Ship Production Rigging Planning Guide

Shipyard Production Process Technology Panel

An Undertaking into the Improvement of Shipyard Rigging Standardization and Documentation of Current Practices

National Steel and Shipbuilding Company

Initial Design & Naval Architecture

Issued: JULY 2009 – Revision (-)

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EXECUTIVE SUMMARY

The main objective of the Rigging Planning Guide is to provide Engineers with a summary of applicable standards, regulations, and rigging practices which can be incorporated towards developing rigging guidance documents and processes for a shipyard. The goal is to provide some of the necessary material to create a knowledgeable rigging engineer work force that in turn can increase safety, reduce distortion of blocks during lifting, and keep the rigging process more efficient. The main guidance information produced was in three parts for quick and easy information access:

- Lift Check Sheet
- Approach Lift Guidance
- Rigging Lift Common Component Catalog

The Lift Check Sheet is a quick reference sheet providing a list of questions or checks which a rigging Engineer should consider before carrying out a lift design. The check list first explains the concept of a critical lift in detail but can be briefly summarized as a lift of an item that is unique, irreplaceable, and vital to a program that would have severe negative impacts including, the delay of operations and affect program commitments if damaged or upset. Different shipyards and organizations have their own definitions of critical lifts but in essence all large high value units in a shipyard are critical. The Lift Check Sheet is then divided into the following sections: Load Weight and center of Gravity, Cranes and Operation, Lifting Attachments, Environmental Considerations, Spreader Bar, Padeye, Shackles, and Slings, with question pertaining to the design of a lifting arrangement for those items.

The Lift Check Sheet is explained in detail by the Approach Lift Guidance document to which an Engineer can turn when the answer or ramifications of a question posed in the Lift Check Sheet is not apparent. This document provides an explanation of each question from the Lift Check Sheet stating the reason for its importance while providing the Engineer with background information and some simplified examples.

The Rigging Lift Common Component Catalog supports the previous documents by providing information on the range of common rigging equipment. The sequence is arranged from the first equipment which attaches to the load, padeyes, shackles, slings, chain falls, spreader beams and finally cranes. The aim of each section is to provide general information on the components and give a detailed review of regulatory requirements and standards for rigging both outside and inside the shipbuilding industry. General properties and behaviors of the components are also provided, however, because of the wide range of equipment and constant improvements in technology, each shipyard should have its own catalog with data geared specifically for the type of equipment they use.

PROPOSED SHIPYARD STANDARDS FOR THE
LIFTING OF SHIP STRUCTURE

Some of the most comprehensive standards for rigging hardware and lifting related equipment are produced by the American Society of Mechanical Engineers with the B30 series on cranes and related equipment.

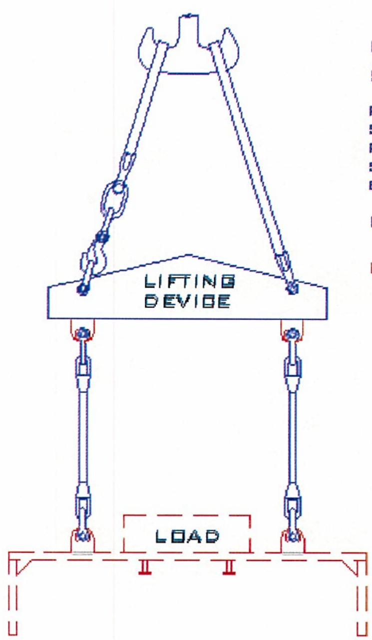
Currently the ASME Design of Below-the-Hook lifting devices BTH-1-2008 standards are confined to covering lifting devices and does not cover the load or padeye, the latter of which it categorizes as a lifting attachment. The standard specifically covers lifting devices used to lift solid objects by clamping, griping, cradling, holding, and the use of magnetic or vacuum attachment to loads to support their weight, such that they can be safely lifted.

If a lifting point is secured to the load it is not considered a device but an attachment. This causes come confusion as a lifting attachment and a lifting device in the end may have the same result but different methods of doing so. There is some indication the BTH committee is seeking to consolidate the different definitions by extending the scope of the standards in the future to cover both lifting devices and attachments.

This would be a reasonable approach as both a lifting device and a lifting attachment facilitate the lifting of a load. Furthermore attachments such as padeye are really no different than pin connections for which recommendations are provided by the standards. Unfortunately deciding where the padeye ends and the load begins may not always be clear, but the application of good Engineering practice should result in all components be sound in accordance with their probability of failure and the results of their failure. If any part of a load were to buckle, fold, or otherwise collapse the result would change its shape and center of gravity, which would inevitably place unintended loads on the attachment points. The resulting loading conditions possible were most probably never intended or designed for and could lead to the failure of the lifting attachments resulting in the endangerment of the well being of workers and property. In other words, a safe attachment and lift requires satisfactory structure throughout the item being lifted.

It is proposed to apply the ASME B30.20 design standards for lifting devices to the entire lifting arrangement. During a lift of typical ship structure some of the highest stresses can typically be found directly at and under the immediate area surrounding a lifting attachment point. This guidance ensures the safety of the lifting arrangement and is probably not very different than similar practices that currently occur at American shipyards today.

EXISTING INTERPRETATION OF ASME GUIDELINES



HOOKS ASME B30.1

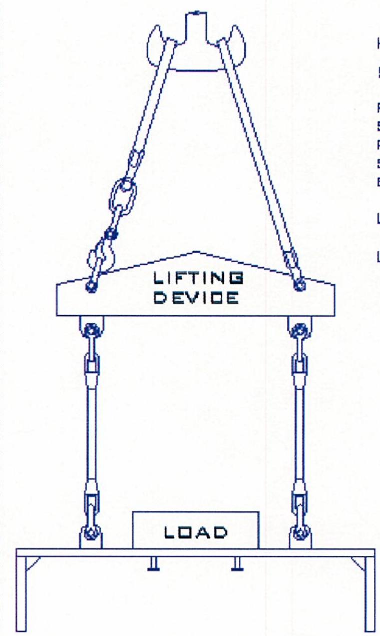
SLINGS ASME B30.9

RIGGING HARDWARE ASME B30.26
SHACKLES ASME B30.26
RINGS ASME B30.26
SWIVELS ASME B30.26
BLOCKS ASME B30.26

LIFTING DEVICES ASME B30.20

LOAD OR PADEYE
NONE OR UNDEFINED

PROPOSED APPLICATION OF ASME GUIDELINES



HOOKS ASME B30.1

SLINGS ASME B30.9

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SHACKLES ASME B30.26
RINGS ASME B30.26
SWIVELS ASME B30.26
BLOCKS ASME B30.26

LIFTING DEVICES ASME B30.20

LOAD OR PADEYE
DESIGN BTH-1-2008 CHAPTER 3

PROPOSED SHIPYARD STANDARDS FOR THE SHORING OF SHIP UNIT STRUCTURE

Supporting large free standing structures during constructions before they can support themselves can take a considerable amount of Engineering and planning. These temporary shoring supports are often referred to as falsework and play an important part of ship construction. They present more of a challenge to design than a typical structure because they are not typically secured to foundations. This means that they are dependant on their own weight for stability.

Traditionally, the support of ships during construction has been done with wood shoring columns similar to that used during the dry docking of a vessel. Although these traditional methods of shoring are well understood, modern construction methods can place different loading conditions on them and in some ways can be different entirely from traditions of the past. The move to larger units and ship blocks places larger loads on what were traditionally wood shoring columns, and may require that greater shoring heights be achieved. The shift to steel supports for large units has in some circumstances become a requirement. With new materials and increased load requirements different design philosophies need to be used with proper standardization and guidance set.

Falsework is often required to safely support a unit for significant periods of time making the probability of increased loading conditions due to environmental factors relevant. These possibly include variable lateral loads imposed by wind, seismic, and yard activity such as minor impacts from the transportation of nearby good and materials or the rough placement of such material on the structure being supported. These structures are also affected by live loads from work being carried out on them. These variable and dynamic loads increase uncertainty and an attempt should be made to account for them.

OSHA has no definition for falsework or guidance for the temporary support of steel structure in a shipyard setting. Although scaffolding equipments is often used in the construction industry for supporting of floors before the concrete has set OSHA does not consider this to be subject to the same requirements of scaffolding and working platforms. Much of the most applicable documentation for falsework comes from the support of steel and concrete bridges.

One of the most frequently referenced standards for falsework is the British standard BS 5975. This standard was developed in 1982 as a result of several falsework collapses at constructions sites. This recommends four main checks which are individual member strength, lateral stability, overturning, and positional stability. Although it is primarily written for the support of concrete slabs and steel bridges further investigation should be undertaken to determine if it is the best applicable standard to apply to shipyard construction.

A PLAN FOR FUTURE RESEARCH

The following topics are areas that it is felt benefit would be obtained from future investigations.

1. There are thousands of lifting related equipment components used by shipyards that can be documented and cataloged. A more complete shipyard specific catalog should be developed with more components used and comparisons of usage made.

2. Synthetic slings are largely replacing wire rope as the sling material of choice. From our brief investigations it is apparent that there is significantly less information publically available than on traditional wire rope. With statically indeterminate lifts the properties of lifting components can greatly affect the distribution of load and better data for these components would certainly be beneficial. Similarly data as to how elasticity is affected during a typical slings working life could be undertaken to provide additional beneficial information. Shipyards should undertake to understand all critical materials that are used and as recent rigging failures have been the result of the failure of synthetic slings, close attention should be paid to these slings and their safe working limits.

3. Shipyards should have a solid understanding of the temporary shoring of large blocks, standards available, and regional environmental loading conditions possible. OSHA does not give any recommendations for how to temporarily support structure and there are few American standards applicable. Some of the foreign standards that have been developed are designed mainly to provide guidance for support of concrete structure before it has full strength. Although shipyards can apply these standards they may not offer the best fit for shipyards needs.

4. Many ships blocks can have lift arrangements designed for them with classical methods of analysis. To facilitate more efficient build strategies, blocks of complicated form and structure are created and require a more detailed analysis that can sometimes only be provided with a Finite Element modeling analysis. Some of these models can take significant time to set up and simplifications are inevitably made. Items considered non structural that will typically be left out are wire runs, equipment, small foundations, piping, and other items considered to have negligible effect on strength or stiffness. It is assumed that the models are still accurate without these items included. In the desire to minimize the amount of time spent to accurately model lifts for ship blocks, an investigation as to what should be included and what can be left out should be undertaken. Specific items and methods of interest include outfitting equipment, the extent that small stiffeners can be ignored, which brackets can be included and which can be left out, whether benefits can be obtained from the increased use of beam elements as opposed to plate or solid elements, and other time saving modeling tricks.

5. As many lifts of ships blocks are statically indeterminate, the use of FEA is required to accurately estimate the resultant forces into each major attachment point. Ship's blocks themselves can vary significantly in rigidity which can have a significant influence on how loads get distributed. Shipyards should investigate how these factors affect the types of blocks they build with the lifting materials they use. Attention should be paid to what variables interact with

each other and what aspect or range of properties are important and which are not. Variables to be investigated with regards to their affects could be; elasticity of slings, tolerance of length of slings, rigidity of block, weight distribution of block, arrangement of main structural stiffeners on block, percentage of steel weight, and others uncovered during the investigation. This will assist in the identification of lifts that might require a more detailed analysis.

6. Each shipyard can create a library of typical ships blocks with tabulated data on pertaining information such as rigidity, average weight distribution, orientation and strength of main structural members such that advisable lifting arrangements can be referenced when dealing with similar blocks in the future. The information learned from FE analysis of typical or hypothetical ships blocks can be compiled into a more detailed training guide for engineers designing critical lifts.

APPENDICES

(A) Lift Check Sheet

(B) Lift Approach Guidance

(C) Rigging Lift Common Component Catalog

(D) Requirements of shipyards.

LIFT
CHECK SHEET

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A check sheet for the aid of the Engineered design of a critical lift may include the following topics and topics and sections:

For additional information with regards to the engineering design of critical lifts see the following documents that accompany this document for this NSRP project.

LIFT APPROACH GUIDANCE

RIGGING LIFT COMMON COMPONENT CATALOG

CRITICAL LIFT DEFINITION

A critical lift can be considered any lift of an item that is unique, irreplaceable, and vital to a program that would have severe negative impacts including, the delay of operations and affect program commitments if damaged or upset. Most ship blocks fall into this category and in this regard should be considered critical lifts. Lifts over critical items, or if the lifting crane itself is a critical capital asset, should be treated as critical lifts as similar disruption can result from a mishap.

OSHA requires a plan to be made for all critical lifts which it defines as a lift that exceeds 75% of the rated capacity of the crane or derrick, or requires the use of more than one crane or derrick. (1926.751) (1926.761)

In addition to doing a lift plan for all critical lifts a shipyard should create a critical lift plan for special lifts that are out of the ordinary with high risk and requiring extra attention. A special critical lift plan can be done for lifts that use more than 95% of a single crane's rated capacity or 85% of either of two cranes capacity for a two crane lift. These special critical lift plans go into significant detail with regards to the lift arrangement, special planning, risk assessment, operation aspects, and special training required.

Different organizations develop their own plans and definitions with regards to what they consider critical lifts. Some define a critical lift as one that uses 95% of a single cranes rated capacity or 70% of one or both crane's rated capacity for a two crane lift. Others consider a critical lift to be more than 80% of one cranes capacity or more than 70% of either of two cranes. In addition some organizations places similar planning requirements on any lift near what is considered critical equipment. Shipyards should develop their own requirements for when additional planning is required based on increased risk to lifts of critical items.

1. LOAD WEIGHT AND CG

- ❑ What are steel weight and outfit weight of block?
- ❑ Is it well known how the weight is distributed in the block?
- ❑ Are the tolerances or unknown proportions of the steel and outfit weight and general certainty of the center of gravity known?

- ❑ How much non-modeled production equipment is present?

- ❑ Has the weight of temporary structure relating to the lifting been accounted for?
- ❑ What is the weight of the rigging gear that will be lifting the block?

- ❑ Are personnel going to be riding the load during the lift?

- ❑ Has a "not greater than" lift weight been determined?

2. CRANES AND OPERATION

- ❑ Is the lift, turn, or movement operation well defined?
- ❑ How many cranes will be needed to lift the given arrangement?

- ❑ Is there sufficient reserve capacity when using calculated or estimated loads?

- ❑ Are there liquids on board that can shift positions during the lift?
- ❑ Have tools and production related equipment that could be a falling or shifting hazard either removed from block before lift or has it been properly secured?

- ❑ If the lift is a multiple crane lift, how will the load be shared by the cranes at different angles of block orientation?

- ❑ Do cranes have the reach to lift block as desired?
- ❑ Do the cranes have reserve capacity both for load and reach?

- ❑ Can cranes travel with block with no obstructions?

- ❑ Is the loading on the crane not required to be adjusted when the crane is moving?

- ❑ Is the foundation below the crane stable and can it support the loads and moments required?
- ❑ Are there any sloping grades during transport?

- ❑ Have dynamic load factors been added to the lifted load based on anticipated crane hook speeds?
- ❑ Have dynamic load factors been added to the lifted load based on anticipated crane travel speeds?

- ❑ Do cranes have proper clearance required for the boom, counter weight, and base?
- ❑ What are the lifting height restrictions?

- ❑ Are cranes kept clear of energized power lines?

3. LIFTING ARRANGEMENT

- ❑ How many pick points are required as dictated by the block structure?

- ❑ For multiple pick points and slings, has the load in every sling been checked?
- ❑ Is the lift condition statically determinate?

- ❑ How will block deflection affect the loads taken from the pick points?
- ❑ Are effects of different initial sling lengths accounted for?

- ❑ For a two crane lift, has load orientation affects been accounted for on each crane?
- ❑ If a turn operation is planned, does the block geometry place different loads on the pick points at different orientations during the lift?

- ❑ Is it essential the lift be level during the move?

- ❑ Is the lifting arrangement stable?
- ❑ Are rigging hooks above the blocks center of gravity during every point of the lift?
- ❑ Can a forced displacement cause the load or weight to shift?

- ❑ Are there positions for appropriate tag lines for controlling loads during lift?

- ❑ Can lift points be reused for another later transport?

- ❑ For a general ground operation or rolling a load in a sand pit, has a dynamic factor been added?

- ❑ Does the designed lifting arrangement equalize the load amount at different lift points?
- ❑ Does a spreader bar act as an equalizer?

4. ENVIRONMENTAL CONSIDERATIONS

- ❑ Are the affect of wind forces on the load been accounted for and understood?
- ❑ Is a wind speed calculated that, above which, the deflection of lifting lines be too severe?
- ❑ Is the ambient temperature within acceptable limits for the critical link components?
- ❑ Are fumes vapors, sprays, mists, acids, loose dirt and debris or other chemicals that may damage non- metallic slings present?

5. BLOCK STRUCTURE

- ❑ Do lifting locations minimize internal moments and stresses in the block?
- ❑ How many lift points will be needed to minimize internal bending moments?

- ❑ Is the block sufficiently rigid?
- ❑ What are estimated maximum deflections?

- ❑ Are bulkheads and frames strong enough to support load?
- ❑ What are the internal moments and stresses in the block anticipated to be?

- ❑ Will outfit items take load or are they considered dead weight?

- ❑ Is buckling of thin plate in block structure accounted for in lift calculation?
- ❑ Can bulkheads resist bucking caused by compressive forces?

- ❑ Are additional shoring and stiffeners required in/on block?

6. SPREADER BAR

- ❑ What spreader bars would need to be used to achieve desired lift?
- ❑ What are sling forces on spreader bar?
- ❑ What moments are in the spreader bar?
- ❑ Does the aspect ration of the chosen spreader beam significantly affect the loads at different angles of orientation?
- ❑ How will an error in CG estimate affect angle of block and forces in slings during lift?
- ❑ Has a free body diagram been produced to calculate angles and loads attached?

7. PADEYE

- ❑ What padeyes are strong enough for the load?
- ❑ Is selected padeye designed for anticipated load diresction?
- ❑ If a turn operation is required has a turn applicable padeye been selected?

- ❑ What are the angles of the load to the padeye as installed in its ideal position?
- ❑ How will unknown weights likely affect the magnitude and angle of the force on the padeye?
- ❑ Has weak axis loading on padeye been checked?
- ❑ How will wind forces likely affect the magnitude and angle of the force on the padeye?
- ❑ How great is the likelihood of the padeye being installed in the correct position and orientation?

- ❑ Can "built in" padeye be used in particular application?

- ❑ Do padeye see different load amounts in all planes and orientations of lift?

- ❑ Are there manholes, temporary access holes, or equipment when padeyes are to be installed that would weaken the structure or prevent padeyes from being installed?
- ❑ Are there any lightening holes, equipment penetrations, or construction clearance allowances under or near the planned padeye?

- ❑ Is the weld strong enough on padeye and structure under padeye?
- ❑ Is the padeye thickness adequately matched to the attachment structure?
- ❑ Is the structure in proximity to the padeye fully welded?

8. SHACKLES

- ❑ Will shackles be loaded in their proper manor, or is twisting, bending, side load, or binding a possibility?
- ❑ Is the shackle pin uniformly loaded?
- ❑ Is there the possibility of the shackle pin unscrewing?
- ❑ Has the correct shackle been chosen for the padeye or lifting attachment?
- ❑ Is sling saver shackle used for sling attachments?
- ❑ Is bunching of a sling severe?

9. SLINGS

- [ ] Has the efficiency of the sling termination been factored into its strength?
- [ ] Has sling eye size been appropriately selected for attachments required?

- [ ] Has bearing area for a basket lift been calculated?
- [ ] Have corner softeners been used to prevent small sling radius load rating been checked?
- [ ] Is binding or chafing of the straps on other gear or equipment a possibility?

- [ ] Has bend radius of wire rope been calculated and the corresponding reduction of strength been accounted for?
- [ ] Have corner softeners been used to prevent sharp corners for chain slings?

- [ ] For choking, lifts has the sling been derated based on the angle of the choke?

- [ ] Does the arrangement make chainfalls susceptible to binding or twisting?

- [ ] Are chainfalls required to level the structure?
- [ ] Are chainfalls required to lower the load?
- [ ] Is a sufficient air source available to operate an air hoist?

- [ ] Will a difference in sling length greatly affect the strains and thus loads seen by each sling?
- [ ] Is sling lengths known exactly?
- [ ] Are slings for lift all the same type, age, and have similar working history?

- [ ] Are chemicals, vapors, or loose grit and debris present that could degrade Synthetic slings?

- [ ] Is a method of adjusting sling length planned to account for variations in CG?

LIFT APPROACH GUIDANCE

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Authors Note

This document may at times repeats information that is in different sections and also with information the other accompanying documents. Such repetition is by design to present the reviewer of any particular section with relevant information. It is seen as preferable to repeat information rather than have that information overlooked.

This document has detailed information on all topics covered in the Lift Check Sheet document and is intended to provide information for the design of critical lifts at shipyards. It should be noted that no check sheet can be complete and cover all information needed or any set circumstance and thorough Engineering review should be undertaken whenever the well being of personnel or property is endangered.

Proper analysis of stresses within ships blocks during rigging lifting arrangements requires significant experience and detailed knowledge to approximate solutions. Although these documents provide a small foundation of the information needed for the design of critical lifts, it is no substitute for the application of sound Engineering judgment accompanied with analytical thought.

This document is part of a packet which includes:

LIFT CHECK SHEET

LIFT APPROACH GUIDANCE

RIGGING LIFT COMMON COMPONENT CATALOG

For the final analysis and design of any lift, ultimate responsibility and application of guidance referenced rests with the user.

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1. LOAD

- ❑ What are steel weight and outfit weight of block?
- ❑ Is it well known how the weight is distributed in the block?
- ❑ Are the tolerances or unknown proportions of the steel and outfit weight and general certainty of the center of gravity known?

Figure 1: Lift of a Block

Accurately determining the weight of what is being lifted is one of the most important tasks to be done when planning a lift. Along with the weight of the object, the object's center of mass, or location of the summation of gravitational forces on the item being lifted, can be assumed to be concentrated. The location of the center of mass is critical because, for a single crane lift, the block will orientate itself such that this point is directly below the hook. Offset errors in calculating the magnitude and location of the center of mass will result in a shifting of the lifted body to equilibrium, with the center of mass below the hook.

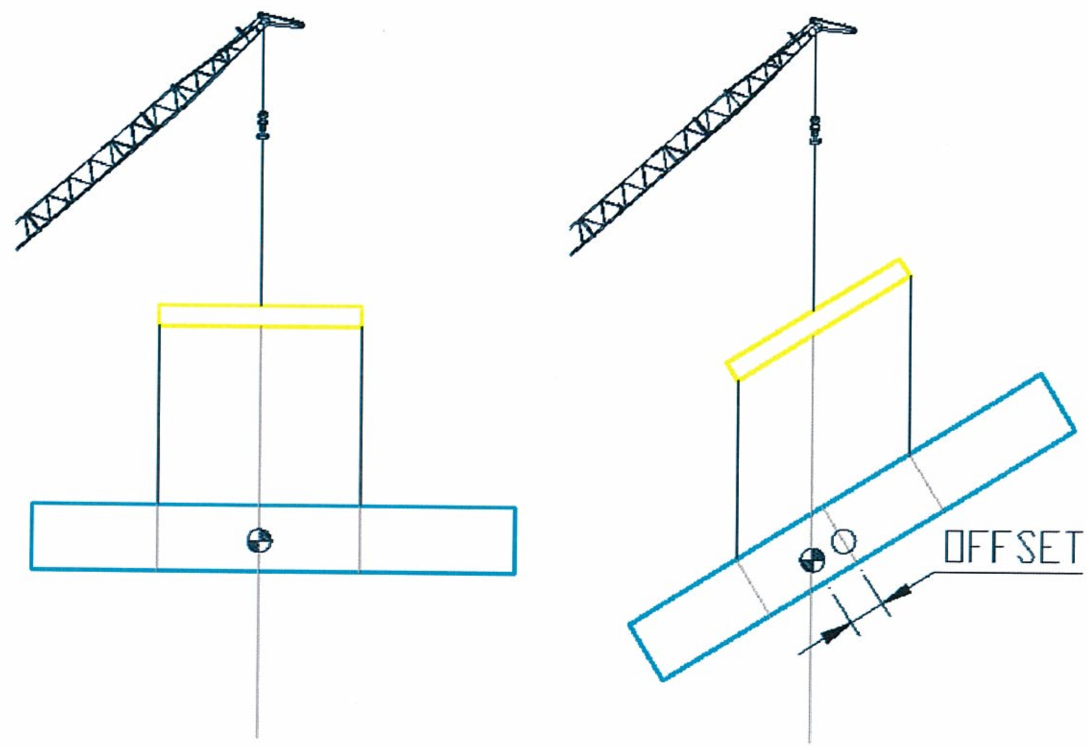

Figure 2: Center of Gravity in Relation to Block Orientation due to Unplanned Offset

The steel weight of a ship block is generally well known as it is easiest to calculate or estimate. Luckily this weight typically is the largest for a ship's block. There is considerable more variation with weights which are highly block dependant as block boundaries do not always terminate on zone boundaries. So it is possible that a block can be half tank and half machinery which can affect weight and outfit distribution. Furthermore equipment may not always be modeled correctly and given weights listed may not be accurate. Rigging Engineers should work diligently with other departments to ensure installed weights for items are as accurate as possible when designing a lift.

	Steel	Electrical & Electronics	Outfit & Furnishings	Machinery& Propulsion
SWBS	100	300 & 400	600	200 & 500
<u>Block Type</u>				
Tank	80-99%	0-2%	0-5%	1-10%
General Cargo	50-75%	0-2%	1-20%	5-30%
House Accommodations	40-80%	1-10%	1-40%	5-55%
Machinery	50-90%	0-20%	1-20%	5-35%

Percentage of Ship Block Weight Per SWBS Group

Figure 3: Table of Weight Estimation Reference

Different ship yards will inevitably have different methods of weight control and the values estimated in should be verified. Also, it should be noted that all blocks start as all steel weight and gradually the percentage of outfit and machinery increases as equipment is added to the block. Figure 3: Table of Weight Estimation Reference shows typical weights for 100% completed and erected blocks.

- ❑ How much non-modeled production equipment is present?

There is often the desire to reduce the number of lifts required to get equipment to the final stage of construction. For instance, rather than erect a block in its final location and then lift equipment such as; tools, electrical cable, joiner bulkheads, make up pipe spools, etc, these items will often be secured in the block for transport with the block during erection. These items will generally not show up in any computer model of the final ship and may have weights that are grossly understated. As critical lift planning often occurs many months before these items are known about and planned for, allowance should be made and final estimates of block weight should be updated and cross checked as often as possible. Also, efforts should be made to contact interested parties to determine what requests may come in and the desired loads as early as possible.

- ❑ What is the weight of the rigging gear that will be lifting the block?
- ❑ Has the weight of temporary structure relating to the lifting been accounted for?

Spreader beams required for large ship block lifts can be very heavy, ranging from a few, to several tons each. Weights of these materials as well as shackles and slings are commonly available and should not be forgotten when summing up the total weight the crane will see during the lift.

Similarly, temporary structure used for stiffening the block for the lift will also be weight seen by the hook of the crane and should be properly estimated and accounted for.

- ❑ Are personnel going to be riding the load during the lift?

Standard practice when personnel are riding the lift is to double the total factor of safety for all components of the lift to ensure that the safety and well being of employees is maintained.

However, there is almost never the need to have personnel on the lift during transport. It should be noted that this doubling of the safety factor may not need apply to the initial pick up and final landing of the block during which small inch by inch adjustments are being made and not all of the weight may be suspended.

OSHA has additional requirements for personnel platforms in 29 CFR 1926.550 (g) which covers capacity limits of the crane and slings as well as the platform itself.

- [ ] Has a "not greater than" lift weight been determined?

Due to various factors, loads seen by various components can increase during the lift operation. Factors that can increase loads seen are such factors as, wind speed, internal weights shifting, multi crane positional tolerances, deflection of structure, orientation of the lifted structure, accelerations and motions.

An initial weight should be set that could compromise the safety or reduce the probability of a successful lift, if an unforeseen factor increases the planned lift load. This weight should be set for a total lift weight, and also a per crane weight for a multi crane lift to account for errors in determining the location of the center of gravity.

2. CRANES AND OPERATION

- ❑ Is the lift, turn, or movement operation well defined?
- ❑ How many cranes will be needed to lift the given arrangement?

Figure 4: Lift Operation for a Ship Engine

There are three main types of moves of large ship structure. These are erections, lifts and moves, and turns.

ERECTIONS are when a block is lifted into position on the ship under assembly. These lifts require a critical control over the block when finally placed in its ship's position. Usually special temporary guide structure is installed to guide it into is final position. Also, deflection of the block at this time is critical and must be controlled where critical ship structure joins and usually must be in almost exact alignment. Precise alignment can be maintained with extra strongbacks that can be used to fix critical structure at its designed locations.

General LIFTS AND MOVES are the most frequently performed lift during which blocks are moved from one yard location to another.

TURNS in which ship structure is picked up and rotated, about a horizontal axis, typically 180 degrees. These lifts place the block structure under loads that it was never designed to encounter. This can result in the necessary addition of extra structure to shore up the block. These lifts almost always require two cranes of which one typically will be required to hold the entire structure at some point during the maneuver. These lifts are quite common during the construction of ship structure as building structure upside-down results in significant cost saving due to the complication of working on overhead structure.

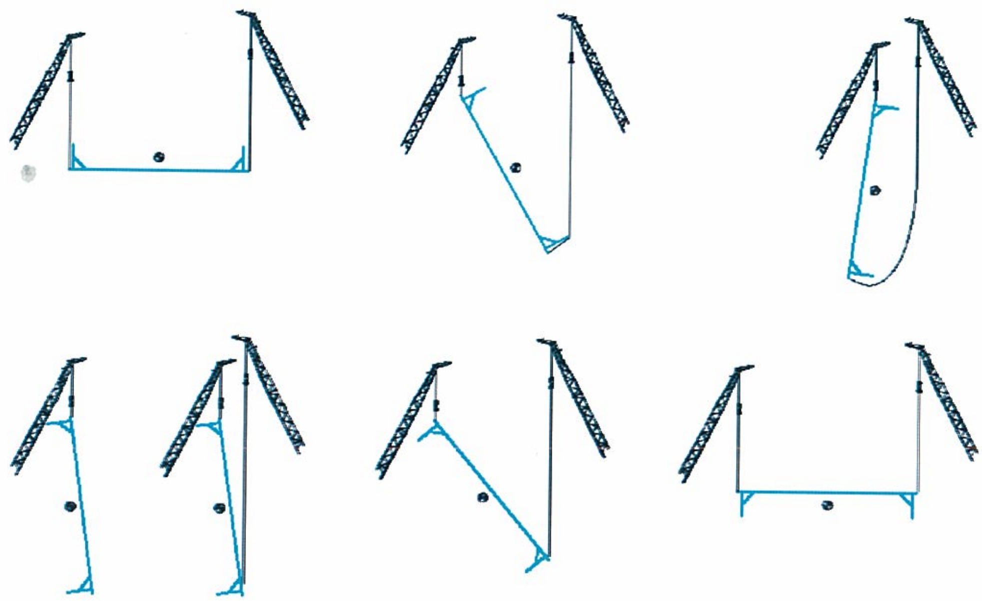

Figure 5: Choreography of a Turn Operation

- [ ] Is there sufficient reserve capacity when using calculated or estimated loads?

Various factors can cause the static engineering load to increase. These factors can be a result of a built in error in the estimated weight of the unit to unknown variables such as wind speed at the time of the lift that may be difficult to plan for. Many cranes have loads sensors that if overloaded will only allow the load to be lowered and not raised. This can cause a significant safety and operation hazard as it is possible for the load to become "stuck" during a time of worsening environmental loads. For this reason a healthy reserve capacity of the cranes should be kept to minimize this possibility. No lift should be designed that uses more than 90% of a cranes capacity.

Figure 6: Turing Operation of a Block

- ❑ Are there liquids on board that can shift positions during the lift?
- ❑ Have tools and production related equipment that could be a falling or shifting hazard either removed from block before lift or have been properly secured?

Many erection lifts at shipyards use a significant percentage of a cranes lifting capacity. These lifts should not be subject to shifting loads that may overload the rigging equipment or the crane itself. Free ride equipment must be accounted for and firmly secured as shifting will increase the loads in critical structural members.

Similarly blocks should be emptied of all small equipment and loose debris such as collected rainwater and sand blast grit which can shift during a lift with potentially disastrous consequences. Small equipment, if not secured, can also be a falling hazard endangering the rigging team.

If a tank is being lifted that is filled with fluid such as collected water, or waste fuel or lube oil, special precautions should be taken and potential stability issues researched pertaining to the criteria for the given lift.

- ❑ If the lift is a multiple crane lift, how will the load be shared by the cranes at different angles of block orientation?

A typical lifting arrangement will have the pick point at some height above the center of gravity of the block which general results in good lift stability. However, if the lift is required to be angled during the lift (as may occur if block being erected on a sloped launching ways), the weights seen by the cranes lifting the block can change. An exaggerated example can be seen in Figure 12.

With highly outfitted blocks, interferences during final erection may occur that can be overcome by angling the block in such a way to slide or maneuver by the obstructions. For these reasons, ample variation in the orientation of the block should be allowed for and loads seen by the respected cranes should be taken into account.

- [ ] Do cranes have the reach to lift block as desired?
- [ ] Do the cranes have reserve capacity both for load and reach?

A crane can be considered a mechanical lever which allows suspending a load at some distance removed from the balance point or fulcrum. The crane capacity must decrease as the distance away from the pivot point increases if stability is to be maintained. A simplified example is shown in Figure 7: where the capacity of the crane is reduced as the distance from the furculum increases.

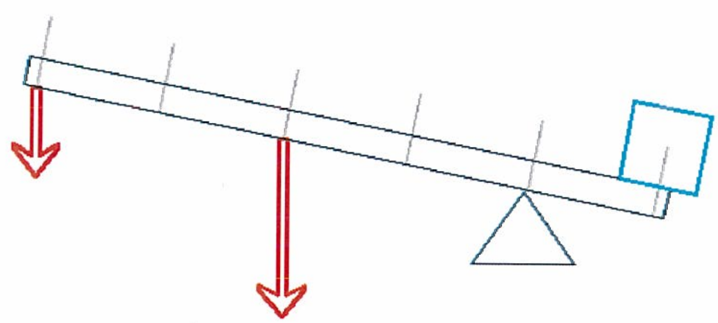

Figure 7: Decrease in Lift Capacity with Increase of Moment Arm

Real cranes have many additional limitations as well. For instance, the maximum limit may be set by the strength of the hook, or wire rope hoist cable. Similarly, due to allowable boom angles there may be a minimum distance for lifting loads as well as a maximum one. Also, there is not a simple fulcrum point as shown in Figure 7 as the base of a crane spreads out in three dimensions and varies in shape for different points on the compass. These factors combine to produce more complex allowable load at radius plots as shown in Figure 8.

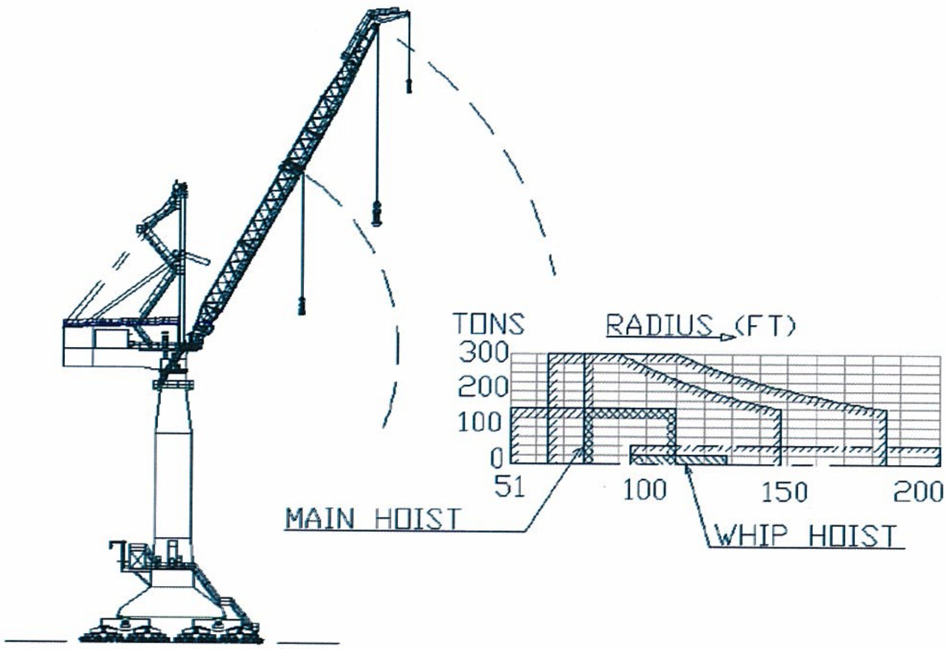

Figure 8: Generalized Lift Capability versus Boom Radius Plot

❑ Can cranes travel with block with no obstructions?

Many more loads can be lifted than lifted and moved. With large complicated critical lifts that involve several cranes, the exact position, boom angle, boom length, and travel speed may need to be constantly adjusted during these complex maneuvers.

Lift and travel sequencing diagrams should be done for these complicated critical lifts to provide guidance to all parties involved as to what boom angles and positions should be approximated at different times of the movement. An example of such a sequence diagram can be seen in Figure 8.

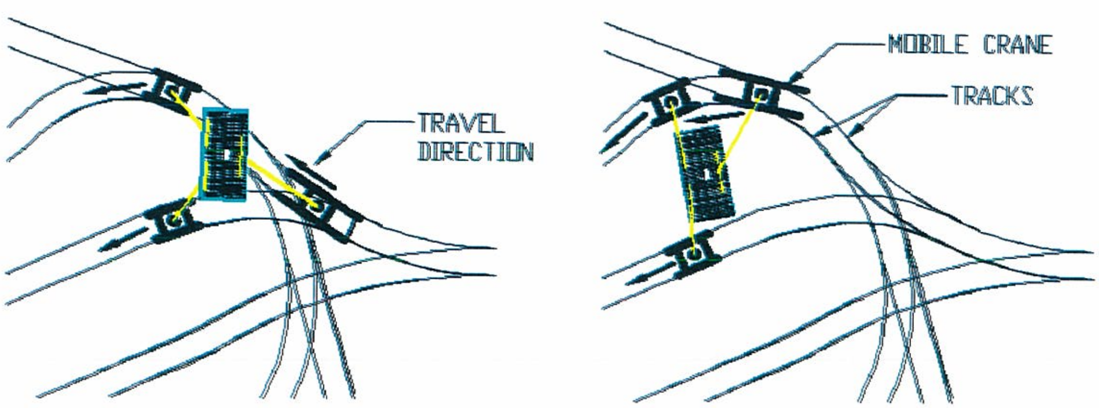

Figure 9: Sequencing Diagrams Showing Maneuvering of Loads

- ❑ Is the loading on the crane not required to be adjusted when the crane is moving?

Adjusting multiple controls during a lift can lead to mistakes. As a general rule, only one operation should be performed at a time, in small step intervals so that loads, angles, interferences, and progress can be carefully monitored. Designing a lift that requires multiple maneuvers at once should be avoided. During multiple cranes lifts, as shown in Figure 9, movements must be very slow and in small steps to accomplish this and designed to keep as many operations and variables as constant as possible.

- ❑ Is the foundation below the crane stable and can it support the loads and moments required?
- ❑ Are there any sloping grades during transport?

The bearing forces on the ground that a crane with a load creates, can be considerable. There are limitations as to where cranes can travel based on the installed foundation and soil conditions present under the crane supports. Detailed maps should be created and well maintained that label restrictions as to limits based on loads and boom amounts for specific cranes at any given locations. Similarly sloping grades will affect where the cranes can travel and the load they can carry.

- ❑ Have dynamic load factors been added to the lifted load based on anticipated crane hook speeds?
- ❑ Have dynamic load factors been added to the lifted load based on anticipated crane travel speeds?

Hook and crane motions will inevitably be associated with stops and starts of that motion. These stops and starts of this motion will be caused by acceleration and its associated force. This force will increase the load that is on the hook and imparted onto the block being moved. The slower the planned and actual movement, the lower these forces will be.

When a large crane and block movement is taking place there will inevitable be some vibration and oscillation due to the movement of the crane. The slower the movement of the crane the less the imparted forces will be.

General rules of thumb are a dynamic factor of 50% should be added for a crane travel speed of greater than 20 feet per minute, and 10% for hook speed greater than 20 feet per minute.

- ❑ What are the lifting height restrictions?
- ❑ Do cranes have proper clearance required for the boom, counter weight, and base?

Specific clearances should be set for how close cranes and the objects being lifted should be allowed. As a general rule of thumb, 10 feet is a good clearance for cranes, loads, and fixed objects near the path of travel (Figure 10). However, this could be reduced if dimensions relating to the objects in question are well known and the supervisor conducting the lift is well aware of the potential impacts and can have spotters ready to watch for danger.

Wind speed can impart additional motion onto a load being lifted. Lifting during relatively high wind speeds will not only increase the forces on the load but increase the required distance margin to ensure safety is maintained. Average wind speeds and wind gusts at shipyards should be well documented and integrated into lifting plans.

For example, a 30 second wind gust of 20mph could put a force of on the order of two and a half tons on a 106' wide x 30' high x 50' long block. If this panel had a mass of 200 short tons and was 150 feet below the sheave at the top of the boom, it would be displaced by the wind at least two feet. This represents a hook angle change at the sheave of the crane of almost one degree.

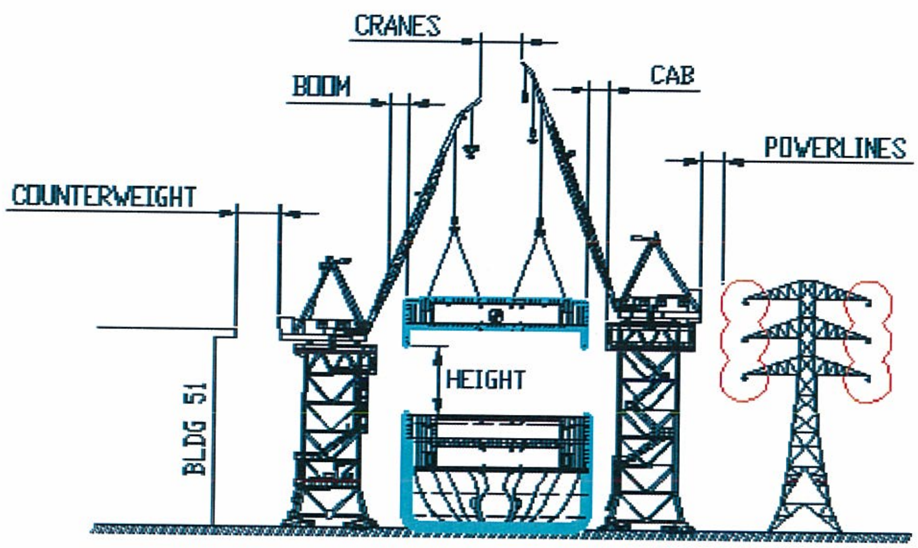

Figure 10: Clearances to Consider when Planning Rigging Operations

❑ Are cranes kept clear of energized power lines?

The Code of Federal Regulations sets forth specific criteria for distances that cranes must stay clear of energized power lines. These can be found in Title 29 CFR Subpart N 1926.550 regulations for construction.

The required clearances set forth are:
(i) For lines rated 50 (kV). or below, minimum clearance between the lines and any part of the crane or load shall be 10 feet

(ii) For lines rated over 50 (kV), minimum clearance between the lines and any part of the crane or load shall be 10 feet plus 0.4 inch for each 1 (kV) over 50 (kV), or twice the length of the line insulator, but never less than 10 feet

(iii) In transit with no load and boom lowered, the equipment clearance shall be a minimum of 4 feet for voltages less than 50 (Kv), and 10 feet for voltages over 50 (kV), up to and including 345 (kV), and 16 feet for voltages up to and including 750 (kV).

Tabulated distances for given voltages are as follows:

50 (kV)	10 ft
200 (kV)	15 ft
350 (kV)	20 ft
500 (kV)	25 ft
750 (kV)	35 ft
1000 (kV)	45 ft

3. LIFTING ARRANGEMENT

- ☐ How many pick points are required as dictated by the block structure?

When determining the number of pick points or location of padeye, and thus number of slings a number of factors must be accounted for. Typically the arrangement is determined by where on the block padeyes can be placed as there are usually only a few locations that are strong and rigid enough for handling the load that will be imparted by the anticipated lift configuration.

With increasing large loads in concentrated areas handling of rigging equipment can become a driving factor for a design. A Crosby wide body shackle for 125 Short tons weighs 161 lbs and is about the limit that can be readily installed by yard personnel without special tools or handling equipment for the shackles themselves. For this reason, if larger loads are required in concentrated areas it has been found easier to use two padeye in close proximity. However careful attention must be paid to exact location of the padeye and the sling lengths to ensure that the load gets divided approximately equally between the pair.

If the block that is desired to be lifted is relatively flexible, one needs to look carefully at the weight distribution in the block and try to balance the load with padeye such that each padeye will take its equal share of the load to minimize any internal moments in the block. In these cases, the block will typically see significantly more displacement due to flexing than high modulus synthetic sling will in stretching, which helps remove some of the double variables of such statically indeterminate lifts.

- ☐ Is the lift condition statically determinate?
- ☐ For multiple pick points and slings, has the load in every sling been checked?

Critical lifts almost always have the load divided among more than three slings. This means that for a one crane four point lift it cannot be known for certain what the exact loads in each sling are. One method of approximation would be using integral numerical models such as finite element modeling in which ultimately, deflection is calculated and strain related back to actual slings loads. Further complicating any analysis is that the slings elasticity is usually not linear and varies with the load and each slings individual history. Many times with light structure and high modulus synthetic slings, the deflection in the block is greater than the deflection in the slings causing the block structure being the primary driver of ultimate loading in the individually slings. Conversely with an infinitely rigid block, the stiffest of the multiple lines may take most of the load. Ship production blocks can vary quite substantially with some being quite rigid such as box structures and some quite flexible such as plate panels. Statically indeterminate lifts of large blocks are the largest challenges presenting rigging engineers for large possible variances exist in expected values of load and stress on different components.

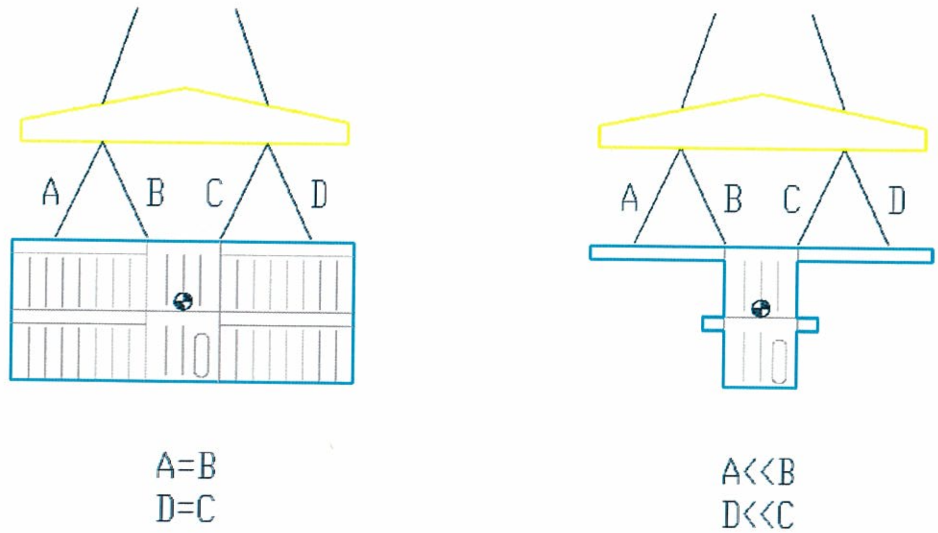

Figure 11: Sling Load may be a Function of Block Rigidity and Weight Distribution

- ❑ How will block deflection affect the loads taken from the pick points?
- ❑ Are effects of different initial sling lengths accounted for?

Typically the slings that are used to lift a ship's block have different working histories and may have slightly different initial lengths based on general manufacturing tolerances. Furthermore a sling's working history can reflect on its current strength and elasticity. These differences in sling history and length can vary the forces in different slings especially when the structure is part of a statically indeterminate lift.

- ❑ For a two crane lift, has load orientation effects been accounted for on each crane?
- ❑ If a turn operation is planned, does the block geometry place different loads on the pick points at different orientations during the lift?

Lift points are typically located above the center of gravity for load stability, accessibility, and to properly tie into main structural members. The amount of load either crane may hold is directly proportional to the relative distance the center of gravity is between the two cranes. Depending on the orientation of the load, the center of gravity may not remain at a constant distance between the two hooks. This means the amount of load that any given crane may see will vary. This can be seen in Figure 12 as an exaggerated angle has been shown.

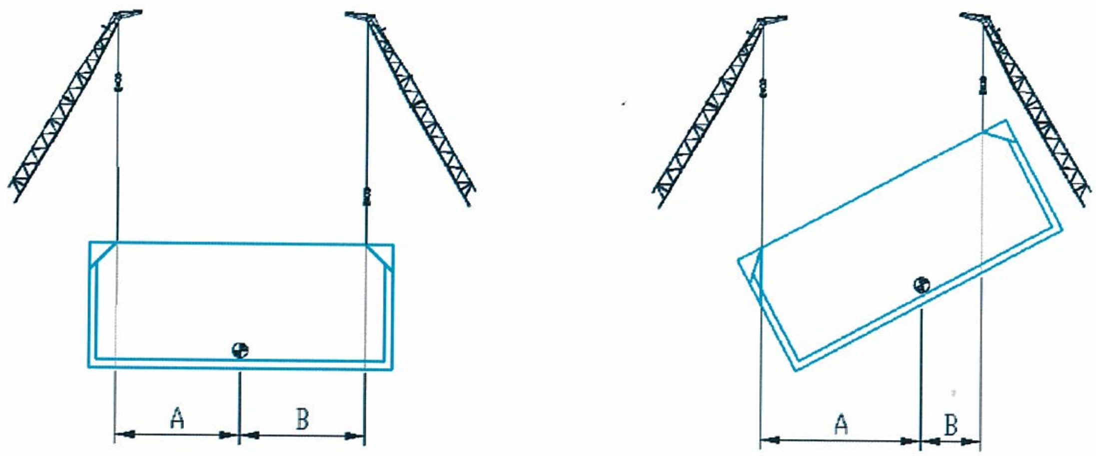

Figure 12: A Block Orientations Affect on Load Sharing

- ❑ Is it essential the lift be level during the move?

Although, it is not necessary for a lifted object to be level when it is moved, it can be critical during erection lifts where the tolerances as to where the block can be set are measured in fractions of an inch. Similarly, many times ships blocks under construction are set on stands and other blocking arrangements during construction. With shapely blocks such as bow and stern units, the number and required height of stands becomes a driver for leveling the load. Lowering a large block such that it contacts all supports at nearly the same time becomes important because standard aerial drift motion of the load during landing can force side loads into the supports or possibly even topple them.

For a single crane lift, the only way to level the load is by adjusting the sling length. This can be accomplished by the use of chain falls or airhosts if precise adjustments are necessary . Also, adding and replacing additional shackles in a given sling can create more approximate adjustments.

- ❑ Is the lifting arrangement stable?
- ❑ Are rigging hooks above the block's center of gravity during every point of the lift?
- ❑ Can a forced displacement cause the load or weight to shift?

Care must be taken to assure that loads being lifted remain stable during the entire lift. An example of a lift which can lose stability when lifted is a lift that has the center of gravity above the pick points. In this example case a slight angular displacement will cause an increase in the force on the lower of the pick points, this in turn will cause greater deflection of the slings, and of the cranes boom which will lead to a further increasing the force and displacement angle. If this rotation has a tendency to reinforce itself, the lift may be unstable. This is especially true if the sling is wrapped over the lifting hook or shackle and not firmly secured to it as shown in Figure 13. Although initially stable, the lift as shown is only so because it is held by the friction on the sling through the hook. A slight displacement will cause an accelerated destabilization.

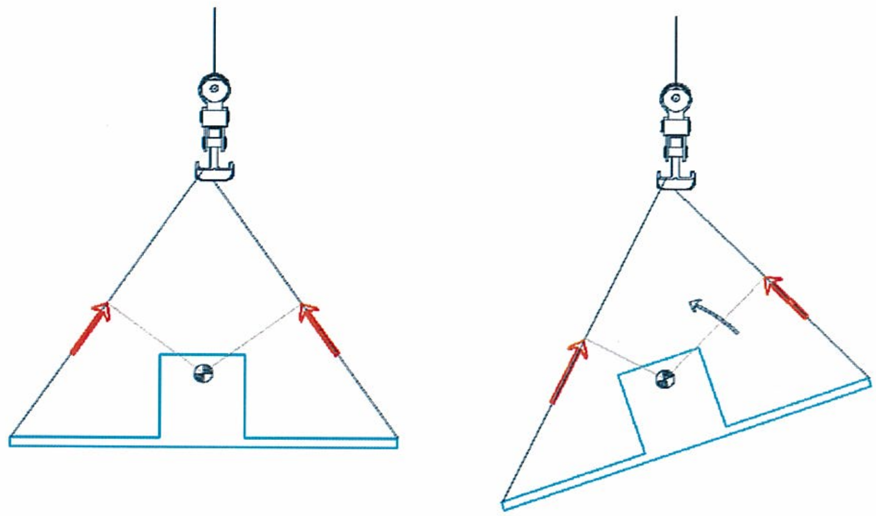

Figure 13: Unsecured Sling Destabilization Scenario

- ❑ Are there positions for appropriate tag lines for controlling loads during lift?

Generally rigging Engineers leave the control of lifts up to the rigging foreman and supervisors of the lift to decide how they want to control the load. However, given the specific arrangement of some critical lifts, it may be necessary to indicate restrictions or recommendations as to where control lines can be placed.

- ❑ Can lift points be reused for another later transport?

The movement of material and finished panels in a shipyard is continuous and attempts made to reduce the number of lifts and the number of different padeyes required can result in cost savings. If possible, pick points should be selected that return maximum utility through multiple uses. Some shipyards have specially designed padeyes that have multiple pin connections for both lifting and turning operations.

- ❑ For a general ground operation or rolling a load in a sand pit, has a dynamic factor been added?

Small, relatively heavy items, such as castings, can present a challenge to riggers in that it may be difficult for them to be held by more than one crane due to potential boom interference. These items are often sturdy enough to be rolled over in soft areas such as sand pits, however care must be taken to reduce the chance of impact loads when the center of gravity goes over the top. Although, this can be avoided with careful planning the padeye, shackles, slings, and crane capacity should have sufficient allowances to safely account for the possibility. Pick points should also be carefully selected to cradle the load, and be under load, during all angles of the lift.

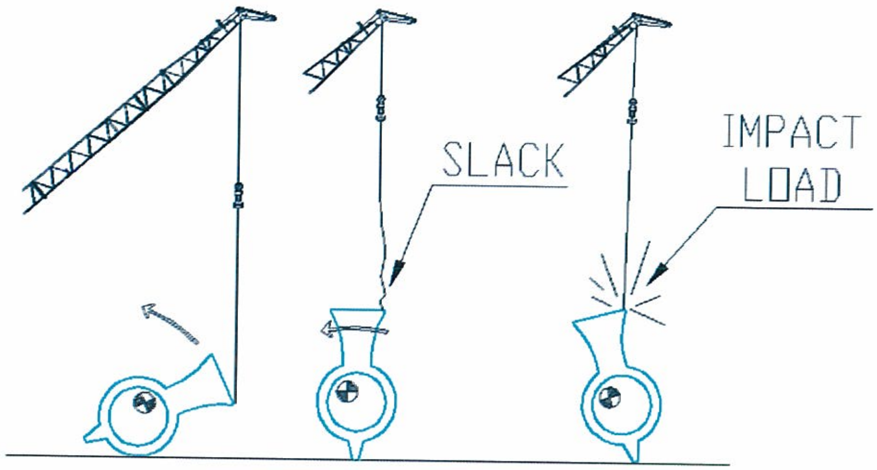

Figure 14: Impact Loads Due to Rolling of Compact Casting in Sandpit

Figure 15: Sand Pit Turning

Furthermore, extra caution must be taken when handling items on the ground. These items may be either frozen to the ground or stuck due to hydraulic suction or embedment and may take considerable extra force to pull them free. When it does come free it will rebound taking any stretch out of the lifting lines and may start to bounce in a pendulum like swing increasing the loads seen and possibly jeopardizing the item and the cranes stability.

- ❑ Does the designed lifting arrangement equalize the load among the lift points?
- ❑ Does a spreader bar act as an equalizer?

Designing a lift with multiple attachments such that all forces in all lift points are equal is nearly impossible. This would require that the exact center of gravity is known and that there will be no environmental factors such as wind adding additional and variable forces to the load. Furthermore, tolerances in the sling properties, length, exact installed location of the lifting attachments, and estimated block deflections would need to be more precise than could be reasonably expected. Different arrangements for lifting the same object will place varing loads in the components of the rigging hardware, resulting in different load reactions.

Figure 16 shows two lifting arrangements and the block reactions that would result from an exaggerated deviation or offset in the estimated center of gravity. It can be seen that an offset in the center of gravity with a lifting beam type of arrangement will result in less of an angular offset of the block. The other arrangement shown which acts as more of an equalizer beam will result in much larger angular offsets as a result of the same offset in the center of gravity. For large critical lifts, two main factors drive the former as the most often utilized type of lifting arrangement. A given angular offset corresponds to a very large measurement for the typical dimensions of a ships block, and since there is the desire to keep the load as level as possible, this can be disadvantageous. Also, given the loads that will be generally be lifted, the internal moment in the equalizer beam, as a result of the forces applied, significantly increases its weight and complexity. Increasingly heavy spreader beams means ships blocks will have to weigh less to accommodate crane restrictions.

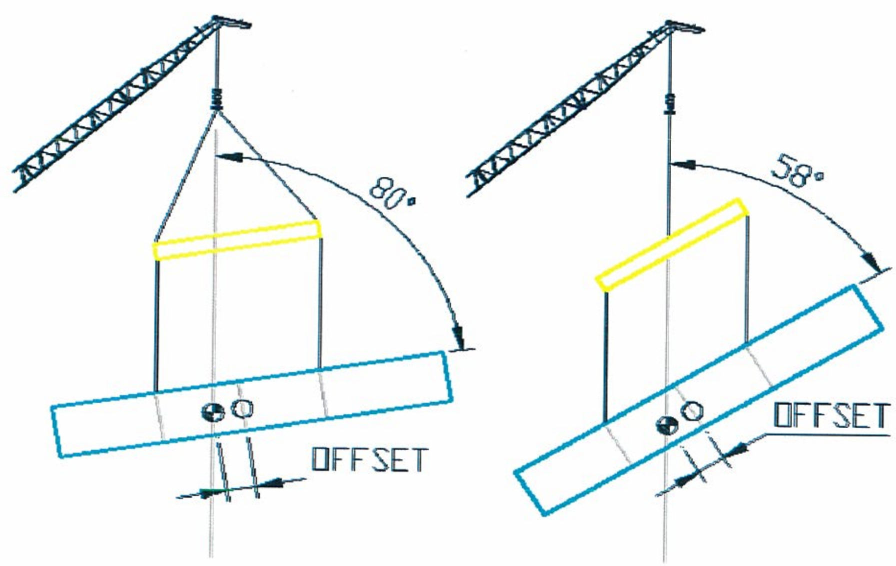

Figure 16: Effects of Sling and Spreader Arrangement on Angular Displacement

4. ENVIRONMENTAL CONSIDERATIONS

❑ Are the affect of wind forces on the load being accounted for and understood?

Different locations have different environment wind conditions and prevailing wind speeds and directions. It should be well understood what characterize a given area. It should be known what wind speed can be expected and, with relatively short notice, what wind speed may occur. These should be factored into a yard's specific criteria which govern what wind speeds should be designed for a typical lift.

It should also be understood what wind speeds are accounted for in the lifting cranes rated load. Mobile cranes are typically designed to withstand a side wind of 20 mph at the rated load.(Ref Shapiro) However, ship blocks can be of significant size with a very large wind profile areas that can impose further side loading on the boom than it was originaly designed for. Particular information with regard to design philosophy relating to the cranes in any given shipyard should be tabulated for reference and maximum safe values estimated.

❑ Is a wind speed calculated that, above which, the deflection of lifting lines will be too severe?

Wind force on blocks may place additional side loads on the padeye or lifting attachments. This can be especially true during turning operations where a very large profile area may be exposed to the wind. A check should always be done to estimate how the load will react to expected wind conditions and what the increased sling tensions could be.

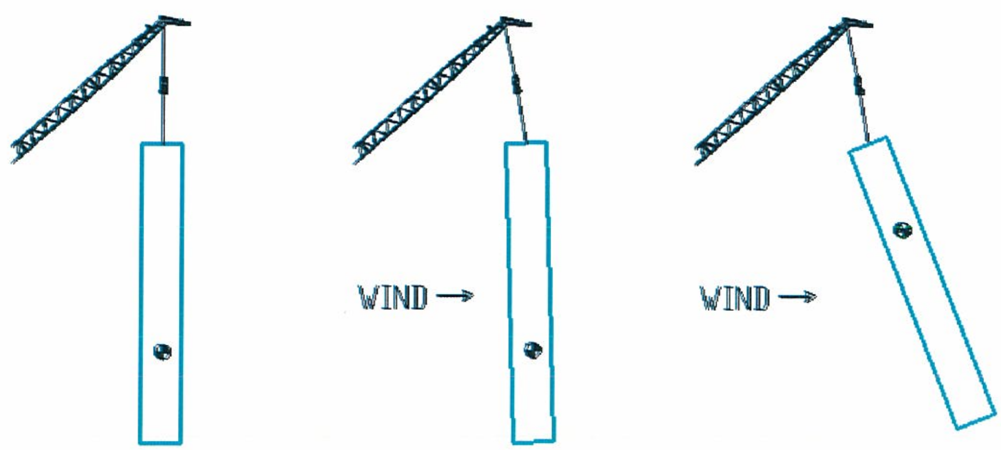

Figure 17: Possible Effects of Wind on Block

❑ Is the ambient temperature with in acceptable limits for the critical lift components?

Cold weather below the transition temperature of common grade A steel may change the mode of failure from one of ductility and energy absorption to failure of a brittle nature and making it especially venerable to shock loading. If lifting conditions have the possibility to be scheduled at times of the year that may have low temperatures, using a higher quality of steel Such as ABS Grade D or E may be advisable in order to reduce the probability of sudden brittle fracture on key rigging hardware.

Figure 18: Lift of bow block using synthetic sling

Similarly, many synthetic slings such as high molecular polyethylene in particular have specified maximum exposure temperature as low as 140 degrees (F). Continued exposure to temperatures of this level may cause melting resulting in permanent damage and reduction of strength. Synthetic slings have different exposure and operating temperature that should be known before selecting a sling. Also during lifts, internal friction within slings will inevitably elevate the temperature of the sling. Caution should always be exercised as even partially melted sling fibers will have significantly different properties.

Also wet and subsequently frozen synthetic slings should be avoided, in accordance with most manufacturer's recommendations.

❑ Are fumes vapors, sprays, mists, or liquid acid, loose dirt and debris or other chemicals that may damage non metallic slings present?

Synthetic slings have enormous strength when compared to wire rope on a pound for pound basis. However, the plastic materials of these slings have some disadvantages with regards to chemical resistance. These affects are highly material and temperature dependant and may be immediately destructive or only after months of immersion and exposure. Chemicals relating to painting, prepping, cleaning and other yard activities should be checked for compatibility. A brief synopsis of how some synthetic slings are affected is as follows:

- Aramid fibers are attacked by strong acids and bases and sodium hypo-chlorite bleach particularly at elevated temperatures.
- High molecular polyethylene resist many chemical agents but can be slightly affected by Clorox and other bleaching agents.
- Nylon fibers are affected by most acids and bleaching agents including Formic Acid, Phenolic compounds, calcium chloride, zinc chloride, benzyl alcohol, to name a few. Strength reduction may occur immediately or over a period of hours and is highly temperature dependant. Nylon losses approximately 15% of its strength when wet.
- Polyester will disintegrate with concentrated sulfuric acid but is generally not significantly affected and resistant to most chemicals.

5. BLOCK STRUCTURE

- ❑ Do lifting locations minimize internal moments and stresses in block?
- ❑ How many lift points will be needed to minimize internal bending moment?

Generally the optimum lift strategy for a block will result in the smallest internal loads in the block with the fewest number of attachment points.

- ❑ Is the block sufficiently rigid?
- ❑ What is estimated maximum deflection?

Generally ship blocks that are only one deck high produce the most problems with regards to deflection and erection installation. These blocks are significantly less rigid especially if there are no continuous transverse bulkheads. Although, in theory, the block should spring back to its designed and built shape when released from the crane, often stanchions, frames, and bulkheads can dig in and hold the block in a stressed position. Concentrated loads bearing into the deck below (as a result of sharp corners on welding bevels) can exacerbate the gripping potential and hold members from returning to their original position. Often rigging works with shipwrights to add additional guidance clips to slide or force the block closer to the desired position. Strongbacks can also be added to physically restrain critical parts and limit large deviations from required tolerances.

- ❑ Are bulkheads and frames strong enough to support load?
- ❑ What are the internal moments in the block anticipated to be?

Proper classical analysis of stresses within ships blocks during rigging lifting arrangements requires years of experience and detailed knowledge to approximate solutions. It is known that bulkheads and large frames do the bulk of providing rigidity for the block. These largest and strongest members provide the most stiffness, and therefore they resist bending the most and generally have the highest loads and possibly stresses. Sound engineering judgment accompanied with significant experience is the only way to tackle such problems with confidence.

- ❑ Will outfit items take load or are they considered dead weight?

Generally, for the lift of a block, in accordance with good engineering practice, one only looks at the steel structure for the rigidity and structure of the block, and it is assumed that all installed pipes and equipment are just dead load. However, it is important to understand that when the block deflects as it is lifted it will impart some amount of forced displacements onto all items on the block. A rigging Engineer should be aware of these effects and look out for unintended loadings in miscellaneous outfit items because these stresses can possibly result in the block's damage.

- ☐ Is buckling of thin plate in block structure accounted for in lift calculation?
- ☐ Can bulkheads resist buckling caused by compressive forces?

The internal moments in the block structure will result in areas of the block experiencing compressive loads. Vertically stiffened bulkheads that provide significant rigidity for the block are especially vulnerable when loaded with large moments and should be checked to see if the compressive loads in the bulkheads may result in bulking. These compressive forces that may be present in the block can be compounded further if the sling angle is set low enough such that large compressive loads are imposed on the block as a whole as well. These forces will combine to high compressive forces especially around cutouts for doors or hatches that naturally concentrate loads and reduce local stiffness.

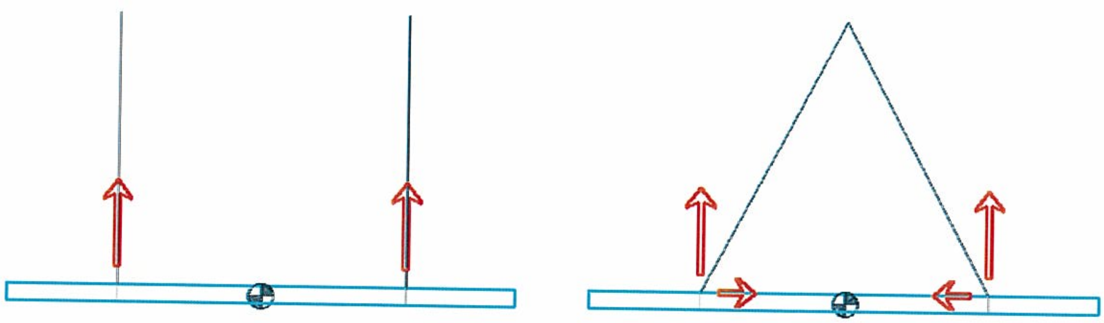

Figure 19: Compressive Forces Created by Sling Angles

- ☐ Are additional shoring and stiffeners required in/on block?

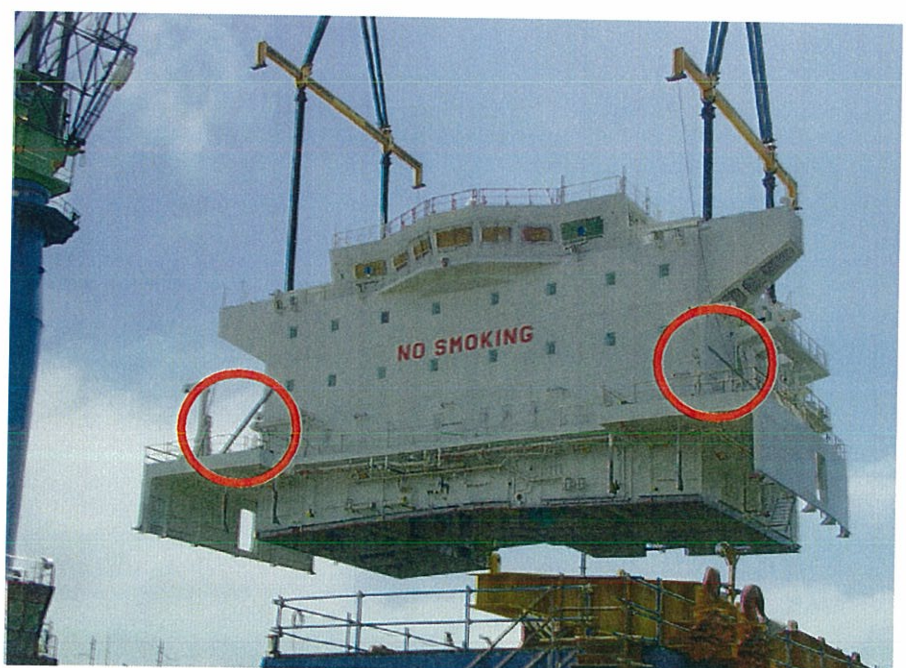

Figure 20: Angle Brackets (Circled) for Additional Support

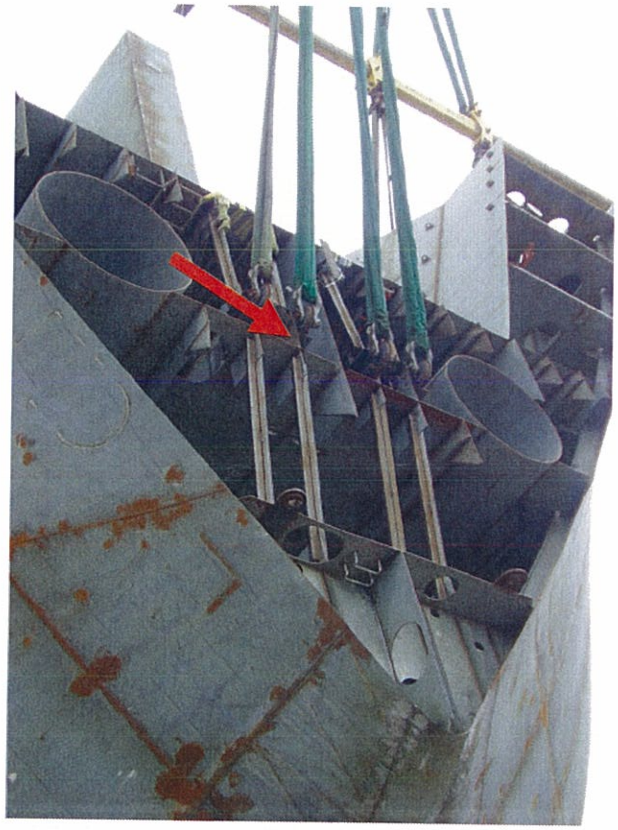

Figure 21: Several Sets of Double Angle for Additional Support

To prevent buckling of bulkheads, control deflections for the alignment of critical structure, and strengthen members to support main lifting attachments, additional shoring is often added. Typically installed parts are brackets, flat bar, angles, and double angles. To ensure that loads are being properly transferred through smaller beams and therefore reducing stresses in main load carrying bulkheads, triangular brackets are often added to the structure . Sections of standard forty foot flatbar lengths can typically be added to bulkheads to stiffen them and prevent buckling around openings such as doors and windows. Angles and double angles are often added to strengthen members or tie bulkheads and decks together. Having a standard set of brackets, flatbars and angles to select from can expedite the rigging design process.

6. SPREADER BAR

❑ What spreader bars would need to be used to achieve desired lift?

Very few critical lifts do not require a spreader bar to distribute the load. Typically, a single spreader beam can be used to distribute the load to two or four places. Examples of typical spreader arrangements for the lift of ship blocks can be seen in Figure 22. These arrangements show typical rigging geometries that may exist for different crane lifts. It should be noted that for two of the cases depicted a second crane would be required to ensure stability, and only one crane's rigging gear has been shown for clarity.

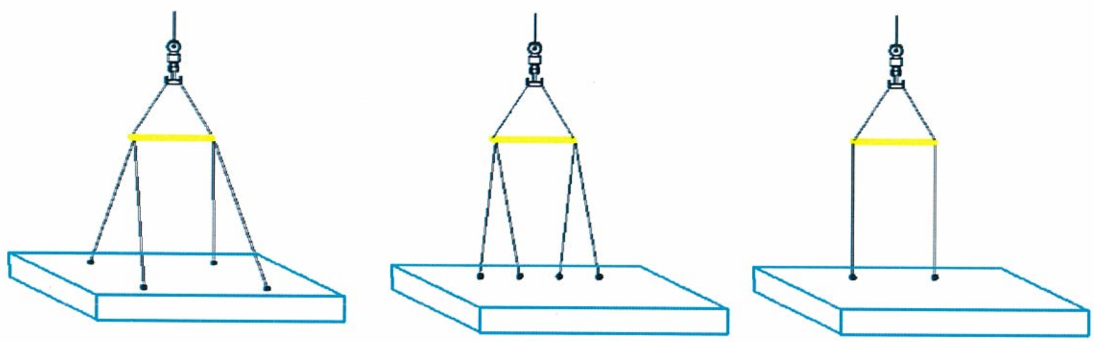

Figure 22: Common Rigging Sling Geometries

❑ What are sling forces on spreader bar?

For simple one crane lifts it is known that the center of gravity of the block is under the hook. For simple two crane, four sling lifts it is known that the center of gravity lays on a vertical plane linearly between the two crane hooks and the total force on one spreader beam must balance such that the vertical loads of the two slings proportionally equal the hook load. For a rigid block with rigid slings this answer is readily calculated and reality does not deviate too much from this as the deflections usually observed are relatively small.

❑ What moments are in the spreader bar?

Depending on the locations and forces in the spreader bar, internal bending moments can develop in it. This is especially true if the spreader beam is being used as an equalizer as shown in Figure 23.

There are spreader beams that can have three or more slings attached to them. One needs to be careful as these sling forces may be arranged in a statically indeterminate fashion and thus the exact values may not be known and most probably will not all be equal. This can result in the internal moments being higher than anticipated, and it would be wise for the designer of such a lift to de-rate the capacities accordingly.

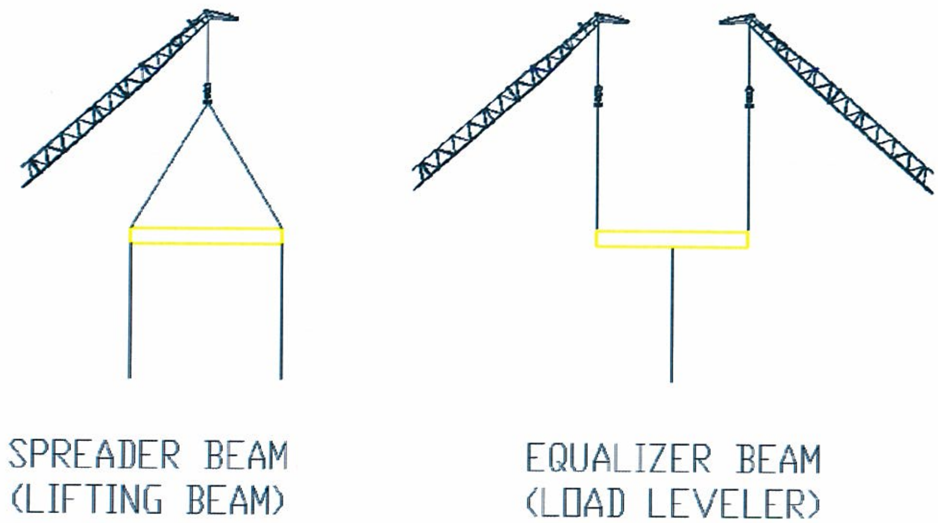

Figure 23: Uses of Spreader Beams

- ❑ Does the aspect ration of the chosen spreader beam significantly affect the loads at different angles of orientation?

The aspect ratio of a spreader beam can effect the loads that will be taken by individual slings in a given lift arrangement. As seen in Figure 24, spreader beams used as equalizers with lower aspect ratios will balance the load better and cause less angular offset as a result of an error in estimating the center of gravity. Also, in this configuration, the spreader is required to resist a large moment. Having a taller spreader beam will typically creates greater section modulus which supports the moment developed. The drawbacks to having a taller spreader beam is that it will reduce the total height that one can lift a given arrangement, and can result in a heavier beam reducing lifting capacity of the arrangement.

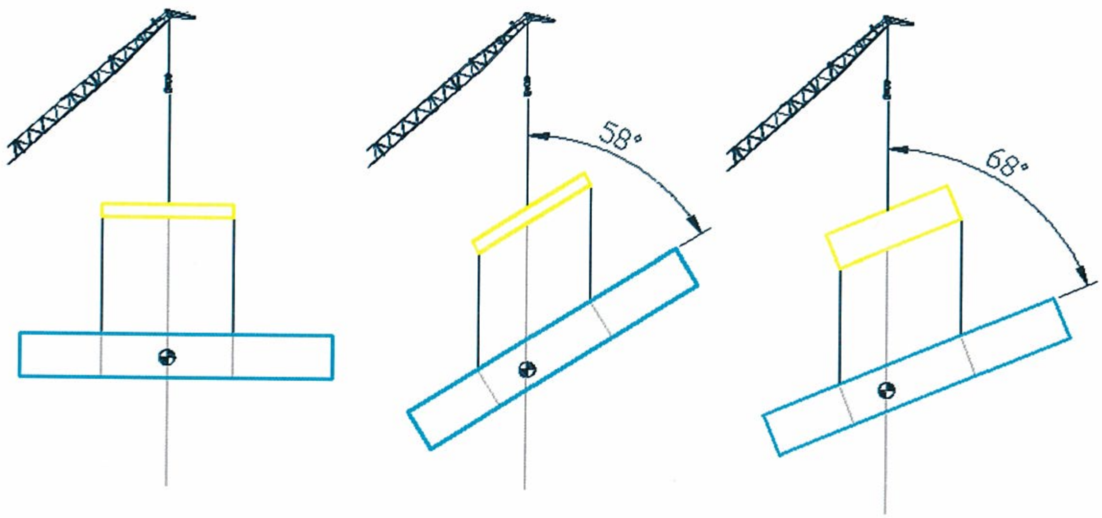

Figure 24: Lower Spreader Beam Aspect Ratio Improves the Load Balance

- ❑ How will an error in CG estimate affect angle of block and forces in slings during lift?

On the "first of a class" ship, with no historical lifting data to guide a lifting arrangement for the first time a block is lifted, there can be errors in calculating the center of gravity. This is especially true for blocks that have a significant amount of outfitting. Estimations should be made to calculate what offset of the center of gravity can be safety designed and allowed for.

- ❑ Has a free body diagram been produced to calculate angles and loads attached?

A short amount of time invested in a free body diagram as basic and simple as it may seem can have significant benefits. This will quickly allow one to determine the moments inside the beam and forces applied.

7. PADEYE

- ❑ What padeye are strong enough for the load?
- ❑ Is selected padeye designed for anticipated load direstion?
- ❑ If a turn operation is required has a turn applicable padeye been selected?

Rigging Engineers should have a complete catalog of padeyes readily available for use so that unique designs do not have to be produced for every lift. This design catalog should have all information with regards to common loads seen, and limits as to what can be considered acceptable. The information cataloged could include:

- Bearing stress of padeye shackle hole.
- Fracture strength of padeye pin connection.
- Double shear of padeye pin connection.
- Dishing or buckling failure load.
- Maximum allowable vertical lifting load.
- Maximum allowable horizontal turning load.
- Maximum allowable weak axis loading for various expected angles for both turning and lifting loads.
- Minimum weld size connecting padeye to deck.
- Minimum weld size and length for connecting primary bulkhead or frame structure to deck directly under padeye.
- Minimum size structure that padeye can safely be welded to.
- Restriction on holes and other penetrations in structure adjacent to padeye connection
- Guidelines for reuse and affects on padeye strength.
- Minimum temperature limits for padeye.

- ❑ What are the angles of the load to the padeye as installed in its ideal position?
- ❑ How will unknown weights likely affect the magnitude and angle of the force on the padeye?
- ❑ Has weak axis loading on padeye been checked?
- ❑ How will wind forces likely affect the magnitude and angle of the force on the padeye?
- ❑ How great is the likelihood of the padeye being installed in the correct position and orientation?

Many padeye are hundreds of time stronger when loaded on their strong axis that on their weak axis. Padeye are typically installed directly in line with block structural members which may not always be oriented in line with the force of the load to which they are subjected. Weak axis loading should be checked with the understanding that prescribed and drawn installation angles may not be what actually is installed. On the complex curvatures of some ship structure, it may be difficult to sight the references required for accuracy within one degree. Furthermore environmental affects such as wind may affect the magnitude and angle of load on the padeye.

- ❑ Can "built in" padeye can be used in particular application?

A significant part of the cost pertaining to a lifting padeye is involved in the man hours spent installing and removing them. This activity will inevitably affect many disciplines including fitters, welders, and the paint department. Integrated padeyes can save a significant amount of this work and even produce stronger attachments as there can be no welded connections or alignment issues. There is often little weight affect as additional boss plates required are partially canceled by offset of the hole.

- ❑ Do padeye see different load amounts in all planes and orientations of lift?

Different orientations of a block may produce different loads at slightly different angles during the lift operation. Regardless of whether the variations in loading magnitudes and angles are due to environmental factors or geometric orientations of the structure, attempts should be made to estimate and calculate them.

These orientation effects are the most pronounced for ship structure such as main decks and inner bottom that may have significant amount of shape to them. When making arrangements for a turning operation to flip such structure to ships position, it must be remembered that the distances between the padeye and spreader or hook may change. Especially for statically indeterminate lifts, this will affect the loads seen in the respective slings. An exaggerated example of this can be seen in Figure 25.

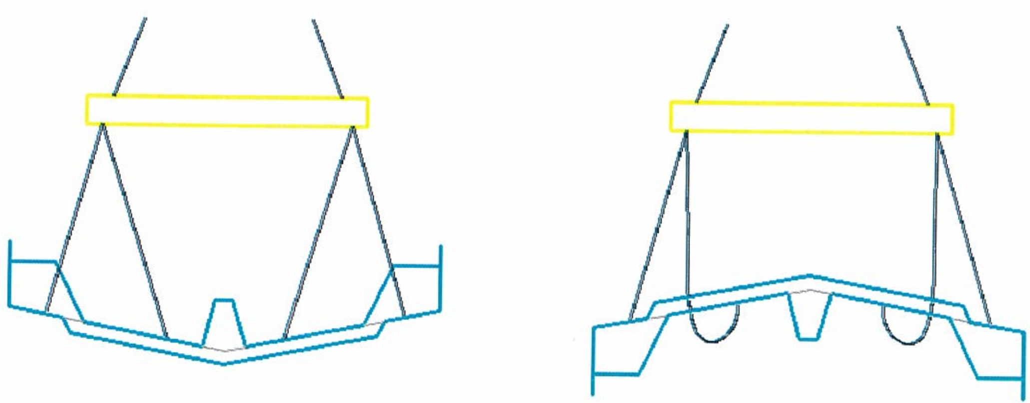

Figure 25: Effects of Shape on Forces During a Turn

- ❑ Are there manholes, temporary access holes, or equipment when padeyes are to be installed that would weaken the structure or prevent padeyes from being installed?
- ❑ Are there any lightening holes, equipment penetrations, or construction clearance allowances under or near the planned padeye?

Some of the highest stresses areas of blocks during lifts are directly under the padeye. This is especially true with padeye placed on relatively light structural members. Lightening holes, fabrication clearances, piping, electrical and HVAC penetrations can substantially weaken the structure in these locations. There is often little choice as to where padeye can be placed for a given lifting arrangement, and as a result careful attention should be paid with regards to stress concentration near such discontinuities in block structure. Holes such as lightening and clearance should be eliminated where possible or with the use of collars to stiffen the latter. Outfitting penetrations that are required should be strengthened with such options as ring stiffeners, sections of the girder's web thickened, or the temporary structure either tying decks together or strengthening the girder itself.

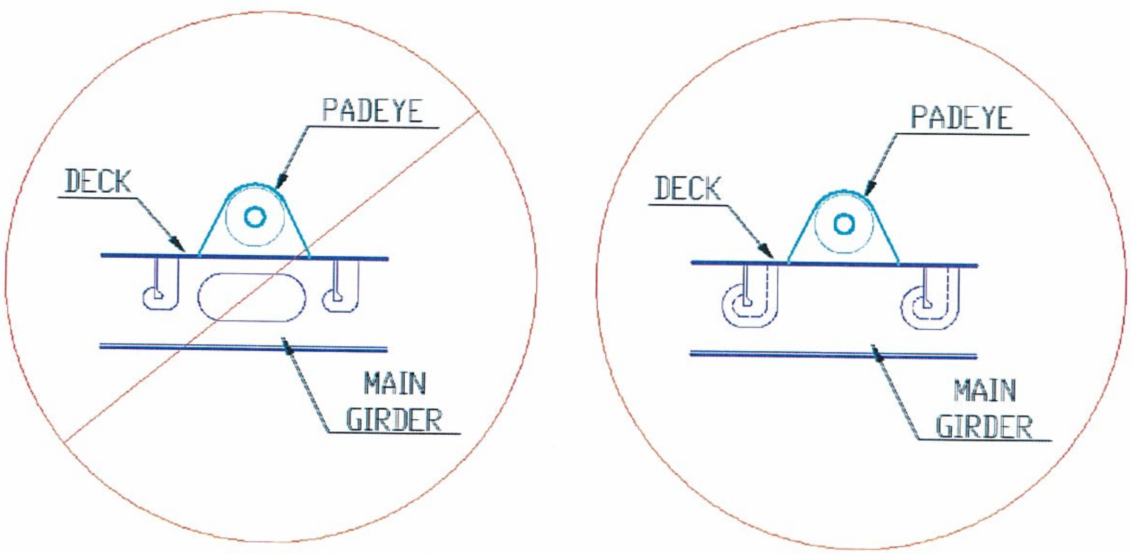

Figure 26: Choosing Padeye Placement

- ❑ Is the weld strong enough on padeye and structure under padeye?
- ❑ Is the padeye thickness adequately matched to the attachment structure?
- ❑ Is the structure in proximity to the padeye fully welded?

A padeye's maximum rated design load may place significant stress in the base material of the padeye. Furthermore, padeyes are often made from thicker material than may exist in the block structure that is lifted, especially for blocks higher in elevation on the vessel. This can result is stress concentration effects at the transition of material thickness in addition to the stress being amplified by the fact that the same load is now being held by less material. A critical lift designer should have access to tables of loads and thickness relationships that are allowable for a given set of padeye. These should include information pertaining to, padeye type, bulkhead or frame thickness, shell or deck plate thickness, type of load and direction, amount and continuous length of weld attaching bulkhead to deck plate, and alignment considerations required to effectively transfer the load.

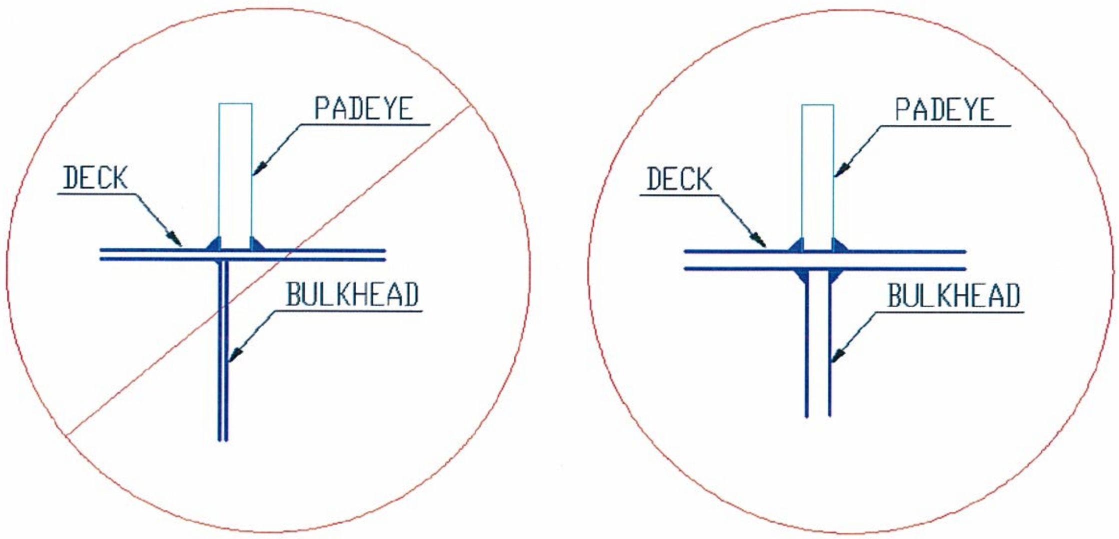

Figure 27: Padeye Alignment, Welding, and Transitions to Block Structure

8. SHACKLES

- ❑ Will shackles be loaded in their proper manor, or is twisting, bending, side load, or binding a possibility?
- ❑ Is the shackle pin uniformly loaded?

Ideal loading conditions for shackles is a normal straight line pull for which the fittings were designed. Irregular loading of shackles that applies excessive bending, torsion, or shear should be avoided. Ideal loading of a shackle pin would be a uniform load covering eight tenths of the exposed length.

Some manufactures have efficiencies calculated specifically for screw pin and bolt shackles. These tables suggest that loads that produce a side load of 45 degrees should be de-rated to 70% of working load limit and loads that are 90 degrees from in-line should be de-rated to 50% of working load limit. These reductions apply only to loads that are also in plane with the bow of the shackle. For further explanation into proper shackle use consult with information compiled by manufacturers.

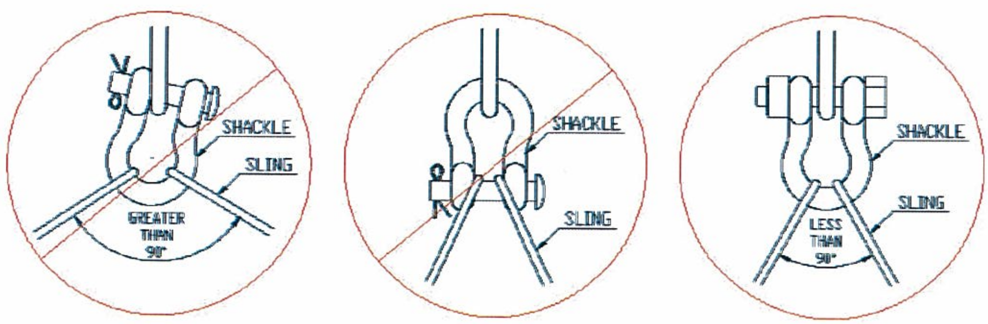

Figure 28: Best use of Shackles

Special sling saver shackles are made for use with synthetic and wire rope slings. These shackles provide an increased bow radius to increase the bend radius that the sling will see. This greatly improves the working life of the sling, the strength of wire rope subject to bend radius affects, and helps prevent bunching that reduces effectively of synthetic slings. For sling attachment to shackles on critical lifts, these types of shackles are highly recommended.

- ❑ Is there the possibility of the shackle pin unscrewing?

Under certain circumstances with a wire rope or other slings running through a shackle it is possible during the translation of that wire rope that frictional forces between the wire rope and the shackle pin will cause it to unscrew. Design of lifting arrangements that could lead to this type of failure should be avoided.

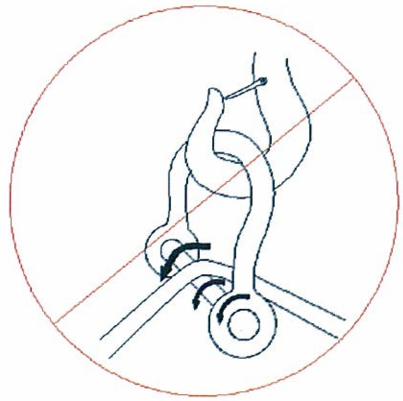

Figure 29: Possibility of Shackle Pin Unscrewing

- [ ] Has the correct shackle been chosen for the padeye or lifting attachment?

Shackles with different load ratings have different size pin diameters, with increasing size pin diameter for increasing load rating. Pin connections, such as in a padeye, are typically designed such that the shackle that is intended to go through the hole in the padeye is no less than 90% the diameter of the hole. This helps provide proper contact area on the inside of the hole reducing bearing stress on the inside of the padeye hole. The distribution of this load over a larger area also reduces wear on the pin connection.

When selecting a shackle for a pin connection or padeye, unless noted otherwise in the listed design requirements, the shackle pin should be no smaller than 90% of the padeye hole diameter.

- [ ] Is sling saver shackle used for sling attachments?
- [ ] Is bunching of a sling severe?

Sling saver shackles have a larger radius on the top surface such that the radius that the sling is wrapped around is as large as possible. This helps prolong the working life of the sling and provides a stronger termination.

Also special padding can be obtained to cover the pin on the shackle that fulfills a similar function for the attachment of slings to the pin of the shackle.

Caution should be exercised when attaching synthetic slings to shackles as bunching may occur if the sling is too wide for the shackle in use. Specific synthetic slings requirements should be checked to ensure a proper connection is made.

9. SLINGS

- ❑ Has the efficiency of the sling termination been factored into its strength?
- ❑ Has sling eye size been appropriately selected?

For both wire rope and synthetic slings, the type of termination or attachment has significant affects on the strength. One common attachment is putting a shackle or trunnion directly through the eye of the sling. Two factors reduce the strength with this type of attachment, the sling is now subject to bending loads around the pin, and the splice is under force to cause the eye to split. These two factors tend to counter each other such that a pin passing through the eye of a synthetic sling should never be larger than one third the eye length or larger than the natural width of the eye. Also, a particular sling's mechanical bearing and minimum radius properties will limit the minimum size of a pin passing through the eye. The wire rope technical board suggests that the minimum size pin through an eye as twenty percent of the quantity of the width of the eye plus twice the length of the eye.

Critical lift designers also need to be aware that the connection method on the end of wire rope will reduce the strength of the wire rope. For wire rope, the most efficient type of termination is a socket. This is a cone shaped attachment that is filled with spelter, molten zinc, or resin. This termination is rated at 100% efficiency such that the strength of the rated wire rope is not affected at all and the end connection has the strength of the rope.

A Mechanical Spliced Sleeve (Flemish eye) for wire rope with a loop or a thimble will have rated efficiencies of 90-95%. It is important to note that some of these efficiencies will vary for wire rope core or fiber core wire ropes.

A Loop or Thimble Spliced-Hand Spliced (Tucked) end termination for wire rope has an efficiency of 80-90% for carbon steel rope.

Wedge Socket efficiency is highly dependant on the type of design but ranges from 75-80% the strength of the wire rope.

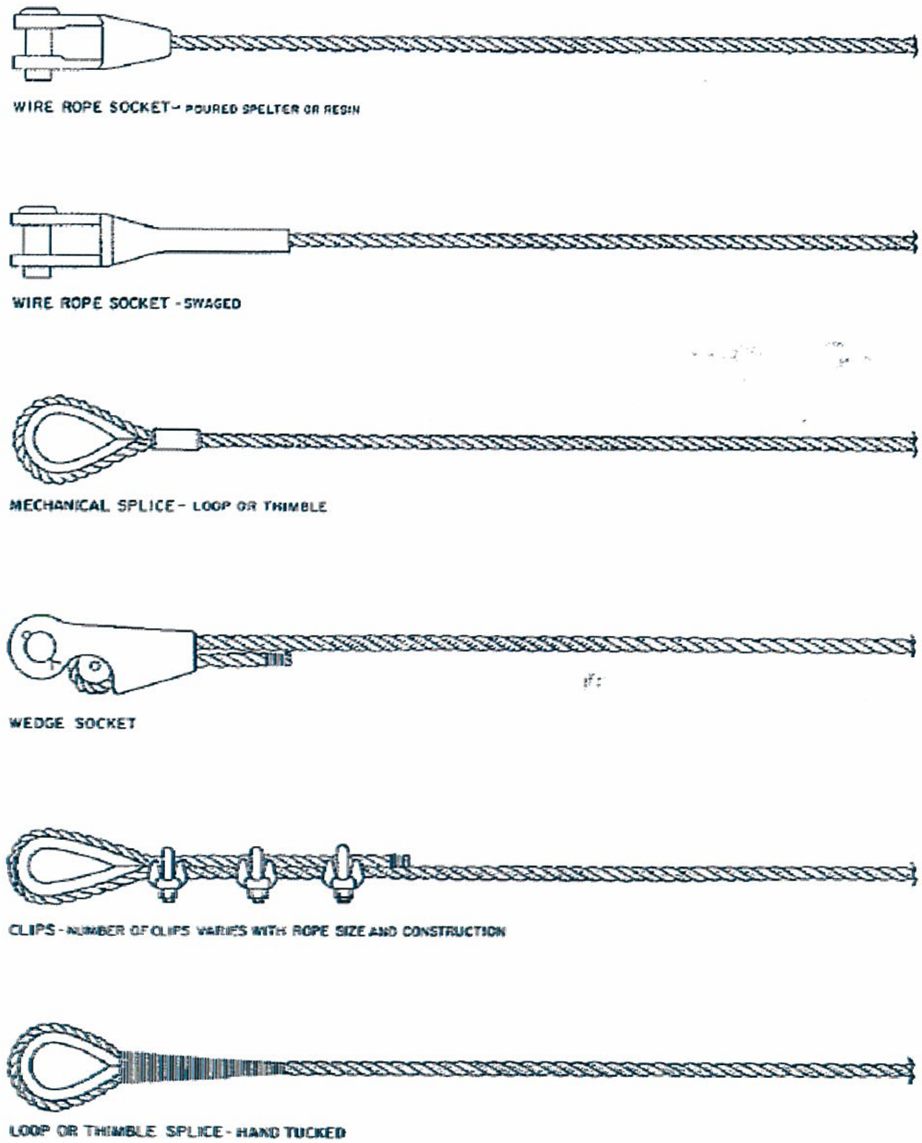

Figure 30: Examples of Wire Rope Connections
Figure reprinted with permission from the
WIRE ROPE TECHNICAL BOARD

- ❑ Has bearing area and stress in slings been calculated?
- ❑ Have corner softeners been used to prevent small sling radius load rating been checked?
- ❑ Is binding or chafing of the straps on other gear or equipment a possibility?

Wire rope has recommended bearing pressures above which the rope can be damaged. The allowable bearing pressure for wire rope is dependant on the type of lay, the classification of rope, and the material the rope is bearing into. For cast iron or carbon steel sheaves allowable radial bearing pressure will range from 300 to 1450 (psi).

Specific manufacturing data should be referenced for classification of rope, material, and bearing area specifications.

It is quite common to use softener pads with synthetic slings as they are especially susceptible to cutting. These pads can be inserted in shackles to prevent exposed shackle threads or other sharp spots from inflicting damage, or wrapped around hard corners of items being lifted. Many materials have been designed with a wide range of attachments and allowable bearing pressures.

- ❑ Has bend radius of wire rope been calculated and its reduction of strength been accounted for?
- ❑ Have corner softeners been used to prevent sharp corners for chain slings?

Slings have the highest rated force when it is in tension. Any bending stress that can develop in the sling will reduce the load that it can safely hold. Tabulated reductions in strength or efficiencies exist for wire ropes. These tabulated values are highly dependant on the classification of the wire rope as the lay of the rope and the geometry of the core can greatly affect flexibility.

It is important to know what type of wire rope one is dealing with when designing a lift that requires a high amount of bend to be imparted to the wire rope. Of the two main types of wire rope regular and lang lay, lang lay is more flexible but should not be operated at small bend radiuses as it is more subject to crushing than regular lay wire rope.

Synthetic slings are less influenced by bending as they are more flexible and generally have a flatter cross-section. However, synthetic slings are more susceptible to being cut by corners or adjacent objects that they may bear upon. Corner softeners and bearing pads can be obtained to reduce harmful wearing affects of such contact.

- ❑ For choking lifts, has the sling been derated based on the angle of the choke?

Choking lifting arrangements are rarely used for critical lifts. However, it should be understood that the choke places a bend in the sling and will have similar reduction in strength effects. Tables exist that correlate the material, attachment and angle of the choke to allowable load.

- ❑ Does the arrangement make chainfalls susceptible to binding or twisting?

The use of wire rope comes with the problem that as the rope is loaded up it will have a slight tendency to twist. Depending on the type of wire rope one uses, this affect can vary substantially. Each manufacture will have tables regarding the specific properties of the wire rope they sell and can provide rotational constants. There is non-rotational wire rope that can be obtained that produces significantly less rotation when under load. Also, swivels are made that can be used to allow rotation in certain sections of the rigging arrangement, but these have addition constraints regarding there use. The best practice would be not to use wire rope in series with a chainfall, but if one has no other choice non-rotational wire rope should be used.

Wire rope with very high rotation characteristics should not be used with a swivel under any circumstances as it may damage the rope by allowing excessive rotation and the unlaying of the rope. Similarly, the rotation that swivels allow tend to reduce the service life of wire rope as the rotation they allow results in the wear between inner and outer layers of the rope.

- ❑ Are chainfalls required to level the structure?
- ❑ Are chainfalls required to lower the load?
- ❑ Is a sufficient air source available to operate an air hoist?

When designing critical lifts with the use of chainfalls or airhoists, it should be remembered that it is much easier to lower a load with the use of a chainfall than to raise it. If the arrangement is set up such that the unknowns pertaining to the block are skewed such that any adjustment to be made required the lowering of load with the chainfalls operations can progress more smoothly. This is particularly true with manually adjusted chainfalls.

Pneumatically powered chain falls or air hoists required a supply of compressed air to allow the load to be raised or lowered. When designing a lift that requires the use of pneumatically powered equipments make sure air sources are available. Both air pressure and volumetric supply need to be available.

- ❑ Will a difference in sling length greatly affect the strains and thus stresses seen by each sling?
- ❑ Are slings for lift all the same type, age, and have similar working history?
- ❑ Is sling length known exactly?

Slings may vary with life cycle and grow longer and stiffer as time and wear take affect on them.

Wire rope has three phases of stretch over the course of its life. After manufacture it will relatively quickly break in due to its operating conditions and straightening out. During this phase its modulus will be lower and more strain can be expected. The amount of constructional stretch to be expected depends on the type of wire and a definite value cannot be assigned. Wire rope with fiber cores can be expected to stretch from 1/2 to 1% where as rope with an independent wire rope core will only have construction stretch of 1/4 to 3/4%. Through out most of its life, it will have a nearly constant modulus with effects of wear and fatigue having only a slight affect on the length of the rope. The third and final phase of a wire ropes life results in permanent stretch becoming more significant as a point of rapid degradation has resulted from prolonged subjection to abrasion, wear, and fatigue. Wire rope slings in this third phase of life should be identified and removed from service immediately. As many critical lifts contain multiple slings and may be statically indeterminate, the load on any given sling is a direct function of the elasticity of the sling. For this reason, slings should have the same working history to ensure that the elastic properties are similar, resulting in a greater probability that they can share the load equally.

Synthetic slings also vary in length and initial manufacturing tolerances are typically on the order of plus or minus two to four percent. Data as to the amount of elongation of a synthetic sling during its life if not well known at this time. Depending on the weave and type of fiber, some synthetics will shrink and others may lengthen.

- [ ] Are chemicals, vapors, or loose grit and debris present that could degrade Synthetic slings?

Synthetic slings have enormous strength when compared to wire rope on a pound for pound basis. However, these synthetics have some disadvantages with regards to chemical resistibility. These effects are highly material and temperature dependant and may be immediately destructive to sling after months of emersion. Chemicals relating to painting, prepping, cleaning and other yard activities should be checked for compatibility. A brief synopsis of how some synthetic slings are affected is as follows:

- Aramid fibers are attacked by strong acids and bases and sodium hypo-chlorite bleach particularly at elevated temperatures.

- High molecular polyethylene resist many chemical agents but can be slightly affected by Clorox and other bleaching agents.

- Nylon fibers are affected by most acids and bleaching agents including Formic Acid, Phenolic compounds, calcium chloride, zinc chloride, benzyl alcohol, to name a few. Strength reduction may occur immediately or over a period of hours and is highly temperature dependant. Nylon losses approximately 15% of its strength when wet.

- Polyester will disintegrate with concentrated sulfuric acid but is generally not significantly affected and resistant to most chemicals.

- [ ] Is a method of adjusting sling length planned to account for variations in CG?

Due to variations in the estimated or actual location of the center of gravity of a block, sling length may be required to be variable to allow the load to be leveled. Typically for critical lifts this can be done with the addition of shackles or the substitution of larger shackles to incrementally increase the length of the sling.

References:

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RIGGING LIFT COMMON COMPONENT CATALOG

National Steel and Shipbuilding Company
Initial Design & Naval Architecture

Issued: JULY 2009 – Revision (-)

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NASSCO ENGINEERING
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Authors Note

This document may at times repeats information that is in different sections and also with information the other accompanying documents. Such repetition is by design to present the reviewer of any particular section with relevant information. It is seen as preferable to repeat information rather than have that information overlooked.

This document has information for many of the rigging components commonly used in a shipyard and is intended to provide relevant information for the design of critical lifts using these components. It should be noted that no catalog can be complete and cover all information needed, all manufacturers, or any set circumstance, and thorough Engineering review should be undertaken whenever the well being of personnel or property is endangered.

Proper analysis of stresses within ships blocks during rigging lifting arrangements requires significant experience and detailed knowledge to approximate solutions. Although these documents provide a small foundation for the information needed for the design of critical lifts, it is no substitute for the application of sound Engineering judgment accompanied with analytical thought.

This document is part of a packet which includes:

LIFT CHECK SHEET

LIFT APPROACH GUIDANCE

RIGGING LIFT COMMON COMPONENT CATALOG

For the final analysis and design of any lift, ultimate responsibility and application of guidance referenced rests with the user.

Table of Contents

Figures

Tables

OVERVIEW

A qualified Rigging Engineer at a shipyard needs to know information about ship structure, yard practices, procedures, and capabilities in addition to having a solid grasp of Rigging Engineering fundamentals. The goal of this catalog is to give an Engineer a list of common parts, regulations and restrictions regarding these practices, general engineering data useful for using rigging components, and descriptions as to how these parts are used and interface with each other. This is intended to complement the Lift Check Sheet and the Lift Approach Guidance document with additional manufacturer and item specific information. The following items are included:

PADEYES
SHACKLES, MASTER-LINK RINGS
SLINGS (wire rope, synthetic, & chain)
CHAIN-FALLS, AIR HOISTS
SPREADER BEAMS
HOOKS
CRANES

Ideally every shipyard should have a catalog of its own equipment integrated into an extensive library of acceptable arrangements and loads. This will reduce the time spent on the non-value added work of figuring out lift arrangements, and what are acceptable limits for individual components in such an arrangement. This is beneficial for training new employees, or used as a collaborating reference for seasoned ones, all of which will allow the work load to be better distributed during times of high demand. These catalogs of relevant information should be geared towards increasing the learning curve and improving the efficiency of employees.

A catalog of common shipyards components that are used for lifts can quickly become quite extensive as significant amounts of information can be generated and accumulated. It is important to keep a specific focus on items added to this catalog with a regard to what is relevant information. It is suggested that the item specific information in a catalog of critical components includes the following:

- ❑ Manufacturers of such components should be cataloged such that one can always contact the source directly if a question prompts the need for more detailed or current information. Also, comparisons can quickly be made with similar parts that may provide a better solution for a particular arrangement.

- ❑ Size and dimensions of components should be available for parts used such that critical dimensions can be checked against mating surfaces and overall sizes may give indications of possible interferences.

- ❑ Capacity of lift components should be available so the proper one can be selected without significant probability of failure.

- ❑ Properties of components are important for they may degrade under certain conditions or have limitations based on environmental, fatigue, wear, or other operations factors.

- ❑ End connections of items should be documented so it is known what items canbe linked to other and where limitations exist.

- ❑ Regulations and standards that affect the use of an item should be that when checking physical limitations, regulatory requirements can be reviewed.

1. PADEYE

Design Philosophy

A Padeye, is type of pin connection used for connecting structure to a shackle. Typically, on a ships block under construction, they will be welded to the hull over or onto a structurally significant part of the block. This is usually a sturdy frame or bulkhead. As the type, strength, and orientation of the structure and lift can vary substantially, many different shapes and geometries of padeyes have been created.

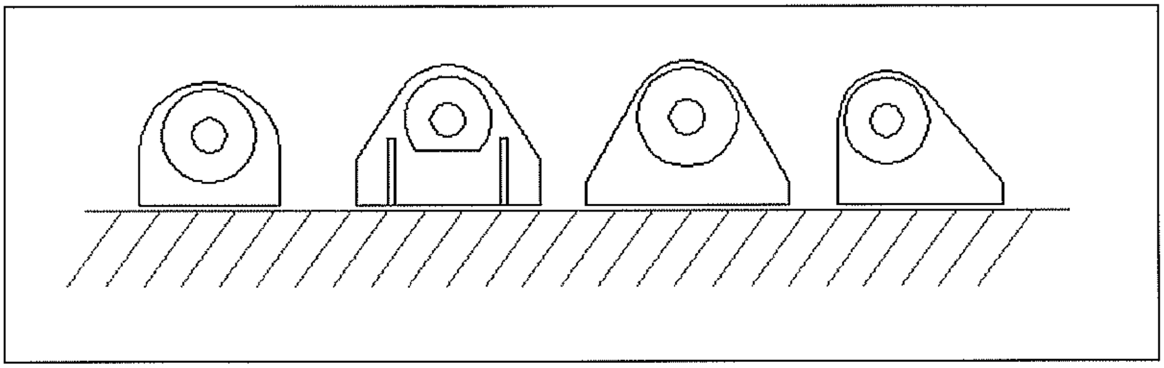


Figure 1: Examples of Padeyes

Padeyes are typically shipyard specific as many shipyards have there own designs that have been designed and built in house. This familiarity helps guide the rigging engineering design process as the potential limits are better understood. There are, however, consultant engineering firms that can design and engineer padeye.

A typical padeye will have circular boss plates on both sides surrounding the shackle pin hole. These plates perform several critical functions. Many documented steel single plate padeye failures are due to shear in this highly stressed region, and there are well documented standards and guidelines for stresses due to bearing forces, tensile forces near the shackle hole, splitting and fracture of the surface beyond the hole, and shearing or tearing near the edges of the hole. These well documented modes of failure result in well defined requirements and a similarity among most padeyes surrounding the pin connection hole. The exception being aluminum padeyes that may or may not have brass or bronze inserts pressed inside of the shackle hole to provide a harder bearing surface.

There is significant variance in the lower half of many padeye that reflects individual designer choices as well as load requirements based on particular design criteria. Some padeyes are designed with ample space beneath the shackle hole such that the padeye can be trimmed off and reused multiple times. Also, some padeyes have chocks or gusset plates to help stabilize the weak axis of the padeye if out of plane loads are anticipated. The types of structures the padeye will be welded will also influence the geometry of the padeye. If the structure is relatively thin in comparison to the padeyes thickness, the padeye may need to be lengthened to spread the load over a greater length of the thin block structure. Also, whether the padeye is just used with only vertical loads, or if the padeye is intended for turning operations with horizontal loads, will greatly affect the shape at the attachment to the structure.

Turning operations may require a padeye to be loaded through 180 degrees during a single lift. This often requires a padeye to have its shackle hole extended over the end of the structure that it is attached. Two approaches to this problem are to lap the padeye onto the structure, and to cantilever the padeye out over the edge. From the designs reviewed there seems to be no clear consensus as to the best way to do this or what the best geometry might be.

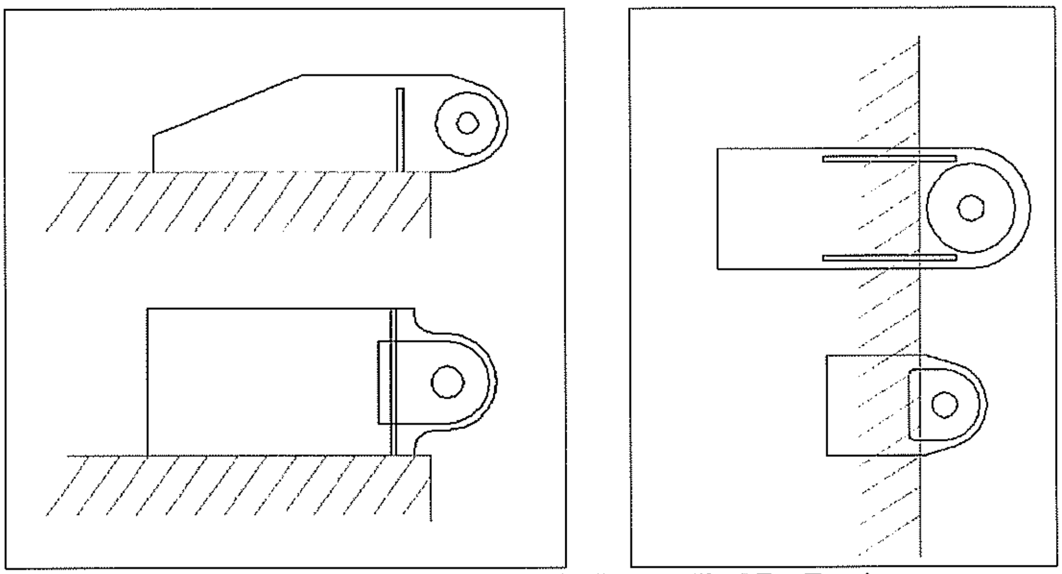


Figure 2: Blade and Lap-On Padeyes Used For Turning

One approach to lifting and turning operations is with the use of trunions. Typically these are cylindrical posts sticking proud that a sling or line can be wrapped around. This arrangement can allow loads to be applied in any direction in the radial plane. Often two trunions are used on either side of the center of gravity to facilitate easy rotation of an object. They have limited use in large block shipbuilding lifting as multiple lifting points are usually required, and in order to structurally integrate trunion into most structure they must be effectively buried making removal difficult.

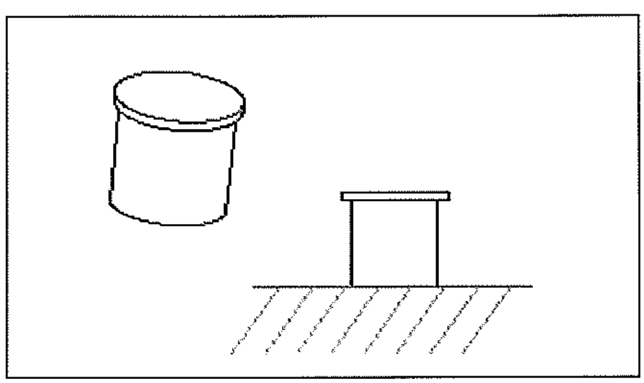


Figure 3: Trunion

Standards and Regulations

There are no published standards specifically applicable to padeyes used for ship construction. NAVSEA however has a guidance drawing, (No. 5184133) pertaining to permanently installed padeye for machinery lifting. The best document to govern lifting padeye design would be the American Society of Mechanical Engineers Design of Below the Hook Lifting Devices. (ASME BTH-1-2005) This design standard gives very detailed advice as to the design of single plate pin connections which is the heart of many padeyes. The structural design section of this document also gives clear advice as to how to apply recommended design factors to either calculated Von Mises stresses or classically calculated shear or moment forces on different sections. Many of the formula prescribed are based on AISC allowable stress design formula with slight modification resulting in increased design factors. These have been added to allow for the increased failure consequences rigging items face.

2. SHACKLES, MASTER LINK RINGS

The most common types of rigging hardware are shackles and rings which allow different components to be attached together. As key links in any rigging arrangement, it is important to understand how they should be loaded and what their limitations are. Different manufactures have slightly different recommendations, so specific requirements for a given shackle should be confirmed with the manufacturer.

Manufacturers

The main shackle provider for rigging equipment for large lifts is Crosby. Skookum is another major US shackle provider. NASSCO primarily uses these manufacturers as a source for shackles. Other manufactures of shackle certainly do exist and can provide shackle functionally similar to them. These manufactures include: Chicago Hardware and Fixture, Van Beest, Yoke, Suncore, Sea-Fit, LGH-Lifting Gear Hire, BLB Superstorre, Bishop Lifting products, Taylor Chain, KWS Thiele, and Hale Iron.

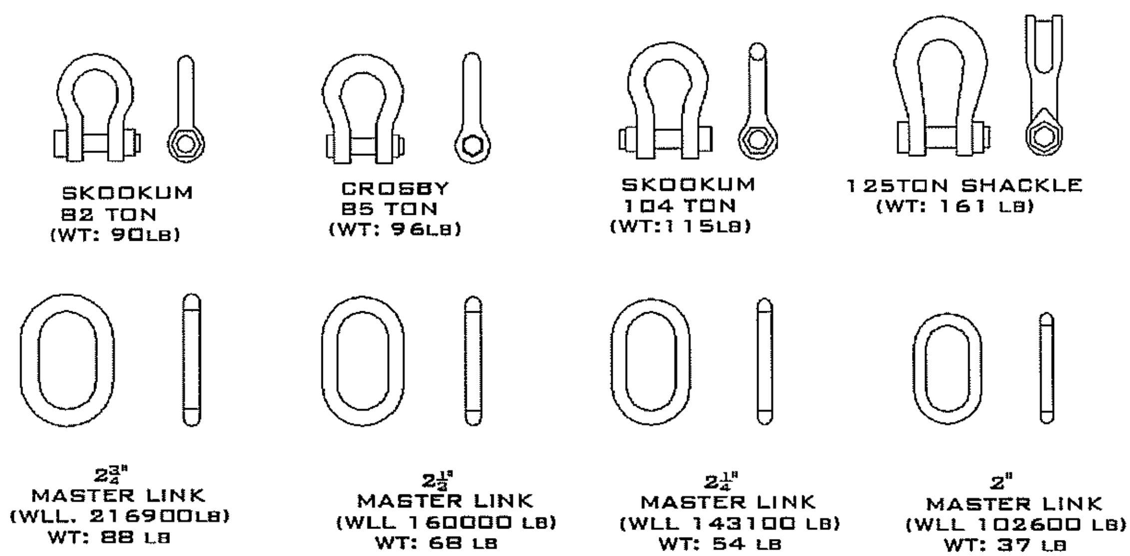


Figure 4: Selection of Typical Shackles

Loading Restrictions and Recommendations

The most ideal way to load the pins of shackles is with a uniform section that is 80% as wide as the opening of the shackle. This loading method will reduce the bending moment on the pin.

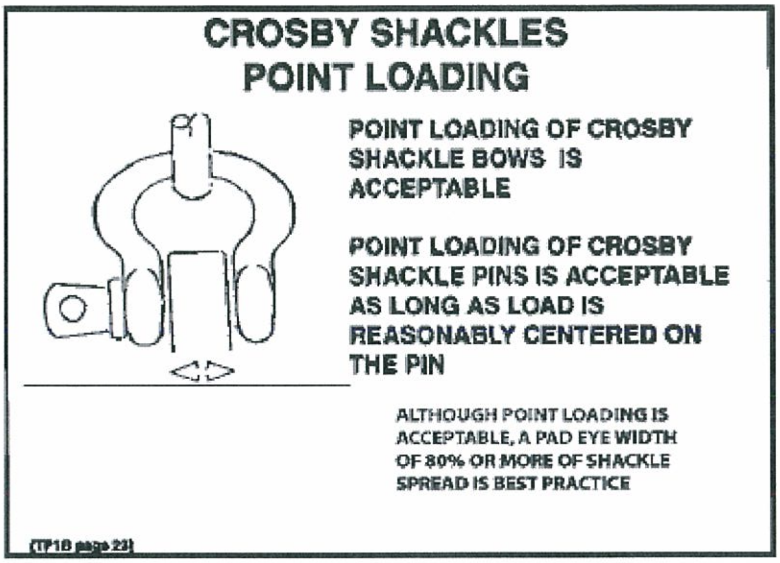
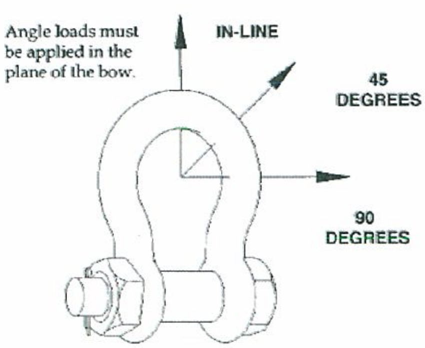


Figure 5: Recommended Distributed Loading of Shackle Pins
Figure reprinted with permission from the
CROSBY GROUP

Shackles will have their greatest strength when loaded in-line such that the load will be evenly divided on both halves with minimal bending when transferred back to the pin connection. When multiple lines are connected to the same shackle there will inevitably be some angle between the loads and thus they will not be in-line with the ideal loading condition. If the angle the loads are applied to the shackle is taken to an extreme, with the angle between them being almost 180 degrees and the lines themselves being at almost 90 degrees from in-line, it can easily be seen how this load orientation could reduce the strength of the shackle. With this extreme loading condition significant bending forces will be placed in the shackle and the pin will be under tension. Crobsy has recommendations to derate the shackle under these conditions as shown in Table 1. It should also be noted that it is never acceptable to put these extreme loading condition on a shackle with the pin held in place with a cotter pin as this configuration will not handle tension.



Side Loading Reduction Chart
For Screw Pin and Bolt Type Shackles Only †

Angle of Side Load from Vertical In-Line of shackle	Adjusted Working Load Limit
0° In-Line *	100% of Rated Working Load Limit
45° from In-Line *	70% of Rated Working Load Limit
90° from In-Line *	50% of Rated Working Load Limit

* In-Line load is applied perpendicular to pin.
† DO NOT SIDE LOAD ROUND PIN SHACKLES

Table 1: Side Loading Load Reduction
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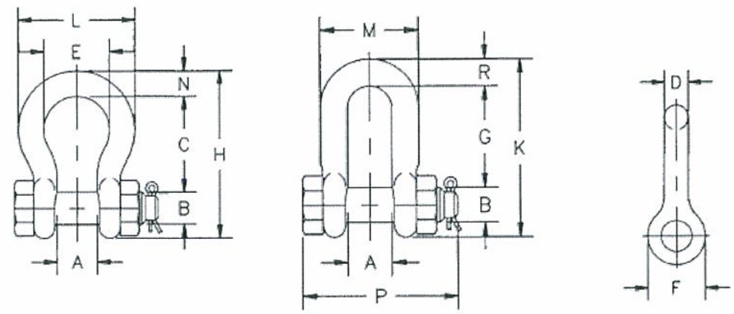
Typical sizes and strengths of Crosby G-shackles and Chain shackles can be seen in Table 2



2130 2150

Nominal Size (in.)	Working Load Limit * t	Weight Each (lbs.) G-2130 S-2130	Weight Each (lbs.) G-2150 S-2150	Dimensions (in.) A	B	C	D	E	F	G	H	K	L	M	N	P	R	Tolerance +/- C&G	A
3/16	1/3	.06	—	.38	.25	.88	.19	.60	.56	—	1.47	—	.98	—	.19	—	—	.06	.06
1/4	1/2	.11	.13	.47	.31	1.13	.25	.78	.61	.75	1.84	1.59	1.28	.97	.25	1.56	.25	.06	.06
5/16	3/4	.22	.23	.53	.38	1.22	.31	.84	.75	1.00	2.09	1.91	1.47	1.16	.31	1.82	.31	.06	.06
3/8	1	.33	.33	.66	.44	1.44	.38	1.03	.91	1.22	2.49	2.30	1.78	1.41	.38	2.17	.38	.13	.06
7/16	1 1/2	.49	.49	.75	.50	1.69	.44	1.16	1.06	1.42	2.91	2.66	2.03	1.62	.44	2.51	.44	.13	.06
1/2	2	.79	.75	.81	.63	1.88	.50	1.31	1.19	1.63	3.28	3.03	2.31	1.81	.50	2.80	.50	.13	.06
5/8	3 1/4	1.68	1.47	1.06	.75	2.38	.63	1.69	1.50	2.00	4.19	3.75	2.94	2.31	.69	3.53	.63	.13	.06
3/4	4 3/4	2.72	2.52	1.25	.88	2.81	.75	2.00	1.81	2.38	4.97	4.53	3.50	2.75	.81	4.07	.81	.25	.06
7/8	6 1/2	3.95	3.85	1.44	1.00	3.31	.88	2.28	2.09	2.81	5.83	5.33	4.03	3.19	.97	4.71	.97	.25	.06
1	8 1/2	5.66	5.55	1.69	1.13	3.75	1.00	2.69	2.38	3.19	6.56	5.94	4.69	3.69	1.06	5.31	1.00	.25	.06
1 1/8	9 1/2	8.27	7.60	1.81	1.25	4.25	1.13	2.91	2.69	3.58	7.47	6.78	5.16	4.06	1.25	5.90	1.25	.25	.06
1 1/4	12	11.71	10.81	2.03	1.38	4.69	1.25	3.25	3.00	3.94	8.25	7.50	5.75	4.53	1.38	6.51	1.38	.25	.06
1 3/8	13 1/2	15.83	13.75	2.25	1.50	5.25	1.38	3.63	3.31	4.38	9.16	8.28	6.38	5.00	1.50	7.21	1.50	.25	.13
1 1/2	17	20.80	18.50	2.38	1.63	5.75	1.50	3.88	3.63	4.81	10.00	9.06	6.88	5.38	1.62	7.73	1.62	.25	.13
1 3/4	25	33.91	31.40	2.88	2.00	7.00	1.75	5.00	4.19	5.75	12.34	10.97	8.86	6.38	2.25	9.05	2.12	.25	.13
2	35	52.25	46.75	3.25	2.25	7.75	2.00	5.75	4.81	6.75	13.68	12.28	9.97	7.25	2.40	10.41	2.00	.25	.13
2 1/2	55	98.25	85.00	4.13	2.75	10.50	2.62	7.25	5.69	8.00	17.84	14.84	12.87	9.38	3.13	13.56	2.62	.25	.25
3	† 85	154.00	124.25	5.00	3.25	13.00	3.00	7.88	6.50	8.50	21.50	16.88	14.36	11.00	3.62	16.50	3.50	.25	.25
3 1/2	†120 ‡	265.00	—	5.25	3.75	14.63	3.62	9.00	8.00	—	24.63	—	16.50	—	4.12	19.00	—	.25	.25
4	†150 ‡	338.00	—	5.50	4.25	14.50	4.10	10.00	9.00	—	25.69	—	18.42	—	4.56	19.75	—	.25	.25

* NOTE: Maximum Proof Load is 2.0 times the Working Load Limit. Minimum Ultimate Strength is 6 times the Working Load Limit. For Working Load Limit reduction due to side loading applications, see page 20.
† Individually Proof Tested with certification.
‡ Furnished in Anchor style only. Furnished with Round Head Bolts with welded handles.

Table 2: Typical Crosby Shackles
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The Oregon Department of Occupational Safety and Health Division has created a table that matches wire rope sling size to required shackle size which can be found in their rigging and rigging processes handbook part 437-007-0635. This table roughly matches wire rope allowable load based on a factor of safety to minimum breaking strength of 5 and shackle working load and can be referenced in Table 3: Recommended Shackle Size for Wire Rope Sizes (OROSHA).

This table provides useful information given certain assumptions that may not always be listed or easily identifiable. This particular table should be used with caution as wire ropes and shackles can vary in strength depending on the specific manufacture and construction. Furthermore this table makes no allowance for termination type of the wire rope which will reduce its strength unless a socket connection is used. This is a good example that one should exhibit caution when referencing tables and always apply good

Engineering judgment over all references and components in a given rigging arrangement.

G	SHACKLES / METAL SPAR GUYLINE SAFETY STRAPS	Oregon Administrative Rules Oregon Occupational Safety and Health Division

(22) The minimum size of shackles required for joining or attaching lines are shown in Table 7-5.

Table 7-5
Bell Shaped and Sleeve Shackles Used to Join or Attach Lines

Wire Rope Size In Inches	Shackle Size In Inches	Wire Rope Size In Inches	Shackle Size In Inches
1/2	5/8	1	1 1/4
9/16	3/4	1 1/8	1 3/8
5/8	7/8	1 1/4	1 1/2
3/4	1	1 3/8	1 5/8
7/8	1 1/8	1 1/2	2

(23) The minimum size of flush pin straight-sided shackles for joining or attaching skyline extensions are shown in Table 7-6.

Table 7-6
Flush Pin Straight-Sided Shackles Used for Attaching Skyline Extensions

Wire Rope Size In Inches	Shackle Size In Inches	Wire Rope Size In Inches	Shackle Size In Inches
1/2	5/8	1	1 1/8
9/16	3/4	1 1/8	1 1/4
5/8	3/4	1 1/4	1 3/8
3/4	7/8	1 3/8	1 1/2
7/8	1	1 1/2	1 5/8

Table 3: Recommended Shackle Size for Wire Rope Sizes (OROSHA)

Standards and Regulations

There are well defined requirements and safe working loads for common rigging items such as shackles and rings, that can be found in OSHA federal standards under safety and health regulations for general construction Part 1926. These requirements are followed by US manufacturers and it is common rigging practice to use ratings developed by US manufacturers. The OSHA Part 1915 specifically pertaining to shipyards has significantly less information on rigging hardware and their requirements, but most shackles for rigging will exceed or conform to Part 1926 and the requirements there in.

The code of federal regulations title 29 part 1926.251 deals with rigging equipment for material handling and subpart (f) deals specifically with shackles. It states as follows:

> (1) Table H–19 shall be used to determine the safe working loads of various sizes of shackles, except that higher safe working loads are permissible when recommended by the manufacturer for specific, identifiable products, provided that a safety factor of not less than 5 is maintained.

TABLE H–19—SAFE WORKING LOADS FOR SHACKLES

[In tons of 2,000 pounds]

Material size (inches	Pin diameter (inches)	Safe working load
1/2	5/8	1.4
5/8	3/4	2.2
3/4	7/8	3.2
7/8	1	4.3
1	1 1/8	5.6
1 1/8	1 1/4	6.7
1 1/4	1 3/8	8.2
1 3/8	1 1/2	10.0
1 1/2	1 5/8	11.9
1 3/4	2	16.2
2	2 1/4	21.2

Table 4: Shackle Safe Working Loads (OSHA)

Modern manufacturers shackles will typically exceed these load ratings of Table 4: Shackle Safe Working Loads (OSHA) based on pin size as there have been much advancement in material technology since the table was formulated. The new materials in use still provide a safety factor of 5 as required by the OSHA standards but do so with reduced weight and size.

3. SLINGS

Slings for rigging lifts are typically made from chain, wire rope, or synthetic materials. Of these materials, synthetic slings are the most common for the largest lifts in shipyards. This is because wire rope and especially chain slings have significant weight and there are many benefits of keeping the rigging hardware as light as possible.

Many engineered lifts are statically indeterminate and proper analysis of them can only be conducted if the properties of various components are well known. General information regarding stress and strain of the slings is required to actually estimate the load in them for statically indeterminate lifts.

Wire Rope

Modern wire rope is perhaps the most widely used rigging sling material and has been in use for over one hundred and seventy years. This long history of use has allowed an evolution of improvements and significant knowledge being accumulated with regards to its properties and performance. This long working history gives it reliability unmatched by other materials and makes it ideal for reducing risk for critical lifts. The one main drawback is its size and weight which can make it time consuming to install and fraction of full strength when subject to bending.

Manufacturers

There are many manufactures of wire rope for use as rigging slings such as Bridon, Crosby, Contental Cabel, Diepa, Landmann, Premier, Loosco, Peway, Python, Galin, Strand Core, Yarbrough and many others.

Strength and Selection

The strength of wire rope varies considerably as the wires themselves can be made of many different types of steel. Common wire types are Traction Steel (TS), Extra High Strength traction (EHS), Improved Plow Steel (IPS), Extra Improved Plow Steel (EIPS), and Extra Extra Improved Plow Steel (EEIPS). Wire rope intended for service in the marine environment may even be of stainless or monel. The core of a wire rope also affects its strength as it may be fiber or of steel wire. Furthermore the number and rotation of the wires themselves also affects the strength and general properties. This results in significant combinations of wire ropes to be obtained with countless desired properties. Unfortunately, this results in many things one needs to consider when selecting a specific wire rope. An abbreviated list of considerations one should be familiar with when selecting a wire rope includes:

- Classification
- Strength of individual strand
- Fiber core or internal wire rope core
- Lay of wire in rope
- Rotation resistance
- Fatigue resistance
- Bearing strength
- Design factor required
- Sheave or shackle diameter intended
- Compacted wire rope
- Plastic filled or coated
- Corrosion resistance

As significant data has been compiled about wire rope libraries of failed wire ropes have been photographed, compiled, and tables produced cataloging the resulting failure modes that one should be familiar with. Typical modes of failure for wire rope are well documented and include:

- Ropes of incorrect size, construction or grade
- Ropes allowed to drag over obstacles.
- Ropes operating over sheaves or drums of to small a diameter.
- Ropes overwinding or crosswinding on drums.
- Ropes operating on sheaves or drums that are out of alignment, or improver fitting grooves and broken flanges.
- Ropes permitted to jump sheaves.
- Ropes subject to moisture or acid fumes.
- Ropes permitted to untwist.
- Ropes subjected to excessive heat.
- Ropes kinked.
- Ropes allowed to accumulate grit producing internal wear.

Measured Length

As the length of slings can be critical to keeping a lift level or having each sling share the load equally it should be known how to measure them. When specifying the length of wire ropes they should be measured by the distance between the two pull locations, or the center of the pin to be pulled in the socket. An example of measure lengths are shown in Figure 6

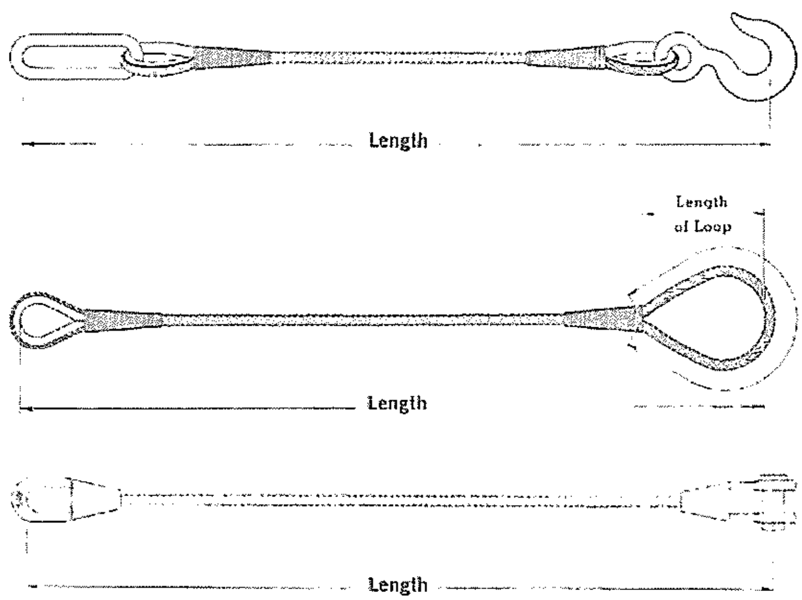

Figure 6: Wire Rope Length Measurements
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WIRE ROPE TECHNICAL BOARD

Strain and Modulus

The stretch of a wire rope is dependant on two factors. First there is the elastic stretch of the steel elements that elongate in proportion to the modulus of elasticity of the metal. An equally important component for wire rope is the structural stretch cause by the compression of the rope core and adjustments of the wires in the rope. This component can vary due to many factors such as the type of core, the length of the lays, the amount of bending the rope is subjected or has seen, vibration, and the complete load history of that particular wire rope. Older wire ropes that have seen heavy duty cycles will see less elongation than new ropes during loading. The structural stretch of the wire rope will also cause the wire rope to twist as it unlays. For very long lengths of wire rope a swivel block can be considered if it is critical that no torsion be transmitted to the attachments, however, for most critical lifts this is not a concern. One must be careful when adding a swivel because some wire ropes cannot be allowed to twist as they are loaded.

Due to the factors mentioned above the modulus of elasticity of a wire rope will vary considerably during its life generally increasing throughout. The greatest portion of the structural stretch occurs during the initial period of its life. Below is a table of commonly used approximate values for modulus of elasticity for various constructions. It can be seen that an Internal Wire Rope Core (IWRC) increases the stiffness of the rope. The values shown below are for wire ropes that are broken in and constructional stretch removed.

Rope Classification	Zero through 20% Loading	21% to 65% Loading
6 x 7 with fiber core	11,700,000	13,000,000
6 x 19 with fiber core	10,800,000	12,000,000
6 x 36 with fiber core	9,900,000	11,000,000
8 x 19 with fiber core	8,100,000	9,000,000
6 x 19 with IWRC	13,500,000	15,000,000
6 x 36 with IWRC	12,600,000	14,000,000
8 x 19 with IWRC	12,000,000	13,500,000
8 x 36 with IWRC	11,500,000	13,000,000

*Applicable to new rope with constructional stretch removed.

Table 5: Approximate Modulus of Elasticity for Wire Rope in psi
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WIRE ROPE TECHNICAL BOARD

End Connections

There is a large variation in the types of end connection possible with wire rope. The two main types are splices and sockets. Splices are typically used with a thimble and are not as strong as sockets because of the bend radius that the line is subjected. They will also be subject to a shortened life due to fatigue. Wire rope sockets contain the end of the wire typically with a poured zinc or resin plug. Other plug material can be used however they vary with strength and validation of their strength should be confirmed.

Typically for critical lifts sockets are used that allow the rope to provide its full strength. Closed spelter sockets which are ideal for connecting to the round of a G-shackle and can be obtained with safe working loads of hundreds of tons.

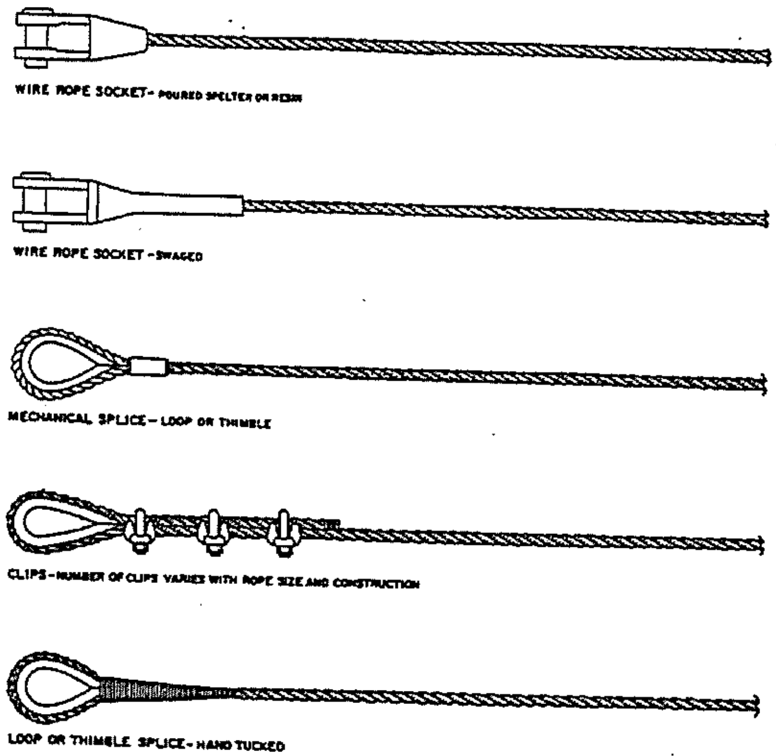

Figure 7: Types of Wire Rope Ends
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Type of Termination	Efficiency Rope with IWRC*	 Rope with FC**
Wire Rope Socket (Spelter or Resin)	100%	100%
Swaged Socket (Regular Lay Ropes Only)	100%	(Not Recommended)
Mechanical Spliced Sleeve (Flemish Eye)		
1" dia. and smaller	95%	92-1/2%
Greater than 1" dia. through 2"	92-1/2%	90%
Greater than 2" dia. through 3-1/2"	90%	(Not established)
Loop or Thimble Splice-Hand Spliced (Tucked) (Carbon Steel Rope)		
1/4"	90%	90%
5/16"	89%	89%
3/8"	88%	88%
7/16"	87%	87%
1/2"	86%	86%
5/8"	84%	84%
3/4"	82%	82%
7/8" thru 2-1/2"	80%	80%
Loop or Thimble Splice-Hand Spliced (Tucked) (Stainless Steel Rope)		
1/4"	80%	
5/16"	79%	
3/8"	78%	
7/16"	77%	
1/2"	76%	
5/8"	74%	
3/4"	72%	
7/8"	70%	
Wedge Sockets*** (Depending on Design)	75% to 80%	75% to 80%
Clips*** (Number of clips varies with size of rope)	80%	80%

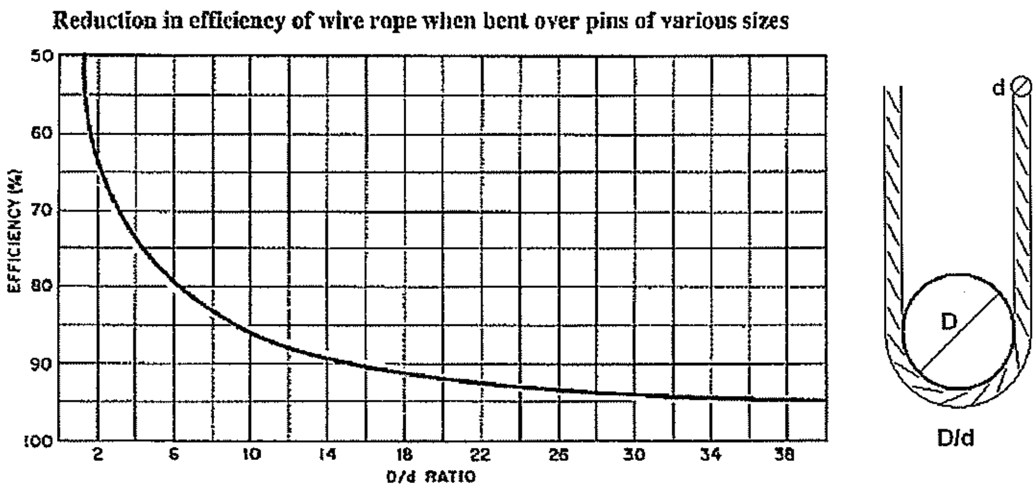
*IWRC=Independent Wire Rope Core **FC=Fiber Core
*** Typical values when terminations are correctly designed, applied and maintained. Refer to fittings manufacturers for exact values and method.

Table 6: Terminal Efficiencies (Approximate)
Efficiencies are applicable to the rope's minimum breaking force
WIRE ROPE TECHNICAL BOARD

Bend Radius

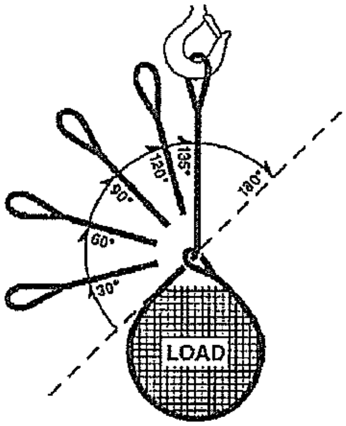
Wire rope is often wrapped under a load and at the corners subject to being wrapped at a given bend radius. The size of this bend radius is critical with regards to the strength of the rope. The reduction of strength associated with these bending restrictions has been tabulated and can be referenced below. A small bend radius will also reduce the life of a wire rope as fatigue onset will be more prone to occur.

Wire ropes are typically bent over the sheaves in the winch and crane, through shackles, or wrapped under items being lifted. Sometimes wire rope is bent about itself as is done during a choker lift in which the sling is terminated to itself. When a wire rope is wrapped all the way around itself as shown in Figure 1 the D/d ration is one. Figure 8 shows that at this ratio the capacity of the wire rope is approximately half its straight pull value. Different angles of choker hitches produce different bend radiuses and have different reductions of efficiency which can be referenced in Figure 9, which is in addition to the standard reduction amount for chocker lifts.



WEIGHTED AVERAGE OF
6x19 AND 6x36 CLASSIFICATION ROPES,
FIBER CORE AND IWRC, REGULAR AND LANG LAY

Figure 8: Wire Rope Efficiencies for Various D/d Ratios
Figure reprinted with permission from the
WIRE ROPE TECHNICAL BOARD



Choker Hitch Capacity Adjustment	
Angle of Choke (degrees)	**Rated Capacity (Percent)**
120to 135	100
90 to 120	87
60 to 89	74
30 to 59	62
1 to 29	49

Figure 9: Choker Hitch Efficiency
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WIRE ROPE TECHNICAL BOARD

The termination efficiency of an eye at the end of a wire rope can be compromised if the diameter of the attachment piece is either to large or too small. If the pin passing through the eye is too large the eye will be subject to splitting where the two sides of the eye reconnect, and failure will occur. Conversely if the pin if too small the strength will also be reduced. A pin of equal diameter to the rope size will effectively create a D/d ratio of one reducing the efficiency of each part by 50%. The fatigue life of a wire rope is also greatly dependant on the bend radius that it is subjected. A wire rope subject to this type of loading with a D/d ratio approaching unity will have very minimal fatigue life somewhat depending on the type of rope. Ropes subjected to this severe loading condition should be thoroughly inspected after every use.

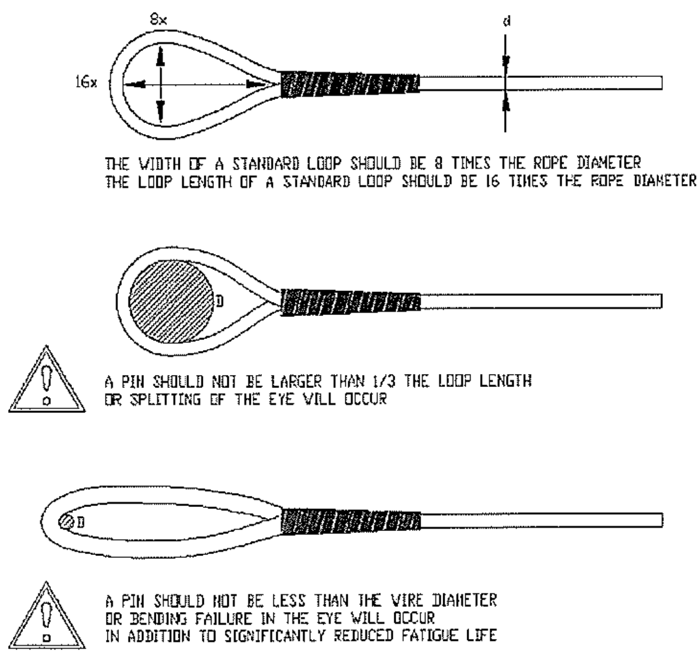

Figure 10: Relationship Between Pin Size and Wire Rope Loop

Standards and Regulations

The Code of Federal Regulations (CFR) sets criteria for different uses of wire rope. OSHA provides tables H-3 to H-14 in 29 CFR 1926.251 with ratings for wire rope capacity for a few selected different types and configurations. These are the same tables, or almost identical, to tables which can be found in ASME B30.9 standards for slings. Wire ropes may have working loads higher than those provided in the tables, provided the breaking strength is five times higher than the intended load. If one knows the straight pull or vertical rated capacity of the cable, the bend radius that it may be subjected to, as well as the efficiency of the termination, basic trigonometry can be used to find the exact rated strength for any angle. Figure 11 below shows the configurations of the five different arrangements which are used in the OSHA tables.

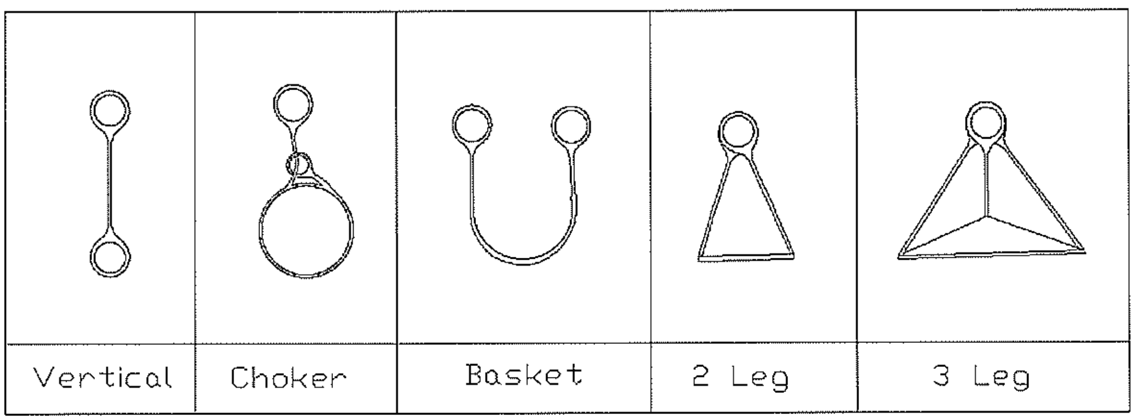

Figure 11: Statically Determinant Lift Arrangements Covered by OSHA Regulations

The rated capacities given by OSHA are of limited use by shipyards rigging personnel designing critical lifts since most of the lifting arrangements used do not confirm to the basic configurations shown in Figure 11. Furthermore it should be understood that many manufactures have wire ropes that exceed the strength characteristics that are assumed from these tables based on the five times breaking strength requirement.

OSHA Table H-3 and Table H-4 gives capacity ratings in short tons for two classification types of steel rope one with fiber core and the other one with independent wire rope core. Three different arrangements are calculated: vertical leg, looped as a basket, and choker. The tables give the capacities based on minimum bend radius requirements, specific termination types and their rated efficiencies.

TABLE H-3—RATED CAPACITIES FOR SINGLE LEG SLINGS

6x19 and 6x37 Classification Improved Plow Steel Grade Rope with Fiber Core (FC)

Rope		Rated capacities, tons (2,000 lb.)								
Dia. (inches)	Constr.	Vertical			Choker			Vertical basket [1]		
		HT	MS	S	HT	MS	S	HT	MS	S
1/4	6x19	0.49	0.51	0.55	0.37	0.38	0.41	0.99	1.0	1.1
5/16	6x19	0.76	0.79	0.85	0.57	0.59	0.64	1.5	1.6	1.7
3/8	6x19	1.1	1.1	1.2	0.80	0.85	0.91	2.1	2.2	2.4
7/16	6x19	1.4	1.5	1.6	1.1	1.1	1.2	2.9	3.0	3.3
1/2	6x19	1.8	2.0	2.1	1.4	1.5	1.6	3.7	3.9	4.3
9/16	6x19	2.3	2.5	2.7	1.7	1.9	2.0	4.6	5.0	5.4
5/8	6x19	2.8	3.1	3.3	2.1	2.3	2.5	5.6	6.2	6.7
3/4	6x19	3.9	4.4	4.8	2.9	3.3	3.6	7.8	8.8	9.5
7/8	6x19	5.1	5.9	6.4	3.9	4.5	4.8	10.0	12.0	13.0
1	6x19	6.7	7.7	8.4	5.0	5.8	6.3	13.0	15.0	17.0
1 1/8	6x19	8.4	9.5	10.0	6.3	7.1	7.9	17.0	19.0	21.0
1 1/4	6x37	9.8	11.0	12.0	7.4	8.3	9.2	20.0	22.0	25.0
1 3/8	6x37	12.0	13.0	15.0	8.9	10.0	11.0	24.0	27.0	30.0
1 1/2	6x37	14.0	16.0	17.0	10.0	12.0	13.0	28.0	32.0	35.0
1 5/8	6x37	16.0	18.0	21.0	12.0	14.0	15.0	33.0	37.0	41.0
1 3/4	6x37	19.0	21.0	24.0	14.0	16.0	18.0	38.0	43.0	48.0
2	6x37	25.0	28.0	31.0	18.0	21.0	23.0	49.0	55.0	62.0

[1] These values only apply when the D/d ratio for HT slings is 10 or greater, and for MS and S Slings is 20 or greater where: D=Diameter of curvature around which the body of the sling is bent. d=Diameter of rope.
HT=Hand Tucked Splice and Hidden Tuck Splice. For hidden tuck splice (IWRC) use values in HT columns.
MS=Mechanical Splice.
S=Swaged or Zinc Poured Socket.

TABLE H-4—RATED CAPACITIES FOR SINGLE LEG SLINGS

6x19 AND 6x37 CLASSIFICATION IMPROVED PLOW STEEL GRADE ROPE WITH INDEPENDENT WIRE ROPE CORE (IWRC)

Rope		Rated capacities, tons (2,000 lb.)								
Dia. (inches)	Constr.	Vertical			Choker			Vertical basket [1]		
		HT	MS	S	HT	MS	S	HT	MS	S
1/4	6x19	0.53	0.56	0.59	0.40	0.42	0.44	1.0	1.1	1.2
5/16	6x19	0.81	0.87	0.92	0.61	0.65	0.69	1.6	1.7	1.8
3/8	6x19	1.1	1.2	1.3	0.86	0.93	0.98	2.3	2.5	2.6
7/16	6x19	1.5	1.7	1.8	1.2	1.3	1.3	3.1	3.4	3.5
1/2	6x19	2.0	2.2	2.3	1.5	1.6	1.7	3.9	4.4	4.6
9/16	6x19	2.5	2.7	2.9	1.8	2.1	2.2	4.9	5.5	5.8
5/8	6x19	3.0	3.4	3.6	2.2	2.5	2.7	6.0	6.8	7.2
3/4	6x19	4.2	4.9	5.1	3.1	3.6	3.8	8.4	9.7	10.0
7/8	6x19	5.5	6.6	6.9	4.1	4.9	5.2	11.0	13.0	14.0
1	6x19	7.2	8.5	9.0	5.4	6.4	6.7	14.0	17.0	18.0
1 1/8	6x19	9.0	10.0	11.0	6.8	7.8	8.5	18.0	21.0	23.0
1 1/4	6x37	10.0	12.0	13.0	7.9	9.2	9.9	21.0	24.0	26.0
1 3/8	6x37	13.0	15.0	16.0	9.6	11.0	12.0	25.0	29.0	32.0
1 1/2	6x37	15.0	17.0	19.0	11.0	13.0	14.0	30.0	35.0	38.0
1 5/8	6x37	18.0	20.0	22.0	13.0	15.0	17.0	35.0	41.0	44.0
1 3/4	6x37	20.0	24.0	26.0	15.0	18.0	19.0	41.0	47.0	51.0
2	6x37	26.0	30.0	33.0	20.0	23.0	25.0	53.0	61.0	66.0

[1] These values only apply when the D/d ratio for HT slings is 10 or greater, and for MS and S Slings is 20 or greater where: D=Diameter of curvature around which the body of the sling is bent. d=Diameter of rope.
HT=Hand Tucked Splice: For hidden tuck splice (IWRC) use Table H-3 values in HT column.
MS=Mechanical Splice.

Table 7: OSHA 1926.251 Tables H-3 to H-4

OSHA Table H-5 and Table H-6 give the give the capacity ratings for single leg sling for construction galvanized aircraft grade rope and IWRC construction improved plow steel grade rope. Three different arrangements are calculated: vertical leg, looped as a basket, and a choker. The tables give the capacities based on minimum bend radius requirements, and an assumed termination of a mechanical splice.

S=Swaged or Zinc Poured Socket.

TABLE H-5—RATED CAPACITIES FOR SINGLE LEG SLINGS

Cable Laid Rope—Mechanical Splice Only

7×7×7 and 7×7×19 Construction Galvanized Aircraft Grade Rope

7×6×19 IWRC Construction Improved Plow Steel Grade Rope

Rope		Rated capacities, tons (2,000 lb.)		
Dia. (inches)	Constr.	Vertical	Choker	Vertical basket[1]
1/4	7×7×7	0.50	0.38	1.0
3/8	7×7×7	1.1	0.81	2.2
1/2	7×7×7	1.8	1.4	3.7
5/8	7×7×7	2.8	2.1	5.5
3/4	7×7×7	3.8	2.9	7.6
5/8	7×7×19	2.9	2.2	5.8
3/4	7×7×19	4.1	3.0	8.1
7/8	7×7×19	5.4	4.0	11.0
1	7×7×19	6.9	5.1	14.0
1 1/8	7×7×19	8.2	6.2	16.0
1 1/4	7×7×19	9.9	7.4	20.0
3/4	[2]7×6×19	3.8	2.8	7.6

TABLE H-5—RATED CAPACITIES FOR SINGLE LEG SLINGS—Continued

Cable Laid Rope—Mechanical Splice Only

7×7×7 and 7×7×19 Construction Galvanized Aircraft Grade Rope

7×6×19 IWRC Construction Improved Plow Steel Grade Rope

Rope		Rated capacities, tons (2,000 lb.)		
Dia. (inches)	Constr.	Vertical	Choker	Vertical basket[1]
7/8	[2]7×6×19	5.0	3.8	10.0
1	[2]7×6×19	6.4	4.8	13.0
1 1/8	[2]7×6×19	7.7	5.8	15.0
1 1/4	[2]7×6×19	9.2	6.9	18.0
1 5/16	[2]7×6×19	10.0	7.5	20.0
1 3/8	[2]7×6×19	11.0	8.2	22.0
1 1/2	[2]7×6×19	13.0	9.6	26.0

[1] These values only apply when the D/d ratio in 10 or greater where: D=Diameter of curvature around which the body of the sling is bent. d=Diameter of rope.

[2] IWRC.

TABLE H-6—RATED CAPACITIES FOR SINGLE LEG SLINGS

8-Part and 6-Part Braided Rope

6×7 and 6×19 Construction Improved Plow Steel Grade Rope

7×7 Construction Galvanized Aircraft Grade Rope

Component ropes		Rated capacities, tons (2,000 lb.)					
Diameter (inches)	Constr.	Vertical		Choker		Basket vertical to 30°[1]	
		8-Part	6-Part	8-Part	6-Part	8-Part	6-Part
3/32	6×7	0.42	0.32	0.32	0.24	0.74	0.55
1/8	6×7	0.76	0.57	0.57	0.42	1.3	0.98
3/16	6×7	1.7	1.3	1.3	0.94	2.9	2.2
3/32	7×7	0.51	0.39	0.38	0.29	0.89	0.67
1/8	7×7	0.95	0.71	0.71	0.53	1.6	1.2
3/16	7×7	2.1	1.5	1.5	1.2	3.6	2.7
3/16	6×19	1.7	1.3	1.3	0.98	3.0	2.2
1/4	6×19	3.1	2.3	2.3	1.7	5.3	4.0
5/16	6×19	4.8	3.6	3.6	2.7	8.3	6.2
3/8	6×19	6.8	5.1	5.1	3.8	12.0	8.9
7/16	6×19	9.3	6.9	6.9	5.2	16.0	12.0
1/2	6×19	12.0	9.0	9.0	6.7	21.0	15.0
9/16	6×19	15.0	11.0	11.0	8.5	26.0	20.0
5/8	6×19	19.0	14.0	14.0	10.0	32.0	24.0
3/4	6×19	27.0	20.0	20.0	15.0	46.0	35.0
7/8	6×19	36.0	27.0	27.0	20.0	62.0	47.0
1	6×19	47.0	35.0	35.0	26.0	81.0	61.0

[1] These values only apply when the D/d ratio is 20 or greater where: D=Diameter of curvature around which the body of the sling is bent. d=Diameter of component rope.

Table 8: OSHA 1926.251 Tables H-5 and H-6

OSHA Table H-7 and Table H-8 gives the rated load capacities for 2 and 3 leg bridle slings arrangements for improved plow grade rope with fiber core or wire core based on the ropes classification. The tables give the capacities based on a termination of a mechanical splice or hand tucked splice.

TABLE H-7—RATED CAPACITIES FOR 2-LEG AND 3-LEG BRIDLE SLINGS—Continued

6x19 and 6x37 Classification Improved Plow Steel Grade Rope With Fiber Core (FC)

Rope		Rated capacities, tons (2,000 lb.)											
		2-leg bridle slings						3-leg bridle slings					
Dia. (inches)	Constr.	30°[1] (60°)[2]		45° angle		60°[1] (30°)[2]		30°[1] (60°)[2]		45° angle		60°[1] (30°)[2]	
		HT	MS	HT	MS	HT	MS	HT	MS	HT	MS	HT	MS
5/8	6x19	4.8	5.3	4.0	4.4	2.8	3.1	7.3	8.0	5.9	6.5	4.2	4.6
3/4	6x19	6.8	7.6	5.5	6.2	3.9	4.4	10.0	11.0	8.3	9.3	5.8	6.6
7/8	6x19	8.9	10.0	7.3	8.4	5.1	5.9	13.0	15.0	11.0	13.0	7.7	8.9
1	6x19	11.0	13.0	9.4	11.0	6.7	7.7	17.0	20.0	14.0	16.0	10.0	11.0
1 1/8	6x19	14.0	16.0	12.0	13.0	8.4	9.5	22.0	24.0	18.0	20.0	13.0	14.0
1 1/4	6x37	17.0	19.0	14.0	16.0	9.8	11.0	25.0	29.0	21.0	23.0	15.0	17.0
1 3/8	6x37	20.0	23.0	17.0	19.0	12.0	13.0	31.0	35.0	25.0	28.0	18.0	20.0
1 1/2	6x37	24.0	27.0	20.0	22.0	14.0	16.0	36.0	41.0	30.0	33.0	21.0	24.0
1 5/8	6x37	28.0	32.0	23.0	26.0	16.0	18.0	43.0	48.0	35.0	39.0	25.0	28.0
1 3/4	6x37	33.0	37.0	27.0	30.0	19.0	21.0	49.0	56.0	40.0	45.0	28.0	32.0
2	6x37	43.0	48.0	35.0	39.0	25.0	28.0	64.0	72.0	52.0	59.0	37.0	41.0

HT=Hand Tucked Splice.
MS=Mechanical Splice.
[1] Vertical angles.
[2] Horizontal angles.

TABLE H-8—RATED CAPACITIES FOR 2-LEG AND 3-LEG BRIDLE SLINGS

6x19 and 6x37 Classification Improved Plow Steel Grade Rope With Independent Wire Rope Core (IWRC)

Rope		Rated capacities, tons (2,000 lb.)											
		2-leg bridle slings						3-leg bridle slings					
Dia. (inches)	Constr.	30°[1] (60°)[2]		45° angle		60°[1] (30°)[2]		30°[1] (60°)[2]		45° angle		60°[1] (30°)[2]	
		HT	MS	HT	MS	HT	MS	HT	MS	HT	MS	HT	MS
1/4	6x19	0.92	0.97	0.75	0.79	0.53	0.56	1.4	1.4	1.1	1.2	0.79	0.84
5/16	6x19	1.4	1.5	1.1	1.2	1.81	0.87	2.1	2.3	1.7	1.8	1.2	1.3
3/8	6x19	2.0	2.1	1.6	1.8	1.1	1.2	3.0	3.2	2.4	2.6	1.7	1.9
7/16	6x19	2.7	2.9	2.2	2.4	1.5	1.7	4.0	4.4	3.3	3.6	2.3	2.5
1/2	6x19	3.4	3.8	2.8	3.1	2.0	2.2	5.1	5.7	4.2	4.6	3.0	3.3
9/16	6x19	4.3	4.8	3.5	3.9	2.5	2.7	6.4	7.1	5.2	5.8	3.7	4.1
5/8	6x19	5.2	5.9	4.2	4.8	3.0	3.4	7.8	8.8	6.4	7.2	4.5	5.1
3/4	6x19	7.3	8.4	5.9	6.9	4.2	4.9	11.0	13.0	8.9	10.0	6.3	7.3
7/8	6x19	9.6	11.0	7.8	9.3	5.5	6.6	14.0	17.0	12.0	14.0	8.3	9.9
1	6x19	12.0	15.0	10.0	12.0	7.2	8.5	19.0	22.0	15.0	18.0	11.0	13.0
1 1/8	6x19	16.0	18.0	13.0	15.0	9.0	10.0	23.0	27.0	19.0	22.0	13.0	16.0
1 1/4	6x37	18.0	21.0	15.0	17.0	10.0	12.0	27.0	32.0	22.0	26.0	16.0	18.0
1 3/8	6x37	22.0	25.0	18.0	21.0	13.0	15.0	33.0	38.0	27.0	31.0	19.0	22.0
1 1/2	6x37	26.0	30.0	21.0	25.0	15.0	17.0	39.0	45.0	32.0	37.0	23.0	26.0
1 5/8	6x37	31.0	35.0	25.0	29.0	18.0	20.0	46.0	53.0	38.0	43.0	27.0	31.0
1 3/4	6x37	35.0	41.0	29.0	33.0	20.0	24.0	53.0	61.0	43.0	50.0	31.0	35.0
2	6x37	46.0	53.0	37.0	43.0	26.0	30.0	68.0	79.0	56.0	65.0	40.0	46.0

HT=Hand Tucked Splice.
MS=Mechanical Splice.
[1] Vertical angles.
[2] Horizontal angles.

Table 9: OSHA 1926.251 Tables H-7 and H-8

OSHA Table H-9 and Table H-10 gives the rated load capacities for 2 and 3 leg bridle slings arrangements for improved plow grade rope and aircraft grade rope. The tables give the capacities based on an assumed termination of a mechanical splice.

TABLE H-9—RATED CAPACITIES FOR 2-LEG AND 3-LEG BRIDLE SLINGS

Cable Laid Rope—Mechanical Splice Only

7x7x7 and 7x7x19 Construction Galvanized Aircraft Grade Rope

7x6x19 IWRC Construction Improved Plow Steel Grade Rope

Rope		Rated capacities, tons (2,000 lb.)					
		2-leg bridle sling			3-leg bridle sling		
Dia. (inches)	Constr.	30° [1] (60°) [2]	45° angle	60° [1] (30°) [2]	30° [1] (60°) [2]	45° angle	60° [1] (30°) [2]
1/4	7x7x7	0.87	0.71	0.50	1.3	1.1	0.75
3/8	7x7x7	1.9	1.5	1.1	2.8	2.3	1.6
1/2	7x7x7	3.2	2.6	1.8	4.8	3.9	2.8
5/8	7x7x7	4.8	3.9	2.8	7.2	5.9	4.2
3/4	7x7x7	6.6	5.4	3.8	9.9	8.1	5.7

Table 10: OSHA 1926.251 Tables H-9

TABLE H-9—RATED CAPACITIES FOR 2-LEG AND 3-LEG BRIDLE SLINGS—Continued

Cable Laid Rope—Mechanical Splice Only

7x7x7 and 7x7x19 Construction Galvanized Aircraft Grade Rope

7x6x19 IWRC Construction Improved Plow Steel Grade Rope

Rope		Rated capacities, tons (2,000 lb.)					
		2-leg bridle sling			3-leg bridle sling		
Dia. (inches)	Constr.	30° [1] (60°) [2]	45° angle	60° [1] (30°) [2]	30° [1] (60°) [2]	45° angle	60° [1] (30°) [2]
5/8	7x7x19	5.0	4.1	2.9	7.5	6.1	4.3
3/4	7x7x19	7.0	5.7	4.1	10.0	8.6	6.1
7/8	7x7x19	9.3	7.6	5.4	14.0	11.0	8.1
1	7x7x19	12.0	9.7	6.9	18.0	14.0	10.0
1 1/8	7x7x19	14.0	12.0	8.2	21.0	17.0	12.0
1 1/4	7x7x19	17.0	14.0	9.9	26.0	21.0	15.0
3/4	7x6x19 IWRC	6.6	5.4	3.8	9.9	8.0	5.7
7/8	7x6x19 IWRC	8.7	7.1	5.0	13.0	11.0	7.5
1	7x6x19 IWRC	11.0	9.0	6.4	17.0	13.0	9.6
1 1/8	7x6x19 IWRC	13.0	11.0	7.7	20.0	16.0	11.0
1 1/4	7x6x19 IWRC	16.0	13.0	9.2	24.0	20.0	14.0
1 5/16	7x6x19 IWRC	17.0	14.0	10.0	26.0	21.0	15.0
1 3/8	7x6x19 IWRC	19.0	15.0	11.0	28.0	23.0	16.0
1 1/2	7x6x19 IWRC	22.0	18.0	13.0	33.0	27.0	19.0

[1] Vertical angles.
[2] Horizontal angles.

TABLE H-10—RATED CAPACITIES FOR 2-LEG AND 3-LEG BRIDLE SLINGS

8-Part and 6-Part Braided Rope

6x7 and 6x19 Construction Improved Plow Steel Grade Rope

7x7 Construction Galvanized Aircraft Grade Rope

Rope		Rated capacities, tons (2,000 lb.)											
		2-leg bridle slings						3-leg bridle slings					
Dia. (inches)	Constr.	30° [1] (60°) [2]		45° angle		60° [1] (30°) [2]		30° [1] (60°) [2]		45° angle		60° [1] (30°) [2]	
		8-Part	6-Part	8-Part	6-Part	8-Part	6-Part	8-Part	6-Part	8-Part	6-Part	8-Part	6-Part
3/32	6x7	0.74	0.55	0.60	0.45	0.42	0.32	1.1	0.83	0.90	0.68	0.64	0.48
1/8	6x7	1.3	0.98	1.1	0.80	0.76	0.57	2.0	1.5	1.6	1.2	1.1	0.85
3/16	6x7	2.9	2.2	2.4	1.8	1.7	1.3	4.4	3.3	3.6	2.7	2.5	1.9
3/32	7x7	0.89	0.67	0.72	0.55	0.51	0.39	1.3	1.0	1.1	0.82	0.77	0.58
1/8	7x7	1.6	1.2	1.3	1.0	0.95	0.71	2.5	1.8	2.0	1.5	1.4	1.1
3/16	7x7	3.6	2.7	2.9	2.2	2.1	1.5	5.4	4.0	4.4	3.3	3.1	2.3
3/16	6x19	3.0	2.2	2.4	1.8	1.7	1.3	4.5	3.4	3.7	2.8	2.6	1.9
1/4	6x19	5.3	4.0	4.3	3.2	3.1	2.3	8.0	6.0	6.5	4.9	4.6	3.4
5/16	6x19	8.3	6.2	6.7	5.0	4.8	3.6	12.0	9.3	10.0	7.6	7.1	5.4
3/8	6x19	12.0	8.9	9.7	7.2	6.8	5.1	18.0	13.0	14.0	11.0	10.0	7.7
7/16	6x19	16.0	12.0	13.0	9.8	9.3	6.9	24.0	18.0	20.0	15.0	14.0	10.0
1/2	6x19	21.0	15.0	17.0	13.0	12.0	9.0	31.0	23.0	25.0	19.0	18.0	13.0
9/16	6x19	26.0	20.0	21.0	16.0	15.0	11.0	39.0	29.0	32.0	24.0	23.0	17.0
5/8	6x19	32.0	24.0	26.0	20.0	19.0	14.0	48.0	36.0	40.0	30.0	28.0	21.0
3/4	6x19	46.0	35.0	38.0	28.0	27.0	20.0	69.0	52.0	56.0	42.0	40.0	30.0
7/8	6x19	62.0	47.0	51.0	38.0	36.0	27.0	94.0	70.0	76.0	57.0	54.0	40.0
1	6x19	81.0	61.0	66.0	50.0	47.0	35.0	22.0	91.0	99.0	74.0	70.0	53.0

[1] Vertical angles.
[2] Horizontal angles.

Table 11: OSHA 1926.251 Tables H-9 to H-10

OSHA Table H-11 through Table H-14 gives the rated capabilities for continuous loops of wire rope in various configurations, for various classifications, with hand tucked or mechanical spliced joints for improved plow steel grade rope, construction improved steel plow rope and aircraft grade rope. Three different arrangements are calculated being a vertical leg, looped as a basket, and used as a choker. The tables give the capacities based on minimum bend radius requirements where applicable.

TABLE H-11—RATED CAPACITIES FOR STRAND LAID GROMMET—HAND TUCKED

Improved Plow Steel Grade Rope

Rope body		Rated capacities, tons (2,000 lb.)		
Dia. (inches)	Constr.	Vertical	Choker	Vertical basket[1]
1/4	7×19	0.85	0.64	1.7
5/16	7×19	1.3	1.0	2.6
3/8	7×19	1.9	1.4	3.8
7/16	7×19	2.6	1.9	5.2
1/2	7×19	3.3	2.5	6.7
9/16	7×19	4.2	3.1	8.4
5/8	7×19	5.2	3.9	10.00
3/4	7×19	7.4	5.6	15.0
7/8	7×19	10.0	7.5	20.0
1	7×19	13.0	9.7	26.0
1 1/8	7×19	16.0	12.0	32.0
1 1/4	7×37	18.0	14.0	37.0
1 3/8	7×37	22.0	16.0	44.0
1 1/2	7×37	26.0	19.0	52.0

[1] These values only apply when the D/d ratio is 5 or greater where: D=Diameter of curvature around which rope is bent. d=Diameter of rope body.

TABLE H-12—RATED CAPACITIES FOR CABLE LAID GROMMET—HAND TUCKED

7×6×7 and 7×6×19 Construction Improved Plow Steel Grade Rope

7×7×7 Construction Galvanized Aircraft Grade Rope

Cable body		Rated capacities, tons (2,000 lb.)		
Dia. (inches)	Constr.	Vertical	Choker	Vertical basket[1]
3/8	7×6×7	1.3	0.95	2.5
9/16	7×6×7	2.8	2.1	5.6
5/8	7×6×7	3.8	2.8	7.6
3/8	7×7×7	1.6	1.2	3.2
9/16	7×7×7	3.5	2.6	6.9
5/8	7×7×7	4.5	3.4	9.0
5/8	7×6×19	3.9	3.0	7.9
3/4	7×6×19	5.1	3.8	10.0
15/16	7×6×19	7.9	5.9	16.0
1 1/8	7×6×19	11.0	8.4	22.0
1 5/16	7×6×19	15.0	11.0	30.0
1 1/2	7×6×19	19.0	14.0	39.0
1 11/16	7×6×19	24.0	18.0	49.0
1 7/8	7×6×19	30.0	22.0	60.0
2 1/4	7×6×19	42.0	31.0	84.0
2 5/8	7×6×19	56.0	42.0	112.0

[1] These values only apply when the D/d ratio is 5 or greater where: D=Diameter of curvature around which cable body is bent. d=Diameter of cable body.

TABLE H-13—RATED CAPACITIES FOR STRAND LAID ENDLESS SLINGS-MECHANICAL JOINT

Improved Plow Steel Grade Rope

Rope body		Rated capacities, tons (2,000 lb.)		
Dia. (inches)	Constr.	Vertical	Choker	Vertical basket[1]
1/4	[2]6×19	0.92	0.69	1.8
3/8	[2]6×19	2.0	1.5	4.1
1/2	[2]6×19	3.6	2.7	7.2
5/8	[2]6×19	5.6	4.2	11.0
3/4	[2]6×19	8.0	6.0	16.0
7/8	[2]6×19	11.0	8.1	21.0
1	[2]6×19	14.0	10.0	28.0
1 1/8	[2]6×19	18.0	13.0	35.0
1 1/4	[2]6×37	21.0	15.0	41.0
1 3/8	[2]6×37	25.0	19.0	50.0
1 1/2	[2]6×37	29.0	22.0	59.0

[1] These values only apply when the D/d ratio is 5 or greater where: D=Diameter of curvature around which rope is bent. d=Diameter of rope body.
[2] IWRC.

TABLE H-14—RATED CAPACITIES FOR CABLE LAID ENDLESS SLINGS-MECHANICAL JOINT

7×7×7 and 7×7×19 Construction Galvanized Aircraft Grade Rope 7×6×19 IWRC Construction Improved Plow Steel Grade Rope

Cable body		Rated capacities, tons (2,000 lb.)		
Dia. (inches)	Constr.	Vertical	Choker	Vertical basket[1]
1/4	7×7×7	0.83	0.62	1.6
3/8	7×7×7	1.8	1.3	3.5
1/2	7×7×7	3.0	2.3	6.1
5/8	7×7×7	4.5	3.4	9.1
3/4	7×7×7	6.3	4.7	12.0
5/8	7×7×19	4.7	3.5	9.5
3/4	7×7×19	6.7	5.0	13.0
7/8	7×7×19	8.9	6.6	18.0
1	7×7×19	11.0	8.5	22.0
1 1/8	7×7×19	14.0	10.0	28.0
1 1/4	7×7×19	17.0	12.0	33.0
3/4	[2]7×6×19	6.2	4.7	12.0
7/8	[2]7×6×19	8.3	6.2	16.0
1	[2]7×6×19	10.0	7.9	21.0
1 1/8	[2]7×6×19	13.0	9.7	26.0
1 1/4	[2]7×6×19	16.0	12.0	31.0
1 3/8	[2]7×6×19	18.0	14.0	37.0
1 1/2	[2]7×6×19	22.0	16.0	43.0

[1] These values only apply when the D/d value is 5 or greater where: D=Diameter of curvature around which cable body is bent. d=Diameter of cable body.
[2] IWRC.

Table 12: OSHA 1926.251 Tables H-11 to H-14

Synthetic Slings

Modern polymer materials are rapidly replacing steel for countless tasks. Synthetic slings are becoming an alternative to steel slings as they are lighter and easier to handle. This results in a time savings, but is not the only reason for there wide spread adaptation. Some are significantly less affected by bend radius so they can be wrapped around objects small and large. Synthetic slings can also be made relative flat to reduce bearing pressures on objects being lifted, and due to their soft nature are less likely to damage a load.

However, synthetic slings have disadvantages as well. They are significantly more likely to be cut by edges protruding from an object regardless of how sharp the edge is. They can be damaged by many chemicals and have their strength significantly reduced with exposure to sunlight. This type of damage may not be visually apparent. Internal friction of the strands during a lift will increase the sling temperatures which is problematic due to their already low melting temperatures. Round slings have significantly lower allowable bearing pressures then flat slings which may not be immediately apparent on manufacturing literature.

Synthetic slings are relatively new and do not yet have copious amounts of historic data documenting failures and problems as compared to wire ropes. This means engineers must be even more aware of potential problems that these new materials bring.

Manufactures

The entry barrier into synthetic sling manufacture is possibly higher than other sling material which has resulted in fewer manufactures making specific fiber materials. One of the largest makers of synthetic slings material is Slingmax which in turn licenses manufacturing rights to assemble specific slings to approximately 22 manufactures in North American alone. These include: American rigging, Bishops lifting, Lift-it, Rasmussenco, Slingset, Yarbrough, and many others.

Sligmax is a producer of synthetic slings for heavy lifts. For lighter lifting needs there are more companies that make slings with capabilities under 100 tons. An example of this is Lamco which makes sling with up to 66 short ton lift capacity.

Strength and Strain

The properties of synthetic sling varies tremendously depending on what material they are made out of. The most common material for critical lifts are Nylon, Polyester, Armaid fibers, High Molecular Polyhylene and K-Spec. The modulus of synthetic slings is generally given as a elongations at the working load limit. It should be noted that for most synthetic slings the elongation with load is not linear, as slings will get stiffer with increasing load.

To increase the allowable load in a sling and prolong its life, special wear protection is recommended. The wear protection can cover the entire body sliding on the sling for adjustment, or be sewn to the sling. Additional wear protection is often used as to protect the edges or corners and protect the eye of the sling.

End Connections

Synthetic sling connections are different then wire rope in that they connect metal to non metallic parts. This has so far resulted in fewer types of connections or terminations as most end connections are based on a loop of sling. This loop may take shape as an eye or be part of the sling as an endless circular band. The two most common connection types are:

Endless- circular design, longer life and versatile because hook and load points can be rotated. It can be used in vertical, basket hitches and choker lifts

Eye – can be either flat or half twist, straight piece of sling with flaps folded and eyes sewed flat or twisted. The eye which is twisted allows for better choking lift configurations. It can be used for vertical, basket hitches and chokers lifts

Bunching of the sling in the shackle is a common problem resulting in uneven loading and reduction of contact surface between the shackle and the sling. Sever bunching of sling can result in reduced load rating. Care should be taken to ensure proper bearing area for synthetic slings.

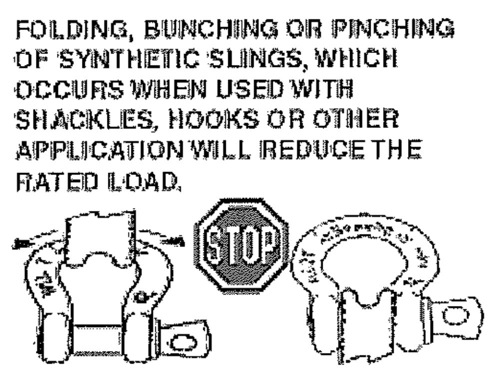

Figure 12: Bunching of a Sling in a Shackle
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CROSBY GROUP

An example of bunching can be seen in Figure 12 above. One way to get around this problem is to use a shackle pin pad, these pads protect the sling form the sharp corners of the shackle, or threads or pin, provide a larger softer larger bearing area.

Chemical and Environmental Considerations

Nylon- is not affected by greases and oil. Nylon materials are affected by most acids and bleaching agents. Hydrochloric acids and Sulfuric acids even in deluded form even can cause a significant loss of strength. Some of the chemicals which act as solvents for nylon are formic acid, phenolic compounds, calcium chloride, zinc chloride, benzyl alcohol. Nylon looses 15 % strength when wet. Its operating temperature is between -40 ˚ F (-40 ˚C) and 194˚F (90˚C).

Over time nylon webbing will shrink, when not used the webbing will shrink 5% of its length. When webbing is knitted tightly it will shrink less compared to when it is loosely knitted. Humidity and temperature has an effect on the shrinking rate. At working load limit nylon will stretch 6-8 %, however when new elongation will be larger until broken in.

Polyester- will disintegrate when in contact with concentrated sulfuric acid. Polyester is resistant to aqueous solutions and strong alkalis at room temperatures, however when brought to boil these substances will destroy the material. Polyester's strength is not affected by moisture. The temperature range for polyester is -40 ˚F (-40 ˚C) to 194˚ F (90˚C). Stretch at work limit is 3-4 %.

Aramid- is affected by strong acids, bases, and sodium hypo-chlorite bleach, especially at high concentrations and temperatures. Stretch at work limit is 1%.

K-Spec (Slingset) high strength and low elongation, used for many high load lifts. Stretches significantly less then nylon and it is more resistant to chemicals and sunlight. The temperature range for K-spec is -40 ˚F (-40 ˚C) to 194˚ F (90˚C). Stretch at work limit is 1 %.

High Molecular polyethylene- can resist most chemical agents. However, Clorox can disintegrate the material up to 10% in 6 months. The max temperature it can be exposed to is 140˚ F (60˚C). Stretch at work limit is 1 %.

Nomex- is more resistant to acid then nylon, but less resistant to it then polyester. It is disintegrated by strong alkalis at high temperatures.

Standards and Regulations

OSHA has a disclaimer that they may not have updated their standard to reflect newer types of slings made of newer materials. In general one should follow 29 CFR 1915.112 for sling use. These shipyard regulations call for the slings to have a breaking strength of five times the rated load..

ASME B30.9-2006 gives information on steel chain, wire rope, metal mesh, synthetic rope, synthetic webbing and synthetic round sling. On each component it provides information on materials and components, fabrication and configuration, design factor, rated loads, proof test requirements, effects of the environment, inspection, removal and repair.

Chain

Manufactures

Rigging chain is required by regulation to be of a higher grade of material. This limits the availability of suitable chain to certain manufactures. Some of the common manufactures of rigging grade chain are Crosby, KWS Thiele, Pewag, and Laclede.

Strength and Strain

As with many rigging products toughness or ability to be overloaded without sudden brittle failure is required. For this reason only alloy steel chain of grade 80 and 100 should be used. Alloy chain or suitable grade 80 or 100 will be marked and sold as 8, 80, or 800; or 10, 100, or 1000 respectively. Chain used as a sling should have a design factor of 4 and manufactures load ratings should be ensured to conform to these requirements if specifying for a lift requirement.

Table 13 below gives the allowable chain loading based on chain size straight pull for grade 80 and 100 alloy steel chain manufactured by Cosby. The tables give the working limits in pounds of the chain with a design factor of 4 to 1. Working limits of chain should be further reduced if chain is used as a choker to account for the angular choke, similar to wire or synthetic slings a minimum angle of choke of 120 degrees is recommended.

Spectrum 8® Alloy Chain Size		90°
(in.)	(mm)	Single Leg
7/32	6	2500
1/4 (9/32)	7	3500
5/16	8	4500
3/8	10	7100
1/2	13	12000
5/8	16	18100
3/4	20	28300
7/8	22	34200
1	26	47700
1-1/4	32	72300

Spectrum 10® Alloy Chain Size		90°
(in.)	(mm)	Single Leg
—	6	3200
1/4 (9/32)	7	4300
5/16	8	5700
3/8	10	8800
1/2	13	15000
5/8	16	22600
3/4	20	35300
7/8	22	42700
1	26	59700
1-1/4	32	90400

Table 13: Load Ratings based on Chain Dimensions
Figure reprinted with permission from the
CROSBY GROUP

Chain experiences a reduction in strength when exposed to high temperatures although is much more suitable for high temperature than synthetics or wire rope. Table 14 below give the percentage reductions based on the temperatures. Normal operating temperatures for slings are from -40 to 400 degree Fahrenheit. For the most part these temperature extremes are outside of any probable expectations for a typical shipyard unless casting of specific parts is actively performed. Chemical interaction should also be considered when working in chemically active environments.

Table 1

Use of Crosby Grade 80 Chain At Elevated Temperatures

Temperature of Chain		Temporary Reduction of Rated Load at Elevated Temperature*	Permanent Reduction of Rated Load after exposure to Temperature**
(F°)	(C°)		
Below 400	Below 204	None	None
400	204	10%	None
500	260	15%	None
600	316	20%	5%
700	371	30%	10%
800	427	40%	15%
900	482	50%	20%
1000	538	60%	25%
Over 1000	Over 538	OSHA 1910.184 requires all slings exposed to temperatures over 1000° F to be removed from service.	

* Crosby does not recommend the use of Alloy Chain at temperatures above 800° F.
** When chain is used at room temperature after being heated to temperatures shown in the first column.

Table 2

Use of Crosby Grade 100 Chain At Elevated Tempertures

Temperature		Temporary Reduction of Rated Load at Elevated Temperature*	Permanent Reduction of Rated Load after exposure to Temperature**
(F°)	(C°)		
Below 400	Below 204	None	None
400	204	15%	None
500	260	25%	5%
600	316	30%	15%
700	371	40%	20%
800	427	50%	25%
900	482	60%	30%
1000	538	70%	35%
Over 1000	Over 538	OSHA 1910.184 requires all slings exposed to temperatures over 1000 F to be removed from service.	

* Crosby does not recommend the use of Alloy Chain at temperatures above 800° F.
** When chain is used at room temperature after being heated to temperatures shown in the first column.

Table 14: Temperature based Chain Rating
Figure reprinted with permission from the
CROSBY GROUP

When designing lifts attention has to be paid to how the chain wraps around the corners and pads should be used when chain is in contact with sharp corners. This is shown in Figure 12 below.

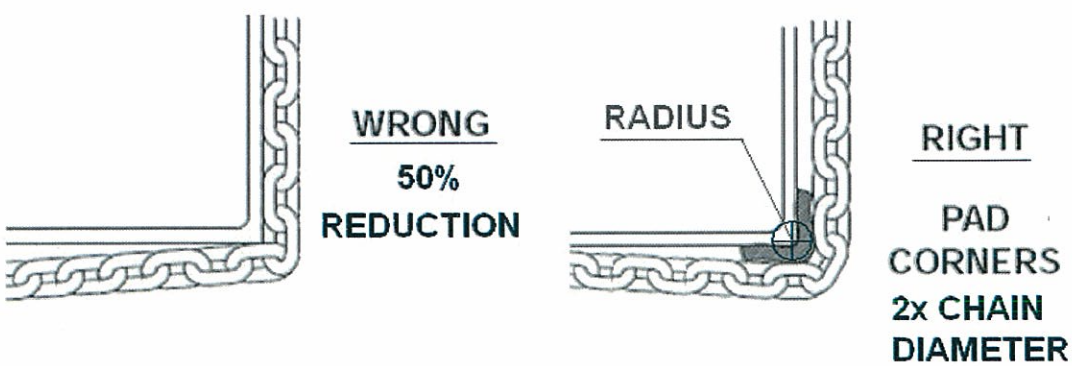

Figure 13: Corners and Chain

Chain is one of the stiffest sling materials when used in the vertical direction. At angles other than vertical the weight of the chain becomes an important factor as catenary factors allow the chain to apparently lengthen as the load increases. As these translations and deflection are significantly larger that the ductility of steel, they will therefore govern the elongation and can be relatively tricky to figure out as the effects are non linear.

End Connections

Chain has the benefit that one can easily vary the length of the sling by moving the attachment one link down the chain. Several companies make attachments that a link can be dropped trough securing a connection. Usually chain slings are manufactured with hooks, and master links permanently fixed on either end of the chain.

Standards and Regulations

OSHA Standards for Chain, Table 15 gives rated capacity in pounds for alloy steel chain slings based on chain diameter, number of sling branches and sling angles. Alloy steel has to have permanently affixed durable identification including size, grade, rated capacity and sling manufacturer. Hooks, rings and other attachments used with alloy steel chain need to have rated capacity of greater then the alloy chain steel. In OSHA's H-2 table they provide allowable wear of the chains job hooks and links.

TABLE H-1—RATED CAPACITY (WORKING LOAD LIMIT), FOR ALLOY STEEL CHAIN SLINGS [1]

Rated Capacity (Working Load Limit), Pounds

[Horizontal angles shown in parentheses] (2)

Chain size (inches)	Single branch sling—90° loading	Double sling vertical angle (1)			Triple and quadruple sling vertical angle (1)		
		30° (60°)	45° (45°)	60° (30°)	30° (60°)	45° (45°)	60° (30°)
1/4	3,250	5,560	4,550	3,250	8,400	6,800	4,900
3/8	6,600	11,400	9,300	6,600	17,000	14,000	9,900
1/2	11,250	19,500	15,900	11,250	29,000	24,000	17,000
5/8	16,500	28,500	23,300	16,500	43,000	35,000	24,500
3/4	23,000	39,800	32,500	23,000	59,600	48,600	34,500
7/8	28,750	49,800	40,600	28,750	74,600	61,000	43,000
1	38,750	67,100	54,800	38,750	101,000	82,000	58,000
1 1/8	44,500	77,000	63,000	44,500	115,500	94,500	66,500
1 1/4	57,500	99,500	81,000	57,500	149,000	121,500	86,000
1 3/8	67,000	116,000	94,000	67,000	174,000	141,000	100,500
1 1/2	80,000	138,000	112,500	80,000	207,000	169,000	119,500
1 3/4	100,000	172,000	140,000	100,000	258,000	210,000	150,000

[1] Other grades of proof tested steel chain include Proof Coil, BBB Coil and Hi-Test Chain. These grades are not recommended for overhead lifting and therefore are not covered by this code.

(1) Rating of multileg slings adjusted for angle of loading measured as the included angle between the inclined leg and the vertical.

(2) Rating of multileg slings adjusted for angle of loading between the inclined leg and the horizontal plane of the load.

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TABLE H-2—MAXIMUM ALLOWABLE WEAR AT ANY POINT OF LINK

Chain size (inches)	Maximum allowable wear (inch)
1/4	3/64
3/8	5/64
1/2	7/64
5/8	9/64
3/4	5/32
7/8	11/64

TABLE H-2—MAXIMUM ALLOWABLE WEAR AT ANY POINT OF LINK—Continued

Chain size (inches)	Maximum allowable wear (inch)
1	3/16
1 1/8	7/32
1 1/4	1/4
1 3/8	9/32
1 1/2	5/16
1 3/4	11/32

Table 15: 1926.251 OSHA 1926.251 Table H-1 and H-2 Chain Slings

Additional references for regulations and standards which cover chain are OSHA 1910.184 for Slings, and ASME B30.9-"Slings".

4. CHAIN-FALLS AND AIR-HOISTS

Chain falls and air hoist offer infinite precision with regards to adjusting the length of a sling and therefore the load in it and the angle of the block being lifted. This allows erected blocks to be aligned precisely in their final ships position before being released by the crane. Also tolerance critical items such as shafting or propellers can be leveled and installed precisely. These rigging tools are used extensively in shipyards for block and equipment lifting arrangements.

Manufactures

There are many manufactures of chain falls and air hoists. Some popular makers are Ingersoll-Rand, J. D. Neuhaus, Harrington Hoist and Cranes, Budgit, Coffing, and Yale. Most typical sizes are less than ten tones but larger models are made for large lifts such that take place in shipyards.

Figure 14: 100 Short Ton Manual Chain fall

Size

Chain falls and air hoist can be obtained from multiple manufactures in sizes up to 100 tons. Typically these hoists are not made for material handling but for precision lifting as the speeds that they reel in and out are quite slow at only a few feet per minute. The weight of the chain fall itself can be considerable and the weight per length of the chain must not be forgotten as the amount of chain can be varied to accommodate different lift length. Air hoists require air pressure to operate and without suitable air pressure will not engage for lifting or lowering. Popular heavy lift air hoists made by J. D. Neuhaus require at least 80 psi of air pressure with flow rates of up to 425 cubit feet per minute for a 100 ton hoist. These require considerable hose sizes that must be available at both locations of the lift and erection. For this reason manually operated chain hoists have benefit.

End Connections

Typically large chain falls used in a rigging arrangements used for large lifts have standard hooks at the top and bottom. These hooks can be used for both connecting to slings or shackles and allow that particular sling leg to be varied in length.

Standards and Regulations

The Occupational Safety and Health Administration has a specific section for the use of chain fall at shipyards which can be found in 29 CFR 1915.114. This section covers regulations for properly labeling chain falls, regular inspection, and required the mounting structure to be adequate to load and secure the hook from coming loose.

Other standards that relate to the design of chain falls and airhosts include ASME B30.16 which covers air powered and manual overhead hoists. ASME also has performance standards for hoists for evaluating the performance of particular hoists.

HST-5M Performance Standard for Air Chain Hoists,
HST-4M Performance Standard for Overhead Electric Wire Rope Hoists and
HST-6M Performance Standard for Air Wire Rope Hoists

5. SPREADER BEAMS

Manufactures

Typical shipyards will require spread lifting capabilities matching the lifting capacity of their largest crane, or a rough average of about 300 tons. This capacity is larger than most commercially available bar manufactures produce and can require a custom order or design.

Readily, available commercial spreader bars have primarily smaller lifting capabilities than but larger working loads can be obtained. Spreader beam manufactures include, Bushman Cadwell, Modulift, Tandemloc Inc, and Vestil.

NASSCO has roughly 24 spreader bars in regular use, ranging form 2.5 to 295 short tons lifting capability and form 4 ft to 42 ft in spreadable length. The largest spreader bar matches the lifting capability of the largest crane . Many of the spreader bars have a unique geometry and lifting attachments to accommodate a large range of lifts. All spreader beams have been custom designed in house.

End Connections

Spreader beams are used to spread the load of an object being lifted and they achieve this by different forms of attachments. Typical attachments points are hooks, permanently secured master links, or pin connections for shackles or endless slings. Most critical lifts are secured with either padeyes and shackles or pins and endless synthetic slings .

Standards and Regulations

The best standards for spreader beams are the American Society for Mechanical Engineers Below the Hook Lifting Devices Design Guide and associated standard B30.2. Special considerations need to be made during the design of spreader beams as the long life cycle can have significant effect on the design. It is possible that during this life cycle they will perform tens of thousands of lifts potentially of unknown loads and variable conditions. A respectable design factor should be chosen as bearing wear, fatigue, corrosion, and other effects of ageing that will set in.

Allowable Loads

As large spreader beams are typically unique they will have specific allowable loads associated with them. It is recommended that for any given spreader beam documentation be created that explains what these allowable loads are. An abbreviated example of such a guide is shown in Figure 15 where allowable loads at specific location can be referenced.

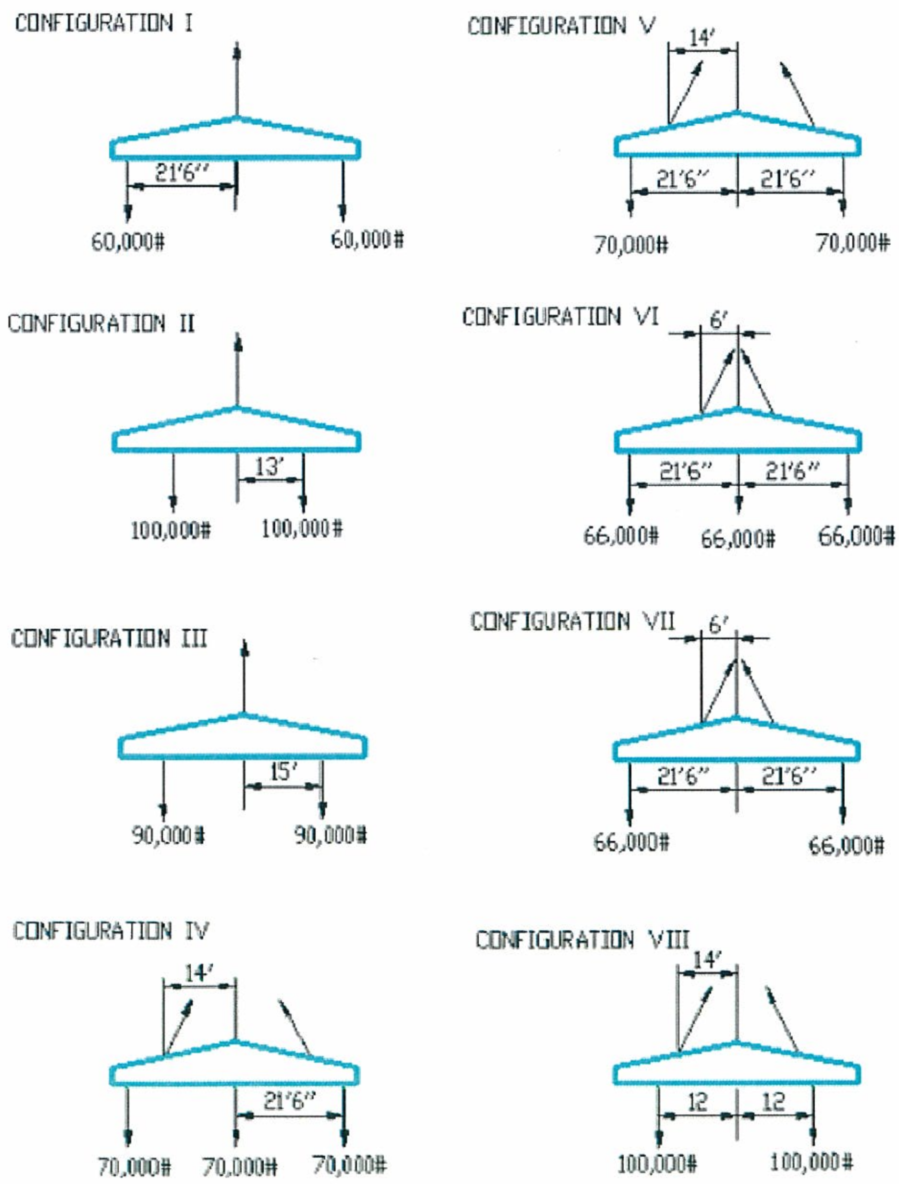


Figure 15: Typical Spreader Beam Allowable Load Guidance

Sizes and Standard Types

Box Spreader Beam

NASSCO spreader bars include, four adjustable box beams, two with 295 ton lift capability and two with 170 ton capability. The 295 ton spreader bars have top and bottom lifting attachment which always travel together and span 14 feet to 50 feet with 5 configurations in between. These beams, however, cannot be used as equalizers and are not deigned to withstand much internal moment.

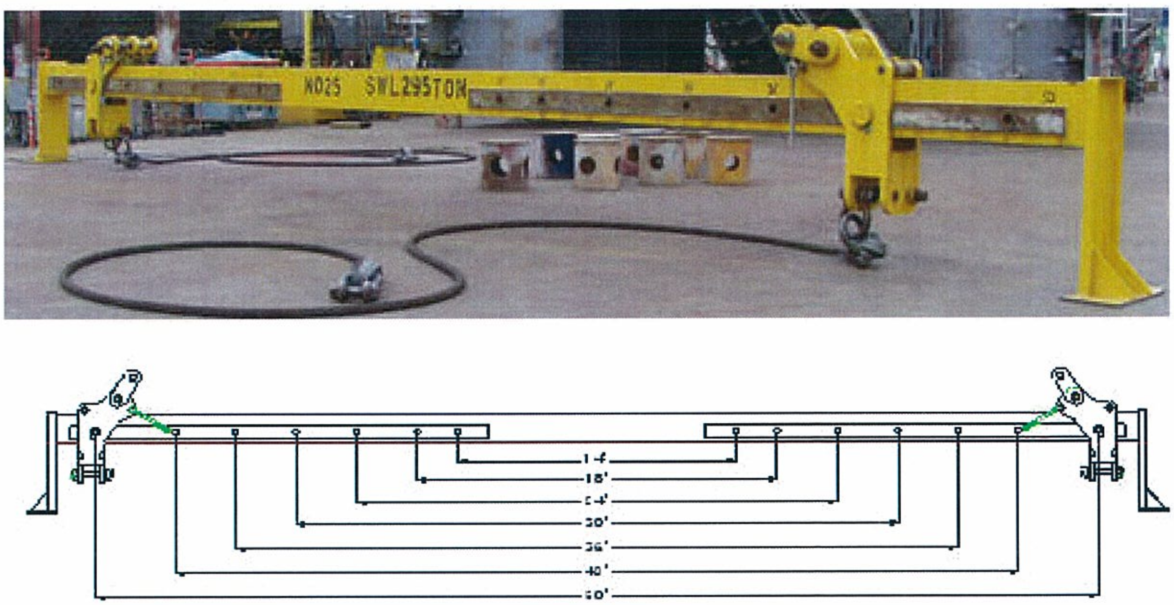


Figure 16: Adjustable Box Bar Spreader Beam

Round Spreader Beam

Round bar has a lift capability of 210 tons and span of 14 ft, with effectively two padeyes on top and two on bottom, located on each end. This spreader is similar to the adjustable box beam spreader for use but cannot be adjusted with regards to spread distance.

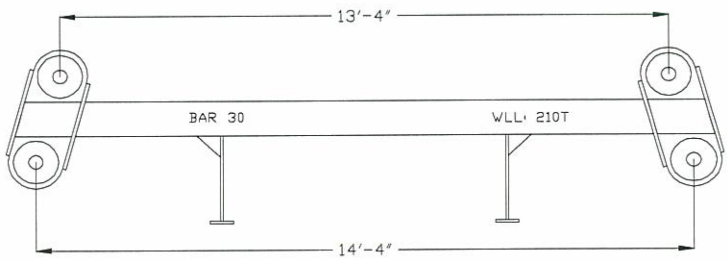


Figure 17: Round Bar Spreader Beam

Telescoping Spreader Beam

Other spreader bars in existence include modular, and telescoping spreader bars. These have the advantage of relatively easily breaking down or reducing in size such that can be transported or stored easily.

An example of a telescopic bar can be seen in Figure 18Figure 18: Telescoping Spreader Beam which has a 50 ton lifting capability, up to 65 ft in length with 6 in adjustment increments. With significant adjustment possible vertical slings can be used minimizing internal moments and compressive forces will be imparted into the ships block during the lift. These spreader beams typically cannot be used as an equalizer because they are not designed for internal moment.

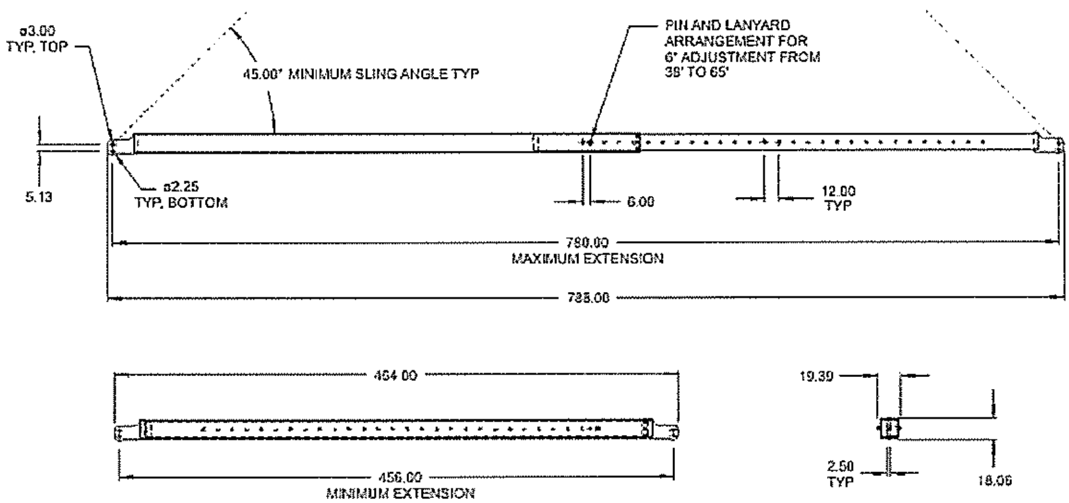
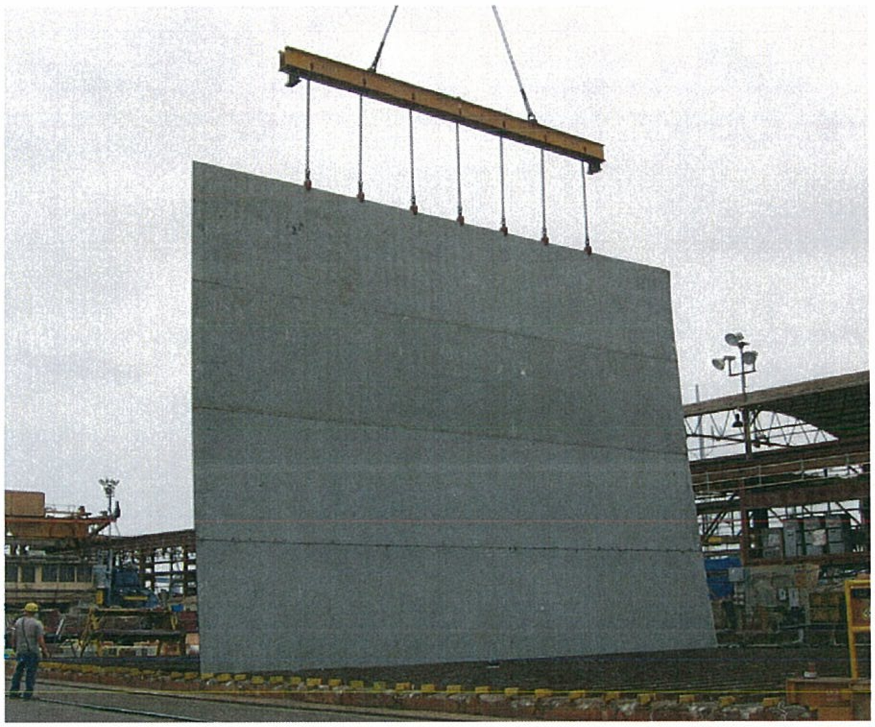


Figure 18: Telescoping Spreader Beam
Figure reprinted with permission from Tandemloc Inc

A similar concept to the telescoping spreader beam is modular spreader beams which have bolt together sections that can be added or removed to vary the length of the beam.

Equalizer Plate Clamp Spreader Beam

Three Equalizer Type bars with 30, 35 and 64 ton ratings, spreading 17, 35 and 42 ft. These bars have two top attachments and permanent chain attachments with plate clamps underneath located on average every 3 ft. The ones at NASSCO are designed to be used with plate clamps to equally spread the load out over a large area. This is particularly useful if lifting large plates that are not well stiffened and required multiple pick points.



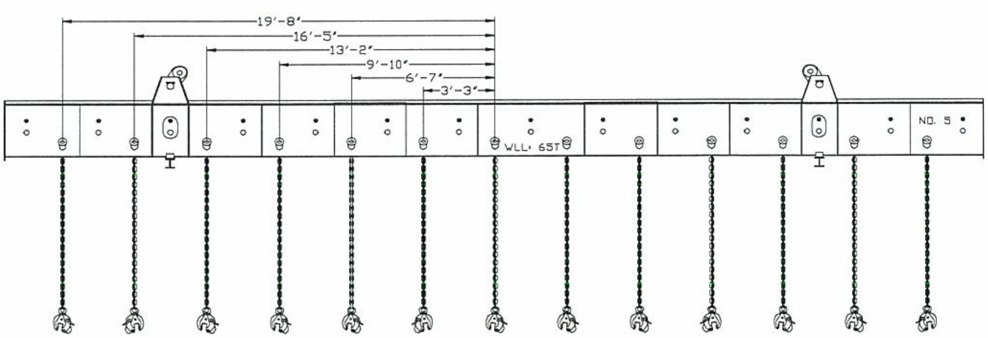


Figure 19: Plate Clamp Equalizer Spreader Beam

Roller Spreader Beams

NASSCO has four beams that are referred to as roller beam bars, with lifting capabilities of 99,124,141,173 short tons and respectively 12ft, 8ft, 20ft and 12 feet in length. These beams are essentially an I-beam with padeyes attached on both top and bottom, located on roughly every 5 ft.

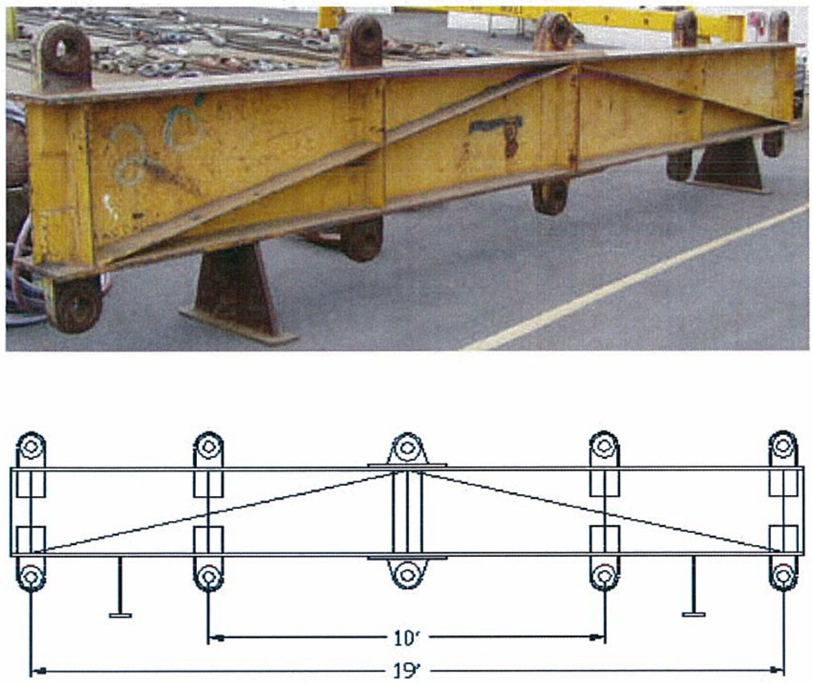


Figure 20: Roller Spreader Beam

Single Web Girder Spreader Beams

NASSCO has three Single Web Girder Bars with lift capabilities of 40, 70 and 80 ton and lengths of 45 feet. These spreader bars are capable of many different lift arrangements and can be used as equalizers. Figure 15 shows a load rating for many different typical lifting arrangements.

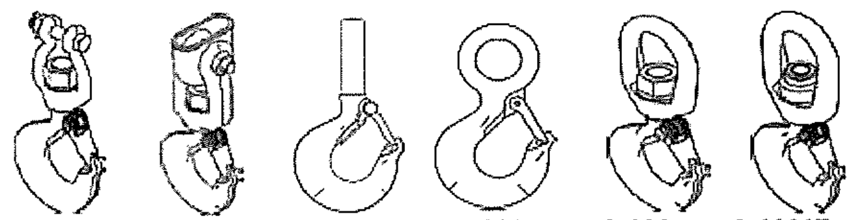
Figure 21: Single Web Girder Spreader Beam

6. HOOKS

In almost all lifting arrangements a hook is used somewhere. Typically for most critical lifts the hook that is used in on the crane and has a rating greater than that of the crane. It is however important to know some of the loading restrictions that hooks have. Hooks used in rigging have been used as long as lifts have been needed and standard shapes and sizes have been established.

Size and Strength

Table 16 below gives the working load limits for Crosby Hooks as well as the chain and wire rope dimensions typically used with these smaller hooks.



S-3316 | S-3319 | S-319 Series | S-320 Series | S-322 Series Positioning Only | S-3322B

Crosby Hook Identification & Working Load Limit Chart+

S-1316A & S-1317A Only Grade 100 Chain			S-316A, S-317A, S-318A, S-326A					S-318A Only	
Chain Size		Working Load Limit (lbs.)** 4:1	Grade 80 Chain			Wire Rope XIP Mechanical Splice		Maximum Shank Diameter (in.)	Minimum Thread Size (in.)
			Chain Size		Working Load Limit (lbs.)** 4:1	Wire Rope Size (in.)	Working Load Limit (lbs.)* 5:1		
(in.)	(mm)		(in.)	(mm)					
—	6	3200	—	6	2500	5/16	2000	.72	1/2" - 13 UNC
1/4	7	4300	1/4 - 5/16	7 - 8	4500	7/16	3800	.94	5/8" - 11 UNC
5/16	8	5700	—	—	—	—	—	—	—
3/8	10	8800	3/8	10	7100	1/2	5000	1.06	3/4" - 10 UNC
1/2	13	15000	1/2	13	12000	5/8	7800	1.19	1" - 8 UNC
5/8	16	22600	5/8	16	18100	7/8	15200	1.38	1-1/4" - 7 UNC
3/4	18/20	35300	3/4	18/20	28300	1	19700	—	—
7/8	22	42700	7/8	22	—	—	—	—	—
1	26	59700	1	26	—	—	—	—	—

* Ultimate Load is 5 times the Working Load Limit based on XIP Wire Rope.
** Ultimate Load is 4 times the Working Load Limit based on Grade 80 or Grade 100 Chain.
+ Working Load Limit - The maximum mass of force which the product is authorized to support in general service when the pull is applied in-line, unless noted otherwise, with respect to the centerline of the product. This term is used interchangeably with the following terms: 1. WLL, 2. Rated Load Value, 3. SWL, 4. Safe Working Load, 5. Resultant Safe Working Load.

Table 16: Hook Working Limits
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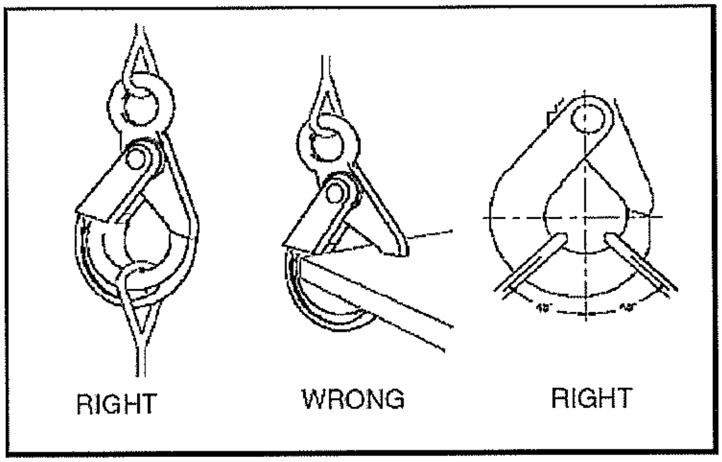

Figure 22: Use of Hooks
Figure reprinted with permission from the
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Despite the apparent simplicity of hooks there are many ways in which hooks can be improperly loaded, Figure 22 and Figure 23 gives some examples of proper and improper loading of some hooks.

Some hooks are designed with an additional safety latch. When using these hooks caution needs to be used to never allow the load to be supported by the latch. The latches are not designed to with stand the rated loading of the hooks.

When using more then one sling on the hook the angle between the hook legs should be less then 90 degrees.

When threading in the hooks, the amount of thread engaged should be no less then 1 thread diameter, caution needs to be used as the thread may corrode over time causing the hook weaken and to eventually pull out.

Side loads, back load and tip loads should be avoided when rigging with hooks as many are not designed for these loading conditions.

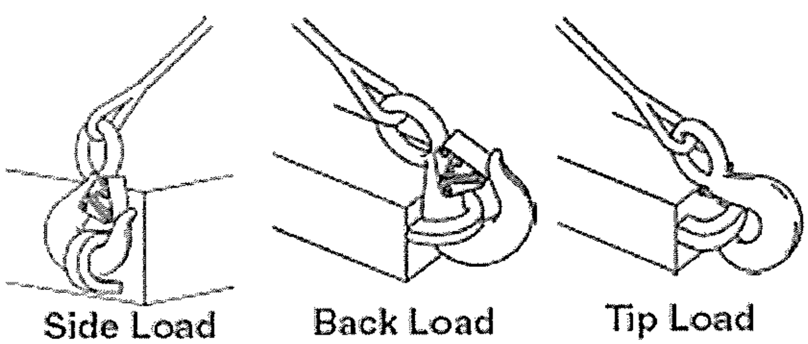

Figure 23: Ways of Loading Hooks
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Standards and Regulations

The code of federal regulations title 29 part 1926.251 deals with rigging equipment for material handling and subpart (f) deals specifically hooks. Safety factor for hooks is listed as the following:

> .
> (2) The manufacturer's recommendations shall be followed in determining the safe working loads of the various sizes and types of specific and identifiable hooks. All hooks for which no applicable manufacturer's recommendations are available shall be tested to twice the intended safe working load before they are initially put into use. The employer shall maintain a record of the dates and results of such tests.

Additional standards for hooks can be referenced in ASME B30.10- 2005 Hooks.

7. CRANES

Cranes are required for lifting items in a shipyard. Typically for most large critical lifts the cranes used are relatively unique and not mass produced off the shelf items. Shipyards should have thorough documentation created with regards to the extent of the cranes capabilities.

Standard types

Cranes are mechanical devices which are used to lower, lift and move horizontally material. Cranes come in different varieties: mobile, crawler, wheel-mounted, gantry and overhead cranes.

Gantry

Gantry Cranes consist of a hoist in a trolley which runs horizontally along a rail or a pair of rails fitted under a beam. The crane can move along the rails and typically has a hook or set of hooks. These cranes can also be mounted to the side of the buildings using one wall of the building for support.

Whirly / Mobile

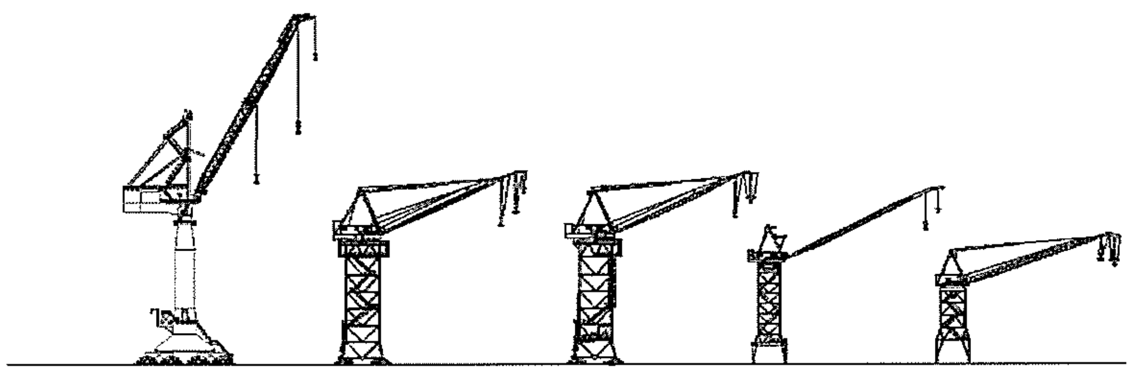

Figure 24: Whirly / Mobile Cranes at NASSCO

Mobile crane is made up of a truss, latticed or telescopic boom which moves around on rails, wheels or caterpillar tracks. The boom which is hinged at the bottom is raised and lowered by cables or hydraulic cylinders. Hooks are suspended from the boom by wire ropes which are operated through a variety of transmissions. Mobile crane with caterpillar tracks are typically referred to as crawlers and have hydraulic extendable supports which can increase stability but eliminate mobility.

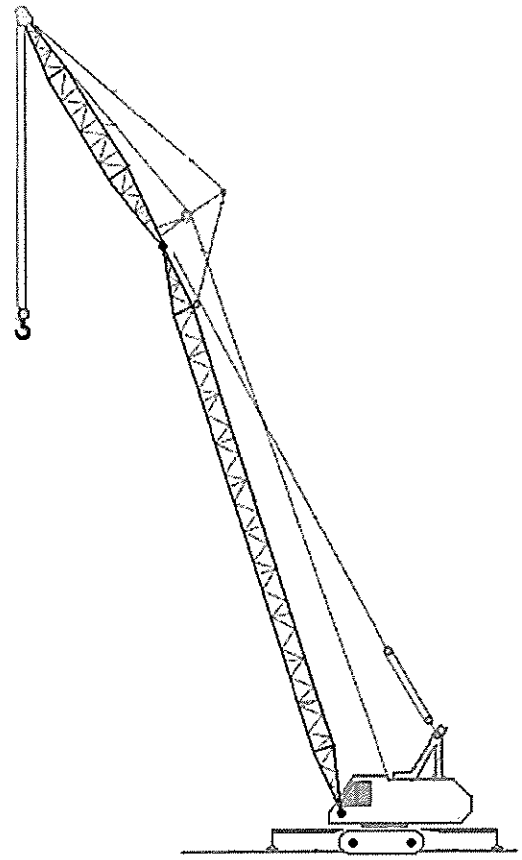

Figure 25: Typical Crawler Crane

Standards and Regulations

OSHA 1926 Subpart N- Cranes, Derricks, Hoists, Elevators AND Conveyors
    1926.550 Cranes and Derricks
ASME B30.2 1990 Overhead and Gantry Cranes
Crane Certification Association of America
Crane Manufacturers Association of America

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ASME B30.2 B30.4 B30.7 B30.11 B30.17, 2005 Safety Standards for Cableways, Cranes, Derricks, Hoists, Hooks , Jacks Slings, Below the Hook Lifting Devices, American Society of Mechanical Engineers, New York, New York.

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SHIPYARD
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National Steel and Shipbuilding Company

Initial Design & Naval Architecture

Issued: 14 JUL 2009 – Revision (-)

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RANGE OF SHIPYARD LIFTS

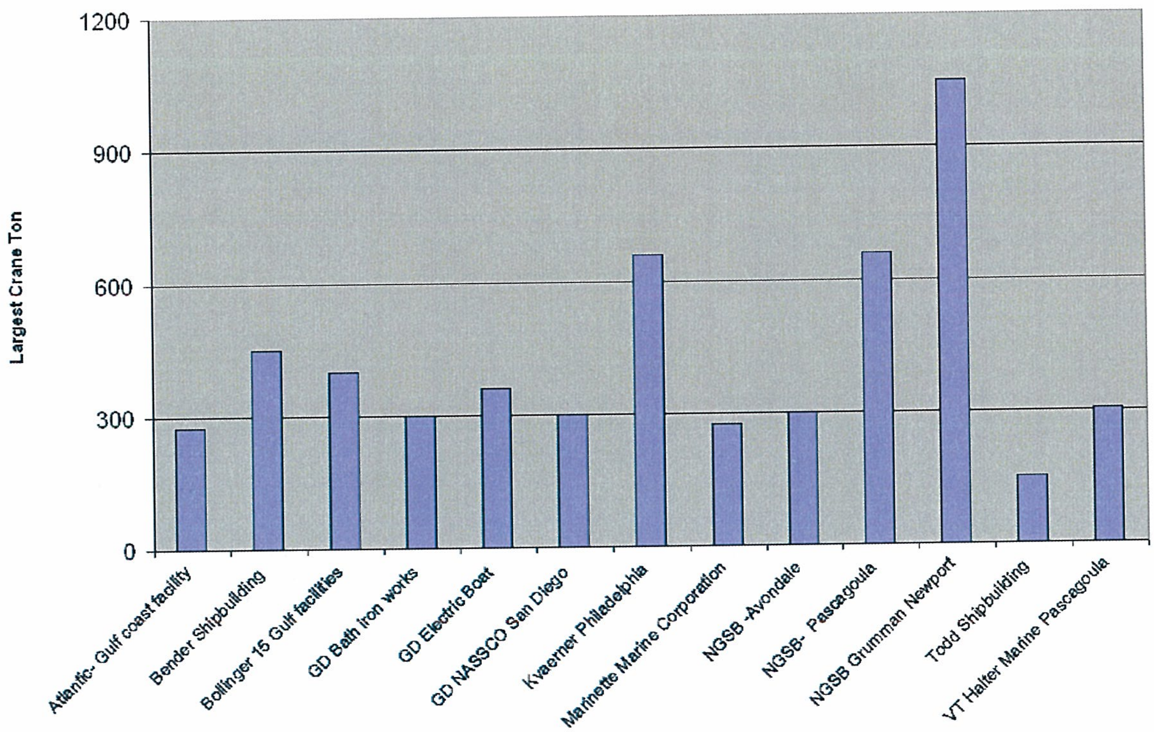
Shipbuilding has changed and evolved tremendously in the last century to make shipbuilding more efficient and to lower cost where possible. This has placed more and more demands on shipyard lifting and rigging operations. Ships were traditionally were built one plate at a time, but now ship are built as modules, structural units or blocks. These blocks, may be scattered throughout a shipyard, and are finally brought together and assembled. This method of ship construction allows the ships blocks to be built to be closer to vital support equipment during construction, minimizing the time doing nonproductive activities. The trade off of this new shipbuilding philosophy is that significantly larger lifts, and more of them are required during ship construction.

To accomplish this new build strategy, many United States new construction shipyards have cranes that can lift loads of approximately 300 tons. The largest active shipbuilding crane in the United States is at Northrop Grumman's Newport News facility which is a gantry crane that can lift up to 1050 tons.

Figure 1 – NGSB 1050 Ton Gantry Crane

Further demands are placed on rigging and lifting requirements because shipyards can be spread over many acres and it can be required to move ships blocks hundreds of feet. Some yards have specially designed ground transporters capable of supporting and rolling very heavy structures which can greatly reduce the amount of engineered lifting that is required but still requires engineered movement. There is always a requirement to lift and transport large and heavy objects. Some of the largest cranes used for these tasks are gantry cranes which, due to their broad support on both sides of the block or unit lifted, can lift much heavier objects. The limitation of gantry cranes is however that they are generally straight railed and have limited mobility. Most yards have crawlers, "Whirley" or other mobile cranes to aid the movement of large blocks of ship structure. These types of cranes have much more mobility but are less stable and therefore have lower lifting capacities reflecting this.

Figure 2 – Selected Shipyard Largest Crane Capacities Publicly Listed

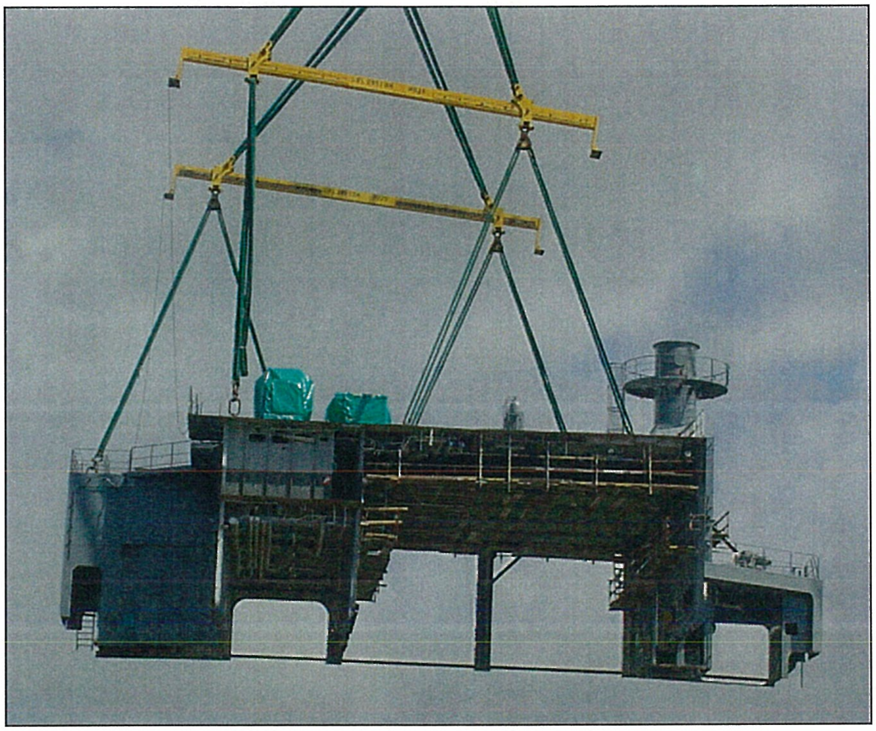


The majority of lifts performed at shipyards are small lifts relating to the transport of basic materials and individual parts, tooling, and small assemblies that are in early stages of construction. Shipyards may typically have a generalized cut off weight or size that above which the lifts become engineering by a qualified rigging engineer. Lifts below this cut off level represent about 80% of all lifts, of the remaining engineering lifts an even smaller percentage are large erection lifts which are certainly critical lifts requiring significant engineering design to minimize the probability of failure.

These critical lifts requiring significant engineering design and planning can be defined as a lift of an item that is unique, irreplaceable, and vital to a program that would have severe negative impacts including the delay of operations and affect program commitments if damaged or upset. Most ship blocks or structural units fall into this category and should be considered critical lifts. Items lifted over critical items, or lifts that use almost all of a single cranes rated capacity or a significant portion of either of two cranes capacity for a two crane lift, should also considered critical lifts as damage can result in similar negative consequences.

Large shipyard lifts, including the final erection of blocks, require special attention to minimize the interferences of ship structures and equipment between the landing structure and the erected ship. This forces special attention to be paid to deflection of the structure, often with the addition of extra structure to help support the loads. These large lifts can be disruptive to shipyard operations in many ways. An example is that production many need to be stopped in large areas of space during their lift and transport reducing the efficiency of the yard with increased downtime.

Figure 3 – Ship Block Lift with Extra Structure For Lift



Most yards employ a time saving construction strategy of building ship structures upside down to minimize the amount of work that is done in the overhead position. This complicates the lifting process and places special demands on the rigging department to engineer the turning of these ship blocks to ships position with multi-crane lifts. At most yards this is accomplished with specially designed turning padeyes. Some shipyards employ "sand pits" or other soft surfaces to help roll more rigid and robust ship structure directly on the ground without the need for multiple cranes or the need to design complicated lifting arrangements.

Turning a ships block can place significant demands on the rigging equipment and the cranes used at the shipyard. These operations almost always require more than one crane as the block must be lifted straight up, and then slowly released by one of the cranes such that the turn is now half complete. The result of this is that the remaining crane carries all the weight of the block which limits the weight of a turning operation to a function of the cranes available in the yard and their respective capabilities.

Figure 4 – Large Ship Bow Block Halfway Through Turn Operation