U. S. Department of Agriculture
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Design Note No. 5*

Subject: Some Comments on Flexural and Anchorage Bond Stresses

National Engineering Handbook, Section 6 establishes, subject to certain modifications, the American Concrete Institute Standard "Building Code Requirements for Reinforced Concrete" as the basic design code for reinforced concrete in the Soil Conservation Service. See NEH-6, 4.2 Design Codes and Criteria. There has been some question concerning the background, interpretation, and effect of the first sentence contained in ACI Code section 1301(c).

The chapters on bond in the latest revision of the ACI Code (ACI 318-63) contain an important shift in the philosophy of providing for bond. The terms "flexural bond" and "anchorage or development bond" have been introduced. Flexural bond stress is a function of the rate of change of moment with respect to distance along the span, that is, shear. Anchorage bond stress is the average bond stress between a point of peak bar stress and the end of the bar where the stress is zero.

In members in which the longitudinal tension steel is parallel to the compression face, the nominal flexural bond stress for the tension steel at any section is given by

$$u = \frac{V}{\Sigma o \; jd}.$$

Critical sections for flexural bond stresses for tension bars occur where the rate of change of moment is greatest or where the steel perimeter is least, or both. For simple spans, critical sections are at the faces of supports. For continuous spans: for negative steel, critical sections are located at faces of supports and at locations where bars terminate; for positive steel, critical sections are at points of inflection.

Although the above relation is exact for the conditions assumed in its derivation, i.e., beam of constant depth and constant longitudinal steel made up of equal bar sizes all in one layer, the relation is more idealistic than realistic. Flexural bond stress distribution is actually much more complex than the above relation suggests. The distribution is also affected by bond concentrations and complications arising from such things as the usual assumption that concrete takes no tension, the flexural and diagonal tension cracking of concrete, the presence or absence of web reinforcement, and the cutting off or bending of longitudinal bars across the web of the beam. Thus, it has long been recognized that many

*Prepared by Edwin S. Alling of the Design Unit, Design Branch, Hyattsville, Maryland bond stress calculations with the flexural bond stress formula are not very factual.

Flexural bond stresses also exist between concrete and longitudinal compression steel. However, such stresses are not critical and need not be considered in design. Flexural bond stresses for compression steel are low because the change in total compression between any two sections is shared between the concrete and the steel.

If a reinforcing bar in a beam has enough embedment in concrete, it cannot be pulled out of the concrete. The minimum embedment length necessary to develop, by bond, a given bar force, $T = f_s A_s$, is

$$L = \frac{f_s A_s}{u\Sigma o} = \frac{f_s D}{4u}.$$

If the actual length of a bar, from any point of given steel stress to its nearer free end, is equal to or larger than the above minimum length (called development length or anchorage length), the bar will not fail by bond. For instance, if the given steel stress is equal to the yield stress, the bar would fail by yielding of the steel, rather than by bond failure. This is true even though localized bond slips occur in the immediate vicinity of flexural or diagonal tension cracks. Permissible bond stresses have been established, in large part, by beam tests which simulate actual conditions, in preference to the formerly more prevalent bond pullout tests.

Anchorage bond stress, calculated as though it were uniform over the embedded length of a bar, is a function of bar force and bar length and is not determined directly by shear. A reinforcing bar may be developed, or anchored, in a region of tension or a region of compression or partially in both. For instance, negative steel over the support of a continuous member may be partly developed in the region of negative moment and partly developed in the region of positive moment by extending the steel beyond the point of inflection. Thus, for longitudinal steel in flexural members, a main requirement for safety against bond failure is that each bar be provided anchorage length adequate on both sides of every section. If the embedment length is insufficient, special anchorage must be provided to ensure adequate bond strength.

In the past, as a general rule, nominal flexural bond stresses were limited by design so that allowable values were not exceeded at any section. Currently however, in the light of questions regarding the validity of flexural bond stress computations and an increased dependence on anchorage bond stress, nominal flexural bond stresses that are locally higher than allowable are permissible by ACI 318-63. According to the Code, if sufficient anchorage length is provided to reduce the anchorage bond stress to not more than 0.8 times the usual (specified) allowable value, flexural bond need not be considered. Thus, the necessity of checking flexural bond stresses may be avoided, according to the Code, if anchorage lengths are provided that are nowhere less than

$$L = \frac{f_s D}{4(0.8u)}.$$

It should be noted that the necessary anchorage length for tension bars is proportional to the square of the bar diameter since the allowable bond stress is inversely proportional to diameter. This indicates the superiority of small diameter bars, as compared to large diameter bars, from the viewpoint of bond. The use of small bars requires shorter anchorage lengths and a larger number of bars and thus minimizes difficulties in bond.

Experience has shown that the practice of providing reinforcement perimeter, Σo, sufficient to satisfy flexural bond stress requirements produces satisfactory structures under the environmental conditions encountered in Soil Conservation Service hydraulic installations. Provision of adequate perimeter, Σo, to control flexural bond stress often results in additional steel over that required by area, A_s. This additional steel serves to distribute and limit the cracking of the concrete and hence to increase the durability of a structure. Further, it should be recognized that the ACI Code provides for minimum requirements and is oriented toward building frames with their more controlled environment rather than toward hydraulic structures. Hence, it is concluded that the practice of holding flexural bond stresses within allowable limits should be continued. This conclusion is subject to review at such time as further satisfactory experience in neglecting flexural bond is reported in the literature to the profession.

The above considerations explain why National Engineering Handbook Notice 6-2 was recently issued. The notice modifies NEH-6 to remove the option in treatment of bond that existed as a result of the 1963 revision of the ACI Code.

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