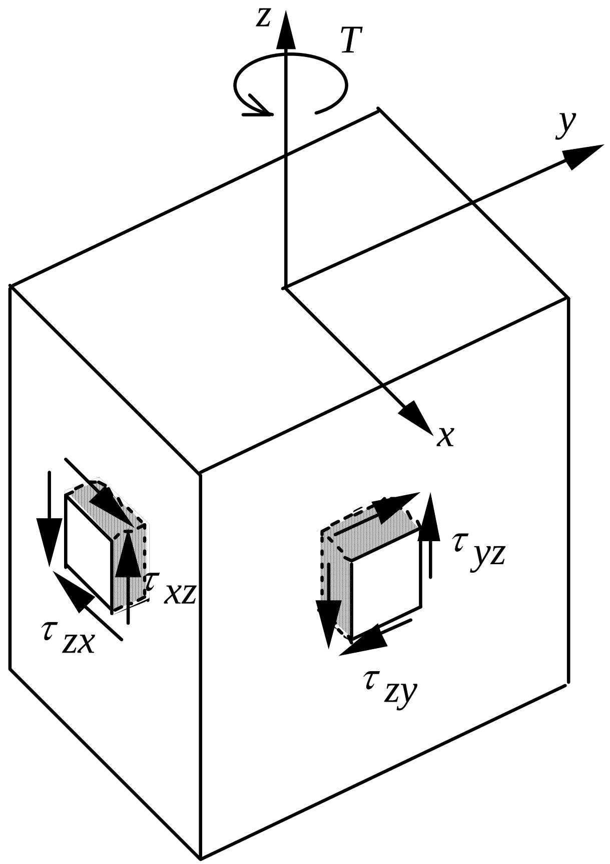
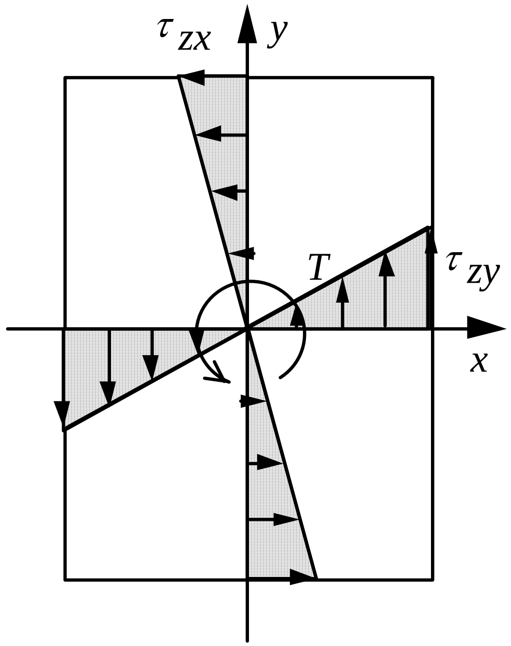
2.4 Torsion Capacity of RC Linear Members

2.4.1 Mechanical Behavior of RC Linear Members Subjected to Torsion

According to torsion, shear stresses are caused in reinforced concrete linear members as shown in Fig. 2.18.



(a) Applied torsion and shear stresses

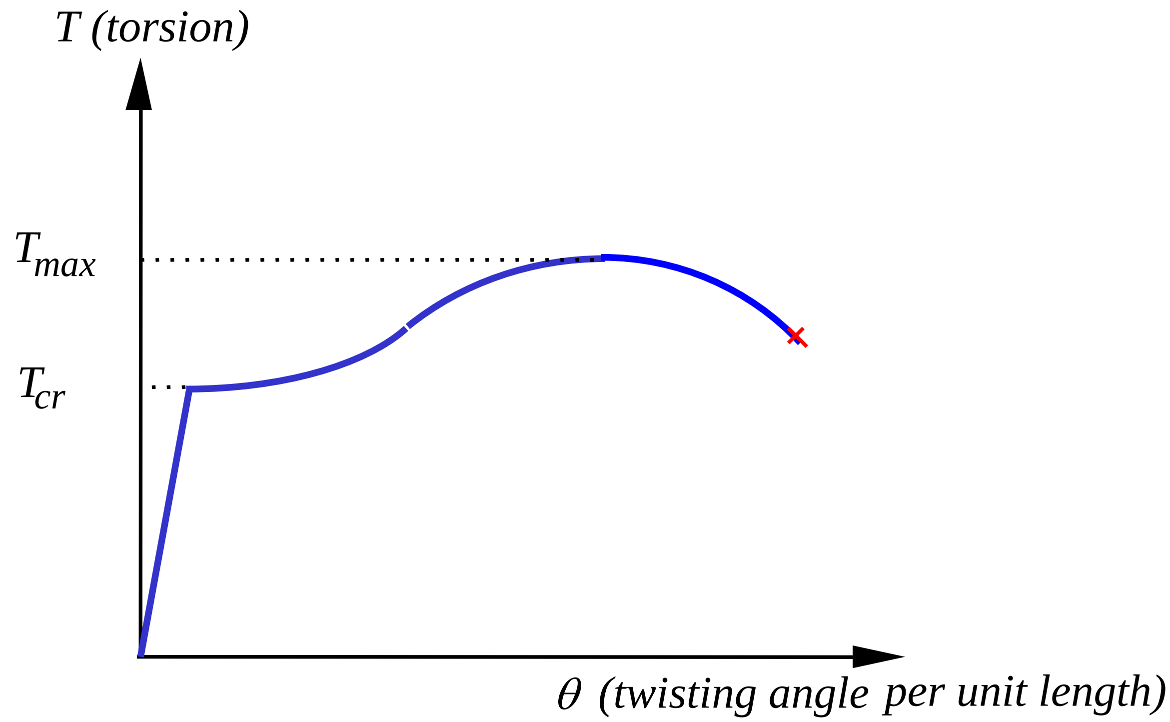


(b) shear stress caused in the cross section due to applied torsion

Fig. 2.18 Applied torsion and shear stresses due to torsion

When the magnitude of applied torsion is small, these shear stresses are small and the principal tensile stress converted from these shear stresses is also small. Therefore, concrete does not have cracks and behaves as an elastic body. However, with the increase in applied torsion, shear stresses are increased and cracks initiate. Torsion cracks generally propagate in a member making *45 degrees* with a member's longitudinal axis. If torsional reinforcement is not provided, the initiation of torsion cracks means the failure of a reinforced concrete member.

Torsional reinforcement consists of *longitudinal* reinforcement and *transverse (or lateral)* reinforcement. Transverse reinforcement should be a closed form and enclose longitudinal reinforcement. When torsional reinforcement is provided in a member, the increase in applied torsion after the torsion cracking can be resisted depending on the amount of reinforcement. A number of torsional cracks can be observed. However, the tangential stiffness is gradually decreasing with the increase in the torsion angle. Finally, due to the crushing of concrete, a member will lose its strength. This behavior is shown in Fig. 2.19.



2.4.2 Shear Flow due to Torsion

According to the elastic theory, the shear stress for a solid cross section can be obtained. However, for a thin-walled tubular cross section, another derivation is available.

Consider a thin-walled tubular cross section subjected to torsion (Fig. 2.20). A small element is taken from this section. From the equilibrium condition in an axial direction, the following relationship can be obtained:

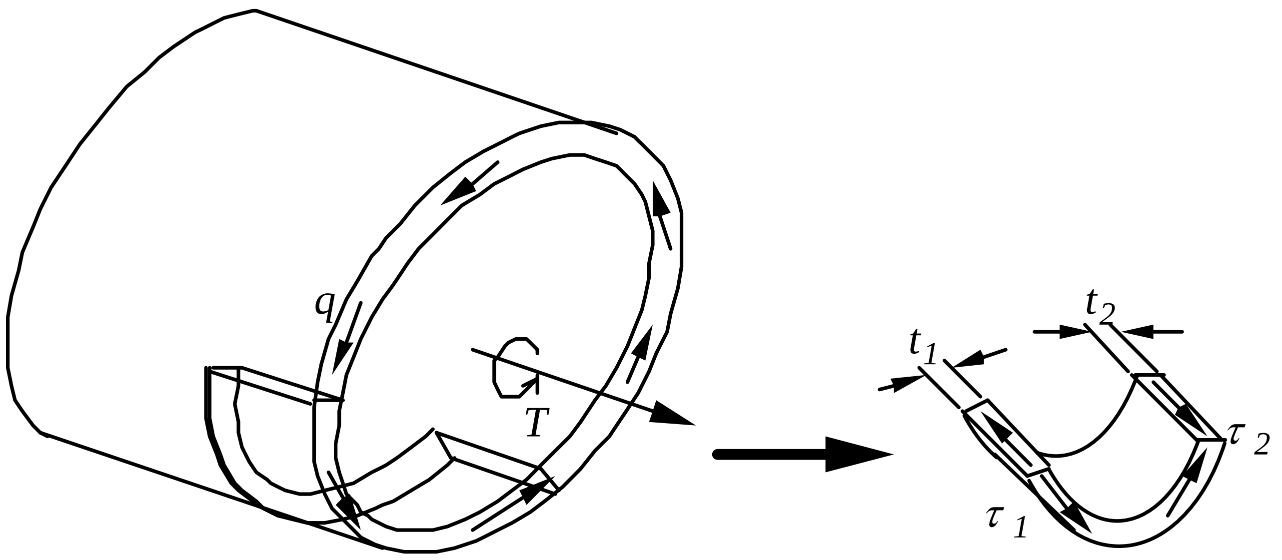


Fig. 2.20 Shear stress of thin-walled tubular cross section subjected to torsion

$$\tau_1 t_1 = \tau_2 t_2 \qquad \textbf{(2.59)}$$

The product of a shear stress and a thickness of wall is defined as *"shear flow (shear force per unit length)"*. Equation (2.59) means the shear flow must be constant throughout a tubular cross section. When the thickness of wall is uniform, the shear stress due to torsion must be constant throughout a tubular cross section.

Consider the small length (*ds*) on the center line of wall thickness (Fig. 2.21). From the equilibrium condition for torsion, the following relationship can be derived between the torsion and the shear flow:

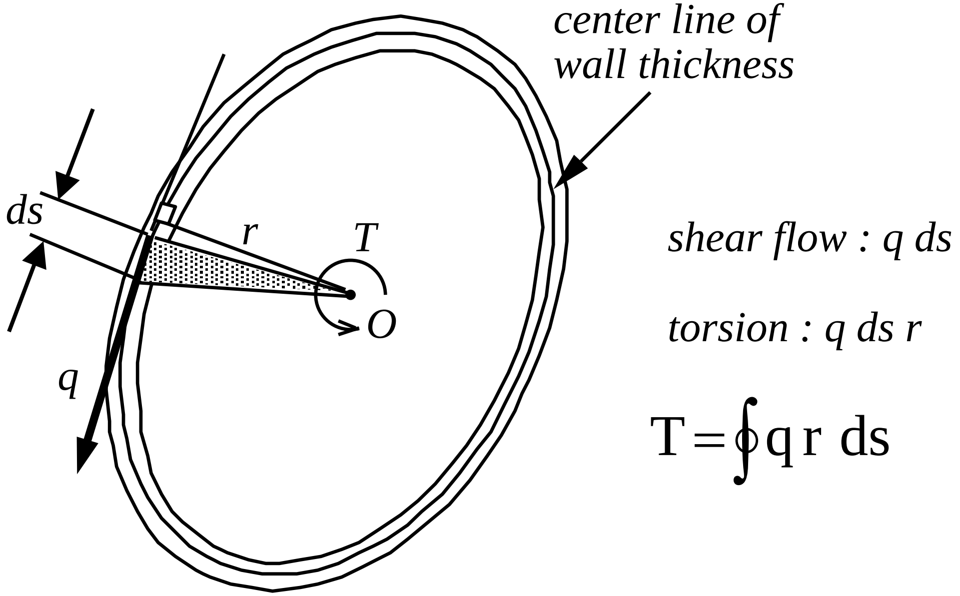


Fig. 2.21 Relationship between shear flow q and applied torsion T

$$T = \oint q\, r\, ds = q \oint r\, ds \qquad \textbf{(2.60)}$$

where, *r* : the distance between the center of a cross section and the shear force (*q ds*). The quantity of (*r ds*) is twice the area of a shadowed triangle. Thus, the integral of (*r ds*) of Eq. (2.60) becomes twice the area enclosed by the center line of wall thickness.

The area enclosed by the center line of wall thickness is defined as the *torsional effective area* A_o. The shear flow can be expressed as follows:

$$q = \tau t = \frac{T}{2A_o} \qquad \textbf{(2.61)}$$

Eq. (2.61) is called as Bredt's formula.

2.4.3 Torsion Capacity of Reinforced Concrete Member Based on Space Truss Analogy

In the *space truss analogy* proposed by Raush, the original solid cross section is converted into an imaginary thin-walled tubular cross section. The following basic assumptions are made to calculate the ultimate torsion capacity.

(1) After torsion cracks initiate and propagate, the core part of concrete in a solid cross section can be neglected and an original solid cross section can be assumed to be equivalent to the imaginary thin-walled tubular cross section. The shear stress due to torsion becomes zero at the center of the cross section and the magnitude of the shear stress will increase when it approaches to the perimeter of a cross section. Moreover, resisting torsion moment is proportionally increasing with the distance from the center of the cross section. Thus, the assumption to neglect the effect of core part of concrete can be accepted.

(2) From Bredt's theory, applied torsion can be converted into an uniform shear flow. If the thickness of the imaginary thin-walled tubular cross section is assumed to be uniform, the shear stress also becomes uniform.