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State-of-the-Art Report on Temperature-Induced Deflections of Reinforced Concrete Members

By ACI Committee 435

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Synopsis: This report summarizes available methods for calculating deflections of reinforced concrete beams subjected to temperature change. Selection of design temperatures and temperature gradients is discussed as well as the effects of cracking on response in the service load range.

Keywords: beams (supports); cracking (fracturing); deflection; modulus of elasticity; moments of inertia; reinforced concrete; temperature; thermal gradient.

The full report appears in the *ACI Manual of Concrete Practice,* Part 3. ACI 435.7R-85 is available as part of *Deflections of Concrete Structures, SP-86.* An abstract of SP-86 was published in the ACI JOURNAL, *Proceedings,* V. 82, No. 4, July-August 1985.

INTRODUCTION

Temperature changes can significantly affect deflections of reinforced concrete building structures. Deflections occur in unrestrained flexural members when a temperature gradient is set up between opposite faces of the member. In cases where deformations due to temperature change are restrained, tensile stresses induced in the member can result in cracking and consequent reduction in flexural stiffness. Because temperature effects do not often affect the ultimate limit state of the structure, effects of temperature on deflection are sometimes not considered in design. However, it has been standard practice to compute thermal stresses and displacements in structures for tall building design. Also, elongation and shortening of bridge superstructures and precast concrete structures are normally computed for support and expansion joint designs.

De Serio (1) states that "Designing for thermal and shrinkage stresses is the most neglected part of today's design practice." With the use of higher strength materials and more refined methods of analysis the need to consider temperature effects is becoming increasingly important.

Most general purpose computer programs have the capability to include temperature changes in the analysis for certain types of members. However, in many cases, particularly those involving relatively simple structures, where computer analysis is not required, or where the computer program does not include the capability for analysis of flexural members subjected to temperature gradient, calculations may be required to investigate the effect of temperature change on serviceability.

The objective of this report is to indicate some of the problems that can result from differential thermal movement and to outline procedures for calculating deflections that result from temperature change. The scope of the report is restricted to performance of structures in service. Temperature effects due to heat of hydration are not considered.

SERVICEABILITY PROBLEMS RELATED TO DIFFERENTIAL THERMAL MOVEMENT

The following examples illustrate potential problems that can result from differential thermal movement in building structures.

Office building - cantilever roof and floor slabs. Daily temperature changes caused deflections of about one inch at the cantilever ends of roof slabs in a four-story building constructed of cast-in-place concrete. The post-tensioned floors and roof were 80 feet by 80 feet in plan. Only four columns were provided and these were 48 feet apart in each direction which resulted in the columns being 16 feet from the edges of the floor and roof slabs in each direction. During construction it was noted that diurnal solar heating caused the roof slab to deflect up and down. The change in elevation was about one inch at the extreme overhanging ends. Fortunately the detail for the connection of the windows, which were located in the perimeter of the floors and roof, provided for sufficient movement that the windows remain attached to the roof when it is its highest position and does not result in the window becoming loaded when the roof is in its lowest position.

Industrial building - cantilever roof slab. Similar temperature-induced movements caused damage at the joint between a cantilever roof slab and exterior wall in a one-storey building that was erected using the lift-slab technique. The post-tensioned waffle roof slabs had significant overhangs at all four exterior walls. The exterior walls were constructed using the tilt-up method. Because of the construction techniques used, the roof was not supported vertically by the exterior walls and the connection of the exterior walls (for horizontal loads) was made when the edges of the roof were in a low position due to the effects of diurnal solar heating. During service the effect of solar heating has been to apply vertical loads to the exterior walls. This has resulted in the vertical cast-in-place concrete closure pours between the wall panels, particularly at the corners of the building, to crack and disintegrate near their bottoms with the passage of time. Reconstructing the destroyed concrete does not solve the problem; it simply disintegrates again. Eventually, attempts to reconstruct the disintegrated concrete were abandoned and steel plates, painted to match the color of concrete, were placed on the affected joints to cover the damage and improve the appearance of the building.

Parking structure - deflection of double tee beams. In a precast parking structure, rotation at bearing ends of beams resulting from deflections caused by diurnal solar heating produced cracking near the ends of the beams. The precast prestressed double-tee beams span about 55 feet. A concrete topping was placed over the top of the double-tee beams. Reinforcing steel was placed in the topping at interior joints in a configuration similar to that used with negative moment reinforcement in cast-in-place construction. At some locations elastomeric bearing pads were placed between the stems of the double-tee beams and their supports; at others, elastomeric bearing pads were not provided under the stems. Measurements showed the deflection caused by diurnal solar heating to be of the order of 0.75 inches at midspan of the double-tee beams. The deflection due to solar heating caused rotations at the ends of the double-tee beams and many of the double-tee beam stems, not provided with elastomeric bearing pads, cracked as a result of the rotation.

Office building - vertical wall panels. Exterior precast wall panels two stories high were supported at the bottom and supported laterally at the top of the second storey. In some locations the panels were placed adjacent to wall construction supported laterally at the top and bottom of the second storey. Seasonal temperature changes caused bowing of the two storey panels resulting in mid panel deflections up to 3/4 in. Relative deflection between the two-storey panels and adjacent walls supported at the bottom of the second storey caused damage to the