Lecture 8
Durability of Concrete

• *Durability of concrete*

Durability is **the ability of concrete to withstand the conditions for which it is designed without deterioration for a long period of years**. And it also may be defined as **the ability of concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties**.

Concrete will remain durable if:

1- The cement paste structure is dense and of low permeability.

2- It is made with graded aggregate that are strong and inert.

3- The ingredients in the mix contain minimum impurities such as alkalis, chlorides, sulphates and silt.

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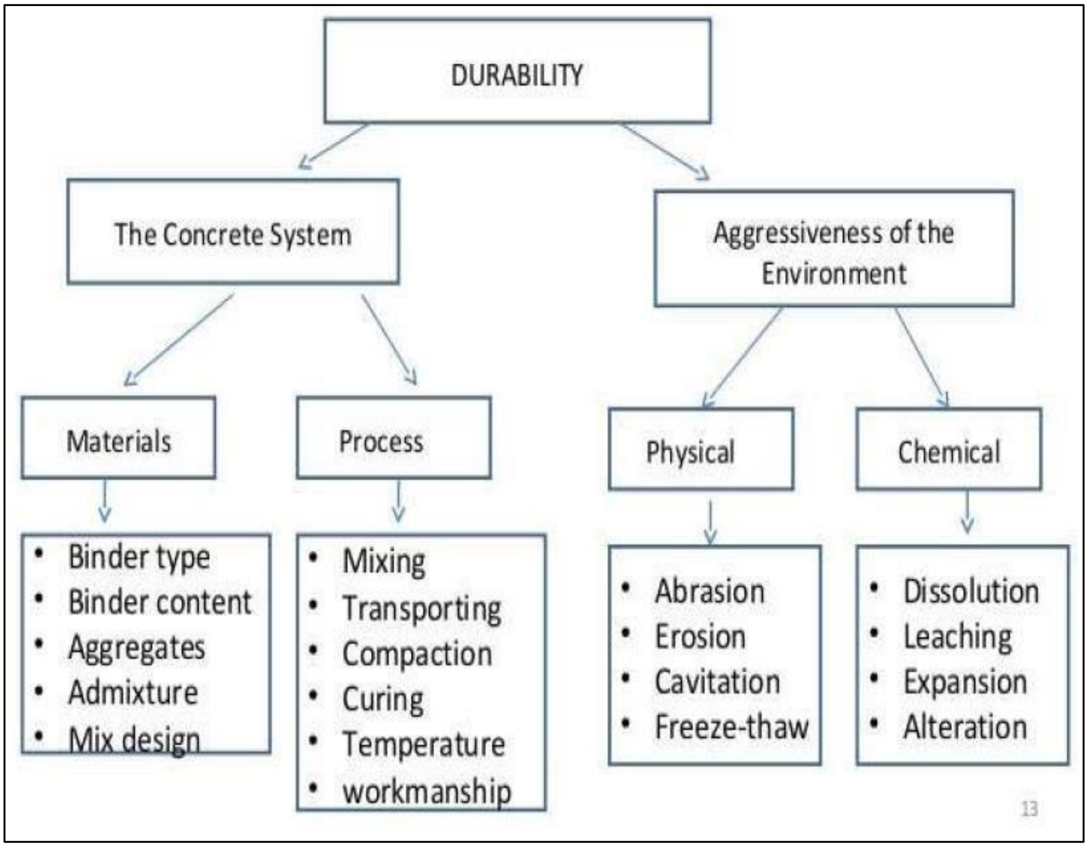
• *Factors affecting durability of concrete*

Durability of Concrete is influenced by the factors shown in the following figure



1- Cement content (Binder content)

- Quantity of cement used in concrete mix is a factor affecting durability of concrete.
- If **cement content** used is **lower** than the required, then water cement ratio reduced and workability also reduced.
- If **excess cement content** is used, problems like drying shrinkage, alkali-silica reaction may occur which finally effects the durability of concrete.

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2- Aggregate Quality

- Use of **good quality aggregates** in concrete mix will surely **increase** the durability of hardened concrete.
- The shape of aggregate particles should be **smooth and round**. Flaky and elongated aggregates reduce workability of fresh concrete,(because their rough texture and irregular shape increase friction and interlocking between particles). While for better bond development between ingredients **rough textured angular aggregates** are recommended but they require more cement content.
- Aggregate should be well graded to achieve dense concrete mix.
- Aggregates should be tested for **its moisture content** before using. Excess moisture in aggregate may lead to highly workable mix

3. Water Quality

- In general, potable water is recommended for making concrete., PH of water used shall be in the range of 6 to 8.

- Water should be clean and free from oils, acids, alkalies, salts, sugar, organic materials etc. Presence of these impurities will lead to corrosion of steel or deterioration of concrete by different chemical reactions.

4. Concrete Compaction

- While placing concrete, it is important to compact the placed concrete without segregation.
- **Improperly compacted** concrete contain number of air voids in it which reduces the concrete strength and durability.

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5. Curing Period

- **Proper curing** in initial stages of concrete hardening result in good durability of concrete.
- **Improper curing** leads to formation of cracks due to plastic shrinkage, drying shrinkage, thermal effects etc. thereby durability decreases.

6. Abrasion

- Deterioration of concrete also occurs due to severe abrasion.
- When concrete is subjected to rapidly moving water, steel tires, floating ice continuously wearing of surface occurs and durability gets negatively affected.
- **Higher the compressive strength higher will be the abrasion resistance**.

7. Wetting and Drying Cycles

- When concrete is exposed to alternate wetting and drying conditions such as tidal waves from sea etc. secondary stresses are developed in concrete. Due to these stresses cracks will form and reinforcement is exposed to atmosphere.
- When chlorides or sulfates from sea water meets reinforcement corrosion occurs and durability of concrete is reduced.
- Use of **low-permeable concrete, proper cover for reinforcement** can prevent this type of problems.

Types of Durability

There are many types but the major ones are:

1. Chemical durability of concrete.
2. Physical durability of concrete.

1. Chemical Durability

When dealing with durability, chemical attack which results in volume change, cracking and consequent deterioration of concrete become a major cause of concern.

Types of the chemical attacks are as follows:

1. **Sulphate attack**
2. **Alkali aggregate reaction**
3. **Chloride ion attack - Corrosion**
4. **Carbonation**
5. **Acid Attack**
6. **Effect on concrete in Seawater**

1. Sulphate attack

- Sulfate attack generally happens when water used for concrete mix contains high sulfate content, unwashed aggregates, when soil around the concrete structure contains sulfates in it etc.
- **Sulphates** in the form of calcium, magnesium, sodium and potassium, calcium sulphate causes minimum damage because of its low solubility while magnesium sulphate causes maximum damage.
- **Sulphate attack** denotes an **increase** in the volume of cement paste in concrete or mortar due to chemical action between the products of hydration of cement and solution containing sulphate, and also sodium, magnesium and Chlorides.
- In hardened concrete, calcium aluminate hydrate (CAH) can react with sulphate salt from outside, product of reaction is calcium sulphoaluminate , which can cause an increase in volume up to 227%.
- **Rate of sulphate attack increases with a saturated sulphate solution**.
- **A saturate solution of magnesium sulphate can cause serious damage to concrete with high w/c ratio.**

Methods of controlling sulphate attack

1. Use SRC (sulphate resisting cement)
2. Quality concrete (low w/c ratio, well designed and compacted dense concrete)
3. Use of air-entrainment
4. Use of puzzolana

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2. Alkali Aggregate Reaction

- Alkali-aggregate reaction (AAR) or alkali-silica reaction (ASR), takes place between alkali content of cement and silica content of aggregates is also a major factor effecting durability of concrete.
- Due to this reaction, Concrete expansion occurs which finally lead to severe cracking and concrete gets deteriorated.

It takes place due to :

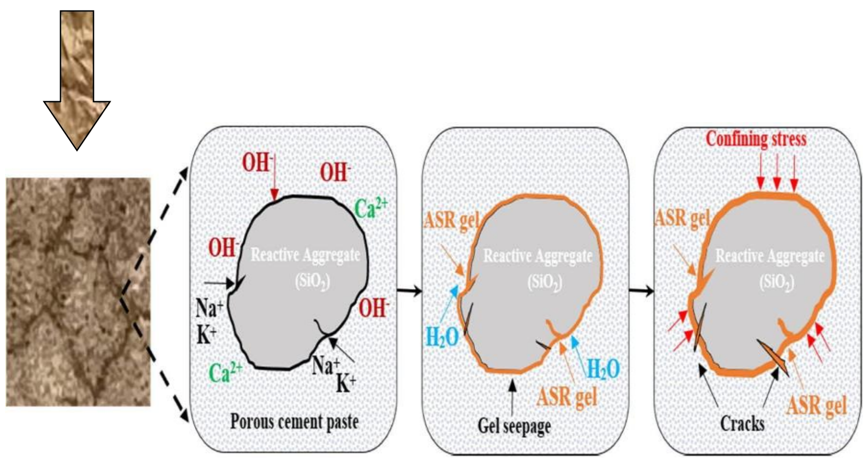
1. **High alkali content in cement (more than 0.6%)**
2. **Reactive silica in aggregate**
3. **Availability of moisture**

Prevention measures:

1. **Use non-reactive aggregates from alternate sources**
2. **Use low-alkali cement**
3. **Reduce cement content in concrete.**

Figure 2:

Alkaaggregate



3. Chlorides in Concrete.

- Chlorides in concrete **increases** risk of corrosion of steel (Electrochemical reaction)
- Higher Chloride content or exposure to warm moist conditions **increase** the risk of corrosion.
- Chlorides can be introduced into the concrete either during or after construction as follows:

1. Before construction Chlorides can be admitted in admixtures containing calcium chloride, through using mixing water contaminated with salt water or improperly washed marine aggregates.

2. After construction Chlorides in salt or sea water, in airborne sea spray and from deicing salts can attack permeable concrete causing corrosion of reinforcement, **The chloride in the presence of water and oxygen reacts with alkaline protected layer around the reinforcement and removes it.**

The rate of Corrosion depends on:

a) Time
b) Depth of cover
c) Concrete density
d) Cement content
e) Water-to-cement ratio
f) The presence of cracks

To minimize the chances of corrosion, the levels of chlorides in concrete should be limited, Total amount of chloride content (as Cl) in concrete at the time of placing is provided by common specifications and standards.

The chloride content in concrete is typically limited to:

- 0.15% by weight of cement for reinforced concrete (ACI 318).
- 0.05% by weight of cement for prestressed concrete (ACI 318).
- 0.10% for structures exposed to carbonation (EN 206).
- 0.40% for structures exposed to chlorides (EN 206).
- Chlorides in water to be less than 2000 mg/ltr for PCC and below 500 mg/ltr for RCC
- Chlorides in aggregates are generally not encountered but, it's a good practice to wash sand containing salt more than 3%
- Chloride traces are also found in chemical admixtures. Chloride free admixtures should be generally preferred.

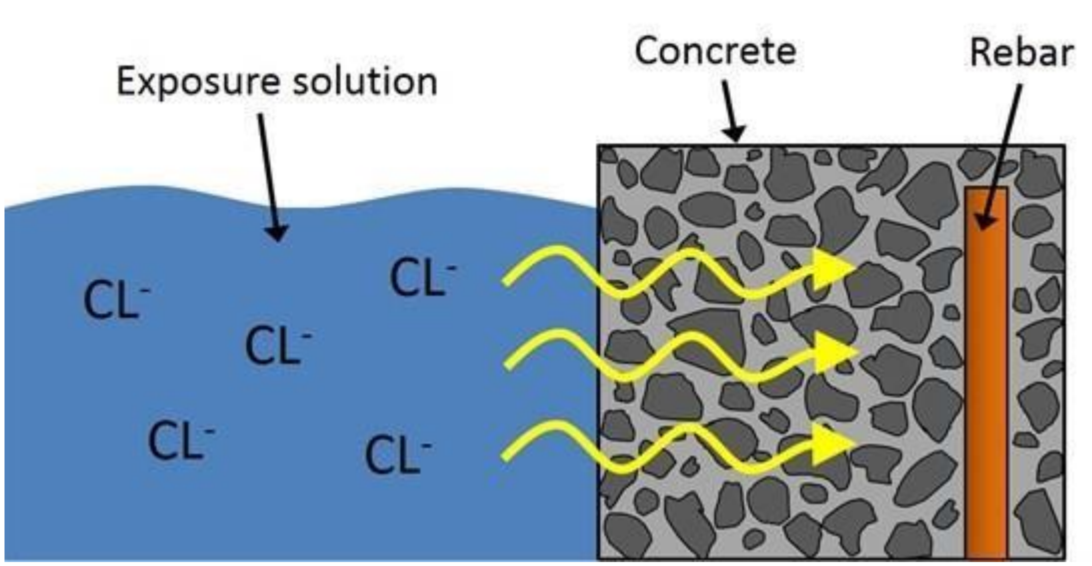


Figure 3: Corrosion in Concrete due to chlorides attack

4. Carbonation

•When moist concrete is exposed to atmosphere, carbon dioxide **CO_2** present in atmosphere reacts with **$Ca(OH)_2$** present in concrete and reduces pH of concrete.

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

Carbonation process involves the following two stages:

- **First,** the atmospheric carbon dioxide (CO_2) reacts with water in the concrete pores to form carbonic acid (H_2CO_3).
- **This is followed by** reaction of the carbonic acid with calcium hydroxide [$Ca(OH)_2$] to form calcium carbonate ($CaCO_3$).
- When pH of concrete reaches below 10, reinforcement present in the concrete starts corroding, Corrosion of reinforcement causes cracks in concrete and deterioration takes place.

Factors Influencing The Rate of Carbonation of Concrete

1. Amount of CO2 in air
2. Relative humidity of concrete
3. Amount of precipitation of CaCO3
4. Concrete carbonation resistance (concrete permeability and amount of $Ca(OH)_2$ in concrete).

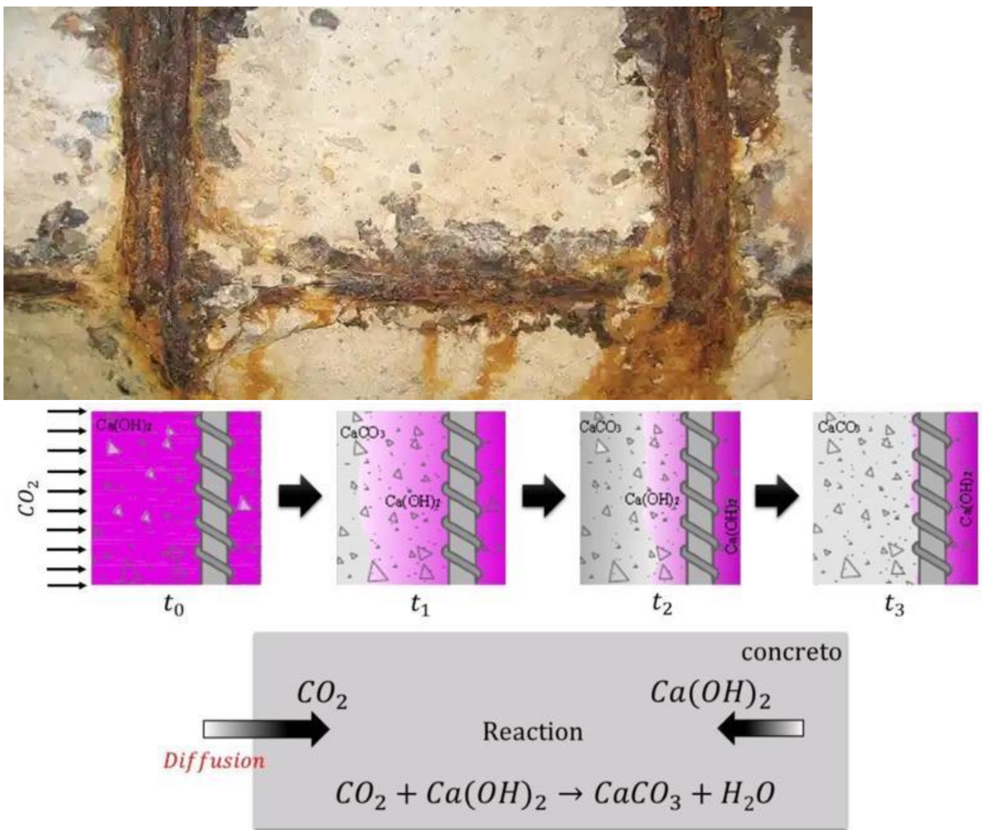


Figure 4:Carbonation of Concrete

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5. Acid Attack

- Concrete is not fully resistant to acids.
- Most acid solutions will slowly or rapidly disintegrate portland cement concrete depending upon the type and concentration of acid.
- Certain acids, such as <u>oxalic acid and phosphoric acids</u> are harmless.
- The most vulnerable part of the cement hydrate is Ca(OH)2, but C-S-H gel can also be attacked.
- Concrete can be attacked by liquids with pH value less than 6.5. But the attack is severe only at a pH value below 5.5. At a pH value below 4.5, the attack is very severe.
- all the cement compounds are eventually broken down and leached away.
- If acids or salt solutions are able to reach the reinforcing steel through cracks or porosity of concrete, corrosion can occur which will cause cracking.

(a) (b)

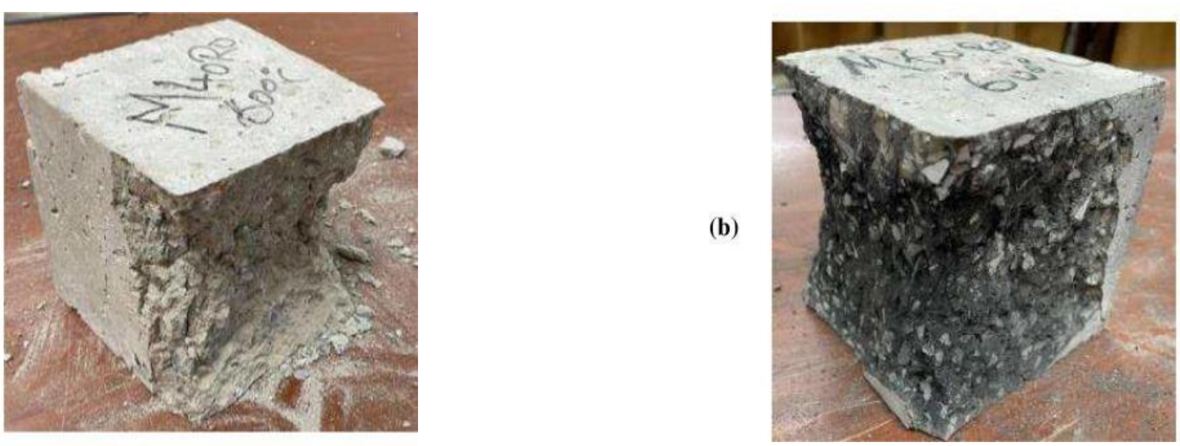

Figure 5: Acid Attack

2. Physical Durability

Physical durability is against the following actions:

1. **Freezing and thawing action.**
2. **Permeability of water.**
3. **Temperature stresses i.e. high heat of hydration.**

1. Freezing and Thawing

•When fully saturated concrete is exposed to repeat cycles of freezing of thawing, it is deteriorated by the action of freezing and softening of water in it.
•Capillary pores are present in concrete and these pores are full of water. **In the cold region or due to excessive winter the pore water is freeze and make ice, due to that the volume of pore water increase.** Due to these phenomena In the capillary pore, the radial pressure increases and the cracks in the concrete become wider. Thus, due to the freezing of water and the thawing of water, concrete disintegrate. Thus, the strength of concrete is reduced. Breakdown of concrete due to freezing of water and thawing of water, **this phenomenon is known as freezing and thawing of concrete.**
•It causes cracking on concrete surface in the form of maps which is called map cracking and effects durability of concrete.
•The coarse aggregate present the concrete also effected by freeze and thaw cycles, spalling of concrete may occurs.

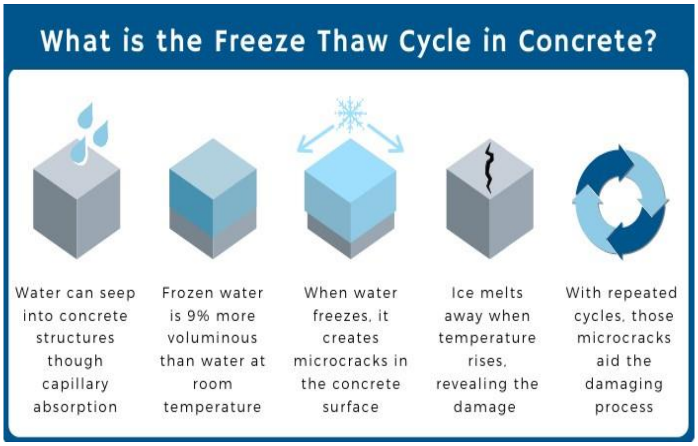

Figure 6: Freezing and Thawing

Prevention Freezing and Thawing

•Keep a low w / c ratio as possible.

•Do enough air entertainment.
•Proper compaction of concrete.
•Use of durable and insoluble(less pores) aggregates.
•Do proper curing of concrete before freeze-thaw
•Provide proper drainage by providing proper slope

2. Permeability of water.

- Concrete durability gets affected when there is a chance of penetrability of water into it.
- Permeability of water into concrete expand its volume and lead to formation of cracks and finally disintegration of concrete occurs.
- Gel pore (28% of the total gel volume) 0.5-4 ηm (diameter). & Capillary pore 10 ηm - 10μm. Gel and capillary pores are known active pore spaces as they affected by hydration of cement and moisture content.
- Generally concrete contains small gel pores and capillary cavities. However, gel pores do not allow penetration of water through them since they are of very small size.
- But, capillary cavities in concrete are responsible for permeability, which are formed due to high water cement ratio.

- **To prevent permeability a-** Lowest possible water cement ratio must be recommended.

b- Use of pozzolanic materials also helps to reduce permeability by filling capillary cavities.

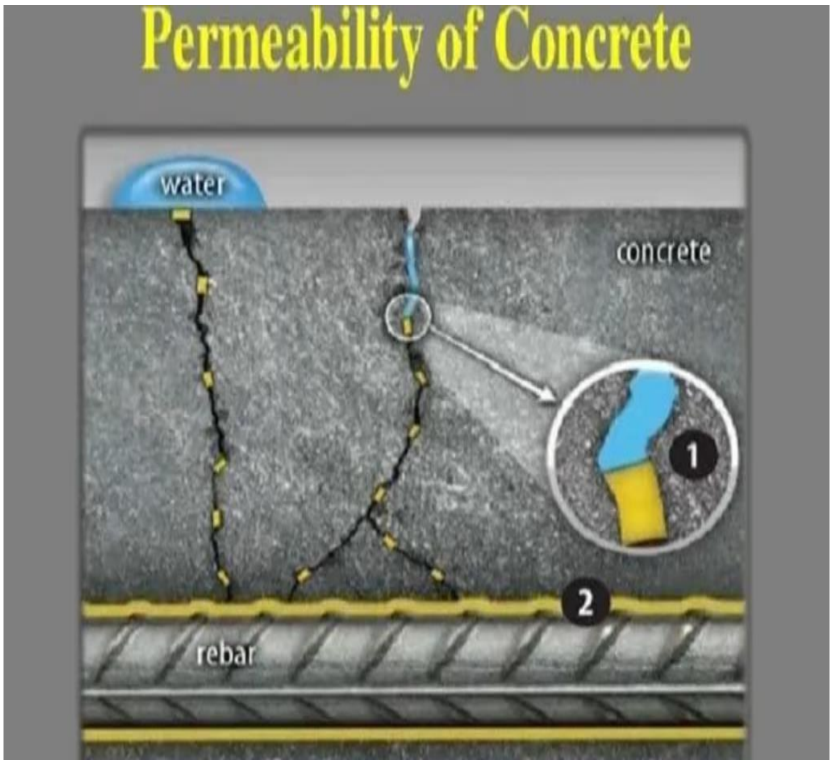

Figure 7: Permeability of water

3. Temperature stresses

- Concrete is heterogeneous material, when fresh concrete is subjected to high temperature rate of hydration gets affected and strength and durability becomes reduced.

- Concrete ingredients have different thermal coefficients, so at higher temperatures, spalling and deterioration of concrete happens.

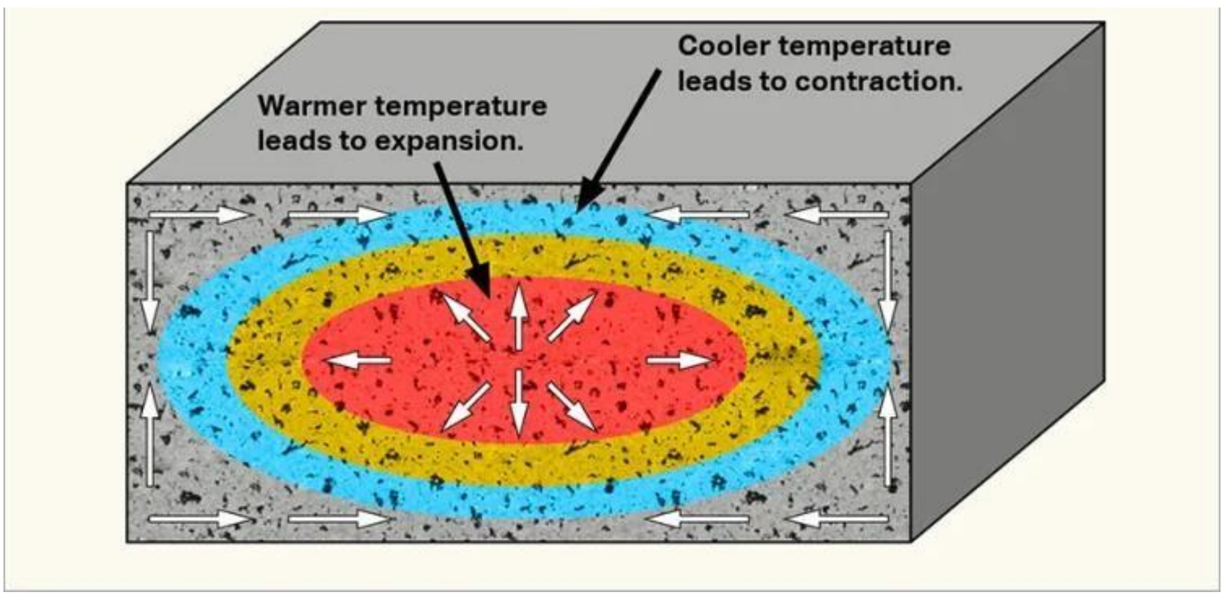

Figure 8: Temperature stresses