CREEP, SHRINKAGE, AND CRACKING OF CONCRETE

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23.1 CREEP

23.1.1 TYPES OF CREEP

The following definitions are used for creep.

- Creep is long term deformation due to loading.
- Total creep is the strain due to loading and drying.
- Basic creep is the strain due to loading with no loss of moisture.
- Specific creep is the creep per unit stress.

Basic creep is almost impossible to measure because it involves keeping a test specimen under load for a long time (often up to 20–30 years), while sealing it to prevent any loss of moisture. Therefore, experimental data generally gives the total creep, but this will depend on the extent and timing of the drying. For most structural purposes, creep is assumed to be proportional to stress, so the specific creep is used.

23.1.2 EFFECTS OF CREEP IN CONSTRUCTION

Creep causes:

- Deflection in structures under continuous loading. This may cause bridges to sag, or cladding systems on buildings to buckle. A tall building may get 50–100 mm shorter during its design life.
- Stress relief that reduces cracking.
- Loss of prestress due to creep of both the concrete and the prestressing steel.

23.1.3 FACTORS AFFECTING CREEP

The factors affecting creep are:

- Water content of the concrete mix. High water contents give high creep.
- Age at load transfer. If structures are permitted to cure for longer before loads are applied, creep will be reduced.
- Section thickness. Thick sections will creep less because moisture movement is reduced.
- Humidity. Creep is higher in humid environments.
- Temperature. Creep increases with temperature.

Most design codes will include a method of calculating specific creep that will take account of many of these factors.

23.2 SHRINKAGE

23.2.1 EFFECTS OF SHRINKAGE IN CONSTRUCTION

Shrinkage causes:

- Cracking – but only if the element is restrained.
- Deflection, normally additional to the creep.
23.2.2 **AUTOGENOUS SHRINKAGE**

This is the inevitable shrinkage that results from the hydration of cement without additional water, and is typically 40 microstrain after 1 month. It is greatest for mixes with a high cement content, but never sufficient to cause cracking. Stresses from it are rapidly relieved by creep, if no other shrinkage occurs. In wet curing, swelling occurs with similar or greater strains.

23.2.3 **THERMAL SHRINKAGE**

Concrete is frequently relatively warm, when initial set occurs. This may be due to the heat of hydration, or other effects such as sunlight on the concrete, or the aggregate storage. When it subsequently cools, it will shrink. Typical coefficients of thermal expansion are 5–10 microstrain °C⁻¹.

23.2.4 **PLASTIC SHRINKAGE**

This occurs before final set, and is caused by bleeding. As water is lost from the concrete, its volume decreases. Rapid drying from the surface (i.e., faster than bleeding) will cause substantial plastic shrinkage.

23.2.5 **DRYING SHRINKAGE**

The effect of early drying is plastic shrinkage. Drying shrinkage is a long-term phenomenon, and occurs when the pore water is lost. Typical values are 500 microstrain at 28 days at 50% RH.

Drying shrinkage is associated more with loss of water from gel pores (formed in the gel during hydration), than with capillary pores that are larger, and are initially occupied by water. Thus, the pastes, which have hydrated more and have a higher proportion of gel pores, will shrink more, for less water loss.

Figure 23.1 shows the effect of various curing environments. Continuous wet curing will cause expansion, continuous drying will cause shrinkage. Sealed curing will just cause autogenous shrinkage. Alternate wetting and drying will cause swelling and shrinkage with each cycle, with a net overall shrinkage or swelling effect depending on the mix.

23.2.6 **CARBONATION SHRINKAGE**

Carbonation is normally of interest for durability because it causes loss of alkalinity, leading to reinforcement corrosion. It does, however, also cause some shrinkage. This shrinkage is closely related to drying shrinkage, and the combined effect of both will depend on the sequence in which they take place (i.e., carbonation during drying or after it). Typical values for mortar are 800 microstrain at 50% RH.

23.2.7 **AGGREGATE SHRINKAGE**

Aggregate shrinkage is discussed in Section 19.6.3. Generally, the aggregate will shrink less than the cement paste, so increasing the aggregate content will reduce shrinkage.
23.3 CRACKING

23.3.1 THE CAUSES OF CRACKING

Cracking occurs when the tensile strain in concrete exceeds its tensile strain capacity. At early ages, when the concrete is weak, this requires far less stress than for mature concrete. Structural cracking occurs when the strains are caused by the loading on the structure. Non-structural cracking is caused by shrinkage. Creep causes “relaxation” of stresses, and will reduce cracking. This is shown schematically in Fig. 23.2.

In the discussion in this chapter, the stress is assumed to be nonstructural. Cracking caused by structural overload would be considered in the topic of structural analysis.

23.3.2 EFFECTS OF CRACKING IN CONSTRUCTION

Cracking may be unacceptable to the client because of its appearance. The significance of the cracks will depend on how easily they may be seen. Thus, while cracks of 0.1 mm may be unacceptable on a major public building at street level, 0.6 mm cracks may not be a problem on parts of a car park that may only be seen from a distance.

Cracks will also cause some loss of durability; in particular, they may form pathways for chlorides to reach the reinforcement. However, defining acceptable widths for durability (i.e., protection of steel) is very difficult because surface width is a poor indicator of crack depth, so corrosion rates do not depend on surface crack width.
The most important point to note about cracking of concrete is that it occurs in most structures, and is generally harmless because, in structural calculations, the concrete is only assumed to carry compressive loads.

### 23.3.3 Autogenous Healing

Cracks in water-retaining structures will cause leaks. However, for watertightness, a width of 0.2 mm \((8 \times 10^{-3} \text{ in.})\) is considered acceptable because, below this width, autogenous healing will probably seal the crack. This is a process in which the water brings cementing minerals into the crack, where they solidify and block it.

### 23.3.4 Drying Shrinkage Cracking

Cracking due to drying shrinkage is most common in thin slabs and walls made with mixes with a high water content. It is a long-term effect, and may take weeks or months to appear.

### 23.3.5 Early Thermal Cracking

Early thermal cracking may occur from 1 day to 2–3 weeks after casting. It is most common in thick walls and slabs, where the heat of hydration causes significant temperature increases, and subsequent rapid cooling occurs.

### 23.3.6 Plastic Settlement Cracking

Plastic settlement cracking is caused by bleeding (see Section 22.3), and is often seen over reinforcing bars, as shown in Fig. 23.3. If there is reinforcement near the top of a reasonably deep section, such as a reinforced footing, this will form a line of cracks above each of the links.

In Fig. 23.4, the concrete settles into the beams due to plastic settlement, but it is restrained at the edges so cracks form.
Plastic cracking may be solved with revibration. It is often considered that this may damage the concrete, but it does not. The immersion vibrators are placed in the concrete as soon as the cracks appear, and this will close the cracks and also disperse any bleed water that has accumulated under the bars. The way to judge whether concrete has set too much for revibration is to inspect the surface after the immersion vibrator is withdrawn. If the surface is flat, without holes in it, then the operation should continue. Simply retroweling the concrete to hide the cracks is not acceptable.

Plastic settlement may be prevented by reducing the water content of the mix, or by using air entrainment.

23.3.7 PLASTIC SHRINKAGE CRACKING

Plastic shrinkage cracking is caused by horizontal shrinkage of slabs. It is common in roads and thin slabs, and may be reduced with improved curing to prevent rapid drying. This keeps the bleed water on the surface, and reduces further bleeding.
23.3.8 CRAZING
Crazing causes a network of fine surface cracks. It occurs when impermeable formwork, such as steel shuttering, is used, that does not absorb any moisture from the wet concrete, and thus has none to re-release back during setting in order to assist with surface hydration. It may also occur on top surfaces of pours that are overtrowelled. It is most common in mixes with a high cement content, and is reduced with improved curing.

23.3.9 REINFORCEMENT CORROSION CRACKING
When reinforcement corrodes, it will normally form a rust, which occupies more volume than the original steel (see Section 25.3.1 for types of corrosion product). This will cause cracking and spalling of the concrete. The only way to prevent it is to prevent the corrosion of the steel.

23.3.10 ALKALI AGGREGATE REACTION
This will cause map cracking on the surface, characteristically with three cracks radiating from a single point. The causes are discussed in Section 19.6.2.

23.4 PREVENTING PROBLEMS CAUSED BY SHRINKAGE AND CRACKS
23.4.1 CRACK CONTROL STEEL
The purpose of crack control steel is to produce a large number of fine cracks (below the critical widths), rather than a smaller number of larger cracks.

23.4.2 CRACK INDUCERS AND EXPANSION JOINTS
Figures 23.5 and 23.6 show the use of a crack inducer. This is a strip of plastic that is placed into the wet concrete. It is made in two parts, so the upper part can be removed after the concrete has set to make space for a sealant to be placed. By inducing cracks at regular intervals in the slab, the tensile stresses are reduced, and no other cracks form.
23.4.3 FILLING CRACKS

Figure 23.7 shows one of many different details that can be used to fill shrinkage cracks. The void is formed between adjacent pours with an inflatable void former that is then extracted, and the wall is left until all of the shrinkage has taken place. The void is then grouted to form a seal that is adequate for a liquid retaining structure.

Plan view of a section of the top of a wall. A typical wall of this type may be constructed using “hit-and-miss” construction in which alternate panels are cast first and then the in-fills are cast between them.
23.5 CONCLUSIONS

- Basic creep is almost impossible to measure, so total creep that includes drying shrinkage is normally measured.
- Creep can cause deflection of structures, or loss of prestress.
- Almost all concrete will shrink due to effects associated with cooling and drying.
- There are a number of different causes of nonstructural cracking, and it is important to identify the cause, if it is to be prevented.
- In structures, it is generally best to permit cracking to occur in a controlled manner, rather than trying to stop it.