Progress Report 3
PP 24-08 Fast Docking System Study

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Rev A

Prepared for:

National Shipbuilding Research Program

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Contents

1. Executive Summary

The primary method of drydocking ships in the United States includes stacking and cutting wood to the shape of the hull of a ship to create ship supports. US Navy ships are drydocked to very high standards, and so this wood must be high quality and accurately cut for each ship. This requires a lot of skilled labor and wasted materials for each drydocking. This is a slow and inefficient process that has not advanced for hundreds of years. Modern advancements have been made in ship support systems and are being utilized in other countries. The US has been very slow to adopt these drydocking technologies. Can hopefully address this problem.

One innovative company in the drydocking technology space is Syncrolift. Their Fast Docking systems include hydraulically operated ship supports that replace side blocks. This project will provide a comprehensive analysis of these systems in accordance with the conservative US Navy standards and pragmatic recommendations from the shipyard operators. This report is intended to be a steppingstone for the potential adoption of this technology by shipyards throughout the US. ECB Member Shipyard Fincantieri Marinette Marine and US Navy Shipyard Naval Base San Diego Graving Dock, see the industry need for this research and have endorsed this project.

The two specific systems chosen for this study are:

Bilge Support Arms

Figure 1: Photo of Bilge Support Arms

Bilge Support Arms are hydraulically actuated mechanisms made to secure a vessel near the bilge of the hull. These arms pivot about a fixed based, extending outwards at an adjustable angle to conform to the hull. The arm's movements are controlled by a hydraulic cylinder, ensuring gradual movement. Once extended, the arm can be locked into place using a series of adjustment holes, intended to prevent movement and increase load capacity. The bilge support arms are attached to a reinforced structural frame.

This design functions similarly to traditional side blocks while providing adjustability to accommodate various hull shapes.

Side-Support Arms

Side support arms are extendable truss structures designed to provide lateral support to a vessel's hull during drydocking. They extend outward from the dry dock walls using a scissor-like mechanism, allowing for adaptation to different hull shapes. When extended, the arms brace the vessel at a higher point compared to the bilge support arms.

This design functions similarly to traditional shores while providing adjustability to accommodate different beam sizes.

Figure 2: Photo of Side Support Arms

2. Progress Report

Remaining Work to Finish

DMC plans the following work to finish this project:

- Perform calculations on the sidewall support arms system to confirm adequacy in accordance with American design standards
- Perform calculations on the bilge support arms system to confirm adequacy in accordance with American design standards
- Discuss and analyze use of Fast Docking Systems in American shipyards

3. Bilge Support Arms On-Site Observations and Recommendations

General

The Bilge Support Arms Fast Docking system installed into the floating drydock at Fiskerstand shipyard in Norway. Support arms use hydraulic cylinders to extend from prefabricated steel girders placed onto the pontoon deck. The support arms replicate the same type and location of support as would be provided by traditional bilge blocks. At least two support arms are engaged along the vessel during the docking process.

Components

The support arm system consists of the arms with hydraulic cylinders, girders running along the pontoon deck in the transverse direction (one per pair of support arms), a hydraulic power pack, and a control system.

The arms themselves are constructed from steel and include pivoting pins, padeyes, and clevises to facilitate connection of the moving components and the hydraulic cylinders. The cylinders are dual acting cylinders with locking valves when not in use, and one cylinder is provided for each arm. The locking valves ensure that, should one cylinder lose pressure and no longer be properly engaged to support the vessel, the remainder of the system, including the other hydraulic cylinders, remain properly engaged. The upper part of the support arms is constructed with an articulating flat plate that can rotate to accommodate deadrise and longitudinal shape. The face is covered with hardwood and softwood, similar to a traditional side block.

Figure 3: Photo of Bilge Support Arms

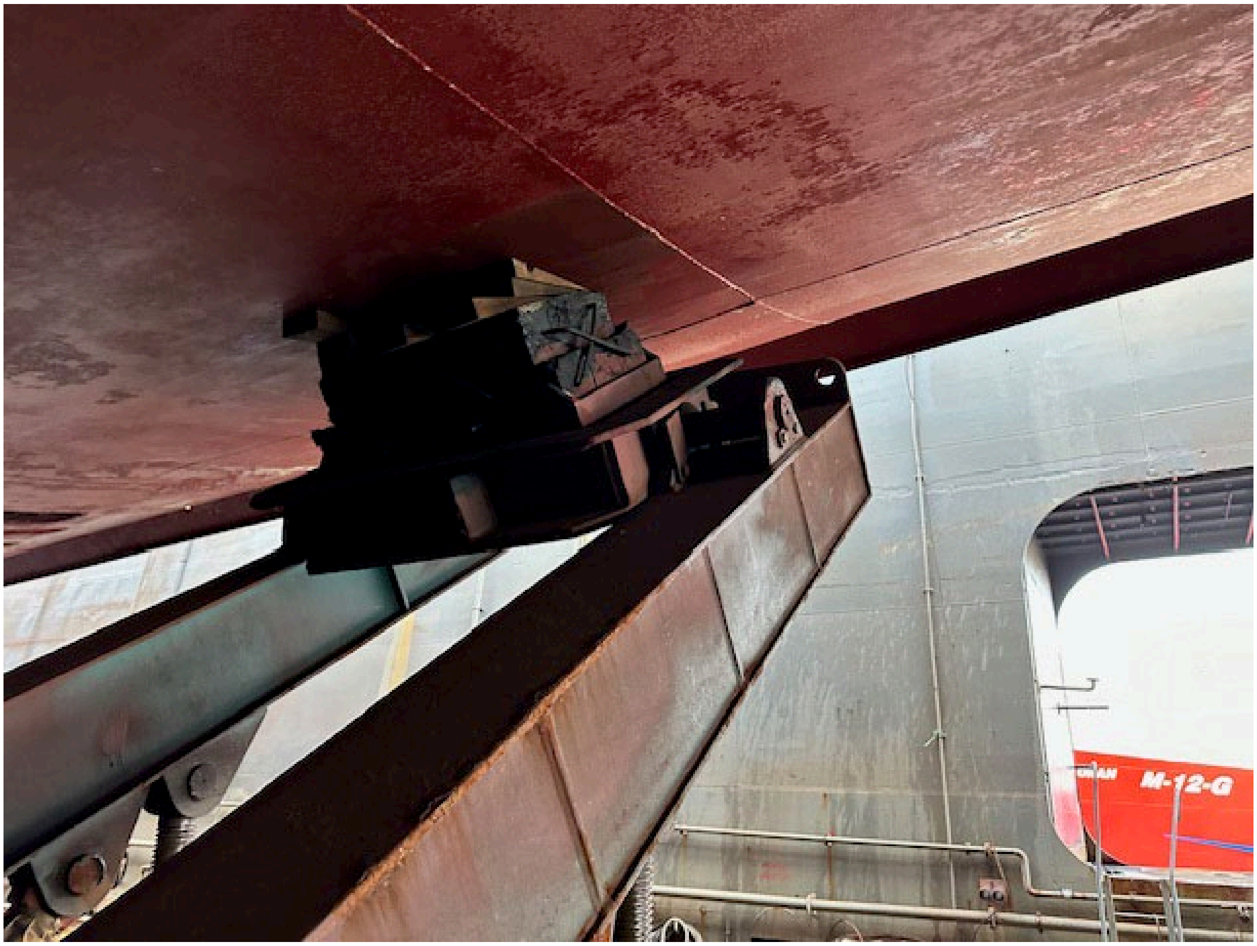

Figure 4: Photo of Bilge Support Arms Upper Rotating Face

The girders are large steel girders that span between each pair of bilge support arms. These are able to be moved using the dock crane to any location along the length of the dry dock. The girders have holes and notches along their length to allow for positioning the hydraulic arms at different positions to accommodate different vessel shapes and breadths.

Two large turnbuckles are installed connecting each hydraulic arm to the girder below. The turnbuckles are used to manually lock the hydraulic arms after docking.

A hydraulic power pack is installed in the wingwall to provide hydraulic power for the system. The hydraulic power pack is a typical / standard hydraulic power pack with redundant pumps, accumulator, hydraulic fluid tank, etc. The hydraulic arms on both sides of the dock are powered from the same HPU. Hoses are run from the top of the wingwall to the arms prior to docking.

Figure 5: Photo of Bilge Support Arms HPU

The hydraulic cylinders are controlled with local control stations installed at regular intervals along the top deck. There are more control stations along the length than the number of bilge block support arms. If the support arms are relocated to the next frame, they are controlled by the control station at that frame rather than one dedicated control station. A control panel was supplied with the system to be installed into the drydock control room, but this control panel has not been installed. HPU control is performed locally at the HPU, with a start stop and emergency shut off all directly mounted to the HPU. There are no remote controls for the HPU. The hydraulic cylinders are fitted with failsafe valves that will lock at their current position if the system loses pressure.

Figure 6: Photo of Bilge Support Arms Local Controls

System Maintenance

Maintenance of the system is straightforward and typical of hydraulic systems installed in a saltwater environment. Some maintenance items include Zerk fittings for lubrication of all pivot points and corrosion protection for the steel components and turnbuckles.

System Advantages

Use of the support arm system completely eliminates the need to build side blocks. The keel blocks are prepared in the same manner, except that the girders must be accommodated to pass transversely through the keel block string. The hydraulic support arms can be relocated along the length of the dry dock to accommodate different length vessels or multiple vessels to be docked during a single docking evolution.

There are some dockings where the side blocks are the limiting height factor of docking a vessel. This is especially true when docking relatively large tugs and research vessels on small dry docks in shallow basins on floating dry docks along the gulf coast. This system eliminates the side blocks as a vertical obstacle by eliminating the side blocks altogether.

Fleeting of the blocks is very simple. The hydraulic system is activated, and the block to be fleeted is simply retracted (provided at least two other side blocks are engaged onto that side of the vessel).

System Disadvantages

This system does have some disadvantages or nuances that the shipyard must consider when docking. Firstly, although overall labor hours related to this system are greatly reduced when considering the amount of time required to make side blocks, the system does increase the amount of maintenance time required for the dry dock. Shipyards, especially commercial shipyards, and not typically known for their expansive dry dock maintenance programs. Secondly, the system uses hydraulic hoses that are routed on the pontoon deck and subject to wear and tear or damage if run over by vehicles. The risk of damage to the hoses is mitigated by being the last thing run on the dock floor prior to docking and the first thing removed after the turnbuckles are secured.

The system, similar to sliding blocks, must be used in pairs for vessels with high deadrise. If repairing a damaged vessel on one side iwo traditional side blocks, the side block may be omitted just the side with damage. However, when using this system, they must have a counteracting mate on the opposite side of the ship to prevent sliding with vessel of high deadrise.

System and Block Load Calculations

Loads in the system can be calculated by using existing calculation methods and applied to whatever standard to which the dry dock is operating.

Drydock Operations

Drydock operations with this system are very similar to previous dry dock operations, except with adding a step to engage the system and a step after docking to mechanically secure the arms. In preparation for blocking, the dockmaster reviews the vessel plan and locates side blocks in a very similar manner to planning for traditional fixed side blocks. The girders are moved into position over dock frames. The keel blocks are prepared in the same manner without regard to system installation. Just before docking, the hydraulic hoses are installed and the system is tested for leaks and operation.

The vessel is brought into the dock using the same ship handling system as was already in use by the dock. The vessel is centered and landed onto the keel blocks in the same manner as was in place before installing the system. Similar to using sliding blocks, the dock is pumped to positively land the vessel, but stopped short of the draft at instability. The hydraulic blocks are then engaged by an operator on the wingwall, being careful to observe the system pressure to know when the blocks are engaged but not applying enough pressure to lift the vessel off of the keel blocks.

Once engaged, the dock is complete dewatered. After the pontoon deck is dry, the keel blocks and hydraulic arms are inspected per normal shipyard protocol. Finally, the turnbuckles are engaged to lock the system prior to shutting down the hydraulic system.

Shipyard Personnel Interview

During DMC's visit to the Fikerstand yard, the dock master was interviewed regarding the system. He reported that the system has greatly reduced the cost and time to dock a vessel. It has also greatly reduced the time required between dockings.

The yard has not encountered a vessel on which the system cannot be used, although they do maintain their old side block capabilities just in case they need to dock a vessel for which the system cannot work.

The dockmaster reported that the shipyard does not intend to install control panel into the dock control room, and that local control may be an even better solution as it simplifies the system and allows for direct visual observance of the vessel to make sure that the operator does not lift the vessel.

When asked about calculations, the dockmaster reported that the shipyard does loading calculations in the exact same manner as before the system was installed.

Recommendations for Improvement

The control console that was intended to be installed into the control room included a remote shut down capability of the hydraulic power unit. Since this control panel is no longer intended to be installed, DMC recommends installing a separate emergency shutdown system, to include a shut down button in the control room and one on the top deck of each wingwall. Furthermore, DMC recommends installing additional smoke and heat detectors inside the wingwall above the hydraulic power unit.

4. Side Support Arms On-Site Observations and Recommendations

General

The Side Support Arms Fast Docking system installed into the graving dock at Hamek shipyard in Norway. Support arms use hydraulic cylinders to extend from the sidewall in a manner similar to a horizontal scissor lift. The support arms provide all of the lateral support to the ship throughout the dry docking period. At least two support arms are engaged along the vessel during the docking process.

Figure 7: Photo of Hamek Shipyard

Components

The support arm system consists of the arms with hydraulic cylinders, a lifting mechanism to move the arms vertically, a hydraulic power pack, a control system, and arm extensions.

The arms themselves are constructed from steel and include pivoting pins, padeyes, and clevises to facilitate connection of the moving components and the hydraulic cylinders. The cylinders are dual acting cylinders with locking valves when not in use, and two cylinders are provided for each arm. The locking valves ensure that, should one cylinder lose pressure and no longer be properly engaged to support the vessel, the remainder of the system, including the other hydraulic cylinder on the same arm, remain properly engaged. The ends of the arms are fitted with hardwood where the engage the vessel.

Figure 8: Photo of Sidewall Support Arm Engaged onto Vessel

A lifting mechanism is used to move the support arms vertically up and down the dry dock side wall so that they can be used on a larger number of vessels. The lifting mechanism has two large rails that run vertically along the graving dock wall and allow for large bearing loads on the dock wall. The lifting mechanism is also installed with a brake system for locking the support arms from moving vertically. This brake system uses a passive mechanism so that it is engaged in the event of power failure, preventing free fall of the support arm.

Figure 9: Photo of Sidewall Support Lifting Track

Figure 10: Photo of Sidewall Support Lifting Mechanism

A hydraulic power pack is installed near the graving dock to provide hydraulic power for the system. The hydraulic power pack is a typical / standard hydraulic power pack with redundant pumps, accumulator, hydraulic fluid tank, etc.

Figure 11: Photo of Sidewall Support HPU

The graving dock control house was rebuilt when the system was installed to include a control console for the sidewall support arm system. The system includes controls for all of the system functionality as well as safety systems, system monitoring, and a CCTV system. Other control components installed outside of the control house include shut off buttons at the HPU and near each arm, vertical measuring instruments to give the operator the elevation of the arms above the dock floor, and horizontal measuring instruments to give the operator the distance from the dock wall for each arm.

Figure 12: Photo of Sidewall Support Control Console

Finally, the system is fitted with several support arm extension sections. The sections can be added before docking in order to extend the support arm lateral length. There are three extension sections per arm. Wider vessel require less or no extensions where as narrower vessels require more extensions. Each extension piece is also fitted with hardwood at the face that is in contact with the vessel.

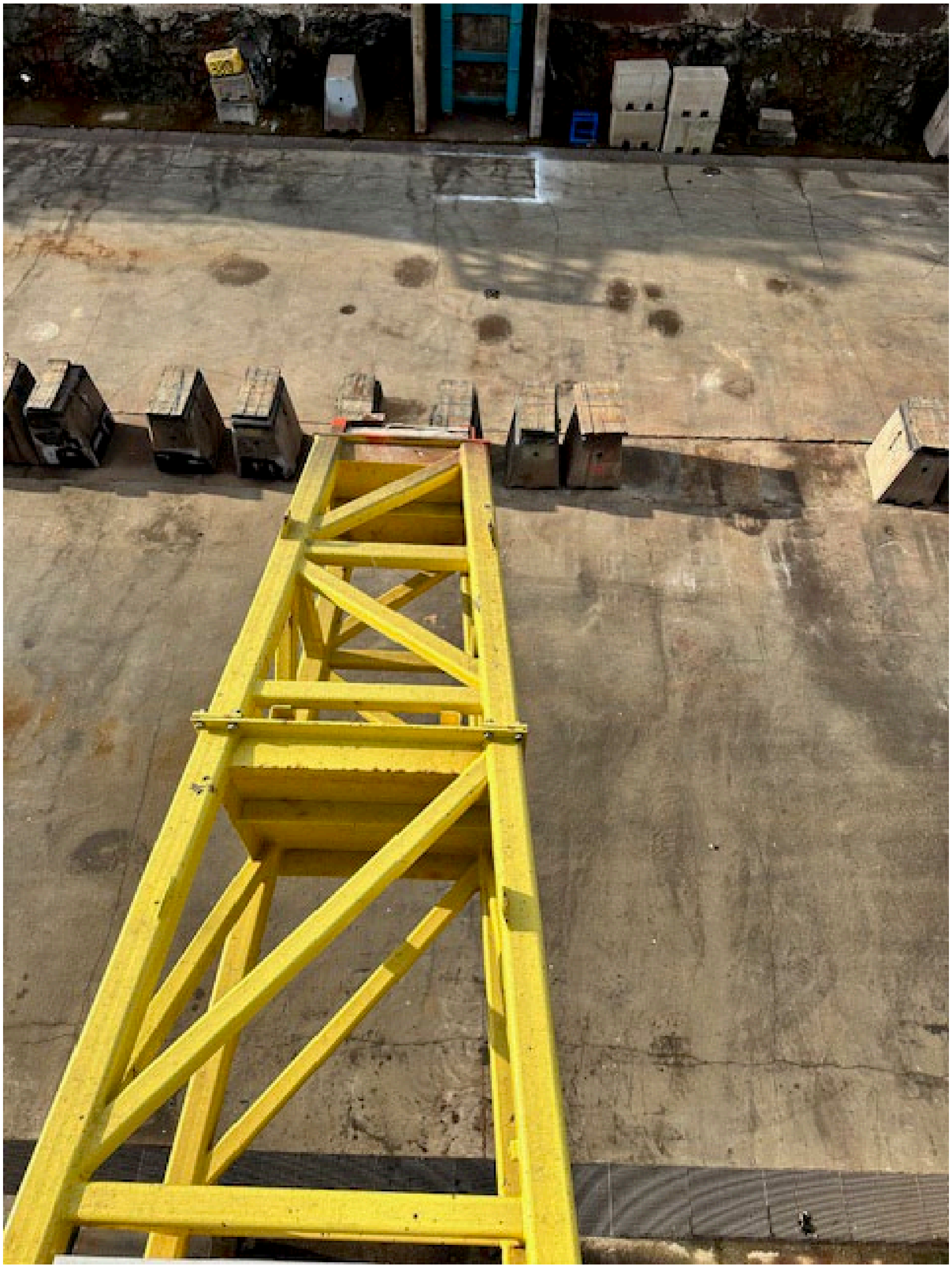

Figure 13: Photo of Sidewall Support Arm Extension

System Maintenance

Maintenance of the system is straightforward and typical of hydraulic systems installed in a saltwater environment. Some maintenance items include Zerk fittings for lubrication of all pivot points, maintenance of the lifting mechanism including inspection of the wire rope, corrosion protection for the steel components, and replacement of wear parts for the vertical braking system.

System Advantages

The support arm system has several advantages over traditional side blocks. There are no side blocks at all when the ship is dry docks, meaning that access to the vessel bottom for painting is completely unfettered. In fact, the sidewall support arms should be placed onto the vessel as high as possible to decrease the lateral structural loads in the system and provide the most support. This means that the sidewall support arms are almost always engaged onto the vessel above the waterline. Docking with this system means that the only blocks that need to be fleeted are the keel blocks in order to paint all underwater surfaces. If needed, the arms can be retracted individually to allow access for painting or renewal, provided that the vessel is still properly supported with the single arm disengaged.

Figure 14: Photo of Sidewall Support Arm Showing Typical Vessel Support

Figure 15: Photo of Sidewall Support Arm Showing Sidewall Engagement

Note: DMC recommended that the support arm should have been lowered to fully engage the vessel sideshell.

Furthermore, dock floor access for moving large sections of bottom plate is also unfettered. Rather than maneuvering smaller sections and building repair sections in place around the side blocks, large panels can be pre-fabricated in the shipyard panel shop, moved to the dock floor, and then installed onto the ship.

This system drastically reduced the preparatory time of the dry dock for each vessel. The majority of time spent by shipyards preparing blocks are spent on building and shaping the keel blocks. With this system, that time is completely eliminated, leaving only the keel blocks to be prepared. The only adjustment between dockings required for this system is to install or remove the support arm extensions if docking vessels of varying breadth.

Several systems exist for centering vessels within the dry dock over the blocks, but none of the systems are fool proof. Most involve mooring lines from the dry dock walls that must be manipulated throughout the vessel landing process, leaving much to be desired for lateral and longitudinal accuracy. Using this system improves vessel centering in two very important ways. First, the system itself tracks the lateral position of the arms from the dock wall to the mm and synchronizes their movement (unless overridden by the operator). Therefore, this system is also used to center in the dry dock far more accurately than most existing centering systems. The arms have flat faces, and most vessels have flat sides. Using this flat geometric relationship, the arms can be extended to center the vessel, then retrated a small amount when pumping the dock, allowing the vessel to freely settled down onto the blocks but while still maintaining center. The arms have the capacity to push the vessel to center if needed, eliminating the need for mooring lines for transverse control. Note, mooring lines are still required for longitudinal control.

The second major advantage of centering the vessel is the fact that the shaped side blocks no longer exist, expanding the allowable tolerances of the vessel being off center. The most critical part of centering a vessel is to make sure that the shaped side blocks hit the vessel at the correct locations. The keel of vessels, whether shaped, flat, or bar keels, have much more tolerance on where to land, so long as the center of the keel lands within the middle third of the keel block. The current typical tolerance is 1” in the long or transverse direction. For a 4’ square keel block, the tolerance now expands to 4’ / 3 = 1’-4”. Finally, the system can be used to heel the vessel if the vessel final docked position has a minor heel to it.

There are some dockings where the side blocks are the limiting height factor of docking a vessel. This is especially true when docking relatively large tugs and research vessels on small dry docks in shallow basins on floating dry docks along the gulf coast. This system eliminates the side blocks as a vertical obstacle by eliminating the side blocks altogether.

Using this system, the time between dockings can be greatly reduced, or eliminated entirely if the two ships to be docked are similar in size.

It is not unusual for commercial vessel owners to have very little knowledge of their vessels underwater arrangement. While obstructions can be installed along the keel, most obstructions such as transducers, coolers, and seachests are installed away from the keel. If the location of these appurtenances are unknown, then they are at risk for damage during docking. Use of the arms occurs above the waterline, meaning that the dry dock operator can visually confirm that the area to be supported with clear prior to engaging the system.

System Disadvantages

This system does have some disadvantages or nuances that the shipyard must consider when docking. Firstly, the current system design is fixed along the longitudinal direction of the vessel. This means that the shipyard is limited to using the arms only when the vessel is long enough to span between at least two of these support arms. Secondly, although overall labor hours related to this system are greatly reduced when considering the amount of time required to make side blocks, the system does increase the amount of maintenance time required for the dry dock. Shipyards, especially commercial shipyards, and not typically known for their expansive dry dock maintenance programs.

System and Block Load Calculations

In the design of the currently block arrangements for USN projects, the vertical and lateral load systems are combined onto the side blocks. Combining these loads is not difficult, but it does introduce assumptions and inconsistencies in load sharing between the keel blocks and side blocks. Using the sidewall support arm system eliminates the conflagration of vertical and lateral load support systems. Using this system, the keel blocks take 100% of the vertical weight of the ship, This means that the ship weight distribution curve can be used to almost directly calculate the load in each keel block, allowing for more accurate load prediction and therefore reduced damage to the lifted vessel where current assumptions and predictions would possibly be inadequate or overly conservative. Secondly, the lateral load resulting from earthquake or wind events can also be more accurately calculated and compared to the allowable load of the system.

Drydock Operations

The system is integrated into the drydocking operations seamlessly as it simply automates several steps that were otherwise manual for the drydock prior to implementing the system. The keel blocks are prepared in the same manner without regard to system installation. No side blocks are prepared. The vessel is brought into the dock using the same ship handling system as was already in use by the dock. Once line handling has been transferred to the dock walls, the system is then extended to engage and center the vessel. Simultaneously, the vessel is also centered in the longitudinal direction. Once centered, the support arms are retracted slightly (approximately 1') while the dry dock is pumped to lower the vessel. When the vessel is approaching the keel blocks, the arms are then fully re-engaged in order to center the vessel completely. Finally, the dry dock is pumped dry and the keel blocks / vessel position are inspected in the same manner as before the system install. Finally, the system is locked and shut down to transition into vessel repair mode.

Shipyard Personnel Interview

During DMC's visit to the Hamek yard, the dock master and yard engineer were interviewed regarding the system. Both were emphatic about how much the system has improved the dry dock. They both reported that the system has already paid for itself several times over just when considering that no side blocks have been built by the yard since installing the system. The yard has not encountered a vessel on which the system cannot be used, although they do maintain their old side block capabilities just in case they need to dock a vessel for which the system cannot work.

When asked about calculations, the dockmaster reported that they do not do any block loading calculations. When interviewing the system designers at Syncrolift, they reported that the arms were designed to accommodate the maximum expected vessel within that dry dock.

The operators reported that they would use three arms per vessel when first installed. They reported that they have grown comfortable with only using two arms, allowing the dock to be used for two smaller vessel simultaneously. However, they also reported that they have gotten down to using one arm on occasion for very small vessels.

Recommendations for Improvement

Based on DMC's discussions with the designers and the operators of this system, two areas of the system require improvement for use in American shipyards. Firstly, the arms need a better locking mechanism of some kind. Currently, the locking mechanism for lateral movement is based on the hydraulic system. DMC recommends adding a mechanical lock of some sort.

DMC does not recommend dry docking vessels without doing calculations for confirming keel block loading and side support system loading and structural adequacy, regardless of the type of dry dock or the type of lateral load support system.

Finally, DMC recommends keeping at least two arms engaged at all times or supplementing the arms with side blocks installed with wedges if the side blocks need to be retracted during the vessel repair stage. DMC fully and wholeheartedly recommends against using only one single arm for any vessel, regardless of size.

5. Engineering Analysis

The engineering analysis is broken into two sections. This first section relates to the substitution of these systems for side blocks, quantifying the loads and noting differences between the two systems.

Validation of these systems will be done in accordance with the Seismic and Wind Calculations from the US Coast Guard standard SFLC Standard Specification 8634. Please note that the analysis there is equivalent to the applicable US Navy Standard NSTM 997, however the Coast Guard standard is not a restricted document.

Basic Theory

The primary objective of this analysis is to validate the use of Syncrolift mechanical side supports in replacement of traditional side blocks, particularly in their ability to protect against catastrophic failures in cases of seismic events or severe wind conditions. In situations such as these, overturning is the most common failure mode for side block systems. This study adapts the USCG SFLC Standard Specification 8634 calculations – originally designed for traditional side blocks – to account for the unique design and function of the hydraulic side supports and mechanical shores.

The calculations used in this analysis will validate the performance of the mechanical side supports by balancing moments generated during seismic or wind events. Transverse overturning of the ship occurs when the overturning moment exceeds the maximum resisting moment supported by the side supports. The key components of the moment balance are as follows:

- Pivot Point: The ship pivots about the center of the keel.
- Overturning Moment: Generated by seismic or wind forces.
- Resisting Moment: Provided by the mechanical side supports.

Specific Adjustments

The standard calculations have been adapted for the Bilge Support Arms and the Side Support Arms through several key adjustments. The height and distance from the keel of the bilge side supports are now used to calculate the angle of the normal force, replacing the half-breadth that is traditionally used when analyzing side blocks. For the side-support arms, height is used in place of half-breadth. For both mechanical supports, the contact area will be considered to determine the resisting force.

Normally, the calculations consider the dead load of the ship, which refers to the static weight distribution between the keel blocks and the side supports. Traditional side blocks are assumed to support 15% of the ship's weight, while the keel blocks support the remaining 85%. For the bilge support arms, this assumption remains, while for the side-support arms no weight distribution is applied, as they are not designed to bear the ship's load.

These adjustments are meant to align the calculations with these systems while maintaining compatibility with the industry standards.

Pressure Validation

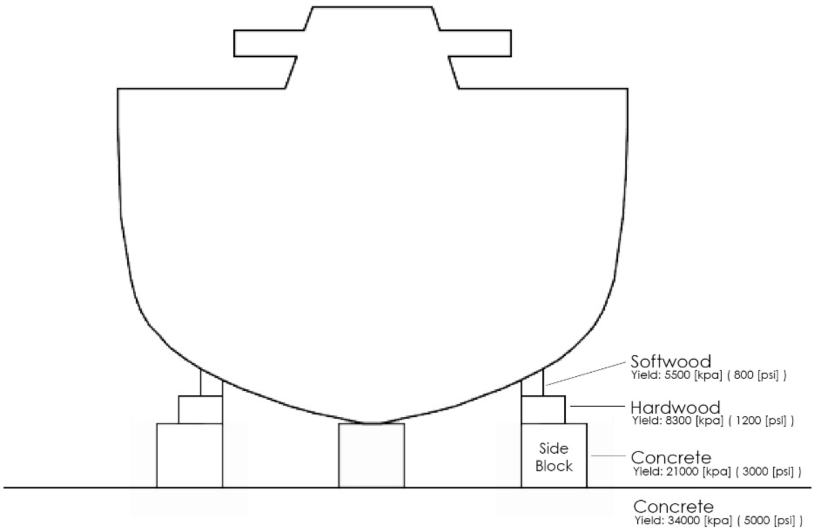

Figure 16: Side Blocks Maximum Crushing Stress

The softwood is used against the ship and acts as a “crush layer”, which absorbs any abnormalities in the ship, block, or dry dock ensuring good contact. However, the tradeoff is that softwood is the first point of failure in the side support system. This assumption is factored into the US Navy calculations in which the side supports are validated by confirming the softwood’s maximum allowable stress is not exceeded in the worst-case loading scenario.

These calculations validate side blocks by solving for the pressure exerted on a softwood crush layer, typically Douglas Fir, that of which has a maximum crushing strength of 800 PSI. This softwood layer accommodates for any abnormalities of the ship, blocks, and dry dock. The softwood normally serves as the first point of failure in the system.

Unlike traditional side blocks, the mechanical side supports do not utilize often use softwood materials. The hydraulics themselves will take up any discrepancies in the ship, blocks, and dry dock.

Hydraulic Bilge Support Arms

The hydraulic bilge supports are activated during the drydocking process to provide resistance against overturning moments. Secondary locking mechanisms are installed after the drydocking process to provide additional safety. It is important to note that the calculations in this study are performed before the secondary locking mechanisms are in place representing a worst-case scenario. This approach ensures that the hydraulic bilge support arms can safely withstand seismic and wind forces independently of these additional safety measures.

Longitudinal and Transverse Forces

The Navy standard calculations predominantly address transverse forces, as these are the primary contributors to overturning moments. However, longitudinal forces caused by wind or seismic events may also impact the mechanical side supports. While longitudinal forces are not quantitatively addressed in the existing Navy standards, further analysis of these components may be warranted to better understand potential failure modes or overall loading conditions.

Seismic Loading

During a seismic event, the docked vessel experiences additional lateral forces due to a shifting center of gravity. The lateral acceleration generates an overturning moment that must be resisted by the side supports. The analysis calculates this induced stress on the side support systems and assesses whether the load applied is greater than the rated capacity of each system.

The earthquake overturning moment is denoted by M_E. This moment is expressed mathematically as:

$$\boldsymbol{M_E = EAF \times Disp \times KG}$$

where…

- $\boldsymbol{EAF}$ is the Earthquake Acceleration Factor
- $\boldsymbol{Disp}$ is the ship's displacement
- $\boldsymbol{KG}$ is the vertical distance from the keel to the center of gravity

Also contributing to the load on each block is the dead load, L_D, which accounts for the static weight supported by the side blocks:

$$\boldsymbol{L_D = \frac{Disp \times SBPL}{2 \times 100}}$$

where…

- $\boldsymbol{SBPL}$ is the side block percent load
    - Bilge support arms: $\boldsymbol{SBPL = 15\%}$
    - Side support arms: $\boldsymbol{SBPL = 0\%}$

The total applied load, $\boldsymbol{L_A}$, at the side supports incorporates both the overturning moment and the dead load:

$$\boldsymbol{L_A = \frac{M_E}{d} + L_D}$$

where…

- $\boldsymbol{d}$ is the average half breadth of the side blocks.

The stress of the side blocks, $\boldsymbol{S_{SB}}$, is the computed as:

$$\boldsymbol{S_{SB} = \frac{L_A \times CF_W}{\left(\frac{n_{SB}}{2}\right) \times A_{SB}}}$$

where…

- $\boldsymbol{CF_W}$ is the weight conversion factor
- $\boldsymbol{n_{SB}}$ is the number of side blocks
- $\boldsymbol{A_{SB}}$ is the contact area of a single block

Using this, we check that the stress on the side blocks is less than the maximum allowable crushing stress of the wooden soft cap $\boldsymbol{S_{MC}}$:

$$\boldsymbol{S_{SB} < S_{MC}}$$

Additionally, we must calculate the load per individual side block $\boldsymbol{N}$:

$$\boldsymbol{N = \frac{L_A}{\cos(\theta) \times \left(\frac{n_{SB}}{2}\right)}}$$

Where…

- $\boldsymbol{\theta}$ is the inclination angle of the side supports

This must satisfy the capacity check that ensures the side supports can withstand the applied load. This check is done in accordance with the rated capacities, denoted $\boldsymbol{CAP}$, provided by Synchrolift:

$$\boldsymbol{N < CAP}$$

Wind Loading

The forces exerted by wind pressure on the ship's hull generate overturning moments that must be resisted by the side supports. The overturning moment due to wind, $\boldsymbol{M_W}$, is determined by considering the force exerted by wind pressure on the projected area of the ship and its moment arm about the keel:

$$\boldsymbol{M_W = F_W \times M_A}$$

where…

- $\boldsymbol{F_W}$ is the wind force
- $\boldsymbol{M_A}$ is the moment arm, which is the product of the projected area of the ship and the height of the center of pressure above the keel

The wind force is calculated as:

$$\boldsymbol{F_W = \left(\frac{CF_{WP}}{1000}\right) v_W^2}$$

where...

- CF_{WP} is the wind pressure coefficient
- v_W is the wind velocity

Dead load contribution, total applied load, stress on side supports, and the load per individual side block are then all calculated similarly to seismic loading:

Dead Load Contribution: $L_D = \frac{Disp \times SBPL}{200}$	Total Applied Load: $L_A = \frac{M_W}{d} + L_D$
Stress on Side Supports: $S_{SB} = \frac{L_A \times CF_W}{\left(\frac{n_{SB}}{2}\right) \times A_{SB}}$	Load Per Individual Side Support: $N = \frac{L_A}{\cos(\theta) \times \left(\frac{n_{SB}}{2}\right)}$
Crushing Stress Check: $S_{SB} < S_{MC}$	Capacity Check $N < CAP$

Results

In progress

6. Structural Analysis

The structures were checked for structural adequacy in accordance with AISC 325: Manual of Steel Construction, 9th ed. This is the relevant standard called out by Mil Std 1625: Safety Certification Program for Drydocking Facilities and Shipbuilding Ways for U.S. Navy Ships.

The structures were checked using spreadsheet calculations, and the calculations were confirmed using FEA. The FEA program used is Intact Simulation, an FEA plug-in software based on Rhino3D and Grasshopper.

6.1. Bilge Support Arms Structural Analysis

Results

The results of the structural calculations indicate that the structures are designed to accommodate the rated loads in accordance with the AISC Manual of Steel Construction.

Loading

The stated design capacity of the arms are 34 MT for normal operating conditions and 65 MT for the extreme event conditions. These loads were applied to the structure at the bearing pad. The extreme case is checked using a 33% increase in allowable stress.

Alex loading calculations here.

Spreadsheet Calculations

The calculations are given in order from the bearing pad on the vessel to the top of the transverse frame.

6.2. Sidewall Support Arms Structural Analysis

In progress

7. Cost-Benefit Analysis

In progress

8. Distribution

Previous Distribution:

SMM	9/3-6/2024
Dry Dock Training – NA Online	9/23-26/2024
Dry Dock Newsletter	10/1/2024
Dry Dock Training – Norfolk, VA	12/3-6/2024
Dry Dock Training – San Diego, CA	2/4-7/2025

Active Distribution:

DMC Website Home Page Updates	www.DryDockTraining.com
DMC Website Project Page	www.DryDockTraining.com/fast-docking-systems.html

Future planned distribution:

NSRP All Panels Meeting	2/25-27/2025
Dry Dock Training – Mobile, AL	4/1-4/2025
Dry Dock Training – Singapore	4/1-4/2025
Dry Dock Training – Sydney, Australia	4/1-4/2025
Dry Dock Training – Honolulu, HI	4/1-4/2025
Dry Dock Newsletter	4/1/2025
Dry Dock Conference	6/4-5/2025

9. Attachment 1

Structural calculations for bilge support arms.

PP 24-08 Fast Docking System Study
Attachment 1: Bilge Support Arms Calculations

22 Feb 2025
Rev A

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Prepared by:

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San Diego, CA 92129

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Distribution: Distribution unlimited.

1. Determine Load Information

Frame Material:
S355J2+N

Fy=	355	Mpa	51.5	ksi
E=	199955	MPa	29,000	ksi

Find Max Load on Pad

Pallow =	2068.5	kPa	300	psi

Max Load= max pad pressure*pad area

Max Load=	**34**	**MT**	**74.8**	**kips**

AMOD* = 1

*Allowable Stress Modifier is 1.00 for operating conditions and 1.33 for extreme conditions

Check Loading for maximum pressure
Pad Dimensions

Pad Length	840	mm	33.07	in
Pad Width	490	mm	19.29	in
Pad Area	0.412	sq m	637.981	sq in

P = Max Load / Pad Area

P =	808	kPa	117	psi

P / Pallow =	**0.39**	**OK**

Reviewing the structural arrangement, each pin connection can be checked as a padeye with an applied load of Max Load / 2, with the exceptions of the main frame padeye (9) and the hydraulic padeye (11).

Padeye Load =	**17**	**MT**	**37.40**	**kips**

Load on the main frame padeye is half of the padeye load since each side has two padeys.

Main Fm Pad Load =	**9**	**MT**	**18.70**	**kips**

Load on the hydraulic padeye is the reaction from solving the main frame as a simply supported beam. See calculation 10, Main Frame, for loading.

2. Check Inner Frame for Bending

Since this is an indeterminate structure, the inner frame
will be checked by use of FEA software

3. Inner Tilting Frame Pinhole Padeye

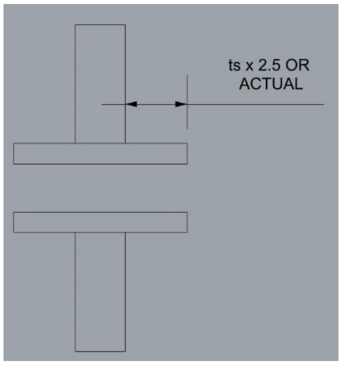
There is a sleeve that passes through the padeye. This sleeve is checked similar to a cheek plate. The effective length of the sleeve (checked as the cheek plate thickness) is calcualted below.

The effective length of the sleeve is calulcated using a shear slope of 2.5 : 1, standard value for steel. However, this is never taken as longer than the actual sleeve length.

Length protruding = Min length protruding
Length protruding = 10 mm
0.39 in

Check max length using 2.5 shear slope
ts = (OD - ID) / 2
ts = 22.5 mm
Max usable length = ts * 2.5
Max usable length = 56.25 mm
2.21 in

tc = the smaller of the two calcs above
tc = 0.39 in



Input

Load Information

Load = 34.7 kips
Allow Stress Mod = 1
Safety Factor = 1
In-Plane Angle = 270 degrees
Out-of Plane Angle = 5 degrees

Main Plate

Length = 34.65 in
Radius = 3.94 in
Thickness = 0.79 in
Fy = 51.50 ksi

Cheek Plates

Radius = 2.80 in
Thickness = 0.39 in
No. of Cheek PL = 2
Weld Thick. = 0.19 in
Plate Fy = 51.50 ksi
Weld Fy = 70.00 ksi

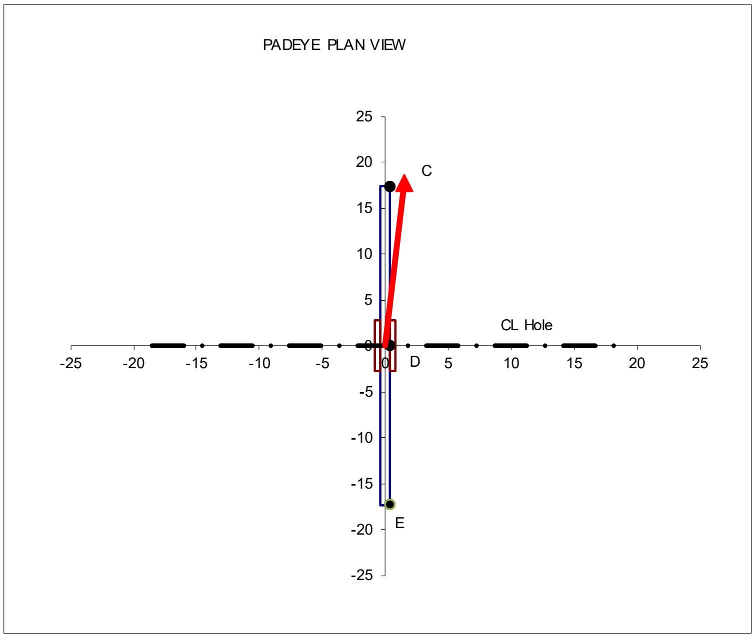
Padeye Section Info

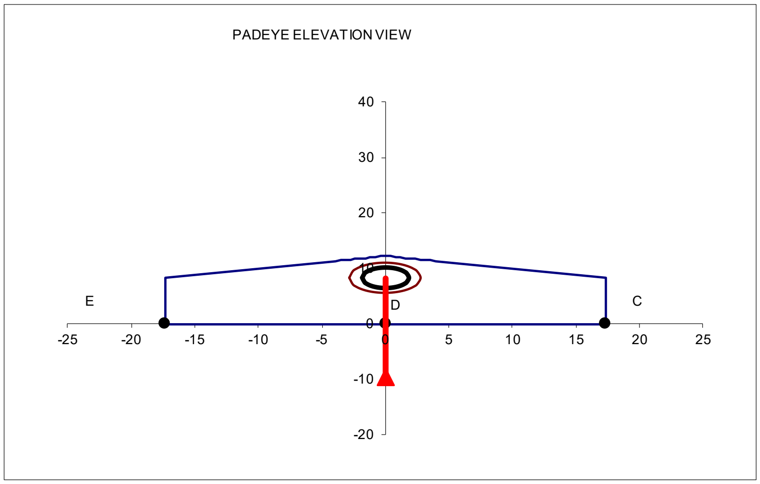
Item	"XX"	"YY"
Shear Area =	27.28 sq in	0.00 sq in
Centroid =	0.00 in	0.00 in
S =	157.5 in3	3.6 in3
I =	2729 in4	1 in4
r =	10.00 in	0.23 in

Total Area = 27.28 sq in

Hole

Hole OD = 3.74 in
Vertical Loc. = 8.27 in
Horizontal Loc. = 0.00 in
Pin OD = 3.74 in





Check Stresses in Eye near Pin

Item	Steel Area	Actual Stress	Allowable Stress	Actual / Allowable	
Bearing	5.9 sq in	5.9 ksi	46.4 ksi	**0.13**	**OK**
Shear at Hole Edges	4.7 sq in	7.4 ksi	20.6 ksi	**0.36**	**OK**
Plug Pull Out	10.0 sq in	3.5 ksi	30.9 ksi	**0.11**	**OK**
Cheek PL Weld	4.7 sq in	7.5 ksi	20.6 ksi	**0.36**	**OK**

Check Stresses at Base as Beam Section

Item	Load	Stress at A	Stress at B	Stress at C	Stress at D	Stress at E	
Axial	-34.7 kips	N/A	N/A	-1.3 ksi	-1.3 ksi	-1.3 ksi	
In-plane Shear	0.0 kips	N/A	N/A	0.0 ksi	0.0 ksi	0.0 ksi	
In-Plane Moment 1	0.0 kip-in	N/A	N/A	0.0 ksi	0.0 ksi	0.0 ksi	
In-Plane Moment 2	0.0 kip-in	N/A	N/A	0.0 ksi	0.0 ksi	0.0 ksi	
Out-of-Plane Shear	3.0 kips	N/A	N/A	0.1 ksi	0.1 ksi	0.1 ksi	
Out-Of-Plane Moment	25.0 kip-in	N/A	N/A	7.0 ksi	7.0 ksi	7.0 ksi	
Total Axial Stress σ		N/A	N/A	5.7 ksi	5.7 ksi	5.7 ksi	
Total Shear Stress τ		N/A	N/A	0.1 ksi	0.1 ksi	0.1 ksi	
Von Mises Stress		N/A	N/A	5.7 ksi	5.7 ksi	5.7 ksi	
Allowabel Stress		N/A	N/A	30.9 ksi	30.9 ksi	30.9 ksi	
Interaction Ratios		**N/A**	**N/A**	**0.18**	**0.18**	**0.18**	**OK**

Notes:

1. Moment 1 - Moment caused by shear (V * Vert Hole Height)
2. Moment 2 - Moment caused by off-center load (Axial force * hor hole offset)
3. Mises Stress = sqrt(s^2 + 3* t^2)
4. Allowable Stress is 0.6*Fy
4. Interaction Ratios IR = Mises /(Allow)

4. Check Inner Tilting Frame Pin for Shear

Part No. p00031461

Description: This is the pin that connects the inner tilting frame to the outer tilting frame

D	80	mm	3.15	in
Fy	799	MPa	116	ksi

1. Check Shear

Assume load on pin is half the Max Load (equally distributed load to both sides of pad)

Determine Shear load

P =	Max Load / 2			
P =	17	MT	37	kips
A=	Pi * D^2 / 4			
A=	50	cm2	8	in2
fv=	P / A			
fv=	32.72	MPa	5	ksi
Fv=	0.4 * Fy * AMOD			
Fv=	319.7	Mpa	46.4	ksi

fv/Fv=	**0.10**	**Shear OK**

5. Outer Tilting Frame Padeye - Small DIA Pinhole

Input

Load Information

Load =	37.4	kips
Allow Stress Mod =	1	
Safety Factor =	1	
In-Plane Angle =	270	degrees
Out-of Plane Angle =	5	degrees

Main Plate

Length =	39.13	in
Radius =	4.43	in
Thickness =	1.18	in
Fy =	51.50	ksi

Cheek Plates

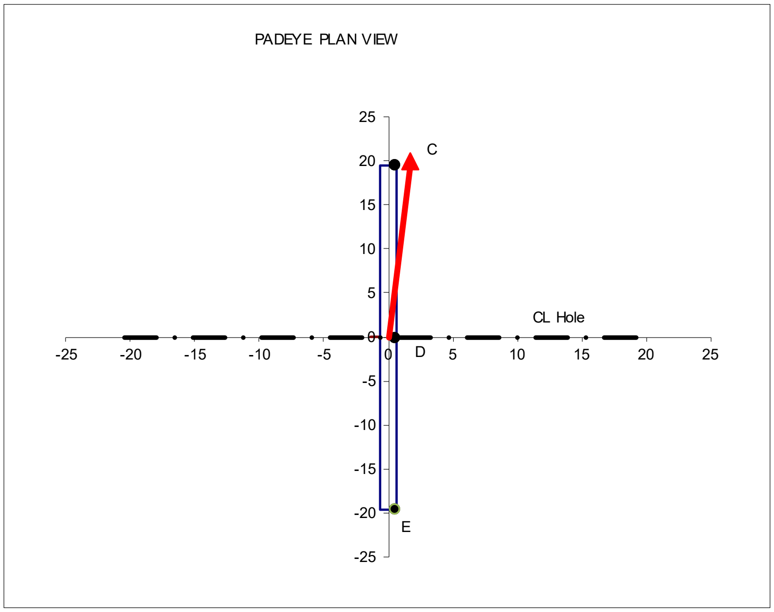
Radius =	0.00	in
Thickness =	0.79	in
No. of Cheek PL =	0	
Weld Thick. =	0.19	in
Plate Fy =	51.50	ksi
Weld Fy =	70.00	ksi

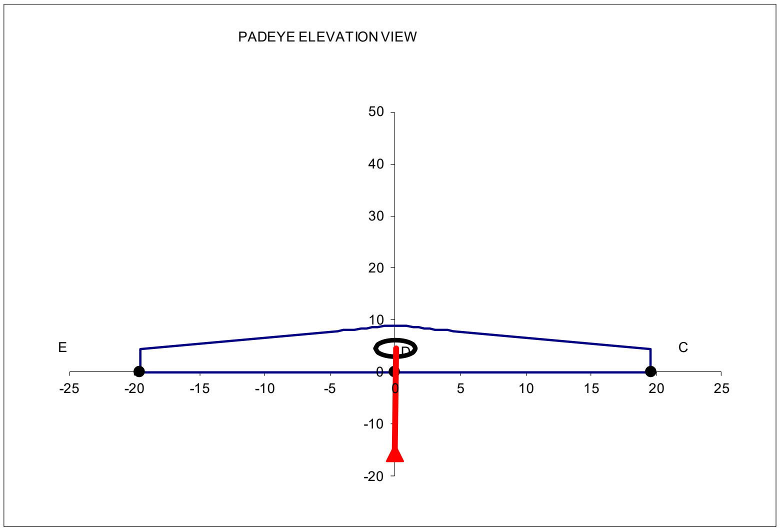
Padeye Section Info

Item	"XX"	"YY"
Shear Area =	46.22 sq in	0.00 sq in
Centroid =	0.00 in	0.00 in
S =	301.5 in3	9.1 in3
I =	5899 in4	5 in4
r =	11.30 in	0.34 in
Total Area =	46.22	sq in

Hole

Hole OD =	3.15	in
Vertical Loc. =	4.53	in
Horizontal Loc. =	0.00	in
Pin OD =	3.15	in





Check Stresses in Eye near Pin

Item	Steel Area	Actual Stress	Allowable Stress	Actual / Allowable	
Bearing	3.7 sq in	10.1 ksi	46.4 ksi	**0.22**	**OK**
Shear at Hole Edges	6.7 sq in	5.5 ksi	20.6 ksi	**0.27**	**OK**
Plug Pull Out	5.2 sq in	7.1 ksi	30.9 ksi	**0.23**	**OK**

Check Stresses at Base as Beam Section

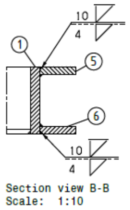
Item	Load	Stress at A	Stress at B	Stress at C	Stress at D	Stress at E	
Axial	-37.4 kips	N/A	N/A	-0.8 ksi	-0.8 ksi	-0.8 ksi	
In-plane Shear	0.0 kips	N/A	N/A	0.0 ksi	0.0 ksi	0.0 ksi	
In-Plane Moment 1	0.0 kip-in	N/A	N/A	0.0 ksi	0.0 ksi	0.0 ksi	
In-Plane Moment 2	0.0 kip-in	N/A	N/A	0.0 ksi	0.0 ksi	0.0 ksi	
Out-of-Plane Shear	3.3 kips	N/A	N/A	0.1 ksi	0.1 ksi	0.1 ksi	
Out-Of-Plane Moment	14.8 kip-in	N/A	N/A	1.6 ksi	1.6 ksi	1.6 ksi	
Total Axial Stress σ		N/A	N/A	0.8 ksi	0.8 ksi	0.8 ksi	
Total Shear Stress τ		N/A	N/A	0.1 ksi	0.1 ksi	0.1 ksi	
Von Mises Stress		N/A	N/A	0.8 ksi	0.8 ksi	0.8 ksi	
Allowabel Stress		N/A	N/A	30.9 ksi	30.9 ksi	30.9 ksi	
Interaction Ratios		**N/A**	**N/A**	**0.03**	**0.03**	**0.03**	**OK**

Notes:

1. Moment 1 - Moment caused by shear (V * Vert Hole Height)
2. Moment 2 - Moment caused by off-center load (Axial force * hor hole offset)
3. Mises Stress = sqrt(s^2 + 3* t^2)
4. Allowable Stress is 0.6*Fy
4. Interaction Ratios IR = Mises /(Allow)

6.1. Check Outer Frame for Bending, Long Side

d	225	mm	8.86	in
bf	120	mm	4.72	in
tf	25	mm	0.98	in
tw	30	mm	1.18	in
Length	994	mm	39.13	in
h	225	mm	8.86	in
Thickness	30	mm	1.18	in



1. Calculate Bending Load

Assume pin at the middle of the beam is a point load.

Assume load on pin is half the Max Load (equally distributed load to both sides of pad)

Determine bending load

P =	Max Load / 2			
P =	17	MT	37	kips
M =	P * L / 4			
M =	42	MT-m	366	kip-in
Ixx =	1/12 * bf * d^3 - 1/12 * (bf - tw) * (d - 2 * tf)^3			
Ixx =	4.25	cm^4	177	in^4
c =	d / 2			
c =	30	mm	4.4	in
Sxx =	Ixx / c			
Sxx =	2.44	cm ^3	40.0	in^3
fb =	M / Sxx			
fb =	1,034	N-m	9.2	ksi

2. Calculate Allowable Bending Load

Lc = min(Lc1, Lc2)
Lc1 = 76 * bf / sqrt(Fy)
Lc1 = 1,271 mm 50.0 in
Lc2 = 20000 / ((d / Af) * Fy)
Lc2 = 5,178 mm 203.9 in

Check for Compactness
Flange:
bf/tf= 4.8
Compact Limiting Ratio= 65 / sqrt(Fy)
Compact Limiting Ratio= 9.05753

Web:
d/tw= 7.5
Compact Limiting Ratio= 640 / sqrt(Fy)
Compact Limiting Ratio= 89.2

Since beam has L less than Lc, and is compact, use section F1, 1 Eq F1-1

Fb= 0.66 * Fy * AMOD
Fb= 234 MPa 33.99 ksi

fb / Fb = 0.27 Bending OK

3. Check Shear

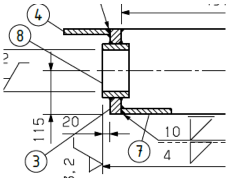
Av = d * tw
Av = 1.62 sq cm 10.5 sq in

fv = P / Av
fv = 25 MPa 3.6 ksi

Fv = 0.4 * Fy * AMOD
Fv = 142 MPa 20.6 ksi

fv / Fv = 0.17 Shear OK

6.2. Check Outer Frame for Bending, Short Side



d	225	mm	8.86	in
bf1	140	mm	5.51	in
bf2	150	mm	5.91	in
tf1	15	mm	0.59	in
tf2	15	mm	0.59	in
tw	30	mm	1.18	in
Length	556	mm	21.89	in
h	225	mm	8.86	in
Thickness	30	mm	1.18	in

1. Calculate Bending Load

Assume pin at the middle of the beam is a point load.
Assume load on pin is half the Max Load (equally distributed load to both sides of pad)

Determine bending load

P =	Max Load / 2			
P =	17	MT	37	kips
M =	P * L / 4			
M =	23	MT-m	205	kip-in

Calculate Sxx using Parallel Axis Theorem

Ayf1=	bf1 * tf1 * (d - tf1 / 2)			
Ayf1=	457	cm3	28	in3
Ayf2=	bf2 * tf2 * (tf2 / 2)			
Ayf2=	17	cm3	1	in3
Ayweb=	(d - tf1 - tf2)* tw * (d /2)			
Ayweb=	658	cm3	40	in3
Ay=	Ayf1 + Ayf2 + Aweb			
Ay=	1132	cm3	69	in3
A=	(bf1 * tf1) + (bf2 * tf2) + ((d - tf1 - tf2) * tw))			
A=	102	cm2	16	in2
ȳ=	Ay/A			
ȳ=	11	cm	4.37	in
Ixx f1=	(1/12 * bf1 * tf1^3 +((bf1 * tf1) * (d - ȳ - tf1 /2)^2)			
Ixx f1=	2,388	cm4	57.37	in4
Ixx web=	1/12 * (tw * (d - tf1 - tf2) ^ 3) + (tw * (d - tf1 - tf2) * (d / 2 - ȳ)^2			
Ixx web=	1,855	cm4	44.57	in4
Ixx f2=	(1/12) * (bf2 * tf2 ^3) + (tf2 * bf2) * (ȳ - tf2 /2)^2			
Ixx f2=	2,412	cm4	57.96	in4
Ixx=	Ixx f1 + Ixx web + Ixx f2			
Ixx=	6,655	cm4	159.89	in4
c=	d - ȳ			
c=	11	cm	4.49	in
Sxx=	Ixx / c			
Sxx=	584	cm3	35.61	in3
fb =	M / Sxx			
fb =	40	Mpa	5.7	ksi

2. Calculate Allowable Bending Load

Lc =	min(Lc1, Lc2)			
Lc1 =	76 * bf / sqrt(Fy)			
Lc1 =	1,483	mm	58.4	in
Lc2 =	20000 / ((d / Af) * Fy)			
Lc2 =	3,625	mm	142.7	in

Check For Compactness

bf/tf=	9.3		9.3	
Compact=	65 / sqrt(Fy)			
Compact=	9.1		9.1	
Noncompact=	13.2		13.2	

Since beam has L less than Lc and is noncompact, use section F1, 2 Eq F1-4

kc=	4.05 / (h / tw)^0.46			
kc=	1.6		1.6	
Fb=	Fy * (0.79 - 0.002 * (bf / 2 * tf) * sqrt(Fy / kc)) * AMOD			
Fb=	262	MPa	38	ksi

fb / Fb =	**0.15**	**Bending OK**

3. Check Shear

Av =	d * tw			
Av =	1.62	sq cm	10	sq in
fv =	P / Av			
fv =	25	MPa	4	ksi
Fv =	0.4 * Fy * AMOD			
Fv =	142	MPa	21	ksi

fv / Fv =	**0.17**	**Shear OK**

7. Outer Tilting Frame Padeye - Large DIA Pinhole

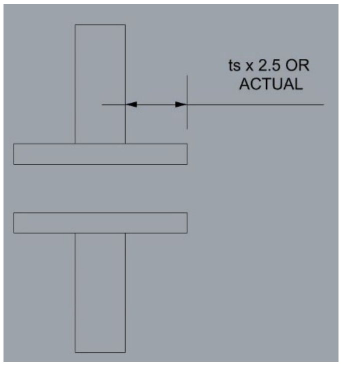
There is a sleeve that passes through the padeye. This sleeve is checked similar to a cheek plate. The effective length of the sleeve (checked as the cheek plate thickness) is calcualted below.

The effective length of the sleeve is calulcated using a shear slope of 2.5 : 1, standard value for steel. However, this is never taken as longer than the actual sleeve length.

Length protruding = (sleeve L - main plate thickness) / 2
Length protruding = 20 mm
0.79 in

Check max length using 2.5 shear slope
ts = (OD - ID) / 2
ts = 15 mm
Max usable length = ts * 2.5
Max usable length = 37.5 mm
1.48 in

tc = the smaller of the two calcs above
tc = 0.79 in



Input

Load Information

Load =	37.4	kips
Allow Stress Mod =	1	
Safety Factor =	1	
In-Plane Angle =	270	degrees
Out-of Plane Angle =	5	degrees

Main Plate

Length =	21.89	in
Radius =	4.43	in
Thickness =	1.18	in
Fy =	51.50	ksi

Cheek Plates

Radius =	2.76	in
Thickness =	0.79	in
No. of Cheek PL =	2	
Weld Thick. =	0.19	in
Plate Fy =	51.50	ksi
Weld Fy =	70.00	ksi

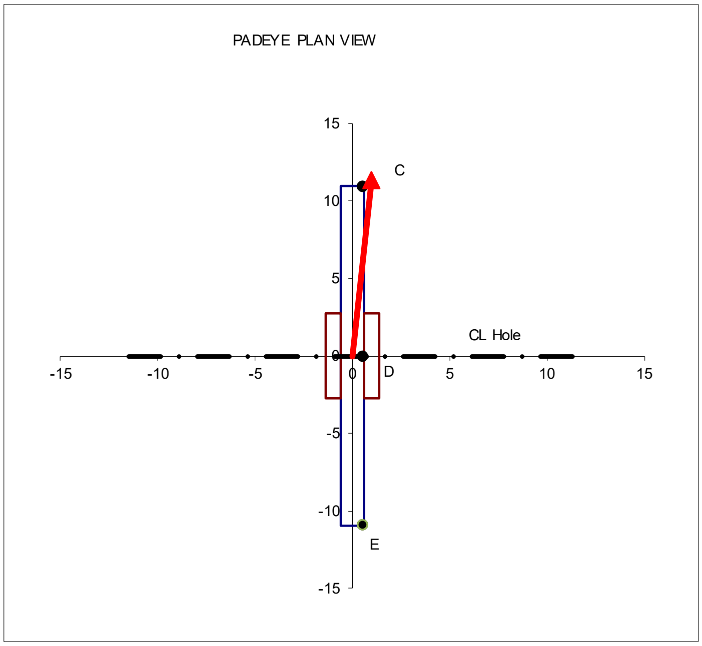
Padeye Section Info

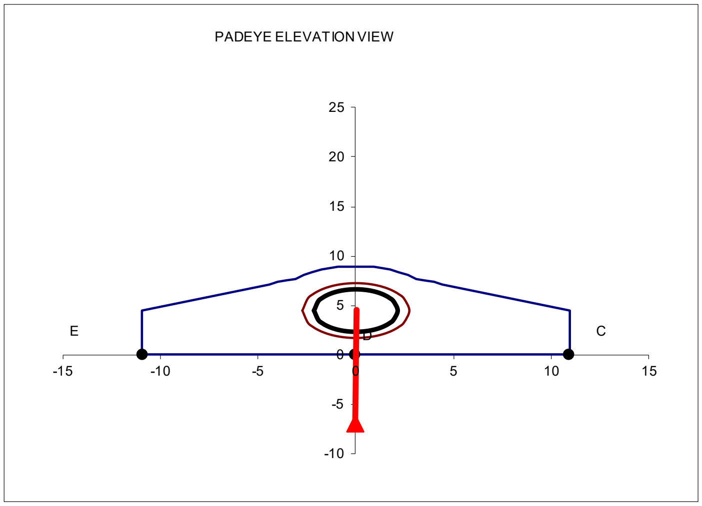
Item	"XX"	"YY"
Shear Area =	25.85 sq in	0.00 sq in
Centroid =	0.00 in	0.00 in
S =	94.3 in3	5.1 in3
I =	1032 in4	3 in4
r =	6.32 in	0.34 in

Total Area =	25.85	sq in

Hole

Hole OD =	4.33	in
Vertical Loc. =	4.53	in
Horizontal Loc. =	0.00	in
Pin OD =	4.33	in





Check Stresses in Eye near Pin

Item	Steel Area	Actual Stress	Allowable Stress	Actual / Allowable	
Bearing	11.9 sq in	3.1 ksi	46.4 ksi	**0.07**	**OK**
Shear at Hole Edges	7.2 sq in	5.2 ksi	20.6 ksi	**0.25**	**OK**
Plug Pull Out	15.5 sq in	2.4 ksi	30.9 ksi	**0.08**	**OK**
Cheek PL Weld	4.6 sq in	8.1 ksi	20.6 ksi	**0.40**	**OK**

Check Stresses at Base as Beam Section

Item	Load	Stress at A	Stress at B	Stress at C	Stress at D	Stress at E	
Axial	-37.4 kips	N/A	N/A	-1.4 ksi	-1.4 ksi	-1.4 ksi	
In-plane Shear	0.0 kips	N/A	N/A	0.0 ksi	0.0 ksi	0.0 ksi	
In-Plane Moment 1	0.0 kip-in	N/A	N/A	0.0 ksi	0.0 ksi	0.0 ksi	
In-Plane Moment 2	0.0 kip-in	N/A	N/A	0.0 ksi	0.0 ksi	0.0 ksi	
Out-of-Plane Shear	3.3 kips	N/A	N/A	0.1 ksi	0.1 ksi	0.1 ksi	
Out-Of-Plane Moment	14.8 kip-in	N/A	N/A	2.9 ksi	2.9 ksi	2.9 ksi	
Total Axial Stress σ		N/A	N/A	1.5 ksi	1.5 ksi	1.5 ksi	
Total Shear Stress τ		N/A	N/A	0.1 ksi	0.1 ksi	0.1 ksi	
Von Mises Stress		N/A	N/A	1.5 ksi	1.5 ksi	1.5 ksi	
Allowabel Stress		N/A	N/A	30.9 ksi	30.9 ksi	30.9 ksi	
Interaction Ratios		**N/A**	**N/A**	**0.05**	**0.05**	**0.05**	**OK**

Notes:

1. Moment 1 - Moment caused by shear (V * Vert Hole Height)
2. Moment 2 - Moment caused by off-center load (Axial force * hor hole offset)
3. Mises Stress = sqrt(s^2 + 3* t^2)
4. Allowable Stress is 0.6*Fy
4. Interaction Ratios IR = Mises /(Allow)

8. Check Outer Tilting Frame Pin for Shear

Part No. d00003091

Description: This is the pin that connects the outer tilting frame to the main frame padeye

D	90	mm	3.54	in
Fy	799	MPa	116	ksi

1. Check Shear

Assume load on pin is half the Max Load (equally distributed load to both sides of pad)

Determine Shear load

P =	Max Load / 2			
P =	17	MT	37	kips
A=	Pi * D^2 / 4			
A=	64	cm2	10	in2
fv=	P / A			
fv=	26	MPa	4	ksi
Fv=	0.4 * Fy * AMOD			
Fv=	320	Mpa	46	ksi
fv/Fv=	**0.08**		**Shear OK**	

9. Main Frame Padeye

Input

Load Information

Load =	18.7	kips
Allow Stress Mod =	1	
Safety Factor =	1	
In-Plane Angle =	270	degrees
Out-of Plane Angle =	5	degrees

Main Plate

Length =	15.75	in
Radius =	2.95	in
Thickness =	1.57	in
Fy =	51.50	ksi

Cheek Plates

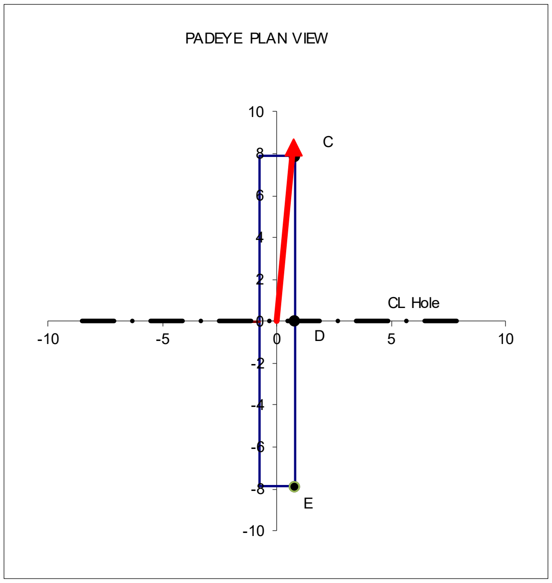
Radius =	0.00	in
Thickness =	0.79	in
No. of Cheek PL =	0	
Weld Thick. =	0.19	in
Plate Fy =	51.50	ksi
Weld Fy =	70.00	ksi

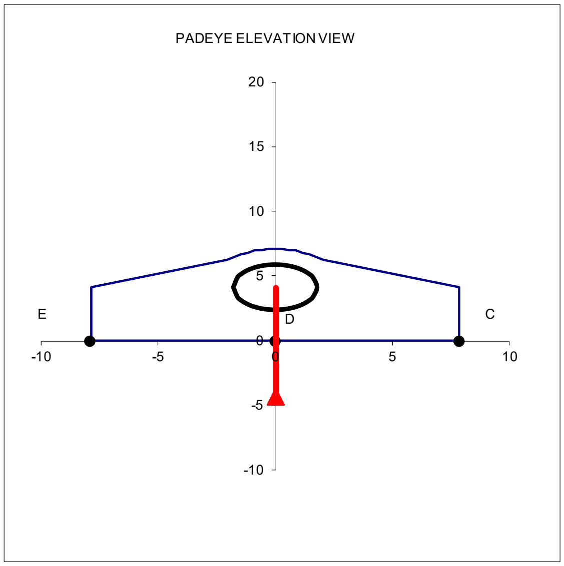
Padeye Section Info

Item	"XX"	"YY"
Shear Area =	24.80 sq in	0.00 sq in
Centroid =	0.00 in	0.00 in
S =	65.1 in3	6.5 in3
I =	513 in4	5 in4
r =	4.55 in	0.45 in
Total Area =	24.80	sq in

Hole

Hole OD =	3.54	in
Vertical Loc. =	4.13	in
Horizontal Loc. =	0.00	in
Pin OD =	3.54	in





Check Stresses in Eye near Pin

Item	Steel Area	Actual Stress	Allowable Stress	Actual / Allowable	
Bearing	5.6 sq in	3.4 ksi	46.4 ksi	0.07	**OK**
Plug Pull Out	4.7 sq in	4.0 ksi	30.9 ksi	0.13	**OK**

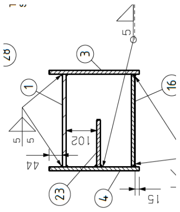
Check Stresses at Base as Beam Section

Item	Load	Stress at A	Stress at B	Stress at C	Stress at D	Stress at E	
Axial	-18.7 kips	N/A	N/A	-0.8 ksi	-0.8 ksi	-0.8 ksi	
In-plane Shear	0.0 kips	N/A	N/A	0.0 ksi	0.0 ksi	0.0 ksi	
In-Plane Moment 1	0.0 kip-in	N/A	N/A	0.0 ksi	0.0 ksi	0.0 ksi	
In-Plane Moment 2	0.0 kip-in	N/A	N/A	0.0 ksi	0.0 ksi	0.0 ksi	
Out-of-Plane Shear	1.6 kips	N/A	N/A	0.1 ksi	0.1 ksi	0.1 ksi	
Out-Of-Plane Moment	6.7 kip-in	N/A	N/A	1.0 ksi	1.0 ksi	1.0 ksi	
Total Axial Stress σ		N/A	N/A	0.3 ksi	0.3 ksi	0.3 ksi	
Total Shear Stress τ		N/A	N/A	0.1 ksi	0.1 ksi	0.1 ksi	
Von Mises Stress		N/A	N/A	0.3 ksi	0.3 ksi	0.3 ksi	
Allowabel Stress		N/A	N/A	30.9 ksi	30.9 ksi	30.9 ksi	
Interaction Ratios		**N/A**	**N/A**	**0.01**	**0.01**	**0.01**	**OK**

Notes:

1. Moment 1 - Moment caused by shear (V * Vert Hole Height)
2. Moment 2 - Moment caused by off-center load (Axial force * hor hole offset)
3. Mises Stress = sqrt(s^2 + 3* t^2)
4. Allowable Stress is 0.6*Fy
4. Interaction Ratios IR = Mises /(Allow)

10. Check Main Frame for Bending



d	320	mm	12.60	in
bf	300	mm	11.81	in
tf	12	mm	0.47	in
tw	12	mm	0.47	in
Length	2595	mm	102.17	in
h	320	mm	12.60	in
Thickness	12	mm	0.47	in

1. Determine Reaction Forces

Assume load is distributed evenly between the two arms

P=	Max Load / 2			
P=	17	MT	37	Kips

L1 is the distance from the main frame pivot point to the Main Hydraulic Padeye

L1	1483	mm	58.39	in

L2 is the distance from the Main Hydraulic Padeye to the center of the Tilting Bracket

L2	1112	mm	43.78	in

R1 is the reaction force at the Main Hydraulic Padeye

R1=	(P *(L1 + L2) / L1)			
R1=	30	MT	65	kips

R2 is the reaction force at the main frame pivot point

R2=	P - R1			
R2=	-13	MT	-28	kips

Determine the Moment Applied to each arm

M=	R2 * L1			
M=	-19	MT-m	-1,637	kip-in

2. Calculate Bending Load

Assume load is distributed evenly between the two arms
Assueme load is applied in the center of the beam

Ixx = 1/12 * bf * d^3 - 1/12 * (bf - tw * 2)*(d - tf * 2)^3
Ixx = 12.85 cm^4 535 in^4

c = d / 2
c = 30 mm 6.3 in

Sxx = Ixx / c
Sxx = 5.18 cm ^3 84.9 in^3

fb = M / Sxx
fb = 133 MPa 19.3 ksi

3. Calculate Allowable Bending Load

Lc = (1950 + 1200 * (M1 / M2))*(bf / Fy)
Lc = 18350 mm 722 in

Check For Compactness
Flange:
b/t= 25 25
Check b/t against limiting width to thickness ratios:

Noncompact= 253 / sqrt(Fy)
Noncompact= 35
Noncompact

Since beam has L less than Lc and is noncompact, use section F3, 2 Eq F3-3 to find Fb

Fb= 0.6 * Fy * AMOD
Fb= 213 MPa 30.9 ksi

fb / Fb = 0.62 Bending OK

4. Check Shear

Av = (bf * tf) * 2 + ((d - tf*2)* tw) * 2

Av = 143 sq cm 22.2 sq in

fv = Max Reaction Foce / Av

fv = 20 MPa 3.0 ksi

Fv = 0.4 * Fy * AMOD

Fv = 142 MPa 20.6 ksi

fv / Fv = 0.14 Shear OK

5. Calculate Hydraulic Padeye Load

The load on the hydraulic arm padeye is half of R1 (Assume equal load to both padeyes)

P = R1 / 2

P = 15 MT 33 kips

11. Main Hydraulic Padeye

Input

Load Information

Load =	33	kips
Allow Stress Mod =	1	
Safety Factor =	1	
In-Plane Angle =	210	degrees
Out-of Plane Angle =	5	degrees

Main Plate

Length =	12.60	in
Radius =	3.15	in
Thickness =	1.18	in
Fy =	51.50	ksi

Cheek Plates

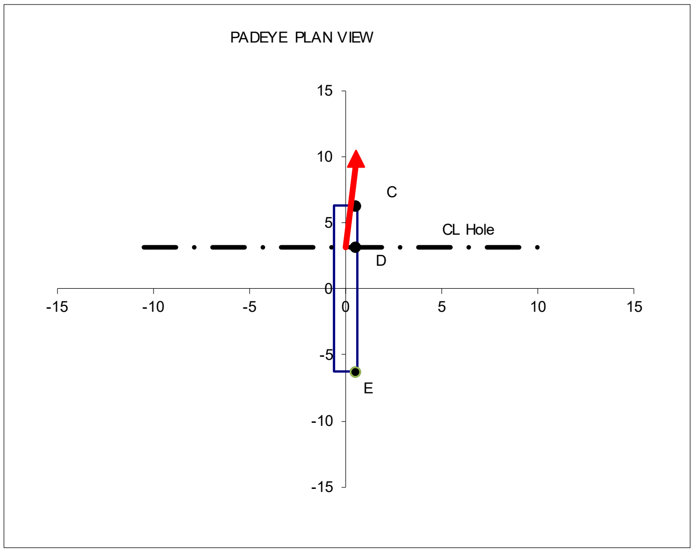
Radius =	0.00	in
Thickness =	0.00	in
No. of Cheek PL =	0	
Weld Thick. =	0.19	in
Plate Fy =	51.50	ksi
Weld Fy =	70.00	ksi

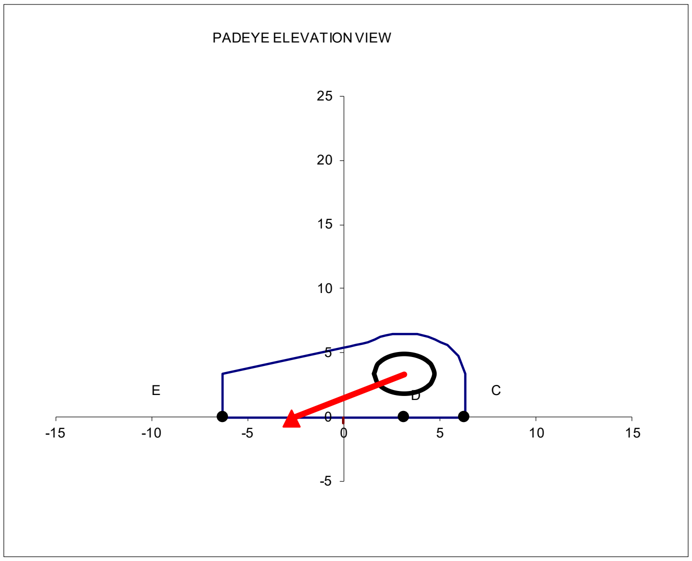
Padeye Section Info

Item	"XX"	"YY"
Shear Area =	14.88 sq in	0.00 sq in
Centroid =	0.00 in	0.00 in
S =	31.3 in3	2.9 in3
I =	197 in4	2 in4
r =	3.64 in	0.34 in
Total Area =	14.88	sq in

Hole

Hole OD =	3.15	in
Vertical Loc. =	3.35	in
Horizontal Loc. =	3.15	in
Pin OD =	3.15	in





Check Stresses in Eye near Pin

Item	Steel Area	Actual Stress	Allowable Stress	Actual / Allowable	
Bearing	3.7 sq in	8.9 ksi	46.4 ksi	0.19	OK
Plug Pull Out	3.7 sq in	8.9 ksi	30.9 ksi	0.29	OK

Check Stresses at Base as Beam Section

Item	Load	Stress at A	Stress at B	Stress at C	Stress at D	Stress at E	
Axial	-16.5 kips	N/A	N/A	-1.1 ksi	-1.1 ksi	-1.1 ksi	
In-plane Shear	-28.6 kips	N/A	N/A	-1.9 ksi	-1.9 ksi	-1.9 ksi	
In-Plane Moment 1	-95.6 kip-in	N/A	N/A	3.1 ksi	0.0 ksi	-3.1 ksi	
In-Plane Moment 2	52.0 kip-in	N/A	N/A	1.7 ksi	1.7 ksi	1.7 ksi	
Out-of-Plane Shear	2.9 kips	N/A	N/A	0.2 ksi	0.2 ksi	0.2 ksi	
Out-Of-Plane Moment	9.6 kip-in	N/A	N/A	3.3 ksi	3.3 ksi	3.3 ksi	
Total Axial Stress σ		N/A	N/A	6.9 ksi	3.8 ksi	0.8 ksi	
Total Shear Stress τ		N/A	N/A	-1.7 ksi	-1.7 ksi	-1.7 ksi	
Von Mises Stress		N/A	N/A	7.5 ksi	4.9 ksi	3.1 ksi	
Allowabel Stress		N/A	N/A	30.9 ksi	30.9 ksi	30.9 ksi	
Interaction Ratios		**N/A**	**N/A**	**0.24**	**0.16**	**0.10**	**OK**

Notes:

1. Moment 1 - Moment caused by shear (V * Vert Hole Height)
2. Moment 2 - Moment caused by off-center load (Axial force * hor hole offset)
3. Mises Stress = sqrt(s^2 + 3* t^2)
4. Allowable Stress is 0.6*Fy
4. Interaction Ratios IR = Mises /(Allow)

12. Check Hydraulic Pin for Shear

Part No. p00031458

Description: This is the pin that conects the hydraulic ram to the hydraulic padeye

D	80	mm	3.15	in
Fy	799	MPa	116	ksi

1. Check Shear

Assume load on pin is half the Reaction Load at Hydraulic Connection

Determine Shear load

P =	Reaction Load / 2			
P =	75	MT	168	kips
A=	Pi * D^2 / 4			
A=	50	cm2	8	in2
fv=	P / A			
fv=	146.54	MPa	21	ksi
Fv=	0.4 * Fy * AMOD			
Fv=	319.7	Mpa	46.4	ksi

fv/Fv=	**0.46**	**Shear OK**

65T Condition

1. Determine Load Information

Frame Material:
S355J2+N

Fy=	355	Mpa	51.5	ksi
E=	199955	MPa	29,000	ksi

Find Max Load on Pad

Pallow =	5516	kPa	800	psi
Max Load=	65 T as stated on the design drawings			

Max Load=	**65**	**MT**	**143.0**	**kips**

AMOD* =	1.33

*Allowable Stress Modifier is 1.00 for operating conditions and 1.33 for extreme conditions

Check Loading for maximum pressure
Pad Dimensions

Pad Length	840	mm	33.07	in
Pad Width	490	mm	19.29	in
Pad Area	0.412	sq m	637.981	sq in

P =	Max Load / Pad Area			
P =	1545	kPa	224	psi

P / Pallow =	**0.28**	**OK**

Reviewing the structural arrangement, each pin connection can be checked as a padeye with an applied load of Max Load / 2, with the exceptions of the main frame padeye (9) and the hydraulic padeye (11).

Padeye Load = 33 MT 71.50 kips

Load on the main frame padeye is half of the padeye load since each side has two padeys.

Main Fm Pad Load = 16 MT 35.75 kips

Load on the hydraulic padeye is the reaction from solving the main frame as a simply supported beam. See calculation 10, Main Frame, for loading.

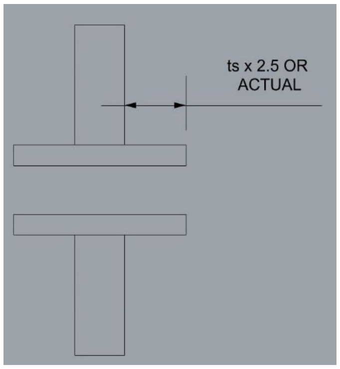
2. Check Inner Frame for Bending

Since this is an indeterminate structure, the inner frame will be checked by use of FEA software

3. Inner Tilting Frame Pinhole Padeye

There is a sleeve that passes through the padeye. This sleeve is checked similar to a cheek plate. The effective length of the sleeve (checked as the cheek plate thickness) is calcualted below.

The effective length of the sleeve is calulcated using a shear slope of 2.5 : 1, standard value for steel. However, this is never taken as longer than the actual sleeve length.



Length protruding = Min length protruding
Length protruding = 10 mm
0.39 in

Check max length using 2.5 shear slope
ts = (OD - ID) / 2
ts = 22.5 mm
Max usable length = ts * 2.5
Max usable length = 56.25 mm
2.21 in

tc = the smaller of the two calcs above
tc = 0.39 in

Input

Load Information

Load = 71.5 kips
Allow Stress Mod = 1.33
Safety Factor = 1
In-Plane Angle = 270 degrees
Out-of Plane Angle = 5 degrees

Main Plate

Length = 34.65 in
Radius = 3.94 in
Thickness = 0.79 in
Fy = 51.50 ksi

Cheek Plates

Radius = 2.80 in
Thickness = 0.39 in
No. of Cheek PL = 2
Weld Thick. = 0.19 in
Plate Fy = 51.50 ksi
Weld Fy = 70.00 ksi

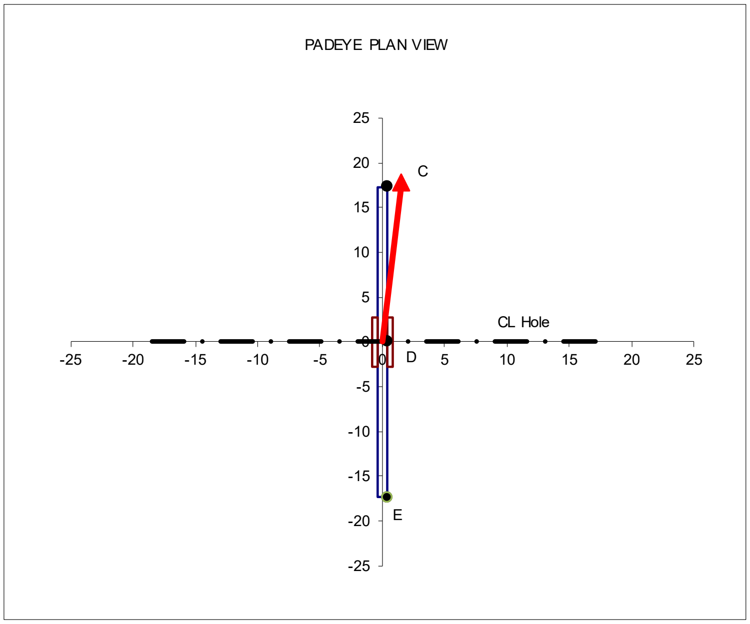
Padeye Section Info

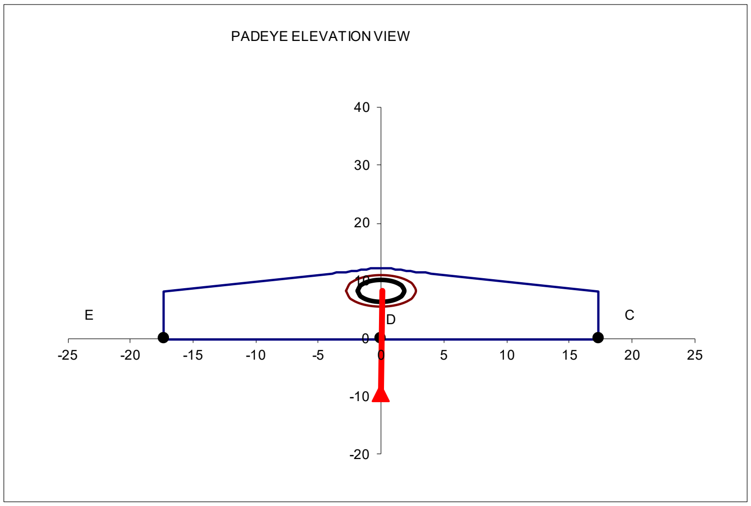
Item	"XX"	"YY"
Shear Area =	27.28 sq in	0.00 sq in
Centroid =	0.00 in	0.00 in
S =	157.5 in3	3.6 in3
I =	2729 in4	1 in4
r =	10.00 in	0.23 in

Total Area = 27.28 sq in

Hole

Hole OD = 3.74 in
Vertical Loc. = 8.27 in
Horizontal Loc. = 0.00 in
Pin OD = 3.74 in





Check Stresses in Eye near Pin

Item	Steel Area	Actual Stress	Allowable Stress	Actual / Allowable	
Bearing	5.9 sq in	12.1 ksi	61.6 ksi	**0.20**	**OK**
Shear at Hole Edges	4.7 sq in	15.2 ksi	27.4 ksi	**0.55**	**OK**
Plug Pull Out	10.0 sq in	7.1 ksi	41.1 ksi	**0.17**	**OK**
Cheek PL Weld	4.7 sq in	15.4 ksi	20.6 ksi	**0.75**	**OK**

Check Stresses at Base as Beam Section

Item	Load	Stress at A	Stress at B	Stress at C	Stress at D	Stress at E	
Axial	-71.5 kips	N/A	N/A	-2.6 ksi	-2.6 ksi	-2.6 ksi	
In-plane Shear	0.0 kips	N/A	N/A	0.0 ksi	0.0 ksi	0.0 ksi	
In-Plane Moment 1	0.0 kip-in	N/A	N/A	0.0 ksi	0.0 ksi	0.0 ksi	
In-Plane Moment 2	0.0 kip-in	N/A	N/A	0.0 ksi	0.0 ksi	0.0 ksi	
Out-of-Plane Shear	6.2 kips	N/A	N/A	0.2 ksi	0.2 ksi	0.2 ksi	
Out-Of-Plane Moment	51.5 kip-in	N/A	N/A	14.4 ksi	14.4 ksi	14.4 ksi	
Total Axial Stress σ		N/A	N/A	11.8 ksi	11.8 ksi	11.8 ksi	
Total Shear Stress τ		N/A	N/A	0.2 ksi	0.2 ksi	0.2 ksi	
Von Mises Stress		N/A	N/A	11.8 ksi	11.8 ksi	11.8 ksi	
Allowabel Stress		N/A	N/A	41.1 ksi	41.1 ksi	41.1 ksi	
Interaction Ratios		**N/A**	**N/A**	**0.29**	**0.29**	**0.29**	**OK**

Notes:

1. Moment 1 - Moment caused by shear (V * Vert Hole Height)
2. Moment 2 - Moment caused by off-center load (Axial force * hor hole offset)
3. Mises Stress = sqrt(s^2 + 3* t^2)
4. Allowable Stress is 0.6*Fy
4. Interaction Ratios IR = Mises /(Allow)

4. Check Inner Tilting Frame Pin for Shear

Part No. p00031461

Description: This is the pin that connects the inner tilting frame to the outer tilting frame

D	80	mm	3.15	in
Fy	799	MPa	116	ksi

1. Check Shear

Assume load on pin is half the Max Load (equally distributed load to both sides of pad)

Determine Shear load

P =	Max Load / 2			
P =	32	MT	72	kips
A=	Pi * D^2 / 4			
A=	50	cm2	8	in2
fv=	P/A			
fv=	62.55	MPa	9	ksi
Fv=	0.4*Fy * AMOD			
Fv=	425.2	Mpa	61.712	ksi

fv/Fv=	**0.15**	**Shear OK**

5. Outer Tilting Frame Padeye - Small DIA Pinhole

Input

Load Information

Load = 71.5 kips
Allow Stress Mod = 1.33
Safety Factor = 1
In-Plane Angle = 270 degrees
Out-of Plane Angle = 5 degrees

Main Plate

Length = 39.13 in
Radius = 4.43 in
Thickness = 1.18 in
Fy = 51.50 ksi

Cheek Plates

Radius = 0.00 in
Thickness = 0.79 in
No. of Cheek PL = 0
Weld Thick. = 0.19 in
Plate Fy = 51.50 ksi
Weld Fy = 70.00 ksi

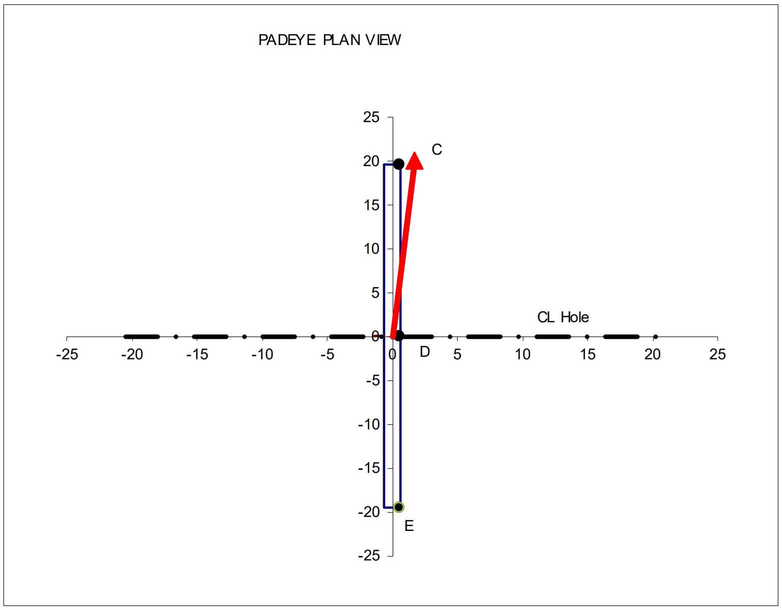
Padeye Section Info

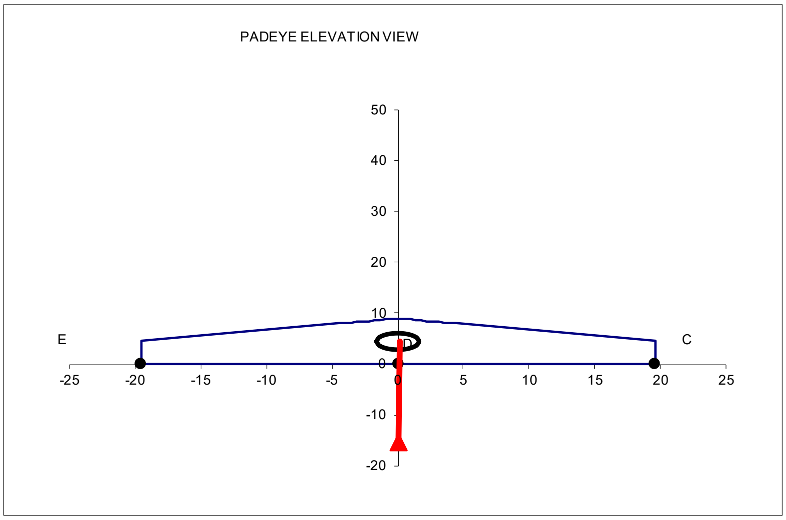
Item	"XX"	"YY"
Shear Area =	46.22 sq in	0.00 sq in
Centroid =	0.00 in	0.00 in
S =	301.5 in3	9.1 in3
I =	5899 in4	5 in4
r =	11.30 in	0.34 in

Total Area = 46.22 sq in

Hole

Hole OD = 3.15 in
Vertical Loc. = 4.53 in
Horizontal Loc. = 0.00 in
Pin OD = 3.15 in





Check Stresses in Eye near Pin

Item	Steel Area	Actual Stress	Allowable Stress	Actual / Allowable	
Bearing	3.7 sq in	19.2 ksi	61.6 ksi	**0.31**	**OK**
Shear at Hole Edges	6.7 sq in	10.6 ksi	27.4 ksi	**0.39**	**OK**
Plug Pull Out	5.2 sq in	13.7 ksi	41.1 ksi	**0.33**	**OK**

Check Stresses at Base as Beam Section

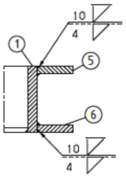
Item	Load	Stress at A	Stress at B	Stress at C	Stress at D	Stress at E	
Axial	-71.5 kips	N/A	N/A	-1.5 ksi	-1.5 ksi	-1.5 ksi	
In-plane Shear	0.0 kips	N/A	N/A	0.0 ksi	0.0 ksi	0.0 ksi	
In-Plane Moment 1	0.0 kip-in	N/A	N/A	0.0 ksi	0.0 ksi	0.0 ksi	
In-Plane Moment 2	0.0 kip-in	N/A	N/A	0.0 ksi	0.0 ksi	0.0 ksi	
Out-of-Plane Shear	6.2 kips	N/A	N/A	0.1 ksi	0.1 ksi	0.1 ksi	
Out-Of-Plane Moment	28.2 kip-in	N/A	N/A	3.1 ksi	3.1 ksi	3.1 ksi	
Total Axial Stress σ		N/A	N/A	1.6 ksi	1.6 ksi	1.6 ksi	
Total Shear Stress τ		N/A	N/A	0.1 ksi	0.1 ksi	0.1 ksi	
Von Mises Stress		N/A	N/A	1.6 ksi	1.6 ksi	1.6 ksi	
Allowabel Stress		N/A	N/A	41.1 ksi	41.1 ksi	41.1 ksi	
Interaction Ratios		**N/A**	**N/A**	**0.04**	**0.04**	**0.04**	**OK**

Notes:

1. Moment 1 - Moment caused by shear (V * Vert Hole Height)
2. Moment 2 - Moment caused by off-center load (Axial force * hor hole offset)
3. Mises Stress = sqrt(s^2 + 3* t^2)
4. Allowable Stress is 0.6*Fy
4. Interaction Ratios IR = Mises /(Allow)

6.1. Check Outer Frame for Bending, Long Side

d	225	mm	8.86	in
bf	120	mm	4.72	in
tf	25	mm	0.98	in
tw	30	mm	1.18	in
Length	994	mm	39.13	in
h	225	mm	8.86	in
Thickness	30	mm	1.18	in



Section view B-B
Scale: 1:10

1. Calculate Bending Load

Assume pin at the middle of the beam is a point load.
Assume load on pin is half the Max Load (equally distributed load to both sides of pad)

Determine bending load

P =	Max Load / 2			
P =	32	MT	72	kips
M =	P * L / 4			
M =	80	MT-m	700	kip-in
Ixx =	1/12 * bf * d^3 - 1/12 * (bf - tw) * (d - 2 * tf)^3			
Ixx =	4.25	cm^4	177	in^4
c =	d / 2			
c =	30	mm	4.4	in
Sxx =	Ixx / c			
Sxx =	2.44	cm ^3	40.0	in^3
fb =	M / Sxx			
fb =	1,977	N-m	17.5	ksi

2. Calculate Allowable Bending Load

Lc = min(Lc1, Lc2)
Lc1 = 76 * bf / sqrt(Fy)
Lc1 = 1,271 mm 50.0 in
Lc2 = 20000 / ((d / Af) * Fy)
Lc2 = 5,178 mm 203.9 in

Check for Compactness
Flange:
bf/tf= 4.8
Compact Limiting Ratio= 65 / sqrt(Fy)
Compact Limiting Ratio= 9.05753

Web:
d/tw= 7.5
Compact Limiting Ratio= 640 / sqrt(Fy)
Compact Limiting Ratio= 89.2

Since beam has L less than Lc, and is compact, use section F1, 1 Eq F1-1

Fb= 0.66 * Fy * AMOD
Fb= 312 MPa 45.21 ksi

fb / Fb = 0.39 Bending OK

3. Check Shear

Av = d * tw
Av = 1.62 sq cm 10.5 sq in

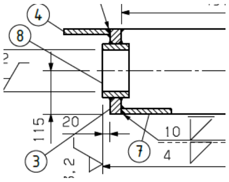
fv = P / Av
fv = 47 MPa 6.8 ksi

Fv = 0.4 * Fy * AMOD
Fv = 189 MPa 27.398 ksi

fv / Fv = 0.25 Shear OK

6.2. Check Outer Frame for Bending, Short Side

d	225	mm	8.86	in
bf1	140	mm	5.51	in
bf2	150	mm	5.91	in
tf1	15	mm	0.59	in
tf2	15	mm	0.59	in
tw	30	mm	1.18	in



Length	556	mm	21.89	in
h	225	mm	8.86	in
Thickness	30	mm	1.18	in

1. Calculate Bending Load

Assume pin at the middle of the beam is a point load.
Assume load on pin is half the Max Load (equally distributed load to both sides of pad)

Determine bending load
P = Max Load / 2
P = 32 MT 72 kips

M = P * L / 4
M = 45 MT-m 391 kip-in

Calculate Sxx using Parallel Axis Theorem

Ayf1= bf1 * tf1 * (d - tf1 / 2)
Ayf1= 457 cm3 28 in3

Ayf2= bf2 * tf2 * (tf2 / 2)
Ayf2= 17 cm3 1 in3

Ayweb= (d - tf1 - tf2)* tw * (d /2)
Ayweb= 658 cm3 40 in3

Ay= Ayf1 + Ayf2 + Aweb
Ay= 1132 cm3 69 in3

A= (bf1 * tf1) + (bf2 * tf2) + ((d - tf1 - tf2) * tw))
A= 102 cm2 16 in2

ȳ= Ay/A
ȳ= 11 cm 4.37 in

Ixx f1= (1/12 * bf1 * tf1^3 +((bf1 * tf1) * (d - ȳ - tf1 /2)^2)
Ixx f1= 2,388 cm4 57.37 in4

Ixx web= 1/12 * (tw * (d - tf1 - tf2) ^ 3) + (tw * (d - tf1 - tf2) * (d / 2 - ȳ)^2
Ixx web= 1,855 cm4 44.57 in4

Ixx f2= (1/12) * (bf2 * tf2 ^3) + (tf2 * bf2) * (ȳ - tf2 /2)^2
Ixx f2= 2,412 cm4 57.96 in4

Ixx= Ixx f1 + Ixx web + Ixx f2
Ixx= 6,655 cm4 159.89 in4

c= d - ȳ
c= 11 cm 4.49 in

Sxx= Ixx / c
Sxx= 584 cm3 35.61 in3

fb = M / Sxx
fb = 76 Mpa 11.0 ksi

2. Calculate Allowable Bending Load

Lc = min(Lc1, Lc2)
Lc1 = 76 * bf / sqrt(Fy)
Lc1 = 1,483 mm 58.4 in
Lc2 = 20000 / ((d / Af) * Fy)
Lc2 = 3,625 mm 142.7 in

Check For Compactness
bf/tf= 9.3 9.3
Compact= 65 / sqrt(Fy)
Compact= 9.1 9.1
Noncompact= 13.2 13.2

Since beam has L less than Lc and is noncompact, use section F1, 2 Eq F1-4

kc= 4.05 / (h / tw)^0.46
kc= 1.6 1.6

Fb= Fy * (0.79 - 0.002 * (bf / 2 * tf) * sqrt(Fy / kc)) * AMOD
Fb= 348 MPa 50 ksi

fb / Fb = 0.22 Bending OK

3. Check Shear

Av = d * tw
Av = 1.62 sq cm 10 sq in

fv = P / Av
fv = 47 MPa 7 ksi

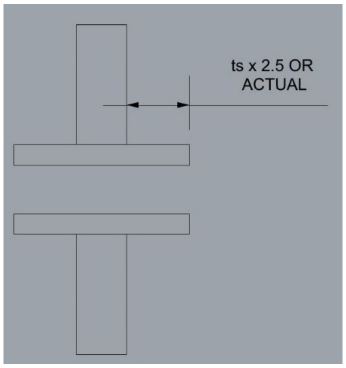
Fv = 0.4 * Fy * AMOD
Fv = 189 MPa 27 ksi

fv / Fv = 0.25 Shear OK

7. Outer Tilting Frame Padeye - Large DIA Pinhole

There is a sleeve that passes through the padeye. This sleeve is checked similar to a cheek plate. The effective length of the sleeve (checked as the cheek plate thickness) is calcualted below.

The effective length of the sleeve is calulcated using a shear slope of 2.5 : 1, standard value for steel. However, this is never taken as longer than the actual sleeve length.



Length protruding = (sleeve L - main plate thickness) / 2
Length protruding = 20 mm
0.79 in

Check max length using 2.5 shear slope
ts = (OD - ID) / 2
ts = 15 mm
Max usable length = ts x 2.5
Max usable length = 37.5 mm
1.48 in

tc = the smaller of the two calcs above
tc = 0.79 in

Input

Load Information

Load =	71.5	kips
Allow Stress Mod =	1.33	
Safety Factor =	1	
In-Plane Angle =	270	degrees
Out-of Plane Angle =	5	degrees

Main Plate

Length =	21.89	in
Radius =	4.43	in
Thickness =	1.18	in
Fy =	51.50	ksi

Cheek Plates

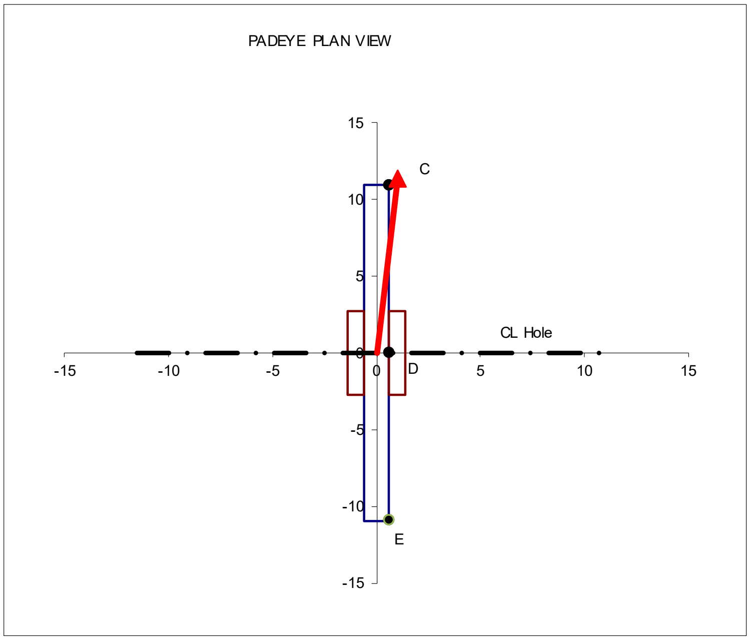
Radius =	2.76	in
Thickness =	0.79	in
No. of Cheek PL =	2	
Weld Thick. =	0.19	in
Plate Fy =	51.50	ksi
Weld Fy =	70.00	ksi

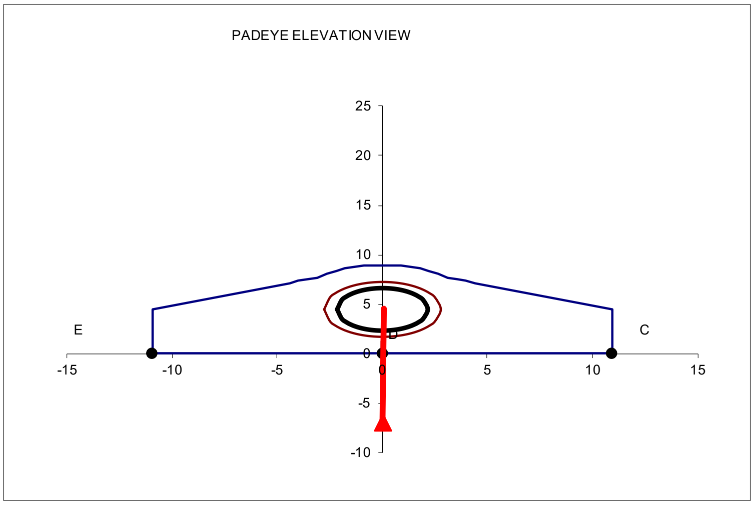
Padeye Section Info

Item	"XX"	"YY"
Shear Area =	25.85 sq in	0.00 sq in
Centroid =	0.00 in	0.00 in
S =	94.3 in3	5.1 in3
I =	1032 in4	3 in4
r =	6.32 in	0.34 in
Total Area =	25.85	sq in

Hole

Hole OD =	4.33	in
Vertical Loc. =	4.53	in
Horizontal Loc. =	0.00	in
Pin OD =	4.33	in





Check Stresses in Eye near Pin

Item	Steel Area	Actual Stress	Allowable Stress	Actual / Allowable	
Bearing	11.9 sq in	6.0 ksi	61.6 ksi	**0.10**	**OK**
Shear at Hole Edges	7.2 sq in	9.9 ksi	27.4 ksi	**0.36**	**OK**
Plug Pull Out	15.5 sq in	4.6 ksi	41.1 ksi	**0.11**	**OK**
Cheek PL Weld	4.6 sq in	15.6 ksi	27.4 ksi	**0.57**	**OK**

Check Stresses at Base as Beam Section

Item	Load	Stress at A	Stress at B	Stress at C	Stress at D	Stress at E	
Axial	-71.5 kips	N/A	N/A	-2.8 ksi	-2.8 ksi	-2.8 ksi	
In-plane Shear	0.0 kips	N/A	N/A	0.0 ksi	0.0 ksi	0.0 ksi	
In-Plane Moment 1	0.0 kip-in	N/A	N/A	0.0 ksi	0.0 ksi	0.0 ksi	
In-Plane Moment 2	0.0 kip-in	N/A	N/A	0.0 ksi	0.0 ksi	0.0 ksi	
Out-of-Plane Shear	6.2 kips	N/A	N/A	0.2 ksi	0.2 ksi	0.2 ksi	
Out-Of-Plane Moment	28.2 kip-in	N/A	N/A	5.5 ksi	5.5 ksi	5.5 ksi	
Total Axial Stress σ		N/A	N/A	2.8 ksi	2.8 ksi	2.8 ksi	
Total Shear Stress τ		N/A	N/A	0.2 ksi	0.2 ksi	0.2 ksi	
Von Mises Stress		N/A	N/A	2.8 ksi	2.8 ksi	2.8 ksi	
Allowabel Stress		N/A	N/A	41.1 ksi	41.1 ksi	41.1 ksi	
Interaction Ratios		**N/A**	**N/A**	**0.07**	**0.07**	**0.07**	**OK**

Notes:

1. Moment 1 - Moment caused by shear (V * Vert Hole Height)
2. Moment 2 - Moment caused by off-center load (Axial force * hor hole offset)
3. Mises Stress = sqrt(s^2 + 3* t^2)
4. Allowable Stress is 0.6*Fy
4. Interaction Ratios IR = Mises /(Allow)

8. Check Outer Frame Pin for Shear

Part No.	d00003091			

Description: This is the pin that connects the outer tilting frame to the main frame padeye

D	90	mm	3.54	in
Fy	799	MPa	116	ksi

1. Check Shear

Assume load on pin is half the Max Load (equally distributed load to both sides of pad)

Determine Shear load

P =	Max Load / 2			
P =	32	MT	72	kips
A=	Pi * D^2 / 4			
A=	64	cm2	10	in2
fv=	P / A			
fv=	49	MPa	7	ksi
Fv=	0.4 * Fy * AMOD			
Fv=	320	Mpa	62	ksi
fv/Fv=	**0.12**		**Shear OK**	

9. Main Frame Padeye

Input

Load Information

Load = 35.8 kips

Allow Stress Mod = 1.33

Safety Factor = 1

In-Plane Angle = 270 degrees

Out-of Plane Angle = 5 degrees

Main Plate

Length = 15.75 in

Radius = 2.95 in

Thickness = 1.57 in

Fy = 51.50 ksi

Cheek Plates

Radius = 0.00 in

Thickness = 0.79 in

No. of Cheek PL = 0

Weld Thick. = 0.19 in

Plate Fy = 51.50 ksi

Weld Fy = 70.00 ksi

Padeye Section Info

Item	"XX"	"YY"
Shear Area =	24.80 sq in	0.00 sq in
Centroid =	0.00 in	0.00 in
S =	65.1 in3	6.5 in3
I =	513 in4	5 in4
r =	4.55 in	0.45 in

Total Area = 24.80 sq in

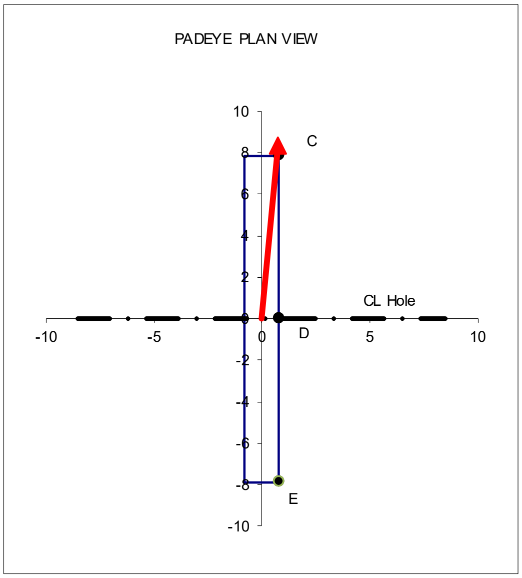
Hole

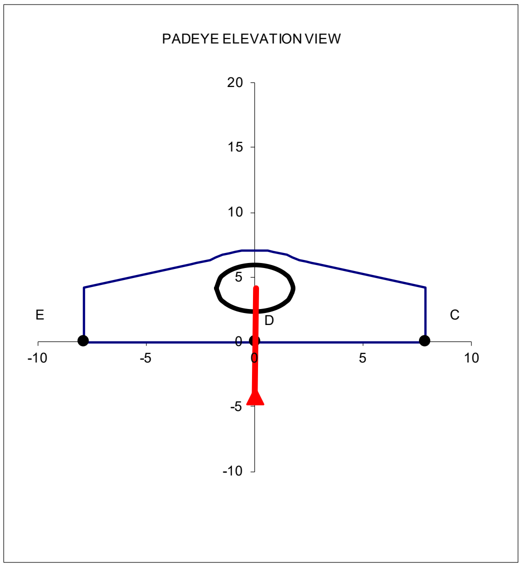
Hole OD = 3.54 in

Vertical Loc. = 4.13 in

Horizontal Loc. = 0.00 in

Pin OD = 3.54 in





Check Stresses in Eye near Pin

Item	Steel Area	Actual Stress	Allowable Stress	Actual / Allowable	
Bearing	5.6 sq in	6.4 ksi	61.6 ksi	0.10	OK
Plug Pull Out	4.7 sq in	7.7 ksi	41.1 ksi	0.19	OK

Check Stresses at Base as Beam Section

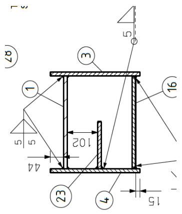
Item	Load	Stress at A	Stress at B	Stress at C	Stress at D	Stress at E	
Axial	-35.8 kips	N/A	N/A	-1.4 ksi	-1.4 ksi	-1.4 ksi	
In-plane Shear	0.0 kips	N/A	N/A	0.0 ksi	0.0 ksi	0.0 ksi	
In-Plane Moment 1	0.0 kip-in	N/A	N/A	0.0 ksi	0.0 ksi	0.0 ksi	
In-Plane Moment 2	0.0 kip-in	N/A	N/A	0.0 ksi	0.0 ksi	0.0 ksi	
Out-of-Plane Shear	3.1 kips	N/A	N/A	0.1 ksi	0.1 ksi	0.1 ksi	
Out-Of-Plane Moment	12.9 kip-in	N/A	N/A	2.0 ksi	2.0 ksi	2.0 ksi	
Total Axial Stress σ		N/A	N/A	0.5 ksi	0.5 ksi	0.5 ksi	
Total Shear Stress τ		N/A	N/A	0.1 ksi	0.1 ksi	0.1 ksi	
Von Mises Stress		N/A	N/A	0.6 ksi	0.6 ksi	0.6 ksi	
Allowabel Stress		N/A	N/A	41.1 ksi	41.1 ksi	41.1 ksi	
Interaction Ratios		N/A	N/A	0.01	0.01	0.01	OK

Notes:

1. Moment 1 - Moment caused by shear (V * Vert Hole Height)
2. Moment 2 - Moment caused by off-center load (Axial force * hor hole offset)
3. Mises Stress = sqrt(s^2 + 3* t^2)
4. Allowable Stress is 0.6*Fy
4. Interaction Ratios IR = Mises /(Allow)

10. Check Main Frame for Bending

d	320	mm	12.60	in
bf	300	mm	11.81	in
tf	12	mm	0.47	in
tw	12	mm	0.47	in
Length	2595	mm	102.17	in
h	320	mm	12.60	in
Thickness	12	mm	0.47	in



1. Determine Reaction Forces

Assume load is distributed evenly between the two arms

P= Max Load / 2

P= 33 MT 72 Kips

L1 is the distance from the main frame pivot point to the Main Hydraulic Padeye

L1 1483 mm 58.39 in

L2 is the distance from the Main Hydraulic Padeye to the center of the Tilting Bracket

L2 1112 mm 43.78 in

R1 is the reaction force at the Main Hydraulic Padeye

R1= (P *(L1 + L2) / L1)

R1= 57 MT 125 kips

R2 is the reaction force at the main frame pivot point

R2= P - R1

R2= -24 MT -54 kips

Determine the Moment Applied to each arm

M= R2 * L1

M= -36 MT-m -3,130 kip-in

2. Calculate Bending Load

Assume load is distributed evenly between the two arms

Assueme load is applied in the center of the beam

Ixx = 1/12 * bf * d^3 - 1/12 * (bf - tw * 2)*(d - tf * 2)^3

Ixx = 12.85 cm^4 535 in^4

c = d / 2

c = 30 mm 6.3 in

Sxx = Ixx / c

Sxx = 5.18 cm ^3 84.9 in^3

fb = M / Sxx

fb = 254 MPa 36.9 ksi

2. Calculate Allowable Bending Load

Lc = (1950 + 1200 * (M1 / M2))*(bf / Fy)
Lc = 18350 mm 722 in

Check For Compactness
Flange:
b/t= 25 25
Check b/t against limiting width to thickness ratios:

Noncompact= 253 / sqrt(Fy)
Noncompact= 35
Noncompact

Since beam has L less than Lc and is noncompact, use section F3, 2 Eq F3-3 to find Fb

Fb= 0.6 * Fy * AMOD
Fb= 283 MPa 41.1 ksi

fb / Fb = 0.90 Bending OK

3. Check Shear

Av = (bf*tf)*2+((d-tf*2)*tw)*2
Av = 143 sq cm 22.2 sq in

fv = Max Reaction Foce / Av
fv = 39 MPa 5.6 ksi

Fv = 0.4 * Fy * AMOD
Fv = 189 MPa 27.398 ksi

fv / Fv = 0.21 Shear OK

4. Calculate Hydraulic Padeye Load

The load on the hydraulic arm padeye is half of R1 (Assume equal load to both padeyes)
P = R1 / 2

P = 28 MT 63 kips

11. Main Hydraulic Padeye

Input

Load Information

Load = 63 kips
Allow Stress Mod = 1.33
Safety Factor = 1
In-Plane Angle = 210 degrees
Out-of Plane Angle = 5 degrees

Main Plate

Length = 12.60 in
Radius = 3.15 in
Thickness = 1.18 in
Fy = 51.50 ksi

Cheek Plates

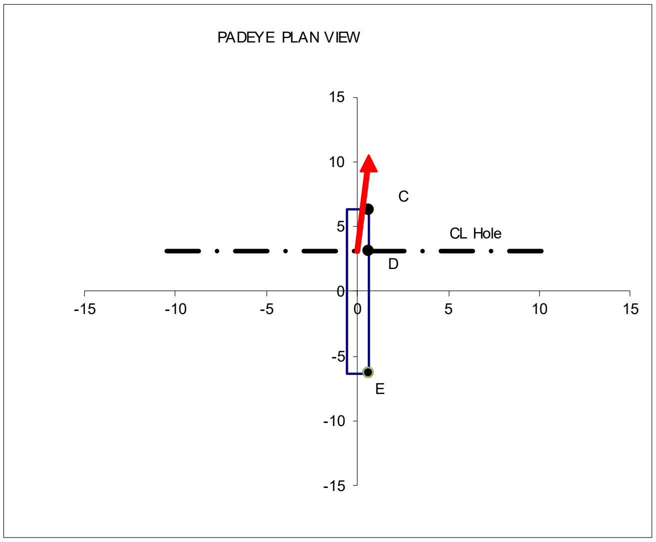
Radius = 0.00 in
Thickness = 0.00 in
No. of Cheek PL = 0
Weld Thick. = 0.19 in
Plate Fy = 51.50 ksi
Weld Fy = 70.00 ksi

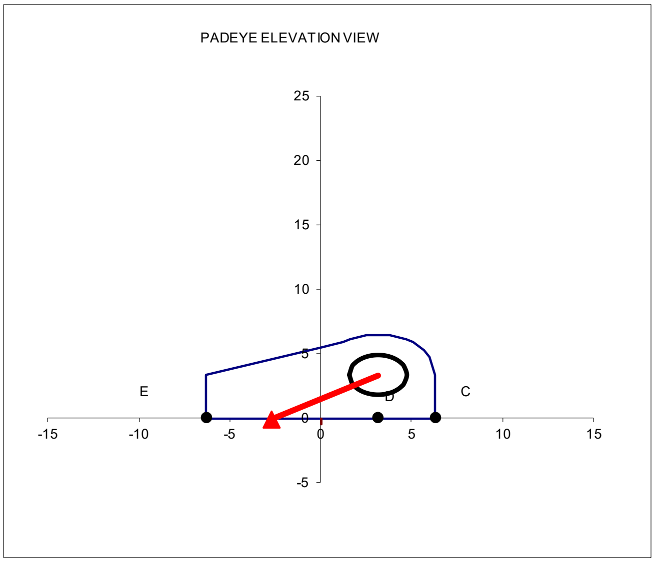
Padeye Section Info

Item	"XX"	"YY"
Shear Area =	14.88 sq in	0.00 sq in
Centroid =	0.00 in	0.00 in
S =	31.3 in3	2.9 in3
I =	197 in4	2 in4
r =	3.64 in	0.34 in
Total Area =	14.88	sq in

Hole

Hole OD = 3.15 in
Vertical Loc. = 3.35 in
Horizontal Loc. = 3.15 in
Pin OD = 3.15 in





Check Stresses in Eye near Pin

Item	Steel Area	Actual Stress	Allowable Stress	Actual / Allowable	
Bearing	3.7 sq in	16.9 ksi	61.6 ksi	**0.27**	**OK**
Plug Pull Out	3.7 sq in	16.9 ksi	41.1 ksi	**0.41**	**OK**

Check Stresses at Base as Beam Section

Item	Load	Stress at A	Stress at B	Stress at C	Stress at D	Stress at E	
Axial	-31.5 kips	N/A	N/A	-2.1 ksi	-2.1 ksi	-2.1 ksi	
In-plane Shear	-54.6 kips	N/A	N/A	-3.7 ksi	-3.7 ksi	-3.7 ksi	
In-Plane Moment 1	###########	N/A	N/A	5.8 ksi	0.0 ksi	-5.8 ksi	
In-Plane Moment 2	99.2 kip-in	N/A	N/A	3.2 ksi	3.2 ksi	3.2 ksi	
Out-of-Plane Shear	5.5 kips	N/A	N/A	0.4 ksi	0.4 ksi	0.4 ksi	
Out-Of-Plane Moment	18.4 kip-in	N/A	N/A	6.3 ksi	6.3 ksi	6.3 ksi	
Total Axial Stress σ		N/A	N/A	13.2 ksi	7.3 ksi	1.5 ksi	
Total Shear Stress τ		N/A	N/A	-3.3 ksi	-3.3 ksi	-3.3 ksi	
Von Mises Stress		N/A	N/A	14.4 ksi	9.3 ksi	5.9 ksi	
Allowabel Stress		N/A	N/A	41.1 ksi	41.1 ksi	41.1 ksi	
Interaction Ratios		**N/A**	**N/A**	**0.35**	**0.23**	**0.14**	**OK**

Notes:

1. Moment 1 - Moment caused by shear (V * Vert Hole Height)
2. Moment 2 - Moment caused by off-center load (Axial force * hor hole offset)
3. Mises Stress = sqrt(s^2 + 3* t^2)
4. Allowable Stress is 0.6*Fy
4. Interaction Ratios IR = Mises /(Allow)

12. Check Hydraulic Pin for Shear

Part No. p00031458

Description: This is the pin that conects the hydraulic ram to the hydraulic padeye

DIA	80	mm	3.15	in
Fy	799	MPa	116	ksi

1. Check Shear

Assume load on pin is half the Reaction Load at Hydraulic Connection

Determine Shear load

P =	Reaction Load / 2			
P =	75	MT	168	kips
A=	Pi * D^2 / 4			
A=	50	cm2	8	in2
fv=	P/A			
fv=	146.54	MPa	21	ksi
Fv=	0.4 * Fy * AMOD			
Fv=	319.7	Mpa	61.712	ksi

fv/Fv=	**0.35**	**Shear OK**

FEA Model

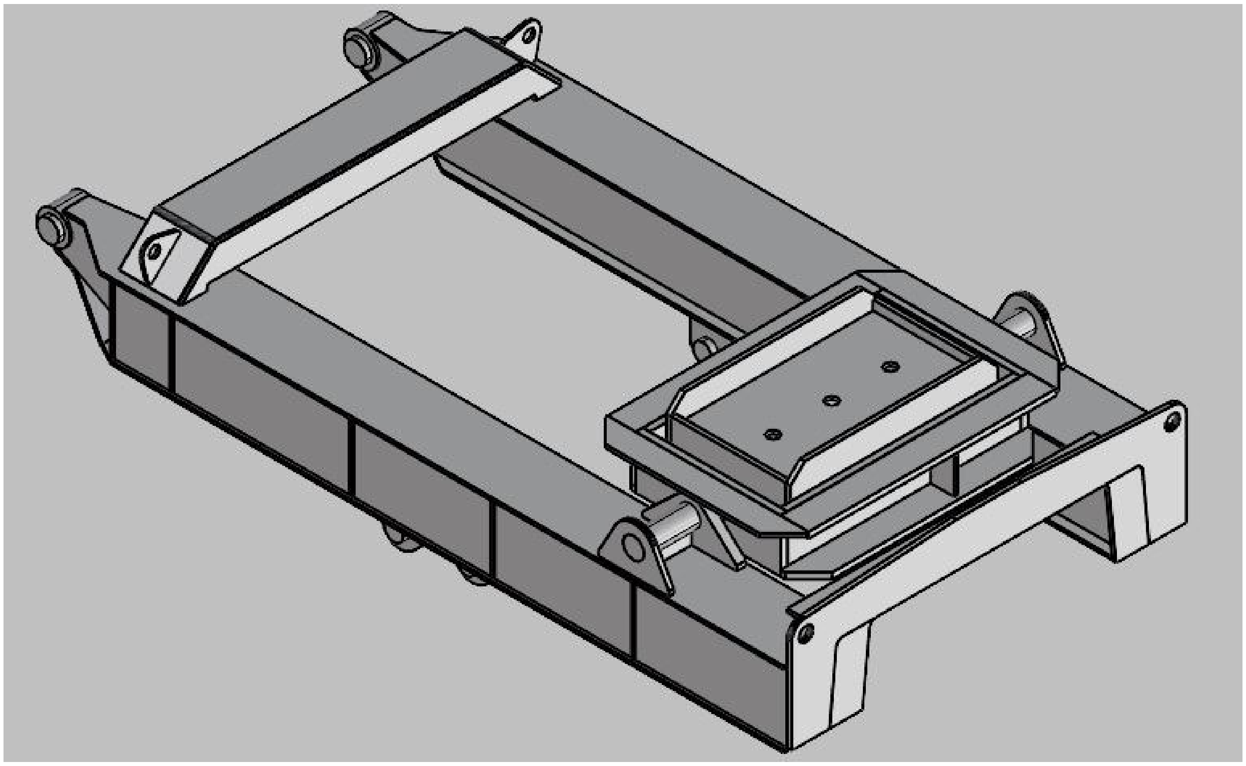


Figure 1: Bilge Support Arm Modeled in Rhino 8 for FEA Analysis