22.3.1.2 Ultimate limit state

For confirmatory tests to determine if the ultimate resistance is adequate, the applied force shall be that due to the factored loads, as specified by Clause 6.2, divided by the appropriate resistance factor from Clause 6.4.

22.3.2 Performance tests

Note: *Performance tests defined in this Clause are meant to determine the maximum load that can be carried prior to the attainment of an agreed level of distress.*

22.3.2.1 Nominal Resistance

For performance tests, the highest load that the joint, member, or assembly can sustain without rupture, collapse, or excessive deformation shall be measured. The nominal resistance shall be taken as the mean of the ultimate test loads minus *k* standard deviations:

$R_n = X_m - k\sigma$

where

R_n = nominal resistance

X_m = mean of test loads

k = statistical coefficient based on the number of tests n. k is a one-sided factor for 99% of the population exceeding R_n with a confidence of 95%. Values of k shall be as listed in Table 10

σ = standard deviation

Excessive deformation shall be a measurable distortion that is agreed by the purchaser or the purchaser's representative.

Table 10
Statistical coefficient *k*
(See Clause 22.3.2.1.)

n	***k***	***n***	***k***	***n***	***k***
3	10.55	14	3.59	25	3.16
4	7.04	15	3.52	30	3.06
5	5.74	16	3.46	35	2.99
6	5.06	17	3.42	40	2.94
7	4.64	18	3.37	45	2.90
8	4.35	19	3.33	50	2.86
9	4.14	20	3.30	60	2.80
10	3.98	21	3.26	70	2.76
11	3.85	22	3.23	80	2.73
12	3.75	23	3.21	90	2.70
13	3.66	24	3.18	100	2.68

22.3.2.2 Adjustment for variation in yield and ultimate strength and dimensions

If the yield or ultimate strength of the material of the test item exceeds the specified value, the measured test loads shall be multiplied by the following:

a) for the gross area in tension or bending,

$$\left(\frac{A}{A'}\right)\frac{F_y}{F'_y}$$

b) for the net area in tension or bending,

$$\left(\frac{A}{A'}\right)\frac{F_u}{F'_u}$$

For failure due to buckling, the test load shall be multiplied by:

$$\frac{F_y}{F'_y} + \left(\frac{\bar{\lambda}}{1.5}\right)\left(\frac{1 - F_y}{F'_y}\right) \leq 1$$

where

A = nominal area, mm²

A' = actual area, mm²

F_y = specified yield strength, MPa

F'_y = measured yield strength, MPa

F_u = specified ultimate strength, MPa

F'_u = measured ultimate strength, MPa

$\bar{\lambda}$ = normalized slenderness (see Clause 10.1.2)

22.3.2.3 Adjustment for roofing and siding thicknesses

When panels of the same configuration with only different aluminum material thicknesses are tested, the nominal flexural resistance for intermediate thicknesses of the aluminum material may be interpolated using the following equation if

a) the panel configuration with the thinnest and thickest material thicknesses are tested;

b) the panel mode of fail is in flexure.

$$\log M_i = \log M_1 + \left(\frac{\log t_i - \log t_{min}}{\log t_{max} - \log t_{min}}\right)(\log M_2 - \log M_1)$$

where

M_i = nominal flexural resistance of member of intermediate thickness t_i, N•mm

M_1 = nominal flexural resistance of member of thinnest thickness t_{min}, N•mm

M_2 = nominal flexural resistance of member of thickest thickness t_{max}, N•mm

t_i = thickness of intermediate thickness material, mm

t_{min} = thickness of thinnest material tested, mm

t_{max} = thickness of thickest material tested, mm

23 Fatigue

23.1 General

In addition to meeting the fatigue requirements of Clause 23, all members and connections shall meet the requirements for the static load conditions using the factored loads. Specified loads shall be used for all fatigue calculations. Load effects shall be calculated using ordinary elastic analysis and the principles of mechanics of materials and include stresses that might result from bending moments due to joint eccentricities. A specified load less than the maximum specified load but acting with a greater number of cycles can govern and therefore shall be considered. Members and connections subjected to fatigue loading shall be designed, detailed, and fabricated so as to minimize stress concentrations and abrupt changes in cross-section.

23.2 Live-load-induced fatigue

23.2.1 Design criteria

For load-induced fatigue and constant amplitude fatigue loading, the following design requirement shall apply:

$$F_{sr} \geq f_{sr}$$

where

F_{sr} = fatigue resistance, MPa

$$= \left(\frac{\gamma}{nN}\right)^{m} \geq F_{srt}$$

where

γ = fatigue life constants (see Figure 3, Tables 11 and 12)

n = number of stress range cycles at given detail for each application of load

N = number of applications of load

F_{srt} = constant amplitude threshold stress range (see Figure 3, Tables 11 and 12), MPa

f_{sr} = calculated stress range at the detail due to passage of the fatigue load including stresses due to eccentricities, MPa

m = fatigue life constant (see Figure 3, Tables 11 and 12)

23.2.2 Cumulative fatigue damage

The total damage that results from variable amplitude fatigue loading shall satisfy

$$\sum\left[\frac{(nN)_i}{N_{fi}}\right] \leq 1.0$$

where

$(nN)_i$ = number of expected stress range cycles at stress range level i, f_{sri}

N_{fi} = number of cycles that would cause failure at stress range level i, f_{sri}, obtained from Figure 4 for the appropriate fatigue category. Alternatively, it may be calculated as follows:

$$N_{fi} = \gamma f_{sri}^{\;-m}$$

The summation shall include both stress cycles above and below F_{srt}.

The fatigue constant γ shall be as specified in Table 12.

23.2.3 Fatigue constants and detail categories

The fatigue constants γ, m, and F_{srt} shall be as specified in Table 12 and shown in Figure 4. The detail categories shall be obtained from Table 11 and Figure 3.

23.3 Distortion-induced fatigue

23.3.1 General

Members and connections shall be detailed to minimize distortion-induced fatigue that can occur in regions of high strain at the interconnection of members undergoing differential displacements. Whenever practicable, all components that make up the cross-section of the primary member shall be fastened to the interconnection member.

23.3.2 Width-to-thickness ratios of transversely stiffened webs

Plate girders with $h / w > E / \left(67\sqrt{F_y}\right)$ shall not be used under fatigue conditions.

23.4 Unknown load spectra

Where the cyclic stress ranges and their number of repetitions are variable and not sufficiently well known to formulate a spectrum, the stress range that is estimated to be exceeded 10^6 times shall not exceed F_{srt}.

23.5 Low cycle stress limit

For any member or joint, the maximum applied stress, calculated using the net section where applicable, shall not exceed the factored tensile resistance defined in Clause 9.2.2.

23.6 Local stress approaches

23.6.1 Notch stress approach

For members and joints that, except for obvious stress raisers, would be in Category A of Table 11 and Figure 3, the nominal stress range shall be multiplied by the appropriate fatigue notch factor (ratio of the notch stress divided by the nominal stress) and used in conjunction with Category A of Figure 4. The notch factor shall be determined by the engineer by referencing relevant literature on the notch type associated with the stress raiser or performing an elastic finite element analysis of the stress raiser, with a sufficient level of mesh refinement to ensure that the peak stress has been accurately calculated.

23.6.2 Hot-spot stress approach

For the design of welded joints that do not fall clearly into one of the detail categories in Table 11 and Figure 3, the hot-spot stress approach may be used. The applicability of this method is limited to joint geometries where fatigue failure is expected to occur at a weld toe. For this approach, the stress concentration factor (*SCF* = ratio of the local hot-spot stress divided by the nominal stress) shall be determined by the engineer by referencing relevant literature, performing a coarse elastic finite element analysis of the weld joint geometry, or performing strain measurements on a prototype of the weld joint geometry. The resulting hot-spot stress range shall then be compared to a hot-spot stress design curve, which has been calibrated using the same approach, for a similar probability of failure to the nominal stress fatigue design curves in Figure 4. Alternatively, the reference stress approach for determining the design curve may be used. The steps for implementing the reference stress approach shall be as follows:

a) Select a reference detail from Table 11 and Figure 3, which is as similar as possible to the detail being assessed with respect to weld quality and to geometric and loading parameters.

b) Establish a finite element model of the reference detail and the detail to be assessed.
c) Load the reference detail and the detail to be assessed with the stress identified in Item b).
d) Determine the hot-spot stress ranges $f_{hs,r}$ of the reference detail and the hot-spot stress ranges $f_{hs,a}$ of the detail to be assessed.

The fatigue life constant, γ_a, to be used for the design of the assessed detail can then be calculated:

$$\gamma_a = \gamma_r \frac{f_{hs,r}^m}{f_{hs,a}^m}$$

where γ_a and γ_r are the fatigue life constants, γ, associated with the assessed and reference detail, respectively, and m is the fatigue life constant, m, associated with the reference detail. Fatigue design can then proceed using $f_{sr} = (f_{hs,a} / SCF_a)$ and γ_a in place of γ. For evaluation in the infinite life domain, the fatigue threshold, $F_{srt,a}$, for the assessed detail may be approximated as:

$$F_{srt,a} = F_{srt,r} \frac{SCF_r}{SCF_a}$$

23.7 Fatigue performance improving post-weld treatments

The fatigue performance of welds with fatigue-critical weld toes may be improved through the use of post-weld treatments, such as grinding, dressing, or impact treatment (or “peening”). If this is done, the engineer shall determine the resulting increase in fatigue performance by referencing relevant literature. In addition, the treatment process and the weld shall conform to CSA W59.2.

Table 11
Detail categories for load-induced fatigue
(See Clauses 23.2.1, 23.2.3, and 23.6.)

General condition	Situation	Detail category	Illustrative example (see Figure 3)
Plain members	Base metal		1, 2
	With rolled or cleaned surfaces. Edges with a surface roughness not exceeding 25 µm	A	
Built-up members	Base metal and weld metal in components, without attachments, connected by one of the following:		3, 4, 5, 7
	a) continuous full-penetration groove welds with backing bars removed;	B	
	b) continuous fillet welds parallel to the direction of applied stress;	B	
	c) continuous full-penetration groove welds with backing bars in place;	B	
	d) base metal at ends of partial-length cover plates (with or without end welds); or	E	7
	e) weld metal (fillet weld ends).	E	
Groove-welded splice connections with weld	Base metal and weld metal at full-penetration groove-welded splices, as follows:		

(Continued)

Table 11 (Continued)

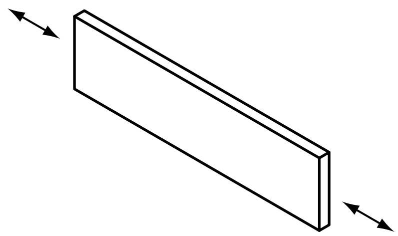
General condition	Situation	Detail category	Illustrative example (see Figure 3)
soundness established by non-destructive testing and all required grinding in the direction of the applied stresses	a) of plates of similar cross-sections with welds ground flush;	B	8, 9
	b) with transitions in width or thickness (with welds ground to provide slopes not steeper than 1.0 to 2.5); and	B	10, 10a
	c) with or without transitions with slopes not greater than 1.0 to 2.5, when weld reinforcement is not removed.	C	8, 9, 10, 10a
Longitudinally loaded groove-welded attachments	Base metal at details attached by full-penetration groove welds, as follows:		
	a) when the detail length in the direction of applied stress is		
	i) less than 50 mm;	C	6, 18
	ii) between 50 mm and 12 times the detail thickness, but less than 100 mm; or	D	18
	iii) greater than either 12 times the detail thickness or 100 mm;	E	18
	b) with a transition radius, *R*, with the ends of welds ground smooth, regardless of detail length:		12
	i) $R \geq 600$ mm;	B	
	ii) 600 mm > $R \geq 150$ mm; or	C	
	iii) 150 mm > $R \geq 50$ mm; or	D	
	c) with a transition radius, *R*, with ends of welds not ground smooth.	E	12
Transversely loaded groove-welded attachments with weld soundness established by non-destructive testing and all required grinding transverse to the direction of stress	Base metal at detail attached by full-penetration groove welds with a transition radius, *R*, as follows:		12
	a) to flange, with equal plate thickness and weld reinforcement removed:		
	i) $R \geq 600$ mm;	B	
	ii) 600 mm > $R \geq 150$ mm;	C	
	iii) 150 mm > $R \geq 50$ mm; or	D	
	iv) $R < 50$ mm;	E	
	b) to flange, with equal plate thickness and weld reinforcement not removed or to web:		
	i) $R \geq 150$ mm;	C	
	ii) 150 mm > $R \geq 50$ mm; or	D	
	ii) $R < 50$ mm;	E	
	c) to flange, with unequal plate thickness and weld reinforcement removed:		
	i) $R \geq 50$ mm; or	D	
	ii) $R < 50$ mm.	E	

(Continued)

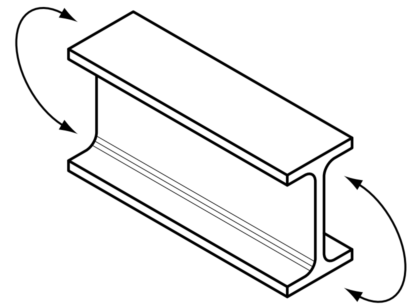
Table 11 (Concluded)

General condition	Situation	Detail category	Illustrative example (see Figure 3)
Fillet-welded connections with welds normal to the direction of stress	Base metal, as follows:		
	a) at details other than transverse stiffener to flange or transverse stiffener to web connections; and	E	19
	b) at the toe of transverse stiffener to flange and transverse stiffener to web welds.	C	6
Fillet-welded connections with welds normal and/ or parallel to the direction of stress	Shear stress on the weld throat	E	16
Longitudinally loaded fillet-welded attachments	Base metal at details attached by fillet welds, as follows:		
	a) when the detail length in the direction of applied stress is		
	i) less than 50 mm;	C	13, 15,18, 20
	ii) between 50 mm and 12 times the detail thickness, but less than 100 mm; or	D	14, 18, 20
	iii) greater than either 12 times the detail thickness or 100 mm:		7, 16, 18, 20
	1) detail thickness < 25 mm; or	E	
	2) detail thickness ≥ 25 mm; and	E	
	b) with a transition radius, *R*, with the ends of welds ground smooth, regardless of detail length:		12
	i) $R \geq 50$ mm; or	D	
	ii) $R < 50$ mm.	E	
Transversely loaded fillet-welded attachments with welds parallel to the direction of primary stress	Base metal at details attached by fillet welds	E	12
Mechanically fastened connections	Base metal at the gross section of slip-critical connections and at the net section of bearing connections, where the joint configuration does not result in out-of-plane bending in the connected material and the stress ratio (the ratio of minimum stress to maximum stress), as follows:		17a
	a) stress ratio ≤ 0;	B	
	b) 0 < stress ratio < 0.5; or	D	
	c) 0.5 ≤ stress ratio.	E	
	(Base metal at the gross section of slip-critical connections and at the net section of bearing connections, where the joint configuration results in out-of-plane bending in connected material.	E	17b
ASTM A325 and ASTM A325M bolts	See CSA S16	—	—

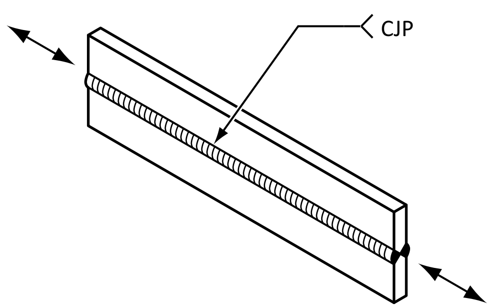
Figure 3
Categories of members and joints for fatigue design
(See Clauses 23.2.1, 23.2.3, 23.6.1, and 23.6.2 and Table 11.)



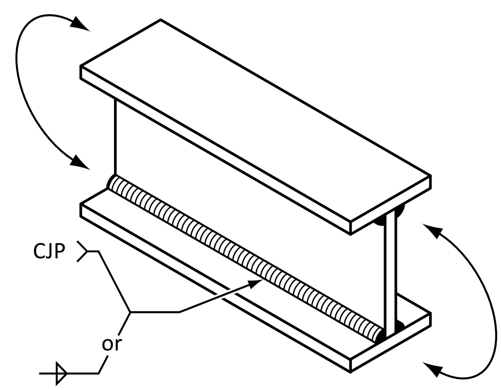
Example 1



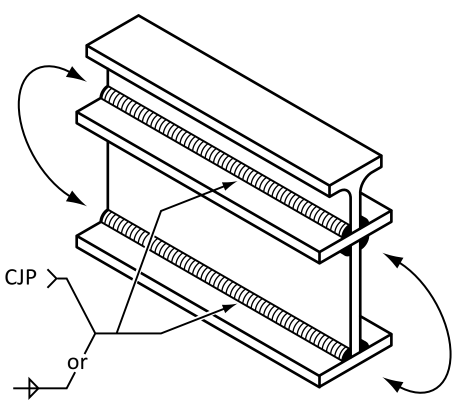
Example 2



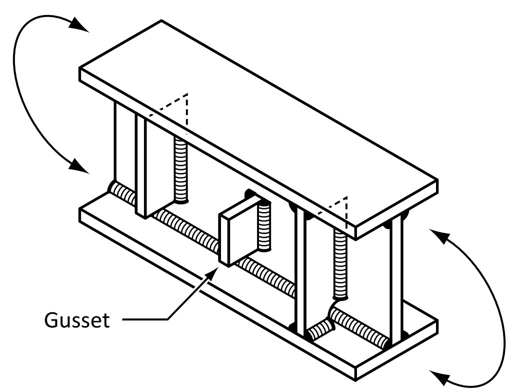
Example 3



Example 4



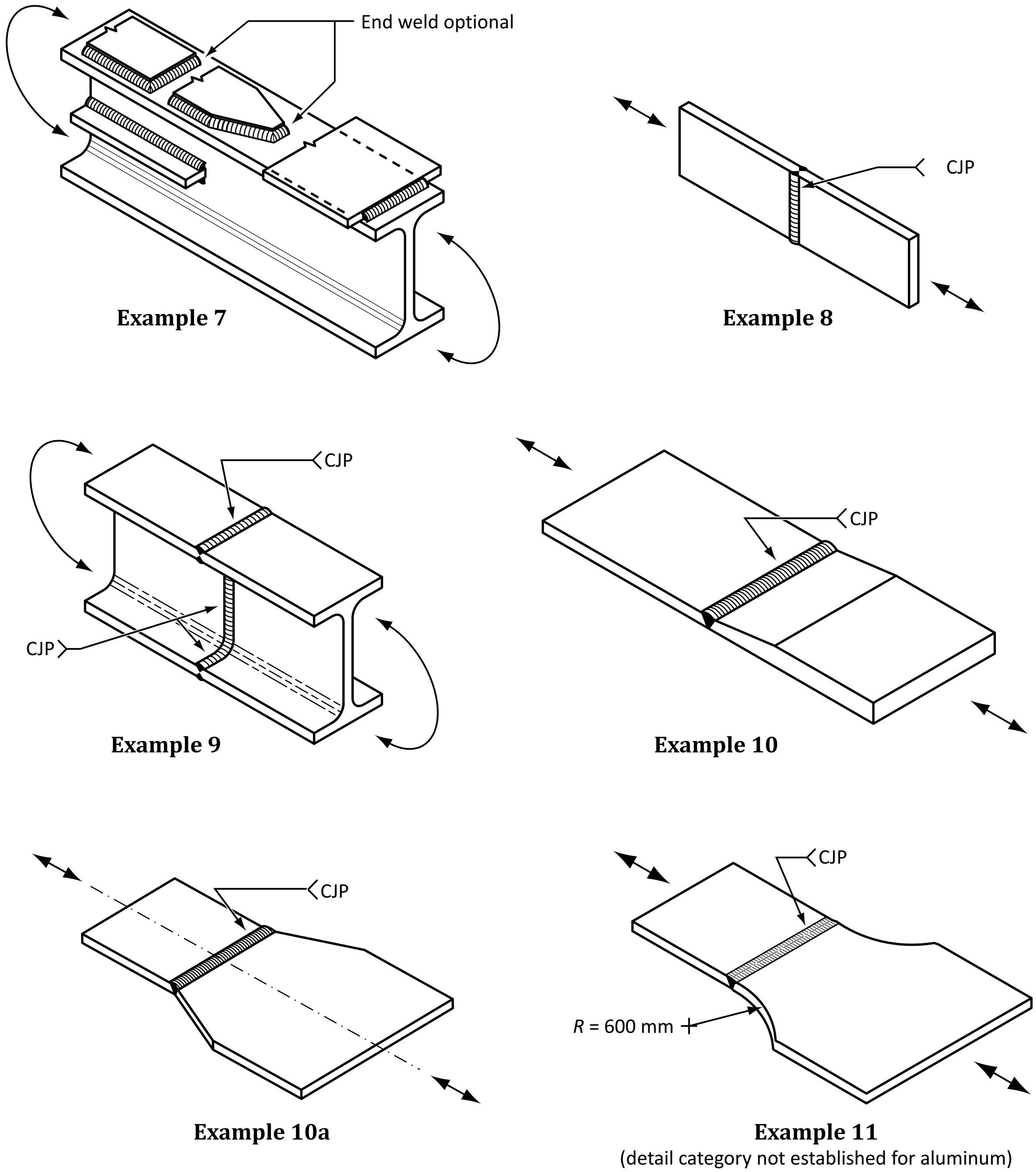
Example 5



Example 6

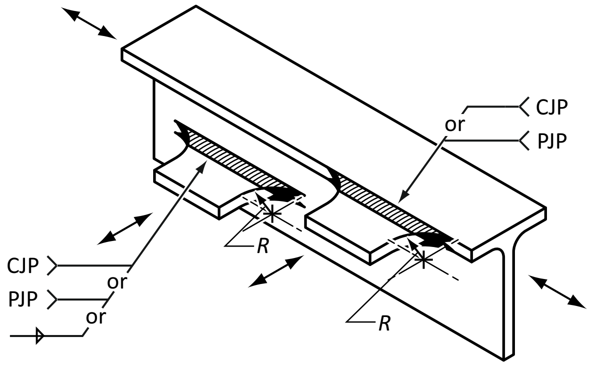
(Continued)

Figure 3 (Continued)

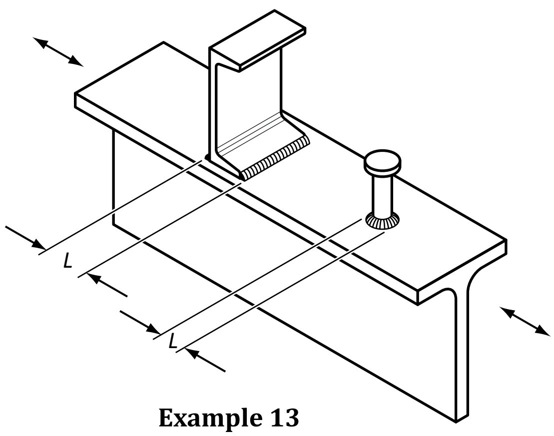


(Continued)

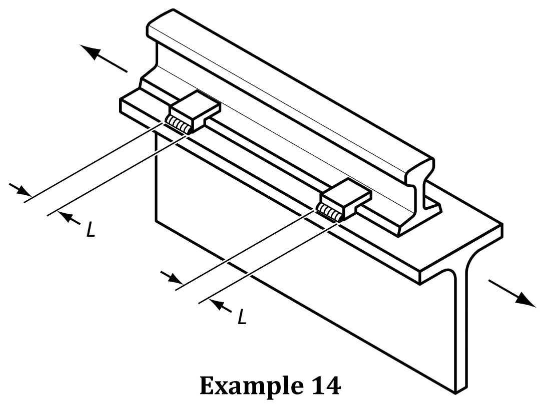
Figure 3 (Continued)



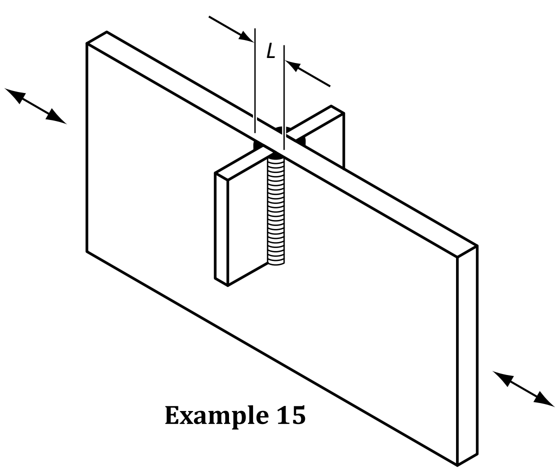
Example 12



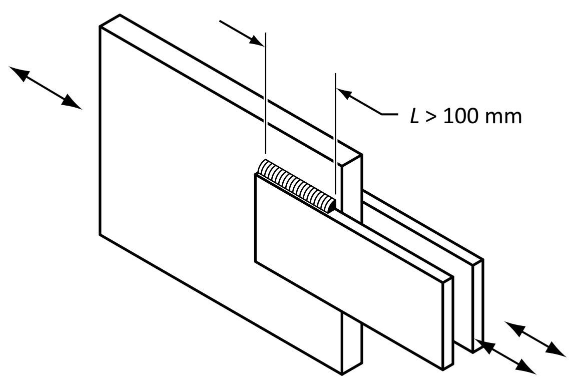
Example 13



Example 14



Example 15



Example 16

(Continued)