



ESDU 84039

Issued April 1986
With Amendments A and B
May 2006

Strength of angles and club-foot fittings (transmitting tensile loads)

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STRENGTH OF ANGLES AND CLUB-FOOT FITTINGS (TRANSMITTING TENSILE LOADS)

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STRENGTH OF ANGLES AND CLUB-FOOT FITTINGS (Transmitting tensile loads)

1. INTRODUCTION

This Item deals with methods of estimating the stresses, deflection and ultimate load capacity of angles and club-foot fittings that are assembled so as to provide a tensile load path across a join or through an intervening member. Sketch 2.1 illustrates such an assembly that is designed to transmit a direct tensile load across a bulkhead. There is a wide variety of designs of such joints and Sketch 2.2 illustrates some of the more common components used.

For even the simplest joint the complex behaviour under load, resulting from the interplay of stiffnesses of the various elements, is not amenable to accurate analysis. Accordingly, it is only possible to provide simplified models that illustrate the major effects of the many factors that influence joint strength or deflection. Such models have the advantage that they prescribe the bounds of influence of the major factors.

2. NOTATION

The following notation relates to the assembly illustrated in Sketch 2.1 but many of the elements of that assembly occur in most angles or club-foot fittings.

Throughout this Item the component parts of the joint will be referred to using the names given in the labels of Sketch 2.1. Thus, for example, the main fastener holding the angles together will be termed the bolt although the data can be related to other types of fastener.

2.1 General

E	modulus of elasticity of material	N/m^2	lbf/in^2
G	shear modulus of material	N/m^2	lbf/in^2
I	second moment of area about z-axis	m^4	in^4
l	length	m	in
t	thickness	m	in
w	width	m	in

2.2 Angle

a	distance from bolt centre-line to leg centre-line (see Sketch 2.1)	m	in
e	length of toe (see Sketch 2.1)	m	in
t_2	0.2 per cent proof stress of angle material	N/m^2	lbf/in^2
r	internal radius at bend (or corner) between leg and foot	m	in

Issued December 1984
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2.3 Nut and Bolt – Assembly

c	distance from bolt centre-line to line of application of load	m	in
d	nominal diameter of bolt	m	in
d'_n	effective diameter of influence on foot of bolt head or nut	m	in
d_w	outer diameter of washer	m	in

2.4 Loads, Moments, Stresses and Deflections

f	direct stress	N/m ²	lbf/in ²
M	moment	N m	lbf in
M_{max}	maximum permissible bending moment	N m	lbf in
P	load applied to joint (tensile positive)	N	lbf
P_b	load in bolt	N	lbf
P_{bt}	bolt pretension	N	lbf
p_{bult}	nominal axial tensile strength of bolt	N	lbf
q	shear stress	N/m ²	lbf/in ²
y_h	heel lift	m	in

2.5 Stiffnesses

K	axial or direct stiffness	N/m	lbf/in
μ	rotational stiffness	N m/rad	lbf in/rad

2.6 Suffixes and Primes

A prime indicates an effective value of a quantity

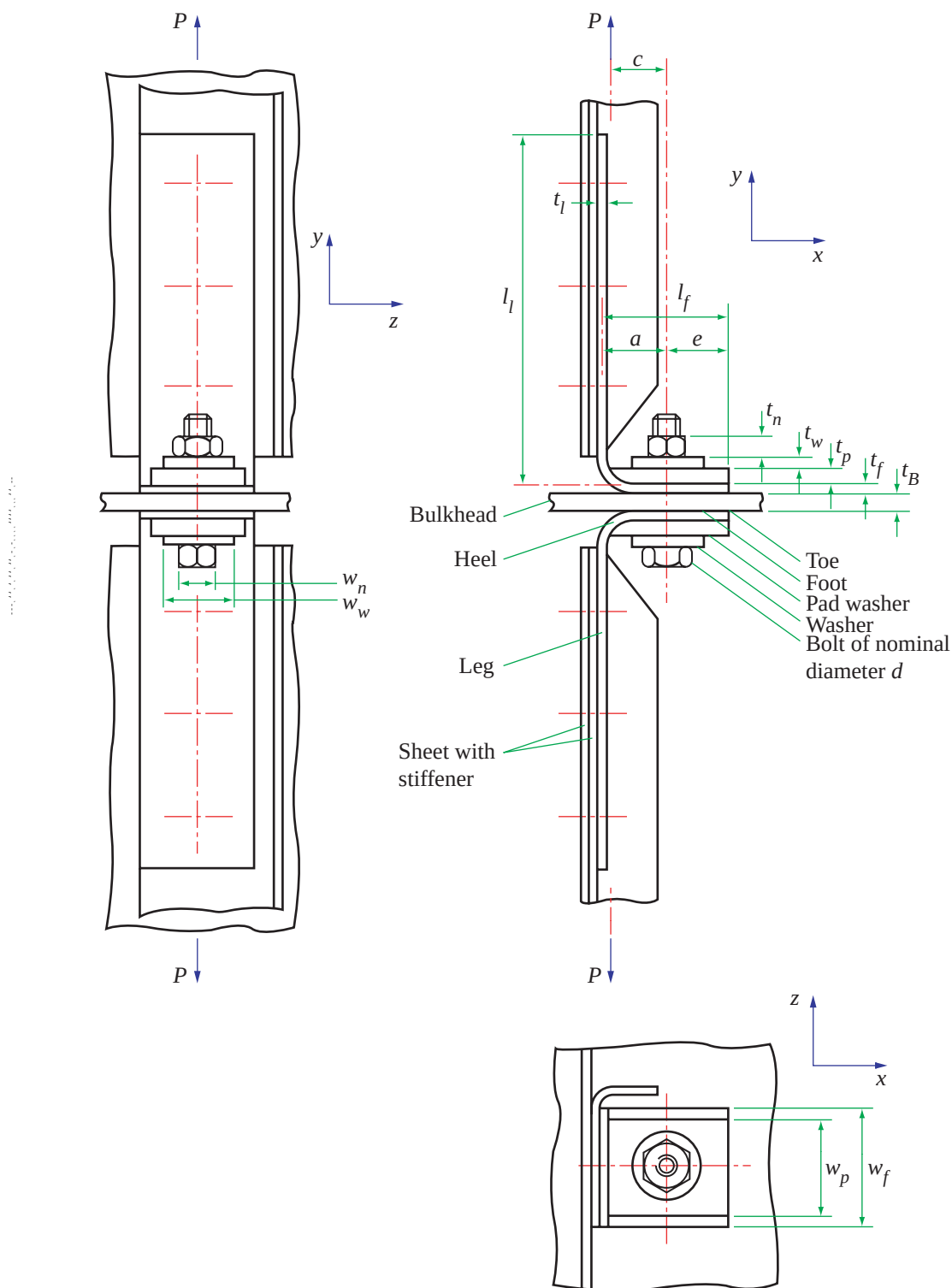
<i>B</i>	bulkhead
<i>b</i>	bolt or 'at bolt', for loads and moments
<i>f</i>	foot
<i>h</i>	'at heel', for loads and moments
<i>l</i>	leg
<i>n</i>	nut or bolt head
<i>p</i>	pad washer (see Section 5.1)
<i>w</i>	washer under nut or bolt head

2.7 Conventions

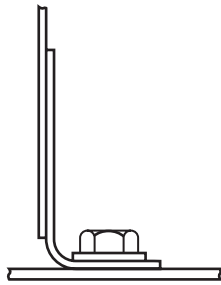
Positive loads, stresses and strains are tensile.

<i>x</i>	parallel to foot, see Sketch 2.1
<i>y</i>	parallel to leg, see Sketch 2.1
<i>z</i>	orthogonal to <i>x</i> - and <i>y</i> -directions, see Sketch 2.1

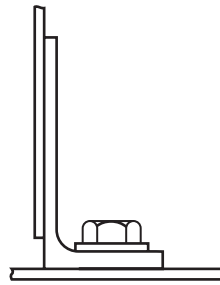
Both SI and British units are quoted but any coherent system of units may be used.



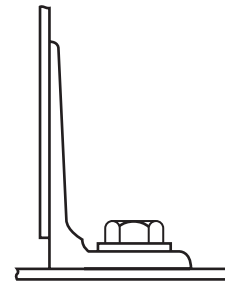
Sketch 2.1 Details of simple assembly with notation



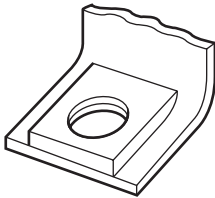
(a) Simple formed angle



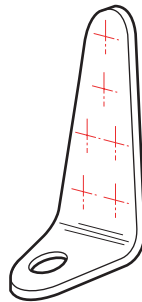
(b) Extruded section angle



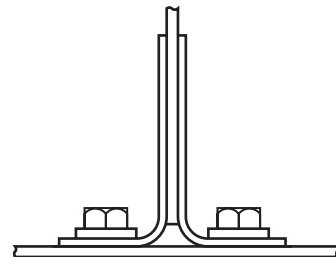
(c) Cast angle



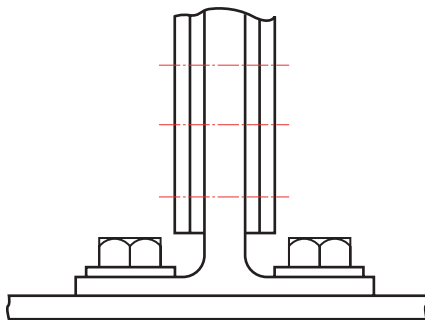
(d) Rectangular pad washer



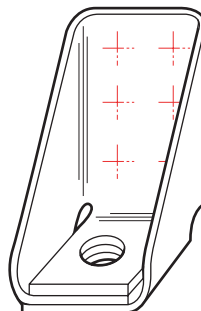
(e) Tapered leg and foot



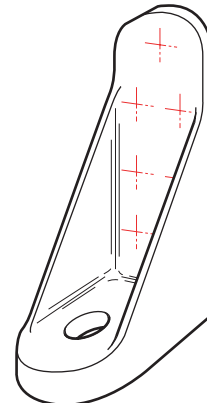
(f) Double-sided (a) type



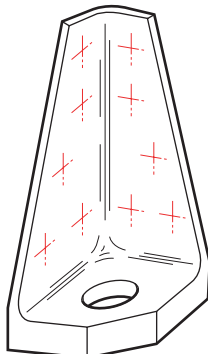
(a) Double-sided machined angle



(h) Formed angle with side support



(i) Machined angle



(j) Corner fitting with side support
on adjacent sides

Sketch 2.2 Various designs of club-foot angles

3. CONSIDERATION OF FAILURE CRITERIA

Joints of the types illustrated in Sketches 2.1 and 2.2 can fail either in static strength, in fatigue or deflect or deform beyond acceptable limits. Normally the maximum stress in the angle under a factored load would be compared with an allowable stress in the angle material. However, the maximum stress is usually the result of bending combined with other loads and is particularly difficult to estimate. Furthermore, the bending can, in the more ductile materials, lead to formation of one or more plastic hinges. These give a non-linear load deflection behaviour in which the deformations can be excessive giving significantly modified geometry. This can lead to a final failure that may be in a different mode to that which was assumed in the simple linear analysis used to determine the first plastic hinge. The final load may also be well above that causing the first plastic hinge to develop. This is illustrated by Figure 1 which shows a curve of deflection, measured as the heel-lift, plotted against increasing applied load obtained from tests on the joint assembly shown with the figure. Initially the load causes no heel-lift owing to bolt pretensioning. When heel-lift occurs it is approximately linear and therefore almost completely recoverable on removal of the load. When yielding occurs the slope changes. As each location within the assembly yields the slope changes with the general trend reducing the slope until failure occurs. However, in practice significant distortion is usually – although not always – undesirable since it can cause redistribution of loads into members not designed to accept them. In the less ductile (more brittle) materials existing stress concentrations are likely to absorb all the available plasticity so that failure occurs before significant plastic hinges can develop. Because of this, failure is not preceded by noticeable plastic deformation.

As a result of the behaviour described in the previous paragraph the choice of design criteria and material for the angle are interlinked. In many designs the stresses will be required to be within the elastic limit of the material under working loads. A further requirement may be the maintenance of a prescribed overall joint stiffness or the prevention of leakage past the joint. Because limitations on deflection or deformation are peculiar to the function of the joint each design must be considered separately and a suitable criterion devised that ensures that the assembly performs its function satisfactorily. Most angles are manufactured from ductile materials and the joints are designed against a proof stress limit and against a deflection limit, which is fully recoverable on removal of load. The overload case, and its associated deflection and/or deformation, is also of interest as is the ultimate failure load. Sufficient fatigue strength under the expected service loading must also be ensured.

This Item considers only failure of the angle or nut and bolt assembly. The following is a list of the possible failure modes in typical joints. The list cannot be exhaustive owing to the wide variety of designs possible.

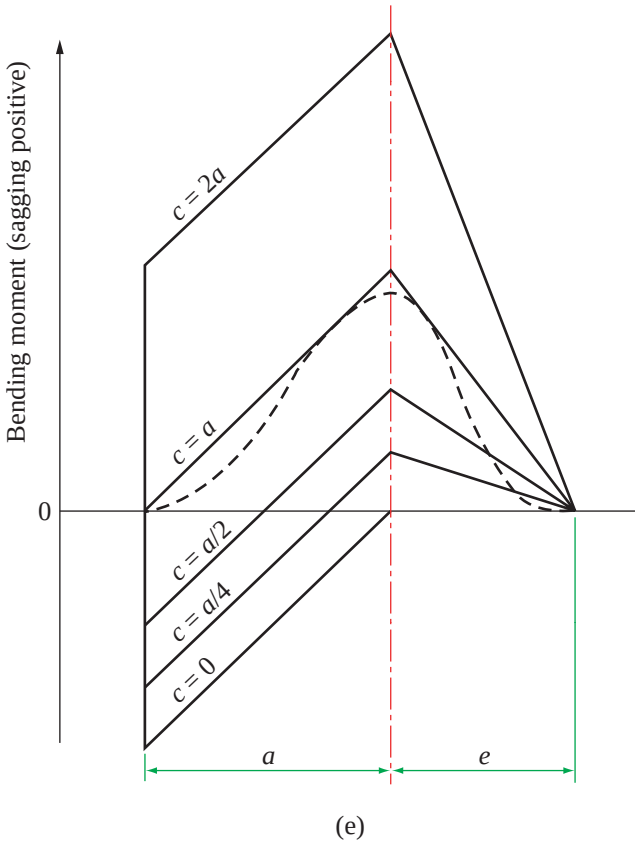
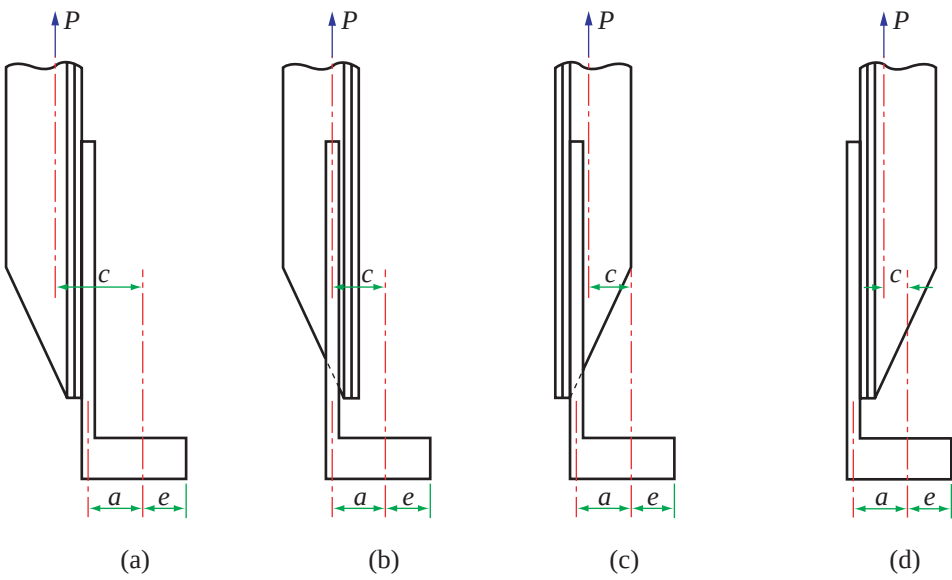
- (a) Nut and/or bolt failures
 - (i) Thread failure, either thread stripping or direct tensile failure.
 - (ii) Failure of shank at junction with head under combined tension and bending.
 - (iii) Unacceptable separation.
- (b) Foot failures
 - (i) Break at bolt hole.
 - (ii) Break near edge of nut or bolt head nearest heel, under combined bending and shear.
 - (iii) Bearing and/or shear failure allowing nut or bolt head (with washer) to pull through foot.
 - (iv) Break below heel at start of corner radius.
 - (v) Unacceptable deformation.
- (c) Leg failures
 - (i) Break above heel at start of corner radius.

- (ii) Leg-to-sheet/stiffener attachment (for example, rivet failures in shear, bearing or head failure).
- (iii) Break at critical section in leg (for example, first rivet).
- (iv) Unacceptable deformation.

4. DESCRIPTION OF BEHAVIOUR OF A SIMPLE ASSEMBLY UNDER LOAD

The behaviour of a simple club-foot fitting (such as those of Sketches 2.2(a), (b) and (c)) under load is largely governed by the deflections and rotations of the foot and heel and the behaviour of the nut and bolt assembly and the region of the foot that they clamp. Although these two major facets are interlinked it is convenient to describe them separately and then to comment on their interaction.

The load is usually applied to the leg of the angle by a major load bearing structural member, such as a stiffener, usually with an associated sheet as shown in Sketch 2.1. Typically such structural members are capable of providing both lateral (x-direction) and rotational restraint against movement of the leg under load. Such restraint comes into play when joint deflections or deformations occur. Major movements are vertical movement of the leg coupled with a rotation about a point in the foot somewhere between the heel and the bolt. The rotation principally occurs as a result of the non-alignment of the bolt with the load path. Sketches 4.1(a) to (d) show four simple arrangements of the leg and surrounding structure. Sketches 4.1(c) and (d) have much reduced moments at the heel of the angle and therefore less rotation would be expected. Sketch 4.1(e) shows, for the simplified case of a totally rigid foot, how the bending moment diagram for the foot changes with the distance c . Note that as c is reduced the bending moment at the bolt also decreases. When $c = a/2$ the bending moments at the bolt and heel are equal but if $c < a/2$ the bending moment at the heel exceeds that at the bolt. The dashed line on Sketch 4.1(e) indicates the form of the bending moment diagram of a practical foot when $c = a$.



Sketch 4.1 Effect of fastener position in relation to load line on foot bending moments

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