T-BEAM FLANGE WIDTH

By

G. CHACOS

POST-TENSIONING INSTITUTE ®

Authorized reprint from: July 2006 issue of the PTI Journal

T-BEAM FLANGE WIDTH

GREGORY P. CHACOS, P.E.

ABSTRACT

This paper presents the influence of variations in flange widths of T-beams on final stresses. Also discussed are requirements of ACI 318 on shrinkage and temperature reinforcement in one-way slabs between the flanges of adjacent T-beams. Recommendations are given for determination of flange widths for common applications.

KEYWORDS

flange width; shrinkage and temperature reinforcement; T-beams.

PTI Journal, V. 4, No. 1, July 2006. Received and reviewed under Institute journal publication policies. Pertinent discussion will be published in the next issue of the PTI Journal if received within 3 months from the publication.

1.0 INTRODUCTION

A matter of concern for many engineers is the appropriate width of flange to be used for prestressed T-beams. (This paper deals specifically with cast-in-place post-tensioned beams.) Section 8.10, T-beam construction, in ACI 318-05[1] states that the width of an interior T-beam for non-prestressed construction shall be the least of 16t + b, ¼ beam span, or the beam spacing. Section 18.1.3 excludes the requirements of Section 8.10 for prestressed beams, but a recommendation for the effective width of a flange is not given. Section 7.12.3 permits the use of prestressing steel (tendons, in this discussion) as a substitution for rebar if the average compression induced by the shrinkage and temperature (SH&T) tendons is at least 100 psi in the slab between the edges of the assumed T-beam flanges.

ACI 318 does not prohibit the use of 16t + b for the effective flange of prestressed beams—it simply gives the designer the option to select another width. The number of SH&T tendons is determined by the distance between the edges of adjacent flanges. It is not mandatory that tendons be used for SH&T reinforcement, but if tendons are not used then minimum SH&T rebar shall be used in accordance with Section 7.12.2, with a maximum spacing of 18 in.

The issue comes down to determination of the correct effective width, if, indeed, there is a correct width. This paper presents the results of calculations that use different flange width criteria to evaluate the influence of flange width on critical stresses for gravity loads.

2.0 PREVIOUS PTI PUBLICATION

Aalami[2] discussed the effective width concept for dealing with shear lag in T-beams in PTI's *Technical Notes* #1. He mentions that some engineers use an effective width of 24t + b, and goes on to propose that the extreme fiber stress at midspan should be determined by using the T-beam properties for calculating the flexural stress, but the precompression should be that due to all tendons, those in the beam and those for SH&T, divided by the gross, full width area. While there is sound logic to this approach, it is not in keeping with custom and practice and is not mandated by ACI 318.

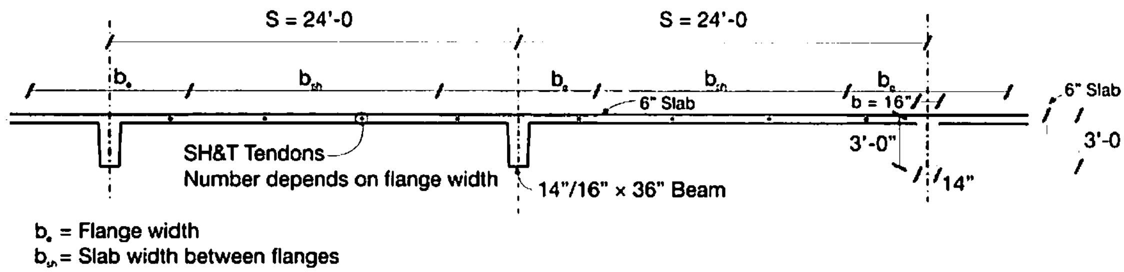

Fig. 1 – Example Beam and Slab Dimensions

A review of the early mathematical studies of this problem, summarized by Aalami, reveals that the theoretical flange width is not constant and varies with the nature and distribution of the loads as well as the proportions of the beams and slabs. In general the effective flange will be relatively wide for uniformly loaded, simple span beams of proportions used by current beam and slab parking structures. However, concentrated loads will reduce the effective flange width, as will loads that are non-uniform along the beam. While uniform loads are assumed for design purposes, most live loads are delivered as concentrated loads. There is no way to accurately define the effective flange width, or to estimate the way it changes along the span while dealing with partial and concentrated loads, so it is reasonable to be relatively conservative.

It has been found that even with multiple spans on stiff columns the critical flexural tension stress will not occur under negative moments, rather it will occur under positive moments at the bottoms of beams. This is important for durability considerations. A target net tension of $9\sqrt{f'_c}$ is used for a 50 psf live load, criteria consistent with this writer's practice for the design and evaluation of many structures. This is a satisfactory design criteria, even in severe exposure conditions, since a beam designed in this manner for a live load of 50 psf results in a net flexural tension stress under a live load of 20 psf (a realistic load for commercial parking structures) well below the modulus of rupture stated by ACI 318 to be $7.5\sqrt{f'_c}$. The general criteria for the design example is given below.

3.0 DESIGN EXAMPLE CRITERIA

The dimensions of the beam, slab, and columns used for the design example are shown by Figures 1 and 2.

The example beam resembles one that might be used in a parking structure, and is treated as such for this paper. However, it should be pointed out that this beam geometry is not typical for cast-in-place post-tensioned parking structures. The dimensions were selected to illustrate the decisions that need to be made concerning the width of the effective T-beam and the SH&T tendons A single span beam on relatively long columns is used to maximize flexural tension at the bottom of the beam at midspan.

a. Tendons are ½ in. 7-wire strand, 270 ksi, unbonded
b. Concrete compressive stress f'_c = 5000 psi at 28 days
c. Effective tendon force = 26.5 kips for beam tendons and for SH&T tendons
d. Target net flexural tension is $9\sqrt{f'_c}$, based on the effective T-beam properties
e. The modulus of rupture is taken to be $7.5\sqrt{f'_c}$. Members with net flexural tension less than $12\sqrt{f'_c}$ are classified as Class U or T and can be analyzed with uncracked properties, per ACI 318-05 Section 18.3.4.

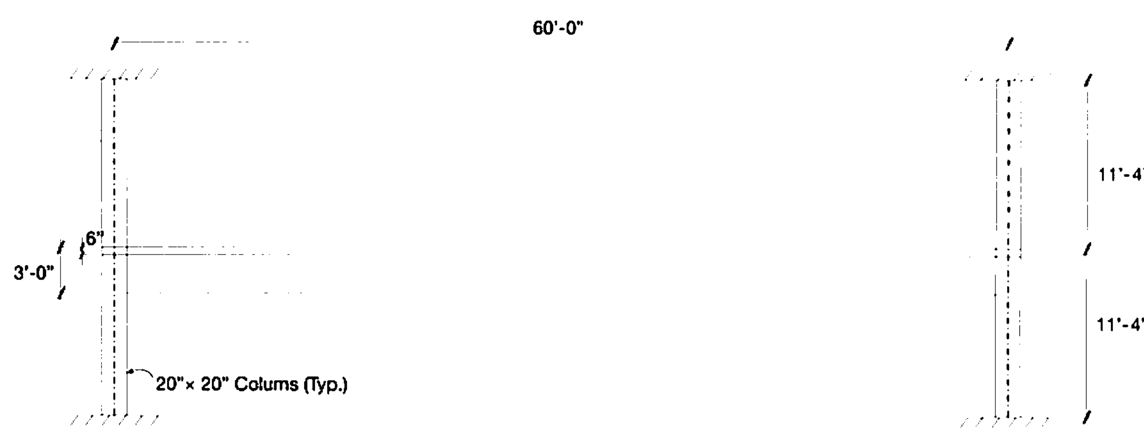

Fig. 2 – Example Beam Elevation

f. The effective compression induced by the SH&T tendons in the in the SH&T slab width shall be a minimum of 100 psi. (No maximum.)
g. Gross area = 2178 in^2 for all cases
h. Critical flexural tension is at the bottom of the beam at midspan.
i. Effective T-beam section properties are those calculated from the area and section modulus (bottom of beam) of the beam stem and the effective flange width.
j. Design live load = 50 psf, checked for realistic service load of 20 psf

The PTData for Windows computer program by Structural Data, Inc. was used for the basic calculations. These were augmented by hand calculations for the stresses using a combination of effective T-beam flexural stresses with the average compression given by all tendons in a tributary width.

4.0 SUMMARY OF RESULTS

Table 1 is a tabulation of calculated stresses for beams using flanges of 16t + b and 24t + b. The driving factor in these designs is a target net allowable tension of $9\sqrt{f'_c}$. The number of tendons in the beams came out to be about 15.4; this was rounded down to 15.0 tendons to use a realistic value. The net flexural tension was allowed to increase because of this, but the increase in stress is relatively small. The number of beam tendons required comes out about the same for effective flanges of 16t + b, 24t + b, or the full tributary width. The rebar required for strength is approximately the same for all cases, but the minimum rebar varies significantly. For the example beam, the minimum negative area steel is 3.0 in^2 for the 16t + b flange, 4.0 in^2 for the 24t + b flange, and 7.0 in^2 for the full tributary width flange. Minimum area requirements will govern for most cases.

5.0 DISCUSSION OF RESULTS

The following observations are made from a review of the results shown in Fig. 3:

- ITEM 4 shows that the 16t + b flange requires four SH&T tendons whereas the 24t + b flange needs three tendons. Either one is reasonable.
- ITEM 6 indicate that the critical net tension stress varies from 672 psi to 658 psi as the effective flange changes, which is a difference of about 2%. These stresses are determined from the effective T-beam properties.
- ITEM 7 shows net tension stresses that vary from 795 psi to 721 psi when calculated using the effective T-beam properties for flexural tension and the gross area and all tendons for precompression. A tensile stress of 795 psi is $11.2\sqrt{f'_c}$ calculated with the most conservative of assumptions, but this stress is still less than $12\sqrt{f'_c}$ and justifies using uncracked section properties. (ACI 318 Section 18.3.4.)
- ITEMS 8 and 9 show stresses calculated using 20 psf with the tendons selected from the 50 psf load cases. The critical cases vary from $4.0\sqrt{f'_c}$ to $5.8\sqrt{f'_c}$, comfortably below the cracking threshold of $7.5\sqrt{f'_c}$.

Table 1 – Summary of Analytical Results

Item	Description	16t + b Effective Flange	24t + b Effective Flange
1	Effective flange width for T-beam	9.33 ft	13.34 ft
2	SH&T slab width	14.67 ft	10.66 ft
3	Beam tendons (Pre-compression in effective T-beam)	15 tendons; 397 kips (289 psi)	15 tendons; 397 kips (282 psi)
4	SH&T tendons (Pre-compression in SH&T width)	4 tendons; 106 kips (100 psi)	3 tendons; 80 kips (104 psi)
5	Total tendons (Average-pre-compression in full width, on gross area)	19 tendons; 503 kips (231 psi)	18 tendons; 477 kips (219 psi)
6	Net flexural tension with effective T-beam properties (50 psf live load)	672 psi = $9.5\sqrt{f'_c}$	658 psi = $9.3\sqrt{f'_c}$
7	Net flexural tension using the effective T-beam properties for flexural tension and the average compression from all tendons on the gross area (50 psf live load)	795 psi = $11.2\sqrt{f'_c}$	721 psi = $10.2\sqrt{f'_c}$
8	Net flexural tension with effective T-beam properties (20 psf live load)	292 psi = $4.1\sqrt{f'_c}$	287 psi = $4.0\sqrt{f'_c}$
9	Net flexural tension using the effective T-beam properties for flexural tension and the average compression from all tendons on the gross area (20 psf live load)	415 psi = $5.8\sqrt{f'_c}$	350 psi = $4.9\sqrt{f'_c}$

There are no rigid rules for selecting an effective flange width. Some engineers use 16t + b because they believe an extra SH&T tendon is a good thing. Some engineers use half the beam spacing with the intuitive logic that the center half of the slab width should be actively precompressed. Others use wider effective flange widths, of which 24t + b seems a good choice. Flanges significantly wider than 24t + b serve no useful purpose and add significant rebar because of the minimum requirements.

Deflections for the example beams vary between 0.4 in. and 0.5 in. for net dead plus live load. This gives a span-to-depth ratio of about 1600, indicating that these beams are relatively stiff.

A two-span structure was run using the same dimensions used for the example cases. Twelve beam tendons were used with a flange of 16t + b. This required four SH&T tendons and gave an average precompression of 195 psi. The maximum bottom fiber tension was 643 psi ($9.1\sqrt{f'_c}$), and the maximum top fiber tension was 409 psi ($5.8\sqrt{f'_c}$). These results would be acceptable.

6.0 GENERAL DISCUSSION

Sooner or later someone will ask what the lowest average precompression should be. Much of the wisdom necessary to answer that question comes from observation of existing structures. It was my policy for many years to use a minimum average precompression of 175 psi for parking structures in severe exposure environments, and to use 150 psi for enclosed, non-severe exposure structures. These values worked well. Currently a more common value for severe exposure conditions is 200 psi, and the code minimum of 125 psi is used in some mild areas for protected structures.

The subject of effective flange width is not worthy of the expenditure of much time. Years of observation of parking structures has convinced me that flexural cracking is never a problem for properly designed members constructed reasonably well, no matter what width of effective flange was used. These structures perform well if shrinkage is addressed in the detailing. Shrinkage is the problem, not flexure, and using conservative values for allowable flexural stresses will not change that. Conservative stress values do nothing but increase the number of tendons in beams, thereby increasing the congestion problem at the anchorages. In addition, the average precompression is frequently increased above prudent values, thereby adding to the volume change problems.

The critical stresses are relatively insensitive to the width selected for the effective flange. There appears to be no need to determine the critical stresses using the average precompression method, as shown by ITEMS 7 and 9 on Fig. 3, although an occasional check might be comforting to some.

We must not forget that we are obliged to design for imaginary loads but are usually free to select allowable, also imaginary, stresses to deal with these loads. Live loads are stipulated by building codes but ACI 318 has generously permitted us wide latitude in selecting allowable stresses for the usual beam designs. It has been found that customary design practices produce structures free of flexural cracking even though we use simplified models. ACI 318 has all that a designer needs to produce an efficient structure, so long as the designer is willing to keep an open mind regarding code loads, allowable stresses, and average precompression. The use of tendons meeting the requirements of Section 7.12.3 for SH&T reinforcement is another of those customary practices that has served us well.

It is worth restating that SH&T reinforcement is required by Section 7.12 for the full width of the slab between the flanges regardless of precompression induced in the SH&T slab width by the beam tendons. This reinforcement can be welded wire, deformed bars, or tendons.

7.0 RECOMMENDATIONS

Determination of effective flange width is one of those things that lend itself to engineering judgment and, if we are lucky, common sense. A few minutes spent with a preliminary design of the most common beams and a calculation pad to evaluate a few trial widths is all that is required. The number of SH&T tendons needed to give reasonable coverage in the slab between the assumed flanges, and a desired average compression, will become obvious very quickly.

For those who need rules, I offer the following:

1. Let the net flexural stresses run between $7.5\sqrt{f'_c}$ and $12\sqrt{f'_c}$ for full design loads.
2. Select an effective flange width and use those properties for calculation of compression and flexural stresses.
3. Use SH&T tendons in accordance with ACI 318-05, Section 7.12.3.
4. Use one of the following criteria for the width of the effective flange:
   a. 16t + b, if you wish
   b. 20t + b (approximately), if you want the flange to be half the beam spacing
   c. 24t + b, because the numbers come out so nicely for many common cases
   d. Some variation of the above
5. Most important rule, in four parts:
   a. Pick a flange width!
   b. Go with it!
   c. Stick with it!
   d. Don't worry about it!

REFERENCES

1 *Building Code Requirements for Strucrural Concrete and Commentary*, ACI 318-05/318R-05, American Concrete Institute, Farmington Hills, MI, 2005.

2 Aalami, B. O., "Effective Width and Post-Tensioning," *Technical Notes*, No. 1, Post-Tensioning Institute, Phoenix, AZ, 1993.

Gregory P. Chacos *has over 40 years experience in structural design of prestressed concrete and has a special interest in post-tensioning. He currently maintains a consulting practice specializing in the investigation of structural problems, and is Chairman of PTI's Technical Advisory Board. He was a member of ACI Committee 318, Building Code Requirements for Structural Concrete, for 12 years, and was a member of ACI-ASCE Joint Committee 423, Prestressed Concrete, for 32 years.*