DISCUSSION

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Behavior and Design of Multistory Building Frames of Unbonded Post-Tensioned Concrete. Paper by James E. Waller and John E. Zimmerman

Discussion by Kenneth B. Bondy and Alan H. Mattock

By KENNETH B. BONDY

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The authors seem to have confused externally applied forces with internal resisting forces, resulting in statically incorrect conclusions. The errors in the article can be demonstrated by considering the statics of an indeterminate member. Consider the indeterminate prestressed beam shown in Fig. A.

The beam is loaded with some external factored load W, and has reactions R_n at supports n which include both the elastic reaction to the load W and the secondary reactions caused by prestressing (with a load factor of unity). Consider, in Fig. B the freebody diagram of the portion of the beam to the left of Section A-A.

In Fig. B M_{ext} is the moment acting at Section A-A which equilibrates all of the other loads, i.e., it is the applied moment due to external loads and it includes the secondary moment (which is produced by the secondary reaction R_{sec} at the left support). It is the statically correct ultimate moment for which the section must be designed. It furthermore is precisely the ultimate design moment specified by the ACI Building Code. The authors of the article feel that the Building Code is nebulous and indefinite and vague in dealing with this subject. It appears to me that the code is clear and merely requires that the designer conform to statics in calculating strength design moments. In any event, the external moment M_{ext} produces a set of internal resisting stresses on Section A-A that are illustrated in Fig. C

where

$$C = F_{pt} + F_r \quad (13)$$

and

$$M_{ext} = F_{pt}j_{pt} + F_rj_r = M_{resist} \quad (14)$$

Contrary to the author's statements, Eq. (14) is statically correct no matter where the tendon force F_{pt} is located, even if it is in the compression zone. In that case the moment strength of the section will be reduced since the tension and compression resultants will be close to each other; however, the calculation of the resisting moment will nonetheless be correct. Depending upon which side of the compression resultant it is located on, the prestress force may actually reduce the section capacity.

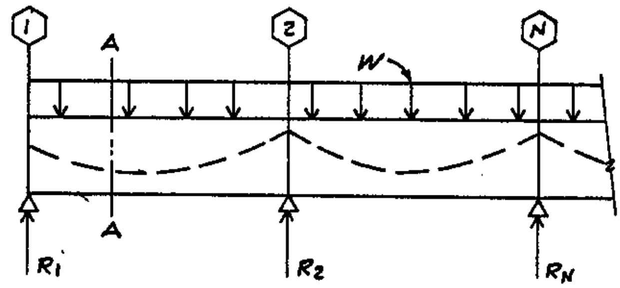

Fig. A

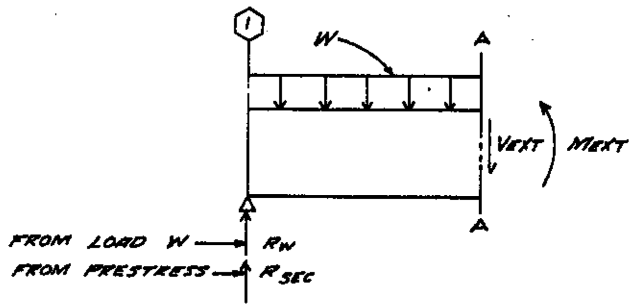

Fig. B

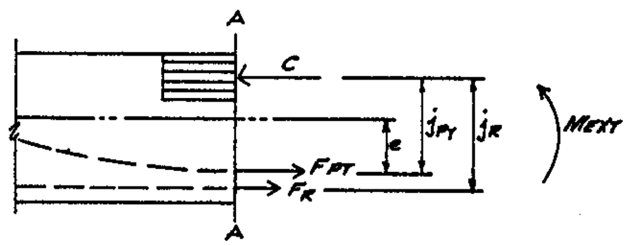

Fig. C

The authors state that "The ultimate resisting moment which results (from ACI) is identical to the sum of the ultimate resisting moment considering only the mild steel reinforcement and the primary post-tensioning moment . . . ." The rest of the authors' sentence is unclear but it seems to say that the depth of the compression zone should consider the effect of the tendon force and that the primary moment should be re-

*See also discussion in March-April 1986 ACI JOURNAL, p. 320.

duced to effective tendon stress levels. In equation form, the author's theory states

$$M_{ext} = F_{pt}e + F_r j_r \qquad (15)$$

where e is the distance between the tendon cgs and the concrete cgc (used to calculate the primary prestress moment).

A comparison between the authors' Eq. (3), which the authors assert as being true, and Eq. (14), which was developed by the principles of statics, shows that the authors' theory of mechanics is only correct in the accidental case when $e = j_{pt}$. This gives the authors the benefit of doubt that the prestress force *Fpt* is the same in both equations. They seem to imply that it is not [i.e., that the tendon force in Eq. (3) should be at effective rather than ultimate stress level]. If this is the case, their theory is even more inaccurate.

In general, I believe the preceding has demonstrated that the authors' theory of strength design for indeterminate prestressed members is statically incorrect and could result in serious errors in predicting strength design moments for such members. The ACI Building Code method, on the other hand, conforms to statics and is analytically correct. Further, the subject ACI code provisions have been shown to be correct experimentally.

As a final point, it should be noted that Chapter 9 of ACI 318-83, including Section 9.2, applies to prestressed concrete frames. If the factored load combinations of Section 9.2 indicate a reversal of moment (one causing tension on the side remote to the tendons) then reinforcement must be provided for that condition. There is, therefore, no need for any additional code provision or code clarification to assure the safety of post-tensioned frames with unbonded tendons under lateral loads.

By ALAN H. MATTOCK

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The authors have provided a thought-provoking discussion of the behavior and design of unbonded post-tensioned concrete frames. However, I believe they are mistaken in their condemnation of the sections of the ACI Building Code that relate to the design of continuous prestressed concrete structures.

The authors develop their equations for the required prestress force and tendon sag from basic principles of mechanics. Unfortunately, their proposals for the design of post-tensioned frames for ultimate conditions and their criticism of the relevant Building Code sections are not developed in a similar manner, but are based on unsupported assertions. This makes reasoned discussion difficult. I believe that their wrong conclusions arise primarily from a confusion of internal and external force effects in member sections.

Section 18.10 of the Building Code applies to all continuous prestressed concrete structures, bonded and unbonded, if it is applied correctly. Section 18.10.3 specifies the required moment strength at any section, that strength to be calculated taking into account all the internal forces acting in that section, including the effect of the force in the prestressing tendons. If the moment strength of the section calculated in this way is greater than the sum of the moments specified in Section 18.10.3, then the section will not fail when the structure is subjected to the specified factored external and dead loads. This is so even if the loading combination results in the prestressing tendon cgs being in the flexural compression zone at ultimate.

The design moments specified in Section 18.10.3 are the moments due to external loads (including self weight) acting on the structure, modified by the influence on compatibility of deformations at ultimate of the prestressing tendon forces. The amount of the modification is equal to the secondary moment caused at the time of prestressing, and for simplicity is expressed in this way in Section 18.10.3. This effect was demonstrated in tests of continuous unbonded prestressed concrete beams[5] and has also been discussed at length elsewhere.[6]

The authors state that the ACI Building Code "recognizes . . ., by omission of any statement to the contrary, that primary post-tensioning moments are not diminished at ultimate loading." This is an incorrect inference. Section 18.10.3 is quite explicit as to what moments are to be considered as acting on the section under consideration. The local effect of the force in the prestressed reinforcement is to be included in the calculation of the resisting moment of the section. The same end result is not obtained by adding the primary prestressing moment to the applied moments and then designing the unprestressed bonded reinforcement to resist the resulting moment; even if the depth of the equivalent rectangular stress distribution is adjusted to allow for the effect of the prestressing force acting on the section. The authors do not support their assertion to the contrary by any systematic development based on mechanics.

The authors include an example of the application of their proposal in the appendix to their paper. Unfortunately they do not follow through with detailed calculations of strength which would result from using the two approaches to design, for this section subject to reversal of moment. The discusser has worked backward from their figures (assuming that the units of the moments listed were kip-ft) and has derived a section which could correspond to the given moments, i.e., $M_D = -30$ k-ft, $M_L = -20$ k-ft, $M_w = +20$ k-ft, and a primary prestressing moment $Fe = +30$ k-ft.

It was assumed that the concrete strength is 4750 psi and that under $PS + DL + LL$ the maximum allowable stress at the top of the section is $6\sqrt{f'_c} = 414$ psi tension, and at the bottom of the section is $0.45f'_c = 2138$ psi. It was found that a 6 in. wide by 14 in. deep section is satisfactory, if it is provided with a prestress-