Durability of Concrete

Lecture No. 21
Durability of Concrete

- A durable concrete is one that performs satisfactorily in the working environment during its anticipated exposure conditions during service.

- The durability of cement concrete is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration. Durable concrete will retain its original form, quality, and serviceability when exposed to its environment.

- One of the main characteristics influencing the durability of concrete is its permeability to the ingress of water, oxygen, carbon dioxide, chloride, sulphate and other potentially deleterious substances.
Durability of Concrete

- Concrete Deterioration can be caused by:
  - The use of inappropriate materials.
  - Poor construction practices.

- Environmental Related Causes of Concrete Durability Problems
  - Temperature.
  - Moisture.
  - Physical factors.
  - Chemical factors.
  - Biological factors.
Durability of Concrete

- These factors may be due to weathering conditions (temperature, and moisture changes), or to abrasion, attack by natural or industrial liquids and gases, or biological agents.

- Durability problems related to environmental causes include the following: steel corrosion, delamination, cracking, carbonation, sulfate attack, chemical attack, scaling, spalling, abrasion and cavitation.
Temperature

- Temperature variations will cause changes in the concrete volume. When temperature rises, the concrete slightly expands, and when temperature falls, the concrete contracts.

- Since concrete is usually restrained by foundations, subgrades, reinforcement, or connecting members, volume changes in concrete can produce significant stresses in the concrete. Tensile stresses can cause the concrete to crack.

Figure 1. Warping of Concrete due to Temperature Difference
Temperature

- Temperatures greater than 95°C (203°F) can have significant effects on concrete.

- The total volume change in concrete is the sum of the volume changes of the cement paste and aggregates.

- At high temperatures, the cement paste will shrink due to dehydration of the calcium silicate hydrate (C-S-H), while the aggregate will expand.

- Seasonal changes in temperature range up to 50°C (90°F) between the summer and winter. Seasonal temperature changes cause higher stresses than daily temperature changes, and they result in more extensive cracking.
Moisture

- Changes in the moisture content in concrete will result in either concrete expansion or contraction.

- When concrete gains moisture, the concrete will slightly expand or swell. When concrete loses moisture, the concrete will contract or shrink.
Moisture

- Further, wetting and drying of the concrete can cause the concrete to alternately swell and shrink.

- This drying and shrinking of the concrete surface will cause the concrete surface to develop tensile stresses and possible cracks.

- If a section of the concrete is restrained, and if concrete joints are not provided, major random cracks may develop.

- The three main problems with moisture and concrete are as follows:
  - 1) Carbonation, 2) The moisture cycle, 3) Contaminants
Moisture
Moisture : Carbonation

- Carbon dioxide (CO2) present in the atmosphere reacts in the presence of moisture with the hydrated cement minerals (i.e. the agent usually being the carbonic acid).

- The extent of carbonation depends on the permeability of the concrete and on the concentration of carbon dioxide in the air.

- The penetration of carbon dioxide beyond the exposed surface of concrete is extremely slow.

- The alkaline conditions of hydrated cement paste are neutralized by carbonation. This neutralization, by dropping the pH from over 12 to about 9, affects the protection of reinforcing steel from corrosion.
Moisture : Moisture Cycles

- Stresses caused by changes in moisture content of the concrete may be additive to stresses caused by temperature changes.

- Tensile stresses usually increase the tendency for cracking, scaling, spalling, and delamination.

- Rapidly fluctuating humidity (up to 70% in one day) can lead to moisture changes in the concrete.

- If the moisture level at the reinforcing steel reaches 60% to 90% and sufficient chlorides are present, the steel will corrode.
Moisture : Moisture Cycles

Table 1. Influence of Relative Humidity on the Corrosion of Steel in Concrete

<table>
<thead>
<tr>
<th>Relative Humidity</th>
<th>Remarks</th>
<th>Corrosion Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete submerged in water</td>
<td>Capillaries filled with calcium hydroxide solution. Oxygen must diffuse through solution-filled capillaries to steel.</td>
<td>No-corrosion to small risk.</td>
</tr>
<tr>
<td>90% to 95%</td>
<td>Pores filled with pore solution through which oxygen must diffuse.</td>
<td>Small to medium risk.</td>
</tr>
<tr>
<td>60% to 90%</td>
<td>Pores only partially filled. Water and oxygen reach steel easily.</td>
<td>Great risk.</td>
</tr>
<tr>
<td>below 60%</td>
<td>No or very little solution in pores.</td>
<td>No risk.</td>
</tr>
</tbody>
</table>
Moisture : Contaminants

- Contaminants in the water that is absorbed into the concrete may cause staining, steel corrosion, or sulphate attack.

- Contaminants include: chloride and sulphate salts, carbonates, etc.

- Alternate cycles of wetting and drying allow the concentration of salts to increase and thereby increase the severity of their attack.

- An increase in the size of salt crystals in the capillaries near the evaporating surface causes cracking and scaling.

- If the salts are drawn to the surface and deposited at places where water evaporates, efflorescence will occur.
Moisture : Contaminants

\[ 2H_2O + O_3 + 4e^- \rightarrow 4OH^- \]

Cathode

\[ 2Fe(OH)_2 \]

Water

Anode

\[ 2Fe^{2+} \]

Iron

\[ 4e^- \]

\[ 2Fe^{2+} + 4e^- \]
Physical Factors

- Under many circumstances, concrete surfaces are subjected to wear. Concrete wear may be caused by the sliding, scraping or impact of objects that fall onto the concrete.

- In hydraulic structures, the action of the abrasive materials carried by flowing water generally leads to erosion of the concrete.

- Another cause of damage to concrete in flowing water is cavitation.

- Abrasion damage to concrete may also be caused by subjecting the concrete to abrasive materials (such as sand) that are carried by wind or water.
Physical Factors

- That abrasion resistance is clearly related to the compressive strength of the concrete.

- Strong concrete has more resistance than weak concrete.

- Since compressive strength depends on the water-cement ratio and adequate curing, a low water-cement ratio and proper curing of the concrete are necessary for abrasion resistance.

- Hard aggregates are more abrasion resistant than soft aggregates.
Physical Factors

- Concrete that is affected by cavitation has an irregular, jagged, and pitted surface.

- After an initial period of small damage, rapid deterioration will occur. This rapid deterioration is followed by damage to the concrete at a slower rate.

- Cavitation can be a problem in any open channel where the velocity of the flowing water is higher than 12 mls. In a closed pipe or conduit, cavitation can occur at velocities as low as 7.5 mls.

- Concretes that have the best resistance to cavitation damage have a high strength, a low water-cement ratio, a small aggregate size that does not exceed 20 mm, and a good paste aggregate bond.
Physical Factors

Abrasion-erosion damage to the stilling basin of Kinzua Dam
Physical Factors
Physical Factors

- Fire around concrete structures can weaken the superstructure and decrease the concrete strength tremendously.

- Damage by fire may include total or partial collapse of the structure, distortion, excessive deflection and expansion, buckling of the steel, spalling and shattering of the concrete, discoloration, and reduction of the physical properties of the steel and concrete.

- The effect of increased temperatures on the strength of concrete is small and somewhat irregular below 250°C (482°F).
Physical Factors
## Physical Factors

**Table 2. Impact of Fire Temperature on Concrete**

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Effect on Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>100°C to 250°C (212°F to 482°F)</td>
<td>Normal color, slight loss in compressive strength</td>
</tr>
<tr>
<td>250°C to 300°C (482°F to 572°F)</td>
<td>Color changes to pink, strength loss increases</td>
</tr>
<tr>
<td>300°C to 600°C (572°F to 1112°F)</td>
<td>Color is pink to red, strength loss continues</td>
</tr>
<tr>
<td>Above 600°C (1112°F)</td>
<td>Color changes to black, gray; very little residual strength</td>
</tr>
<tr>
<td>About 900°C (1652°F)</td>
<td>Color changes to buff; total loss of strength</td>
</tr>
</tbody>
</table>
Biological Factors

- Concrete may be damaged by live organisms such as plants, sponges, boring shells, or marine borers.

- Mosses and lichens, which are plants of a higher order, cause insignificant damage to concrete.

- These plants produce weak acids in the fine hair roots. The acids that are produced from mosses and lichens will attack the cement paste and cause the concrete to disintegrate and scale.

- In some cases, carbonic acids are produced from plants, such as mosses and lichens, when substances from these plants decompose. The carbonic acid that is produced will attack the concrete.
Biological Factors
Biological Factors

- Marine borers, such as mollusks and sponges, tend to form bore holes into underwater concrete structures.

- Marine borers reduce the concrete's load-carrying capacity as well as expose the concrete's outer reinforcing steel to the corrosive seawater.

- As the degree of interconnection increases, the surface material of the concrete crumbles.

- Disintegration of the surface layer exposes a new substrate of the concrete to the boring sponges. Deterioration of concrete due to a boring sponge attack is relatively slow.