Problems in Mechanical Technology

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Preface

This book covers the subject of mechanical technology in the first year of the Higher National Certificate Course in Engineering. Although intended for Higher National Certificate students, it will also be of value in the early years of a Higher National Diploma Course and for those studying for the Part I Examination of the Council of Engineering Institutions. Equally it will be suitable for the new Higher Certificate and Higher Diploma courses to be introduced by the Technical Education Council.

Mechanical technology embraces mechanics of solids and fluids with some thermodynamics. Because of the extensive syllabus, relatively little time may be available in class for the solution of problems, and yet without them neither the basic principles involved, nor their applications, will be properly understood. In addition to a wide selection of fully-worked examples, this book provides a large range of unworked problems, with answers, through which the student may work in his own time. To assist him further, 'guided solutions' have been introduced into each chapter. Here the student is told precisely how to deal with the problem and he is able to make a stage-by-stage check on his work.

I am grateful to the various examining bodies for permission to use their examination questions. The units in some questions have been converted to SI but in all cases acknowledgement has been made.

Finally I would like to thank two of my colleagues: Mr A. Walters for his kindness in checking the solutions to the problems and Mr D.C. Blackwell for his assistance with the thermodynamics section of the book.

1975 J. C.

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Stress and Strain

A. Introduction

(a) The elastic constants

Suppose a bar of metal of length l is distorted elastically by an axial tensile or compressive force (see Figure 1.1) so that a change in length δl occurs. The longitudinal strain is given by $\delta l/l$, and the ratio

$$\frac{\text{longitudinal stress}}{\text{longitudinal strain}}$$

is a constant called the *modulus of elasticity* (E).

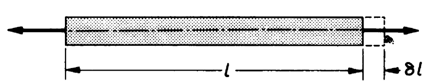


Fig. 1.1

A change in length of the bar will be accompanied by a change in the lateral dimensions. The ratio

$$\frac{\text{lateral strain}}{\text{longitudinal strain}}$$

produced by a single stress, is a constant called *Poisson's ratio* (ν).

Similarly consider an element of material subjected to shearing forces as shown in Figure 1.2. The angle ϕ (radians) through which the element is distorted is a measure of the shear strain, and the ratio

$$\frac{\text{shear stress}}{\text{shear strain}}$$

is a constant called the *modulus of rigidity* (G).

If a body is subjected to a uniform (fluid) pressure p (see Figure 1.3) over its surface, the volume V of the body will be reduced by an amount δV, and the volumetric strain is given by $\delta V/V$. The ratio

$$\frac{\text{volumetric stress}}{\text{volumetric strain}}$$

(where volumetric stress = p) is a constant called the *bulk modulus* (K). E, v, G, and K are the 'elastic constants' of a material.

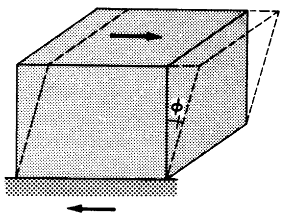


Fig. 1.2

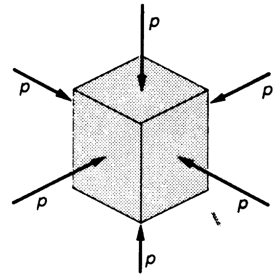


Fig. 1.3

(b) Stress on an oblique plane

Let a bar of metal of cross-sectional area A be subjected to an axial force P (Figure 1.4). The stresses set up on an oblique plane YY may be found as follows. Consider the wedge-shaped element ABC of the bar (see Figure 1.5) whose side AC lies in plane YY. Let the element be of unit thickness. The tensile stress (σ) on all transverse cross-sections of the bar is given by P/A, and consequently this will be the stress on face AB.

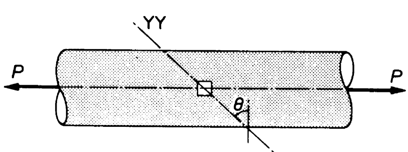
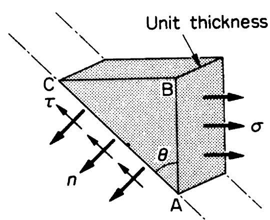


Fig. 1.4



Stresses acting on element ABC

Fig. 1.5

Let the component stresses set up on plane AC be n normal to the plane and τ along the plane (i.e. a shear stress).

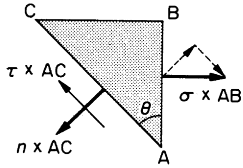
The forces acting on the element (see Figure 1.6) must be in equilibrium. Resolving these forces parallel to AC,

$$\tau \times \text{AC} = (\sigma \text{AB}) \sin \theta$$

$$\therefore \quad \tau = \sigma \frac{\text{AB}}{\text{AC}} \sin \theta$$

$$= \sigma \cos \theta \sin \theta$$

$$= \tfrac{1}{2} \sigma \sin 2\theta$$



Forces acting on element ABC

Fig. 1.6

Resolving these forces perpendicular to AC,

$$n \times \mathrm{AC} = (\sigma \mathrm{AB}) \cos \theta$$

$$\therefore \qquad n = \sigma \frac{\mathrm{AB}}{\mathrm{AC}} \cos \theta$$

$$= \sigma \cos^2 \theta$$

Thus as θ increases from 0 to 90°, the direct stress n will decrease from σ to zero. The shear stress τ is a maximum when sin 2θ is a maximum, i.e. when $2\theta = 90°$ or $\theta = 45°$. Hence $\tau_{max} = \sigma/2$ and then $n = \sigma/2$ also.

(c) Complementary shear stresses

Consider a body subjected to a shearing action such that shear stresses τ are set up on faces AB and CD of a small element ABCD of the body (see Figure 1.7). Let ABCD have a length a, breadth b, and depth d.

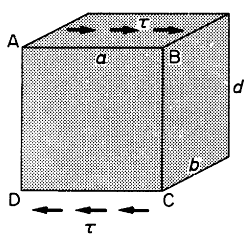


Fig. 1.7

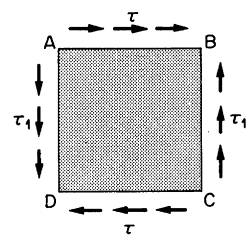


Fig. 1.8

This pair of stresses will set up forces which constitute a couple of magnitude $(\tau \times a \times b) \times d$ and which, if not balanced by an equal couple, would cause the element to rotate. The element is in fact in equilibrium, and so there must be shear stresses along the other surfaces AD and CB in order to create a balancing couple. Suppose these shear stresses are of magnitude τ_1 (see Figure 1.8). Then if the couples are to be equal,

$$(\tau \times a \times b) \times d = (\tau_1 \times d \times b) \times a$$

$$\therefore \tau = \tau_1$$