and there should not be a possibility of a lashing getting slack or another getting overloaded.

- ***Protection against sliding*** – generally if the friction force is not enough to protect against sliding, then dunnage can be utilized for increasing friction. Lashings should be able to provide sufficient restraint against sliding. Alternatively, stoppers can be used in conjunction with lashings
- ***Protection against tipping*** – the lashing design must also provide protection of the cargo against tipping when the vessel rolls/pitches.

Four-point lashing design for a rectangular shaped cargo

A Cargo in the sea will experience forces of surge and sway in the longitudinal and transverse directions, and heave in the vertical direction.

The lashings should be sufficient to resist the transverse forces from either Port or Starboard sides, and also to resist the longitudinal forces from fwd/aft.

Since there are restraints to be provided in four directions, we can imagine a simple system consisting of four lashings are shown in figure below:

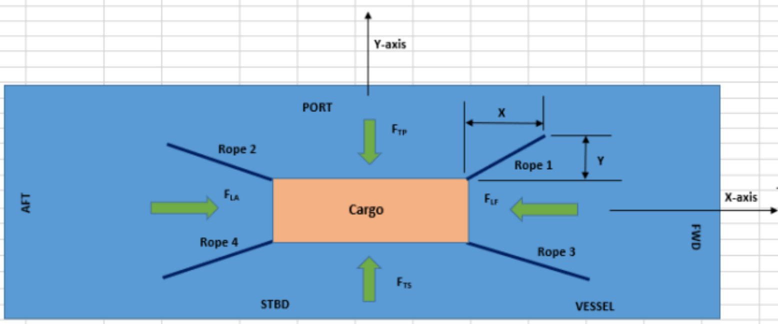


Figure 1 - 4-point Lashing of Cargo onboard Ship (Plan view)

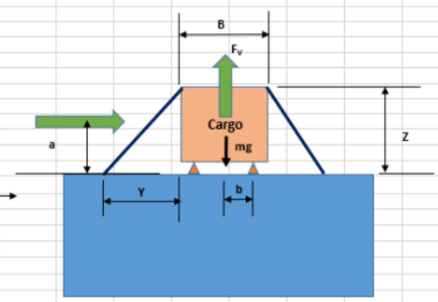


Figure 2 - Sectional View (looking Aft)

We can infer from the above figure that

- The longitudinal force aft is restrained by Lashings 2 & 4
- The longitudinal force fwd is restrained by Lashings 1 & 3
- The transverse force PORT is restrained by Lashings 1 & 2
- The transverse force STBD is restrained by Lashings 3 & 4

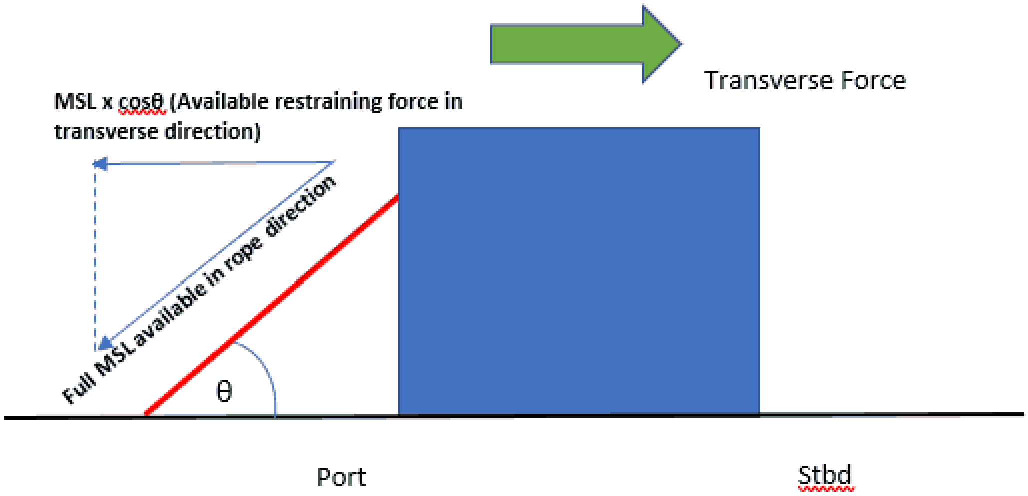
How much of a load a particular line will be able to take up in a given lashing configuration depends purely on the location of the line, its length and the angles it makes relative to the vertical and horizontal planes.

The basic outline of the whole method is:

- Calculate the total restraining forces + friction forces in a particular direction
- Check if the total restraining force in that direction is more than the external force
    - If yes, then lashing is adequate
    - If no, then consider reconfiguring the lashings – change size or strength of lashings and check again

We take an example of the transverse sliding force on the port side.

- We can see that the Ropes 1 & 2 are restraining the port side transverse force
- The restraining force available from each rope is not the full MSL (Maximum Securing Load) of the rope. A rope at an angle of θ to the horizontal will be able to provide a restraint of only $R = MSL \times \cos(\theta)$ in the horizontal direction (See figure below). The MSL is further reduced by a factor of 1.5 as per IMO CSS.
- The restraining forces of each of the ropes 1 & 2 is calculated depending on their orientation in the lashing design. The factors for calculating the restraining forces are provided in IMO CSS, depending on
    - Angle of rope with vertical
    - Angle of rope with horizontal
    - Coefficient of friction between cargo and deck
- If the restraining forces available from the ropes 1 & 2 is F1 and F2, respectively, and if the frictional force on the cargo is F_{fric}, then the total restraining force available in the transverse direction (Port side) is



Available restraining force from a lashing

$$\mathbf{R = F1 + F2 + F_{fric}}$$

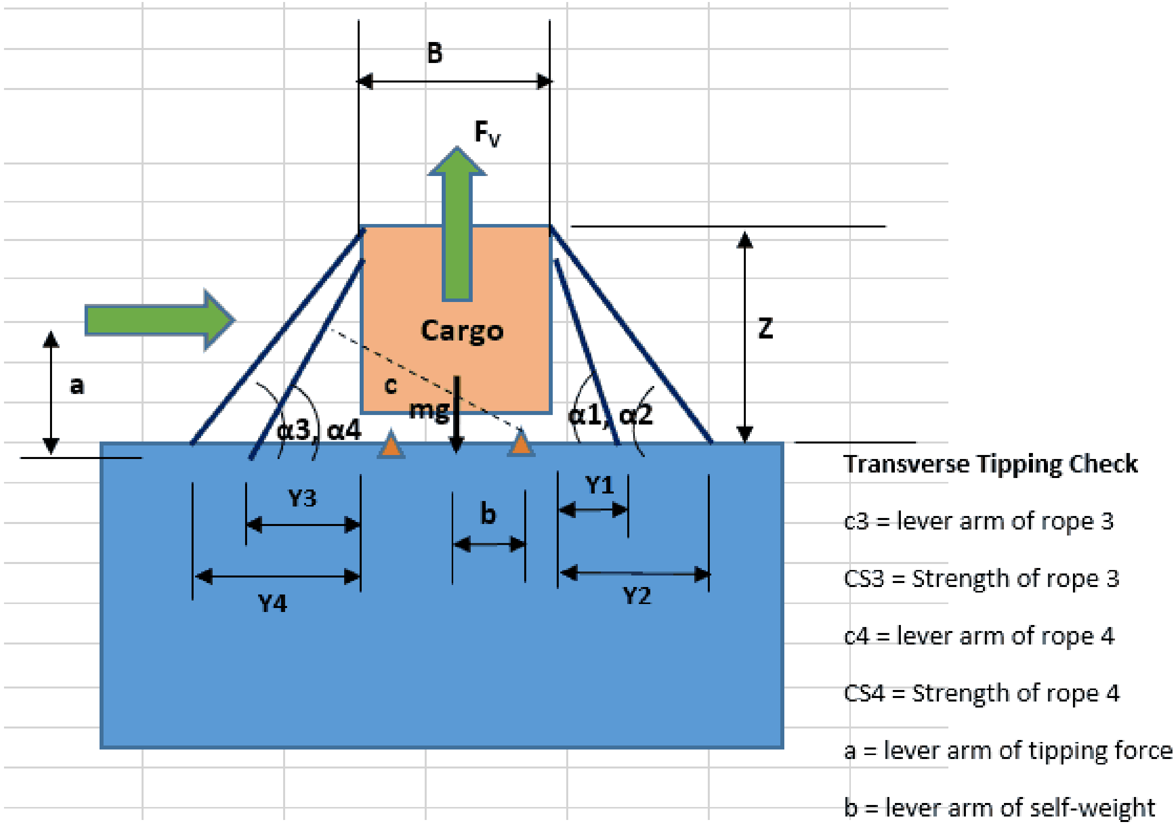
- If the total transverse force on the port side is F_{TP}, then R must be greater than F_{TP} for the lashing design to be adequate.

$$\mathbf{FTP < F1 + F2 + Ffric}$$

Such sliding check shall be done for sliding in all the four directions

Tipping check

The cargo is also prone to tipping at the edges. To demonstrate sufficient restraint against tipping, the levers of the lashing forces are also taken into account and it is to be demonstrated that the total restraining torque available from the lashings is more than the total tipping moment caused by external forces. The self-weight of the Cargo also provides restraining torque against tipping. Generally, tipping is critical only in the transverse direction if the cargo is oriented longitudinally. The figure below demonstrates this



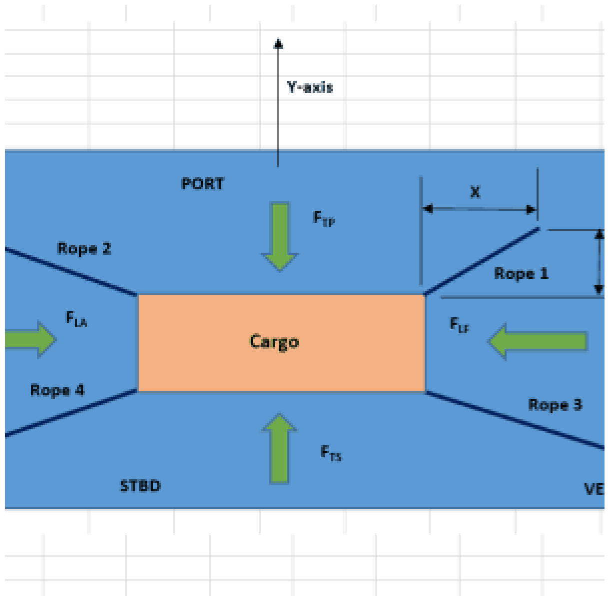
$$F_{TS} \times a < b \times mg + 0.9 \times (c3 \times CS_3 + c4 \times CS_4)$$

Following the above method based on IMO CSS, we can design a simple four-point lashing system for simple cargoes. For any failure in the lashings, the design parameters and/or lashing sizes can be changed to arrive at a design which is adequate.

References

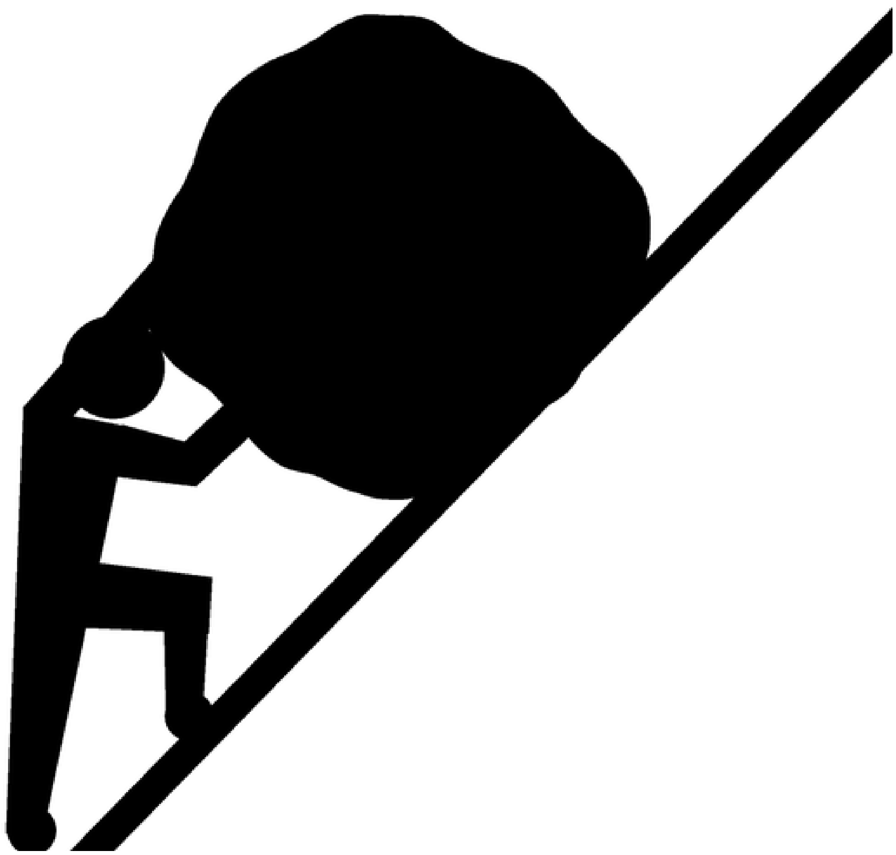
1. "Guidelines for the Preparation of the Cargo Securing Manual" (IMO MSC/Circ.745)
2. "Amendments to the Code of Safe Practice for Cargo Stowage and Securing (IMO MSC/Circ.1026)".

TheNavalArch has its own app for 4-point lashing design based on IMO CSS. Do check it out here:



Lashing Design (4 Point Lashing, IMO CSS)

ARTICLE 3: Cargo Stoppers – why they are critical and how to design them



Introduction

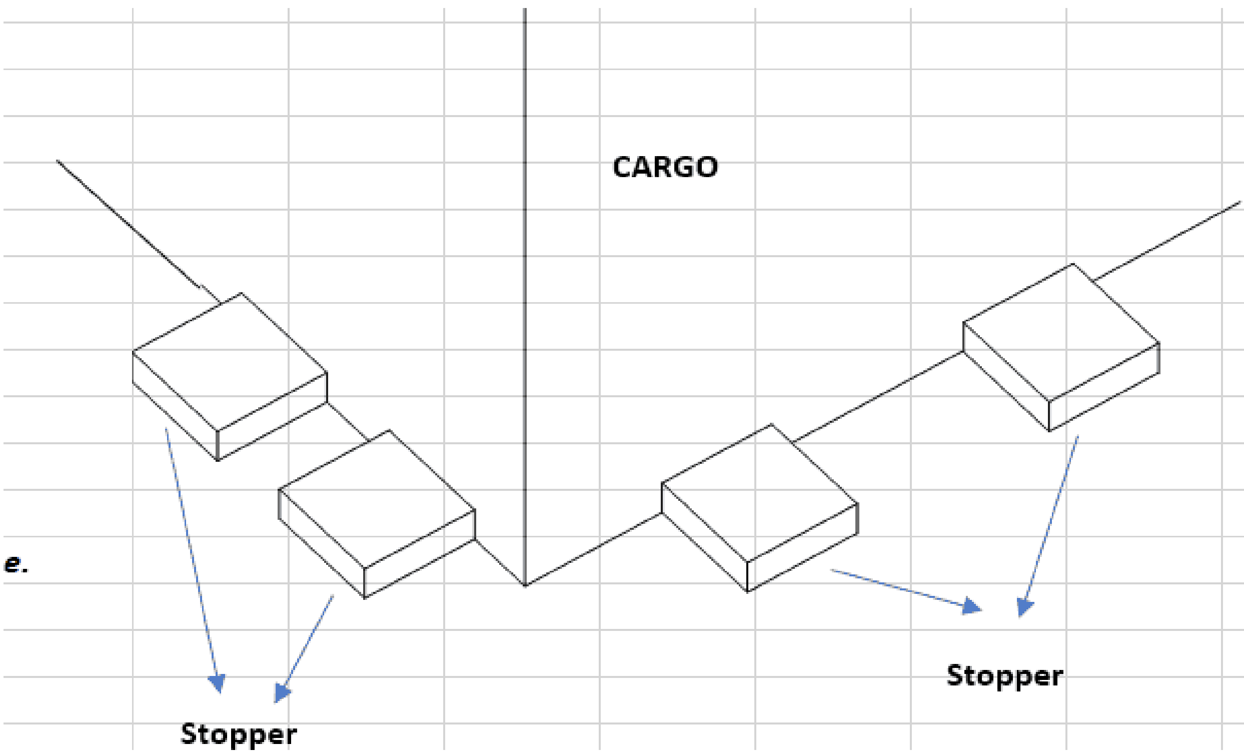
A cargo transported on the deck of a ship is subject to many forces. These forces comprise of the inertial forces due to the ship motions – the three translations and three rotations – and the environmental force of wind.

Due to the combined effect of these forces, the cargo, if left unfastened on the deck of the vessel may not remain static at one location but may move around. To avoid this, it is critical that the cargo is restrained from movement. The design of all accessories to restrain the cargo is called Seafastening design.

A typical and simplest seafastening may comprise of lashing ropes (or wires) fastened to pad-eyes welded on deck of the vessel. However, for some heavy cargoes this may not be enough, and additional arrangements may be required for preventing both translational and rotational motion of the cargo on deck.

A Stopper is a simple structure which is welded to the deck of the vessel to prevent the cargo from sliding (i.e., the translational motion).

The very simplest stopper which can be imagined is simply a metal plate which is welded to the deck, and against which the cargo rests. The below figure should be able to provide a starting point.

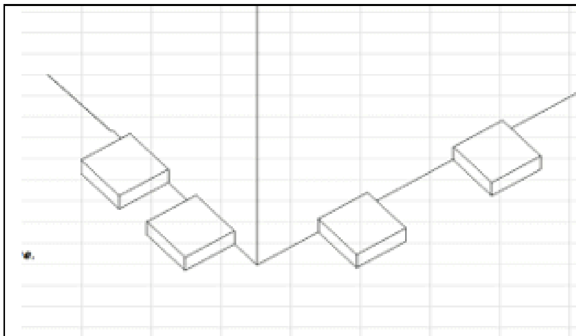


The simplest stopper comprising of a steel bar

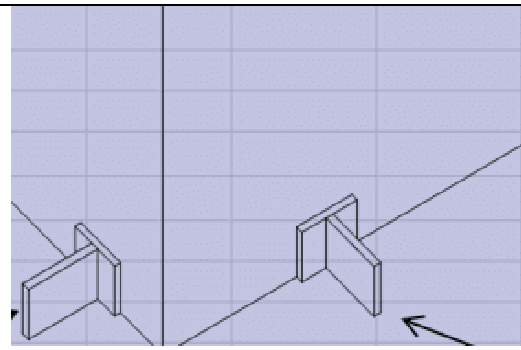
Types of Stoppers

Stoppers can be of many types. The choice of the right stopper depends on the geometry of the cargo, on the weight distribution of the cargo and on forces experienced by the cargo during the voyage. Stoppers can range from simple plate bars to complex H-beams (called Stanchions on ships).

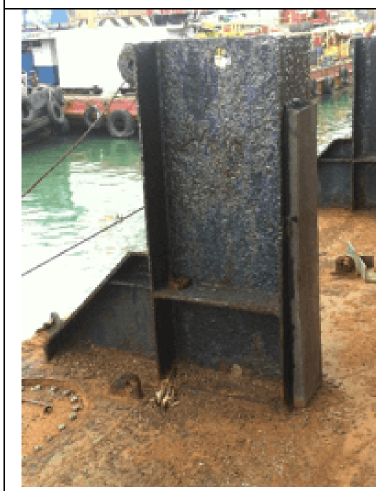
Some of them are shown below:



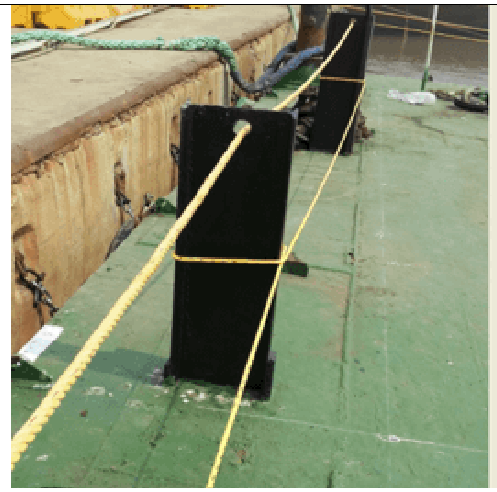
Simple steel bar stopper



Stopper with Face Plate



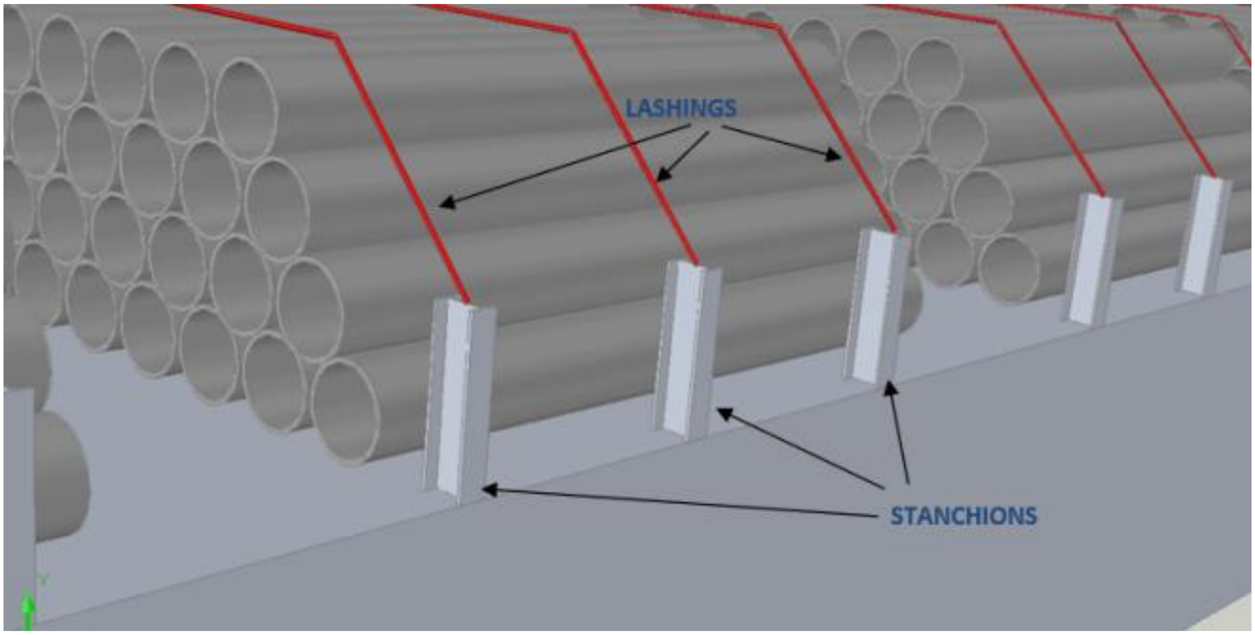
H-beam stopper with support



Simple H-beam Stopper (vertical)

Types of Stoppers

For example, the H-beam stoppers (also called stanchions) are mostly used for restraining pipes being transported. A box shaped cargo with most weight near its base will use a flat plate stopper (with or without face plate).



H-beam stoppers (stanchions) used for restraining pipes

The height of the stopper will depend upon the height where the cargo needs to be supported. For example, in the above pic showing stoppers for pipe transport, the stanchions need to be of a height more than the diameter of the pipe to secure the whole pipe bay adequately. Similarly, box shaped cargo like containers may find the simple steel bar stopper (or one with face plate) enough for restraining.

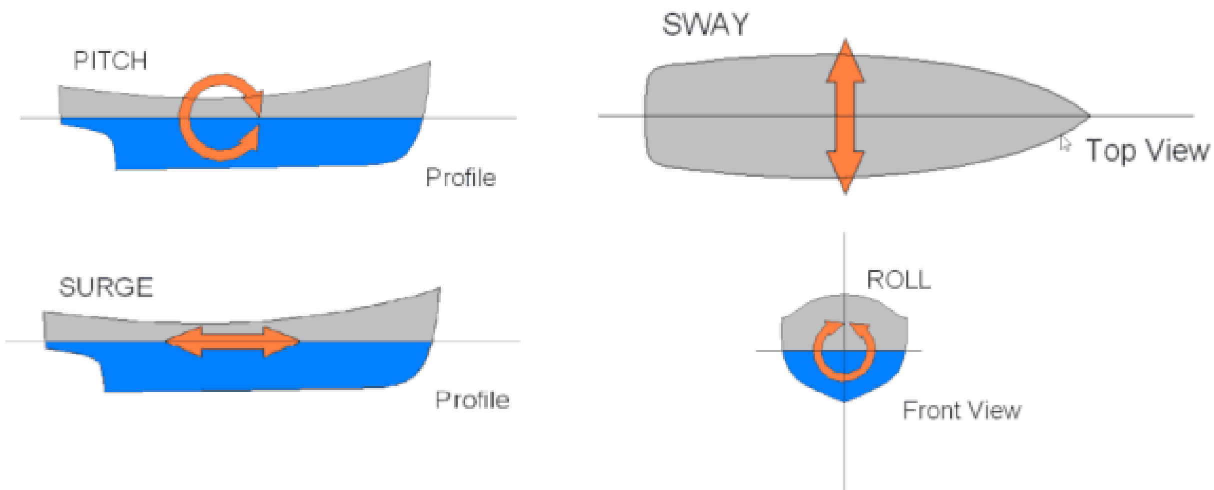
Structural Design of a Stopper

Whatever the shape and type of stopper selected, it should be structurally sound to perform its job – preventing the sliding of cargo, i.e., it should be able to overcome the forces which make the cargo slide. What are these forces?

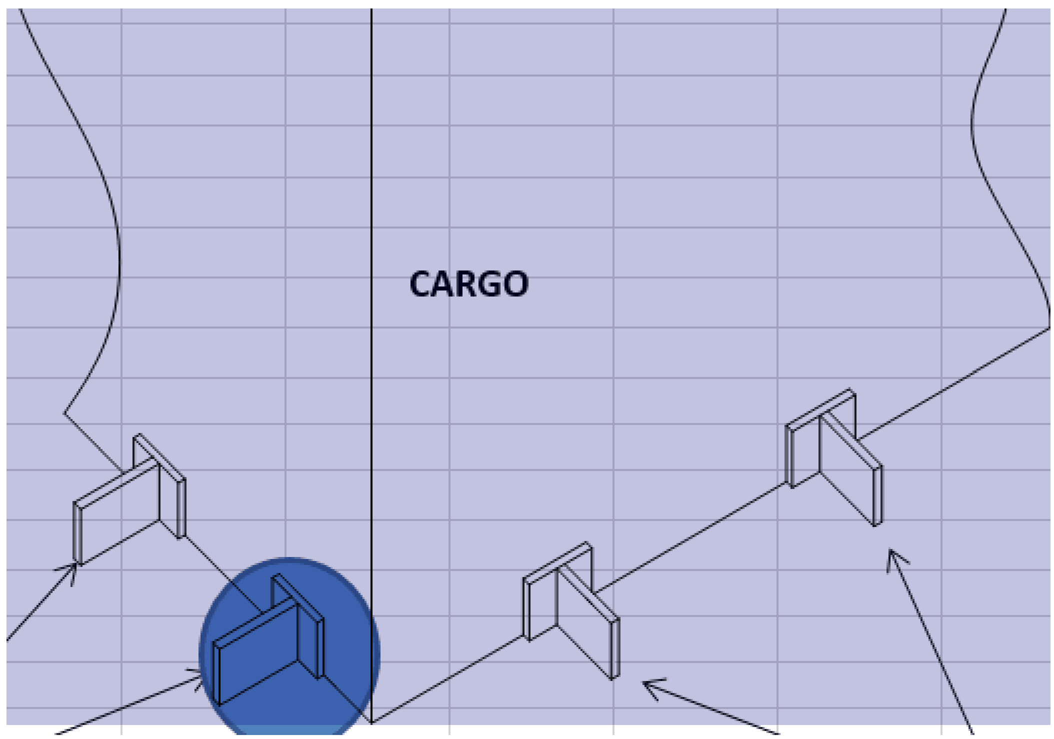
he two forces which may lead to cargo sliding are:

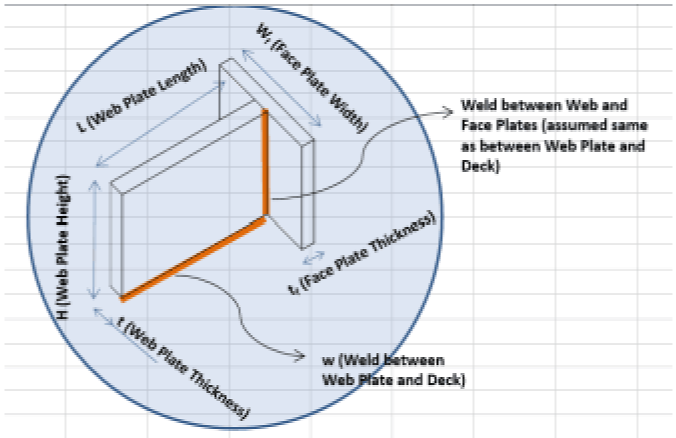
- Transverse force, or the force which makes the cargo slide athwartship, i.e., Port and Starboard. This force arises due to sway and roll motion of the ship
- Longitudinal force, or the force which makes the cargo slide forward/aft. This force arises due to the surge and pitch motions of the ship.

The figure below demonstrates the two sliding forces.



To understand the structural design of a Stopper, let's take an example of a box shaped cargo being restrained by a flat steel stopper with a face plate.

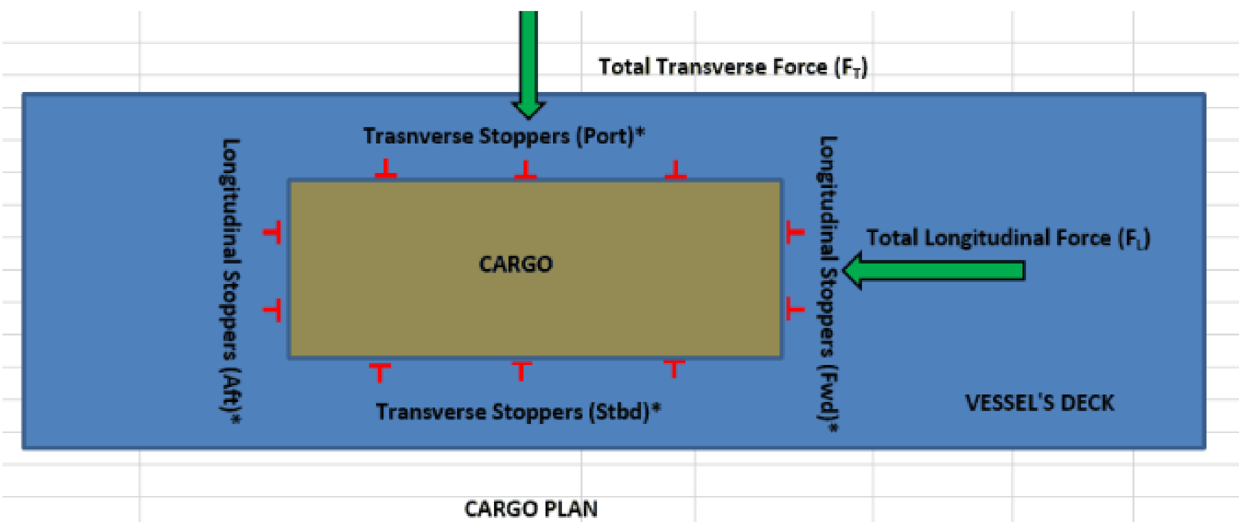




Stopper with a Face Plate

This kind of stopper has two components – a web plate and a face plate which are welded to each other. The face plate is what the cargo rests against, while the web plate is welded to the deck of ship. The details of the weld and configuration of the plate can be seen in the figures above.

Since the vessel experiences forces both in longitudinal and transverse directions, stoppers need to be installed on both longitudinal and transverse faces of the cargo. Taking a simple box shaped cargo as an example, a typical plan showing the stoppers is shown below. We can see that three stoppers on each side (Port/Stbd) are restraining the total Transverse force (F_T), while two stoppers on each side (Fwd/Aft) are restraining the Longitudinal force (F_L). The forces can be obtained from a motions analysis of the vessel, or using some empirical formulae (check out our products for calculating accelerations)

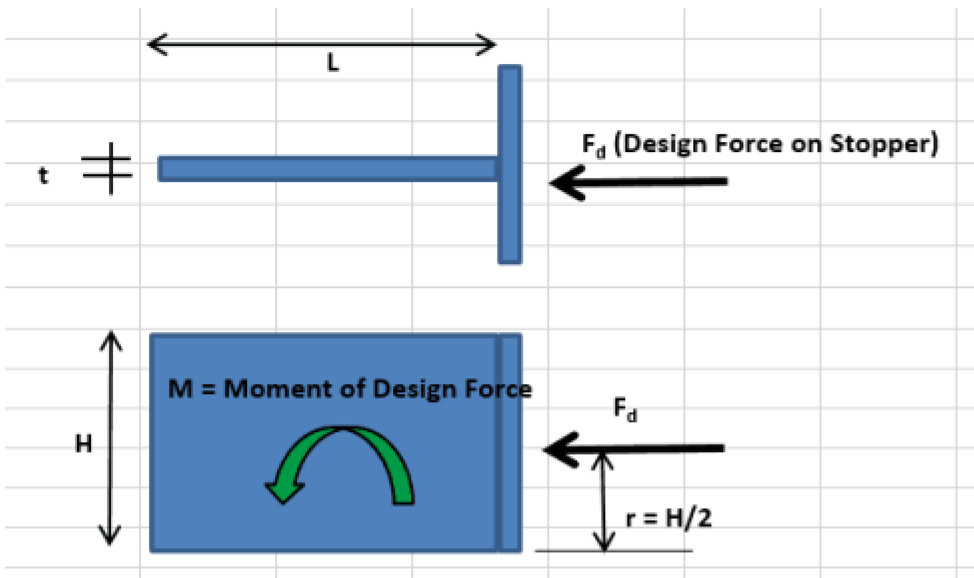


From the figure above, we can see that each transverse stopper takes one third of the total transverse force, while each longitudinal stopper takes one-half of the total longitudinal force.

Total force on each transverse stopper = F_T / 3

Total force on each longitudinal stopper = F_L /2

Zooming down to a single stopper (whether transverse or longitudinal), it will experience a force which is F_T / 3 for transverse stoppers and F_L /2 for longitudinal stoppers. Let's call the force as F_d (Design Force). The design force acts on the face plate of the stopper. The location on the face plate where the force acts can vary depending on how the face plate is in contact with the cargo, but for simplification, we consider that the force is a point force acting at mid-height of the face plate. The figure below depicts this.



The force on the Face Plate is effectively transmitted to the web plate which is welded to the deck. This leads to a shear force on the web plate. Further, the force, acting at a height of H/2 (where H is height of face plate) leads to a turning moment which is transmitted to the base of the web plate, where the web plate is welded to the deck.

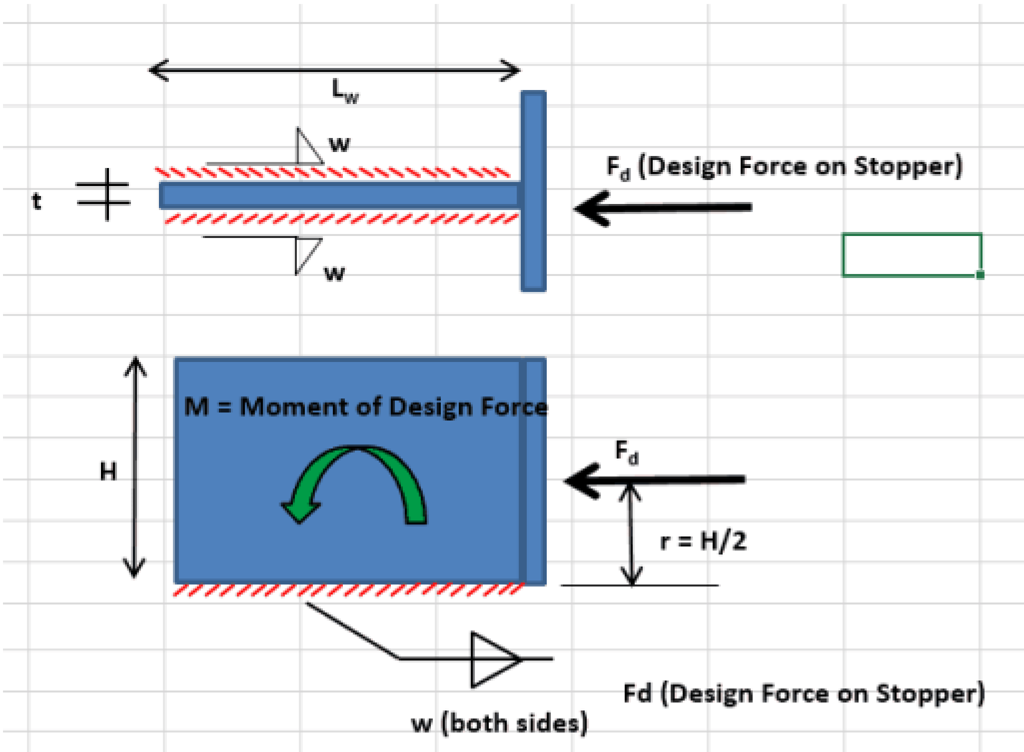
Thus, we need to analyze the web plate for:

- Shear Stress due to force F_d
- Bending Stress due to moment F_d x H/2

Weld Strength Check

Since the weld is what affixes the web plate to the deck, the stresses in the weld are equally important to be evaluated.

Usually the weld type for welding the web to the deck is a fillet weld (two-sided). The weld profile for the stopper with face plate is shown below:



The force F_d and the resulting moment M are transmitted to the weld which is analyzed for:

- Shear stress on the weld
- Bending stress on the weld
- Total (combined) stress on the weld

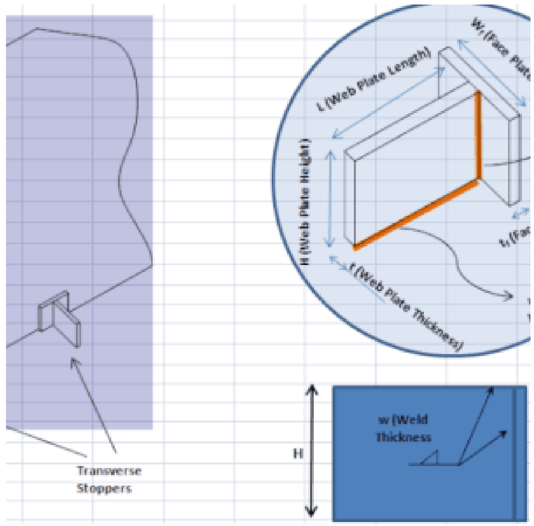
With the above two types of checks (web plate strength check and weld strength check) performed, the stopper's structural design is considered enough.

Similar principles can be applied to the design of other types of stoppers (H-beam stoppers or Stanchions).

To wrap up, stoppers are small structural items but play a vital role in retraining cargo during transport. Thus, their design should be done with due diligence and care to ensure a successful marine operation.


ENGINEERING SERVICES
Seafastening Design & Marine T&I Expertise
Specializing in deck cargo seafastening design.
MWS-approved engineering for Marine T&I operations.
Loadout, sea transport & installation engineering.
Rigging design and lifting calculations.
Offshore structural design & analysis.
Learn more online
https://thenavalarch.com/engineering-service-thenavalarch/
TheNavalArch Pty Ltd
Suite 405, Level 2,
66 Victor Cres
Narre Warren VIC,
Australia 3805
Ph/WhatsApp: +61432185746
info@thenavalarch.com
TheNavalArch

TheNavalArch has its own app for stopper design. Do check it out here:



Stopper Design Spreadsheet

ARTICLE 4: Steel coils loading – its challenges and ways to overcome

by

Mr. Spiros Malliaroudakis

(Founder & Managing Director, S.A. Malliaroudakis Maritime (UK) Ltd)

The loads derived from steel coils loading are very concentrated, leading to higher stresses in the double bottom than would be expected. Calculation of steel coils loading conditions, which reflect actual loading is essential to maintain the required level of safety.

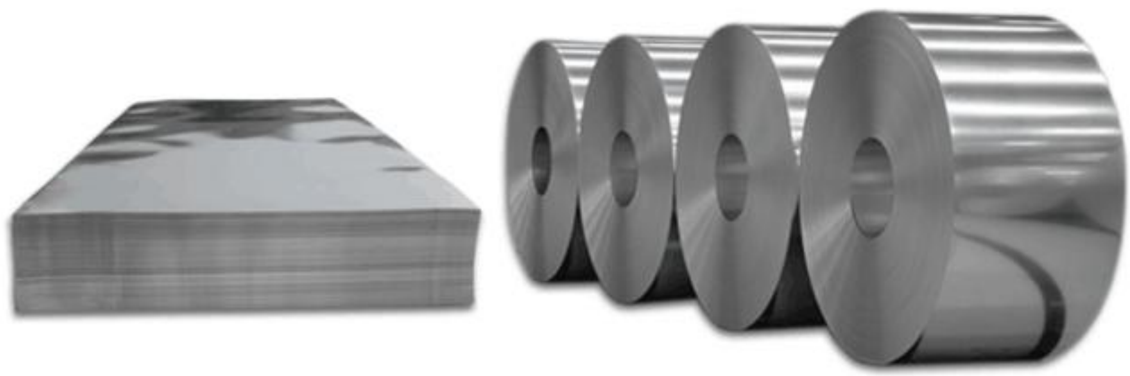
Loading manuals of many ships used in the steel trade that carry coils, contain limited information:

either

- The Max. Tank Top Strength (MT/m2) for uniform loading which however is not advisable criterion for Steel Coils Loading.

or

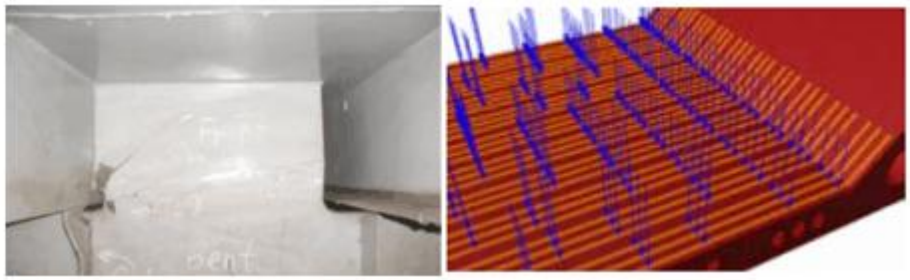
- In the cases where there is some information from the Builders in the Loading Manual, this is usually the bare minimum, e.g. Covers only the case of 2 Tiers of 15t coils, supported by 3 rows of dunnage.



Most operators have adopted the following calculation formula of maximum tonnage per hold on the basis of:

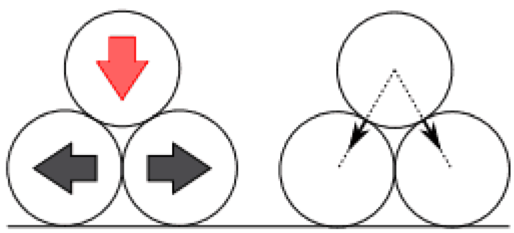
[area of tank top (m^2) x permissible loading tonnes per m^2]

Whilst this is the correct calculation when dealing with homogeneous bulk cargoes, which exert a uniform load on the tanktop**, it is incorrect for steel coils because the load, which they exert, is not uniform**. The crossing point of the coils and the dunnage will give rise to a point load on the double bottom structure. This loading is very different from the uniform loading and will give rise to higher stresses in the tanktop plating as well as the inner bottom longitudinals.



The dominant regulations are CSR-2010 (Common Structural Rules), which consist of the most common method for such calculation adopted by all IACS Members. Nonetheless, the non-CSR built vessels may be regulated by other Class-specific Rules, which do not consider wastage factor in the relevant calculations.

Generally, Class requirements could be considered conservative, as the spirit of the Class requirement is based on the fact that the calculation depends on the worst relative position of coils to the ship's floors. In this respect, the actual Loading of Coils on the entire Tank Top Area may or may not reach the maximum stresses, as allowed by the Regulation.



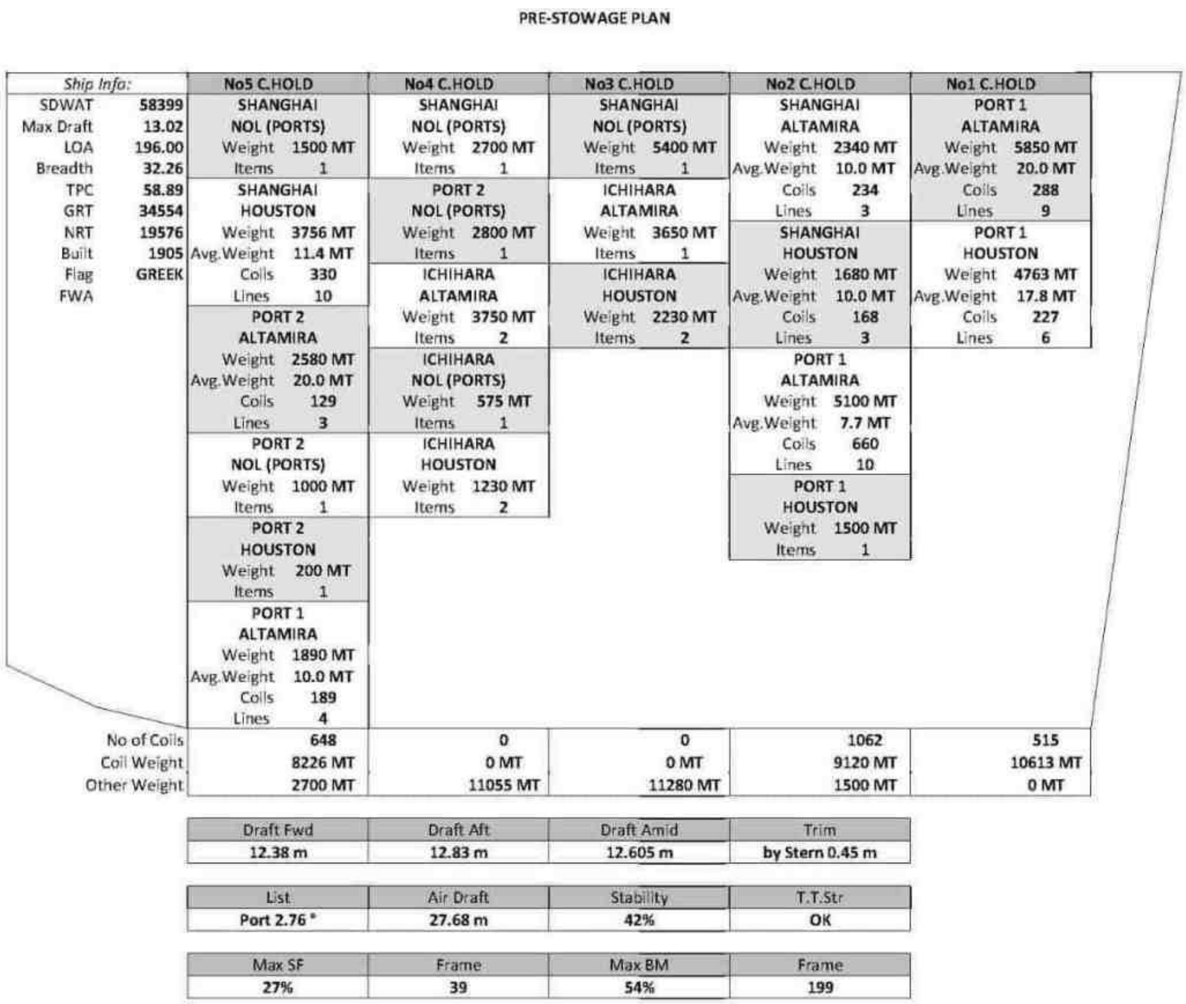
Weight Distribution Example for 1.5 Tier of 15tons Coils

Weight of the top coil is shared equally between the coils lied on Tank Top or 22.5tons Steel Coils Weight

(Average of the Stack)

Concerning the loading of mixed weight / size of coils in each row and/or tier, the involved checks for Steel Coils Loading shall be performed in two levels at first from local strength aspect taking into consideration the Double Bottom Structure & secondly from complete ship loading aspect through specialized Loading Programs covering Longitudinal Strength, Trim, Draughts, Stability, Hold Flooding URS17 etc.) using sophisticated tools with printout, as the one indicated below.

Therefore, provided that the lowest/first tier of Steel Coils is the one that matters in terms of local strength, the Ship Operator usually checks the entire stack of Coils based on the Dimensions of the lowest/first tier Coil (Length & Diameter), using as Coil Weight the average of the stack. Attention should be drawn to the applicable Common Structural Rules that apply officially taking into consideration one type of Coil for the entire .



Specialist software available for pre-stow plan assessment with steel products

used in conjunction with the ship's loading instrument

In case of multiple types of Coils, it is, usually, sufficient for Ship Operator to randomly check the heaviest/shortest coil to arrive at safe operational day-to-day decisions. Following this check (Local Strength Aspects), the Ship Operator may proceed with the entire Pre-Stow Plan check as General Cargo using the vessel's approved Loading Program.

When loaded in a ship's hold, steel coils are placed on dunnage. Dunnage has two functions, to spread the steel's load uniformly in relation to the ship's structure and to provide frictional resistance. One inch thick softwood dunnage is often used with steel coils. Dunnage can be a mixture of imperial and metric measurements, with 8 inch by 1 inch planks used with steel coils. 60mm by 80mm is used with steel plate and bars, and 6 inch by 4 inch is used with heavy steel.

Last but not least, compliance with stowage, securing and lashing principles should be, always, assured.

To conclude with, when carrying steel products by sea, it is essential to ensure that neither the steel nor the ship suffers damage. Its weight presents substantial challenges with overstresses, stowage and securing. The ship must be fit with the appropriate tools to check receivability of the cargo and the safety best practices of stowage, securing and lashing plans.

Disclaimer: This post is not meant to be an authoritative writing on the topic presented. thenavalarch bears no responsibility for the accuracy of this article, or for any incidents/losses arising due to the use of the information in this article in any operation. It is recommended to seek professional advice before executing any activity which draws on information mentioned in this post. All the figures, drawings and pictures are property of thenavalarch except where indicated, and may not be copied or distributed without permission. The views, information, or opinions expressed during series are solely those of the author and do not necessarily represent those of TheNavalArch Pte Ltd and its employees

Author Profile:

Experienced Naval Architect and Marine Engineer (BSc. MSc. (SNAME M)), who has been involved with Marine Operation-Oriented Projects & Software Development (Loading Program Manufacturer) since 1986 and his work distinguished him amongst the significant Marine Consultants and Software Provider in Maritime Industry. He studied in University of Newcastle-upon-Tyne in 1979 being holder of Master's Degree in Naval Architecture and Marine Engineering. He descends from Oinousses-Chios, the origin of an unusual cluster of successful ship-owning families, continuing his legacy as derived from his Masters Mariners generation. Throughout his professional path, he developed collaborations with well-known Corporations (ie. Herbert-ABS in U.S.A.) for evolving projects.

"S. A. MALLIAROUDAKIS MARITIME (UK) Ltd. is an in-house Marine Software and Maritime Consultancy Company that consists of qualified Naval Architects and Marine Engineers and Software & Electrical Engineers providing a wide range of software products and maritime studies & services for day-to-day operations of numerous Shipping Companies."

ARTICLE 5: Designing a stanchion/stopper for sea-fastening of deck cargo

Introduction

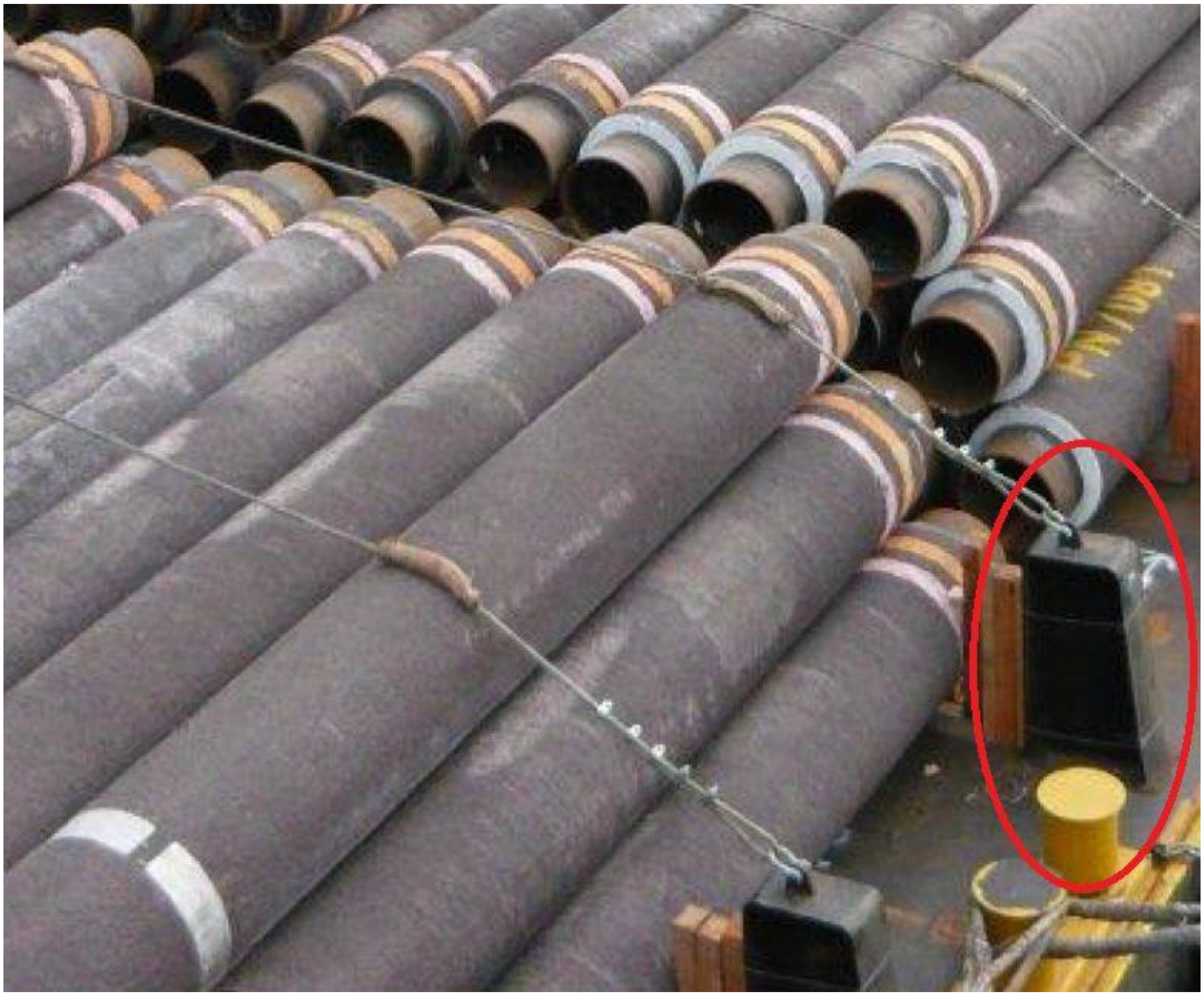
Stanchions – a familiar term for mariners and ship designers. What are Stanchions?

A stanchion is generally a vertical pipe or beam which is used to support some structural item or provide support rails on the deck. In ships, the most common type of stanchion is support rails at the edge of the deck for people onboard to lean on to prevent falling over. It can also be used to support lifesaving appliances like lifebuoys/liferafts etc, and many times reinforced to support heavier structures.

Stanchions for hand rails

Stanchion/Stopper for seafastening

For seafastening of cargo, the stanchion needs to be designed to take the loads on the cargo during seafastening. Basically, the stanchion/stopper is placed at the sides and ends of the cargo to prevent the cargo's sliding in the transverse and longitudinal directions respectively. This can be seen in the figure below:



Stanchion used to support pipes on deck

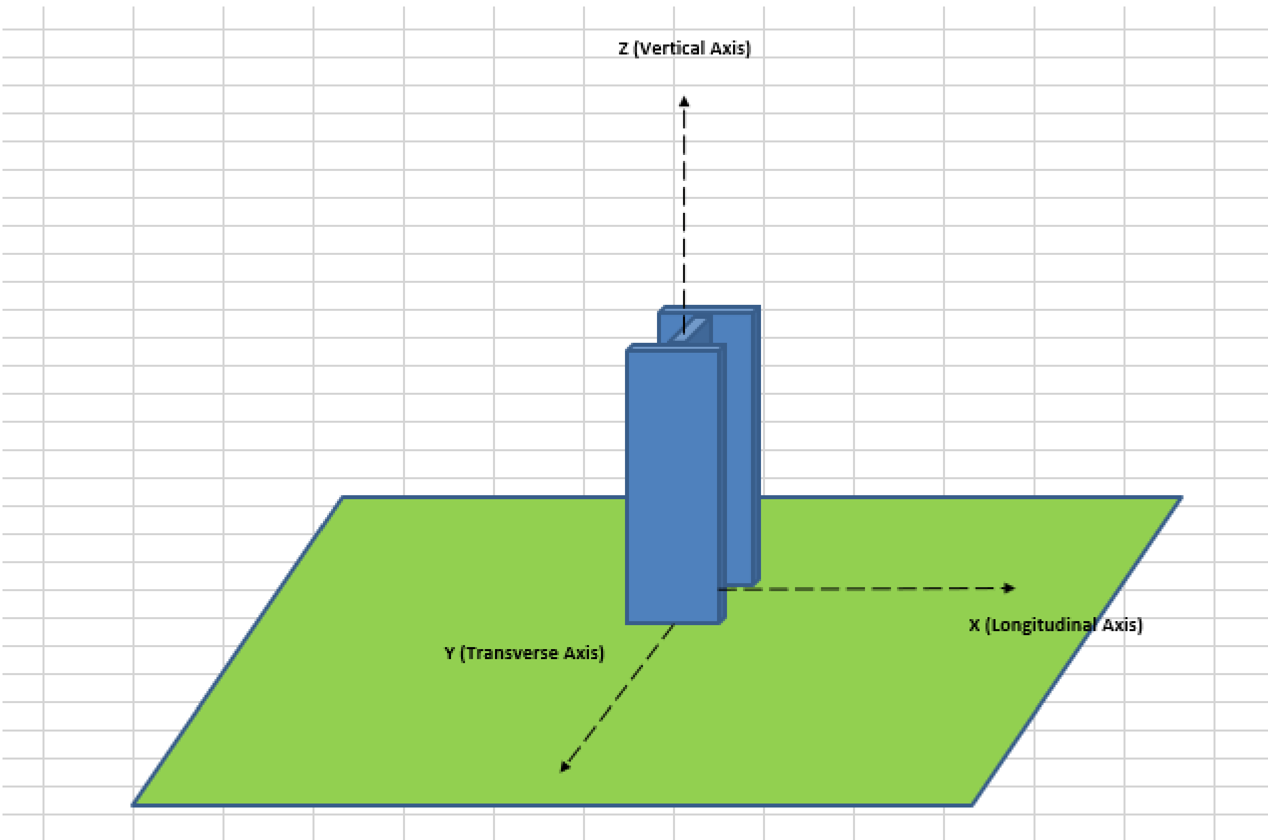
Interchangeably, these stanchions are also called stoppers. However, the stopper is a more generic term and is used to cover other geometries too. For a comprehensive article on stoppers, please check out this article on stoppers.

The most common stanchion used is the H-beam stanchion due to its simplicity. Pipe stanchions may also be used in some cases.

In this article, we will look into the design of an H-beam stanchion and the various stresses that govern its strength.

These principles can be used to assess existing stanchions on the deck of a vessel for their suitability for use with a given cargo too.

A simple H-beam stanchion drawing is shown below:



H-beam Stanchion

In some cases, such a stanchion may be further reinforced at on one side to take greater loads, as shown below:

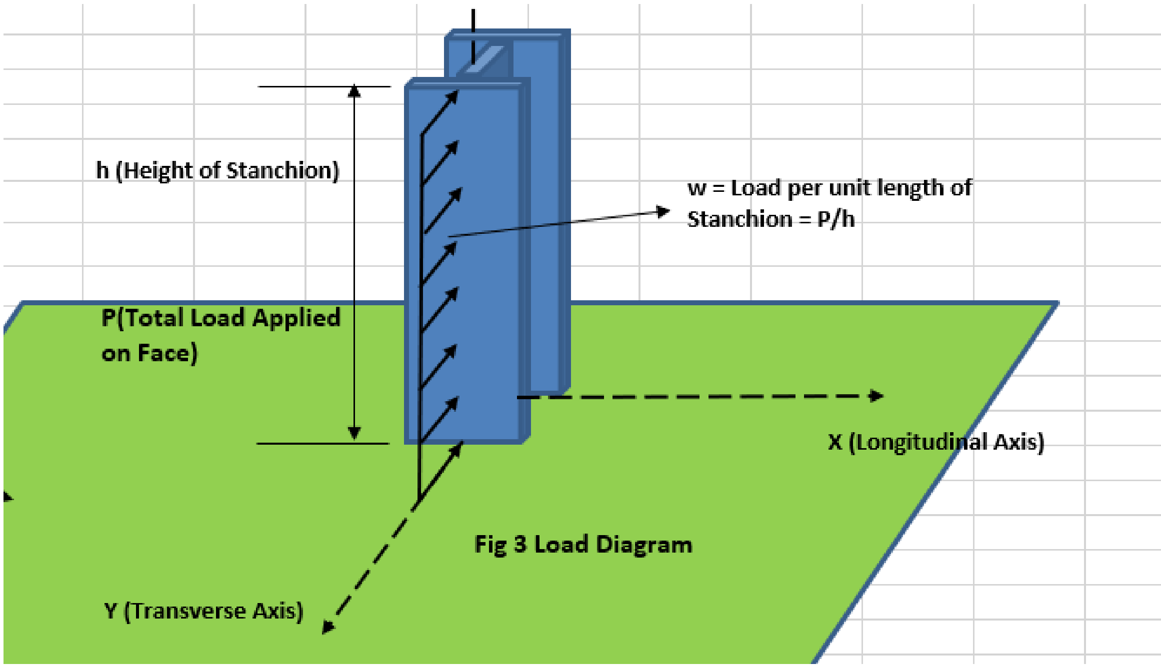
Stanchion with reinforcement at back face

Loads

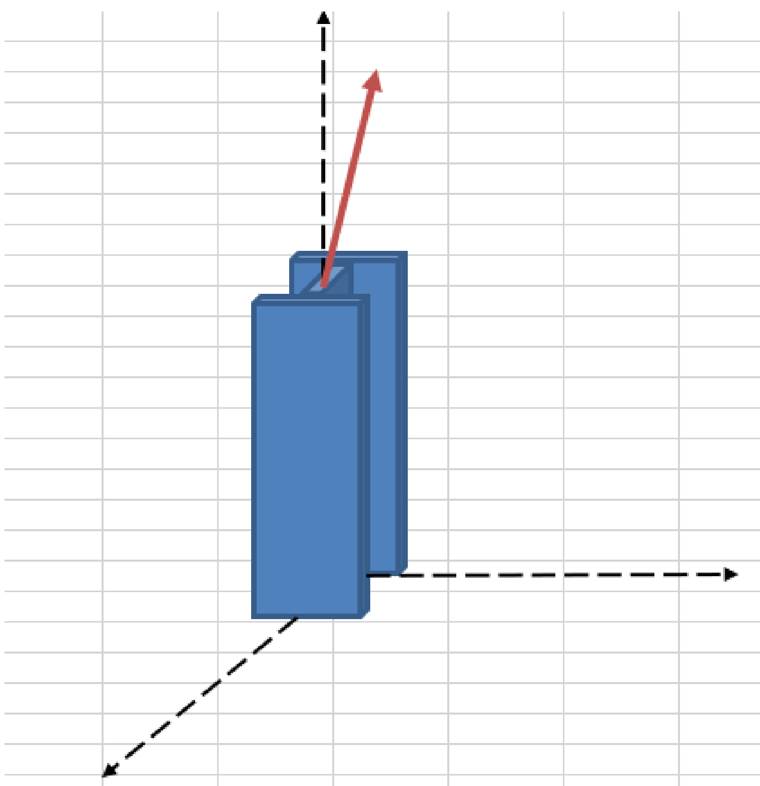
The cargo load on the stanchion can be of two types:

A point load – the stanchion can take a point load if the cargo if fastened to the stanchion using a lashing. In this case, the stanchion generally has an in-built lashing eye, or an external pad-eye can be welded to it (generally at the top) to create the fastening point.

Distributed load – a stanchion takes distributed load when the cargo is resting against it, and full or partial face of the stanchion takes the load.



Stanchion with Distributed Load



Stanchion with point load at the top

Stress Check

In this section, we'll see for the two cases of loading, the applicable stresses, and how to go about calculating them.

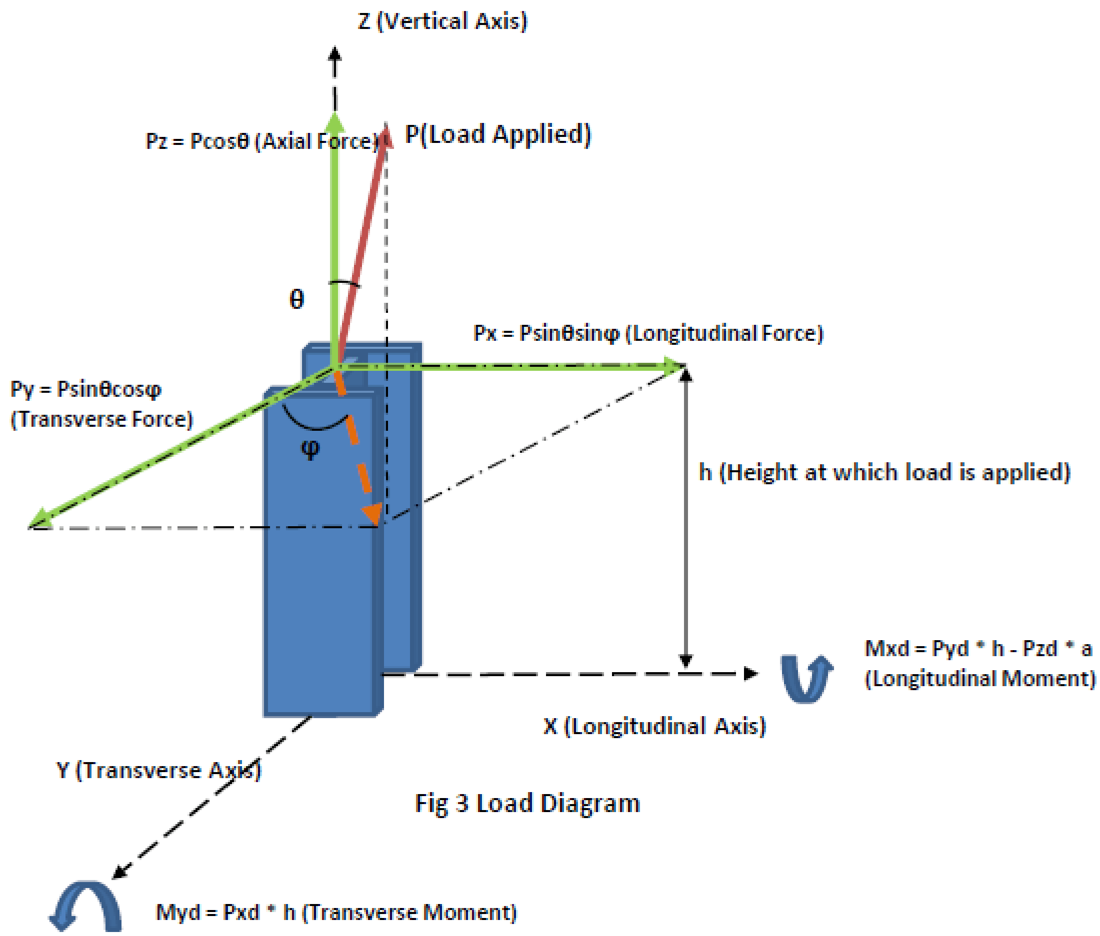
Case 1 – Distributed Load

When the cargo is resting against the face of the stanchion, the total load and stresses on the stanchion can be calculated by the following method:

- Calculate the transverse/longitudinal force on the cargo. The transverse/longitudinal force on the cargo can be calculated using an analysis, or using empirical relations (check out our product Cargo Forces and Accelerations)
- Divide the total transverse or longitudinal force by the number of stanchions in the respective direction. For example, if the total transverse force on the cargo is 100 MT and there are 4 stanchions supporting it, the load on one stanchion in 25 MT
- Calculate the design load per unit length by dividing the load on the stanchion by the total height of the stanchion which takes the distributed load. It is to be noted that not the entire face of the stanchion may take the load, and only the part which takes the load should be taken into account for calculations.
- Calculate the design moment on the stanchion due to the distributed load
- Calculate the section properties of the H-beam section of the stanchion. This includes shear/tensile areas and section moduli about the two axes.
- The stanchion is not subject to axial stress due to no load being in the axial direction.
- The shear stress is calculated by dividing the total transverse/longitudinal load by the shear area
- The bending stress is calculated by dividing the total transverse/longitudinal moment by its respective section modulus.
- Weld Check – it is important to perform strength check for the weld that secures the stanchion to the deck. Similar to the stanchion, shear and bending moment checks need to be performed for the weld too by calculating its shear area and section moduli.

Case 2 – Point Load

When the load on the stanchion is a point load, the steps of calculation still remain the same as for the distributed load, except for the following changes:



Stanchion with point load – force resolution

- The load on an individual stanchion is the load on the lashing between cargo and the stanchion. This load comes from seafastening calculation
- The load on the stanchion will resolve to loads along the three axes of the stanchion as shown below
- These loads will also lead to design moments about both X and Y axes as shown above.
- The stanchion will experience a tensile force as well due to the axial component of the design load
- Out-of-plane bending stresses also need to be checked (for moment about Y-axis)

- A local web-yield check may also need to be performed for stanchions using AISC formula k1-3

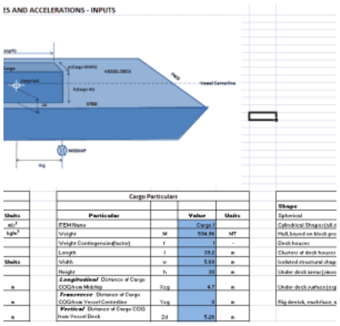
Thus, depending on the type of loading, the stress checks for a stanchion vary. If the stanchion is found to fail in these checks, either a full-fledged FE Analysis may be carried out to further ascertain the suitability of the stanchion, or some strengthening of the stanchion may be recommended.

That brings us to the end of this article on stanchions. Assessing the suitability of an existing stanchion, or designing new ones for a seafastening operation require us to look into every strength aspect of the stanchion in detail.

Please do take some time to explore TheNavalArch's product for stanchion design.

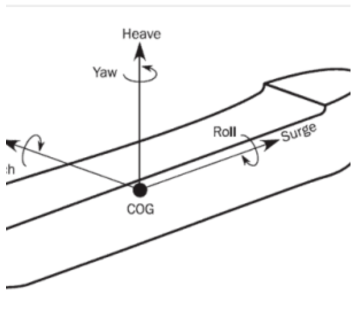
TheNavalArch's Apps for Seafastening Design

TheNavalArch has its own apps to help in various aspects of transportation analysis. Do check them out below:



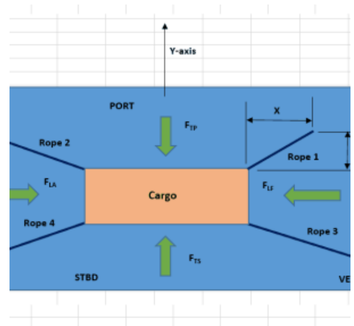
Cargo Forces & Accelerations

Rated **3.00** out of 5

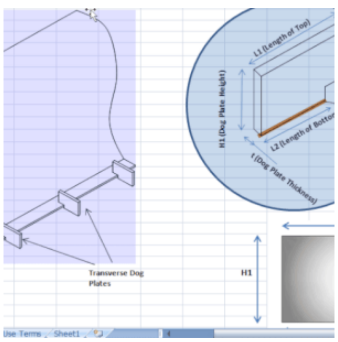


DNV Ship Motion Calculator

Rated **4.00** out of 5

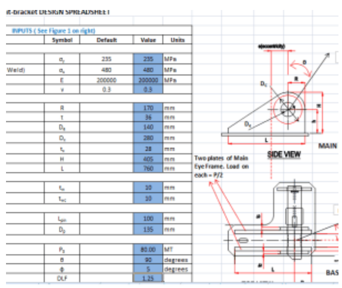


Lashing Design (4 Point Lashing, IMO CSS)



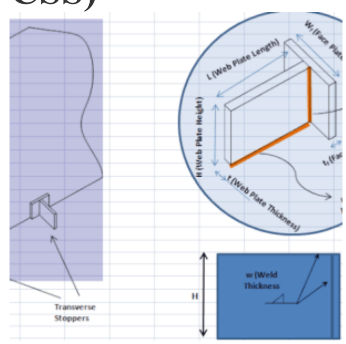
Dog Plate Design Spreadsheet

Rated **4.00** out of 5

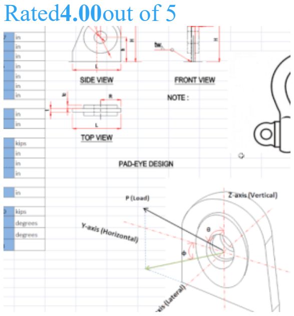


Smit Bracket Design Spreadsheet

Rated **5.00** out of 5

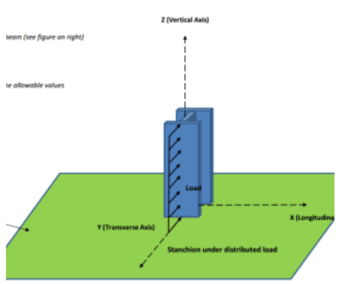


Stopper Design Spreadsheet

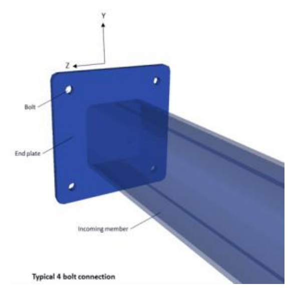


Pad-Eye Design Spreadsheet

Rated **5.00** out of 5



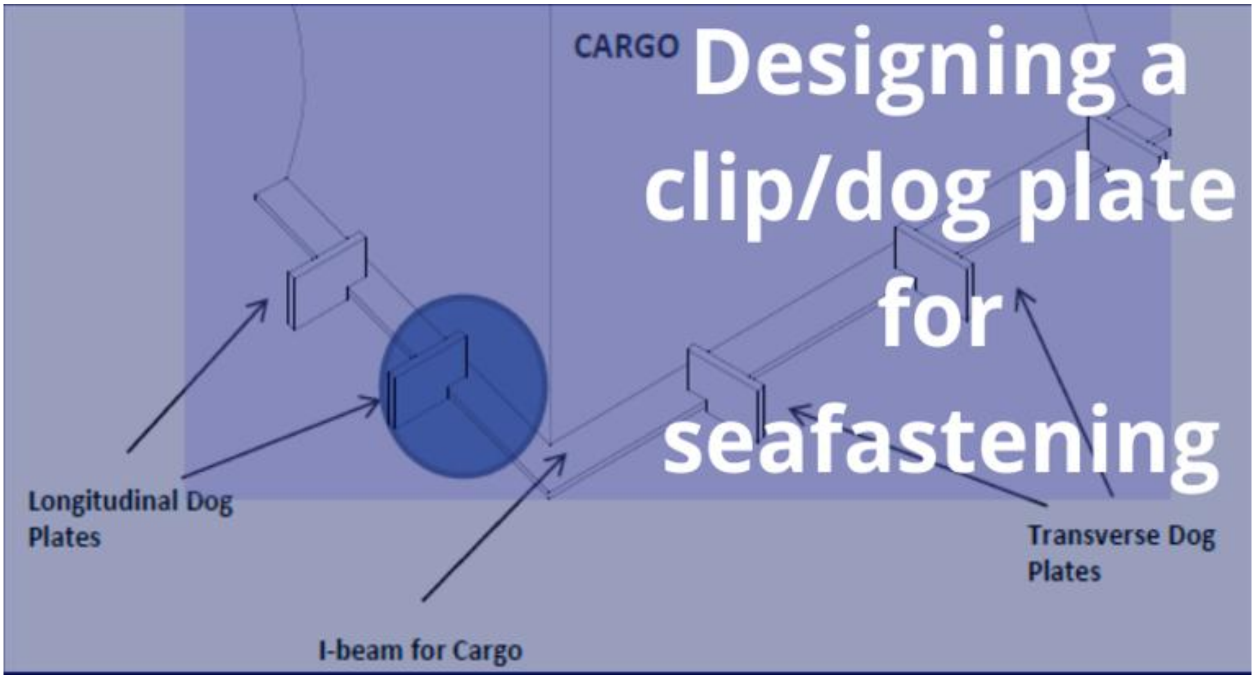
Stanchion Design Spreadsheet



Bolt Check Spreadsheet (based on Eurocode 3)


ENGINEERING SERVICES
Seafastening Design & Marine T&I Expertise
Specializing in deck cargo seafastening design.
MWS-approved engineering for Marine T&I operations.
Loadout, sea transport & installation engineering.
Rigging design and lifting calculations.
Offshore structural design & analysis.
Learn more online
https://thenavalarch.com/engineering-service-thenavalarch/
TheNavalArch Pty Ltd
Suite 405, Level 2,
66 Victor Cres
Narre Warren VIC,
Australia 3805
Ph/WhatsApp: +61432185746
info@thenavalarch.com
TheNavalArch

ARTICLE 6: Designing a clip/dog plate for seafastening



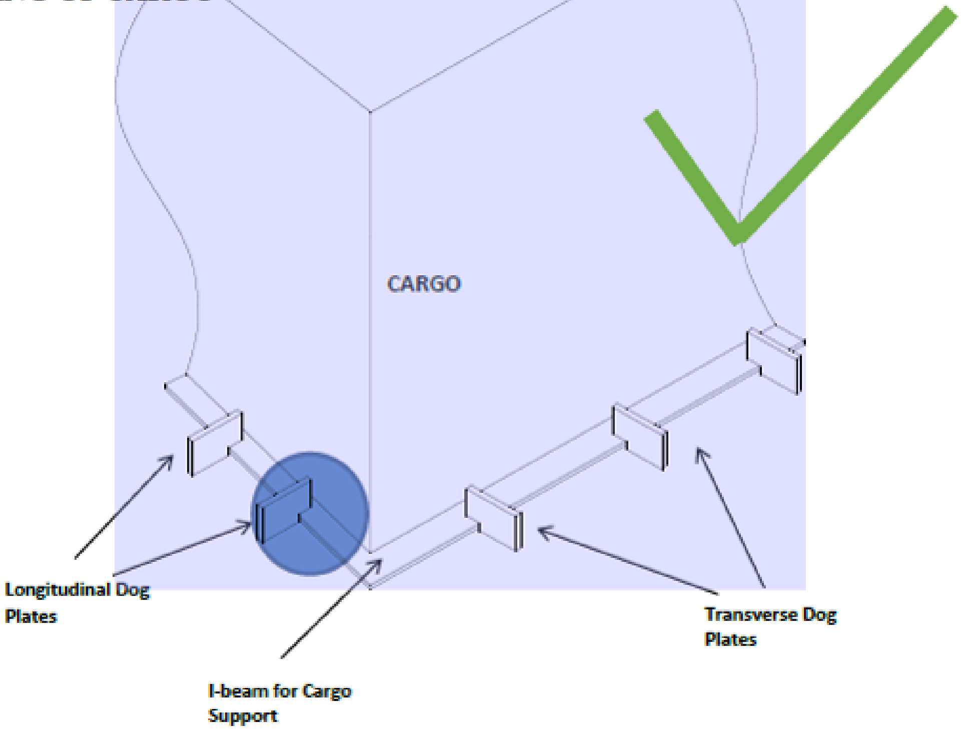
Introduction

In an earlier article, we saw how to design stoppers for seafastening. Stoppers are items that are used to contain the translation movements (longitudinal and transverse directions) of a cargo on the deck/hold of a vessel.

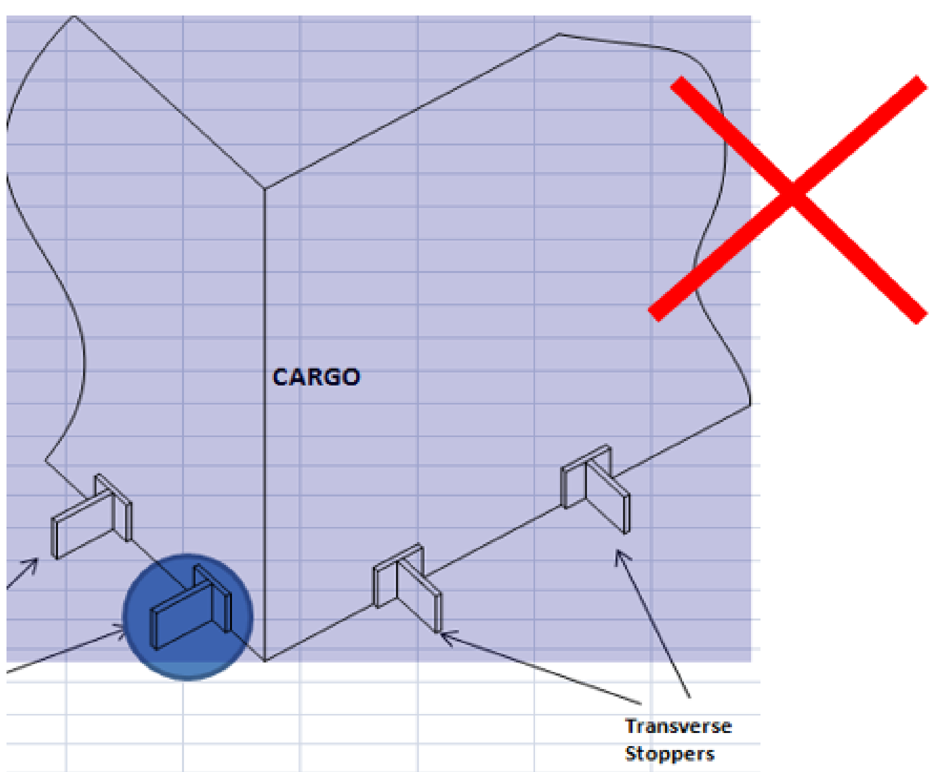
That brings us to the question – what about tipping of the cargo? If the cargo is subjected to external forces that cause it to tip, how do we protect the cargo against tipping?

Thinking in basic terms, to prevent cargo from tipping/overturning, we will need something that pins or clips it to the deck. Such a seafastening item is called a 'Clip' or a 'Dog Plate'. Imagining such an item, it can be an 'L-shaped' structure that clings on to the base of the cargo. If we see the figure below, the dog plate is like a jaw that clamps down on the base frame of the cargo. We can also see that this kind of structure will help prevent the overturning of the cargo, as compared to stoppers which can prevent only translation. At times, both dog plates and stoppers may be used together on the same cargo with dog plates resisting overturning and stoppers resisting translation.

DOG PLATES ARE SUITED FOR CONTAINING TIPPING OF CARGO



STOPPERS ARE NOT SUITED FOR CONTAINING TIPPING



Designing a Dog Plate:

In this section, we'll see how do we go about designing a dog plate for a particular operation.

Any design takes up the following flow:

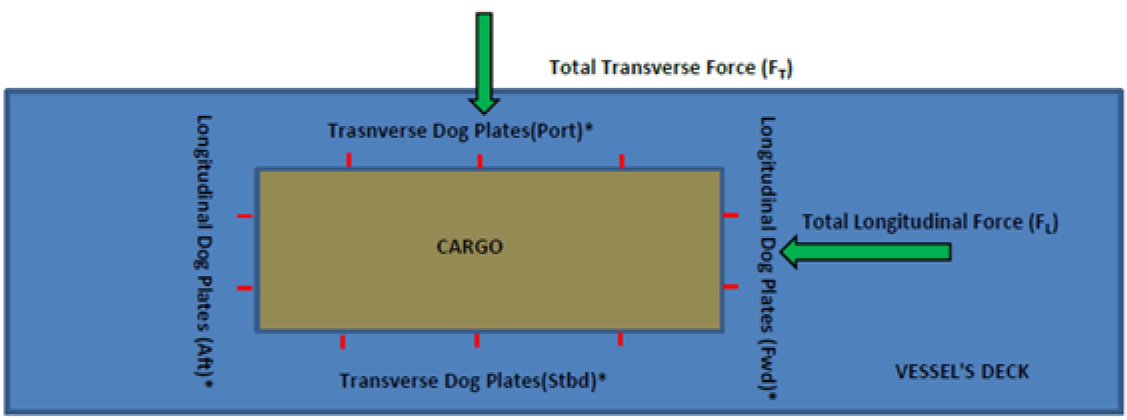
- Evaluate the forces acting on the structure
- Check the stresses on the structure due to the forces
- Iterate the design until the stresses are within the acceptable levels

Forces on the structure:

The cargo on the vessel will experience forces in the three directions – longitudinal, transverse, and vertical (uplift), besides the self-weight of the cargo. The first three forces depend on the environment in which the vessel is operating, and one simple but conservative way of calculating these forces is to follow DNVGL guidelines (See DNVGL-ST-N001, also see our product on Cargo Forces and Accelerations)

Longitudinal or Transverse Forces

In the figure below that shows the plan of a vessel's deck carrying cargo, we can see that there are multiple dog plates in each direction to resist the respective force (transverse or longitudinal).



If the number of dog plates in the transverse direction is nT and the total transverse force on the cargo is FT, then the transverse force on a single dog plate in the transverse direction is

FT1 = FT/nT

Similarly, in the longitudinal direction, the total longitudinal force divided by the total number of dog plates in that direction gives the force on one dog plate.

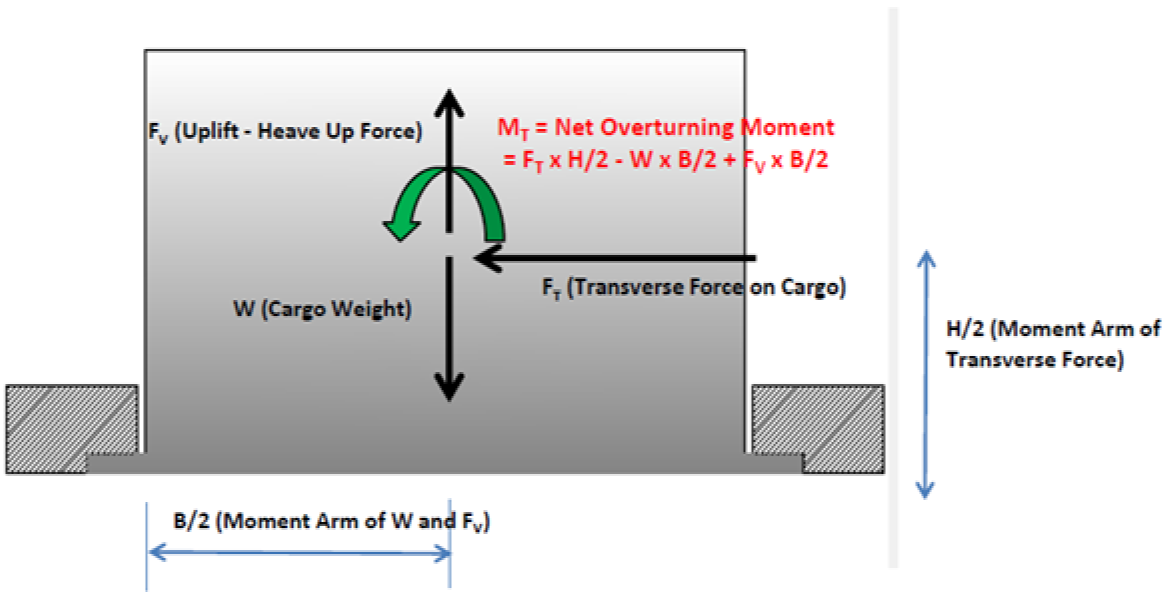
Uplift Force

The uplift force is a vertically upward force due to the cargo motion. It is calculated from a motion analysis or from empirical relations (See our product for Cargo Forces and Accelerations).

Self-Weight of Cargo

The cargo also experiences its own self-weight that acts vertically downwards.

The force diagram of the Cargo can be drawn as below:



We can see that given the location of the dog plate, the following forces and moments will be experienced by it:

The transverse force FT will be borne by all the dog plates.

An overturning moment on the whole cargo, MT, due to FT, Uplift Force, and Self-Weight will also be borne by all dog plates. We can see that while FT and FV will cause the cargo to tip, the restoring moment due to self-weight protects it from tipping.

$M_T = F_T \times H/2 - W \times B/2 + F_V \times B/2$

The above force and moment can be divided by the number of dog plates (nT in the transverse direction) to give the force and moment per dog plate.

$F_{T1} = F_T/n_T$

$M_{T1} = M_T/n_T$

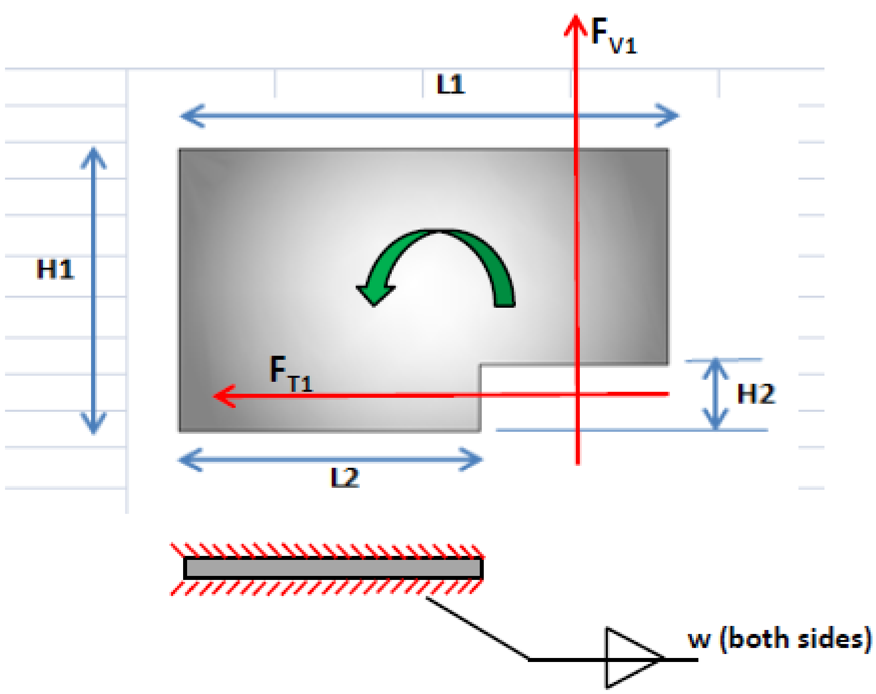
Translation of forces to the Dog Plate

The net overturning moment MT1 on a single dog plate translates effectively to an uplift force on the dog plate due to the moment. Considering the uplift force to be acting at the dog plates on either side, the effective uplift force on each dog plate is

$F_{V1} = M_{T1}/B$

where B is the width of the cargo.

Next, we see the force diagram of the Dog Plate itself:



We can see that the following forces are acting on the dog plate:

- The translation force F_{T1}, which gets directly translated from the cargo
- The uplift force F_{V1}, which occurs due to the overturning moment

Stresses on the dog plate

The above two forces lead to various stresses for which the dog plate needs to be analyzed:

- Shear Stress: The force F_{T1} leads to shear stress on the dog plate
- Tensile stress: The effective tensile force is calculated from the moment of the two forces F_{T1} and F_{V1} about the base, divided by the length of the base, L2.
- Bending Stress: bending moment at the base is calculated by adding the bending moments due to F_{T1} and F_{V1} at the base.
- Weld Check: The weld of the dog plate to the deck also needs to be checked similarly for shear, tensile and bending stresses

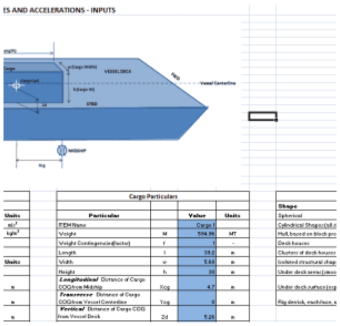
By calculating the forces and moments applicable, the stresses can be calculated, and the suitability of the dog plate evaluated. Some sample calculations are shown below:

DOG PLATE STRENGTH CHECK - TRANSVERSE DIRECTION

Parameter	Symbol	Formula	Value	Unit	
DESIGN FORCES AND MOMENTS					
Total Transverse Force on Cargo	F_T		178.31	MT	
Weight of Cargo	W		331.00	MT	
Net Uplift (Heave Up) Force on Cargo	F_V		145.04	MT	
Net Transverse Overturning Moment on the Cargo (See Fig)	M_T	F_H x H/2 - W x B/2 + F_V x B/2	143.85	MT-m	
No. of Dog Plates in Transverse Direction	n_T		45		
Transverse force on one Dog Plate	F_{T1}	F_T/n_T	3.96	MT	
Overturning Moment on one Dog Plate	M_{T1}	M_T/n_T	3.20	MT-m	
Uplift force due to overturning Moment on one Dog Plate (is applicable only if overturning moment is positive)	F_{V1}	M_{T1}/ B	3.76	MT	
Section Modulus of Web Plate Bottom	Z_s	t x $L2^2/6$	132250	mm^3	
Moment arm of Transverse force F_{T1}	r_{T1}	H2/2	21	mm	
Moment arm of Uplift force F_{V1}	r_{V1}	L2/2 + (L1-L2)/2 = L1/2	142	mm	
Effective Tensile Force	F_{TEN}	$(F_{T1} \times r_{T1} + F_{V1} \times r_{V1})/L2$	2.68	MT	
Moment of Tensile/Uplift forces	M	$(F_{T1} \times r_{T1} + F_{V1} \times r_{V1})$	0.62	MT-m	
STRENGTH CHECK (Transverse Direction)					
Shear Stress on Dog Plate	τ_S	F_{T1} / A_s	11.27	MPa	OK
Tensile Stress on Dog Plate	σ_T	F_{TEN} / A_s	7.63	MPa	OK
Bending Stress on Dog Plate	σ_B	M / Z_s	45.79	MPa	OK
Von Mises Stress on Dog Plate	σ_V	$\{(\sigma_T + \sigma_B)^2 + 3\tau_S^2\}^{1/2}$	56.87	MPa	OK

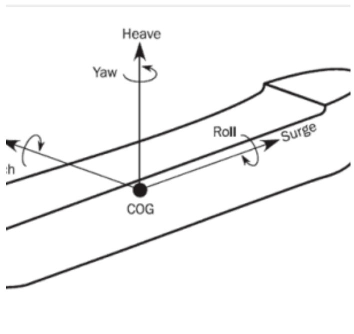
TheNavalArch's Apps for Seafastening Design

TheNavalArch has its own apps to help in various aspects of transportation analysis. Do check them out below:



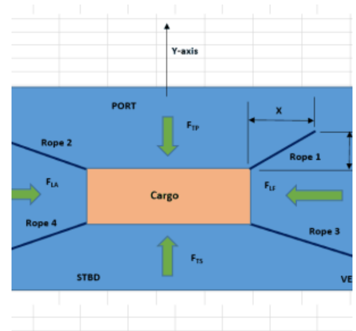
Cargo Forces & Accelerations

Rated**3.00**out of 5

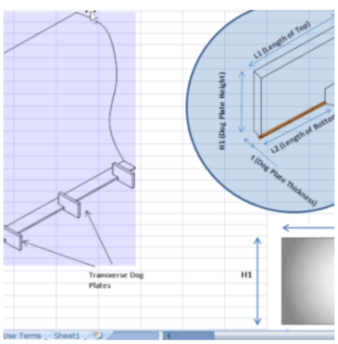


DNV Ship Motion Calculator

Rated**4.00**out of 5

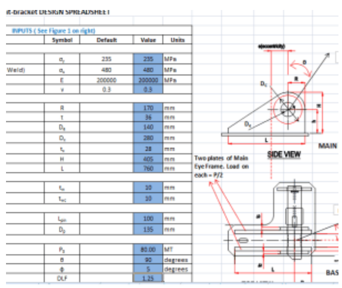


Lashing Design (4 Point Lashing, IMO CSS)



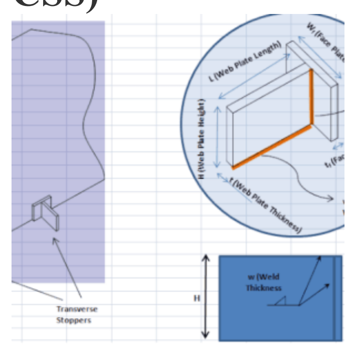
Dog Plate Design Spreadsheet

Rated**4.00**out of 5

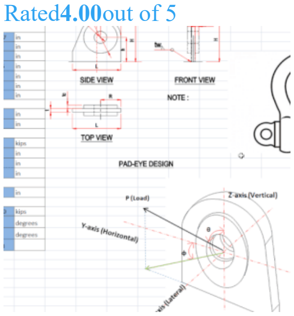


Smit Bracket Design Spreadsheet

Rated**5.00**out of 5

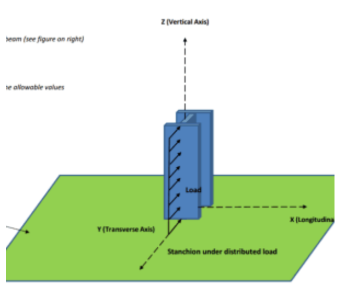


Stopper Design Spreadsheet

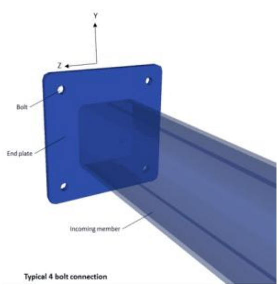


Pad-Eye Design Spreadsheet

Rated**5.00**out of 5

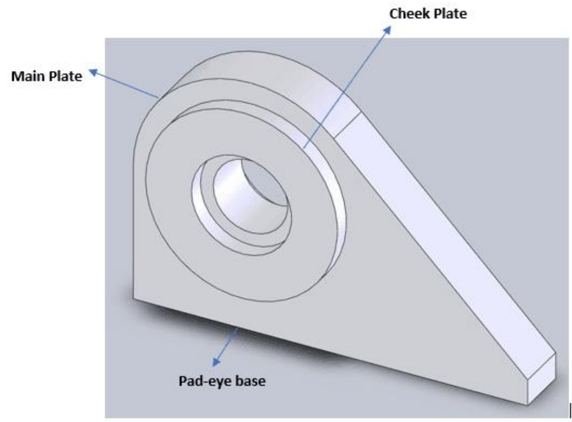


Stanchion Design Spreadsheet



Bolt Check Spreadsheet (based on Eurocode 3)

ARTICLE 7: Designing a pad-eye: little items with big intricacies



Introduction

Pad-eyes are one of the smallest and most universally used structural items in the maritime and Oil & Gas industry. They are used for a variety of purposes too: from a simple seafastening of a cargo to deck of a vessel, to complicated lifting operations involving multiple lifting points. Simple as they may seem, pad-eyes vary a lot in their geometry depending on the purpose they are being used for. When they are used for lifting purpose, they are also called as lifting lugs.

The basic purpose of a pad-eye is to provide a point to which a rope or wire can be fastened, directly or through a shackle. The other end of the rope/wire can be fastened to another pad-eye located elsewhere, or it may be used for lifting.

Let's understand it with an illustration. On ships, the most common purpose of a pad-eye is to fasten a cargo to the deck of the ship. The most common way we can fasten a cargo to deck is to tie it to deck using ropes or wires. The question arises – which point on the deck do we tie it on? What should the connection point look like? Thinking in very basic terms, the connection point should have a slot through which the rope/wire can pass. Also, the connection point should be welded to the deck. The most common connection points used are pad-eyes, as can be seen in the picture below:

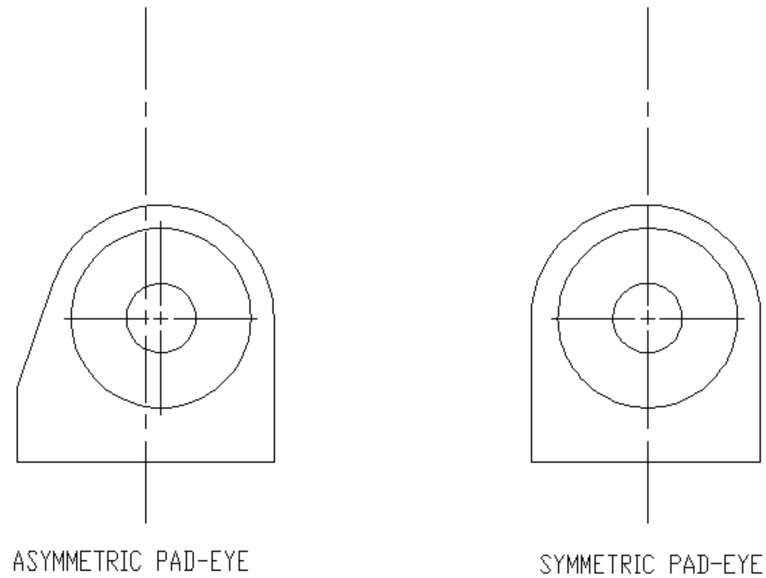
Pad-eye used for lashing cargo to deck

The connection point on the cargo to which the other end of the rope/wire is connected, can also be another pad-eye.

Shape and Size Variations

Size variations for pad-eyes are quite obvious. An operation which imposes higher loads on the pad-eye will require a bigger sized pad-eye. For example, to lift a 1 ton Cargo using single point lifting, the pad-eye size will be much smaller compared to the case with a 10 ton Cargo.

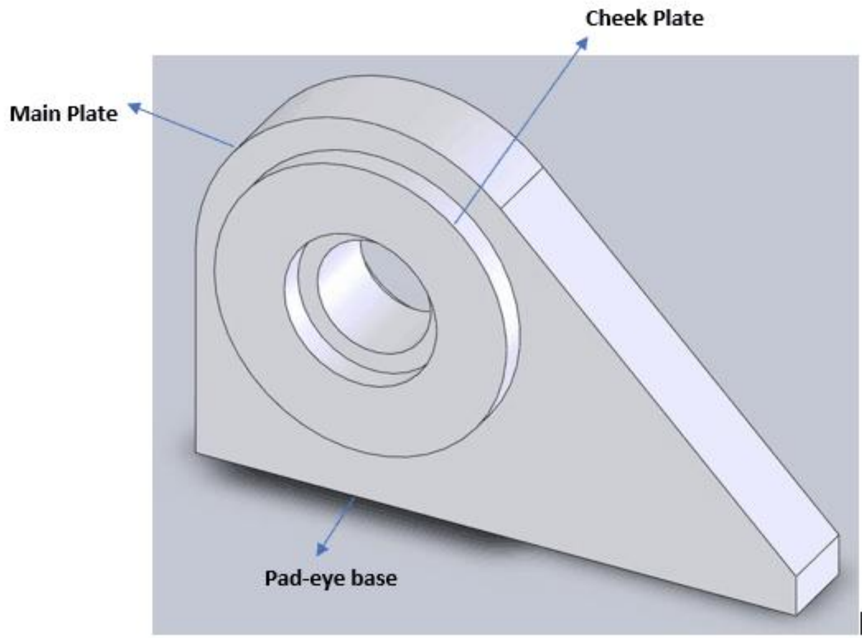
Pad-eye shapes can vary depending on use. When there is only a vertical load expected on the pad-eye (e.g., lifting operations with lifting sling completely vertical), then the pad-eye is generally symmetrical in design. Symmetrical pad-eyes may also be used for sling angles of upto 60 degrees with the horizontal/base of pad-eye. However, if the sling angle with the base of the pad-eye is expected to be less than 60 deg, then an asymmetric pad-eye is recommended.



Asymmetric-vs-Symmetric-Pad-eye

A typical design

In this section, we will present a typical design of an asymmetric pad-eye with single cheek plate on either side, used for lashing operation. It looks like the one shown in picture below:



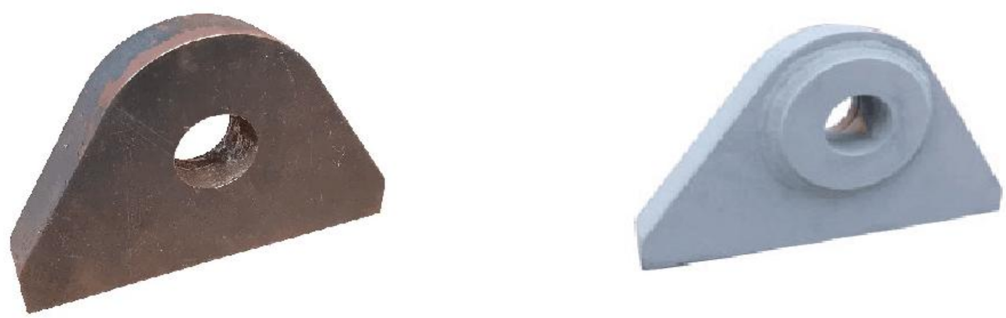
3D view of an Asymmetric Pad-eye

We can see that the pad-eye has three distinctive features:

- The main plate – this is the asymmetric plate with an eye-hole through which the rope passes.
- The pad-eye hole – this is the slot through which the wire/rope passes. The size of the hole is determined by the size of the rope which has to pass through it.
- The cheek plates – not a necessary feature, these are round shaped plates which are welded to the main plate to reinforce the main plate around the hole. The maximum stress region is around the hole, so cheek plates serve to strengthen only this region and save material which would otherwise have been wasted on a thicker main plate. Pad-eyes can also be without cheek plates, and they may also come with two cheek plates on either side.

The base of the pad-eye is generally welded to the item to be lashed against. It can be the deck of the vessel, or it can be the cargo. The base weld of the pad-eye is a critical element in the entire design, and needs to be assessed for the different stresses it experiences.

Following pictures show different pad-eyes with and without cheek plates.



Pad-eye without cheek plate **Pad-eye with single cheek plate on either side**

Pad-eyes with and without cheek plate (sources: alphaweld.com.au, lifting.com)

Design Calculations

Let's now analyze a simple asymmetric pad-eye with cheek plate on either side, and under an external load. A simple figure of the pad-eye with load is shown below:

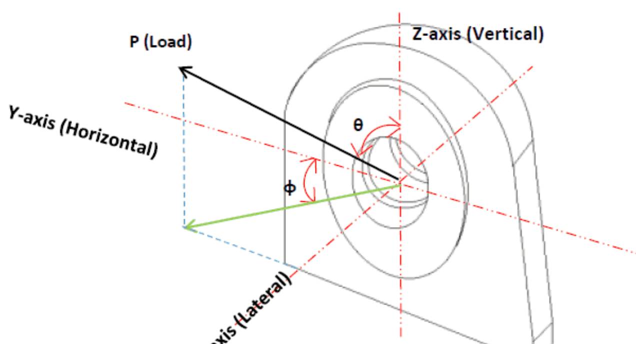


Fig 1: Pad-eye Geometry and Load

A 3d model of a pad-eye with load

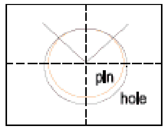
For easily resolving the forces on the pad-eye, we have adopted a 3-dimensional axis system. The horizontal axis is along the length of the pad-eye, the lateral along the width and the vertical along the height of the pad-eye. The origin of the coordinate system is at the centre of the hole. We can see in the picture above that the load on the pad-eye is P, and the load is not along the horizontal axis of the pad-eye. The load is at an angle to both vertical axis (Z-axis) and and the horizontal axis (Y-axis). The horizontal axis (Y-axis) is the weak axis and the lateral axis (X-axis) is the strong axis, and we can see that there is an 'off-axis' load on the pad-eye along the X-axis. Considering the off-axis load in the design is quite critical, as it may lead to very high stresses due to bending along the weak axis. Generally, even if the entire load of the pad-eye is expected along the horizontal axis, a rule of thumb to design the pad-eye for at least 10% of the load acting along the lateral axis, or by taking the load acting at an angle of 5 degrees (angle φ in the picture above) to the horizontal axis.

Stresses

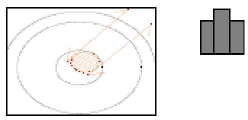
There are different kinds of stresses which different parts of the pad-eye are subject to. Let's analyze them one by one:

The Pin Hole – the immediate point of application of the force is the pin hole of the pad-eye. The hole undergoes multiple types of loadings and these cause different stresses. Let's examine them below

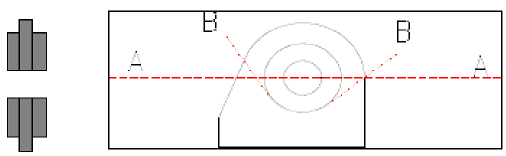
- Bearing Stress: The lashing rope goes through the pad-eye either directly or through a shackle. The diameter of the rope or the shackle will be lesser than that of the hole, and this will create a 'bearing' pressure on the hole, as seen in the picture below. The area which is highlighted as the arc of contact between the pin and the hole is the bearing area. The stress is calculated by dividing the pad-eye load by the bearing area
- Shear Stress: The load also causes a pull effect along the surface of cheek and main plates which causes shear on the pad-eye and may cause deformation. The shear area is the radial sectional area of the main and cheek plates combined together, as shown in the figure below. The stress is calculated by dividing the pad-eye load by the shear area.
- Tensile Stress: The load also leads to a volumetric stress through the body of the pad-eye, with the load acting perpendicular to the area under stress. In this case, the section area is the area of section A-A as shown in the picture below.
- Contact Stress (or Hertz stress): Contact stress is the stress arising out of contact between two objects of curved surfaces. We can see that the pin and the hole are curved surfaces in contact with each other. The stress which resutlts from this is a highly concentrated stress because the contact area is very small (theoretically, it is just a line in this case). This is a very important stress component to be checked for a pad-eye and is checked according to Roark's formula as shown below



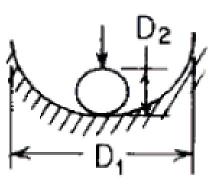
Bearing Contact Area (Assumed at an arc of 90 degrees)



Shear stress area at pin hole



Tensile stress area at pin hole



$$K_D = \frac{D_1 D_2}{D_1 - D_2}$$

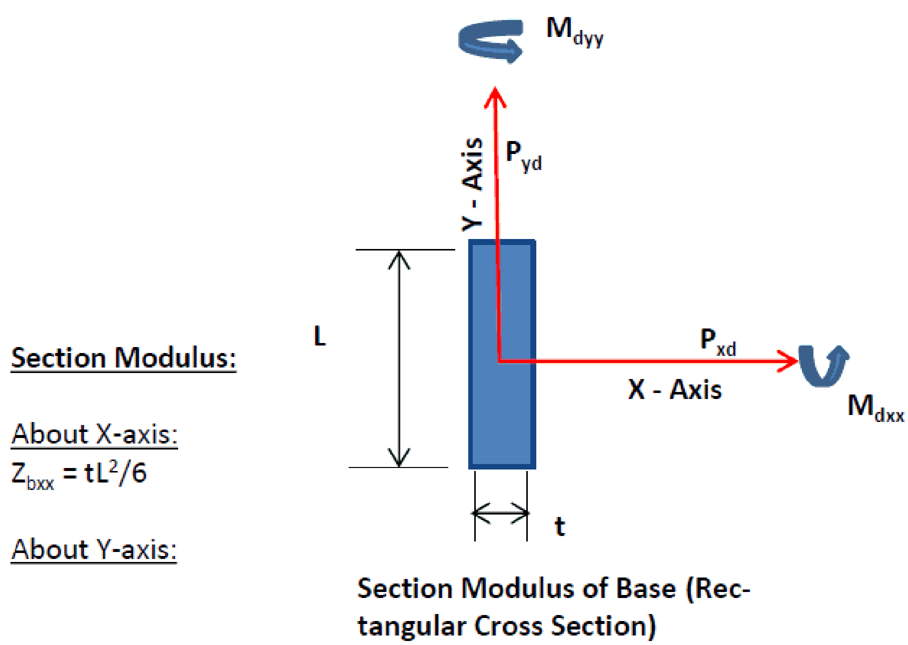
$$(\sigma_c)_{\max} = 0.591\sqrt{\frac{pE}{K_D}}$$

Contact/Hertz Stress at Pin Hole

Various stresses on padeye hole

The Main Plate – the main plate of the pad-eye is subjected to the load which is transferred to the base of the plate where it is welded to the deck of the vessel. There are three types of stresses which the main plate is subject to:

- Tensile stress: tensile stress is caused by the component of the force which is perpendicular to the horizontal section of the base plate, i.e., the vertical component. The bearing area is the area of the base, and stress is calculated from the vertical component divided by the base area.
- Bending Stresses: The force on the pad-eye, when resolved in the three directions, causes bending moments on the pad-eye as well. The component of the force along the horizontal (Y-axis) will make the main plate bend along its strong axis. The vertical force, if not passing exactly through the middle of the base, will add to the moment along the strong axis, while the lateral load will make the plate bend along the weak axis (Y-axis). The stress will be calculated by dividing the moment by the section modulus of its corresponding axis.
- Shear Stresses: Since the plate is loaded in both horizontal and lateral directions, shear stress is calculated in both directions. The shear area is the area of the base
- Von Mises Stress: The Von-Mises Stress is also calculated as a combined body stress on the pad-eye.

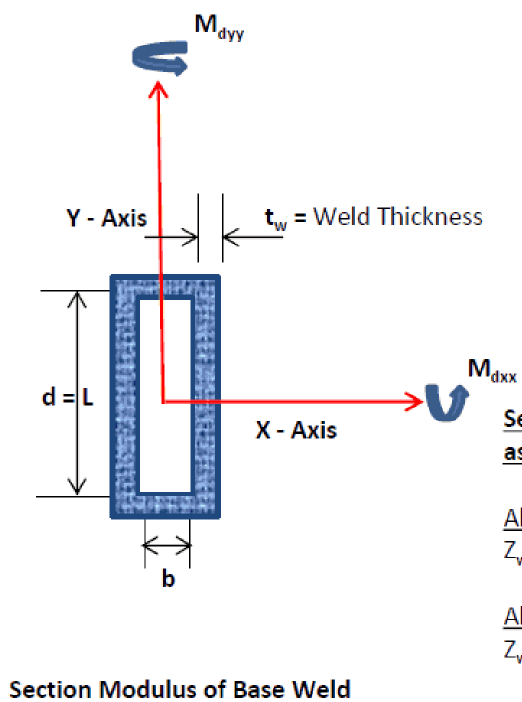


Bearing Area and Forces/Moments on Main Plate

The Base Weld – the base weld of the pad-eye secures the pad-eye to the deck of the vessel. As such, the loads on the pad-eye are transferred to the base weld. Similar to the main plate of the pad-eye, the base weld is subject to the following:

- Tensile stress – the tensile stress on the weld results from the vertical component of the force. The weld bearing area is calculated by multiplying weld throat size with weld length. The stress is calculated by dividing the vertical component of the force by the bearing area.
- Shear Stress – The weld is also subject to shear stresses due to the horizontal and lateral components of the pad-eye load. The bearing area is same as for tensile stress.
- Bending Stresses: similar to the main plate, the weld at base is subject to moments due to the three components of the forces. The moments are about the horizontal and lateral axes. These moments cause bending stresses which can be calculated by dividing the moment by the section modulus of the weld in the respective direction.

The cheek weld: The cheek plate is welded to the main plate with a circular weld. The load on the pad-eye can be considered to apply on the cheek weld in proportion to its thickness compared to the pad-eye's thickness (2 x cheek plate thickness + main plate thickness). The weld area is the throat size x curcumference of the cheek weld. The stress is calculated by dividing the proportional load by the weld area.



Section Modulus (treating the weld as line):

About X-axis:
Z_{wbxx} = $(bd + d^2/3) \times t_w$

About Y-axis:
Z_{wbyy} = $(bd + b^2/3) \times t_w$

Bearing area and forces/moments on base weld

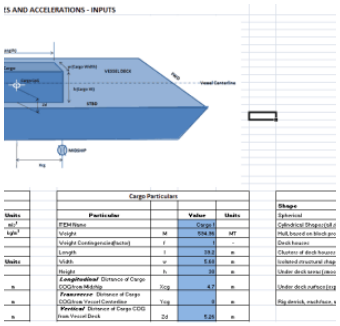
In some cases of pad-eyes being used for heavy duty applications like heavy-lift or transport of heavy cargo, a simple check may not suffice and a full fledged FE Analysis in a tool like ANSYS may be needed.

That brings us to the end of this article. While pad-eyes may look small, their design involves multiple checks and intricacies which come into play depending on the geometry and usage of the pad-eye. Whether designing a new pad-eye from scratch or evaluating an existing pad-eye for suitability to a particular operation, these factors need to be considered carefully for a successful operation.

Please do check TheNavalArch's apps for Seafastening Design on the next page.

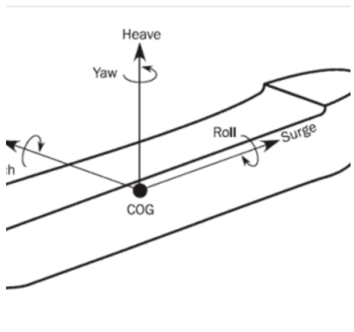
TheNavalArch’s Apps for Seafastening Design

TheNavalArch has its own apps to help in various aspects of transportation analysis. Do check them out below:



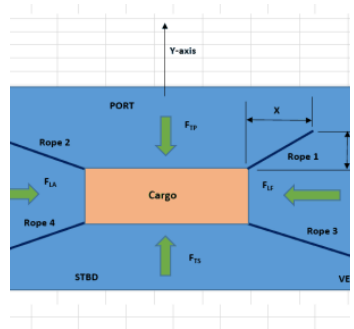
Cargo Forces & Accelerations

Rated**3.00**out of 5

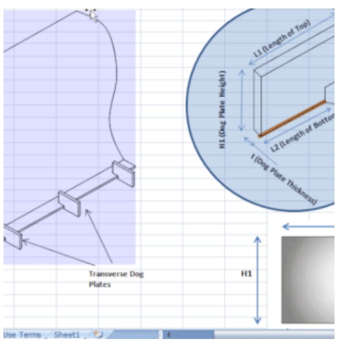


DNV Ship Motion Calculator

Rated**4.00**out of 5

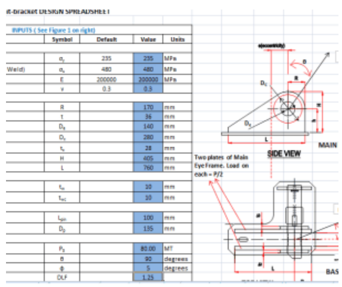


Lashing Design (4 Point Lashing, IMO CSS)



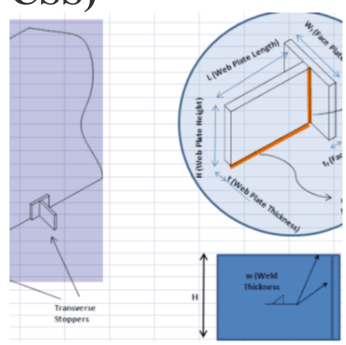
Dog Plate Design Spreadsheet

Rated**4.00**out of 5

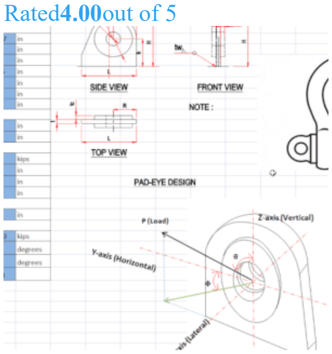


Smit Bracket Design Spreadsheet

Rated**5.00**out of 5

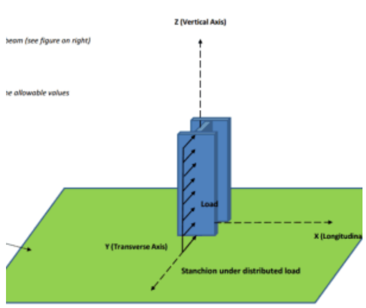


Stopper Design Spreadsheet

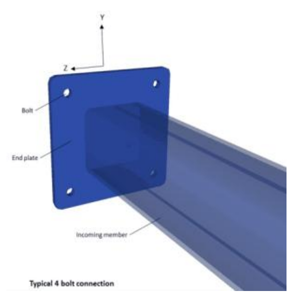


Pad-Eye Design Spreadsheet

Rated**5.00**out of 5



Stanchion Design Spreadsheet



Bolt Check Spreadsheet (based on Eurocode 3)