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Autor: Breen, John E. / Frantz, Gregory C.

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IX

Side Face Crack Control for Large Concrete Girders

Contrôle de la fissuration latérale de grands ponts en béton

Kontrolle einer seitlichen Rissbildung bei grossen Stahlbetonträgern

JOHN E. BREEN
Professor of Engineering
University of Texas
Austin, TX, USA

GREGORY C. FRANTZ
Assist. Prof. of Civil Engineering
University of Connecticut
Storrs, CT, USA

SUMMARY
This paper summarizes an experimental and analytical study of the proper control of side face cracking near middepth on very large concrete members. Very wide web cracking occurred on bridge members, although the crack width at the level of main reinforcement was acceptable. Efficiency of various reinforcement distribution methods are compared and a design procedure is suggested which is shown to control the cracking.

RESUME
Ce rapport résume une étude expérimentale et analytique sur le contrôle de la fissuration latérale au milieu de grands ponts en béton. De larges fissures d'âme se sont produites sur des poutres d'un pont, quoique la profondeur des fissures au niveau des armatures principales soit, acceptable. Différentes méthodes de distribution d'armature sont comparées en ce qui concerne leur efficacité et un plan d'action est suggéré pour le contrôle de la fissuration.

ZUSAMMENFASSUNG
Diese Abhandlung fasst eine experimentelle und analytische Studie über eine angemessene Kontrolle der seitlichen Rissbildung an sehr grossen Betonbalken zusammen. Sehr weite Stegrisse traten an Brückenbalken auf; die Rissweiten waren jedoch annehmbar auf der Höhe der Hauptbewehrung. Die Wirksamkeit von verschiedenen Bewehrungsmethoden wird verglichen und ein Entwurfsverfahren vorgeschlagen, welches das Rissbild kontrolliert.

1. INTRODUCTION

This paper summarizes a detailed investigation of several large reinforced concrete highway bent cap girders which were found to have very wide cracks near middepth on the side faces (see Fig. 1). Although the crack width at the level of main reinforcement was acceptable, the side face cracks near middepth were up to three times as wide, indicating potential durability problems. [1]

2. EXPERIMENTAL STUDY

Laboratory models accurately reproduced the crack pattern and crack widths to scale, as shown in Fig. 2. From this figure, the crack width near midheight of the web can be seen to be approximately three times that at the level of the main (top) reinforcement. A series of 44 specimens was used to investigate variables such as amount and distribution of side face reinforcement, cover, web width, and beam depth. The major effect of the skin reinforcement in controlling the width of side face cracking is in encouraging the distribution of closely spaced deep cracks, such as shown in Fig. 3 (a), which can be contrasted to the relatively few deep cracks and large number of branching cracks shown in Fig. 3(b), in a similar specimen with no skin reinforcement. The effectiveness of skin reinforcement in controlling the wide cracking was dramatically shown in Fig. 4, in which a modest amount of skin reinforcement decreases the crack magnification ratio (the ratio of maximum crack width on the side face to crack width at the main reinforcement level) from approximately 4.0 to approximately 1.8.

3. DESIGN PROCEDURES

A relatively simple two-dimensional finite element analysis was developed and the results of this study generally confirm the laboratory results. This analysis was used for studies such as looking at the effect of skin reinforcement distribution in a given cross section (see Fig. 5).

Based on the test results and analytical studies, a new design procedure was developed to control side face crack widths and was simplified for code usage. To verify the new design procedure, the original model bent cap which had experienced a serious side face cracking problem was redesigned and tested. This test indicated that the new design procedure worked quite well, as shown in Fig. 6. The crack magnification ratio was reduced from approximately 2.5 in the original design to a value of 1.2 in the redesign. This was done with usage of the same amount of reinforcement in the two specimens, but with improved distribution.

4. CONCLUSIONS

The major conclusions from this study are:

(1) Specimens with the prescribed AASHTO and ACI amounts of side face crack control reinforcement had side face cracks that near middepth were well over twice as wide as cracks at the main reinforcement level.

(2) Providing a relatively small amount of side face (or skin) reinforcement significantly reduced the side face crack widths and the crack magnification ratio. As the provided area of skin reinforcement increased, the side face crack width increased, but at a decreasing rate.

(3) Skin reinforcement affected only a narrow strip of concrete along each side face of the web. The effectiveness of the skin reinforcement in controlling crack widths on the side faces was independent of web width in series of otherwise identical specimens.

(4) Without any skin reinforcement a "tree branch" crack pattern developed where several of the cracks originating on the extreme tension face curved and joined together to form one wide crack extending into the web. As the area of skin reinforcement increased, this crack pattern gradually changed to one where more cracks remained vertical and extended further down into the web, resulting in smaller crack widths near middepth. Modification of the crack pattern is one of the principal benefits from using skin reinforcement.

(5) The amount of skin reinforcement can be expressed as a skin reinforcement ratio based on the area of skin reinforcement divided by the edge strip area of concrete affected by the skin reinforcement. These edge strips are symmetrical about the skin reinforcement along each side face with a width defined as twice the distance from the center of the skin reinforcement to the side face and a height defined as the distance from the centroid of the main reinforcement to one bar spacing beyond the skin reinforcement bar farthest from the main reinforcement.

(6) Both the laboratory tests and the finite element analysis indicated it was most effective to place the skin reinforcement as many distributed small bars rather than as a few large bars. Generally, bars evenly distributed along each side face in about one-half to two-thirds of the tension zone closest to the main reinforcement were adequate. To ensure effective distribution, the maximum spacing of these bars should be the smaller of d/10 or 12 in.

(7) As the beam tension depth increased, the side face crack width increased, and the ratio of skin reinforcement required to maintain a maximum side face crack width also increased.

(8) The following skin reinforcement design provision will control such cracking:

> <u>Distribution of Skin Reinforcement</u>. If the depth, d, exceeds 36 in., longitudinal skin reinforcement shall be uniformly distributed along the side faces of the member over the one-half of the depth nearest the principal reinforcement. The proportion of such reinforcement, ρ_{sk}, is the ratio of the total area of skin reinforcement to the sum of the area of strips along each side face, each strip having a height of d/2 and a width of twice the distance from the center of the skin reinforcement to the side face but not more than one-half the web width. For d between 36 and 100 in., $\rho_{sk} \geq 0.00024(d - 30)$, and for d greater than 100 in., $\rho_{sk} \geq 0.011 + 0.000058d$, with d expressed in inches. The maximum spacing of the skin reinforcement shall be the smaller of d/10 or 12 in.
>
> Such reinforcement may be included in strength computations if a strain compatibility analysis is made to determine the stresses in the individual bars or wires.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

1. Frantz, G. C. and Breen, J. E., "Control of Cracking on the Side Faces of Large Reinforced Concrete Beams," Research Report 198-1F, Center for Highway Research, The University of Texas at Austin, September 1978.

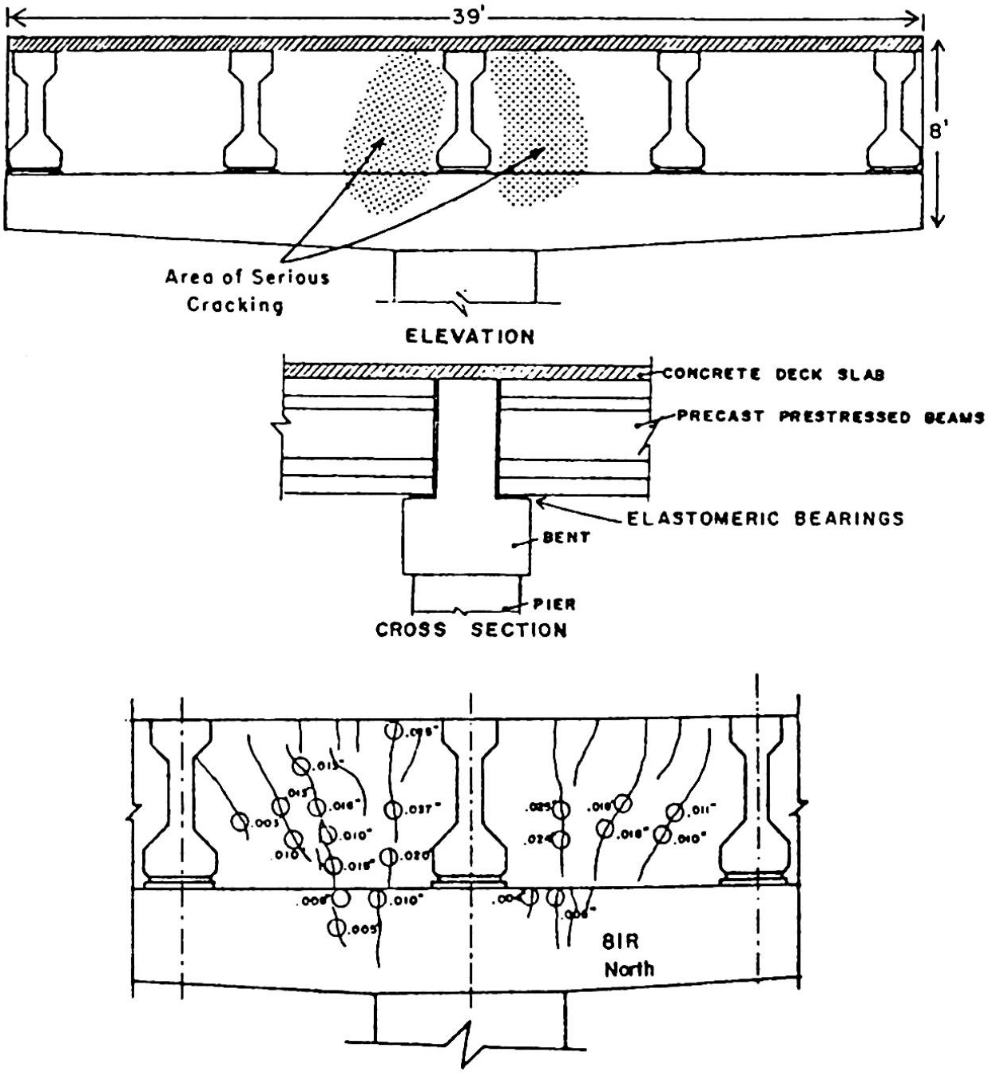

Fig. 1 Crack patterns and crack widths in the bent caps

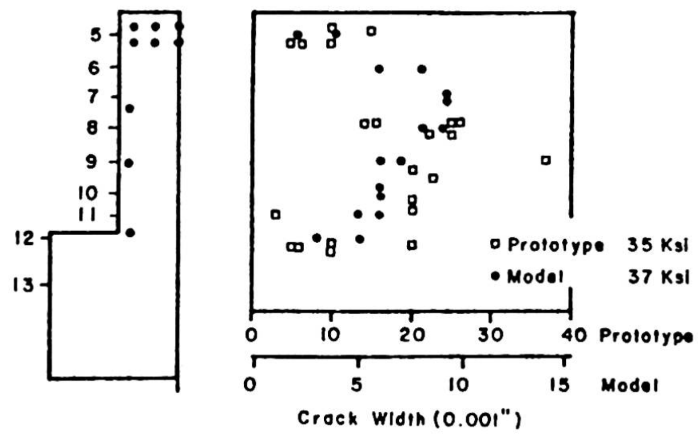

Fig. 2 Comparison of crack widths in prototype and model bent caps, scaled to S_L

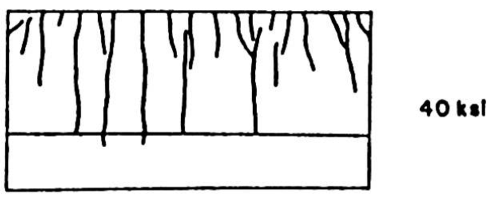

Fig. 3(a) Crack pattern development of A-5 (skin reinforcement = eight #3 bars)

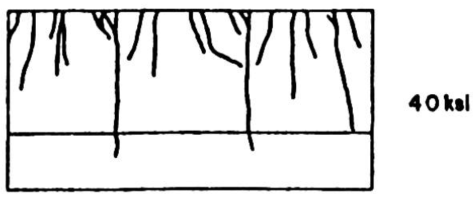

Fig. 3(b) Crack pattern development of A-2-0 (no skin reinforcement)

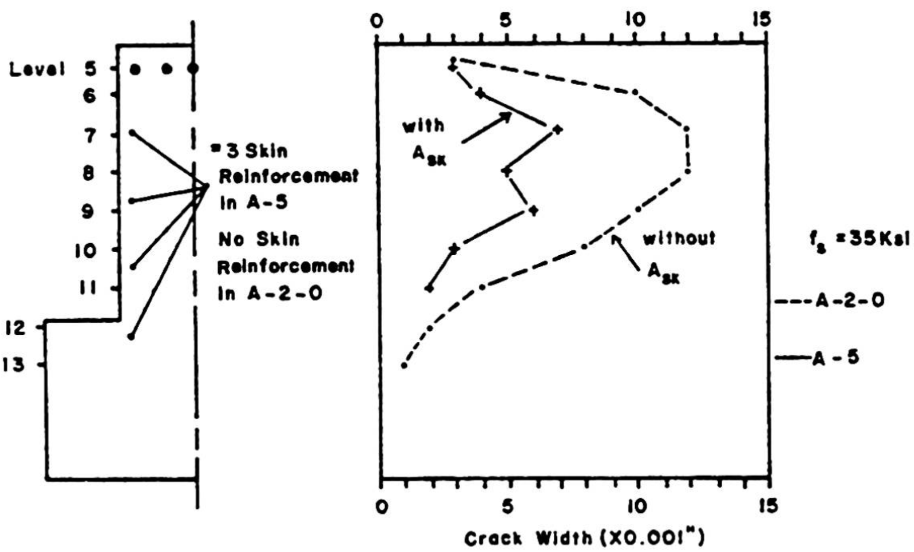

Fig. 4 Crack profile of a single crack in A-2-0 and A-5

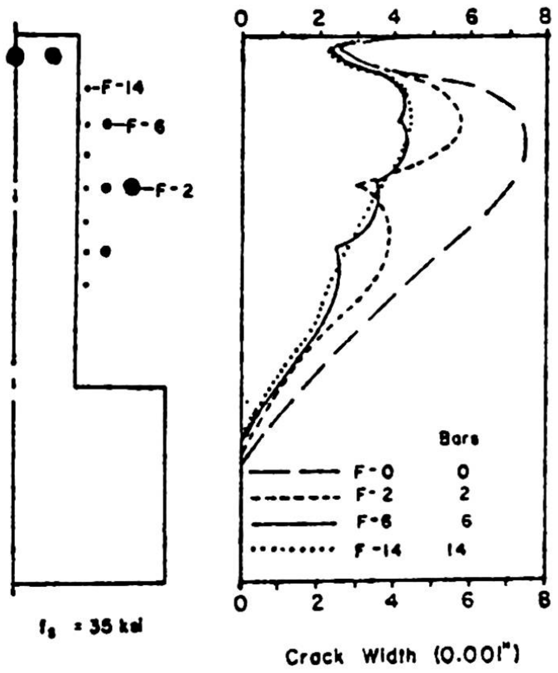

Fig. 5 Effect of skin reinforcement distribution with constant A_{sk} (0.88 sq. in.)

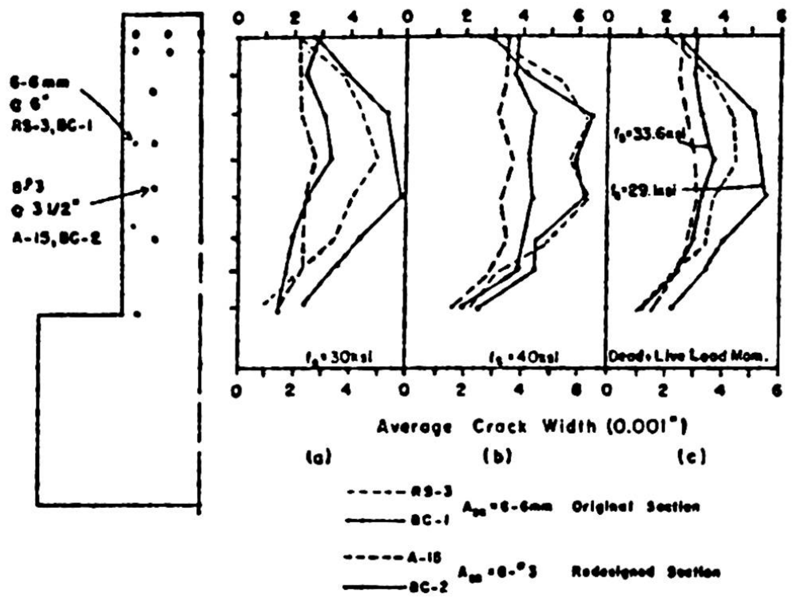

Fig. 6 Crack profiles--original and redesigned model bent caps