Fundamentals and preliminary sizing of sections and joints

Objectives

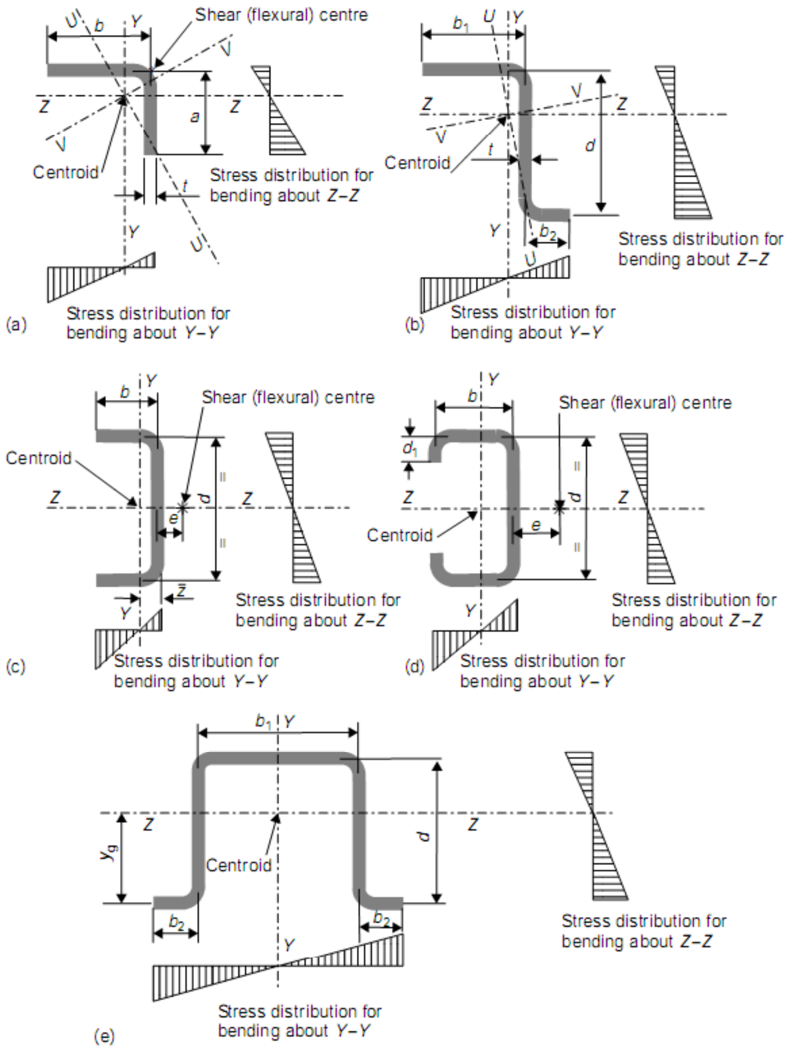
- Overview of section and joint structural behaviour in a design context.
- To outline the design and sizing approach for sections and joints.

Characteristics of thin walled structures

- manufactured with more than one component and joined together by spot welds, seam welds or by an adhesive.
- Two types:
  - Open - the thin sheet metal is formed with a discontinuity
  - Closed - the section forms a complete loop

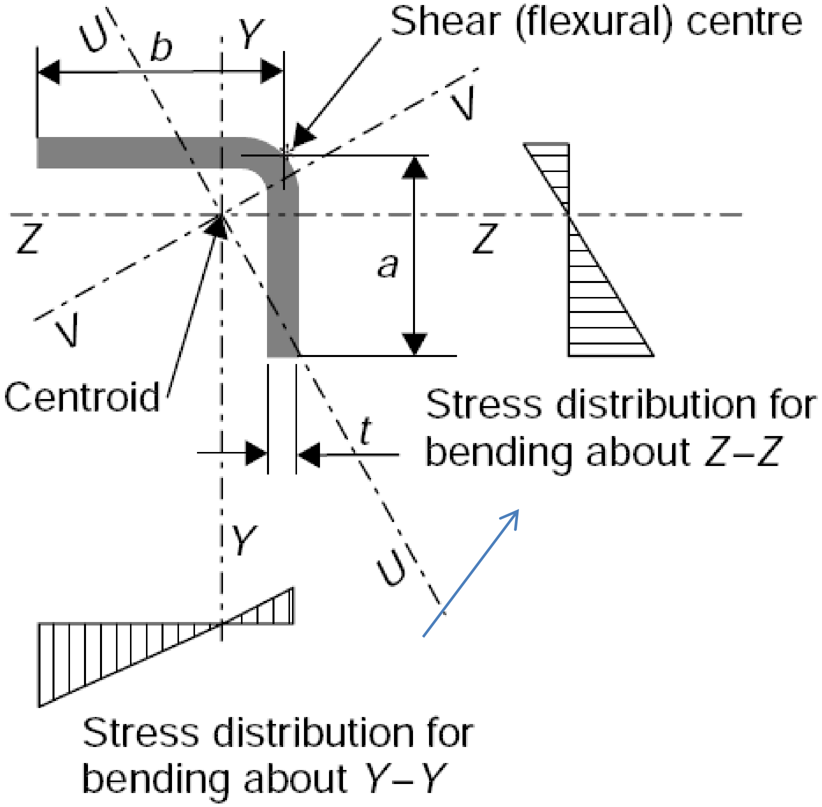
Open Sections

- Some open sections:
  - Angle section
  - Z section
  - Channel
  - Lipped channel
  - Hat section
- Major limitations:
  - lack of Torsional stiffness due to their very low polar secon moment of area.
  - Wharping : under torsion transverse sections do not remain plane, there is axial displacement at various poin on the section



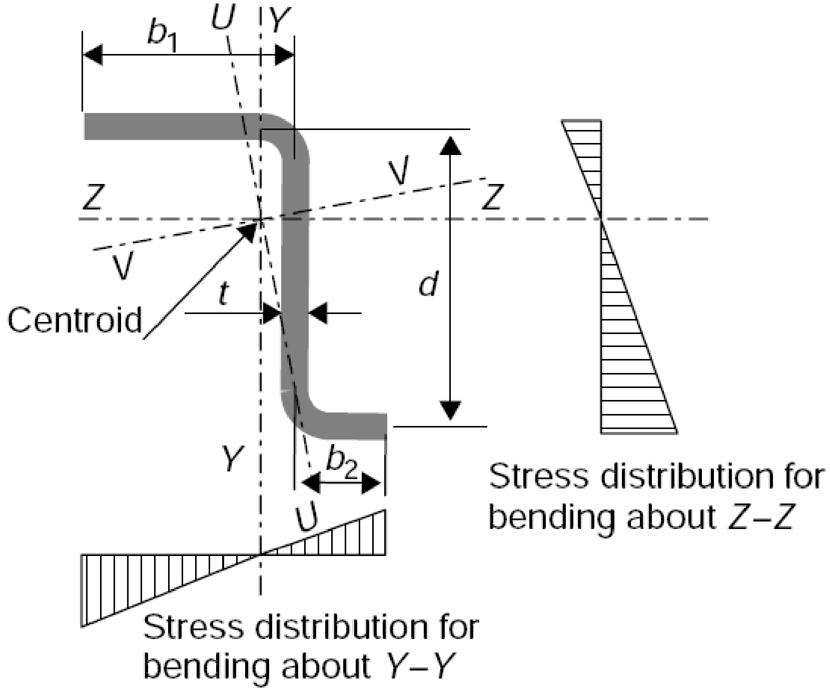
Angle Section

- Not a suitable structural member when considered alone.
- The principal axes U–U and V–V are inclined to the faces of the angle and if bending is applied about either Y–Y or Z–Z bending will occur about both axes.
- Stress distribution is very asymmetric and results in large parts of the section being under-stressed.
- inefficient use of material



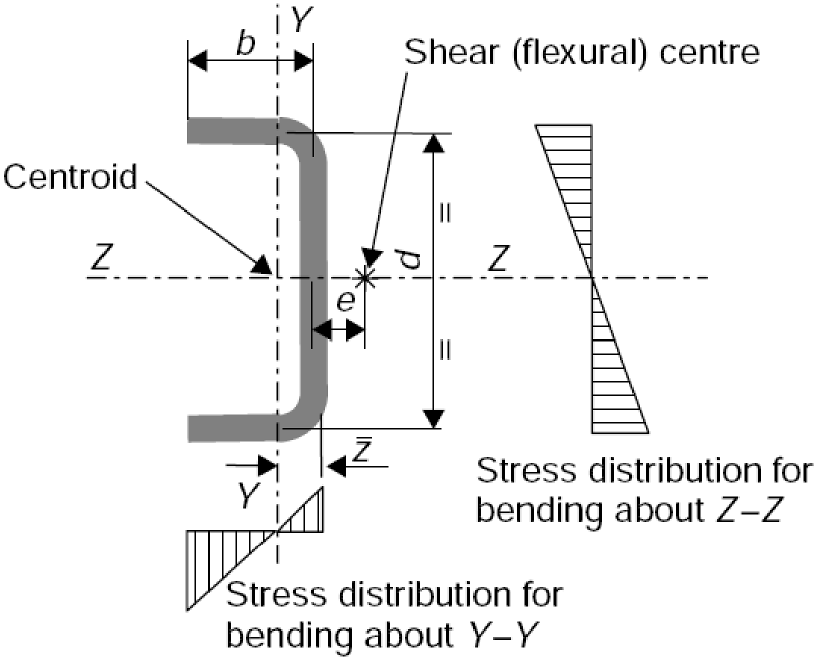
Z section

- Similar undesirable characteristics and hence is not suitable as a section on its own.
- Principal axes of the Z section are inclined.
- Angle of the principal axes U –U and V –V relative to the Y –Y axis will depend on the relative lengths of b1, b2 and d.



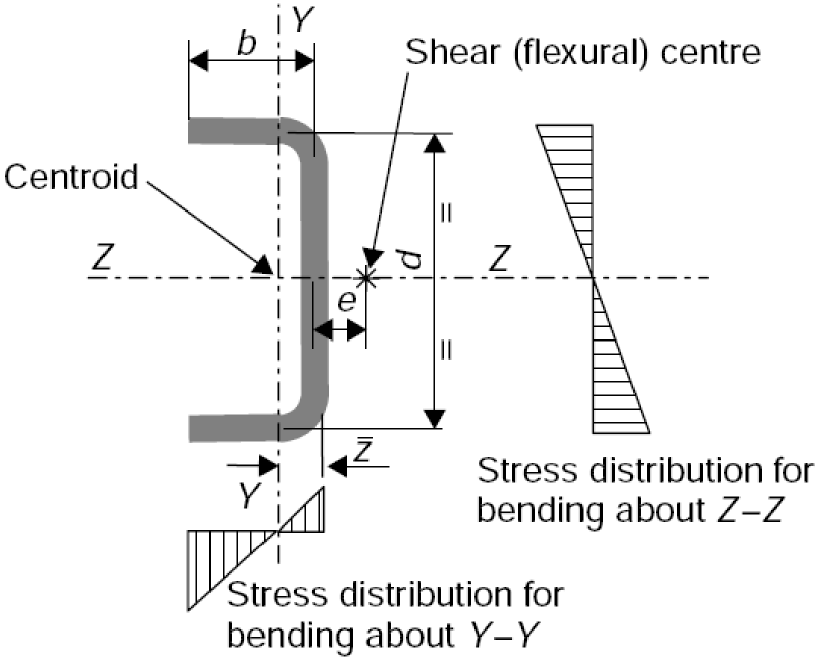
Channel -1/2

- Suitable structural section and used in commercial vehicle chassis and body structures.
- Suitable for bending loads causing moments about the Z–Z axis.
- Care must be taken to ensure that the flange width ‘b’ is not excessive as this can lead to reduced allowable compressive stress



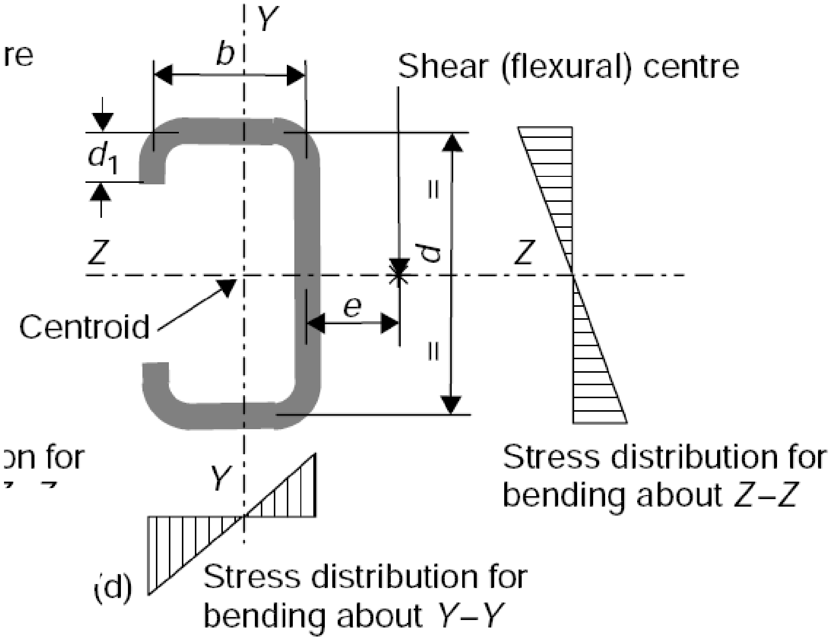
Channel-2/2

- Less satisfactory for bending about the Y –Y axis because it is less stiff (has lower value for I_{yy} than I_{zz}) and has an asymmetric stress distribution.



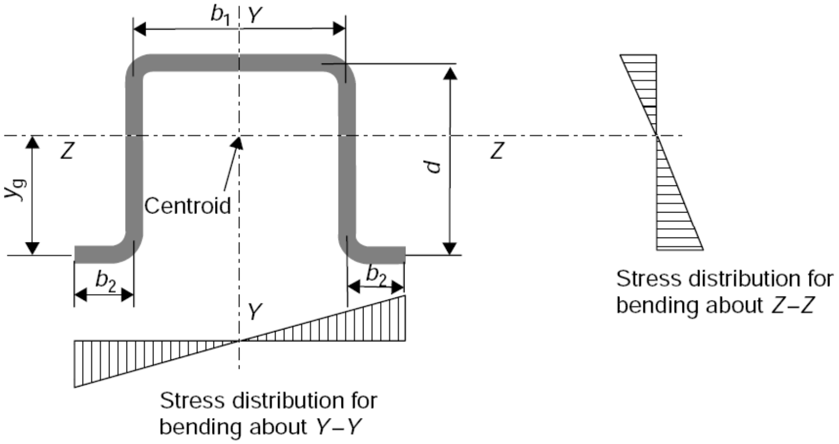
Lipped channel

- The wide flange results in a low stress at which buckling occurs.
- Improvement in buckling stress can be achieved by adding a lip to the channel



Hat section

- Has good bending properties about both Y–Y and Z–Z axes provided the value of $2b_2$ is approximately equal to b_1.

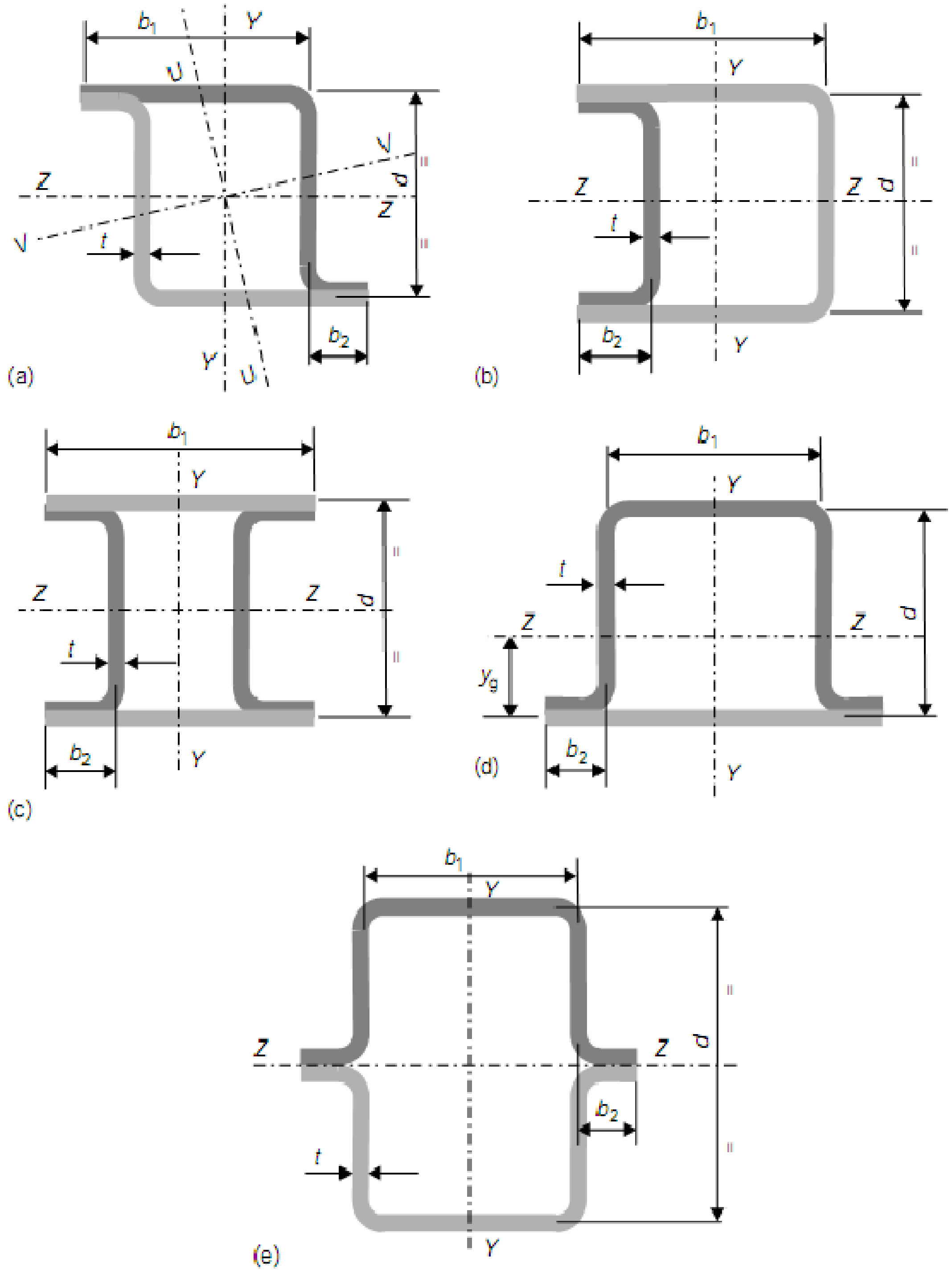


Open Sections

- Polar moments of Inertia of sections J_x
  - Angle $= (a + b)*t^3/3$
  - Z section $= (b_1 + b_2 + d)*t^3/3$
  - Channel $= (2b + d)*t^3/3$
  - Lip Channel $= (2d_1 + d + 2b)*t^3/3$
  - Hat (e) $= (b_1 + 2b_2 + 2d)*t^3/3$
- t is small hence J_x will be smaller
- Hence larger twist angle

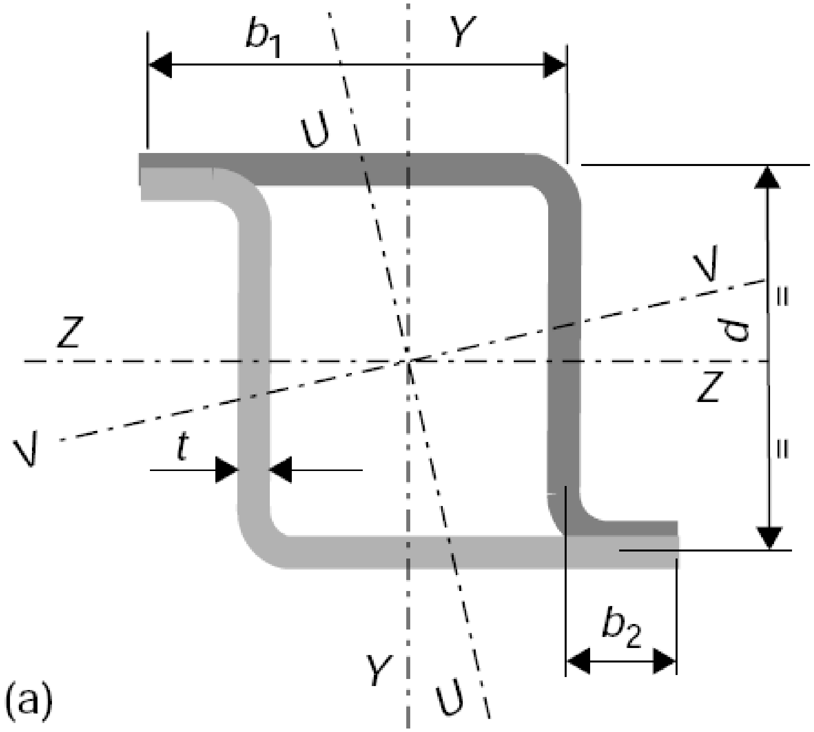
  $\theta = TL/GJ_x$

Closed Sections



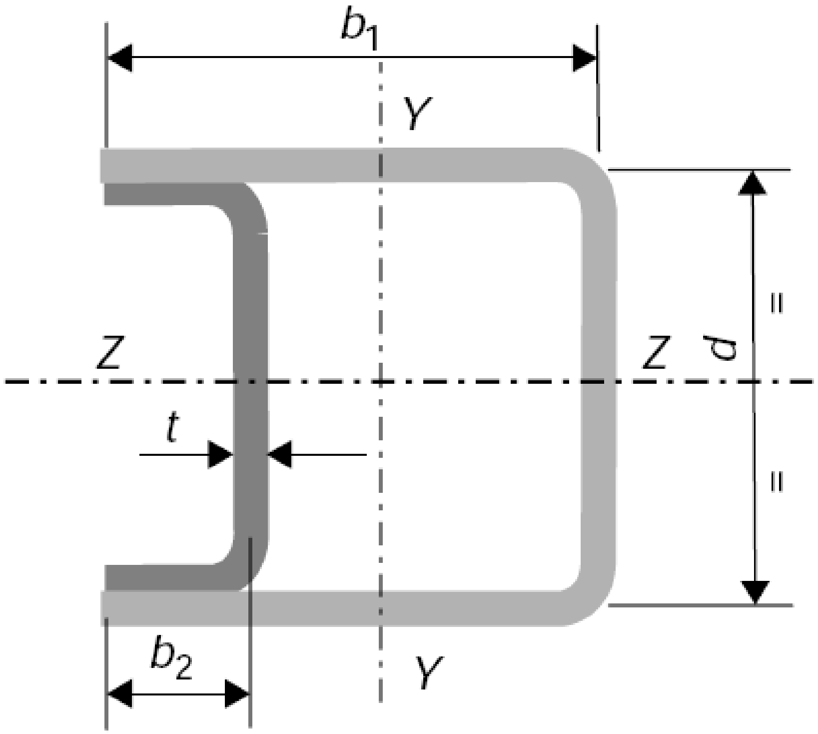
Closed Sections

- Two Z sections with unequal length flanges joined to form a closed rectangular section.
- *Second moments of area about the Y –Y and Z–Z axes are much increased over the open section*

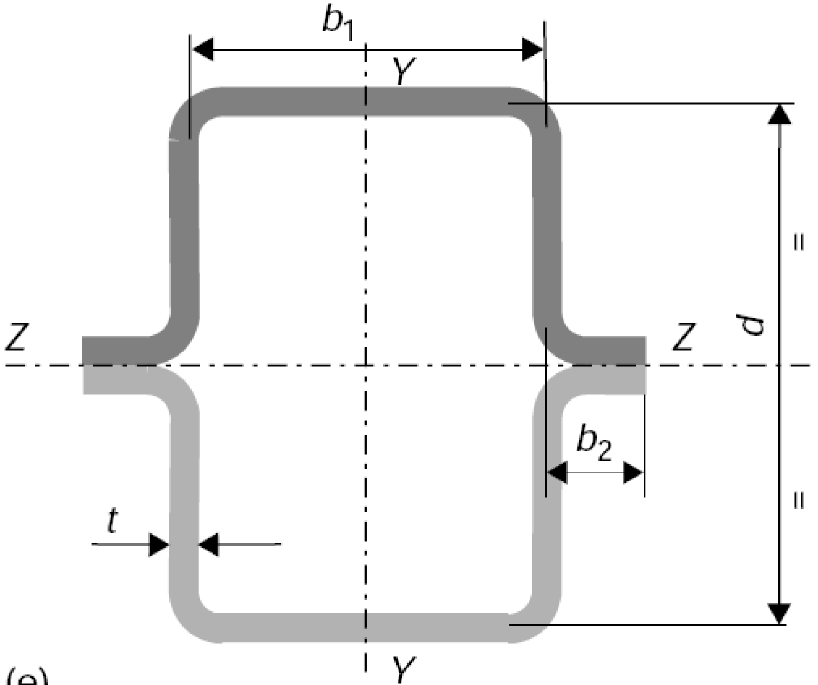


Closed Sections

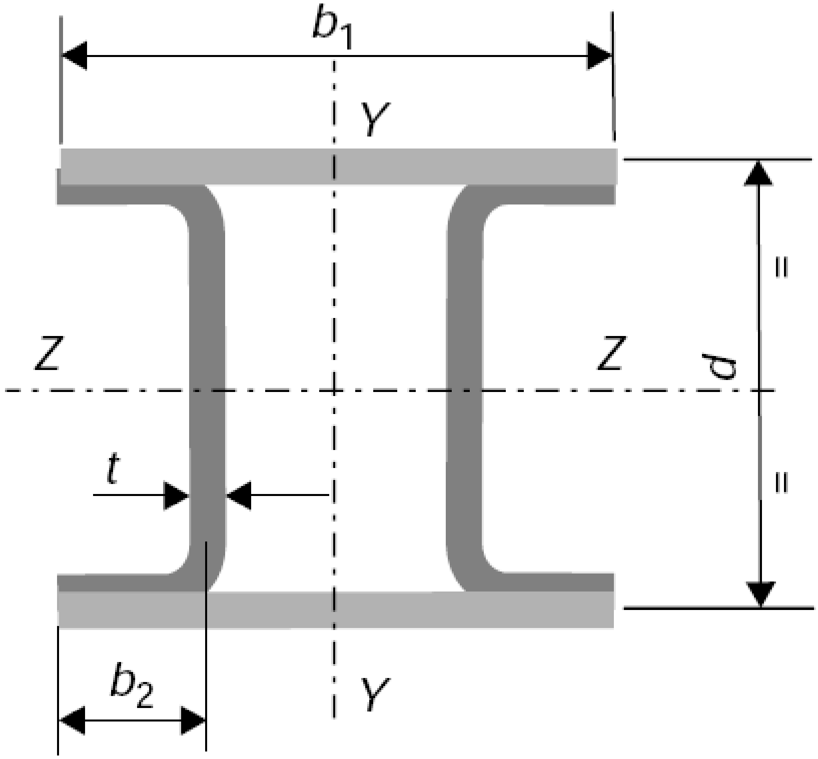
- Combination of two channels, one with wide and one with narrow flanges.
- This combination avoids inclined principal axes and still has substantial second moments of area about *Y –Y and Z–Z axes.*



Closed Sections



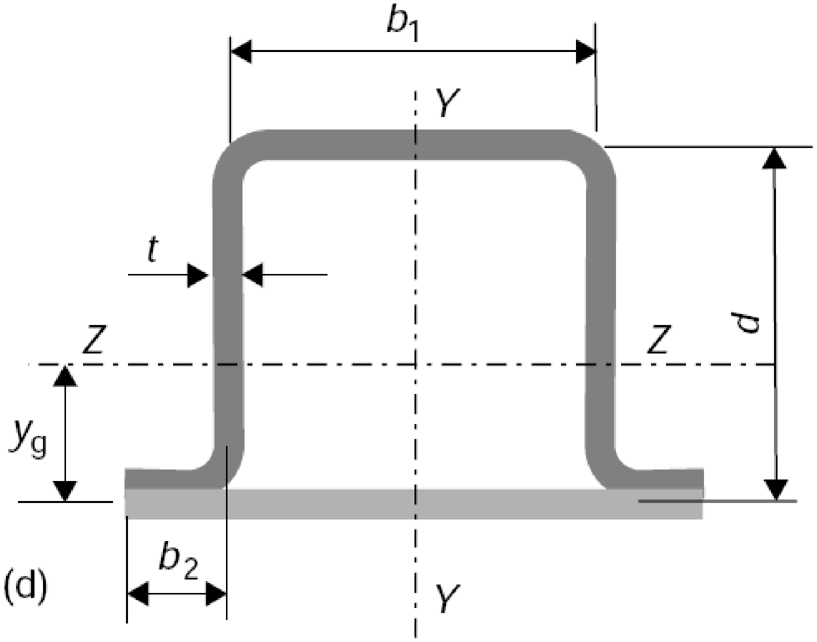
(e)



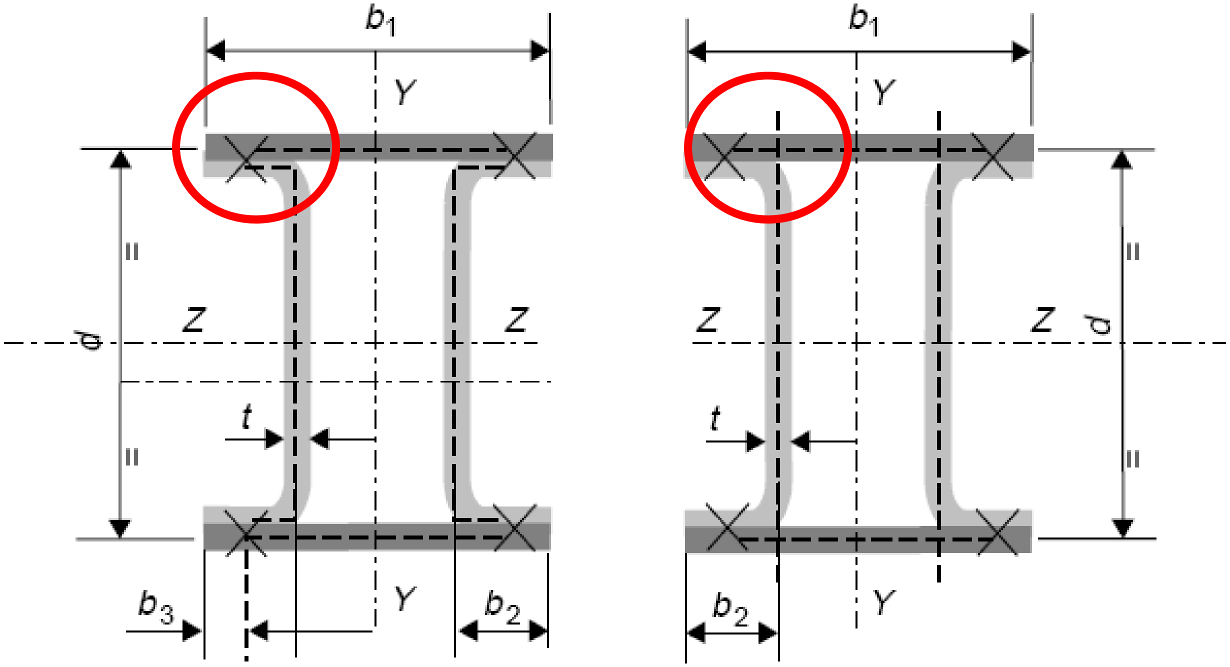
Two hat sections are combined, both of these form effective structural members with good bending properties about *Y –Y and Z–Z axes.*

Closed Sections

- Hat section with a flat closing plate



Closed Sections



- At (a) the enclosed area is:

$A = (b_1 - 2b_2)d + 4(b_2 - b_3)t$

- And the periphery:

$s = 2(b_1 - 2b_3) + 2d + 4(b_2 - b_3)$

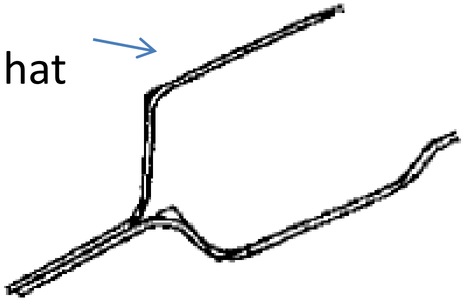
shown at (b) :

$\mathrm{A} = (\mathrm{b}_1 - 2\mathrm{b}_2)\mathrm{d}$

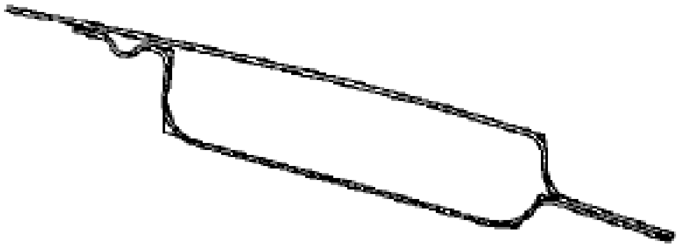
And $\mathrm{s} = 2(\mathrm{b}_1 - 2\mathrm{b}_2) + 2\mathrm{d}$

Some passenger car sections 1/2

One
Shallow hat

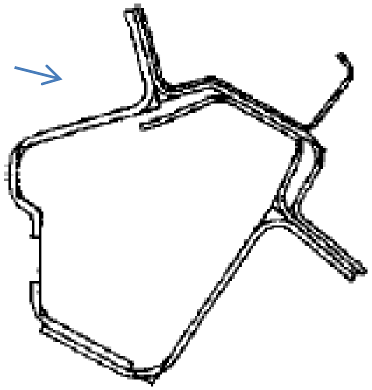


(a) Windshield header rail



(b) Top rail of backlight

Two Shallow
hat



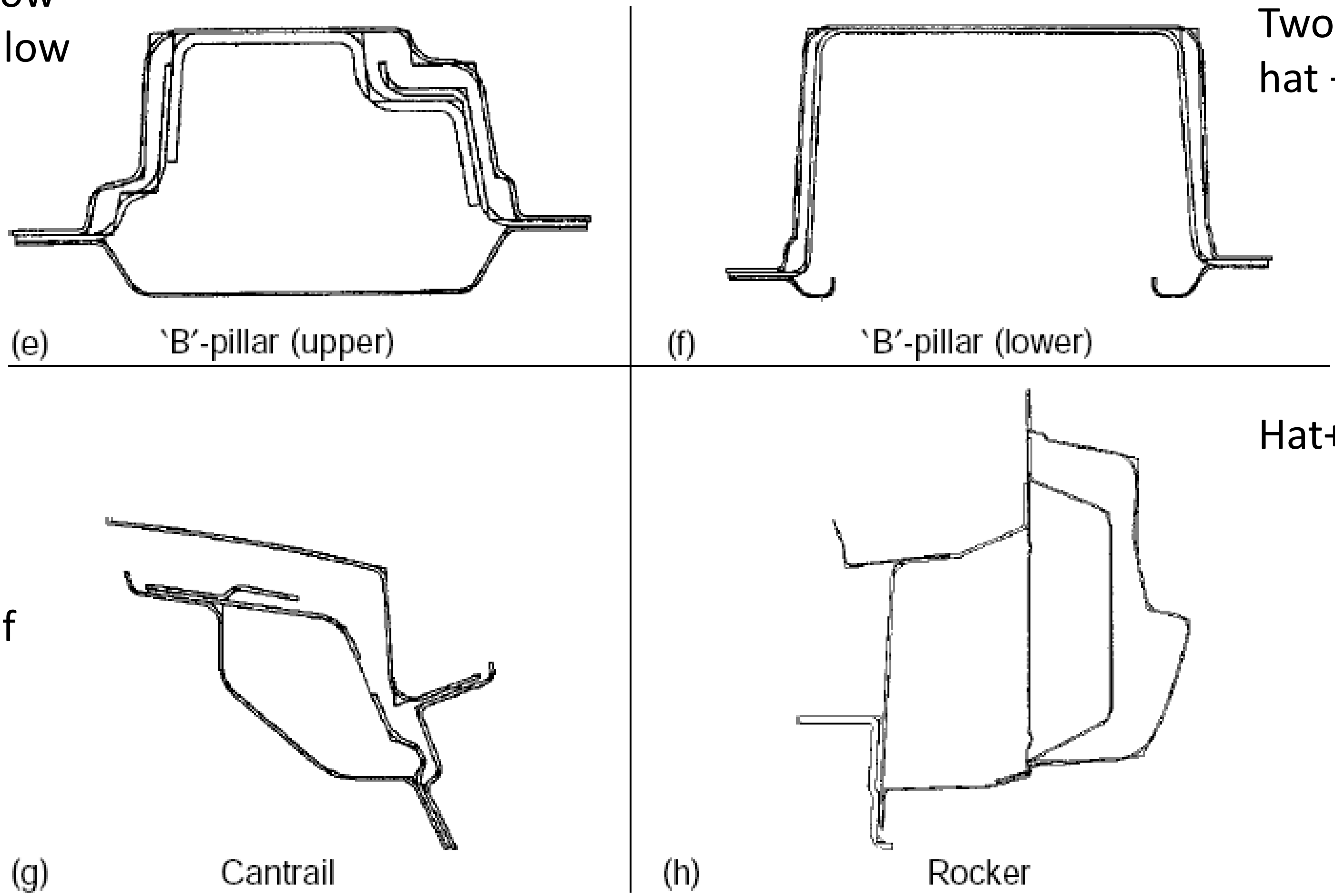
(c) ‘A’-pillar

(d) Lower ‘A’-pillar

Some passenger car sections 2/2

Two Shallow hat + shallow flat

Two shallow hat + flat



(e) ‘B′-pillar (upper)

(f) ‘B′-pillar (lower)

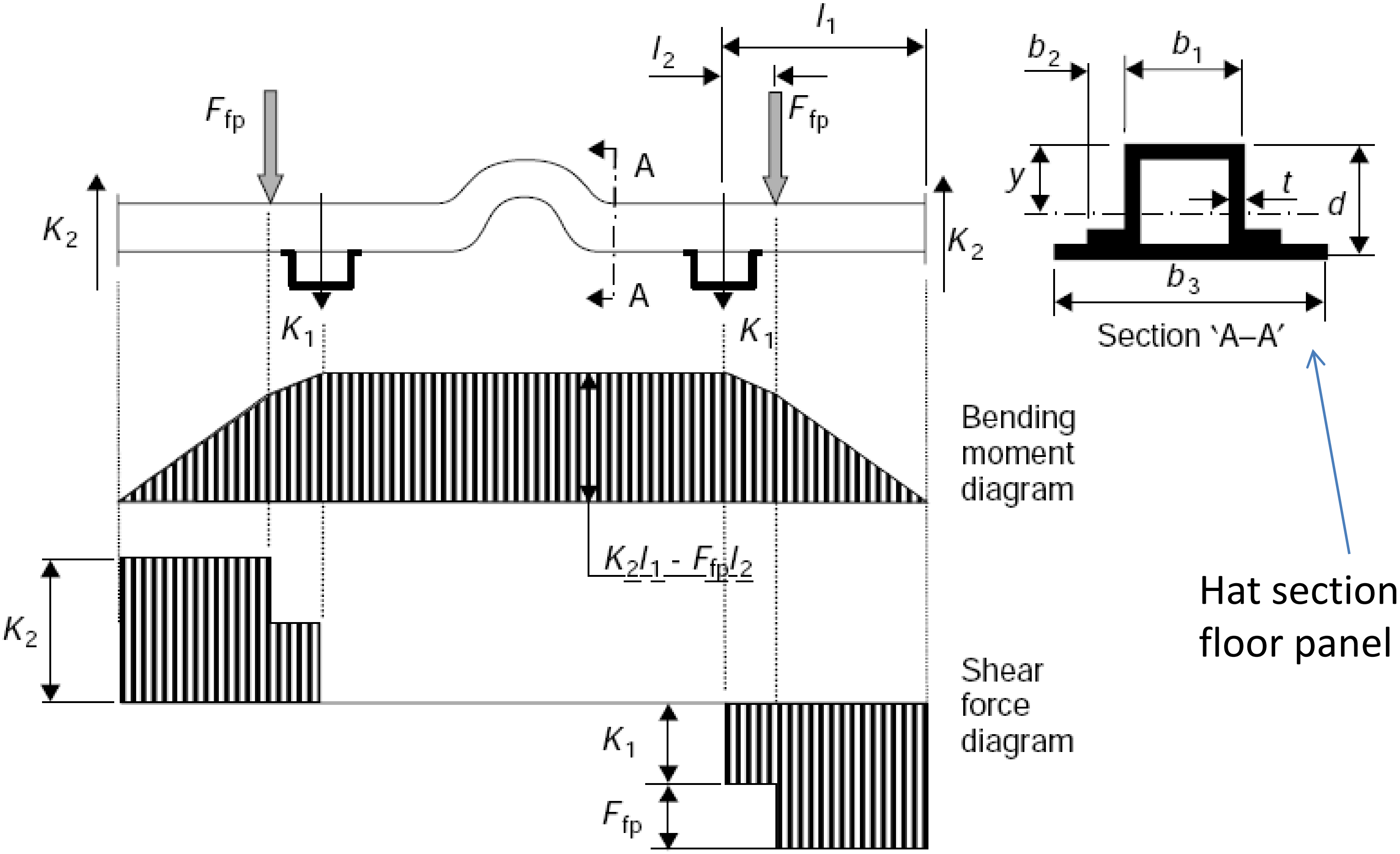
(g) Cantrail

(h) Rocker

Hat+ plate+ Z

Two hat + angle + roof

Floor Cross-Beam



Hat section on floor panel

Floor Cross-Beam

- Loads
  - F_{fp} = Load from passenger/seat
  - K_1 = Load from engine rail
  - K_2 = simple supports reaction with no fixing supports
- Loading condition on the cross-beam is bending and shear.

Floor Cross-Beam

- Bending moment

  $$M = K_2 l_1 - F_{fp} l_2$$

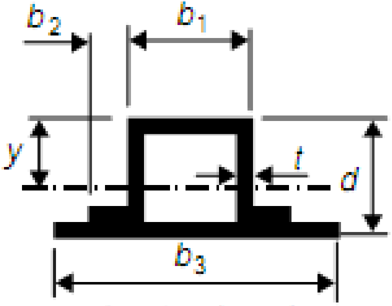
  values of K_2 and F_{fp} must be based on the static loads multiplied by any load factor necessary to allow for dynamic effects.
- Designing for strength use the standard engineer's bending theory to obtain the stress in the beam due to the bending moment:

  $$f = My/I$$

Floor Cross-Beam

- Section properties to be evaluated including a width of approximately 20*t* of the floor panel either side of the hat section

$$b_3 = b_1 + 2b_2 + 40t$$



Section 'A–A'

- Safety factor – 1.5
- For shear - non-linear shear stress theory:

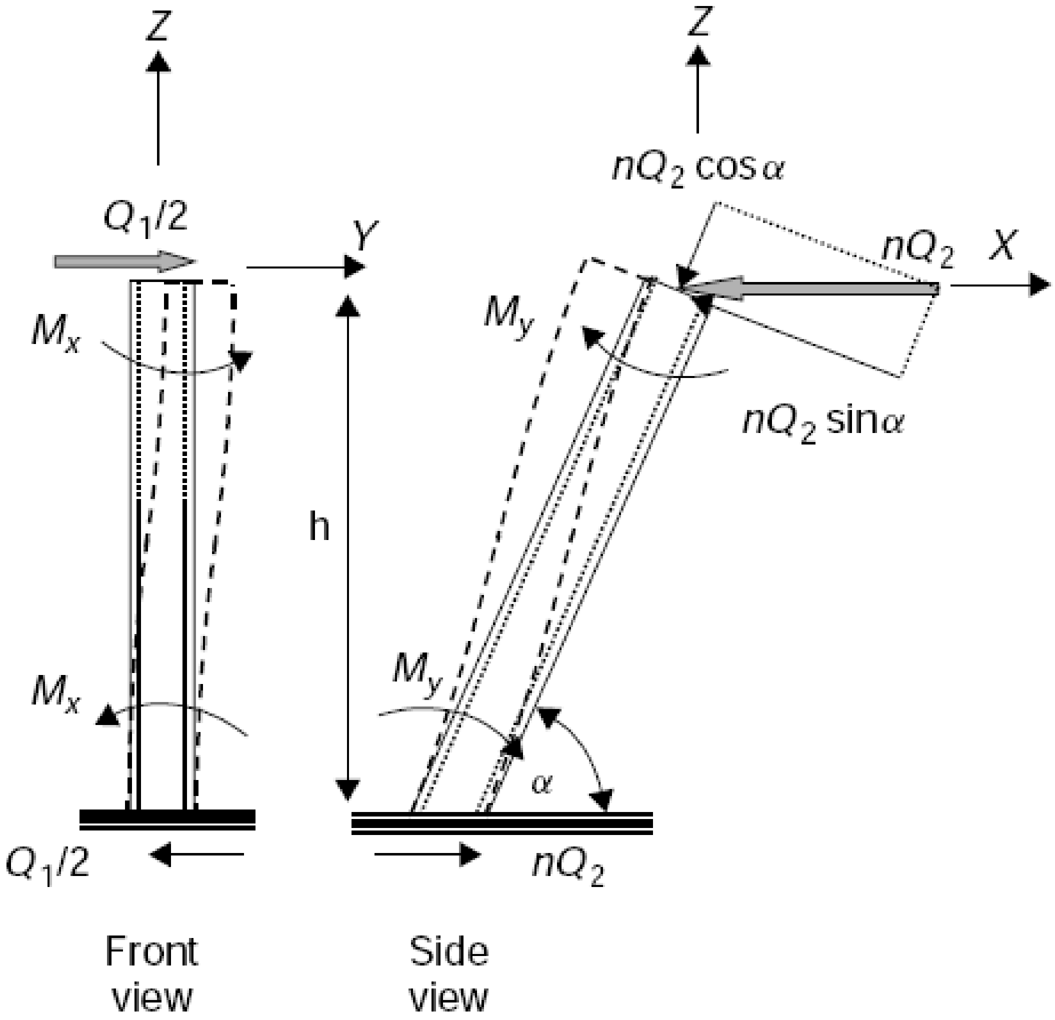
$$\tau = K_2Ay/zI \text{ (y is moment of area,}$$

z is width,

I is second moment of inertia)

$$\tau \approx K_2/2dt \textit{ (as stress in b1 abd b3 is low)}$$

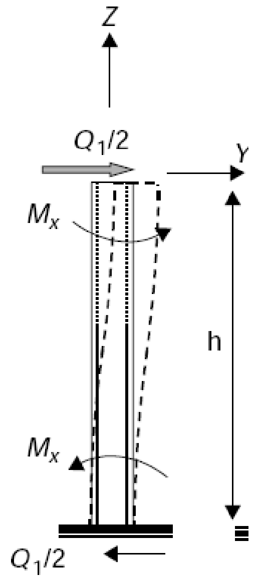
‘A’ Pillar



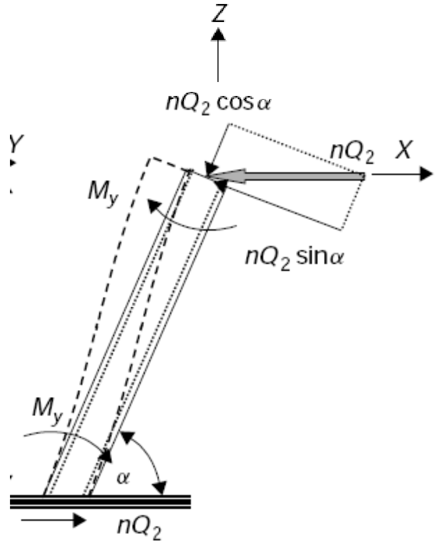
Z
$Q_1/2$
Y
M_x
M_x
$Q_1/2$
h
Front view
Z
$nQ_2 \cos\alpha$
nQ_2
X
M_y
$nQ_2 \sin\alpha$
M_y
α
nQ_2
Side view

‘A’ Pillar

- Large bending loads when the structure is loaded in torsion
- From the roof loads the shear force between the top of the windscreen frame and along the cantrail can be obtained.
    - Q_1 = across the front
    - Q_2 = across the sides
    - proportion ‘n’ of the side frame load Q_2 is that taken by the ‘A’-pillar

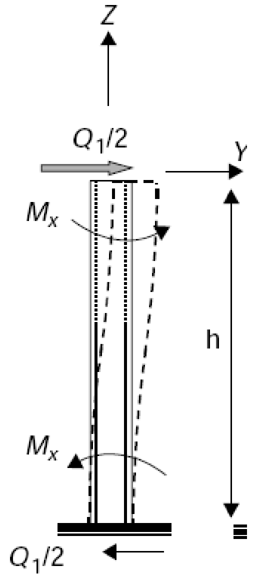


Front view



Side view

‘A’ Pillar



Front view

- Assuming the joint at the top of the ‘A’-pillar to the windscreen header rail/cantrail and the joint to the dash/wing are “fixed supports”
- Bending moments and stresses are

$$M_x = Q_1 h/4$$

$$f_{bx} = M_x b/2I_{xx}$$

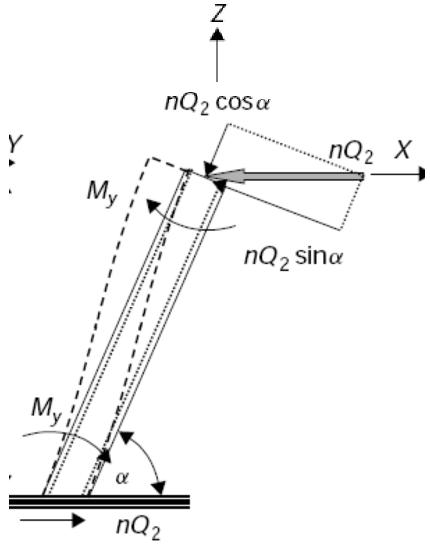
$$M_y = nQ_2 \sin\alpha * h/2 * \cos\alpha$$

$$f_{by} = \frac{M_y d}{I_{yy} 2}$$

- Direct compression stress

$$f_c = nQ_2 \cos\alpha / (2b + 2d)\, t$$

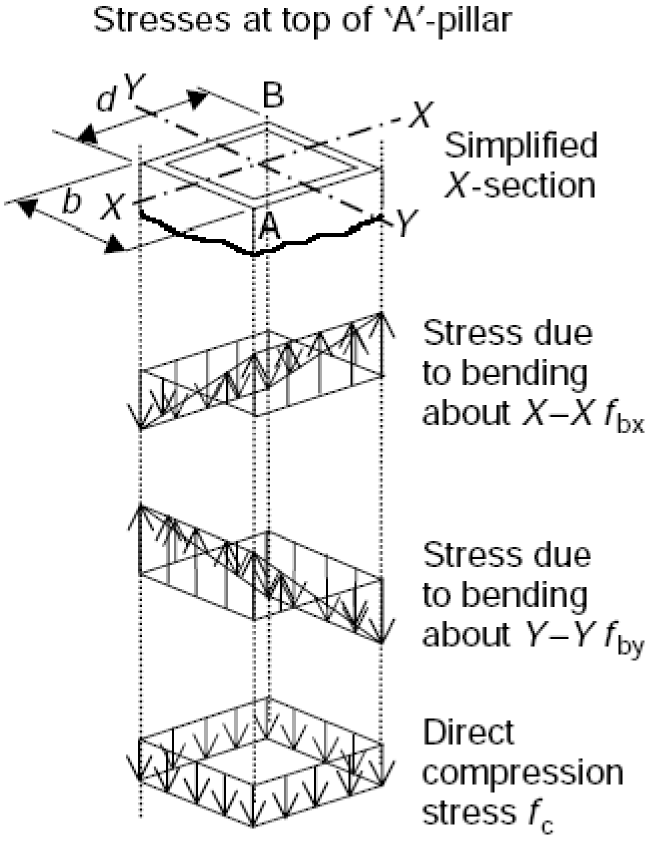
- where (2b + 2d)t is approximately the cross-sectional area



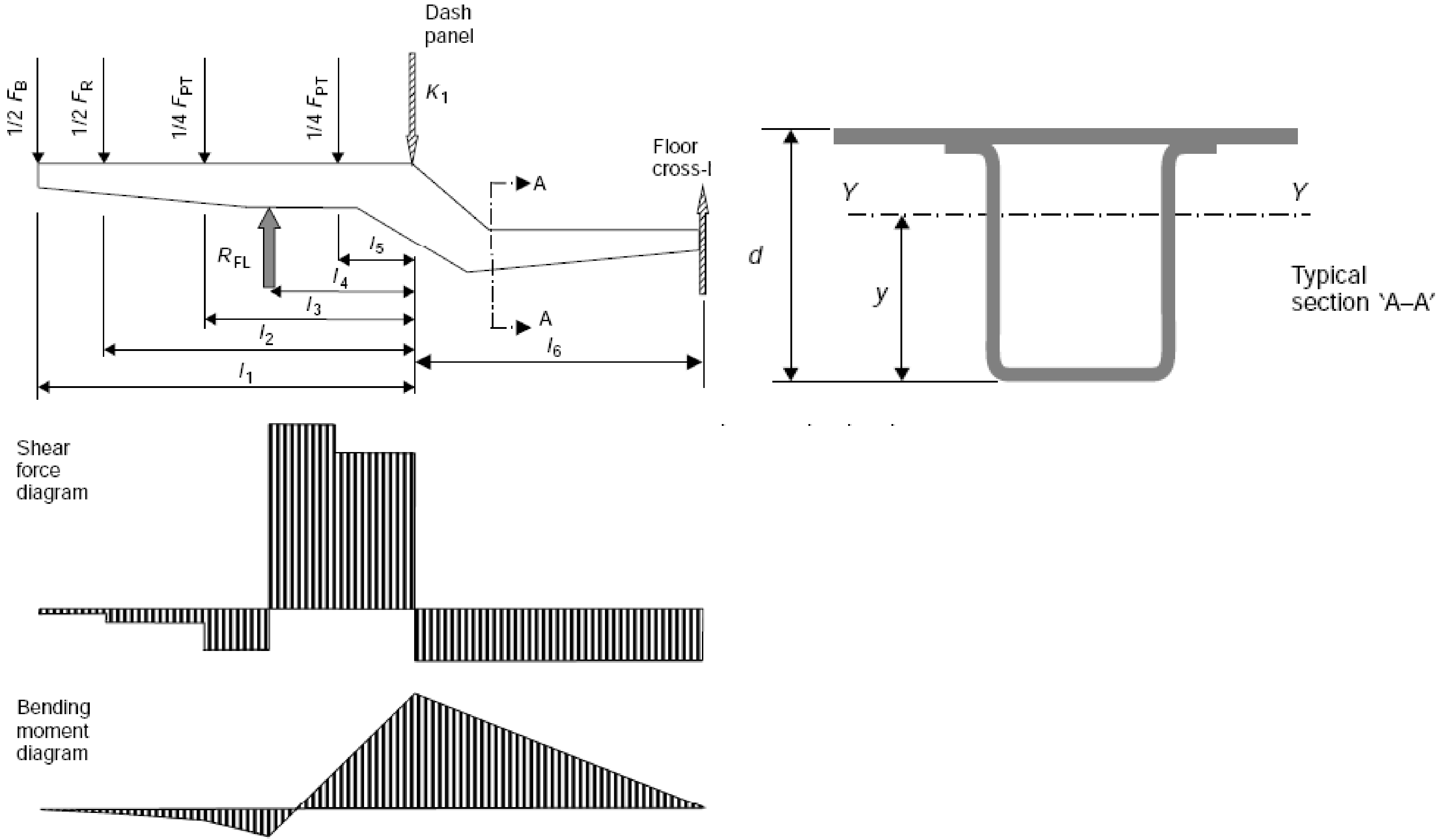
Side view

‘A’ Pillar

- Stress plots show
  - At A, the bending stresses are tensile but the direct stress is again compressive so giving a reduced resultant stress
- Design criteria described are based on the torsion load condition.
- For the ‘A’-pillar section, critical case can be the in-roof crush test SAE J374



Engine longitudinal rail



Engine longitudinal rail

- Shear forces and bending moments.
- Shared Loads:
  - Bumper F_B,
  - Radiator F_R,
  - Power-train F_{PT}
  - Reaction from the front suspension R_{FL}.
- Factors for Dynamic loads
- The engine rail is supported in the structure by the dash panel and by the floor cross-beam situated under the front seats.

Engine longitudinal rail

- Solving for forces on K_1 and K_2
- Resolve vertically:

$$F_B/2 + F_R/2 + 2(F_{PT}/4) + K_1 - K_2 - R_{FL} = 0$$

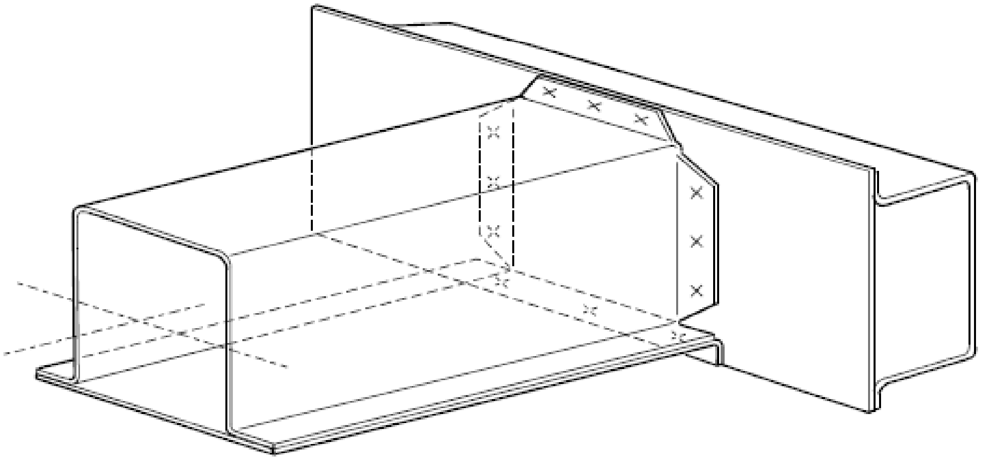
- Moments about K_1:

$$F_B l_1/2 + F_R l_2/2 + F_{PT} l_3/4 + F_{PT} l_5/4 + K_2 l_6 - R_{FL} l_4 = 0$$

Engine longitudinal rail

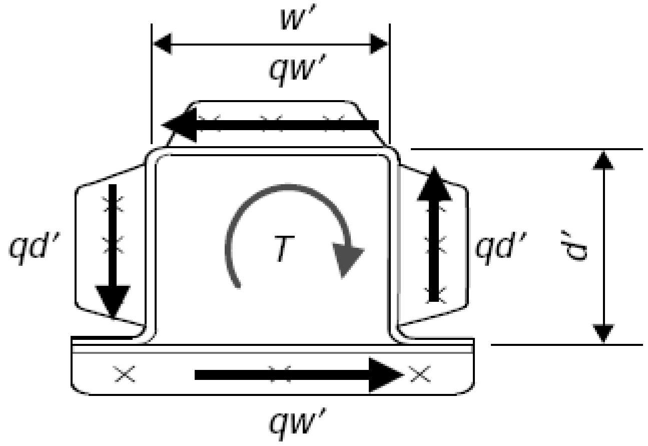
- Plots show high shear between the suspension reaction and the dash panel and the maximum moment is at the dash panel : <u>need for a deeper section</u>
- Design governed by bending strength requirement at the dash panel, hence overall depth ‘d’ should be large.
- Stiffness may also be important and the deflection of the beam calculated.
- This member will also be designed to absorb energy in frontal impacts

Sheet metal Joint



General view of joint

$$q = \frac{T}{2A} = \frac{T}{2d'w'}$$



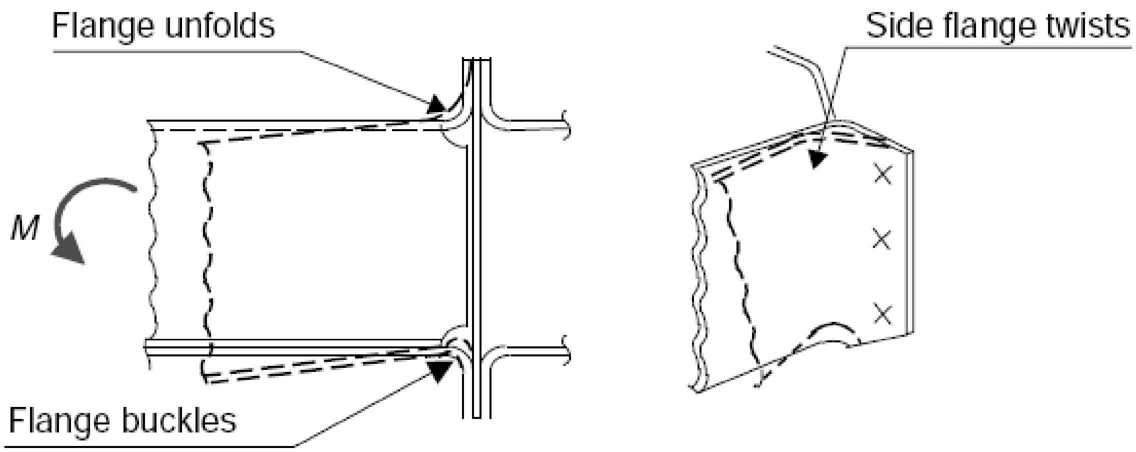
Effect of torsion

Shear flow around the section shows that as the spot welds are spaced further from the beam centre and hence the load will be reduced

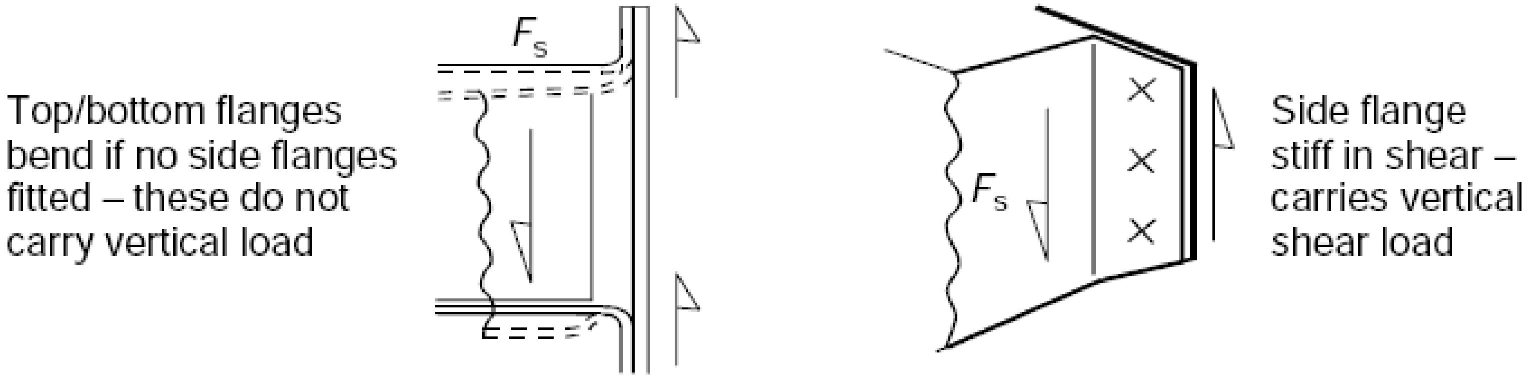
Sheet metal joint

- If a moment M is applied, tension in top of hat and compression in closing plate.
- Vertical shear force is carried by the side flanges, like curved shear panels
  - The top and bottom flanges <u>will not carry</u> any significant vertical force.
  - Side flanges: load is applied normal to their plane they will be ineffective in resisting the force
- When horizontal shear forces are applied the opposite will result.

Sheet metal Joint



(b) Effect of bending in vertical plane

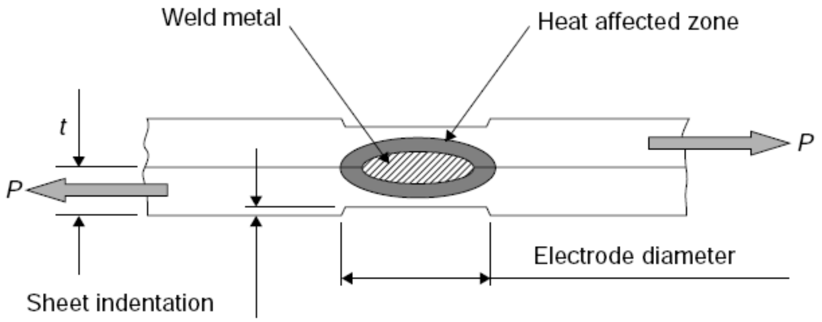


(c) Effect of vertical shear force

Sheet metal joint

- Spot weld joints
- No fixing moment while providing only a shear connection
- From the analysis of this joint we can learn two important rules for designing joints:
  - Avoid out-of-plane bending on thin sections.
  - Load thin sections with in-plane bending and shear.

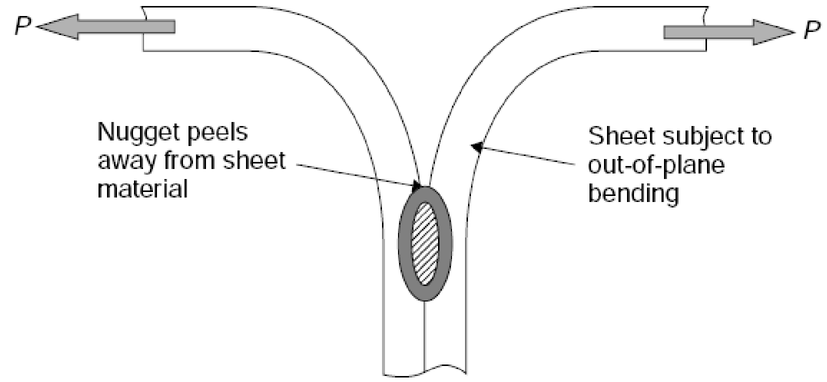
Spot welds Loading



(a) Details of spot-weld and correct shear load

- A centre core which has the microstructure similar to a casting
- There is some working of the metal due to the pressure of the electrodes
- Surrounding the core is a heat-affected zone that has reduced strength compared to the base material

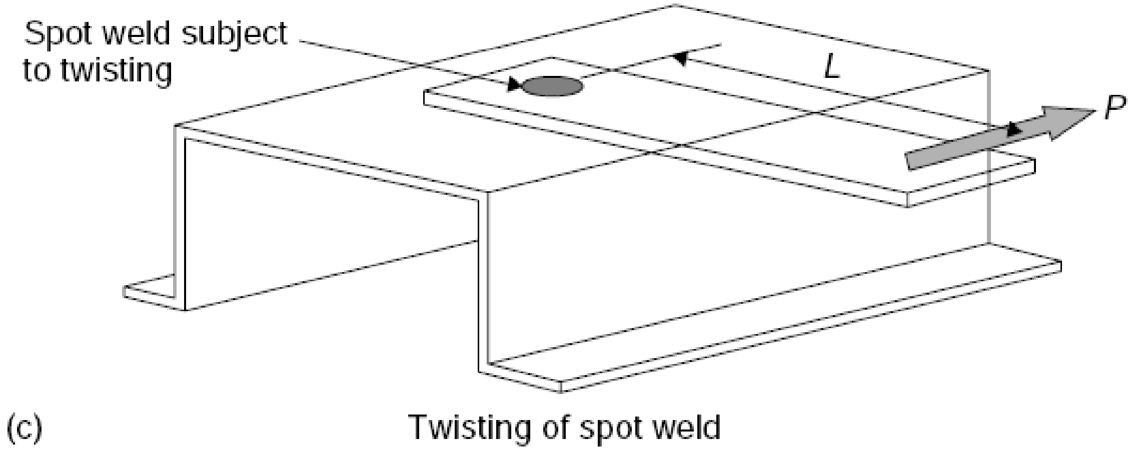
Spot welds Loading



(b) Tensile loads cause peel away of nugget

- The spot weld nugget has peeled away from the base material.
- Parent metal is subject to out-of-plane bending which again is unsatisfactory causing yielding at very low loads

Spot weld Loading



- The small area cannot resist a large twisting moment caused by the long moment arm

Spot weld patterns

- Position of centroid

$$\bar{y} = (3y_1 + 3y_2)/8$$

$$\bar{x} = (2x_1 + 3x_2)/8$$

- Force divided equally all rivets
- Additional shear force for offset torque

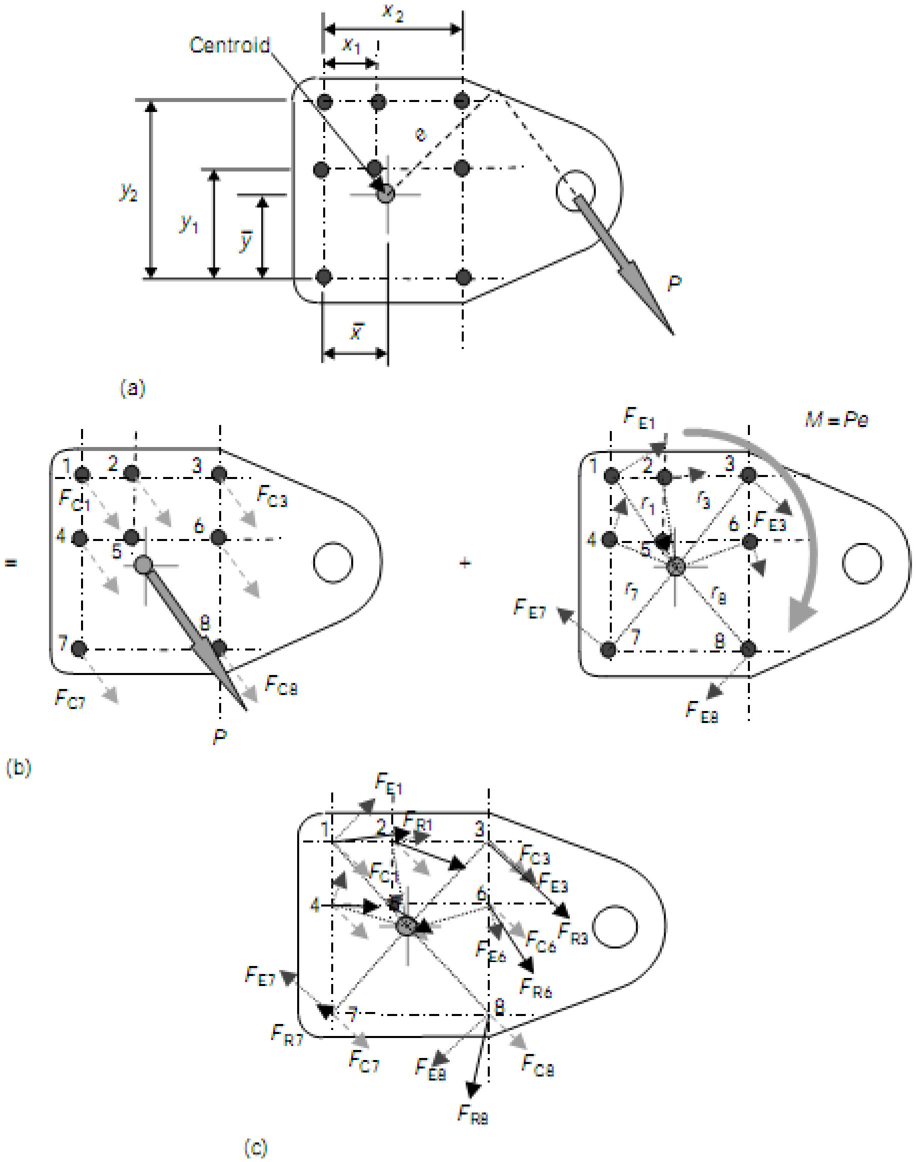
$$\frac{F_{E1}}{r_1} = \frac{F_{E2}}{r_2} \ldots \frac{F_{En}}{r_n} = K$$

$$\sum_1^n F_{En} r_n = M$$

$$F_{En} = \frac{M r_n}{\sum_1^n r_n^2}$$

$$\sum_1^n K r_n^2 = M$$

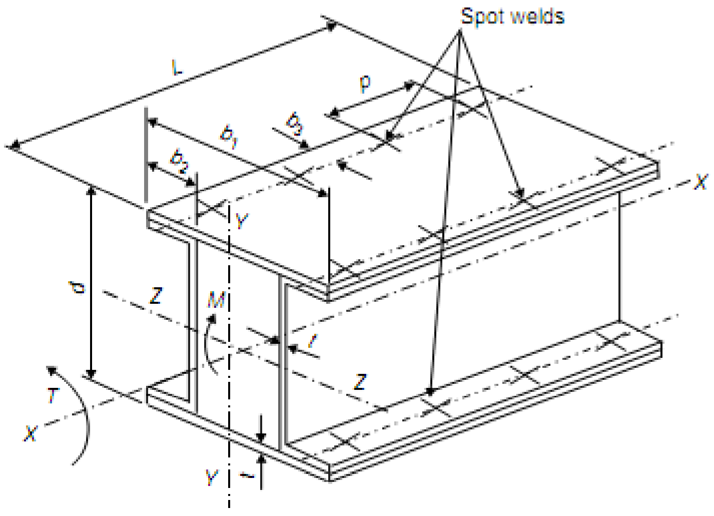
$$K = \frac{M}{\sum_1^n r_n^2}$$



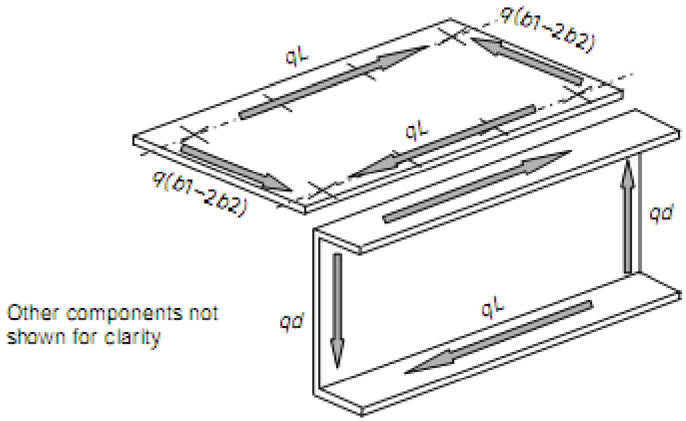
Spot welds along a closed sections

$$\tau = \frac{q}{t} = \frac{T}{2At} = \frac{T}{2d(b_1 - 2b_2)t}$$

$$N = \frac{qL}{F_s}$$



(a) General view of box section



Other components not shown for clarity

(b) Shear on spotweld due to torsion

Shear Panels – Roof panel

- The largest panel in a passenger car and under the torsion load case this may buckle due to shear.
- ESDU 02.03.18/19 data sheet can be used to investigate this phenomenon.
- These data is not ideal because they consider plates with curvature in one direction, but the roof panel has curvature in two directions.

Shear Panels – Roof panel

- Buckling stress

$$\tau = KE(t/b)^2$$

K = Buckling stress co-efficeint
E = modulus of elasticity
T = panel thickness
B = length of curved side

- The coefficient K is presented as a function of the length a, the radius of curvature R, the thickness of the panel t and the ratio a/b (the ratio of the lengths of the panelsides).

Shear panels –Roof panel

- Investigations made into a roof panel 980mm wide by 1250mm long, 1mm thick and radius of curvature of 2425mm resulted in stress to cause buckling of 13.*8N/mm*^{2}which is four times larger than the applied shear stress.
- Other approaches are
  - – ESDU 71005 : flat panels
  - – ESDU 75030 : design for vibrations

Shear panels – Inner fender

- ESDU 71005
- For typical dimensions, applied stress levels may exceed by a factor of 5, hence there is need to provide stiffeners to prevent buckling.
  - This panel in practice has considerable curvature, is restrained at the edges by adjacent parts and also the model is a very simplified representation of the structure.
  - In practice the load will be shared between the engine rail, the fender top rail as well as the panel.
- All these factors will tend to reduce the risk of panel buckling but this does illustrate the need to add stiffeners and swages in this part of the structure.