SIGNIFICANCE OF ALLOWABLE STRESSES IN PRESTRESSED CONCRETE AND GUIDELINES FOR COMPLIANCE[1]

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1 – BACKGROUND

Major building codes predict the initiation of cracking in concrete, and control of crack width through "computed" tensile stresses at the extreme fiber of the member. In the general case, the extreme fiber tensile stress is calculated using the gross cross sectional parameters of the member, even when a section is deemed to have cracked. Presence of reinforcement in sharing the actions on the concrete section, and thereby reducing the tensile stresses is generally not accounted for. Simply, for code compliance, the extreme fiber stress is "computed," using the following relationship:

$$f = (P/A + M/I * c) \qquad \text{(Exp 1-1)}$$

Where

- f = Computed extreme fiber stress;
- P = axial force;
- A = gross cross-sectional area of concrete section;
- M = applied moment;
- I = second moment of area, and
- c = distance from the centroid of the section to the extreme tension fiber.

The computed stress neither represents the value at the tip of a crack, nor is it the average stress on the section. It is referred to as "hypothetical" stress, used as an indicator for the expediency and type of remedial measure, if any.

2 – EXTRME FIBER STRESS AND CRACKING

For sections similar to those shown in Fig. 2-1, cracking initiates when the extreme fiber stress (f_t) exceeds the cracking stress of concrete. Once cracked, the computed crack width is generally obtained through several parameters of the section, such as stress in reinforcement, distance of crack location to the next bar, bar diameter, and more. The relationships commonly used are detailed in other ADAPT Technical Notes. The focus of this Section is the application of the computed tensile stress in practice.

Figure 2-1 identifies two of the parameters.

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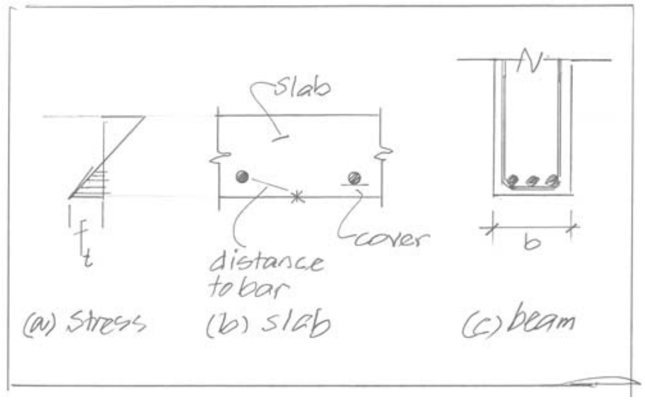


FIGURE 2-1 Identification of Several Parameters Governing Crack Width

3 – SIGNIFICANCE OF COMPUTED CRACK WIDTHS

The credibly of the computed crack widths depends on (i) the accuracy with which the tensile stress (f_t) at the point of interest is evaluated, and (ii) among other parameters, the distance between the point selected for evaluation and the first reinforcement (Fig.2-1).

When dealing with a beam stem, as shown in Fig. 2-1c, the parameters for crack control can be estimated fairly well. The bending moment at a section along a beam results in a uniform tensile stress across the bottom fiber of the beam. Further, the known value of a beam's width and the number of bars in the beam stem, lead to a reasonably good estimate of the farthest distance of a point on the soffit to the nearest rebar. The same is not true for floor slabs. In common construction, neither the stress at a point, nor the distance of a point on slab surface to the first reinforcement can be reliably estimated. The following explains.

A – Distribution of Stress in Slabs

Figure 3A-1 illustrates a panel from a column supported floor system and the associated distribution of bending stress across a section at face of supports. Observe that the stress varies significantly over the tributary of each column support. The degree of variation depends on the geometry of construction and the distribution of loads.

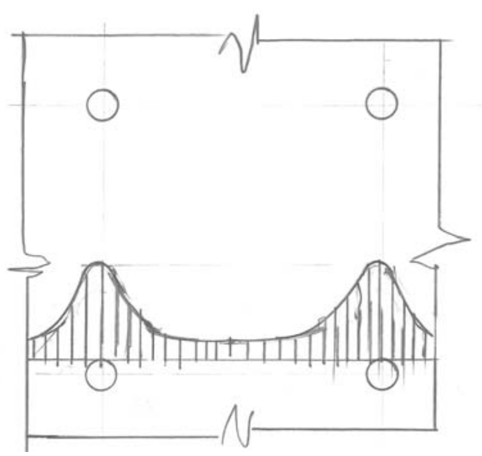


FIGURE 3A-1 Distribution of Flexural Stress Across a Section at Face of Support

Schematics of Fig. 3A-2 illustrate qualitatively the distribution of bending stress across a design section for different support widths. The figure includes both the variation of the actual stress and the associated hypothetical value for code compliance.

Note in part (c) of the figure, where the support line extends over the entire width of the design strip, the distribution of stress at the face of support is uniform. For this condition, the hypothetical and the actual stresses are of the same value. This reflects the scenario of a "one-way" system. On the contrary, where width of support is small (part (a)), the maximum stress is much higher than the hypothetical value of the design section. For dimensions common in construction, the maximum stress can be more than 2.5 times the hypothetical stress calculated for code compliance. This scenario is representative of the "two-way" systems of construction.

On account of large difference between the hypothetical and the actual value of stress at a point in two way systems, the outcome of crack width computations should not be evaluated with engineering judment. The same is not true for one-way systems, since the hypothetical and actual stresses are not far apart.

The preceding adds credence to ACI-318's recommendations for stipulating a higher allowable hypothetical tensile stress for one-way systems, coupled with provision to exceed the threshold, provided crack formation and its impact are recognized and allowed for.

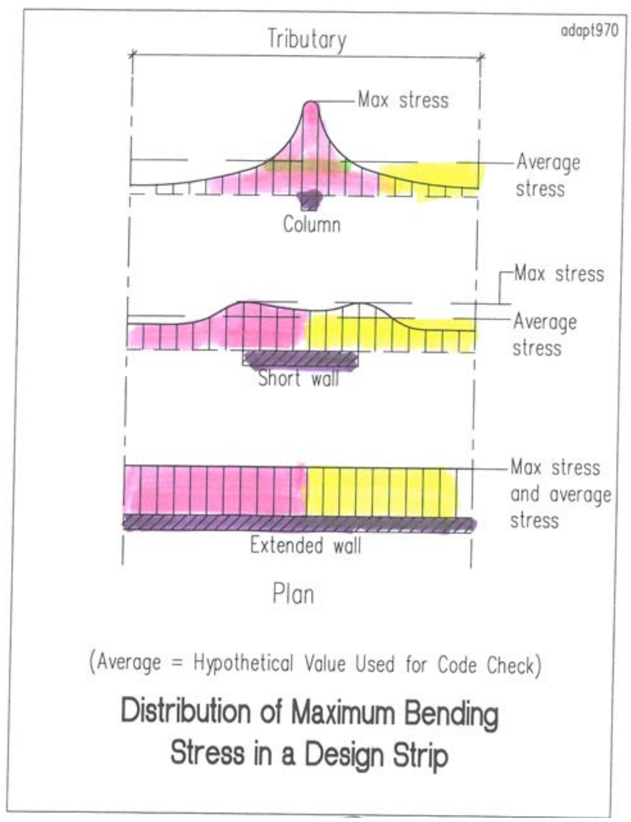


FIGURE 3A-2 Variation of Flexural Stress Across a Design Section with the Width of Support

B – Distribution of Reinforcement

In column supported floor systems, the distance from a probable point of crack formation on a slab surface to the nearest reinforcement is highly unpredictable, since the distribution of reinforcement is not uniform over the support tributary. Figure 3B-1 illustrates two construction views of two-way floor systems. Accuracy of the computed distance of a point on slab surface from nearest bar at construction is questionable. Yet, the distance is a parameter that determines the probable width of crack at the location.

(a) Unbonded slab

(c) Grouted slab construction

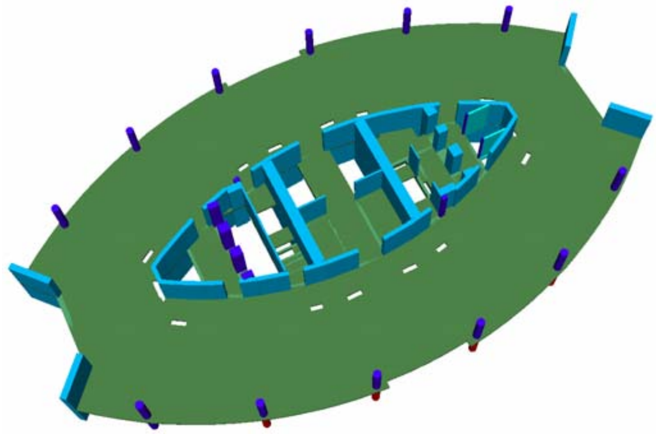
FIGURE 3B-1 Views of an Unbonded and Grouted Construction
Bars are not Uniformly Spaced

FIGURE 3b-2 Construction of a One-Way System, Where Bars are More Uniformly Spaced

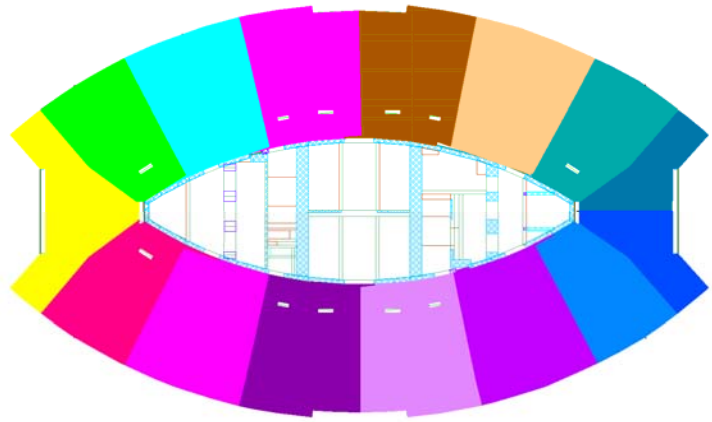
The lack of accuracy in predicting the distance from a computed point on a slab soffit to the nearest reinforcement in the prototype construction, is another reason why computation of crack width for two-way systems has to be evaluated with engineering judgment.

4 – APPLICATION OF ALLOWABLE STRESSES FOR CODE COPLIANCE

Consider the floor system shown in Fig. 4-1. It is a typical upper level of a building tower featuring a core wall at center and column supports at perimeter. Design strips in the radial direction are shown in part (b) of the figure.



(a) Floor view



(c) Radial design strips

FIGURE 4-1 Floor System of a Multi-Story Building and its Radial Design Strips (KSA)

The distribution of extreme fiber stress for the selected radial design strip is shown in 4-2.

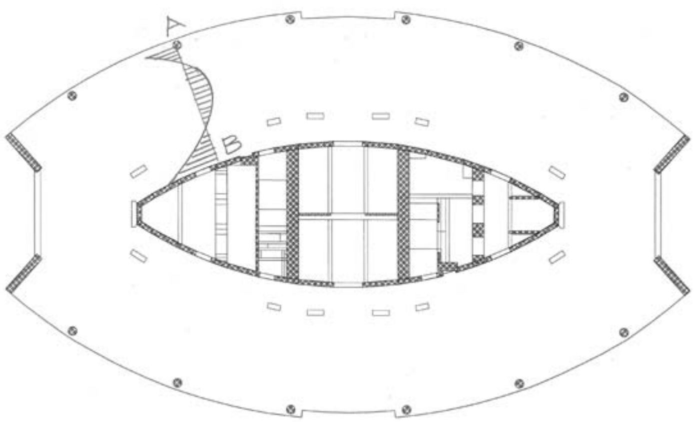


FIGURE 4-2 Distribution of Extreme Fiber Stress Along a Typical Radial Design Strip

Referring to the diagram of stress distribution for different support widths (Fig. 3A-2) and the application of the allowable stress values, it is evident that at connection to the core wall (point B), the one-way allowable stress values apply, whereas over the column support (point A) the two-way values should be used. This is an instance, where within the same design strip, both conditions of one-way and two-way are present. Using ACI-318, there will be no upper limit for the value of computed stress at the core wall, if deflections are calculated and evaluated using cracked sections. However, there will be a maximum threshold value at the face of the column, using the two-way criterion.