VOLUME CHANGES AND CREEP OF CONCRETE
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I. INTRODUCTION

- In our previous discussions of concrete and cement paste, we have not considered the slight changes in length and/or volume which occur during hydration and in service.

- There are several changes which occur, and they become important in large structures or in applications where tolerances are close.

II. DRYING SHRINKAGE

- Withdrawal of water from concrete stored in unsaturated air causes drying shrinkage. A part of this movement is irreversible and should be distinguished from the reversible moisture movement caused by alternating storage under wet and dry conditions.

![Graph of shrinkage strain over time](image)

Fig. 1. The shrinkage strain of a sample of concrete is shown for one cycle of drying and wetting.

- The change in the volume of drying concrete is not equal to the volume of water removed. The loss of free water, which takes place first, causes little or no shrinkage.
II. DRYING SHRINKAGE (Continued...)

- The water in the capillary pores is termed "free water", and its removal will not directly cause shrinkage.

- It should be noted, however, that if hydration is not complete the removal of free water will severely restrict the further hydration of the paste.

- As drying continues, adsorbed water is removed and the change in the volume of unrestrained cement paste at that stage is approximately equal to the loss of a water layer one molecule thick from the surface of all the hydration products.

- A schematic diagram of the structure of C-S-H is shown in Fig. 2 where three classifications of water are identified by their ease of removal.

\[\text{Fig. 2 A schematic diagram of the structure of C-S-H where three classifications of water are identified by their ease of removal.}\]

- The ease of removing water from hydrated portland cement products and the corresponding drying shrinkage is shown in Fig. 3.

\[\text{Fig. 3 (a) The loss of water at room temperature from a portland cement mortar sample is shown as a function of relative humidity; (b) The corresponding shrinkage is shown as a function of water loss. Note the points A, B, and C identify the same points on both figures.}\]
II. DRYING SHRINKAGE (Continued...)

- The Interlayer water is called the "combined water" in Fig. 3 and it is also known as the "water of hydration" which is chemically combined in the C-S-H structure. At high temperatures (over 180°C) this water can be driven out of the structure, but it is not removed by any mechanism at room temperature.

- The similarity between the shrinkage of portland cement products and wood is remarkable.

III. CREEP OF CONCRETE

- In the preceding discussion of shrinkage, we did not assume any applied load. If we now assume a load is applied to the concrete, we find that it has an effect on the long-time dimensions of the concrete sample.

- Of course, there is an instantaneous strain which is called the "elastic" deformation since it can be removed by unloading the sample.

- It is observed that there is a gradual increase in strain for days after a stress has been applied to concrete. This is called the "creep" strain.

- Creep can thus be defined as the increase in strain under a sustained stress; and since this increase can be several times as large as the strain on loading, creep is of considerable importance in structural mechanics.

- The effects of creep are in addition to the shrinkage effects which we have discussed earlier. The deformation of concrete with time is schematically shown in Fig. 4.

* The analogy between the shrinkage of concrete and wood is related to the similarities in removing water from each structure. When a saturated wood is dried no shrinkage occurs until the "fiber saturation" point was reached, and then there was pronounced shrinkage as water was removed from the cell walls. At higher moisture contents than the fiber saturation point the water is thought to be within the lumen (or cell cavities) and these are analogous to the capillary pores in cement paste.
III. CREEP OF CONCRETE (Continued...)

Fig. 4 Time-Dependent strain in a concrete subjected to a sustained load for 90 days and then 30 days without a load.

- Under normal conditions of loading, the instantaneous strain recorded depends on the speed of application of the load and thus includes not only the elastic strain but also some creep.

- It is difficult to differentiate accurately between the immediate elastic strain and early creep, but this is not of practical importance as it is the total strain induced by the application of load that matters.

- If the stress is removed after some period of time, there is an instantaneous recovery of the elastic strain and then slower recovery of some of the creep, but not all. This is shown in Fig. 4 where the particular concrete was loaded at the age of 28 days, with the resulting instantaneous strain. The load was then maintained for 90 days, during which time creep is seen to have increased the total deformation to almost 3 times its instantaneous value. If the load were maintained, the deformation would have continued. When the load was removed the elastic – instantaneous strain – is, of course, recovered, and some creep recovery is seen to occur. If the concrete is reloaded at some later date, instantaneous and creep deformations develop again, as shown.

- Creep in concrete is a post-elastic phenomena. In practice, drying shrinkage and viscoelastic behavior such as creep usually take place simultaneously. Considering the various combination of loading, restaining, and humidity conditions, the following terms are defined:
III. CREEP OF CONCRETE (Continued...)

I. True or Basic Creep: is defined as the creep that occurs under conditions that there is no drying shrinkage or moisture movement between concrete and ambient environment.

II. Specific Creep: is defined as creep strain per unit of applied stress:

\[
\text{Specific Creep} = \frac{\varepsilon_{cr}}{\sigma}
\]

III. Drying Creep: is the additional creep that occurs when the specimen under load is also drying.

IV. Creep Coefficient: is defined as the ratio of creep strain to elastic coefficient. Creep Coefficient = \(\frac{\varepsilon_{cr}}{\varepsilon_E}\)

IV. FACTORS INFLUENCING SHRINKAGE AND CREEP

• One of the most important factors for both shrinkage and creep is the relative humidity of the medium surrounding the concrete.

• This has already been discussed for shrinkage, but there is a striking similarity with creep which is shown in Fig. 5.

• For a given concrete, creep is higher the lower the relative humidity. This is illustrated in Fig. 5(b) for specimens cured at a relative humidity of 100% and then loaded and exposed to different humidities.

Fig. 5 Influence of relative humidity on (a) drying shrinkage and (b) creep of concrete.
IV. FACTORS INFLUENCING SHRINKAGE AND CREEP
(Continued...)

- Concrete which exhibits high shrinkage also generally shows a high creep. This does not mean that the two phenomena are due to the same cause, but they may both be linked to the same aspect of structure of hydrated cement paste. It should not be forgotten that concrete cured and loaded at a constant relative humidity exhibits creep and that creep produces no loss of water from the concrete to the surrounding medium, nor is there any gain in weight during creep recovery.

- Other factors affecting drying shrinkage and creep are outlined below:

  - **Aggregate:**
    a) Modulus of Elasticity
    b) Aggregate content
    Any increment of these two factors reduce the drying shrinkage and creep.

  - **Cement:**
    a) Water/cement ratio:
    For a constant cement content an incremental increase in W/C ratio increases both drying shrinkage and creep.
    b) Cement content:
    For a constant W/C ratio an incremental increase in cement content reduces the creep but increases the drying shrinkage. This is the only case in which exists an opposite effect.

  - **Humidity:**
  An incremental increase on relative humidity of air decreases both the drying shrinkage and creep.

  - **Geometry of the concrete element:**
  Theoretical Thickness \( h = \frac{2A}{P} \); \( A = \text{Section Area} \), \( P = \text{Perimeter} \)
  An incremental increase on the theoretical thickness (\( h \)) reduces the drying shrinkage and creep.

  - **Temperature:**
  Given the same curing history for two specimens, the one that is kept in a higher temperature will have more creep and drying shrinkage than the other one.

  - **Age of loading:**
  There is a direct proportionality between the magnitude of sustained stress and the creep of concrete. Because of the effect of strength on creep, at a given stress level, lower creep values were obtained for the longer period of curing before the application of the load. Shrinkage is not affected by this factor.
Nature of Creep

- Although the nature of creep is still uncertain, its partly reversible character suggests that the deformation may consist of a partly reversible visco-elastic movement (consisting of a purely viscous phase and a purely elastic phase) and possibly also a non-reversible plastic deformation.

- An elastic deformation is always recoverable on unloading. A plastic deformation is never recoverable, can be time-dependent, and there is no proportionality between plastic strain and the applied stress, nor between stress and rate of strain. A viscous deformation is never recoverable on unloading, is always time-dependent, and there is always proportionality between the rate of viscous strain and the applied stress, and hence between stress and strain at a given time. These various types of deformation can be summarized as follows:

<table>
<thead>
<tr>
<th>Type of Deformation</th>
<th>Instantaneous</th>
<th>Time-dependent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reversible</td>
<td>Elastic</td>
<td>Delayed-elastic</td>
</tr>
<tr>
<td>Irreversible</td>
<td>Plastic Set</td>
<td>Viscous</td>
</tr>
</tbody>
</table>

Practical Effects of Creep

- For stresses not exceeding about one-half of the cylinder strength, creep strains are directly proportional to stress. Creep also depends on the average ambient relative humidity, being about twice as large for 50% as for 100% humidity. This is so because part of the reduction in volume under sustained load is caused by an outward migration of free pore water which evaporates into the surrounding atmosphere. Other things being equal, creep is larger for low-strength than for high-strength concretes.