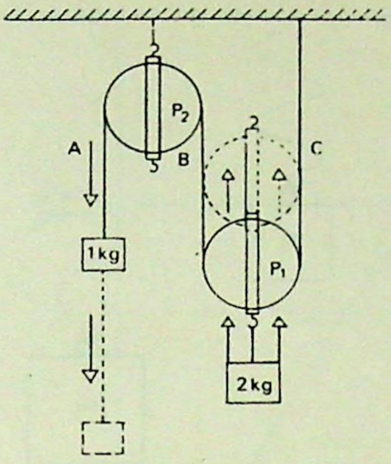


Fig. 2.42 Demonstrates the mechanical advantage offered by inserting more than one pulley in a circuit.

If a second pulley is inserted into the circuit so that a downward pull can be applied to the cord, the mechanical advantage is unchanged. The ceiling still takes half the weight at each suspension point, but the rope can now be moved. As it moves, the loaded pulley will move upwards, but the rope will travel twice the distance that the load will move. In Figure 2.42 the rope C remains stationary but shortens, and rope B moves up and over pulley P_2. Rope A lengthens by the distance pulley, P_1 travels up the rope A and the distance rope B travels over pulley P_2. The load of 1 kg on pulley P_2 balances the load of 2 kg on pulley P_1.

For example:

(1) The tendon of peroneus longus passes around the fixed pulley provided by the lateral malleolus. The direction of pull of the muscle is altered. The tendon of extensor pollicis longus also passes around a fixed pulley, the dorsal tubercle of the radius, in order to change its direction. Neither alters their force value.

(2) The weight and pulley system seen in Fig. 9.29A both alters the direction of the force exerted by the weights and reduces by half the effective force experienced by the patient. That in Fig. 9.30A and B only alters the direction of the applied force.

The behaviour of materials

When a force is applied to a material it will suffer varying degrees of deformation. The internal stress will equal the external load.

Stress

Stress is the intensity of internal force per unit area and may be expressed as:

Stress = force/area

Units: newtons per metre squared (N/m^2).

Stress may be:

(1) Compressive (negative, −ve)
(2) Tensile (positive, +ve).

(Fig. 2.43A and B)

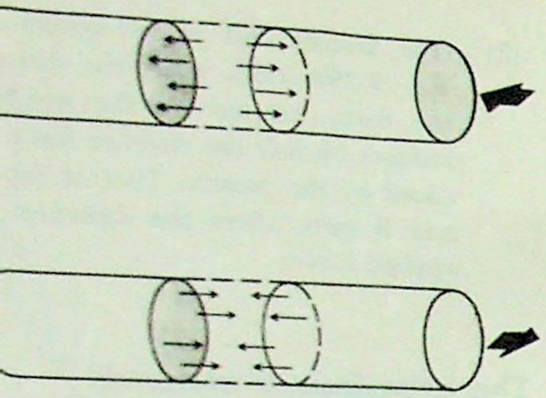
Strain

All materials under load experience a change in shape or length:

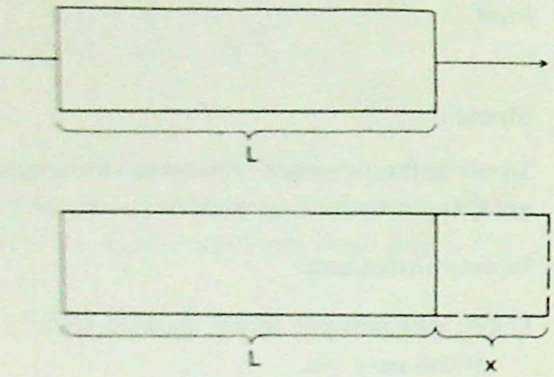
$$\text{Strain } (\varepsilon) = \frac{\text{change in length (x)}}{\text{original length (L)}}$$

(Fig. 2.44A and B).

Strain associated with tension is considered positive; that associated with compression, negative.



.43 Stress forces. A, Compressive; B, Tensile. pplied force. → – stress.



2.44 Strain. A, Unloaded beam; B, Loaded n. L – original length. x – deformation.

The above discussion refers to linear stress strain; both shear and torsional stress strain may occur and are frequent in the nan body which is subject to complex force ems.

ke's Law

ke's Law states that: *Strain is directly pro- onal to the applied stress.*

s/strain = constant *E*.

constant is known as Young's modulus, or odulus of elasticity (Fig. 2.45).

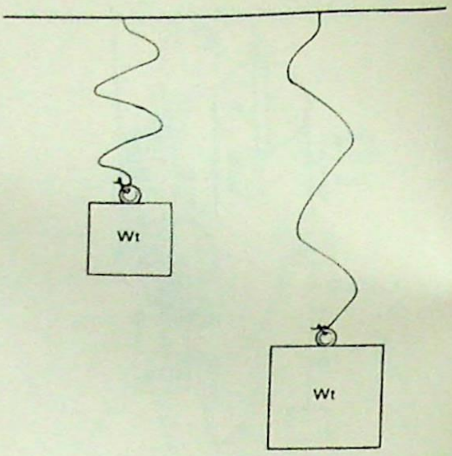


Fig. 2.45 The relationship between stress and strain – the greater the load on the spring the greater the deformation.

Stress–strain curve

The graphical relationship between stress and strain is shown in Fig. 2.46. The behaviour of the material alters as the extension strain increases.

(1) *Elastic behaviour of material*: When a material is stressed within its elastic phase the strain or deformation which occurs is reversible. The material will return to its original length and shape, thus obeying Hooke's Law. This is the region in which it is safe to stress most materials without damage occurring.

(2) The yield point occurs when the material stretches for a period without the addition of any further force.

(3) *Plastic behaviour of material*: Permanent deformation of material arises following the application of stress loads into this phase. Hooke's Law is no longer operational.

(4) The period following the plastic phase leads directly to the point of fracture of

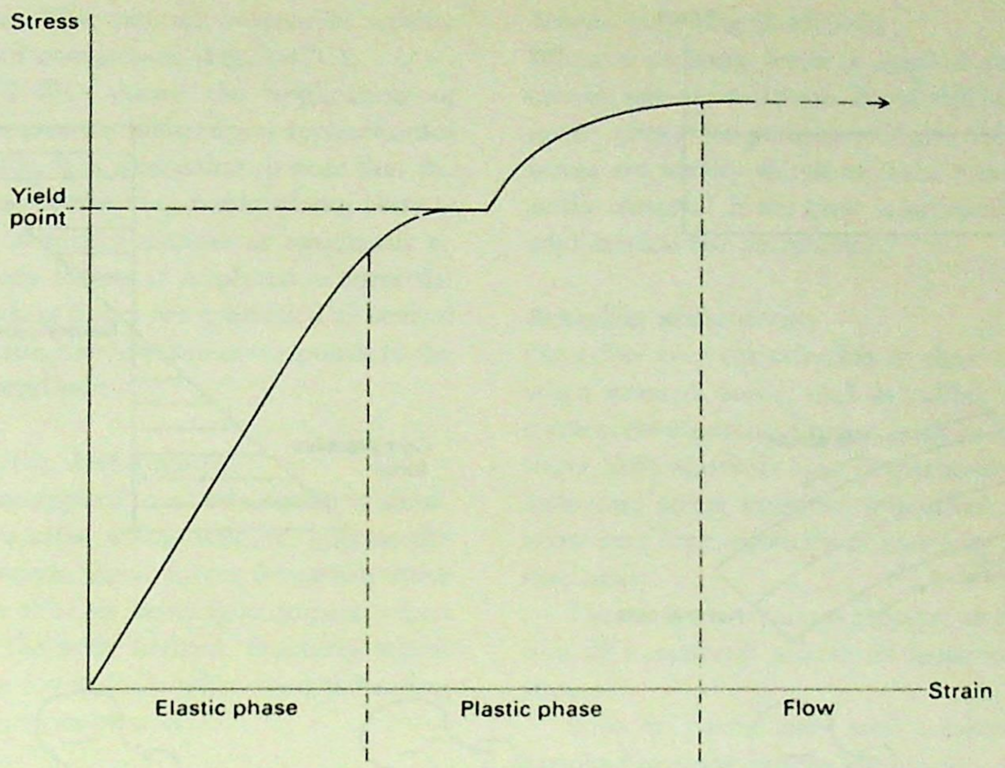


Fig. 2.46 Graph of stress–strain curve.

the material under stress. It consists of a period of localized thinning preceding breakage.

Internal stress patterns

Forces may be applied to a body in a variety of ways and will result in a variety of internal stress patterns. A knowledge of these is useful in determining the way in which a structure will behave under load. For example, it is useful to know how a plaster of Paris splint will behave under direct compression forces and bending forces.

Apart from the previously mentioned direct tensile and compressive forces which may be applied to a body, bending, shear and torsion forces often arise.

Tensile force (Fig. 2.43B)
When a tensile force is applied to a body, opposing patterns of stress arise. The body will resist being pulled apart.

Compressive force (Fig. 2.43A)
When a compressive force is applied to a body, opposing patterns of stress will arise as the body resists being squashed.

Bending force (Fig. 2.47A, B and C)
When a force applied to a body results in bending, tension and compression stresses develop on the convex and concave portions respectively (Fig. 2.47A and B). Greatest stress develops at the periphery of the structure; the neutral axis occurs centrally and is the point at which the stresses change from tensile to

compressive. This neutral surface is neither stretched nor compressed (Fig. 2.47C).

Figure 2.47D shows the application of bending forces to the femur upon application of a lateral force. It is interesting to note that the cortical bone of the long bones of the body is distributed in such a manner as maximally to resist bending forces. It is placed around the periphery where forces are greatest. The central region contains marrow and corresponds to the central, neutral axis.

Shear force (Fig. 2.48A and B)

When a force applied to a body results in shear, stress forces arise which tend to oppose the shearing motion. Shear forces frequently arise at the same time as bending moments, when one end of the body is fixed. Fractures which occur in the lower limb when weight bearing sustain both types of stress.

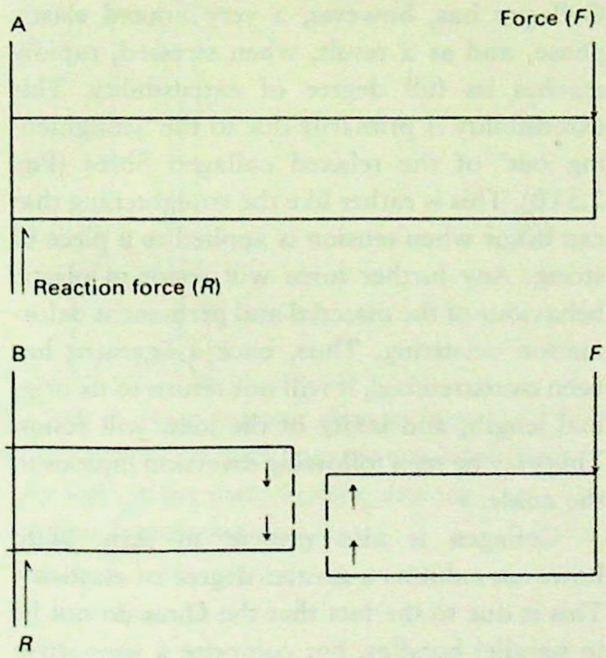


Fig. 2.48 Shear force. A, force applied to beam; B, shear stress occurring in the beam.

Torsion force (Fig. 2.49A–C)

When a twisting force is applied to a body, torsion stresses will arise. These will occur maximally about the periphery of the object. Long bones are ideally suited to resist torsion stress as the material of the bone is primarily distributed around the periphery.

Behaviour under stress

Materials vary considerably in their behaviour when stressed. Some, such as rubber and skin, show great elasticity. Others, such as ligaments, show little elasticity and permanently deform following stress injuries. Still other materials show very little elasticity or plasticity and fracture easily.

The internal structure, shape and orientation of a material affects its behaviour when stressed.

Bone is particularly well adapted to its various functions and the stress applied to it. Its internal structure is modified into two main forms: cortical bone, which is dense, and cancellous bone, which is much lighter though still strong. Cortical bone is present in the shafts of long bones which are relatively slender; cancellous bone is found in the expanded extremities. The latter allows for strength but avoids undue heaviness of the expanded portion. The osteons in both types of bone are orientated along the lines of force, facilitating their transmission through the bone. The trabeculae of the cancellous bone serve the same purpose (Fig. 2.50A). As forces vary in their impact on a bone, the alignment of the osteons and trabeculae can be modified to suit newly arising situations.

The gross shape of the bone is important with regard to its ability to withstand stress. A hollow tube is stronger than a solid cylinder of similar size; a large area allows force to be dissipated and results in less stress per unit area. These two points are seen respectively in the

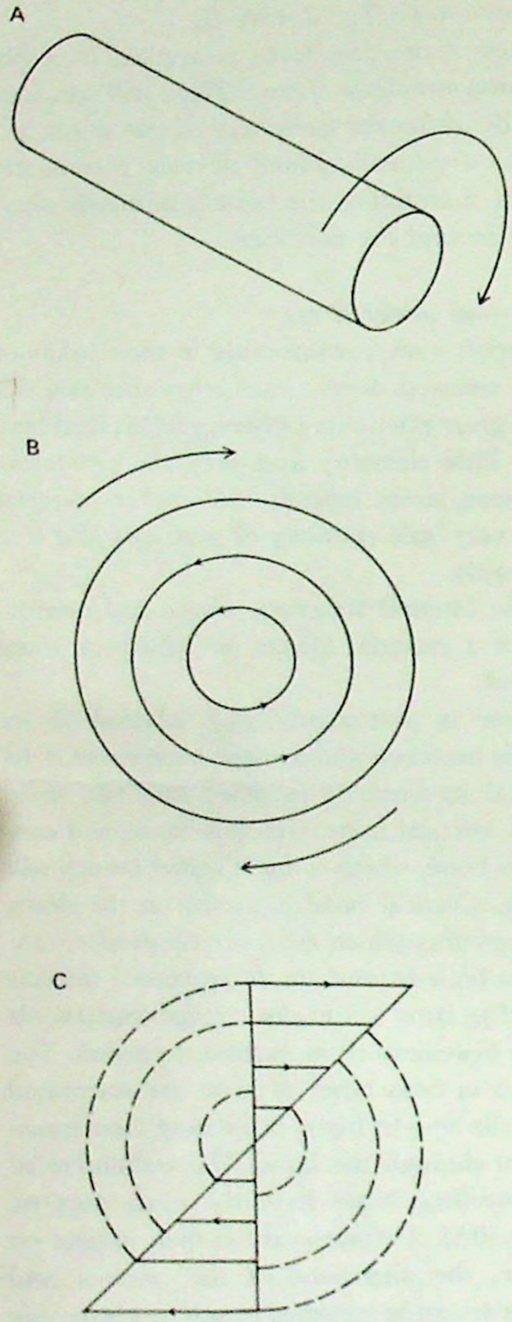


Fig. 2.49 Torsion force. A, applied torque; B, internal stress pattern; C, cross-section through cylinder showing stress pattern.

shaft and extremities of long bones. Bones do not exhibit sudden change in shape which would result in concentration of forces and consequent weak points. Where changes in shape or size do occur, bones will be more susceptible to damage; thus the tibia tends to fracture at the junction between its middle and lower thirds. It is at this point that it is at its thinnest and exhibits a noticeably triangular cross-sectional view (Fig. 2.50B).

Bone has to withstand varying stress patterns; it is strongest in compression and weakest in shear. Tension is reasonably well tolerated. This arrangement suits the stress patterns to which bone is subjected, most of which are compressive.

Collagen, present in ligaments and tendons, is also subject to varying stresses. Its orientation is very important in relation to its response to force. It is unable to resist compressive forces, but is strong in tension; thus ligaments and tendons tend to have their fibres orientated in the direction of greatest force (Fig. 2.51A). Collagen has, however, a very limited elastic phase, and as a result, when stressed, rapidly reaches its full degree of extensibility. This extensibility is primarily due to the 'straightening out' of the relaxed collagen fibres (Fig. 2.51B). This is rather like the straightening that can occur when tension is applied to a piece of string. Any further force will result in plastic behaviour of the material and permanent deformation occurring. Thus, once a ligament has been overstretched, it will not return to its original length, and laxity of the joint will result. This may be seen following inversion injuries to the ankle.

Collagen is also present in skin. Skin, however, exhibits a greater degree of elasticity. This is due to the fact that the fibres do not lie in parallel bundles, but comprise a supportive network. This allows for a greater degree of stretch to be applied to the tissue before the

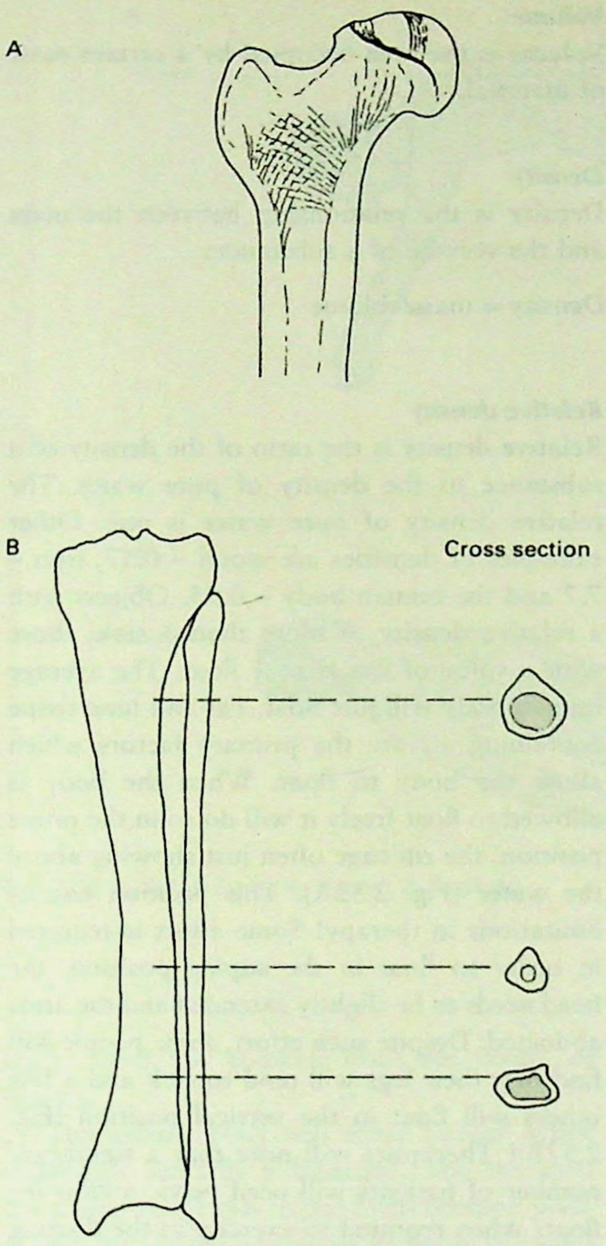


Fig. 2.50 A, Head of femur, showing how trabeculae transmit force from the expanded head to the walls of the shaft; B, Tibia, showing variations in cross-sectional area.

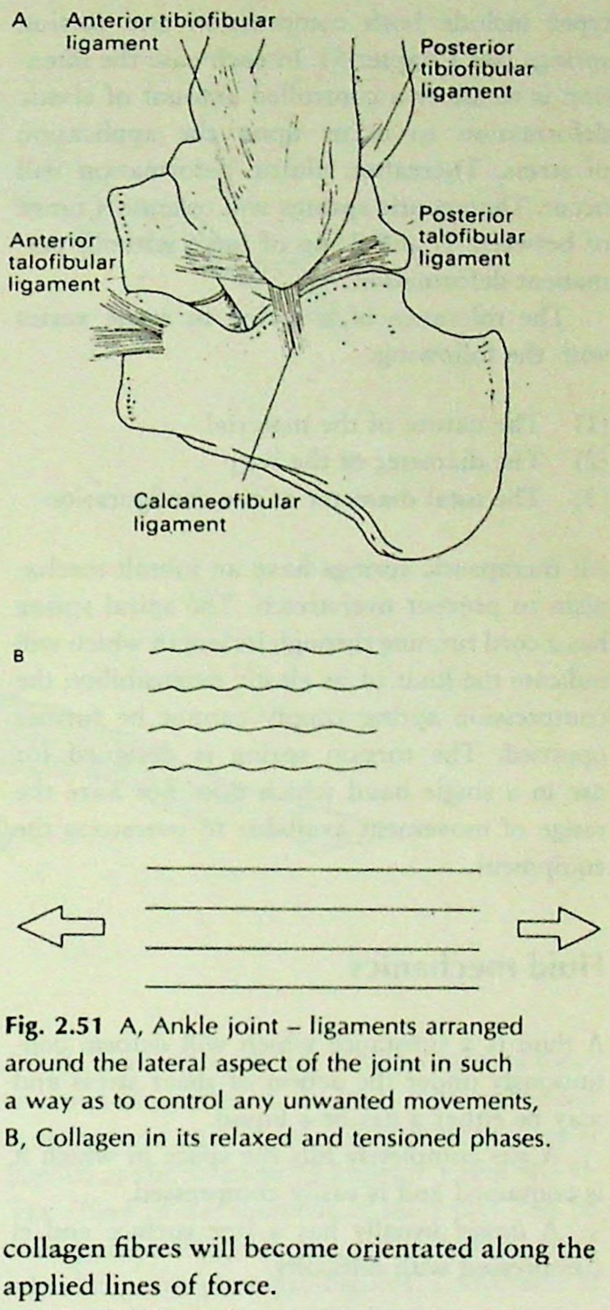


Fig. 2.51 A, Ankle joint – ligaments arranged around the lateral aspect of the joint in such a way as to control any unwanted movements, B, Collagen in its relaxed and tensioned phases.

collagen fibres will become orientated along the applied lines of force.

Non-biological materials are also subject to stress and strain. A spring is a therapeutic example of a structure which is designed to withstand stress and is used to resist muscle work and so strengthen the muscles involved. The wire of which the spring is made may be arranged in a variety of different ways; the spirally wound spring is the most common. Other types include both compression and torsion springs (see Chapter 9). In each case the intention is to allow a controlled amount of elastic deformation to occur upon the application of stress. Thereafter, plastic deformation will occur. Therapeutic springs will tolerate a range of between $^1/_2$ and 25 kg of force without permanent deformation.

The tolerance of a spring to stress varies with the following:

(1) The nature of the material
(2) The diameter of the wire
(3) The total diameter of the configuration

All therapeutic springs have an inbuilt mechanism to prevent overstretch. The spiral spring has a cord running through its length which will indicate the limit of its elastic extensibility; the compression spring simply cannot be further opposed. The torsion spring is designed for use in a single hand which does not have the range of movement available to overstress the equipment.

Fluid mechanics

A fluid is a substance which will deform continuously under the action of shear stress and may be either a gas or a liquid.

A *gas* completely fills the space in which it is contained and is easily compressed.

A *liquid* usually has a free surface and is compressed with difficulty.

Hydrostatics

Hydrostatics is the study of force and pressure in a fluid at rest.

Mass

Mass is the quantity of material present in a body.

Volume

Volume is the area occupied by a certain mass of material.

Density

Density is the relationship between the mass and the volume of a substance:

Density = mass/volume

Relative density

Relative density is the ratio of the density of a substance to the density of pure water. The relative density of pure water is one. Other examples of densities are wood – 0.57, iron – 7.7 and the human body – 0.95. Objects with a relative density of more than 1 sink; those with a value of less than 1 float. The average human body will just float. Fat and lung tissue containing air are the primary factors which allow the body to float. When the body is allowed to float freely it will do so in the prone position, the rib cage often just showing above the water (Fig. 2.52A). This position has its limitations in therapy! Some effort is required in order to float in the supine position; the head needs to be slightly extended and the arms abducted. Despite such effort, some people will find that their legs will tend to sink and a few others will float in the vertical position (Fig. 2.52B)! Therapists will note that a significant number of patients will need pelvic and/or leg floats when required to exercise in the floating position.

Buoyancy and Archimedes' principle

Archimedes' principle states that any body which is wholly or partially immersed will experience an upward thrust equal to the weight of fluid displaced. This upward thrust is termed the *force of buoyancy*; it acts through a point called the *centre of buoyancy*. This