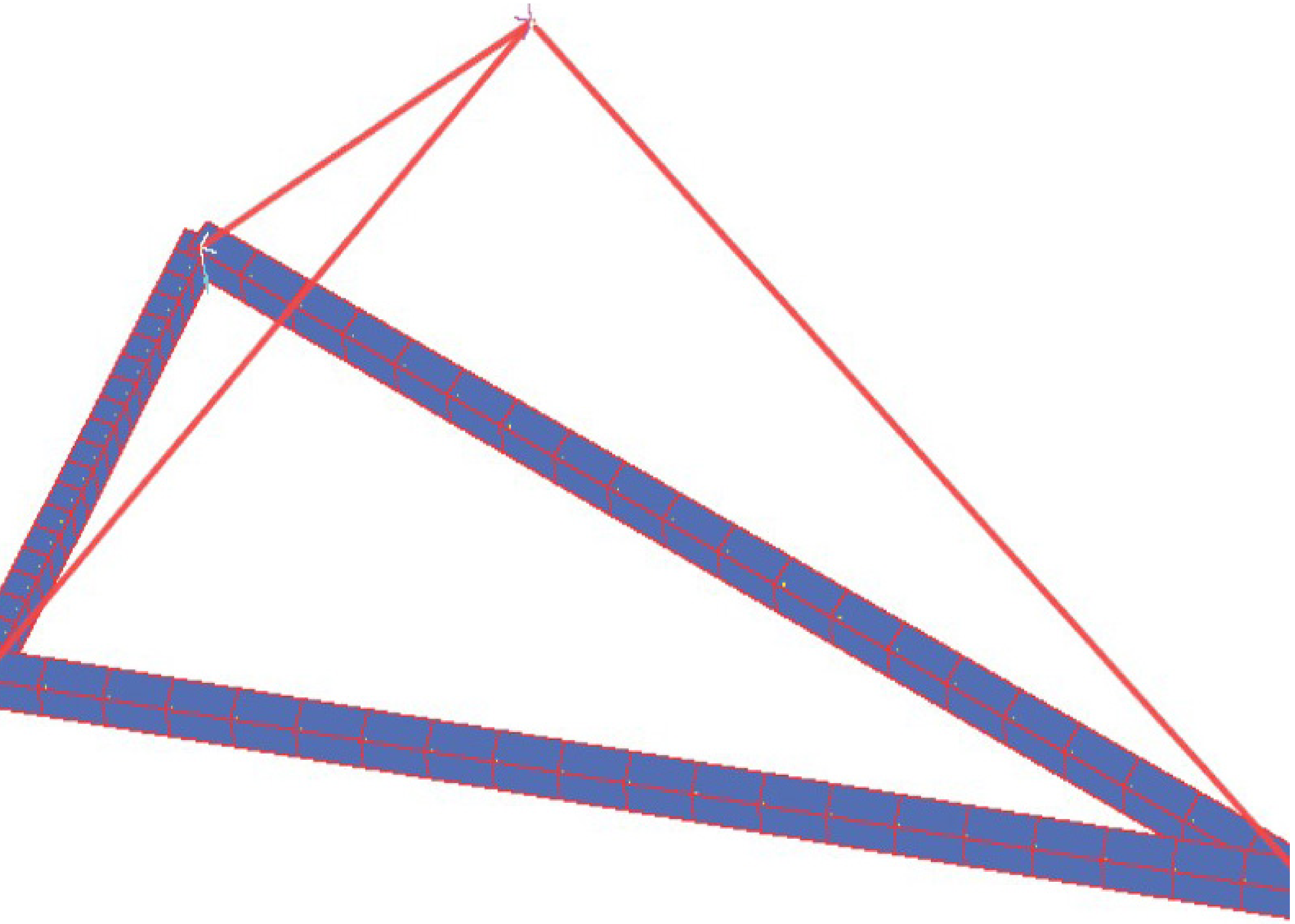
DESIGN AND FABRICATION OF LIFT BEAMS

WRITTEN BY ALASDAIR MACDONALD
TEAM LEADER AND SENIOR STRUCTURAL ENGINEER, MALIN ABRAM



The design and fabrication of lift beams is an involved process requiring both practical knowledge of their function and use as well as technical understanding involved in the structural/ mechanical design. Within the body of regulations Lifting Beams are defined as 'lifting accessories' such that they are not attached to lifting machinery, allow a load to be held, are placed between the machinery and load and are independently placed on the market. The key pieces of legislation relating to lifting beam are as follows:

Design

- Supply of Machinery (Safety) Regulations 2008
-

Operation

- Lifting Operations and Lifting Equipment Regulations 1998 (LOLER)
- Provision of Use of Work Equipment Regulations (PUWER)

It should be noted that Supply of Machinery (Safety) Regulations do not apply to seagoing vessels, mobile offshore units and machinery installed on such vessels. In this case a suitable certification authority is required such as Lloyds Register, DNV, ABS, BV, etc.

This article will discuss the design process for lift beams which is broadly similar for lift beams used in onshore and offshore applications. Note that where the term 'lift beam' is used, it can also be extended to include spreader beams and other types of similar lifting accessories. It is also assumed that these take a similar form consisting of lift point(s) and structural members.

Design

When an object is lifted there is a change in support conditions and as such a change to the load path from the object to the ground now via lifting equipment, accessories and rigging. Lifting and spreaders beams are used as a means of controlling and directing the load path and as such allow objects to be lifted in a safe and controlled manner.

It is suggested that lifting requirements should be considered throughout the design of any heavy, large, or otherwise cumbersome object or structure.

There are several key considerations required for the design of a lift beam.

- Weight of item to be lifted
- Centre of Gravity (CoG) of item to be lifted
- Practicalities
  - Space envelopes
  - Hook height available or required
  - Fabrication

Weight

The overall mass of the object can be determined in a range of ways, varying in accuracy, such as material take-offs, 3d model or physically weighing the structure – it may also be provided by a client. Note: Weight control information should stem from a well-defined and documented system. Depending on the reporting of the weight and maturity of the design it is good practice to include a weight contingency factors. Guideline figures for increasing the weight are provided in the table below.

Once the weight is known, the lift beam can be designated a Safe Working Load (SWL) or Working Load Limit (WLL). The SWL/WLL should also account for rigging required. The SWL/ WLL is a value, or set of values, based on the operational requirements of the lifting beam and is the maximum load that the lifting beam can safely lift, provided it is rigged in the correct manner. It is possible for a lifting beam to be certified to a range of SWLs and corresponding geometric limits. In any case, the SWL/WLL is to be clearly marked on the lift beam.

Centre of Gravity (CoG)

The second key consideration is the Centre of Gravity (CoG) of the item to be lifted. The CoG can also be determined in a number of ways from manual calculations to output from a 3d model – or again it may be provided by a client. Similar to the weight accuracy factor it is also prudent to account for centre of gravity accuracy. There are two primary methods for accounting for CoG inaccuracy

Discipline	Conceptual design	Detailed design		Weighed items
		Agreed basis of design	AFC take off/final supplied weight data sheet	
Non-structural	25%	20%	10%	3%
Structural	25%	10%	5%	3%

There are two primary methods for accounting for CoG inaccuracy in the design with the chosen implementation depending on the type of lift and sensitivity of shifting the CoG:

- Considering a CoG envelope – used for operation where resulting load effects, or operations, are more sensitive to change of CoG position. This is depicted in the following images, or;
- Applying CoG contingency loads factors – used where there is a more linear relationship between CoG shift and resulting load effects.

The first of these considers CoG in extreme positions of a defined envelope and the second increases the entire weight and as such increases the full load but does not change basic load distribution. The size of a lift envelop will be determined by the appropriate design standard – typically these could bed in the region of 0.05L x 0.05B x 0.05H for an early stage design. In the design the most onerous CoG position should be adopted.

The location of the CoG will determine the position of the lift hook point, and from this, the rigging arrangement, and overall lengths. The lift point is to be located in-line with the centre of gravity. Rigging lines typically have a minimum angle of 45° with a preference for 60° (to the horizontal).

Practicalities

Alongside the weight and CoG consideration of the practical elements such as, but not limited to, space/geometry envelopes, crane hook height, fabrication limitations and operational conditions. These factors will influence the type of lifting beam that is designed. To fully understand the practical considerations desktop and/or site survey will be required, in order to fully understand such things as the limits of the lifted item, site, fabrication facility and craneage available.

Lift beam design

Once the above information has been obtained the initial arrangement and sizing can be determined – oftentimes from simplistic, manual calculations. The SWL/WLL is determined from the Static Hook Load (SHL) which consists of gross weight combined with rigging weight. A conservative estimate is often required for the rigging weight which is then revised once the rigging is finalised. It should be noted that it is generally good practice to round up with static hook load to provide a round SWL/WLL number.

The dynamics of the lift are accounted for by applying a Dynamic Amplification Factor (DAF). The DAF is determined through consideration of aspects of the lift beam use such the location (offshore/inshore/onshore), the gross weight and lifting speed.

From this a basic dynamic load is determined. Further to this a proof load is to be determined based on the safe working load of the system. The Proof Load Factor (PLF) is determined from a suitable lifting code such as Lloyds Register of Shipping Lift Appliances in the Marine Environment (LAME).

Gross weight = calculated/measure weight x weight contingency factor (x CoG accuracy)

Duty Factor = A factor depending on the frequency and severity of the load lifted

Static Hook Load (SHL) = Gross weight + Rigging weight (x Duty factor)

Dynamic Hook Load (DHL) = SHL x DAF

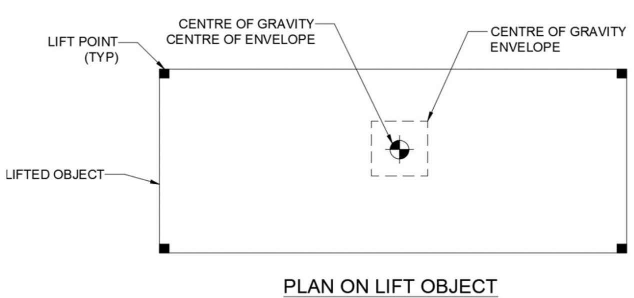


fig. 15/ plan of lift object with CoG in centre of envelope

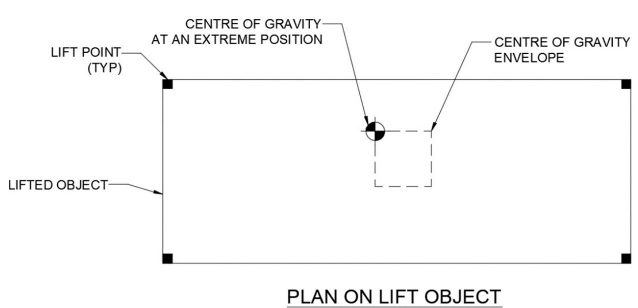


fig. 16/ plan of lift object with CoG at extreme position centre of envelope

Proof Load Factor (PLF) = Additional load factor used for testing the lift beam - typical values are given below taken from the International Labour Organisation Register of Lifting Appliances and Items of Loose Gear [1]

Proof load = SWL x PLF

Proof load factors

These are applicable to lifting beams, spreaders, lifting frames and similar devices as provided by ILO [1]

Load rating	Proof test load
SWL ≤ 10 tonnes	2 x SWL
10 tonnes < SWL ≤ 160 tonnes	1.04 x SWL + 9.6 tonnes
SWL > 160 tonnes	1.1 x SWL

Additional load factors (not all are always applicable) are applied to determine final dynamic load which are dependent on the use of the lift beam. Factors include:

- Skew Load Factor (SKL)
- 2-hook Lift Factor
- 2-Part Sling Factor
- CoG Shift Factor
- Tilt Angle

With the loads calculated calculations can be undertaken to determine the loads in the rigging and lift points. Rigging items are rated items and as such can be specified based on the SWL. It should be noted that where rigging is used in a marine environment (dynamic) consideration should be given to ensure the SWL of the item has sufficient capacity for application.

fig. 17/ spreader beams as used in a complex rigging arrangement

Lift points

The geometry of lift point (also referred to as pad eyes) is initially dictated by the size of shackle, and associated pin, required. The width of the pad eye is typically required to be at least 75% the width of the shackle jaw and similarly the hole is typically sized such the pin is 94% the size of the hole. The pad eyes are to be assessed individually considering the resultant sling force – accounting for in and out of plane actions.

The pad eyes are, normally, aligned with the rigging such as to minimise any out of plane loading. It is however both good practice, and a requirement of some codes, to include a nominal out of plane loading, typically 3-5%. The assessment can either be done by manual calculations or finite element analysis. Manual calculations are the preferred method given that pad eyes are, normally, simple structures. The following critical checks are required in order to fully verify the pad eye structure to a relevant national or international design standard.

The following should be assessed as a minimum:

Considering the Resultant Sling Force (RSF) the following should be considered:

- Bearing stress
- Tear out stress
- Check plate welds

The tensile and shear components of the RSF checking at both the hole, base and any other critical locations:

- Direct tension
- Direct in-plane shear
- Direct out of plane shear
- In-plane bending
- Out of plane bending
- Combined stress

Padeye connection to beam

The connection of the pad eye to the lift beam is to be assessed as well as the structure local to the padeye. The preference for welding is full penetration welds over fillet welds however it is not always possibly to achieve this. Common weld arrangements for penetration welds include direct butt and slotted arrangements. Slotted details are often preferred from a structural point of view as they can eliminate issues such as laminar failings or local stress concentrations – this may not be the case for fabrication. However, the main pad eye plate is often required to be tapered to match the mating structure. Alternative arrangements could include lap welded details, using fillet welds, this may result in additional eccentricities to consider.

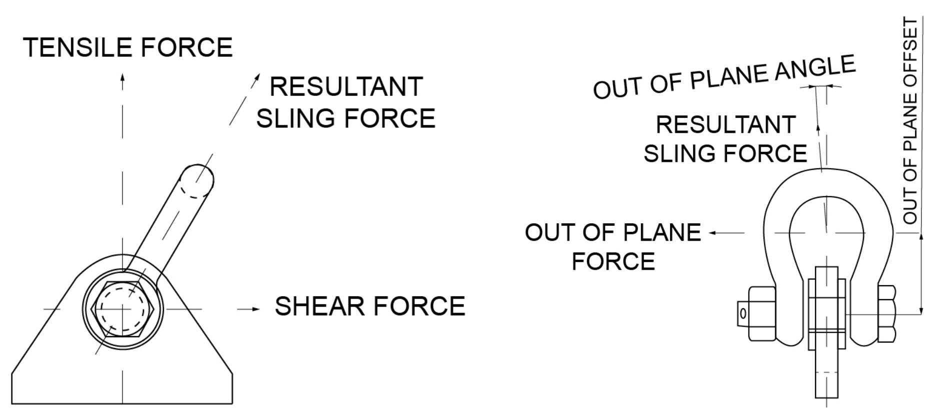


fig. 18/ force acting on a lift point

The engineer should strive to avoid local stress concentrations through good detailing practices. If these are unavoidable for practical reasons, the engineer should ensure they fully understand the load path and verify all aspects.

Lift beam design

The lift point and rigging arrangement will determine the how the forces are transferred through the structure. For example, a lift beam with a single hook point in the centre will be in bending whereas a spreader beam will largely be in compression. This can influence the type of section with spreader beams often fabricated from Circular Hollow Sections (CHS) or other closed sections.

The lift beam itself is to be designed in accordance with a suitable national or international design standard considering the most onerous combination of loading acting on the beam. Typical design codes for this would include Eurocode 3, AISC or Lloyds Register Code for Lifting Appliances in the Marine Environment – with the engineer taking note of the design philosophy (ASD or LRFD). As for the pad eye it is often sufficient to verify the beam by manual calculations, however framework or finite element analysis tools may be required if the beam is sufficiently complex. When using such tools, it is imperative that the engineer has a good understanding of the tool and its limitations, particularly understanding where additional local calculations may be required to fully verify the structure.
Fabrication, marking and testing

The fabrication of a lift beam should be undertaken in accordance to an agreed fabrication standard. Once a fabrication standard has been determined agreement is required on such items as weld procedures, qualifications of welders, non-destructive testing (NDT) procedures, NDT personnel qualifications and NDT acceptance criteria. These items should all in line with the relevant standards.

Proof Load Testing

There are two main means of "justification" for a lift beam – firstly by calculation and secondly by proof load testing.

Lifting points, lifting frames and spreader bars intended for non-routine operations do not require to be proof loaded tested, provided full design calculations are provided and verified by competent person(s) alongside a full programme of inspection. However, where practical proof load tests should be undertaken. The proof load requirements are determined dependent on the SWL and its application, as discussed in the section above.

Where a load test is to be undertaken the test must be representative of the actual design loading conditions with measures taken to ensure the accuracy of the testing equipment. Applied loads should be within +/- 2% - of the proof load requirement and verified by use of calibrated load cells or pre-weighing test weights. Acceptance criteria should be agreed prior to the test and verified after the test.

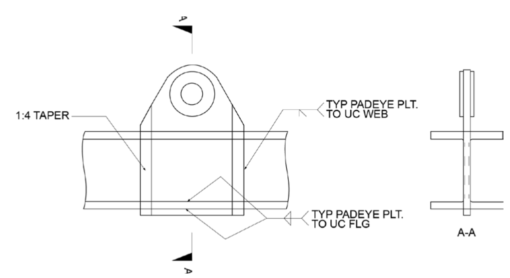


fig. 19/ slotted connection

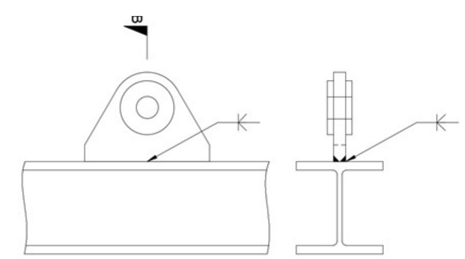


fig. 20/ butt welded connection

fig. 21/ lift beam and spread beams in use

fig. 22/ lift being under test load

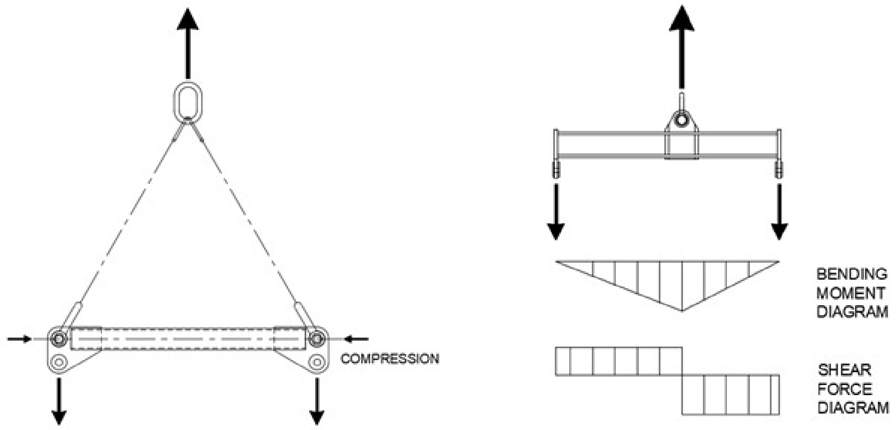


fig. 23/ forces acting on a spreader beam (L) and lift beam (R)

Inspection

Fabrication materials shall comply with the relevant standards ensuring full traceability.

The lift beam will typically be inspected by assessment of the primary structural arrangement and workmanship, ensuring they are as detailed in the approved plans. Where work is not as detailed in the plans it shall be rectified.

Non-Destructive Examination is to be carried out by sufficiently qualified personnel. Note that this should be undertaken prior to painting. Typical requirements for welded construction are given as follows, where a critical weld is one where failure will result in loss of the load, primary welds are those in the main load path and secondary welds do not form part of the main load path (platforms, service fittings, etc).

Butt welds

- Critical welds - 100% Visual, 100% Magnetic Particle Insepction (MPI) & 100% Ultrasonic Inspection
- Primary welds- 100% Visual, 100% Magnetic Particle Inspection (MPI) & 20% Ultrasonic Inspection
- Secondary welds - 100% Visual

Fillet welds

- Critical welds - 100% Visual, 100% Magnetic Particle Insepction (MPI)
- Primary welds - 100% Visual, 100% Magnetic Particle Inspection (MPI)
- Secondary welds - 100% Visual

In addition to welds, it is also often required to inspect the material local to the lift point for laminar discontinuities.

Painting and Marking

Once the testing and inspection has been completed the lift beam can be painted and marked up with required information – specifically the SWL/WLL. For lift beams subject to the Supply of Machinery (Safety) Regulations the following markings are required:

- Marked for UKCA (or EC, if applicable)
- Name and address of the manufacturer
- Serial number
- Year of construction
- Total mass of assembly
- SWL/WLL – including all configurations (where appropriate)

Markings should confirm with published standards such as BS EN ISO 7010 or other appropriate legislation.

References

1. International Labour Organisation, Register of Lifting Appliances, and Items of Loose Gear, 1985