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Chapter 1
Introduction

1.1. Reinforced concrete

Reinforced concrete, as the name suggests, is a strong durable construction material composed of concrete, strengthened or reinforced by steel bars embedded within the concrete. It is important to understand the material behaviour of each of the constituents of reinforced concrete before designing structural elements made from reinforced concrete. One of the great advantages of using concrete in construction is that, in its liquid form, it can be cast into a variety of shapes, as illustrated in Figure 1.1. While the material behaviour of concrete and steel can be very different, when the best features of both materials are combined together, their properties complement each other, particularly in terms of strength and durability.

1.2. Material properties of concrete and steel

A comparison of the material properties of concrete and steel is useful, as presented in Table 1.1. The tensile strength of concrete is low, but that can be augmented by the addition of steel reinforcement, which is strong in tension. The tensile strength of concrete is only about one-tenth of its compression strength. Hence, nearly all reinforced concrete designs assume that the concrete does not resist any tensile forces. The reinforcing steel is designed to carry any tensile forces. Steel is not a very durable material (i.e. it corrodes when exposed to the atmosphere) but its durability can be significantly enhanced by embedding the steel as bars within the concrete, thereby providing corrosion protection to the reinforcement. Both concrete and steel are strong in compression. The coefficients of thermal expansion of the two materials are sufficiently close to ensure that problems with bonding between the steel and concrete, arising from the differential expansion or contraction of the two materials over the normal temperature range, are unlikely to occur. Concrete fails suddenly under a load (brittle failure), whereas steel is a ductile material, gradually failing by a narrowing (necking) of the cross-section, thereby providing some warning of its imminent failure.

1.3. Material behaviour of steel

Steel is primarily composed of the element iron, in addition to small amounts of carbon and alloying elements. Mild steel, which is the most common form of steel, typically has a yield strength of 250 MPa. It contains less than 0.25% of carbon and small amounts of alloying elements. High-yield steel is another low-carbon steel. It also typically contains less than 0.25% of carbon but the steel strength, which typically exceeds 275 MPa, is increased through the addition of manganese or vanadium. The strength of steel can also

Figure 1.1 A reinforced concrete chair (Concrete laboratory, School of Civil Engineering, University College Dublin)

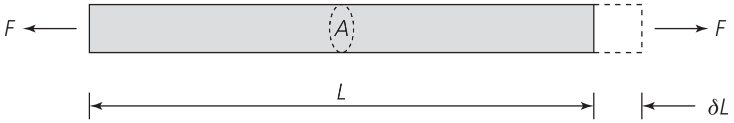
Table 1.1 Material properties of concrete and steel

Material property	Concrete	Steel
Tensile strength	Weak	Strong
Compression strength	Strong	Strong
Durability	Good	Poor
Thermal expansion	10×10^{-6}/°C	12×10^{-6}/°C
Failure mechanism	Brittle	Ductile

be further enhanced through small additions of elements such as chromium, nickel, molybdenum, niobium, zirconium and titanium (Davis, 2001).

To understand the behaviour of steel under load, consider the bar shown in Figure 1.2, initially of length L (mm), of cross-sectional area A (mm^2) and subjected to a tensile force F (N). Under load, the bar stretches or elongates by an amount (δL). The force per unit area is termed the **stress** and the change in length divided by the original length is

Figure 1.2 Steel bar under a tensile force



Example 2.1

A multistorey office block is to be constructed from reinforced concrete. Each concrete floor, 8 m × 8 m in area, is to be 200 mm deep. Each edge of the floor is supported by 8-m-long beams, 300 mm in breadth and 500 mm in depth. Calculate the total design load for each beam.

Solution

Variable loading

From Table 2.2, the characteristic variable loading on each floor = 3 kN/m^2

Partial safety factor for variable loading on each floor = 1.5

∴ Design variable loading on each floor = 1.5 × 3 = 4.5 kN/m^2

∴ Total design variable loading on each floor = 4.5 × 8 × 8 = 288 kN

Assuming each beam carries a quarter of the floor loading:

∴ Total design variable loading on each beam = 288/4 = 72 kN

Permanent loading

From Table 2.1, unit weight of concrete = 24 kN/m^3

Weight = Unit density (kN/m^3) × Volume (m^3)

∴ Characteristic self-weight of floor = 24 × [8 × 8 × 0.2] = 307.2 kN

Characteristic self-weight of beam = 24 × [8 × 0.5 × 0.3] = 28.8 kN

Assuming each beam carries a quarter of the floor loading:

∴ Characteristic permanent load on each beam = 307.2/4 + 28.8 = 105.6 kN

Partial safety factor for permanent loading = 1.35

∴ Total design permanent loading on each beam = 1.35 × 105.6 = 142.6 kN

Total design loading

∴ Total design loading = Design permanent loading + Design variable loading

= 72 + 142.6

= 214.6 kN

Figure 4.4 Arrangement of shear reinforcement

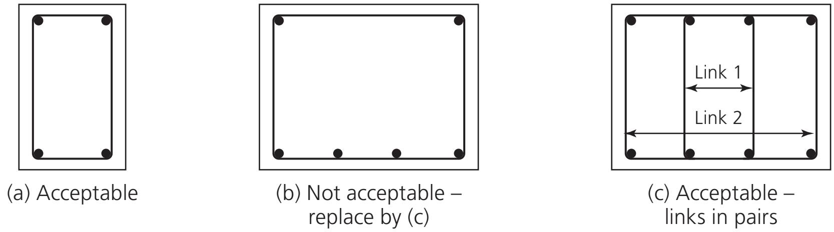


Figure 4.5 Shear reinforcement in the form of vertical links

- If longitudinal compression bars are not specifically required, nominal hanger bars are provided in the compression zone to fix the vertical shear reinforcement securely (Figure 4.5).

Example 4.1

A beam of breadth 300 mm and effective depth 800 mm spans 12 m. It is required to support a uniformly distributed design load of 150 kN/m. The beam is designed for a cross-sectional area of tensile reinforcement equivalent to 2% of the beam effective cross-section. $f_{ck} = 30$ N/mm^2 and $f_{yk} = 500$ N/mm^2.

(*a*) Design the shear reinforcement for the ultimate shear force.
(*b*) Show how the shear reinforcement can be economically spaced to reflect the shear distribution along the beam.

Table 10.1 Typical calculation sheet

By: J. Bloggs	**Job title:** Reinforced concrete beam design	**Date:** 22/06/2021
Reference	**Calculations**	**Output**
Eurocode 2	Data: Singly reinforced concrete beam, design span of 12 m Beam cross-sectional dimensions: 300 mm wide by 850 mm deep Characteristic variable load 14 kN/m $f_{ck} = 30$ N/mm^2 $f_{yk} = 500$ N/mm^2 Unit weight of concrete 24 kN/m^3	
	Loading: Total factored load (w): Design variable load = 1.5 × 14 = 21 kN/m Design self-weight = 1.35[(0.3)(0.85)(1)(24)] = 8.3 kN/m Total design load (w) = 29.3 kN/m Demand bending moment (M): $M = \frac{wL^2}{8}$ $= \frac{(29.3)(12)^2}{8}$ $= 527$ kN m	29.3 kN/m 527 kN m
	Flexural design: Assume 40 mm cover and 25-mm-diameter bars $d = 850 - 40 - \frac{25}{2} = 798\text{mm}$ $K = \frac{527 \times 10^6}{(300)(798)^2(30)} = 0.092$ $\frac{Z}{d} = 0.5 + \sqrt{0.25 - 0.092/1.134} = 0.91$ $A_s = \frac{527 \times \times 10^6}{(0.87)(500)(0.91)(798)} = 1670\,\text{mm}^2$ Provide four high-yield 25-mm-diameter steel bars (1964 mm^2)	4H25