CIP 42- Thermal Cracking of Concrete

WHAT is Thermal Cracking?

Thermal cracking occurs due to excessive temperature differences within a concrete structure or its surroundings. The temperature difference causes the cooler portion to contract more than the warmer portion, which restrains the contraction. Thermal cracks appear when the restraint results in tensile stresses that exceed the in-place concrete tensile strength. Cracking due to temperature can occur in concrete members that are not considered mass concrete.

WHY Does Thermal Cracking Occur?

Hydration of cementitious materials generates heat for several days after placement in all concrete members. This heat dissipates quickly in thin sections and causes no problems. In thicker sections, the internal temperature rises and drops slowly, while the surface cools rapidly to ambient temperature. Surface contraction due to cooling is restrained by the hotter interior concrete that doesn't contract as rapidly as the surface. This restraint creates tensile stresses that can crack the surface concrete as a result of this uncontrolled temperature difference across the cross section. In most cases thermal cracking occurs at early ages. In rarer instances thermal cracking can occur when concrete surfaces are exposed to extreme temperature rapidly.

Concrete members will expand and contract when exposed to hot and cold ambient temperatures, respectively. Cracking will occur if this bulk volume change resulting from temperature variations is restrained. This is sometimes called temperature cracking and is a later age and longer term issue.

Mass concrete

The main factor that defines a mass concrete member is its minimum dimension. ACI 301 suggests that a concrete member with a minimum dimension of 4 feet (1.3 m) should be considered as mass concrete. Some specifications use a volume-to-surface ratio. Other factors where precautions for mass concrete should be taken even for thinner sections are with higher heat generating concrete mixtures - higher cementitious materials content or faster hydrating mixtures.

The main concern with mass concrete is a high thermal surface gradient and resulting restraint as discussed above. These conditions can result during the initial stages due to heat of hydration and during the later stages due to ambient temperature changes. Another factor is a temperature differential between a mass concrete member and adjoining elements. As the mass member cools from its peak temperature, the contraction is restrained by the element it is attached to, resulting in cracking. Examples are thick walls or dams restrained by the foundation.

Thermal cracks in a thick slab

Other Structures

Temperature cracking can occur in structures that are not mass structures. The upper surface of pavements and slabs are exposed to wide ranges of temperature while the bottom surface is relatively protected. A significant temperature differential between the surface and the protected surface can result in cracking. Concrete has a thermal coefficient of expansion in the range of 3 to 8 millionths/°F (5.5 to 14.5 millionths/°C). A concrete pavement cast at 95ºF (35ºC) during the summer in Arizona may reach a maximum temperature of 160ºF (70ºC) and a minimum temperature in winter of 20ºF (-7ºC), resulting in an annual temperature cycle of 140ºF (75ºC). Expansion joints and spacing between joints have to be designed to withstand such temperature induced expansion and contraction to prevent cracking.

HOW To Recognize Thermal Cracking?

Thermal cracks caused by excessive temperature differentials in mass concrete appear as random pattern cracking on the surface of the member. Checkerboard or patchwork cracking due to thermal effects will usually appear within a few days after stripping the formwork. Temperature-related cracks in pavements and slabs look very similar to drying shrinkage cracks. They usually occur perpendicular to the longest axis of the concrete. They may become apparent any time after the concrete is placed, but usually occur within the first year or summer-winter cycle.

HOW To Minimize Thermal Cracking?

The key to reducing thermal or temperature-related cracking is to recognize when it might occur and to take steps to minimize it. A thermal control plan that is tailored to the specific requirements of the project specification is recommended. See Ref. 2 for guidance.

Typical specifications for mass concrete include a maximum temperature and a maximum temperature differential. The maximum temperature addresses the time it takes for the concrete member to reach a stable temperature and will govern the period needed for protective measures. Excessively high internal concrete temperatures also have durability implications. A temperature differential limit attempts to minimize excessive cracking due to differential volume change. A limit of 35ºF (20ºC) is often used. However, concrete can crack at lower or higher temperature differentials. Temperature differential is measured using electronic sensors embedded in the interior and surface of the concrete.

The peak temperature of a concrete mixture can be estimated assuming perfectly insulated conditions. See Ref. 1 and 2. Thermal modeling can also be used to predict temperature and potential for cracking based on thermal controls planned. Two models are HIPERPAV (www.hiperpav.com) for pavements and ConcreteWorks (www.texasconcreteworks.com) for pavements and other mass concrete members. Consultants can also assist with these analyses.

A large part of the responsibility to minimize thermal cracking lies with the designer and contractor. Steps include establishing the concrete mixture, specification limits for temperature of concrete as delivered and in the structure, insulating the structure and termination of protective measures, and in critical conditions, post-cooling of structural members.

Some steps to minimize thermal cracking are:

- Concrete mixture - Reduce heat of hydration by optimizing the cementitious materials using supplementary cementitious materials like fly ash or slag; or using a portland cement that generates a lower heat of hydration. Avoid specifying an excessively low w/cm. Retarding chemical admixtures may delay but not reduce peak concrete temperatures. A cooler initial concrete temperature will reduce the peak temperature in the structure but needs to be balanced with practical feasibility and project costs.
- Mass concrete - Ensure that thermal control measures are agreed upon in a pre-construction meeting. Some things to consider include placement method and details, establishing temperature requirements for concrete as delivered and temperature monitoring of in-place concrete, curing methods and duration that do not increase temperature differentials, use of insulation - including when and how the insulation will be removed, and use of cooling pipes if necessary. Placing concrete in lifts along with timing of successive lifts can minimize the overall peak temperature and time of thermal control but this needs to be balanced against construction joint preparation and the design requirements. Water curing will cool concrete surfaces and water retention curing methods may be more appropriate. Wood forms provide insulation while metal forms do not. Covering forms with insulating blankets may be necessary. The removal of insulation or formwork should be scheduled based on monitored in-place temperature and thermal shock to the surface should be avoided. Reinforcing steel protruding from a massive beam can act as a heat sink to draw heat out of the interior of the beam. When needed, cooling pipes, typically plastic, can be embedded in the concrete about 3 feet (1m) apart to reduce peak internal temperatures.
- Pavements and slabs – Reduce heat gain from solar radiation by misting slabs and pavements or providing shade for the work. Placing concrete in the early morning may result in a more critical situation if the peak temperature from hydration coincides with peak ambient temperature. Wind breaks may increase heat gain if they inhibit evaporative cooling of the concrete. Curing blankets can reduce heat loss from slabs and pavements during cold weather conditions.

Good communication between the designer, contractor, and concrete producer is important.

HOW To Repair Thermal Cracking?

Repairs to concrete structures must be undertaken with the advice and consent of the designer. Inappropriate repair techniques can result in greater damage later. Pavements and slabs can be repaired using acceptable and compatible repair materials or by cutting out the cracked areas and replacing them with infill strips. Repair of mass concrete members will depend on the crack width and the service conditions of the structure. Fine hairline cracks are aesthetically unpleasing and may not require any repair. However, these cracks may prove to be a future durability problem depending on the service conditions. Wider cracks may need to be sealed by epoxy injection followed by a seal coating. Recommendations for crack repair are provided in ACI 224.1R and by the International Concrete Repair Institute (www.icri.org).

References

1. ACI 207.2R, Report on Thermal and Volume Change Effects on Cracking of Mass Concrete, American Concrete Institute, www.concrete.org
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4. Contractor's Guide to Mass Concrete, Bruce A. Suprenant and Ward R. Malisch, Concrete International, ACI, Jan 2008, pp. 37-40.
5. Controlling Temperatures in Mass Concrete, John Gajda and Martha VanGeem, Concrete International, Jan 2002, pp. 59-62.

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