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Design/Evaluation of Overhead Lifting Lugs

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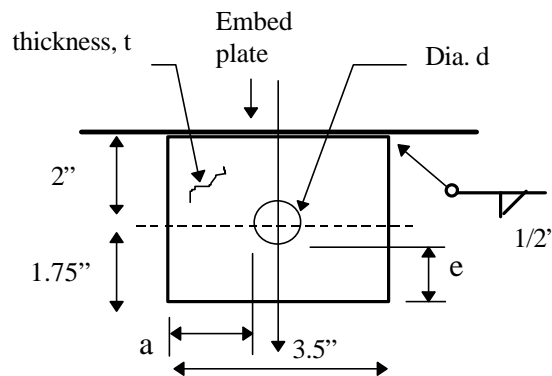
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Introduction

There is very little published information available on the subject of the design/analysis of lifting lugs. Therefore, design engineers are left without adequate technical guidance on this subject. The following provides a systematic method.

Example of an Overhead Lifting Lug



$$\text{kip} = 1000 \cdot \text{lb}$$

$$t = 1.25 \cdot \text{in}$$

$$\text{ksi} = 1000 \cdot \frac{\text{lb}}{\text{in} \cdot \text{in}}$$

$$d = 1.25 \cdot \text{in}$$

$$a = 1.125 \cdot \text{in}$$

$$e = 1.125 \cdot \text{in}$$

$$F_u = 58 \cdot \text{ksi}$$

$$F_y = 36 \cdot \text{ksi}$$

Geometric Guidelines:

There are some geometric guidelines to be considered as recommended in Reference 1. They will be called Rule 1 and Rule 2.

Rule 1:

The dimension "a" must be greater than or equal to half the hole diameter, d.

$$\text{i.e. } a \geq \frac{1}{2} \cdot d$$

For this example, $a = 1.125$ " and since it is greater than $\frac{1}{2} \cdot d$ which is 0.625". Rule 1 is satisfied.

$$\text{Rule}_1 := \text{if}(a \geq 0.5 \cdot d, \text{"OK"}, \text{"NG"})$$

$$\text{Rule}_1 = \text{"OK"}$$

Rule 2:

The dimension "e" must be greater than or equal to 0.67 times the hole diameter, d.

Thus, $e \geq 0.67 \cdot d$

For this example, $e = 1.125"$ and since it is greater than $0.67 \cdot d$ which is $0.8375"$. Rule 2 is satisfied.

Rule_2 := if($e \geq 0.67 \cdot d$, "OK", "NG")

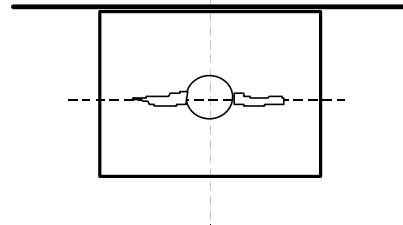
Rule_2 = "OK"

Evaluation based on Failure Modes:**Failure Mode 1:**

This failure mode involves tension failure on both sides of the hole. Therefore, the ultimate tensile load is given by:

$$P_u := 2 \cdot a \cdot t \cdot F_u$$

$$P_u = 163.12 \text{ kip}$$



A factor of safety of 5 is common for lifting components. Therefore, using a factor of safety of 5, the working load is:

$$P_{w1} := \frac{P_u}{5} \quad P_{w1} = 32.625 \text{ kip}$$

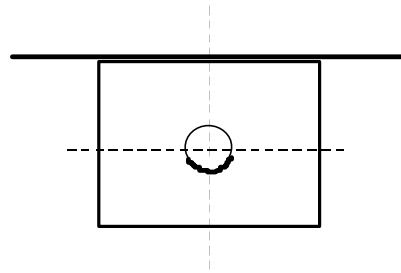
Failure Mode 2:

This failure mode involves bearing failure at the pin/lifting lug interface. Often the pin diameter is much less than the hole diameter. Let us assume a pin diameter 1/2" less than the hole diameter. Using a bearing stress of $0.9 F_y$, and a "factor" of 1.8, we have (See Note 1):

$$d_{pin} := d - 0.50 \text{ in}$$

$$P_{w2} := \frac{0.9 \cdot F_y \cdot t \cdot d_{pin}}{1.8}$$

$$P_{w2} = 16.875 \text{ kip}$$

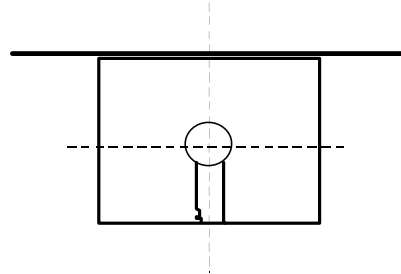


Failure Mode 3:

This failure mode involves shear failure as the pin tries to push out a block of steel through the edge of the lug plate. The shear area is twice the cross-sectional area beyond the hole for the pin. Thus:

$$P_{w3} := \frac{2 \cdot 0.4 \cdot F_y \cdot e \cdot t}{1.8}$$

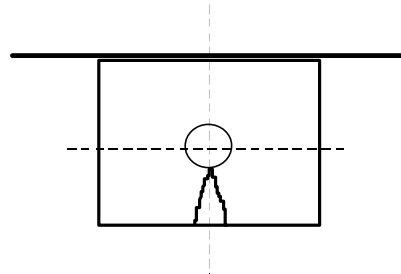
$$P_{w3} = 22.5 \text{ kip}$$

**Failure Mode 4:**

This failure mode involves tensile failure as the pin tries to push out a block of steel through the edge of the lug plate. Assuming a block of steel $0.8d$ in length, allowable load is given by:

$$P_{w4} := \frac{1.67 \cdot 0.67 \cdot F_y \cdot e^2 \cdot \frac{t}{d}}{1.8}$$

$$P_{w4} = 28.322 \text{ kip}$$

**Failure Mode 5:**

This failure mode involves the out-of-plane buckling failure of the lug. Per Ref. 1, this failure is prevented by ensuring a minimum thickness of lug of 0.5 inches and 0.25 times the hole diameter d .

In this example, since $0.25 \times 1.25 = 0.3125$ " and the thickness of the lug is 1.25", this failure mode does not control.

$$\text{Rule_3} := \text{if}(t \geq 0.25 \cdot d, \text{"OK"}, \text{"NG"}) \quad \text{Rule_3} = \text{"OK"}$$

$$\text{Rule_4} := \text{if}(t \geq 0.5 \cdot \text{in}, \text{"OK"}, \text{"NG"}) \quad \text{Rule_4} = \text{"OK"}$$

AISC Code Checks per Section D3.2:

The above section of AISC Code has three separate geometry checks that can be applied to the lifting lug. If these requirements are not met, a smaller value for "a" should be used for the calculation of tensile capacity, a_{eff} .

Requirement 1:

This requirement states that the minimum net area beyond the pin hole, parallel to the axis of the member (A_1), shall not be less than 2/3 of the net area across the pin hole (A_2).

$$\begin{aligned} A_1 &:= t \cdot e & A_2 &:= 2 \cdot a \cdot t \\ A_1 &= 1.406 \text{ in}^2 & A_2 &= 2.813 \text{ in}^2 \end{aligned}$$

Since 2/3 of A_2 is 1.875 in^2 which is more than A_1 , this requirement is not satisfied.

Therefore, the tensile capacity of the lug must be based on a reduced "a" dimension which will satisfy this requirement.

Requirement 2:

This requirement states that the distance transverse to the axis of a pin-connected plate from the edge of the pin hole to the edge of the member, i.e. dimension a, shall not exceed 4 times the thickness at the pin hole.

Since 4 times thickness is $4 \times 1.25" = 5"$ and is greater than $1.125"$. This requirement is satisfied.

Requirement 3:

This requirement states that the diameter of the pin hole shall not be less than 1.25 times distance from the edge of pin hole to the edge of plate, i.e. dimension a.

Since 1.25 times "a" is $1.25 \times 1.125 = 1.406"$ and is greater than the diameter of hole of $1.25"$. This requirement is not satisfied. Therefore, the tensile capacity of the lug must be based on a reduced "a" dimension which will satisfy this requirement.

Combining these three requirements into a single "formula" we have:

$$\begin{aligned} \text{AISC}_{\min} &:= \left(a \quad 1.5 \cdot \frac{e}{2} \quad 4 \cdot t \quad \frac{d}{1.25} \right) \\ a_{\text{eff}} &:= \min(\text{AISC}_{\min}) \end{aligned}$$

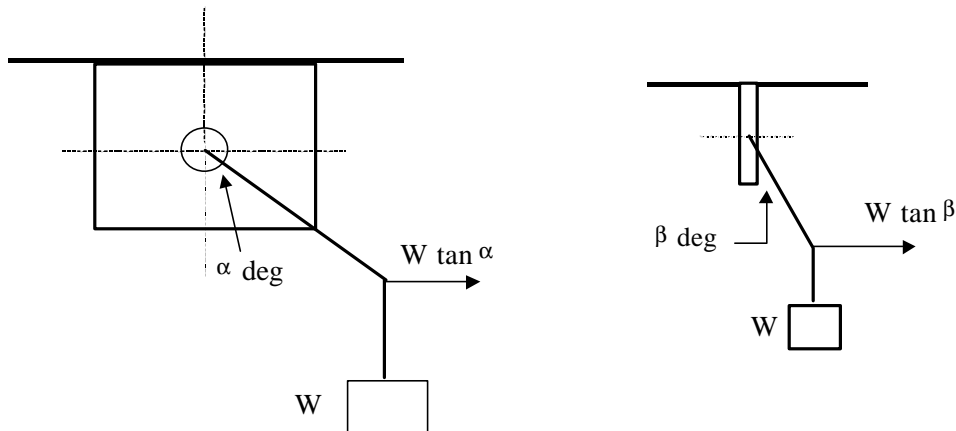
Therefore, load capacity based on AISC is given by:

$$P_{w5} := \frac{2 \cdot a_{\text{eff}} \cdot 0.45 \cdot F_y \cdot t}{1.8}$$

$$P_{w5} = 18.984 \text{ kip}$$

Weld between Lug and Base Plate:

This is typically the weak link in an overhead lifting lug, due to off-set loading. In general, the lug is rarely directly over the item to be rigged. Conservatively, let us assume that the off-set is a maximum of 45 degrees in the plane of the lug and 20 degrees normal to the plane of the lug. The additional loads due to off-set can be determined by statics to be as follows:



Therefore, the maximum load W that can be applied can be calculated as follows:

$W := 1 \cdot \text{kip}$ This is an initial guess for Mathcad

$t_w := 1.25 \cdot \text{in}$ Length of welds along lug thickness

$l := 2 \cdot \text{in}$ Lever arm

$w := 3.5 \cdot \text{in}$ Length of weld along lug width

$f_{\max} := \frac{7423}{1.8} \cdot \frac{\text{lb}}{\text{in}}$ for 1/2 in. fillet weld and 21 ksi allowable shear stress on effective throat

$\alpha := 45$

$\beta := 20$

$$f_1(W) := \frac{W}{(w + t_w) \cdot 2} + \frac{W \cdot \tan(\beta \cdot \text{deg}) \cdot l}{\left(w \cdot t_w + \frac{t_w^2}{3} \right)} + \frac{W \cdot \tan(\alpha \cdot \text{deg}) \cdot l}{\left(w \cdot t_w + \frac{w^2}{3} \right)}$$

Based on Ref. 3

$$f_2(W) := \frac{W \cdot \tan(\beta \cdot \text{deg})}{2 \cdot (w + t_w)}$$

$$f_3(W) := \frac{W \cdot \tan(\alpha \cdot \text{deg})}{2 \cdot (w + t_w)}$$

$$P_{w6} := \text{root} \left[\left(f_1(W)^2 + f_2(W)^2 + f_3(W)^2 \right)^{0.5} - f_{\max}, W \right]$$

$$P_{w6} = 8.198 \text{ kip}$$

Lug Base Material:

The analysis is similar to the weld above except that there is no interaction between tension and shear. The capacity is based on the maximum tensile stress at the base of the lug:

$$W := 1 \cdot \text{kip}$$

$$f_{\max} := \frac{0.75 \cdot F_y}{1.8}$$

$$l_w := 2 \cdot a + d \quad \text{Lug width}$$

$$f_1(W) := \frac{W}{l_w \cdot t} + \frac{W \cdot \tan(\beta \cdot \text{deg}) \cdot l}{\left(l_w \cdot \frac{t^2}{6} \right)} + \frac{W \cdot \tan(\alpha \cdot \text{deg}) \cdot l}{\left(\frac{l_w^2}{6} \cdot t \right)}$$

$$P_{w7} := \text{root} \left[\left(f_1(W) \right) - f_{\max}, W \right]$$

$$P_{w7} = 8.283 \text{ kip}$$

Conclusion:

$$\text{Capacity} := (P_{w1} \ P_{w2} \ P_{w3} \ P_{w4} \ P_{w5} \ P_{w6} \ P_{w7})$$

$$\text{Cap}_{\text{allow}} := \min(\text{Capacity})$$

$$\text{Cap}_{\text{allow}} = 8.198 \text{ kip}$$

Note variation in capacities for each attribute

$$P_{w1} = 32.625 \text{ kip} \quad P_{w4} = 28.322 \text{ kip}$$

$$P_{w2} = 16.875 \text{ kip} \quad P_{w5} = 18.984 \text{ kip}$$

$$P_{w3} = 22.5 \text{ kip} \quad P_{w6} = 8.198 \text{ kip}$$

$$P_{w7} = 8.283 \text{ kip}$$

If additional capacity is desired, the angles α and β can be restricted as needed to increase the capacity of the lug. In the above example, if these angles are made equal to zero, the maximum capacity will increase to 16.875 kips.

References:

1. David T. Ricker, "Design and Construction of Lifting Beams", Engineering Journal, 4th Quarter, 1991.
2. AISC Manual of Steel Construction (ASD), Ninth Edition, 1989
3. Omer Blodgett, "Design of Welded Structures", 1966

Notes:

1. As discussed in Reference 1, using a "factor" of 1.8 on AISC allowables results in a factor of safety of 5 for A36 steel. This is in line with ASME B30.20 which requires a design factor of 3 on yield strength and ANSI N14.6 which requires a design factor of 3 on yield strength and 5 on ultimate strength. This is also in line with the load ratings for other components of the lifting assembly such as slings, shackles, etc.