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OCCURRENCE OF CRACKING IN CONCRETE BUILDINGS

REPORT TO STANFORD LINEAR ACCELERATOR CENTER - ABA No. 79

STANFORD UNIVERSITY SUBCONTRACT S-136

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An inspection was made of the cracks in the concrete in the Test Laboratory and the Administration and Engineering Buildings. The majority of the cracks can be attributed to drying shrinkage of the concrete, but in a few instances in each building the cracks follow a pattern which could be attributed to foundation settlements which occurred as additional loading was applied during construction. There is no evidence of differential foundation settlements which would jeopardize the structural integrity of either building.

Conventional reinforced concrete design tacitly accepts cracking of concrete to the extent that all tensile loads are carried by the reinforcing steel and the concrete is depended on only for compressive loads. Conventional design techniques for concrete slabs with ground support utilize the tensile strength of the concrete but anticipate cracking and aim at prelocating the cracks along straight line patterns so as to avoid the unsightliness of random cracking.

The past status of the local concrete industry was such that complete avoidance of cracks was not possible and control of cracks by conventional techniques was seldom attained. More recently a definite trend is underway to make a much more determined effort to avoid concrete cracking without an unreasonable increase in costs.

<u>Causes of Cracking</u>

Many factors interact to produce cracks in concrete structures. Basically, a crack results any time the tensile stress in the concrete exceeds its tensile strength. Tensile strength of concrete increases with time in a manner similar to the compressive strength, hence, the early ages when tensile strength is not fully developed are especially critical for development of cracks. Tensile stresses are produced by dead and live loads on the structure, and by resistance to drying and thermal shrinkage of the concrete.

Creep in concrete has an effect similar to plastic flow whereby the strain for a given stress increases with time. Surprisingly, there is a creep recovery upon release of stress somewhat similar to the elastic strain recovery. The creep recovery, like the original creep, occurs over a considerable time interval when compared to the elastic strains which are essentially instantaneous. The modulus of elasticity of concrete increases with time and is roughly proportional to the compressive strength. Both creep and elastic strains therefor exhibit a hysteresis effect upon release of sustained loads. The complete recovery of elastic and creep strains for a given stress is less than the original elastic and creep strains because of the intervening increase in the modulus of elasticity. This effect is especially noticeable at early ages when the modulus of elasticity is increasing at a relatively rapid rate.

Any improvements aimed at reducing cracks in concrete must essentially be aimed at reducing drying shrinkage and thermal shrinkage or their effects.

Drying shrinkage results from drying of the concrete and is recoverable if the water content is restored. Permanent maintenance of saturated concrete in a building is obviously impractical, hence, some drying shrinkage is unavoidable in building concrete.

The amount of drying shrinkage is primarily influenced by the following factors:

(1) Type of aggregate- Local Bay area aggregates produce concrete with moderately high drying shrinkage. Available "low shrink" aggregates produce concretes with approximately 1/2 the drying shrinkage of concrete produced by local aggregates.

(2) Type of cement - ASTM Types I and III cause more drying shrinkage than Type II. There are also differences between brands for a given type, and the quanitity of gypsum added during grinding of the clinker has a noticeable effect.

(3) Amount of Water - The higher the unit water content of the concrete mix, the higher the shrinkage. High slumps require more water and, hence, produce more shrinkage. High concrete mix temperatures produce a faster slump loss and, hence, require more water for the same degree of placeability. Smaller maximum sizes of aggregates require more mixing water and, thus, produce more shrinkage. Excessive mixing grinds the aggregates to smaller sizes and therefore requires more mixing water.

(4) Admixtures - The effect of admixtures varies from none to substantial increases in drying shrinkage. Air entraining agents have little effect in normal dosage. The effect of water reducing agents is variable. The gypsum content of the cement appears to influence their effect and the effect of a given agent will sometimes vary between different brands of cement. Tests with the actual concrete ingredients used appear to be the only reliable criteria. Although total shrinkage might not be increased, the shrinkage sometimes occurs at an earlier age when a water reducing agent is used.

Theoretically, it should be possible to place the concrete for a structure at a reduced temperature, and control its temperature rise during the entire period of drying so that the expansion from temperature rise always matched the drying shrinkage. Under such a scheme, no drying shrinkage or thermal stresses would exist in the concrete even if the concrete were fully restrained. Complete control of temperature is obviously impractical.

The temperature of a building normally flucuates through daily cycles during the construction period which are similar to the ambient air variations. When exposed to sunlight, however, the day time range will be considerably higher than the ambient air.

Although concrete in a building is not fully restrained, the effects of subgrade friction, reinforcing steel, and steel framing members are such that the concrete is essentially restrained. Almost all drying shrinkage is therefore evidenced as tensile stress unless relieved by cracking. Any reduction in drying shrinkage is thus a reduction in cracking tendency.

Thermal effects are more complex in their action. The temperature of the concrete at the time of initial hardening determines what might be called the temperature of neutral length. Higher temperatures induce compression stresses in the concrete and lower temperatures produce tension. An initial temperature in the lower range of anticip ted temperature cycles is thus desirable so that subsequent temperature changes will not tend to produce high tensile stresses. Temperature rises, especially at the early ages, have the effect of raising the temperature of neutral length or causing shrinkage of the concrete. This occurs because of the hysteresis effect previously mentioned. Complete "elastic" recovery of the creep which is induced by the stress resulting from the temperature rise is less than the creep which originally occurred because the modulus of elasticity was undergoing an appreciable increase during the same time interval.

Proposed Corrective Action

Concrete building construction to date has demonstrated that conventional . On subsequent project building construction, the following additional measures are proposed:

(1) Use "low shrink" aggregates. This measure alone will reduce the total drying shrinkage to 1/2 the drying shrinkage of concrete produced by local aggregates.

(2) Provide cooling of concrete mix. A low initial temperature tends to reduce the detrimental effects of subsequent "thermal shocks" and drying shrinking by providing the concrete with a lower "neutral" temperature. This results in initial thermal stresses being primarily compression rather than tension.

(3) Use Type II cement. Drying shrinkage is reduced by the use of Type II cement and strength gain is almost as rapid as with Type I.

The first two measures will involve a slight premium cost for the building concrete. With on-site production facilities already available for the accelerator housing concrete, however, the premium cost is estimated at not more than 5% of the in-place cost of the concrete. The added cost of cooling the concrete mix is partially offset by the increase in concrete strength which permits a lower cement content for the same design strength.

A precise level program will be initiated to measure typical footing settlements on subsequent buildings. This program will determine to what degree differential settlements contribute to concrete cracking on these buildings. The effect of elastic foundation settlements aiding the promotion of cracks in slabs on grade can be minimized by leaving an unbonded joint between the slab and all footings. This also destroys the membrane action of the slab in tieing the footings together for added earthquake resistance. In this area the added membrane action is considered more important than the effect on ground slab cracking, hence, it is proposed that the doweling of ground slabs to the footings be continued.

It should be kept in mind that even though the above procedures should greatly reduce cracking of concrete, some cracking will probably still occur.