



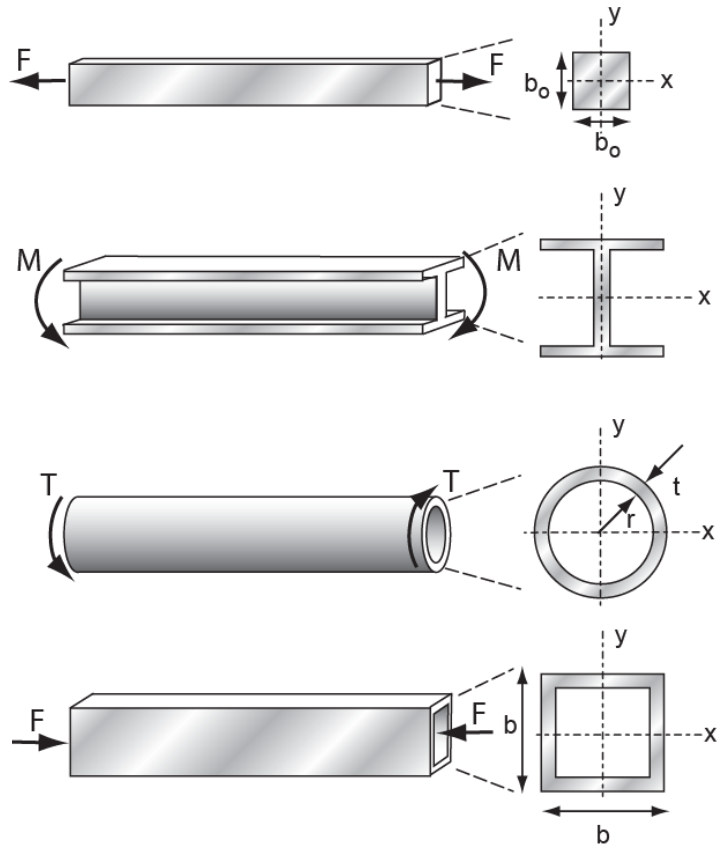
Aalto University  
School of Engineering

# MEC-E1070

# Selection of Engineering Materials

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# Shape factor



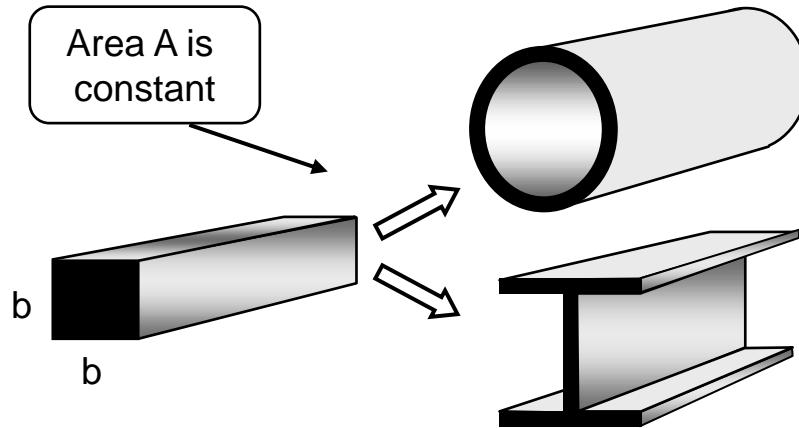
- Efficient shapes: I-beams, tubes, etc.
- The shape factor and shape limits
- Material indices that include shape
- Graphical ways of dealing with shape

# Shape factor: bending stiffness

- Take ratio of bending stiffness  $S$  of **shaped section** to that ( $S_o$ ) of a neutral reference section of the **same cross-section area**
- Define a **standard reference section**: a solid square with area  $A = b^2$
- Second moment of inertia is  $I$ ; **stiffness constraint** as  $EI$ .

$$I_o = \frac{b^4}{12} = \frac{A^2}{12}$$

$$\text{Area } A = b^2$$



$$I = \int y^2 dA$$

Area A and  
modulus E  
unchanged

- Define **shape factor for elastic bending**, measuring efficiency, as

$$\varphi_e = \frac{S}{S_o} = \frac{EI}{EI_o} = 12 \frac{I}{A^2}$$

# Indices that include shape

Function

Beam (shaped section).

Constraint

Bending stiffness = S:

$$S = \frac{CEI}{L^3}$$

$$\varphi_e = 12 \frac{I}{A^2} \quad A = \left( \frac{12I}{\varphi_e} \right)^{1/2}$$

Objective

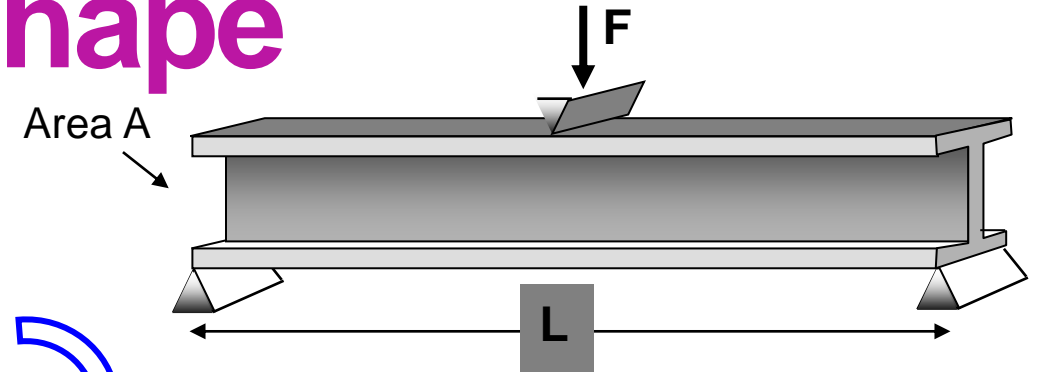
Minimise mass, m, where:

$$m = AL\rho$$

$$m = \left( \frac{12 S L^5}{C} \right)^{1/2} \left( \frac{\rho}{(\varphi_e E)^{1/2}} \right)$$

Chose materials with smallest

$$\left( \frac{\rho}{(\varphi_e E)^{1/2}} \right)$$



m = mass  
A = area  
L = length  
 $\rho$  = density  
b = edge length  
S = stiffness  
I = second moment of inertia  
E = Youngs Modulus

# Selection chart – with shaped-material index

Fixed shape ( $\varphi_e = 1$ ):

$$\frac{\rho}{E^{1/2}}$$

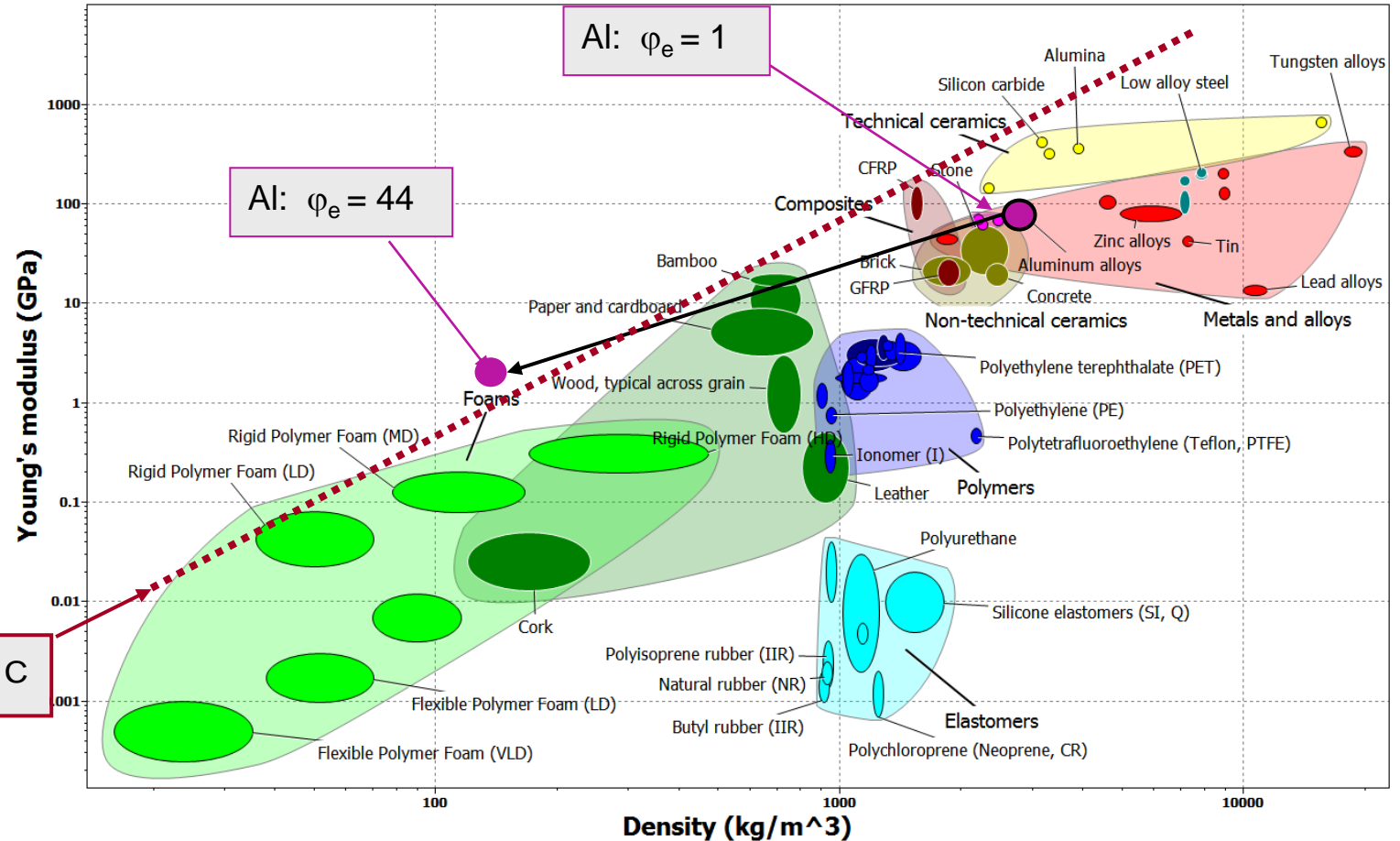
Shaped-material index

$$\frac{\rho}{(\varphi_e E)^{1/2}} = \frac{\rho / \varphi_e}{(E / \varphi_e)^{1/2}}$$

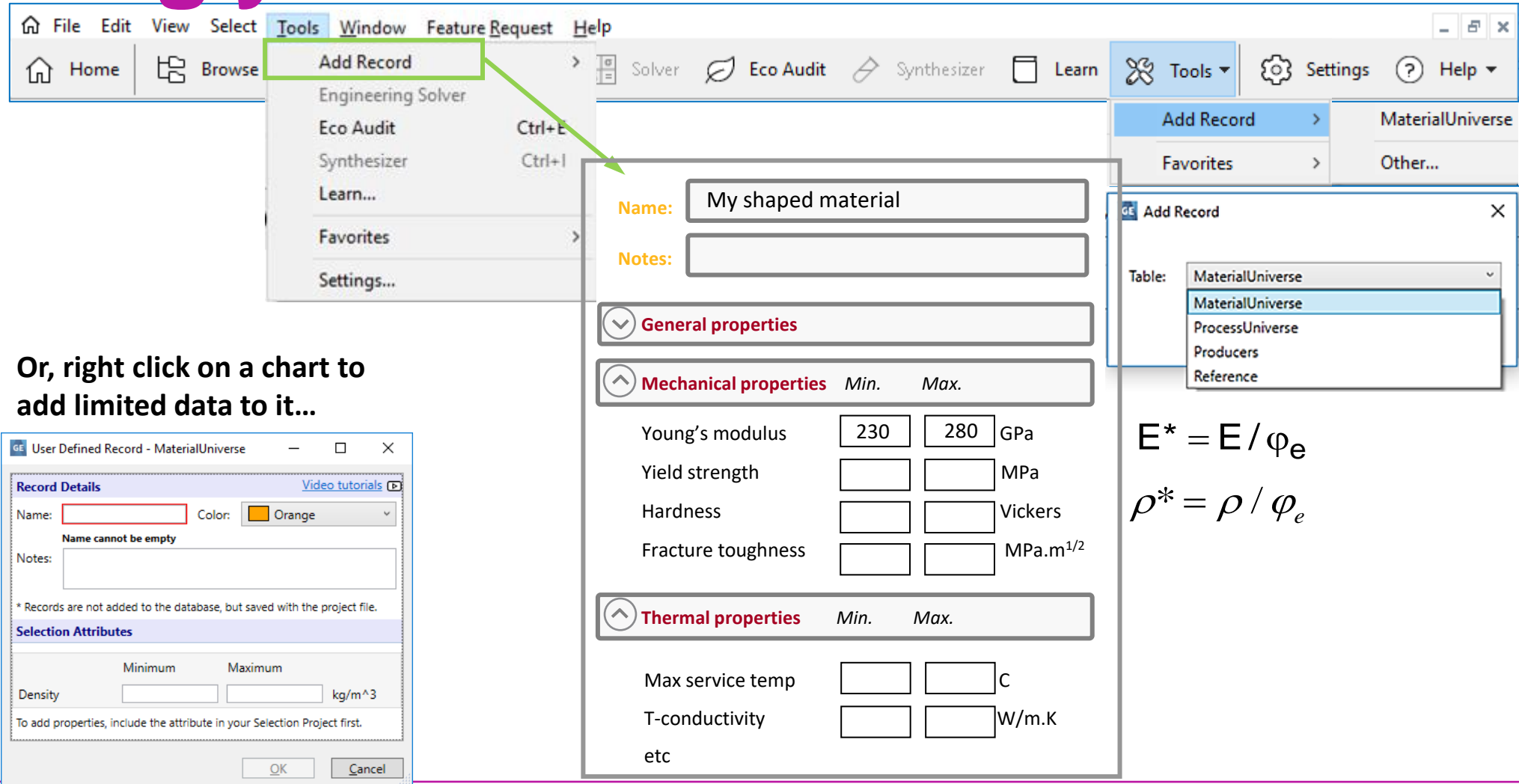
New material with

$$\begin{cases} \rho^* = \rho / \varphi_e \\ E^* = E / \varphi_e \end{cases}$$

$$\frac{\rho}{E^{1/2}} = C$$



# Making your own records



Or, right click on a chart to add limited data to it...

**User Defined Record - MaterialUniverse**

**Record Details**

Name:  Color: Orange

Name cannot be empty

Notes:

\* Records are not added to the database, but saved with the project file.

**Selection Attributes**

	Minimum	Maximum	
Density	<input type="text"/>	<input type="text"/>	kg/m <sup>3</sup>

To add properties, include the attribute in your Selection Project first.

**Add Record**

Table: MaterialUniverse

**Name:**

**Notes:**

**General properties**

**Mechanical properties** *Min.* *Max.*

Young's modulus	<input type="text" value="230"/>	<input type="text" value="280"/>	GPa
Yield strength	<input type="text"/>	<input type="text"/>	MPa
Hardness	<input type="text"/>	<input type="text"/>	Vickers
Fracture toughness	<input type="text"/>	<input type="text"/>	MPa.m <sup>1/2</sup>

**Thermal properties** *Min.* *Max.*

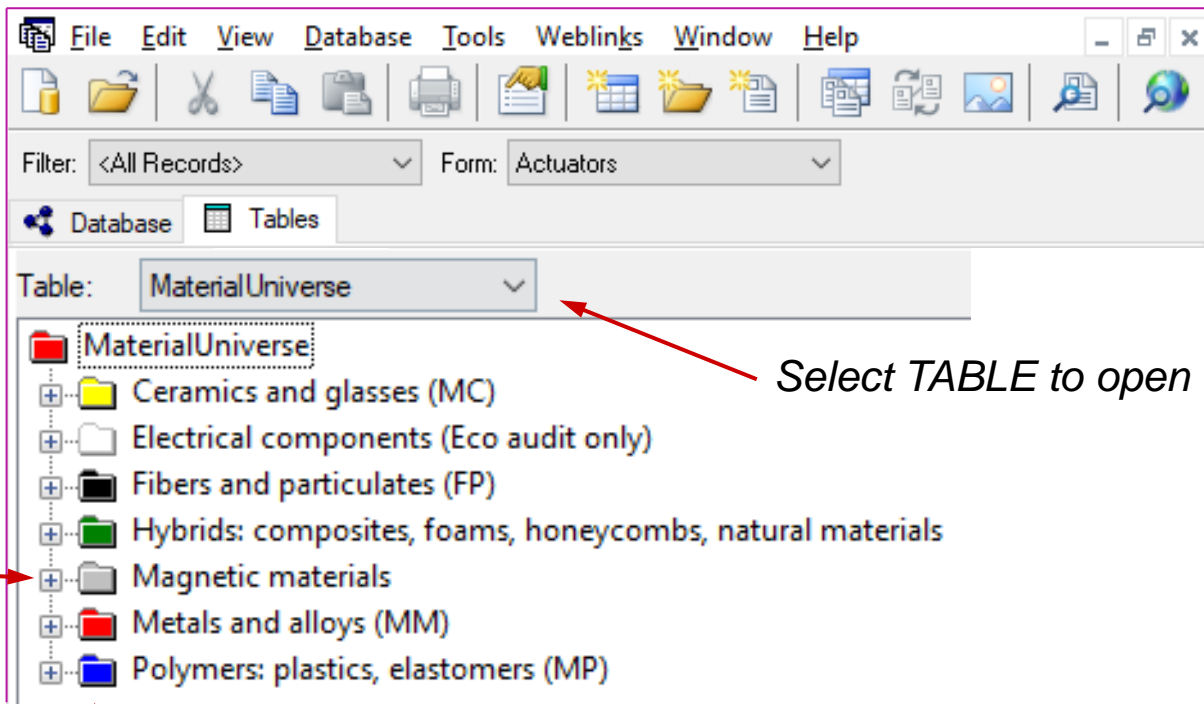
Max service temp	<input type="text"/>	<input type="text"/>	C
T-conductivity	<input type="text"/>	<input type="text"/>	W/m.K
etc			

**Equations:**

$$E^* = E / \varphi_e$$

$$\rho^* = \rho / \varphi_e$$

# Opening a data-table for editing



The screenshot shows a database application window with a menu bar (File, Edit, View, Database, Tools, Weblinks, Window, Help) and a toolbar. Below the toolbar, there are dropdowns for 'Filter: <All Records>' and 'Form: Actuators'. A 'Table:' dropdown is set to 'MaterialUniverse'. Below this, a tree view shows the 'MaterialUniverse' folder expanded, revealing sub-folders: 'Ceramics and glasses (MC)', 'Electrical components (Eco audit only)', 'Fibers and particulates (FP)', 'Hybrids: composites, foams, honeycombs, natural materials', 'Magnetic materials', 'Metals and alloys (MM)', and 'Polymers: plastics, elastomers (MP)'. Annotations include: 'Toolbar' with an arrow pointing to the toolbar; 'Expand and locate record for editing' with an arrow pointing to the expanded 'MaterialUniverse' folder; 'Select TABLE to open' with an arrow pointing to the 'Table:' dropdown; and a red-bordered box containing the text 'The **FILTER** determines which folders and records appear' with an arrow pointing to the 'Filter' dropdown.

Toolbar →

Filter: <All Records> Form: Actuators

Database Tables

Table: MaterialUniverse

MaterialUniverse

- + Ceramics and glasses (MC)
- + Electrical components (Eco audit only)
- + Fibers and particulates (FP)
- + Hybrids: composites, foams, honeycombs, natural materials
- + Magnetic materials
- + Metals and alloys (MM)
- + Polymers: plastics, elastomers (MP)

Expand and locate record for editing →

Select TABLE to open

The **FILTER** determines which folders and records appear

# Editing a Record

- Select which properties to display with the 'Form' drop-down
- Closing the form automatically saves the data  
*don't need to click 'Save'*
- Ensure enter values in the unit displayed  
*Or change the unit system:  
Tools > Options > General  
> Preferred Unit System*
- Question mark ? On the right  
*indicates the value is estimated*

The screenshot shows a software window for editing a material record. At the top, there is a 'Filter' dropdown set to 'All materials' and a 'Form' dropdown menu that is currently open, displaying a list of material categories including 'All attributes', 'Aerospace materials', 'All bulk materials', 'All materials', 'Ceramics', 'ChemFies only', 'Core materials', 'Foams', 'Magnetic materials', 'Metals', 'Polymers - All', 'Polymers - Elastomers', 'Polymers - Plastics', 'Stainless alloys', 'Tool steels', and 'Woods'. The main form area is titled 'High alloy steel, AerMet 10' and 'aged (MMFEHAB)'. It contains several input fields and checkboxes. Under 'Price', there is a 'Price \*' field with the value '29' and a unit 'USD/kg' with a question mark. Below this is a 'Price\_Notes' text area. Under 'Physical properties', there are fields for 'Density' (7.85e3), 'Relative density', 'Porosity (closed)', 'Porosity (open)', 'Cell type', 'Cell size', 'Cells/volume', and 'Anisotropy ratio'. Under 'Mechanical properties', there are fields for 'Young's modulus' (193) and 'Young's modulus\_Notes'. A question mark is visible next to the 'Young's modulus' field. The bottom of the form has a large text area for 'Notes'.



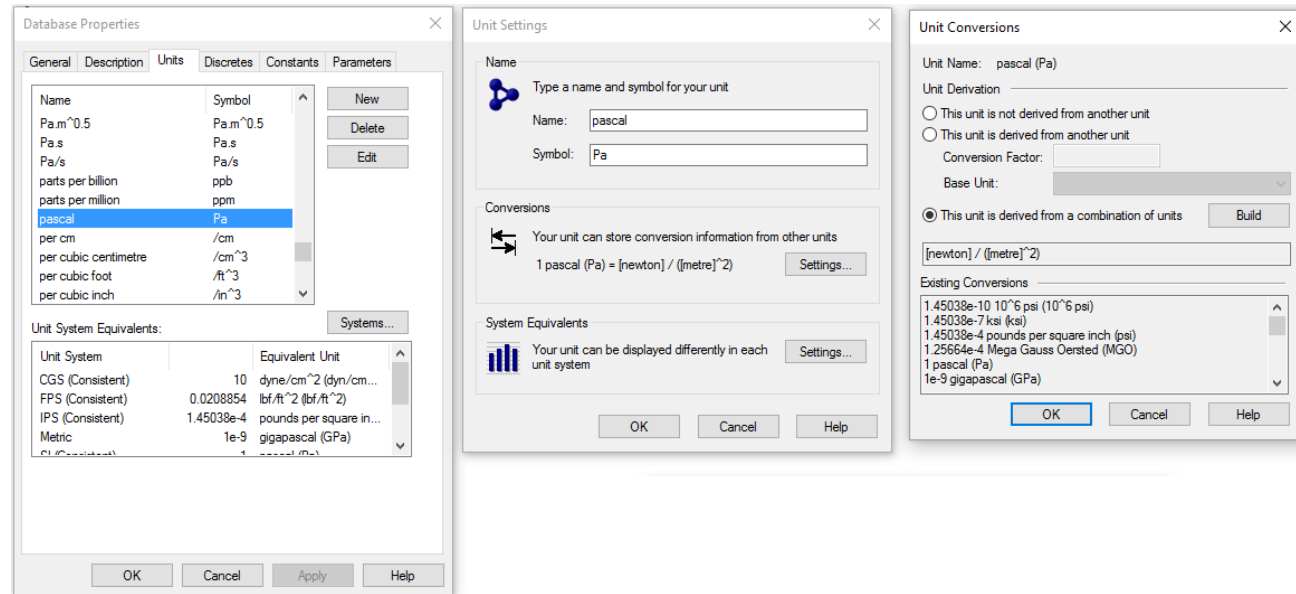
# Customize units

Adding a new unit

- Database menu > Database settings > Units
- Conversions can be defined by their derivation from other base units, eg:

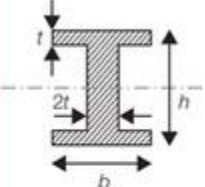
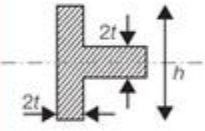
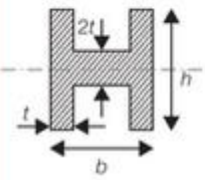
$$[\text{Pa}] = [\text{newton}] / [\text{metre}]^2$$

$$[\text{inch}] = 0.0254 * [\text{metre}]$$



# Task 3.1.1 Second moment of area of I-beam – flange and web thickness

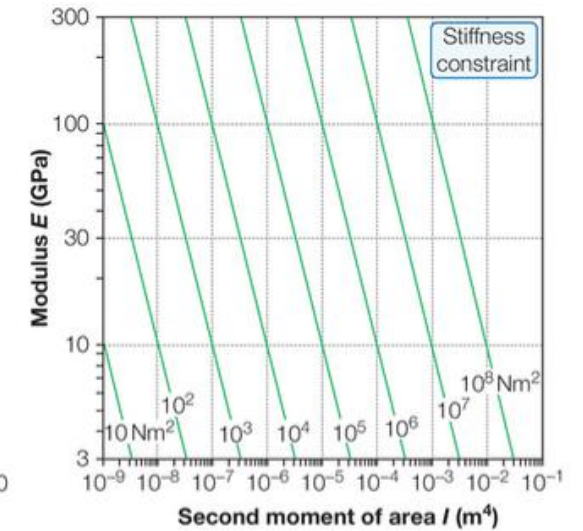
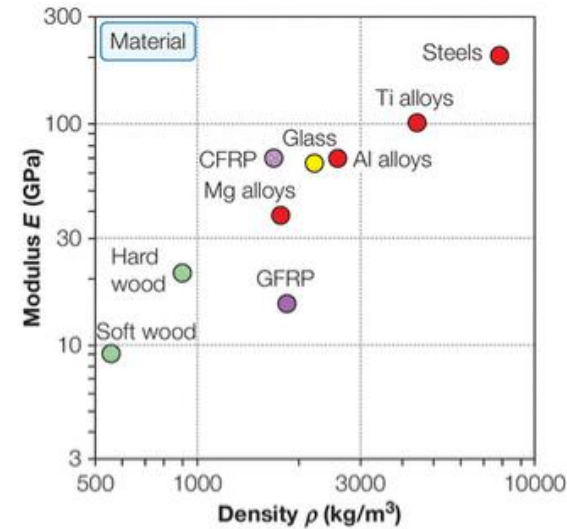
**Table 9.3** *continued*

Section Shape	Bending Factor $\phi_B^e$	Torsional Factor $\phi_T^e$	Bending Factor $\phi_B^f$	Torsional Factor $\phi_T^f$
	$\frac{1}{2} \frac{h}{t} \frac{(1+3b/h)}{(1+b/h)^2}$ ( $h, b \gg t$ )	$1.19 \left(\frac{t}{b}\right) \frac{\left(1 + \frac{4h}{b}\right)}{\left(1 + \frac{h}{b}\right)^2}$	$\frac{1}{\sqrt{2}} \sqrt{\frac{h}{t}} \frac{\left(1 + \frac{3b}{h}\right)}{\left(1 + \frac{b}{h}\right)^{3/2}}$	$1.13 \sqrt{\frac{t}{b}} \frac{\left(1 + \frac{4h}{b}\right)}{\left(1 + \frac{h}{b}\right)^{3/2}}$
	$\frac{1}{2} \frac{h}{t} \frac{(1+4bt^2/h^3)}{(1+b/h)^2}$ ( $h, b \gg t$ )	$0.595 \left(\frac{t}{h}\right) \frac{\left(1 + \frac{8b}{h}\right)}{\left(1 + \frac{b}{h}\right)^2}$	$\frac{3}{4} \sqrt{\frac{h}{t}} \frac{\left(1 + \frac{4bt^2}{h^3}\right)}{\left(1 + \frac{b}{h}\right)^{3/2}}$	$0.565 \sqrt{\frac{t}{h}} \frac{\left(1 + \frac{8b}{h}\right)}{\left(1 + \frac{b}{h}\right)^{3/2}}$
	$\frac{1}{2} \frac{h}{t} \frac{(1+4bt^2/h^3)}{(1+b/h)^2}$ ( $h, b \gg t$ )	$1.19 \left(\frac{t}{h}\right) \frac{\left(1 + \frac{4b}{h}\right)}{\left(1 + \frac{b}{h}\right)^2}$	$\frac{3}{4} \sqrt{\frac{h}{t}} \frac{\left(1 + \frac{4bt^2}{h^3}\right)}{\left(1 + \frac{b}{h}\right)^{3/2}}$	$1.13 \sqrt{\frac{t}{h}} \frac{\left(1 + \frac{4b}{h}\right)}{\left(1 + \frac{b}{h}\right)^{3/2}}$

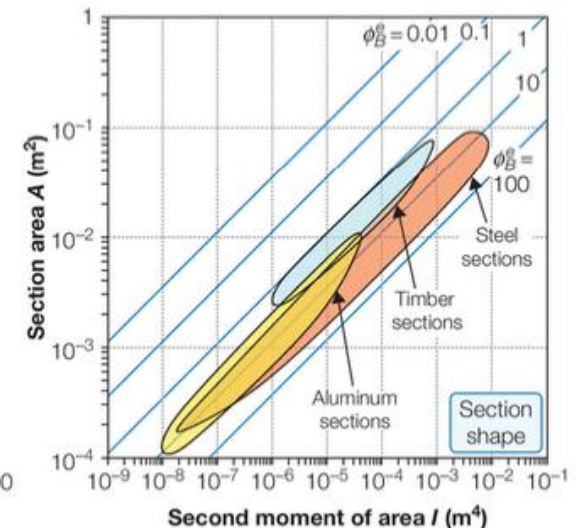
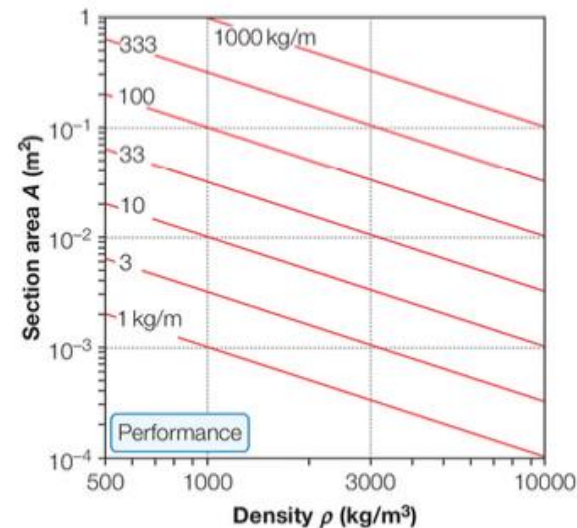
# Task 3.1.2 calculation to include shape

Material property values	Reference shape (Profile a) $\varphi_e = 1$	Profile b $\varphi_e = ?$	Profile c $\varphi_e = ?$	Profile d $\varphi_e = ?$	Profile e $\varphi_e = ?$
Material X	$E_x$ (GPa), $\rho_x$ (kg.m-3)	$E_{xb}$ (GPa), $\rho_{xb}$ (kg.m-3)	$E_{xc}$ (GPa), $\rho_{xc}$ (kg.m-3)	...	...
Material Y	$E_y$ (GPa), $\rho_y$ (kg.m-3)	$E_{yb}$ (GPa), $\rho_{yb}$ (kg.m-3)	$E_{yc}$ (GPa), $\rho_{yc}$ (kg.m-3)		
Material Z	...			...	...

# Task 3.2.1 theoretical / empirical shape factor



# Task 3.2.2 four-field chart (Figure 9.9)



# Summary

- When materials carry bending, torsion or axial compression, the section shape becomes important.
- The “shape efficiency” is the amount of material needed to carry the load. It is measured by the shape factor,  $\phi$ .
- If two materials have the *same* shape, the standard indices for bending (e.g.  $\rho/E^{1/2}$ ) guide the choice.
- If materials can be made -- or are available -- in different shapes, then indices which include the shape (e.g.  $\rho/(\phi E)^{1/2}$ ) guide the choice.

# Demo - bending stiffness map w. shape

$\varphi_e = 1$	$\rho$ (kg.m <sup>-3</sup> )	E (GPa)
Plywood	700-800	5-8
Mg Alloys	1500-1950	42-47
CFRP	1500-1600	69-150

$$\rho^* = \rho / \varphi_e$$

$$E^* = E / \varphi_e$$

$\varphi_e = 5$	$\rho$ (kg.m <sup>-3</sup> )	E (GPa)
Plywood	140-160	1-1.6
Mg Alloys	300-390	8.4-9.4
CFRP	300-320	13.8-30

$\varphi_e = 0.2$	$\rho$ (kg.m <sup>-3</sup> )	E (GPa)
Plywood	3500-4000	25-40
Mg Alloys	...	...
CFRP	...	...