Types of cracking

Because cracking may impair the durability of concrete by allowing ingress of aggressive agents, it is relevant to review briefly the types and causes of cracking. In addition, cracking may adversely affect the watertightness or sound transmission of structures or mar their appearance. With respect to appearance, the acceptable crack width depends on the distance from which it is viewed and on the function of the structure, e.g. a public hall, at one extreme, and a warehouse, at the other. It may be useful to add that ingress of dirt makes the cracks more perceptible; so does the use of white cement in concrete.

As far as water-tightness is concerned, very narrow, non-moving cracks, 0.12 to 0.20 mm (0.005 to 0.008 in.) wide, may leak initially.[10.33,10.34] However, dissolved calcium hydroxide carried by slowly percolating water may react with atmospheric carbon dioxide to deposit calcium carbonate, which would seal the crack[10.33] (see p. 328).

Cracking occurring in fresh concrete, that is, plastic shrinkage cracking and plastic settlement cracking, was discussed in Chapter 9. Another type of early cracking is known as *crazing*, which can occur on slabs or walls when the surface zone of the concrete has a higher water content than deeper in the interior. The pattern of crazing looks like an irregular network with a spacing of up to about 100 mm (4 in.). The cracks are very shallow and develop early, but may not be noticed until etched by dirt; apart from appearance, they are of little importance.

Table 10.8 Classification of Intrinsic Cracks (based on ref. 10.33)

Type of cracking	Symbol in Fig. 10.12	Subdivision	Most common location	Primary cause (excluding restraint)	Secondary causes/ factors	Remedy (assuming basic redesign is impossible); in all cases reduce restraint	Time of appearance	Reference in this book
Plastic settlement	A	Over reinforcement	Deep sections	Excess bleeding	Rapid early drying conditions	Reduce bleeding or revibrate	10 min to 3 h	pp. 399 and 424
	B	Arching	Top of columns					
	C	Change of depth	Trough and waffle slabs					
Plastic shrinkage	D	Diagonal	Pavements and slabs	Rapid early drying	Low rate of bleeding	Improve early curing	30 min to 6 h	pp. 398 and 423
	E	Random	Reinforced concrete slabs					
	F	Over reinforcement	Reinforced concrete slabs	Rapid early drying or steel near surface				

Early thermal contraction	G	External restraint	Thick walls	Excess heat generation	Rapid cooling	Reduce heat and/or insulate	1 day to 2 or 3 weeks	pp. 394 and 399
	H	Internal restraint	Thick slabs	Excess temperature gradients				
Long-term drying shrinkage	I		Thin slabs and walls	Inefficient joints	Excess shrinkage Inefficient curing	Reduce water content Improve curing	Several weeks or months	p. 441
	J	Against formwork	Walls	Impermeable formwork	Rich mixes Poor curing	Improve curing and finishing	1 to 7 days, sometimes much later	p. 525
Crazing	K	Floated concrete	Slabs	Over-trowelling				
Corrosion of reinforcement	L	Carbonation	Columns and beams	Inadequate cover	Poor quality concrete	Eliminate causes listed	More than 2 years	p. 565
		Chloride						
Alkali–aggregate reaction	M		Damp locations	Reactive aggregate plus high-alkali cement		Eliminate causes listed	More than 5 years	p. 517
Blister	N		Slabs	Trapped bleed water	Use of metal float	Eliminate causes listed	Upon touching	p. 528
D-cracking	P		Free edges of slabs	Frost-damaged aggregate		Reduce aggregate size	More than 10 years	p. 544

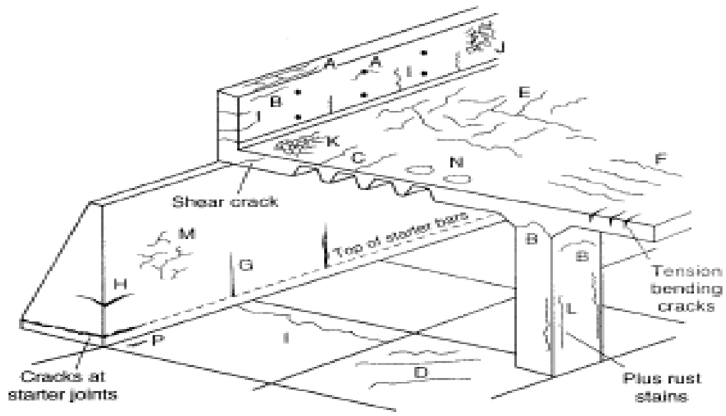

Fig. 10.12 Schematic representation of the various types of cracking which can occur in concrete (see Table 10.8) (based on ref. 10.33)

In addition, a somewhat different kind of surface damage, known as *blisters*, can occur if some bleed water or large air bubbles are trapped just below the surface of the concrete by a thin layer of laitance induced by finishing. Blisters are 10 to 100 mm ($\frac{1}{2}$ to 4 in.) in diameter and 2 to 10 mm (or $\frac{1}{16}$ to $\frac{1}{2}$ in.) thick. In service, the laitance layer becomes detached, leaving behind a shallow depression.

In hardened concrete, cracking may be caused by drying shrinkage or by restrained early-age thermal movement; these were discussed in Chapters 9 and 8, respectively. The various types of non-structural cracks are listed in Table 10.8 and shown schematically in Fig. 10.12.[10.33] It is useful to note that, whereas one particular cause may initiate a crack, its development can be due to another cause.[10.33] Thus a diagnosis of causes of cracking is not always straightforward.

Cracking can also be caused by overloading in relation to the actual strength of the concrete member, but this is the consequence of inadequate design, or of construction not conforming to the specification. It is important to remember that, in reinforced concrete in service, tension is induced in the reinforcing steel and in the surrounding concrete. Surface cracking is therefore inevitable but, with proper structural design and detailing, the cracks are very narrow and barely perceptible. Stress-induced cracks have a maximum width at the surface of the concrete and taper towards the steel, but the difference in width may decrease with time.[10.34] The crack width at the surface is greater the larger the cover to reinforcement.

We should note that, from energy considerations, it is easier to extend an existing crack than to form a new one. This explains why, under an applied load, each subsequent crack occurs under a higher load than the preceding one. The total number of cracks developed is determined by the size of the concrete member, and the distance between cracks depends on the maximum size of aggregate present.[10.106]

Because, under given physical conditions, the total crack width per unit length of concrete is fixed and we want the cracks to be as fine as possible, it is desirable to have more cracks. For this reason, the restraint to cracking should be uniform along the length of the member. Provision of reinforcement controls shrinkage cracking by reducing the width of individual cracks, but not the total width of all the cracks taken together. This topic is outside the scope of the present book.

The importance of cracking, and the minimum width at which a crack is considered significant, depend on the function of the structural members and on the conditions of exposure of the concrete. Reis *et al.*[10.105] suggested the following permissible crack widths, which still offer good guidance:

Interior members	0.35 mm (0.014 in.)
Exterior members under normal exposure conditions	0.25 mm (0.010 in.)
Exterior members exposed to particularly aggressive environment	0.15 mm (0.006 in.).

It may be relevant to mention that, although there is a variation between observers, the minimum crack width that can be seen with a naked eye is about 0.13 mm (0.005 in.). Simple magnifying devices make it possible to determine the crack width. Various specialized techniques, such as electro-conductive paint and light-dependent resistors, make it possible to determine the development of cracking. However, very fine cracks are very common but not harmful, so that intensive searching for cracks serves no purpose.