Design and Construction of Lifting Beams

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Lifting beams (also known as spreader beams) are used to assist in the hoisting process. Most erectors and riggers accumulate an assortment of lifting beams during the course of time. Some common profiles are shown in Fig. 1.

The basic lifting beam is shown in Fig. 1A. This arrangement provides two places of attachment to the object being lifted, thus avoiding the possibility of overstressing if a single attachment were used. This also allows for a straight pull on the object rather than an oblique pull as would result if chokers alone were used. This is sometimes important to minimize unwanted erection stresses or to prevent reversal of stress in certain portions of the lifted object. For instance, the oblique pull in Fig. 2A may cause excess compression in the top chord of the truss at a time when that chord is laterally unbraced. The arrangement in Fig. 2B will help to alleviate this tendency and optimum choker locations can be chosen to minimize the stresses during the erection phase.

Figure 1B illustrates the type of lifting beam that might be employed in Fig. 2B. The beam has multiple holes at the

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underside for attachment to the object to be hoisted, thus providing a large range of adjustment. This arrangement will also prevent the object from tilting excessively should the hook be slightly off-center of the balance point. Figure 1C shows a lifting beam which has good versatility in location of attachments. This is useful if the objects to be lifted vary greatly in size and weight. Figure 1D shows a lifting beam used in an inverted position. Although this condition is relatively rare, there are occasions when it is necessary, such as when two cranes must lift a very heavy object which is beyond the capacity of a single crane. The inverted lifting beam enables the cranes to share the load. Figure 1E shows a lifting beam made for a special purpose and is constructed entirely of plate material. Figure 1F depicts another adaptation which permits the lower shackles to be oriented 90° to their usual position. Figure 3A shows a multiple lifting beam arrangement such as might be used to support a long limber object. Figure 3B illustrates a lifting beam fitted with a chain-fall in order to provide some adjustment if the object must be jockeyed into position. By varying the lengths of chokers a fixed-tilt lifting beam can be made as depicted in Fig. 3C. Expressed in terms of variables noted in Fig. 3C the sling lengths can be calculated using the following formulae:

short sling length: $L_1 = \sqrt{a^2 + H^2 + 2Ha(\sin q)}$

long sling length: $L_2 = \sqrt{a^2 + H^2 + 2Ha(\sin q)}$

Dimension H is commonly selected as approximately 1.2 times the a dimension.
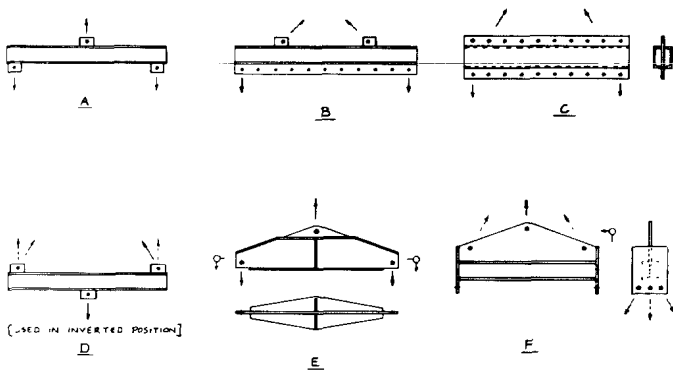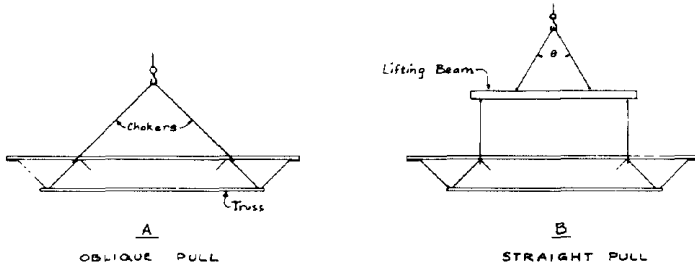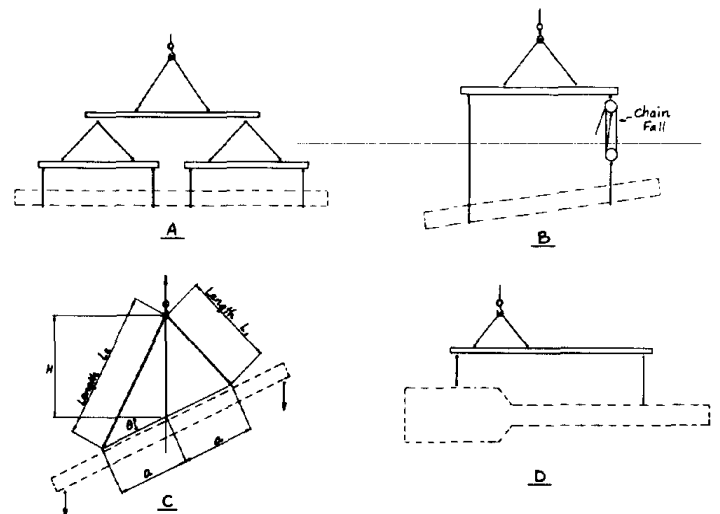

Figure 1.

Figure 2.

Figure 3.

Occasionally non-symmetrical lifting beams are required to hoist objects which are of peculiar shape or have odd weight distribution. Figure 3D shows such an arrangement.

Significant torsion loads are rare in lifting beams. If it is surmised that torsion stresses must be addressed, the lifting beam can be strengthened by adding a plate at each end of the wideflange section as in Fig. 14A or by adding side plates to box the section as in Fig. 14B. The AISC publication, *Torsion Analysis of Steel Members,*[3] will be of value in torsion investigations.

A lifting beam can also be used as a "strong back" to provide multiple lifting points on a relatively flexible object (See Fig. 4A.) Some lifting beams are made with a bottom lug aligned directly below the top lug so that, if the need arises, an occasional straight pick can be made without the inconvenience of having to remove the lifting beam. (See Fig. 4B.) This is but a small sample of lifting beam possibilities and their applications.

Other elements commonly associated with lifting beams are hooks, shackles, chokers, and slings. Shackles are used to connect the lines to the lifting beams. Shackles come in various patterns and capacities and typical examples are shown in Figs. 5 and 6. The loads shown in these tables represent average industry loads and are for comparison purposes only. The capacities of specific rigging components must be verified by the user. Chokers are often used to wrap around the object to be lifted and are usually fastened to the underside of the lifting beam by means of shackles. Slings are used to suspend the lifting beam from the main hook. See Figs. 7 and 8 for various choker and sling sizes.

Hooks are rarely attached directly to a lifting beam because the hole required in the lug plate would need to be excessively large (or oblong) and the required edge distance on the lifting lug would be too great to accommodate the hook profile. However, hooks are often used with shackles or oblong rings. Hooks with safety latches which prevent the shackles or lines from escaping the throat of the hook are recommended.

The shackle properties most significant to this discussion are: load capacity, diameter of pin (or bolt), inside width of jaws, length of shackle, diameter of flange. (See Fig. 9A.) The width of jaw limits the thickness of the lug plate. The length of shackle controls the maximum edge distance available
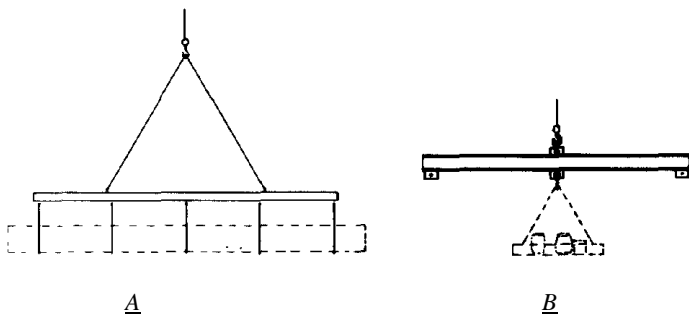

A

B

Figure 4.

at the plate edge. The diameter of the shackle flange influences the minimum distance of the pin hole from the face of the lifting beam. In Fig. 9B the minimum dimension X is the sum of the flange radius and the weld size plus a small allowance for clearance and fabrication variances. There is no reason to make dimension X overly large except in cases where it is desired to increase the effective length of the lug plate weld. An excessive X dimension needlessly increases the Z dimension, shown in Fig. 13, which may diminish the capacity of the lifting beam. Note that for certain cable locations the moment in the lifting beam is increased by the amount of $H \times Z$ as, for example, in Fig. 13C.

The diameters and lengths of of chokers and slings should, of course, be compatible with the capacities and geometry of the lifting beam. Refer to Fig. 2B. The angle should preferably be between 45° and 90° with 60° being a common figure. An angle less than 45° usually requires excessively long slings and an angle greater than 90° results in needlessly high sling loads.

The lug plate with its pin hole is an important component of the lifting beam assembly. Tests have indicated that the ratio of pin diameter to hole diameter has little influence on the ultimate strength of the lug material.[11] In the unlikely event that the pin completely fills the hole in the
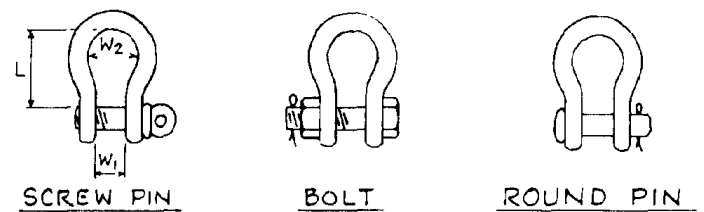
SAFE WORKING LOAD (Tous)	L (in)	W$_1$ (in.)	W$_2$ (in.)	PIN DIAM. (in.)	OUTSIDE OF EYE DIAM.(in.)	WEIGHT (lbs)
3¼	2⅜	$1\frac{1}{16}$	$1\frac{11}{16}$	¾	$1\frac{9}{16}$	1.3
8½	3¾	$1\frac{11}{16}$	$2\frac{11}{16}$	1⅛	2⅜	5.2
12	$4\frac{11}{16}$	2	3¼	1⅜	3⅝	10.1
17	5¾	2⅜	3⅞	1⅝	3⅝	17.9
25	7	2⅞	5	2	$4\frac{5}{16}$	29.5
35	7¾	3¼	5¾	2¼	5	46.1
55*	10½	4⅛	7¼	2¾	6	101
85**	13	5	8½	3¼	6½	179

* *Screw pin and bolt type only*
** *Bolt type only*

NOTE: *Proof load is 2.2 times safe working load. Minimum ultimate strength is 6 times the safe working load.*
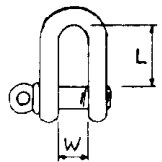
Fig. 5. Forged anchor shackles.

lug plate, the plate must be checked for bearing capacity. The diameter of the hole in the lifting lug should be at least $\frac{1}{16}$ in. greater than the largest pin (or bolt) diameter which is anticipated. However, it is not necessary to have the pin fit snugly in the hole. In fact, the pins are apt to be rough cast and not perfectly round. More often than not, the pin may be considerably smaller than the hole. Pins as small as one half the hole diameter are not rare.

Tests[11,12] have confirmed that there are four potential failure modes for a lug plate:
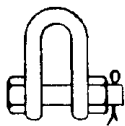
1. Tension failure at the sides of the hole as indicated in Fig. 10A.
2. Crushing above the pin followed by tearing tension fracture at the plate edge as shown in Fig. 10B.
3. Shear failure in the lug plate as the pin attempts to plow its way toward the free edge of the plate.
4. Dishing (out-of-plane buckling) failure of relatively thin lug plates which are laterally unrestrained.

Referring to Fig. 10A, the ultimate tensile load P_{11} can be found from the 9following formula:
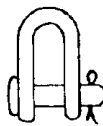
$$P_u = 2atF_u$$

where

a is the least plate width at side of hole (in.)
t is the plate thickness (in.)
F_u is the ultimate tensile strength (ksi).

Since P_u is a theoretical failure load, an appropriate factor of safety must be applied. A factor of safety of five is common in such a case. Allowable $P = 0.2P_u$.

Some guidelines for lug plate geometry are necessary for good performance. It is suggested that dimension a equal or exceed the larger of one-half the hole diameter or twice the plate thickness. For calculation purposes a should not exceed four times the plate thickness at the pin hole (Ref. 1, pg. 5-41). The minimum e dimension as shown in Figs. 10A and 10B should equal or exceed 0.67 times the hole diameter. Calculation of the e dimension is explained later.

Referring to Fig. 10B the plate must be checked for crushing due to bearing above the pin. As may be imagined, the intensity of bearing is not uniform in this area. Local yielding and enlargement of the bearing contact area is anticipated as the load increases. The allowable bearing

Two Leg Bridle Slings
      single rope legs, oblong link.
eye-hoist hooks

Two Leg Basket Slings
    two rope legs and oblong link

Figure 7.

SCREW PIN   BOLT   ROUND PIN

SAFE WORKING LOAD (Tons)	L (in.)	W (in.)	PIN DIAM. (in.)	OUTSIDE OF EYE DIAM. (in)	WEIGHT (lbs)
3¼	2	$1\frac{1}{16}$	¾	$1\frac{9}{16}$	1.5
8½	$3\frac{3}{16}$	$1\frac{1}{16}$	1⅛	2⅜	5.6
12	$3\frac{15}{16}$	2	1⅜	3	10.8
17	$4\frac{13}{16}$	2⅜	1⅞	3⅝	19.0
25	5¾	2⅞	2	$4\frac{5}{16}$	314
35	6¾	3¼	2¼	5	45.0
55*	8	4⅛	2¾	6	83.6
85**	8½	5	3¼	6½	139

* Screw pin and bolt type only.
** Bolt type only.

<u>NOTE:</u> *Proof load is 2.2 Times safe working load. Minimum ultimate strength is 6 Times the safe working load.*

Fig. 6. Forged chain shackles.

stress F_p should equal $0.9F_y$ ksi. (Do not use an allowable bearing stress equal to $1.2F_y$ as this value requires the clamping action of a bolt or rivet which is not present in a shackle and pin arrangement.) If a lug plate proves to be deficient in bearing strength, washer plates can be welded around the hole to increase the thickness. (See Fig. 11.)

When the pin fits snug in the hole the allowable crushing load $P_p = 0.9F_ytd$ where F_y is the yield strength (ksi), t is the lug plate thickness (in.), and d is the hole diameter (in.).

If the pin is less than a snug fit the lug plate must be designed to prevent tearing tension failure at the plate edge as shown in Fig. 10B. Tear-out results when the pin attempts to plow through the plate edge, often resulting in a bulge whose outer edge is in severe local tension. The dimension e must be adequate to prevent tear-out but small enough so it will accommodate the shackle length. The following procedure is suggested: Assume that a block of steel $0.8d$ in length, e in height, and with a thickness the same as the lug plate performs as a fixed-end beam. Refer to Fig. 15B. The allowable load is calculated using the following formula (as derived in Fig. 15B):

$$\text{Allowable } P = \frac{1.67\,F_b t e^2}{d}$$

$$\text{Required minimum } e = \sqrt{\frac{Pd}{1.67F_b t}}$$

where

P is allowable load (kips)
F_b is allowable bending stress of lug (ksi)

t is lug plate thickness (in.)
e is distance from edge of hole to edge of plate parallel to the load direction (in.)
d is the diameter of the hole (in.)

As stated previously, regardless of its calculated value, e should never be made less than $0.67d$. In order to prevent the line or shackle from fouling the square corner of the lug plate, the corner may be cut on a diagonal as shown in Fig. 11 or it may be rounded. Regardless of how the corner is treated the same rules for determining e will also apply at the cut area.

The third failure mode is shear whereby the pin may push out a block of steel as it attempts to plow through the edge of the lug plate. The approximate allowable shear load
$P_u = 2(0.4)F_yet$

where

F_y is yield stress of lug plate (ksi)
e is the distance from edge of hole to edge of plate parallel to load (in.)
t is thickness of lug plate (in.)

This will give conservative results. A more refined treatment of this topic is given by Tolbert and Hackett.[12]

The fourth failure mode, dishing, is conveniently prevented by establishing a minimum thickness limit. It is suggested that plate thickness be not less than $0.25 \times$ hole diameter but never less than ½ in. This recommendation does not apply to the webs of W, S, and C sections which benefit from the stiffening effects of the neighboring flanges. (See Ref. 11 for more on dishing.)
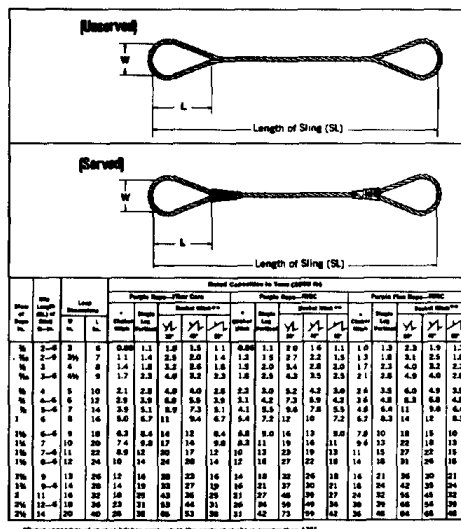
The top lifting lug may be a short plate as shown in
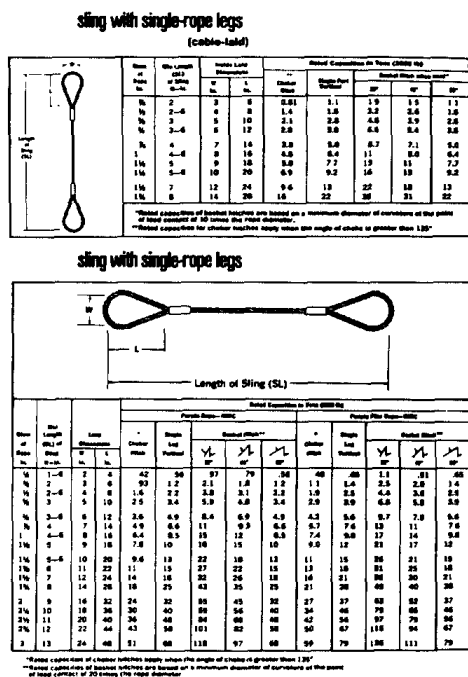
Figure 8.

Figs. 1A, 1B, and 1D or it may be continuous as shown in Fig. 1C. It may be fillet or groove welded. Since lifting beams are often used and stored outdoors, it is recommended that welds be made water tight to prevent hidden corrosion. Top lugs may be subject to straight pulls as shown in Fig. 1A or oblique pulls as shown in Figs. 1B, 1C, and 1D. They must be oriented so that the plate will not be bent sideways when loaded. (See Fig. 15A.) The weld should be sized to account for any eccentricities which may result from various angles of pull. The thickness of the lug should be such that it will accommodate the "jaw" opening of the shackle. This usually results in a lug thickness of approximately 1 to 2 inches. It is not necessary that the lug plate fit snugly in the jaw opening. However, a gross mismatch may cause the lifting beam to hang slightly out-of-vertical which may result in undesirable torsion stresses. A suggested rule of thumb is lug thickness should be no less than one-half the jaw opening width.

Bottom lugs are treated much the same as top lugs except that they are apt to be continuous plates as shown in Fig. 1B in order to be more versatile. Since most of the bottom lug loads hang vertically or nearly so, the weld is sized as shown in Fig. 12. The effective length of weld is that subtended by an angle of 120° immediately above the load. This recognizes the contribution of the bending strength of the adjacent lug plate areas. This is shown as distance 3.4*a*. This rule can be used with very little error even if the pull is not absolutely vertical.
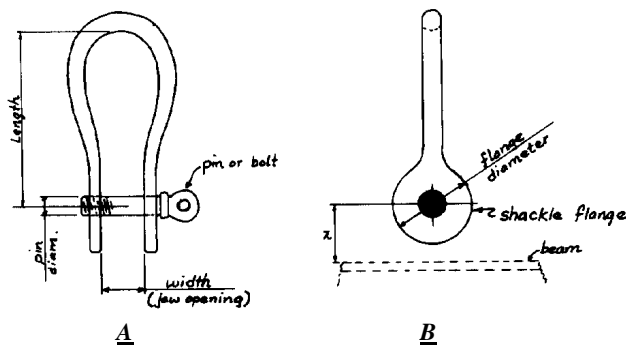
When a thick lug is welded to a beam with a relatively thin web, the beam web should be checked for tension in the immediate vicinity of the lug plate.

In designing a lifting beam the maximum desired lifting capacity must be established and also the governing geometry, that is, the maximum length and the spacing of the top and bottom lugs. Any beam depth limitations should be considered. The line angle should be established (angle *q* in Fig. 2B, for example). If the pull angle is subject to fluctuation the maximum and minimum governing cases should be identified. It must be decided whether to use a beam with a constant or a varying cross section. Constant section beams are most common. Since dead weight is sometimes a factor, it may be desirable to use high strength steel. Lifting beam deflection is hardly ever a governing factor. Column sections, that is wide-flange shapes that are approximately as wide as they are deep, are popular for lifting beams because they generally have longer L_c and L_u lengths permitting the use of allowable bending stresses of $0.66F_y$ or $0.60F_y$ rather than a reduced value. For reduced bending stresses refer to AISC Spec. Sect. F1.1 and F1.3.[1] The unsupported length of a lifting beam is the length between the outermost lifting holes.

In establishing the lifting capacity of a lifting beam, several factors must be considered in addition to the static weight of the objects to be lifted. The estimated weight of lifting beam, shackles, and lines must be included. In addition, the effects of impact, acceleration, deceleration, wear, deterioration, and abuse must be considered. These are often difficult to predict. An effective way to account for these unknowns is to apply an additional factor of safety to the static load. If the normal allowable stresses are reduced by a factor of 1.8, the resulting maximum working
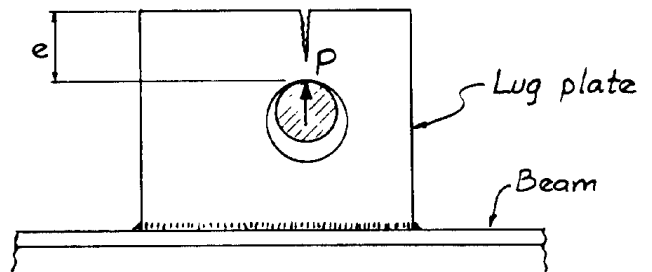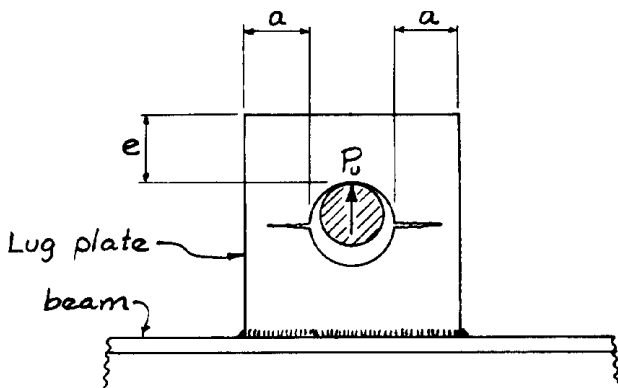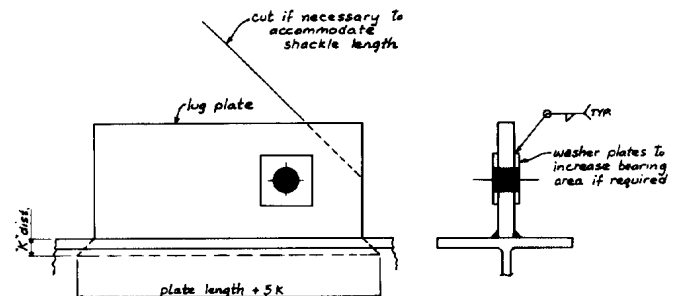

Figure 9.

Figure 10B.

Figure 10A.

Figure 11.

bending stress in the lifting beam will be about a fifth of the minimum ultimate bending strength of the steel.

$$F_b = 0.6F_y = 21.6 \text{ ksi}$$

$$\text{factored } F_b = \frac{21.6 = 12}{1.8} \text{ ksi}$$

for A36 steel $F_b/F_u = \dfrac{12}{58} = 0.21$

This is in line with other components of the lifting assembly such as the shackles, lines, and hooks, which are usually load rated for ¼, ⅕, or ⅙ of their ultimate capacity. (Note that the shackles shown in Figs. 5 and 6 have an ultimate strength six times their safe working load.)

ANSI/ASME Standard B30.20[9] requires that lifting beams be designed using a minimum design factor of 3 based on yield strength, for load bearing structural components. This establishes maximum allowable stresses in the material. Using their criteria the maximum F_b for A36 material is 36/3 = 12 ksi, and for A572 GR.50 material F_b = 50/3 = 16.7 ksi. (ANSI Standard N45.6[10] defines the requirements for lifting devices for use in nuclear work.)

Regardless of how the lifting capacity is established, the next step is to calculate the forces that act on the beam. Using the maximum bending moment, a target section modulus for the lifting beam can be calculated which can be confirmed or adjusted later on. A trial and error method must be used to arrive at the required section size.

Quite often it is desired to modify the existing lifting beams by adding reinforcing or changing the lifting lugs. If welding is required, it is recommended that low hydrogen electrodes be used in case the beams are made of high strength steel. If a lifting beam becomes bent or twisted for any reason, it should immediately be taken out of service.

Lifting beams and associated lines and equipment should be inspected before and after use. ANSI/ASME Standard B30.30[9] Requires scheduled inspections and

B30.30[9] requires scheduled inspections and this is sound advice. This same standard also requires rated load tests of lifting beam assemblies prior to initial use, or after being altered, modified, or repaired. HA Specifications 1926.251.(a)(4) requires that a lifting beam be tested to 125% of its rated capacity prior to service use. Guidelines for inspection and testing are given in the referenced standards and readers are advised to acquaint themselves in this regard. Lifting beam investigations involve either analysis or design. The following is a typical design procedure:

Assume that the desired lifting beam geometry is as depicted in Fig. 13, that there are no depth restrictions, and the beam will never be used in an inverted position.

1. Assume a dead weight for the lifting assembly including shackles, lines, and beams.
2. Establish the geometry of the beam:
   a. Length.
   b. The quantity and location of the top and bottom lifting lugs.
3. Using an appropriate safety factor, multiply the entire weight to be lifted, including dead weight, by the factor of safety. This establishes the design load. In allowable stress design it is difficult to establish a base for an overall factor of safety because some allowable stresses are based on ultimate stresses and some on yield stresses and the relationship of these stresses is not uniform as we change steel types. For ASTM A36 steel based on a bending stress, a factor of 1.8 multiplied by the actual weight will produce a factored design weight which can be used in subsequent design calculations. The resulting factor of safety is approximately 5.
4. Calculate the forces for the governing factored design load conditions. (Maximum bending forces are apt to exist when the beam is used in an inverted position. However, as stated above, in this exercise the beam will not be inverted.) Draw the force diagrams (Figs. 13B and 13C).
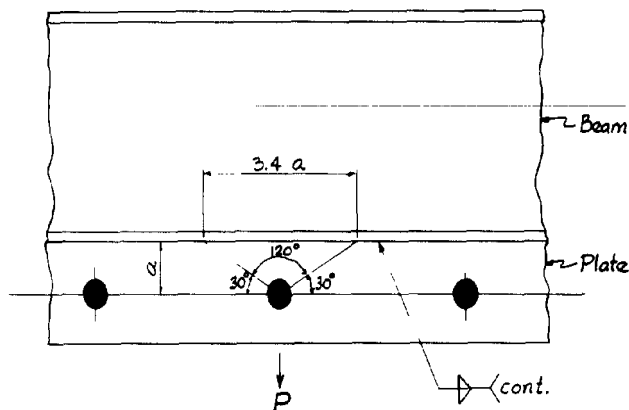
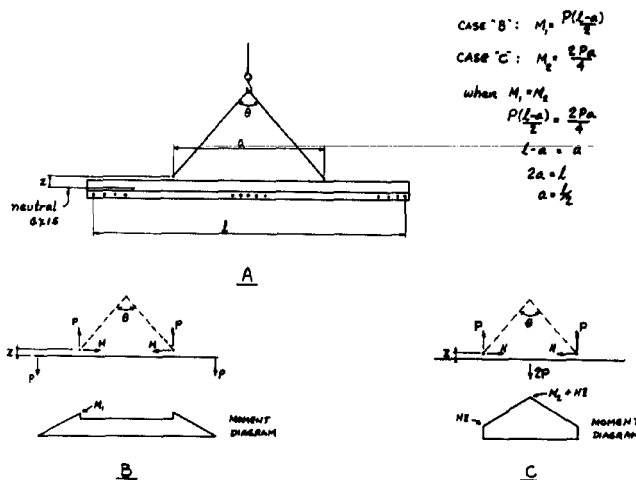Required weld strength = $\dfrac{P}{2(3.4a)} = \dfrac{P}{6.8a}$ K/in

Figure 12.

Figure 13.

5. Select the type of material to be used for the lifting beam, A36, A572-GR.50, and A588 are common choices.
6. Select a trial section.
7. Calculate the exact section properties. Include continuous lug plates, if applicable. If plates are included, make sure they comply with requirements for compact sections. (AISC Specification Section B5.2[1])
8. Check for beam shear capacity.
9. Check for beam bending capacity:
   a. L_c and L_u limits must be reviewed.
   b. Make a bending stress reduction check, if necessary.
   c. Establish the allowance of F_b. (AISC Specification Sect. F1[1])
   d. Check beam in its inverted position if applicable.
10. When torsion is a problem:
    a. Identify possible causes of torsion:
       1. Bent lugs.
       2. Shackle binding.
    b. Consider adding end plates or side plates.
    c. Consider adding stiffeners.
    d. Consider using box shaped sections.
11. Select shackle sizes based on maximum line loads.
12. Design top lugs:
    a. The pin size is determined by shackle selected.
    b. Select a hole size based on this pin size or perhaps a larger anticipated pin size (for future use).
    c. Use critical angle of force and establish a trial shape.
    d. Design weld for top lug. (One should check for a straight pull as well as an angular pull.)
    e. Check full sized pin bearing capacity using a trial plate thickness.
    f. Check for tension failure at sides of hole.
    g. Check for tear-out, should a smaller pin be used.
    h. Check shear capacity at the lug hole.
    i. Check for compliance with dishing failure criteria.
13. Design bottom lugs or continuous plate following a similar procedure as for the top lug.
14. Calculate the weight of the beam assembly including lugs, shackles, slings, and chokers. Compare the actual weight with the assumed weight and adjust forces, if required.
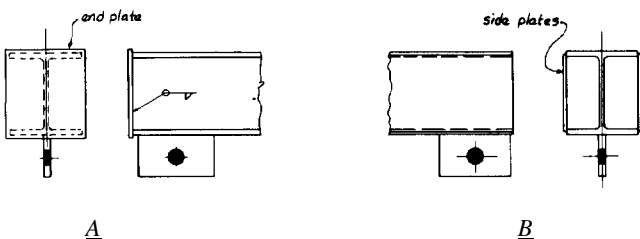
If it is necessary to determine the capacity of an existing lifting beam of unknown potential, an analysis can be made using the following procedure:

1. Measure the beams, lugs, lug locations, pin hole diameter and location, and weld size and extent.
2. Establish the beam properties and type of steel.
3. Identify the critical governing geometric conditions.
4. Calculate force diagram.
5. Calculate shear capacity of the beam.
6. Calculate moment capacity of the beam.
7. Calculate lug plate weld capacities.
8. Calculate bearing capacity of lug plates.
9. Calculate tear-out capacity of lug plates.
10. Calculate shear capacity of lug plates.
11. Establish maximum shackle size and capacity which pin hole diameter and location will accommodate.
12. Calculate weight of beam assembly, including shackles, lines, etc.
13. Select the added factor of safety, usually about 1.8.
14. Identify the governing load from the previous calculations and apply the factor of safety. This will produce a factored load capacity.
    Example:
    Calculated load capacity = 21 kip
    Factor of safety = 1.8
    Weight of lifting beam, shackles, and lines = 2 kip
    Rated load = 21/1.8 – 2 = 9.67 or 4.8 tons

After the beam has been assembled and welded, it is usually cleaned and given a coat (or coats) of rust-inhibitive paint. The color should be a light hue and one which contrasts sharply with the primer colors normally used by the fabricator. White, yellow, buff, and pale blue are popular colors. The lifting capacity of the beam in tons should be clearly stenciled on both sides of the beam in block numbers and letters at least 5 in. in height. If the lifting beam must be used in the upright position only, the top of the beam must be stenciled: USE THIS SIDE UP ONLY. Very often
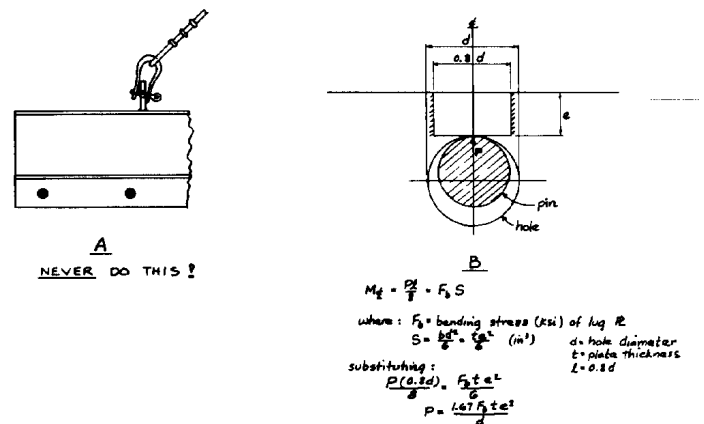

Figure 15.

Figure 14.

the fabricator or erector will want to stencil the company name on the lifting beam for advertising and identification purposes. Although stenciling in paint is the most common means of marking, a more positive method consists of bead welding the messages onto the beam. Welded figures will endure even if the beam is repainted at a future time.

Equally as important as the strength of the lifting beam is the strength of the other components used in conjunction with the beam. These are the lines, chokers, hooks, and shackles. Only a knowledgeable experienced rigger should be entrusted with the selection of these other items.

There are several types and grades of wire rope in common use today. Chains can also be used. A rule of thumb for the strength of wire rope is as follows:[7]

$$\text{Safe working load} = (\text{diameter})^2 \times 8$$

Where safe working load is expressed in tons and diameter of wire rope in inches. Readers are advised to verify the strength of the specific materials and equipment they intend to use.

Example: For 0.5-in. diameter wire rope the safe working load equals $(0.5)^2 \times 8 = 2$ tons. (This is based on a factor of safety of about 5.)

Catalogues of manufacturers and supply houses are excellent sources of information on rigging equipment as are riggers handbooks. References 4 through 8 are good examples.

EXAMPLE

Given:

A concrete contractor must hoist precast concrete panels which weigh up to 8 tons and which vary in length from 6 to 32 feet.

Required:

Design an appropriate lifting beam.

Procedure:

1. The panel weight to be lifted by the beam equals the maximum precast panel weight of 6 tons plus an estimated additional 2 tons for dunnage and chokers. The total is 8 tons (16 kips), including the weight of the lifting beam.

2. The extreme lifting points must be 30 feet apart to match lifting inserts on the longest concrete panels. Two top lifting lugs are selected at 15 feet apart so that maximum positive moment and maximum negative moment are more or less equal. Also, the 15 foot distance will permit the use of normal length slings. (The derivation of length a is shown in Fig. 13.)

   It is decided to use a continuous plate on the bottom of the lifting beam with holes at 1-ft 0-in. centers in order to provide the necessary versatility required by the various panel sizes.

3. Select an additional factor of safety and apply it to the assumed lifted weight.

$$\text{Design load} = 16(1.8) = 28.8 \text{ kips}$$

(At this stage, do not fuss over the fact that some of the lines, lugs, and shackles are above the lifting beam.)

4. Two governing cases will be investigated. Figure 13B shows the loads at the extreme end of the lifting beam and Fig. 13C depicts the load concentrated at the beam center line. The moment diagram for each condition is shown. For arithmetical ease, the lifted weight is equated to $2P$. Hence $P = 28.8/2 = 14.4$ kips. (For the sake of simplifying the freebody diagrams, the beam is now assumed to be weightless.) For the case in Fig. 13B, the maximum moment is $7.5(14.4) = 108$ kip-ft. For the case in Fig. 13C, the maximum moment is 108 kip-ft + $Z(H)$. H is equal to P when q is 90°, which is the maximum which should be permitted by good practice. At this stage Z is estimated to be 10 in. giving a moment of $108 + 0.83(14.4) = 120$ kip-ft.

5. It is decided to use A36 steel.

6. From the tables on page 2-171 of the AISC 9th Edition, *Manual of Steel Construction,* investigate the two cases at hand:
   $M = 108$ kip-ft with length = 30 ft
 $M = 120$ kip-ft with length = 15 ft

   It should be pointed out that the continuous bottom plate is part of a compound section and this should be considered when the trial sections are selected.

   For the first case the table indicates a beam in excess of W18×65 and for the other case a W14×48.

   Obviously, the first case governs. Try a W18×65 with a continuous 6×1 plate.

7. Calculate centroid location and section modulus:

Piece	Area	d	Ad
W18×65	19.1	9.18	175
Plate 6×1	6	21.35	128
	$\Sigma=25.1$		$\Sigma=303$
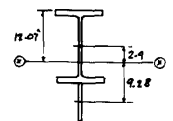
$$d = \frac{Ad}{A} = \frac{303}{25.1} = 12.07 \text{ in.}$$

Piece	A	x	Ax^2	I_o	ΣI
W18	19.1	2.9	161	1070	1231
Plate	6	9.28	517	—	517
					$\Sigma=1748$ in.^{4}

$$c = 9.28 + 3 = 12.28 \text{ in.}$$

$$S = \frac{\Sigma I}{c} = \frac{1748}{12.28} = 142 \text{ in.}^3$$

8. Check beam shear capacity:

Allowable $V = 0.4F_y (A) = 0.4(36)(18.35 \times 0.45 + 6(1)) = 205$ kip.

Since 205 kip exceeds the actual shear of 14.4 kip, the member is OK in this regard. (Shear is hardly ever critical in lifting beams.)

9. Check for beam bending capacity:

$$L_c = \frac{20,000}{d/A_f \, (F_y)} = \frac{20,000}{3.22(36)} = 172 < 12(30) \text{ (AISC Spec. F1.1)}$$

therefore a reduced F_b must be calculated (AISC formula F1-8 governs).

$$F_b = \frac{12,000A_f}{ld} = \frac{12,000(7.59)(.75)}{30(12)(18.35)} = 10.34 \text{ ksi}$$

Allowable $M = F_bS = 10.34(142) = 1468$ kip-in. $= 122$ kip-ft > 108 **OK**

10. Torsion is not a problem in this example, as stated previously.

11. Select shackle size for upper slings:

From Fig. 13C the maximum line load is $14.4 \times 1.414 = 20.4$ kip when angle q is at the 90° limit.

A 12-ton shackle is selected (see Fig. 5). The jaw width is 2¼ in., pin diameter is $1\frac{3}{8}$ in., flange diameter is 3 in., and inside length is $4\frac{11}{16}$ in. Select shackle size for lower slings: referring to Fig. 13B the load is 14.4 kip and a 8½-ton shackle would be in order. For Fig. 13C the load is 28.8 kip and a 17-ton shackle will suffice.

12. Design top lug:

A trial lug plate thickness of 1¼ in. is chosen to be compatible with the 12-ton shackle. A trial size is shown in Fig. 16A with the dimensions picked to accommodate the 12-ton shackle. The work line of the diagonal load is made to intersect the center of the weld when the load is at its maximum practical angle of 45°. At this angle the load is 20.4 kip.

$$\text{Required weld } = \frac{20.4}{2(12)} = 0.85 \text{ kip/in.}$$

To meet AISC Specification Table J2.4, a minimum size fillet weld of $\frac{5}{16}$ in. is required.

Check the weld requirements for a vertical pull of 14.4 kip:

Using the Line Method (Omer Blodgett, *Design of Welded Structures,* pages 7.4-6[2]).

$$S_w = \frac{d^2}{3} = \frac{12^2}{3} = 48 \text{ in.}^2$$

$$M = 3(14.4) = 43 \text{ kip-in.}$$

$$f_1 = \frac{M}{S_w} = \frac{43}{48} = 0.9 \text{ kip.in.}$$

$$f_2 = \frac{14.4}{24} = 0.6 \text{ kip/in.}$$

$$f_w = f_1 + f_2 \; = 0.9 + 0.6 = 1.5 \text{ kip/in.}$$

$\frac{5}{16}$-in. fillet weld $\rightarrow$ 4.6 kip/in. > 1.5 **OK**

In order to keep the weather out, use an all around weld. The hole is made 1½ in. dia. to accept the 1⅜ in. dia. pin. The corner of the plate is lopped off to accommodate the inside length of the shackle minus the line diameter.

Min. $a = 0.5(d) = 0.5(1.5) = 0.75$ in. $< 3 - 0.75$ **OK**

Min. $e = 0.67(d) = 0.67(1.5) = 1.0$ in. < 2.25 **OK**

Check for dishing:

Min. $t = 0.25(d) = 0.375$ in. < 1.25 **OK**

Check for tension tearing at sides of hole:

Ultimate Load $P_u = 2atF_u = 2(2.25)(1.25)58 = 326$ kip

Apply factor of safety of 5.

Design $P = 326/5 = 65$ kip > 15 **OK**

Check for lug tearout:

$$\text{Allowable } P = \frac{1.67F_bte^2}{d} = \frac{1.67(24)(1.25)(3 - 0.75)^2}{1.5}$$

$= 169$ kip > 20.4 **OK**

13. Design of bottom lugs:

Instead of individual lugs, it was decided previously to use a continuous plate with holes at 1 ft 0 in. on center. The assumed thickness of 1 in. easily accommodates the jaws of the 8½-ton shackle. The holes will be made 1½-in. dia. to accept the $1\frac{1}{8}$-in. dia. pin or a larger pin, if desired. (If it is anticipated that the beam will be used as in Fig. 4B, the center hole should be made 1¾-in. dia. to accept the $1\frac{5}{8}$-in. dia. pin of the 17-ton shackle.)
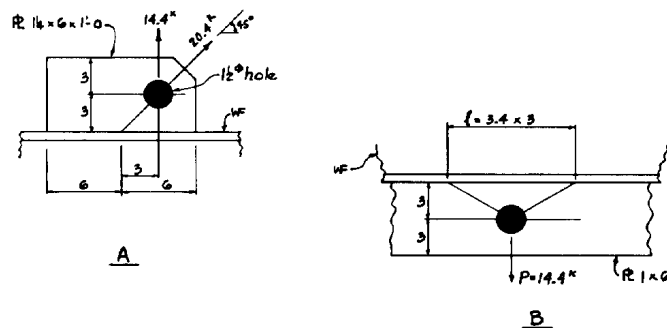

Figure 16.

From Fig. 12 it can be seen the effective length of weld = 3.4(3) = 10.2 in.

$$\text{Required weld size} = \frac{14.4}{2(10.2)} = 0.71 \text{ kip/in.}$$

The thickness of material dictates a minimum fillet weld of $\frac{5}{16}$ in. $\rightarrow$ 4.6 kip/in. > 0.71 **OK**

Do not be tempted to use an intermittent weld. For weather protection and fatigue considerations use continuou welds. By inspection it is seen that tear-out is not critical. If a continuous plate is to be considered as a compression part of a compound section, its width to thickness ratio *w/t* should not exceed $65 / \sqrt{F_y}$ or it will not qualify for compact section status.

14. Calculate exact weight of the assembly:

Beam	31×65	=	2015 lb
Plate	31×20.4 =		632 lb
Two top lugs	2×25.5 =		51 lb
Two 12-T shackles	2×9.24 =		18 lb
Two 8½-T shackles	2×4.63 =		9 lb
50 ft of wire rope +			
loops, thimbles, hook, etc.		=	400 lb
		Total	3125 lb

This is well within the original estimate of two tons so further refinement is unnecessary.

A review of this design example identifies the bending moment as the governing criteria. The section furnished supplied a moment capacity when used at the 30-ft length of 122 kip-ft. which exceeds the required 108 kip-ft. Consequently, the rated capacity of the beam could be increasedcapacity of the beam could be increased slightly over the 8-ton requirement. However, such refinement is usually not pursued in view of the variety of assumptions already incorporated into the design procedure.

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