Sources of cracks in concrete structures due to temperature gradients

. . . And Means For Their Prevention

By Professor
Dr.-Ing. Fritz Leonhardt

The September 1969 issue of CONCRETE CONSTRUCTION included an article titled “How to Prevent Cracks in Concrete.” In response to this article Professor Leonhardt of the University of Stuttgart in Germany submitted a very informative paper concerning a factor he considers to be an important cause of cracks and possible structural failure in concrete: internal stresses produced by temperature gradients in hardened concrete. Professor Leonhardt’s article provides not only technical explanations of how temperature gradients cause stresses that result in cracks but also suggestions as to precautions that may be taken to reduce the incidence of such stresses. Figures are provided to illustrate the mathematical formulae for calculations of stresses and some examples of stress situations are discussed: side walls in swimming pools, bridge superstructures, and large hollow-box beams. Because of space limitations, a summary is presented here.

Daily and annual variations of atmospheric temperature, especially those caused by the heat of the sun, produce a wide variety of temperature gradients in hardened concrete that are known to cause stress within a structure. In designing structures that will be subjected to such conditions, the codes of design engineers should include recommendations for prevention of these resultant stresses and, thereby, the cracks or even structural failures they can produce.

Internal stresses

Internal restraint of deformation develops under certain conditions when changes of ambient temperature occur and produce a temperature gradient across the cross section of a structural member. In addition to being a function of time, the temperature distribution across the section depends on thickness of the member and on thermal properties of the material (coefficient of heat transfer from atmosphere to concrete and coefficient of thermal conductivity). In a homogeneous and monolithic body the different fibers cannot deform independently from each other and a state of stress develops because of this internal restraint of deformation. Because of the equilibrium conditions, there can be no integration of the stresses and, thereby, no stress resultants and no support reactions can be created. The stresses are independent of whether a structure is or is not statically determinate.

External restraint of deformation

Where external restraint of deformation is present, as is the rule in statically indeterminate structures, additional stresses due to temperature gradients are produced which are superimposed on the internal stresses. In contrast to the stresses attributable to internal restraint, integration of the stresses from external restraint is present over the cross section and the structure is subjected to stress resultants such as bending moments, shear and normal forces. The magnitude and distribution of these resultants depends on the nature and degree of temperature variation, type of structure, and the degree and distribution of the tensional and flexural stiffness of the different members of the structure.

Cracks in swimming pools

Regarding stresses and resultant cracks in side walls of swimming pools, Dr. Leonhardt points out that side walls are often cast several weeks after concreting of the bottom slab. In a cool night after concreting of the walls the shortening of the walls is restrained by the older concrete of the bottom slab and longitudinal tensile stresses are caused in the walls. Additional longitudinal restraint can be caused by the supports of the structure as a whole. Tensile stresses can be intensified by differential shrinkage between bottom slab and wall.

Bending moments in bridge superstructures

In continuous beams of bridge superstructures a temperature gradient that is constant over the length of the structure creates bending moments. In most such structures the center of gravity is located within the upper half of the depth and thus resultant stresses are higher in the bottom fiber than in the top fiber; this is particularly true with relatively deep T-beams. Where temperature at the upper surface exceeds that at the lower surface the resultant bending moments produce tensile stresses in the bottom fibers. In continuous bridges the compressive stress of the bottom fiber caused by dead load plus prestressing is generally lowest at sections near intermediate supports. In this area additional longitudinal tensile stresses in the bottom fiber can be produced by inadequate tracing of the prestressing tendons and high concentration of compressive stresses in the vertical direction through transfer of support reactions. Generally, the highest tensile stresses occur in two-span bridges because the bending moment due to temperature gradients increases with decreasing number of continuous spans. In addition, tensile stresses in T-sections are higher than those in hollow-box sections because the compressive stress reserve near intermediate supports is lowest in T-sections and because the stress increase of the bottom fiber accelerates if the center of gravity moves toward the top of the cross section. In some bridges, cracking has occurred in hollow-box beams in sections near the quarter points of the span. In these instances the bottom plate becomes thicker near the intermediate supports, and the highest tensile stresses due to dead load, prestressing and temperature gradients occur near the quarter points of the span.

Bridge decks—web thickness

On a warm day in even a moderate climate the surface of a bridge deck can reach 150 degrees Fahrenheit and the air inside the hollow box will reach 85 to 100 degrees. During a rapid drop in temperature outside the box, the air inside the box maintains its temperature for a considerable time. The resulting temperature gradient between outside and inside produces bending moments in the transverse direction that are particularly high in cross sections having increased thickness of web and bottom plate, as is often found in regions near intermediate supports. Furthermore, due to shrinkage or to transverse prestressing of the deck slab, additional tensile stresses can occur near the lower edge of the hollow box. Because the tensile strength of the concrete in the transverse direction is decreased by simultaneously acting longitudinal compressive stresses, cracks may easily occur in sections with thick webs and a thick bottom plate.

Conclusions and preventive measures

The stresses due to temperature gradients as described here are those due to inner or outer restraint and thus their magnitude depends largely on the thickness or stiffness of the structural members. When cracks occur stiffness decreases considerably, leading to a corresponding decrease of the temperature stresses. Thus it is not necessary to provide reinforcement for the full amount of stresses as calculated for the uncracked section. Nevertheless, a sufficient amount of non prestressed reinforcement (preferably with small bar diameters and close spacing) must be provided along outer surfaces of the members to avoid the large opening and extension of cracks that can be detrimental to the load bearing capacity of the structure. In addition to reinforcement, measures recommended for reduction of the magnitude of tensile stresses would include the avoidance of thick members and—in the case of hollow-box sections—avoidance of joining thin members to thick members. If the latter is not possible, the thick members should be put under compression by slight prestressing. This would hold also for very long members with longitudinal restraint, e.g., swimming pool side walls. To minimize longitudinal tensile stresses at the bottom fiber of continuous beams near intermediate supports, it is recommended that the builder use small radii of curvature for prestressing tendons above supports and for additional longitudinal reinforcement in the lower third of the cross section, especially in the case of T-beams.

PUBLICATION#C710335

Copyright © 1971, The Aberdeen Group
All rights reserved