

### 3.1 Mass and weight

The concept of *mass* and *weight* has already been introduced in sections 7.7 and 7.8 of *Basic Engineering*.

MASS is the quantity of 'matter' or material in a component and is a constant quantity. The SI Unit for mass is the kilogramme (kg).

$$1\ 000\ \text{gramme} = 1\ \text{kilogramme}$$

$$1\ 000\ \text{kilogramme} = 1\ \text{tonne}$$

WEIGHT is the name given to the effect of the force of gravity acting on the mass of the component.

A mass of 1 kg equals a weight of 9.81 N approximately at sea level.

Table 3.1 shows some calculations of mass and weight. For most *workshop calculations* it is normal to work on the conversion of:

$$1\ \text{kg mass} = 10\ \text{N weight}$$

This not only makes the problem easier to work out, it also gives a 'margin of safety'.

Table 3.1 Mass/weight conversion

MASS TO WEIGHT			
1.	<i>A steel casting has a mass of 3 810 kg. Calculate its weight in newtons (N).</i>		
	(1 kg mass	=	10 N weight [9.81 N to be more precise])
	3 810 kg mass	=	3 810 × 10
		=	38 100 N weight
		=	<u>38.1 kN (kilo-newton)</u>
2.	<i>A brass screw has a mass of 27 g. Calculate its weight in newtons (N).</i>		
	27 gramme	=	27 ÷ 1 000 = 0.027 kg.
	0.027 kg mass	=	0.027 × 10 = <u>0.27 N weight.</u>

*Note* how the mass in grammes had to be converted to kilo-grammes before the calculation could proceed.

**WEIGHT TO MASS**

3. An aluminium casting weighs 2 850 N. Calculate its mass in kilogramme (kg).

$$\begin{aligned} (1 \text{ N weight} &= 0.1 \text{ kg mass}) \\ 2 \text{ 850 N weight} &= 2 \text{ 850} \div 10 \\ &= \underline{285 \text{ kg mass}} \end{aligned}$$

4. A large machine weighs 50 kN. Calculate its mass in tonnes.

$$\begin{aligned} (1 \text{ kilo-newton} &= 1 \text{ 000 newton}) \\ 50 \text{ kN} &= 50 \text{ 000 N} \\ 50 \text{ 000 N} &= 50 \text{ 000} \div 10 \\ &= 5 \text{ 000 kg} \\ 1 \text{ 000 kg} &= 1 \text{ tonne} \\ 5 \text{ 000 kg} &= \underline{5 \text{ tonne}} \end{aligned}$$

It is useful to be able to calculate the mass and weight of components in the workshop. For example:

1. To check if lifting tackle is adequate to lift the component safely.
2. To calculate the material cost, as most raw materials are sold by 'weight'.
3. To calculate the charge of a furnace to see if there is sufficient metal to make the casting.

### 3.2 Density

Density is defined as *mass per unit volume*.

$$\text{That is, density} = \frac{\text{mass}}{\text{volume}}$$

For example, the density of copper is 0.008 9 g/mm<sup>3</sup> or, each cubic millimetre of copper has a mass of 0.008 9 gramme.

$$\text{MASS} = \text{VOLUME} \times \text{DENSITY}$$

**EXAMPLE:** Calculate the mass of a component of volume 0.3 metre<sup>3</sup>. The density of copper is 0.008 9 g/mm<sup>3</sup>.

$$\begin{aligned} \text{Mass} &= \text{volume} \times \text{density} \\ &= 0.3 \times 10^6 \times 0.008 \text{ 9 (convert volume to mm}^3\text{)} \\ &= 2 \text{ 670 gramme} \\ &= \underline{2.67 \text{ kilo-gramme}} \end{aligned}$$

The corresponding weight of the component would be:

$$\begin{aligned} \text{weight} &= \text{mass} \times \text{acceleration due to gravity} \\ &= 2.67 \times 9.81 \text{ (mass must be in kg)} \\ &= \underline{26.2 \text{ newton (N)}} \end{aligned}$$

For workshop purposes it would be accurate enough to calculate the weight as:

$$\begin{aligned} \text{weight} &= 2.67 \times 10 \\ &= \underline{26.7 \text{ N}} \end{aligned}$$

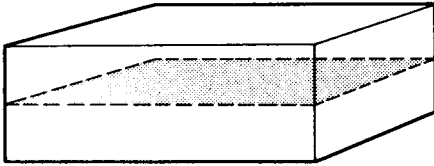
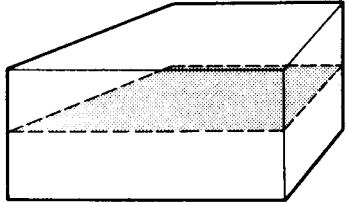
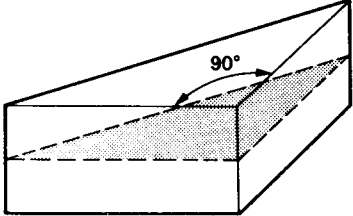
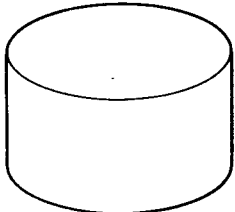
The 'error' of 0.5 N is on the right side to give a margin of safety.

Table 3.2 gives the densities for some typical engineering materials.

Figure 3.1 shows how the mass and weight of the solids given in *Basic Engineering*, table 3.23, can be calculated.

**Table 3.2 Densities of common engineering materials**

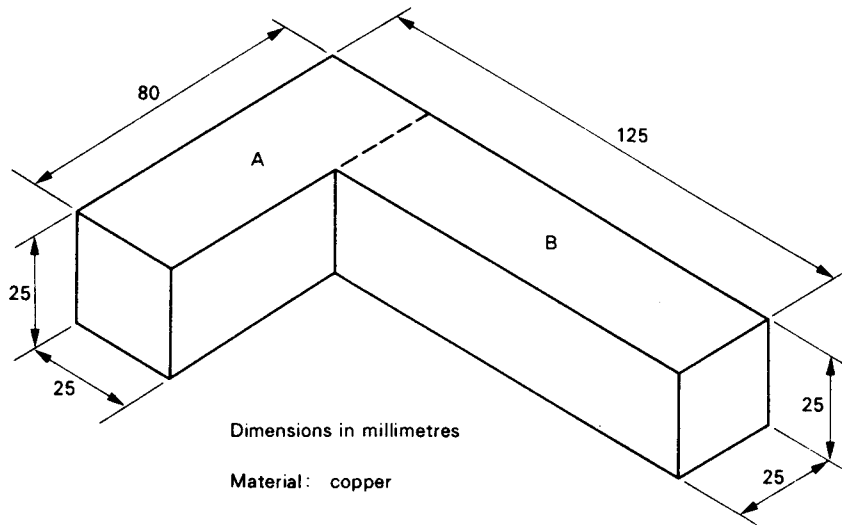
MATERIAL	DENSITY		
	g/mm <sup>3</sup>	g/cm <sup>3</sup>	kg/m <sup>3</sup>
Aluminium	0.002 56	2.56	2 560
Brass (70/30)	0.008 21	8.21	8 210
Bronze	0.008 52	8.52	8 520
Copper	0.008 65	8.65	8 650
Lead	0.011 4	11.4	11 400
Steel	0.007 73	7.73	7 730
Tin	0.007 3	7.3	7 300
Zinc	0.007	7.0	7 000

SOLID	DATA	CALCULATIONS	
		MASS	WEIGHT
 <p>Rectangular prism (copper)</p>	<p>Volume = 72 000 mm<sup>3</sup></p> <p>Density = 0.008 65 g/mm<sup>3</sup></p>	<p>Mass = volume × density</p> <p>= 72 000 × 0.008 65</p> <p>= <u>622.8 g</u></p>	<p>622.8 g = 0.622 8 kg</p> <p>0.622 8 kg = 0.622 8 × 10</p> <p>= <u>6.228 N</u></p>
 <p>Trapezoidal prism (steel)</p>	<p>Volume = 27 000 mm<sup>3</sup></p> <p>Density = 0.007 3 g/mm<sup>3</sup></p>	<p>Mass = volume × density</p> <p>= 27 000 × 0.007 3</p> <p>= <u>197.1 g</u></p>	<p>197.1 g = 0.197 1 kg</p> <p>0.197 1 kg = 0.197 1 × 10</p> <p>= <u>1.971 N</u></p>
 <p>Triangular prism (aluminium)</p>	<p>Volume = 300 000 mm<sup>3</sup></p> <p>Density = 2.56 g/cm<sup>3</sup></p>	<p>300 000 mm<sup>3</sup> = 300 cm<sup>3</sup></p> <p>Mass = volume × density</p> <p>= 300 × 2.56</p> <p>= <u>768 g</u></p>	<p>768 g = 0.768 kg</p> <p>0.768 kg = 0.768 × 10</p> <p>= <u>7.68 N</u></p>
 <p>Cylinder (brass)</p>	<p>Volume = 4 713 000 mm<sup>3</sup></p> <p>Density = 8 210 kg/m<sup>3</sup></p>	<p>4 713 000 mm<sup>3</sup> = 0.004 713 m<sup>3</sup></p> <p>Mass = volume × density</p> <p>= 0.004 713 × 8 210</p> <p>= <u>38.7 kg</u></p>	<p>38.7 kg = 38.7 × 10</p> <p>= <u>387 N</u></p>

Note: The volumes of these solids were calculated in Basic Engineering, table 3.23

Fig.3.1 Calculations of volume, mass and weight

Most engineering components can be broken down into the basic shapes shown in Fig. 3.1. Figures 3.2 and 3.4 inclusive give some examples of calculations of the mass and weight of simple engineering components.



The figure can be broken down into two rectangular prisms A and B

1. Volume of Prism A

$$\begin{aligned} \text{Volume} &= \text{length} \times \text{breadth} \times \text{thickness} \\ &= 80 \times 25 \times 25 \\ &= \underline{50\,000 \text{ mm}^3} \end{aligned}$$

2. Volume of Prism B

$$\begin{aligned} \text{Volume} &= 100 \times 25 \times 25 \\ &= \underline{62\,500 \text{ mm}^3} \end{aligned}$$

3. Total volume = 50 000 + 62 500 = 112 500 mm<sup>3</sup>

Density of copper from table 3.2 = 0.008 65 g/mm<sup>3</sup>

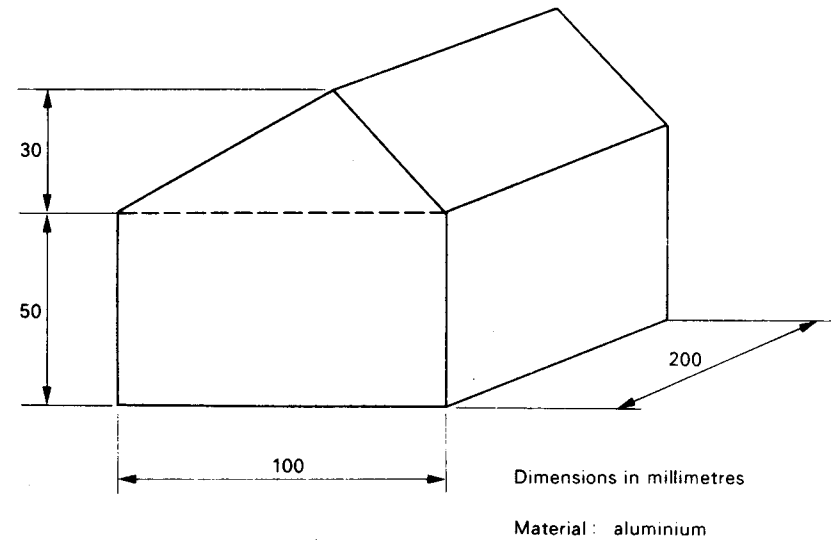
4. Mass = volume × density

$$\begin{aligned} &= 112\,500 \times 0.008\,65 \\ &= \underline{973.125 \text{ g}} \end{aligned}$$

5. Weight = mass (kg) × 10

$$\begin{aligned} &= 0.973\,1 \times 10 \\ &= \underline{9.731 \text{ N}} \end{aligned}$$

Fig. 3.2 Example – volume, mass and weight (1)



The figure can be broken down into a rectangular prism and a triangular prism

1. Volume of rectangular prism

$$\begin{aligned} \text{Volume} &= \text{length} \times \text{breadth} \times \text{thickness} \\ &= 100 \times 50 \times 200 \\ &= \underline{1\,000\,000 \text{ mm}^3} \end{aligned}$$

2. Volume of triangular prism

$$\begin{aligned} \text{Volume} &= \frac{1}{2} \text{ base} \times \text{height} \times \text{thickness} \\ &= \frac{1}{2} \times 100 \times 30 \times 200 \\ &= \underline{300\,000 \text{ mm}^3} \end{aligned}$$

3. Total volume = 1 000 000 + 300 000 = 1 300 000 mm<sup>3</sup> = 1 300 cm<sup>3</sup>

Density of aluminium from table 3.2 = 2.56 g/cm<sup>3</sup>

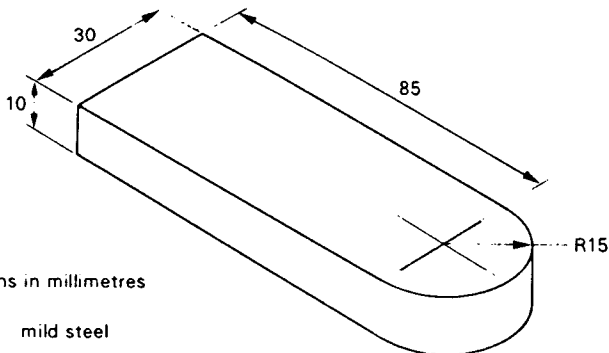
4. Mass = volume × density

$$\begin{aligned} &= 1\,300 \times 2.56 \\ &= \underline{3\,328 \text{ g}} \end{aligned}$$

5. Weight = mass (kg) × 10

$$\begin{aligned} &= 3.328 \times 10 \\ &= \underline{33.28 \text{ N}} \end{aligned}$$

Fig. 3.3 Example – volume, mass and weight (2)



Dimensions in millimetres

Material : mild steel

*The figure can be broken down into a rectangular prism and half a right cylinder*

1. *Volume of rectangular prism*

$$\begin{aligned}
 \text{Volume} &= \text{length} \times \text{breadth} \times \text{thickness} \\
 &= 85 \times 30 \times 10 \\
 &= \underline{25\,500 \text{ mm}^3}
 \end{aligned}$$

2. *Volume of half cylinder*

$$\begin{aligned}
 \text{Volume} &= \frac{1}{2} (\pi R^2) \times 10 \\
 &= \frac{1}{2} \times 3.14 \times 15 \times 15 \times 10 \\
 &= \underline{3\,532.5 \text{ mm}^3}
 \end{aligned}$$

3. *Total volume* = 25 500 + 3 532.5 = 29 032.5 mm<sup>3</sup>

Density from table 3.2 = 0.007 73 g/mm<sup>3</sup>

4. *Mass* = volume × density

$$\begin{aligned}
 &= 29\,032.5 \times 0.007\,73 \\
 &= \underline{224.4 \text{ g}}
 \end{aligned}$$

5. *Weight* = mass (kg) × 10

$$\begin{aligned}
 &= 0.224\,4 \times 10 \\
 &= \underline{2.244 \text{ N}}
 \end{aligned}$$

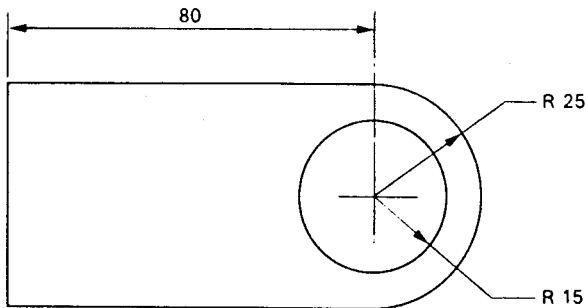
**Fig.3.4 Example – volume, mass and weight (3)**

### 3.3 Sheet metal components

Sheet metal is often sold by *mass per unit area* for a given thickness, rather than by using volume and density. Table 3.3 gives some examples for sheets of typical engineering materials. Figure 3.5 shows how blank weights can be calculated using the data in table 3.3.

**Table 3.3 Mass/unit area for sheet metal**  
(The values given are for mild steel. For other metals see notes.)

THICKNESS (mm) ISO R388		MASS/UNIT AREA		NOTES ON USE OF TABLE
1st choice	2nd choice	g/cm <sup>2</sup>	kg/m <sup>2</sup>	
0.020		0.015 5	0.155	1. The mass/unit area given in the tables can be converted to the values for metals other than steel by use of the following multiplying factors.  Aluminium × 0.331 1 Brass × 1.062 (70/20) Bronze × 1.102 Copper × 1.119 Lead × 1.475 Tin × 0.944 Zinc × 0.906  2. To calculate the mass/unit area of 1 mm thick copper sheet.  Mass/unit area for 1 mm thick steel is 7.73 kg/m <sup>2</sup> multiplying factor for copper is 1.119. Therefore mass/unit area for copper 1 mm thick will be.  $7.73 \times 1.119$  $= \underline{8.65 \text{ kg/m}^2}$
	0.022	0.017 0	0.170	
0.025		0.019 3	0.193	
	0.028	0.021 6	0.216	
0.032		0.024 7	0.247	
	0.036	0.027 8	0.278	
0.040		0.030 9	0.309	
	0.045	0.034 8	0.348	
0.050		0.038 7	0.387	
	0.056	0.043 3	0.433	
0.063		0.048 7	0.487	
	0.071	0.054 9	0.549	
0.080		0.061 8	0.618	
	0.090	0.069 6	0.696	
0.100		0.077 3	0.773	
	0.112	0.086 5	0.865	
0.125		0.096 6	0.966	
	0.140	0.108 2	1.082	
0.160		0.123 7	1.237	
	0.180	0.139 1	1.391	
0.200		0.154 6	1.546	
	0.224	0.173 2	1.732	
0.250		0.193 3	1.933	
	0.280	0.216 4	2.164	
0.315		0.243 5	2.435	
	0.355	0.274 4	2.744	
0.400		0.309 2	3.092	
	0.450	0.347 9	3.479	
0.500		0.386 5	3.865	
	0.560	0.432 9	4.329	
0.630		0.487 0	4.870	
	0.710	0.548 8	5.488	
0.800		0.618 4	6.184	
	0.900	0.695 7	6.957	
1.00		0.773 0	7.730	
	1.120	0.865 0	8.650	
1.25		0.996 2	9.962	
	1.40	1.082 2	10.822	
1.60		1.236 8	12.368	
	1.80	1.391 4	13.914	
2.00		1.546 0	15.460	
	2.24	1.731 5	17.315	
2.50		1.932 5	19.325	
	2.80	2.164 4	21.644	
3.15		2.434 9	24.349	
	3.5	2.744 1	27.441	
4.00		3.092 0	30.920	



Dimensions in millimetres

Material: 1.25mm Thick mild steel

1. Area of rectangle =  $80 \times 50 = \underline{4\,000\text{mm}^2}$

Area of semi-circle =  $\frac{1}{2} \times 3.14 \times 25 \times 25 = \underline{981\text{mm}^2}$

Area of hole =  $3.14 \times 15 \times 15 = \underline{706\text{mm}^2}$

Total area of blank =  $4000 + 981 - 706 = \underline{4\,275\text{mm}^2}$

Mass/unit area for 1.25 mm thick mild steel = 0.996 g/cm<sup>2</sup> (Table 3.3)

Area of blank in cm<sup>2</sup> =  $4\,275 \div 100 = \underline{42.75\text{cm}^2}$

Therefore, mass of blank =  $42.75 \times 0.996$   
 = 42.6 g (mass)  
 = 0.426 N (weight)

2. If aluminium sheet was used instead of mild steel, the multiplying factor  $\times 0.3311$  would have to be used (Table 3.3)

Mass/unit area for 1.25mm thick aluminium =  $0.996 \times 0.3311$   
 = 0.329 7g/cm<sup>2</sup>

Therefore, mass of blank in aluminium =  $42.75 \times 0.329 7$   
 = 14.1 g (mass)  
 = 0.141 N (weight)

**Fig. 3.5 Calculation of sheet metal blank weights**

### 3.4 Bar components

Bar is often sold by mass per unit length for a given cross-section, rather than by using volume and density. Table 3.4 gives some examples for bars of typical engineering materials. Figure 3.6 shows how blank weights can be calculated using the data in table 3.4.

**Table 3.4 Mass/metre run for mild steel bars**

CIRCULAR SECTION		SQUARE SECTION		HEXAGONAL SECTION	
Diameter mm	Mass kg	Size mm	Mass kg	Size (A/F) mm	Mass kg
4	0.098	4	0.125	4	0.107
5	0.152	5	0.194	5	0.168
6	0.200	6	0.280	6	0.240
7	0.296	7	0.380	7	0.330
8	0.390	8	0.495	8	0.430
9	0.495	9	0.630	9	0.545
10	0.610	10	0.774	10	0.670
12	0.875	12	1.13	12	0.965
14	1.190	14	1.52	14	1.34
16	1.558	16	1.99	16	1.70
18	1.97	18	2.52	18	2.00
20	2.43	20	3.10	20	2.68
25	3.80	22	3.74	22	3.24
30	5.47	24	4.47	24	3.57
35	7.45	26	5.25	26	4.53
40	9.75	28	6.08	28	5.75
45	12.3	30	6.97	30	6.05
50	15.3	32	7.91	32	6.88
60	22.0	34	8.96	34	7.79
70	29.8	36	10.3	36	8.70
80	39.0	38	11.4	38	9.70
90	49.1	40	12.4	40	10.75
100	61.0	42	13.65	42	11.85
125	95.0	44	15.00	44	13.00
150	137.0	46	16.4	46	14.4
175	186.0	48	17.9	48	15.5
200	242.0	50	19.3	50	16.8
225	308.0	55	23.4	55	20.2
250	380.0	60	28.0	60	24.1
300	549.0	65	32.6	65	28.3



Note: To use the above tables for materials other than mild steel, use the multiplying factors given with table 3.3.

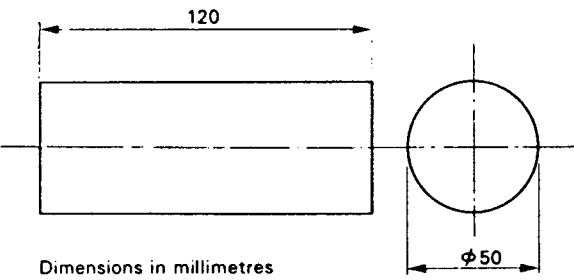
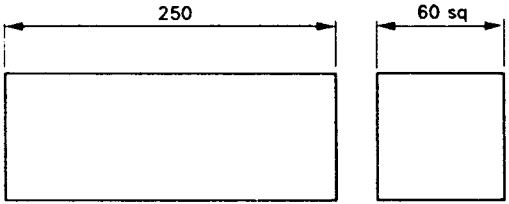
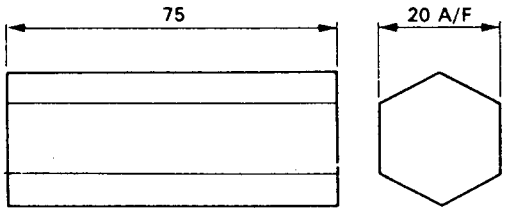
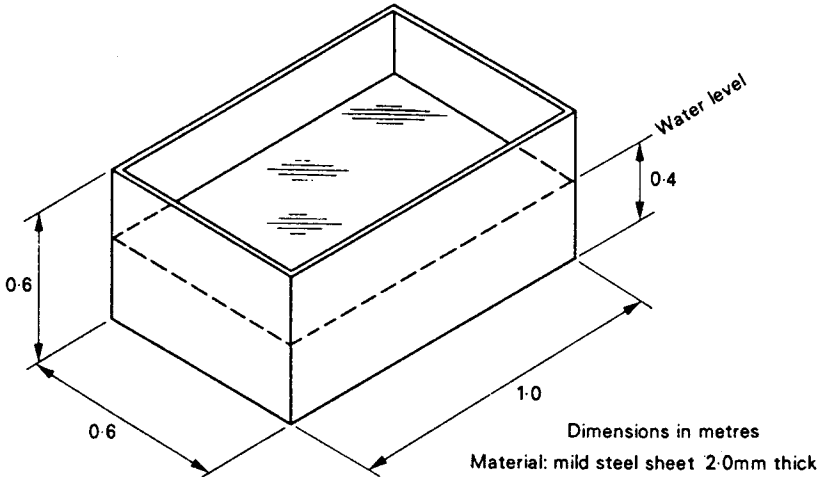
BLANK	DATA	CALCULATION
 <p>Dimensions in millimetres Material: mild steel</p>	<p>Mass / metre for mild steel 50 mm diameter is <u>15.3 kg per metre run</u> (table 3-4)</p>	<p>Length of blank = 120 mm = <u>0.12 m</u> Mass / metre = 15.3 kg Mass of blank = 15.3 × 0.12 = <u>1.84 kg</u> Weight of blank = <u>18.4 N</u></p>
 <p>Dimensions in millimetres Material: brass 70/30</p>	<p>Mass / metre for brass rod 60mm square is 28 × 1.062 = <u>29.7 kg per metre run</u> (table 3-4)</p>	<p>Length of blank = 250mm = <u>0.25m</u> Mass / metre = 29.7 kg Mass of blank = 29.7 × 0.25 = <u>7.4 kg</u> Weight of blank = <u>74 N</u></p>
 <p>Dimensions in millimetres Material: aluminium</p>	<p>Mass / metre for hexagonal aluminium rod 20 A/F is 2.68 × 0.3311 = <u>0.887 kg per metre run</u> (table 3-4)</p>	<p>Length of blank = 75mm = <u>0.075 m</u> Mass / metre = 0.887 kg Mass of blank = 0.887 × 0.075 = 0.067 kg = <u>67 g</u> Weight of blank = <u>0.67 N</u></p>

Fig. 3.6 Calculation of metal blank weights (bars)

### 3.5 Mass of the contents of a container

If the volume of a container is known and the density of the fluid or powder stored is known then the mass of the fluid or powder can be calculated as shown in Fig. 3.7.



To find the mass of the open-topped container shown together with water filled to a depth of 0.4 m

Area of sheet metal:

$$\text{ends: } 2 \times 0.6 \times 0.6 = 0.72\text{m}^2$$

$$\text{sides: } 2 \times 1.0 \times 0.6 = 1.20\text{m}^2$$

$$\text{bottom: } 1.0 \times 0.6 = 0.60\text{m}^2$$

$$\text{Total area} = 2.52\text{m}^2$$

Mass per unit area for 2.0 mm thick mild steel = 15.46 kg/m<sup>2</sup> (table 3.3)

$$\text{Mass of tank} = 2.52 \times 15.46 = \underline{38.96 \text{ kg}}$$

Volume of water (allowing for thickness of sheet metal)

$$\text{Volume} = 0.398 \times 0.596 \times 0.996$$

$$= \underline{0.236 \text{ m}^3}$$

Density of water = 1.0g/cc

$$\text{Mass of water} = 1 \times 0.2362 \times 1\,000\,000$$

$$= 236\,200 \text{ g}$$

$$= \underline{236.2 \text{ kg}}$$

$$\text{Total mass of tank and water} = 38.96 + 236.2$$

$$\approx \underline{275 \text{ kg}}$$

no	log
0.398	$\bar{1}.5999$
0.596	$\bar{1}.7752$
0.996	$\bar{1}.9983$
<u>0.236 2</u>	<u><math>\bar{1}.3734</math></u>

Fig.3.7 Mass of contents of container