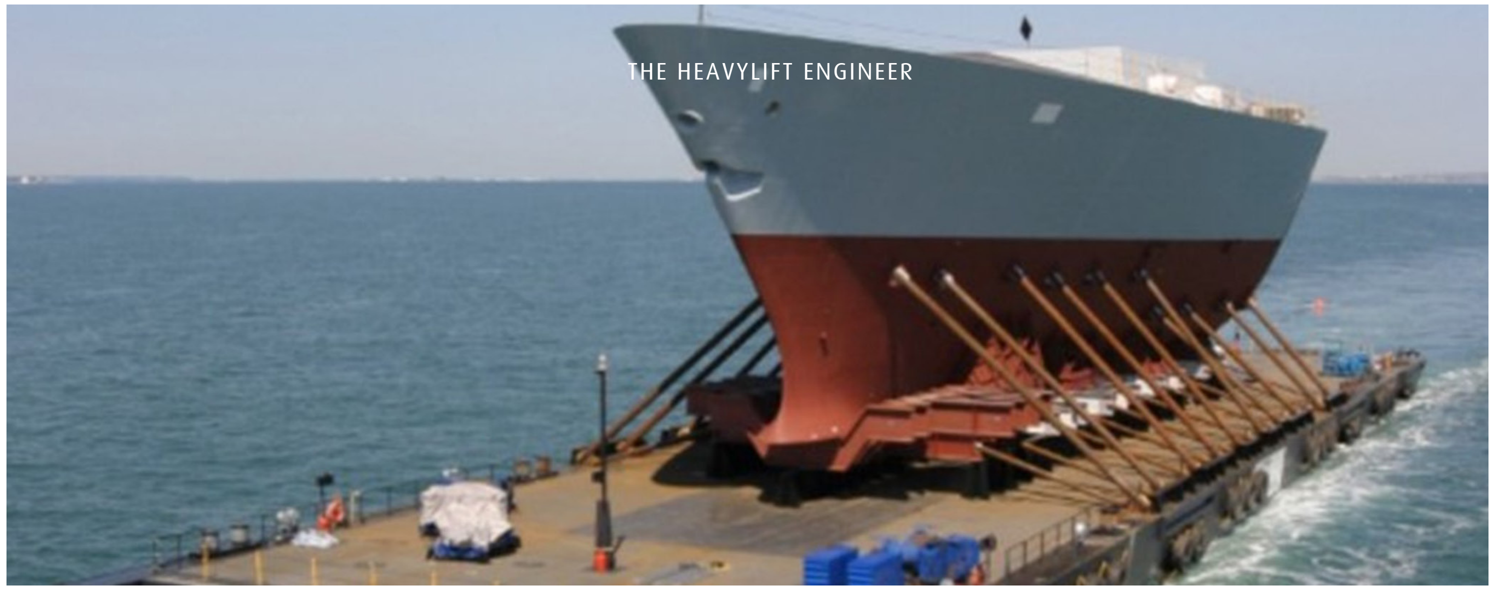

fig. 5/ sea transportation of vessel block with roll bracing

fig. 6/ roll braces

SEA FASTENING DESIGN - ROLL AND PITCH BRACES

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Overview
Welded braces, described here as roll braces, are a type of sea fastening typically consisting of a closed structural section and gusset plates. They are often used for large pieces of cargo where the centre of gravity (CoG) is located at a significant height above the deck and it is unfeasible to design out the restraining force as shear and uplift at the cargo base.

The braces typically consist of Circular Hollow Sections (CHS) with gusset plates slotted through either end of the section. The gussets are then either welded or bolted to the cargo and vessel deck, or grillage with the gusset plates profiled to suit each brace location.

The braces are typically positioned in the way of the cargo or grillage's primary steelwork nodes with the section centroids aligned to minimise bending effects. This is illustrated in fig. 7 where the roll bracing alligns with primary framing of the module. It is critical that load transfer, due to both global and local effects, is considered as part of the overall design. In addition, the earlier the sea fastening arrangement can be established, the easier it will be to account for in the design of the main structure; it will result in a more efficient design, allowing any potential issues to be designed out rather than designed around.

The connection to the cargo/supporting structure is typically a welded connection with the gusset plate welded directly to the cargo. An alternative to welding is a bolted connection as shown in fig. 6. To acheive this a standalone, receiving gusset plate is required on the cargo/support structure, which the roll brace can be bolted to. This option has the potential to reduce onsite hotworks and in some cases, where the gusset can be left in-situ, remove the need for remedial works altogether. A secondary advantage to using bolted connections is that a degree of flexibility can be built into the design. Bolt holes may be match marked and drilled on site however, it is not always possible to leave behind attachment points and in this case remediation work will be required regardless.

In a similar manner, the connection to the vessel deck requires consideration to ensure a suitable point with sufficient capacity is selected.

The alignment of connection detail into the deck or grillage is also critical in order to align the gusset with suitable deck structure. Some flexibility may be built into the design here through the addition of green material which can be removed as required on site.

Where roll braces land between frames or hard points, they can be tied into small grillages which span between frames and spread the load into the vessel's primary structure. The weld detail between under deck stiffening and deck or hatch plating also needs consideration to ensure that it is capable of transferring the load especially in situations where the brace experiences tension.

fig. 7/ offshore modules with roll bracing aligned with primary structure

Design

The design of roll braces requires an understanding of both seagoing forces and structural design expertise. The derivation of seagoing forces has been covered in an earlier article.

Depending on the complexity of the cargo and support arrangement, the load may either be determined from hand calculations or via a finite element analysis (FEA) model. Where roll braces are required, the structure is usually sufficiently complex to justify an FEA/framework model to ensure accurate load distribution, as well as assessment of the cargo under the seagoing forces and support conditions. Less common is the requirement of a combined barge/vessel and cargo model, however this can be required where the length of the cargo is sufficiently large that it interacts with the hog and sag of the barge/vessel is a seaway. This can be extended with the use of hydrodynamic analysis tools, which enable you to more accurately determine the vessel motions in a seaway and thereafter derive the acceleration and inertial forces imposed on the cargo.

The design of the braces can be thought of in three parts where manual calculations are typically sufficient to validate the design.

1. Main member design
2. Gusset plate design
3. Connection to cargo/deck

Main member

The design of the member itself should be undertaken to a suitable design code or rule set, considering all modes of failure. Braces are typically designed as truss members, however the engineer should consider the stiffness of the structural arrangement to determine appropriate end fixity conditions which can have a significant effect on the capacity of the braces.

Gusset plate

The design of the gusset plate here considers both the local interaction with the brace and gusset plate itself. The gusset plate is welded to the hollow section with an all-round fillet weld of capacity and centroid so as to ensure no net moment is introduced due to eccentric or asymmetric weld groups.

The two failure mechanisms for slotted joints are circumferential failure and tear out (or block shear) as discussed fully in 'Design Guide for Circular Hollow Joints Under Predominantly Static Loading' [1]. It is typical to provide a slotted depth of 1.3 – 1.5 times the brace diameter, which will generally ensure that a capacity greater than the yield capacity of the brace is provided.

Assessment of the gusset itself should ensure it does not yield or buckle. For the purposes of design calculations the gusset plate is considered to have an effective area, which is generally less than the actual available plate. Whitmore's method [3] is generally applicable whereby a 30° load distribution is considered allowing the gusset plate to be assessed as a rectangular plate. This method can be applied to both bolted and welded gusset plates .

For bolted gusset plates the Whitmore effective width concept is generally applicable as described in "Hollow sections in Industrial Applications" [2]. Assessment of

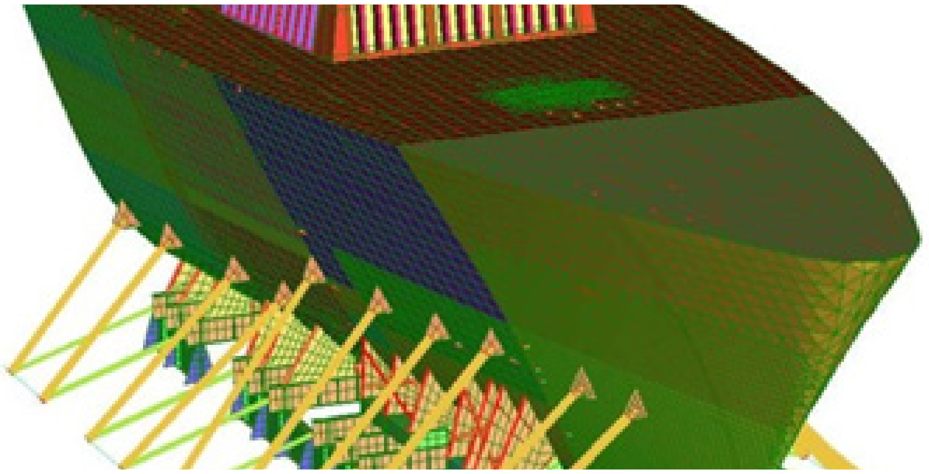


fig. 8/ FEA model of vessel block with roll bracing

fig. 9/ typical detail for roll and pitch bracing common 'hard point' on the cargo

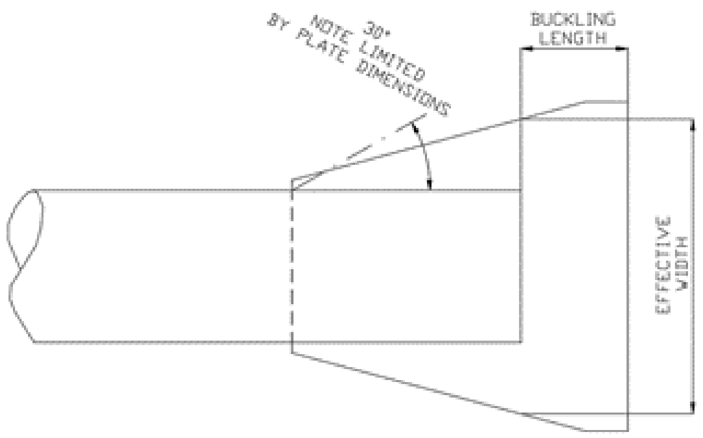
Existing structures

Proper assessment of the existing structures in both the cargo and vessel are critical Braces should be aligned with underdeck structure to avoid damage to the vessel. Note that it is often the case that cargo strong points and deck structure will not perfectly align and additional grillage may be required to suitably transfer the load. The cargo should be assessed for the seagoing forces with support conditions as per the proposed seafastening arrangement. Where the cargo is large there can also be the requirement to undertake more detailed assessment where the combined barge/vessel stiffness interaction is considered.

Overall, as with all structural design, an understanding of the practical, as well as the theoretical is required to produce robust, efficient designs for the required situation.

References

1.Design guide for circular hollow sections (CHS) joints under predominantly static loading, 2nd edition, J. Wardenier et al, CIDECT, 2008
2.Hollow Sections in industrial Applications
3.Behaviour of a Gusset Plate Connection Under Compression, The Civil Engineering Journal 1-2017, Bardot et al.



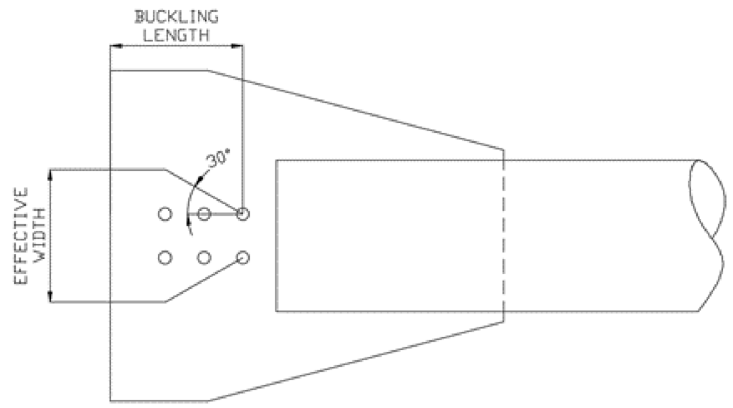


fig. 11/ effective width for Whitmore's method - bolted connection