Welded Wire Reinforcement in Precast Double Tee Flanges

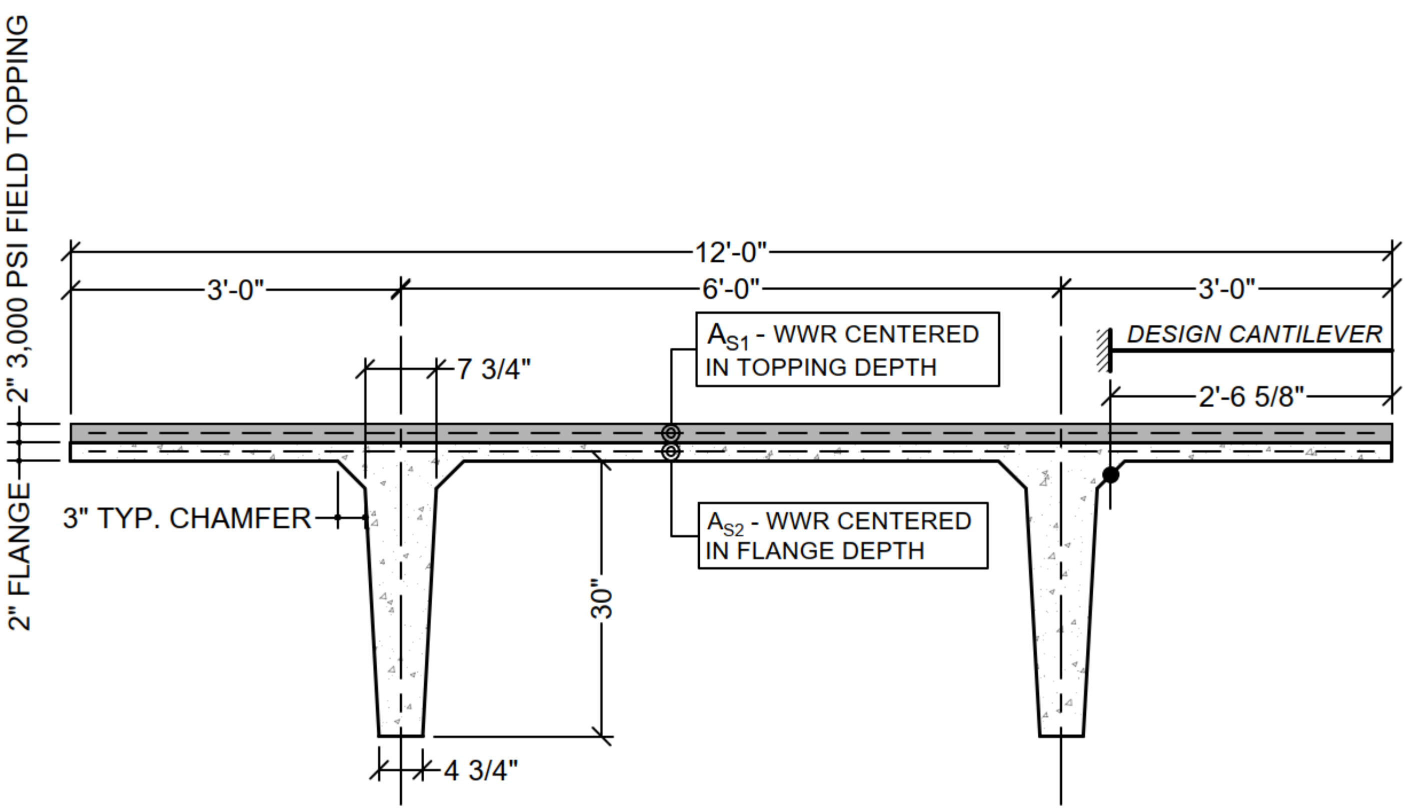
The use of welded wire reinforcement (WWR) in precast concrete double tee (DT) flanges for the purpose of flexural strength in the transverse direction is common practice in the precast concrete industry. This article provides various design examples for reader consideration. Examples include determination of WWR requirements in the following:

1. Field-topped DT with load-sharing
2. Field-topped DT without load-sharing
3. Pre-topped DT with load-sharing
4. Pre-topped DT without load-sharing

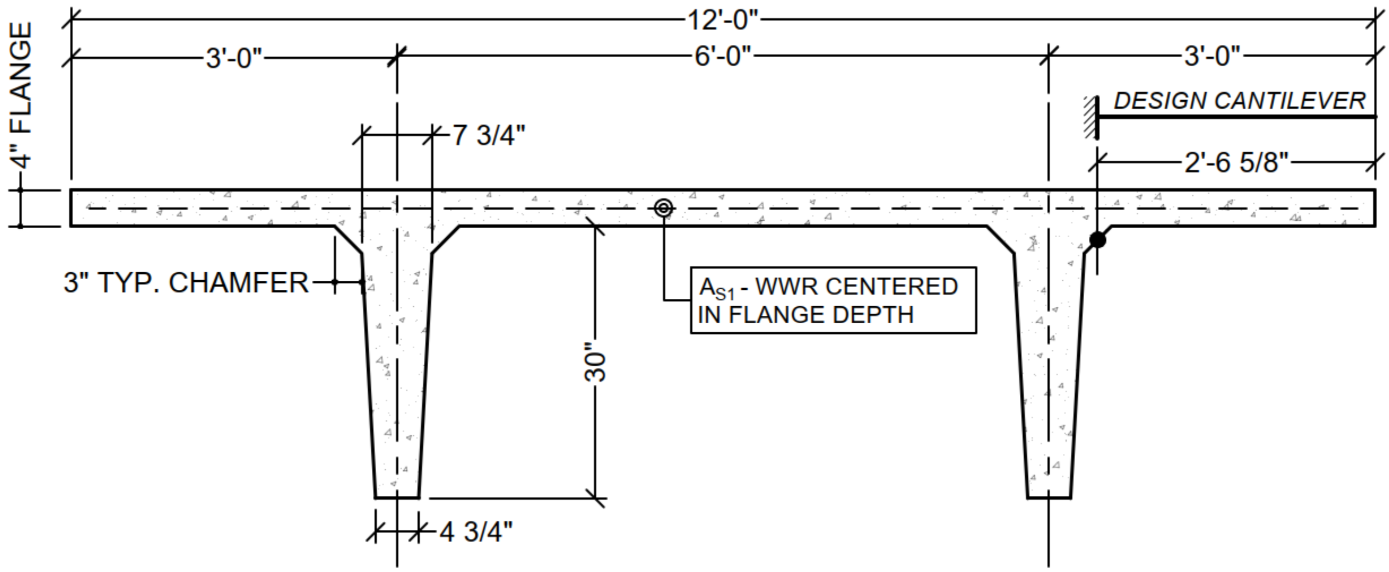
Superimposed live load to be considered in the transverse flexural design of DT members is outlined in the building code (for this article, we reference the 2021 Edition of the International Building Code):

> **Table 1607.1**: *For Garages with passenger vehicles only, the minimum uniformly distributed live load is 40 pounds per square foot (psf).*
>
> or
>
> **Section 1607.7**: *For garages restricted to passenger vehicles accommodating not more than nine passengers, 3,000 pounds acting on an area of 4.5 inches by 4.5 inches.*

For the four examples included herein, we will carry out design based on the following two DT geometries and compositions, focusing on the 3,000 pound concentrated live load:



5,000 PSI FIELD-TOPPED DOUBLE TEE

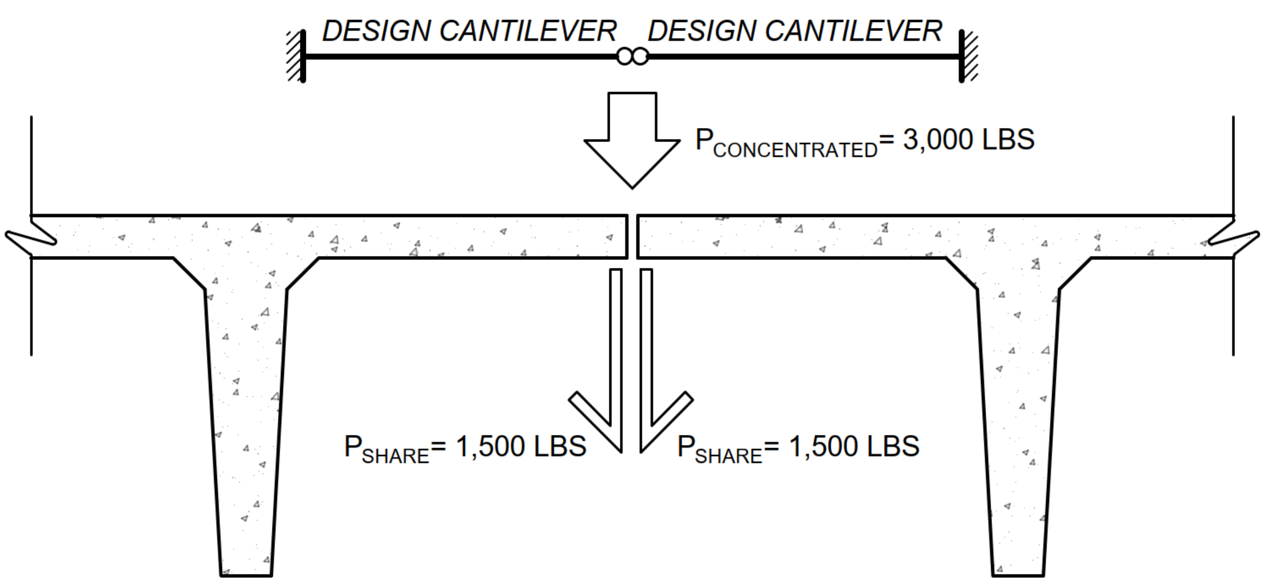


5,000 PSI PRE-TOPPED DOUBLE TEE

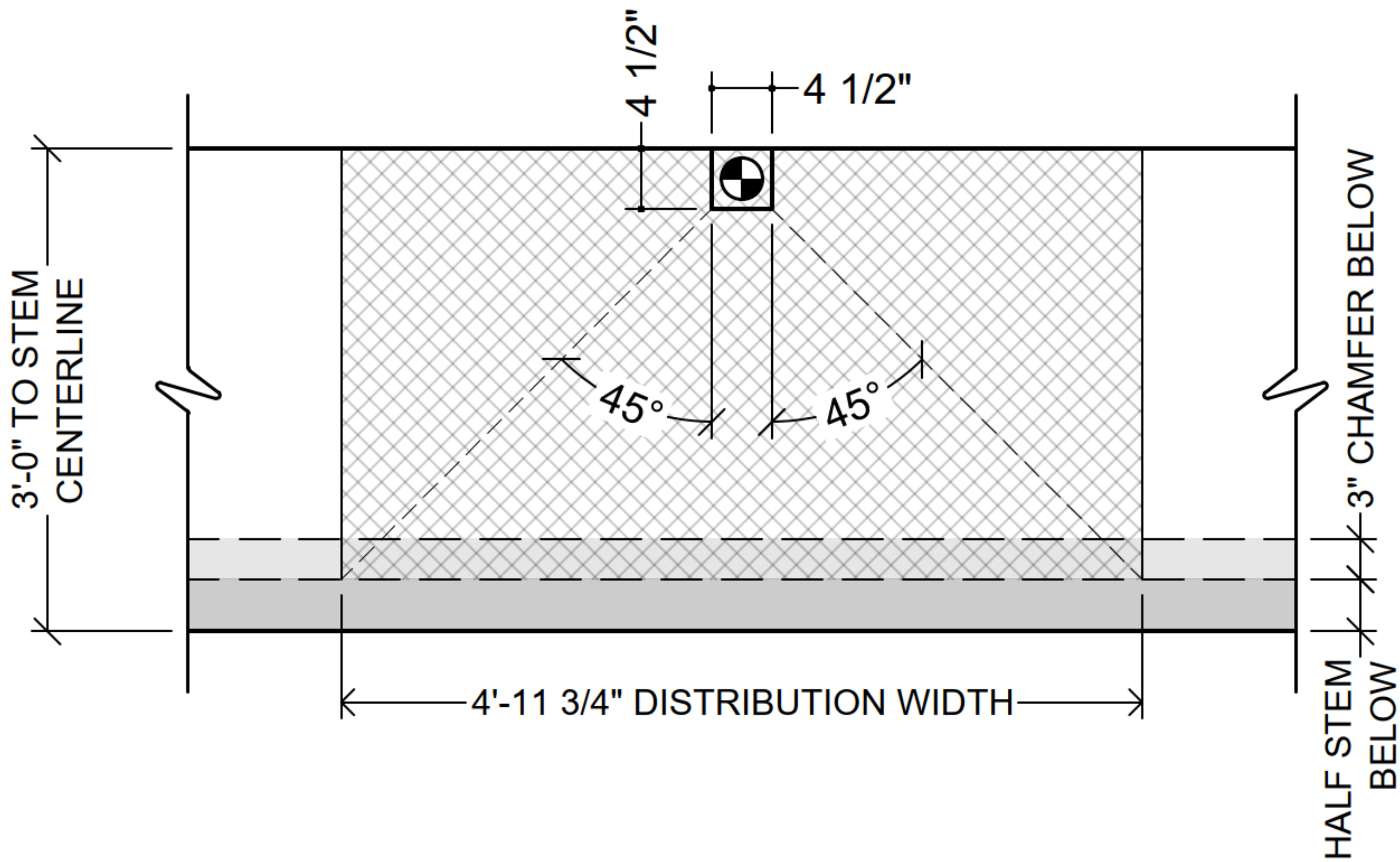
Note in the above diagrams that the "design cantilever" is defined as the cantilever segment of the DT flange, measured from the flange end to half the width of the illustrated chamfer. *A slightly more conservative approach would be to use a measurement extending to the face of the stem. Ultimately this is a matter of designer's judgment.*

Two important considerations in the derivation of DT flange reinforcement are as follows:

A. ***Are adjacent DT flange tips mechanically connected in a manner that can be relied upon to create vertical "load-sharing" between the two DTs*?** Conceptually, this would be two cantilever elements joined together at their tips by a hinge-like connection that has flexural discontinuity and shear continuity. If such a connection exists, then the diagram below reflects the distribution of loading to each cantilever end. If no such reliable mechanical connection exists, then a single DT cantilever flange must support the 3,000 pound concentrated load entirely.



B. ***What is the load distribution across the horizontal surface of the DT flange?*** Limiting the distribution of loading to the code-defined 4.5 inch x 4.5 inch surface area would be unnecessarily conservative. ACI 318-19 states in Section 4.12.1.5 that distribution of forces that act perpendicular to the plane of the precast members shall be established by analysis or test. In the absence of such tests, the definition of an appropriate distribution profile is a matter of engineering judgment. For this example we will use a horizontal distribution angle of 45-degrees relative to the loaded area, illustrated below in plan view, resulting in a 4'-11 3/4" distribution width.



With the above criteria established, the flexural designs are summarized below.

<u>Calculated maximum flexure in DT flange on distribution width</u>:

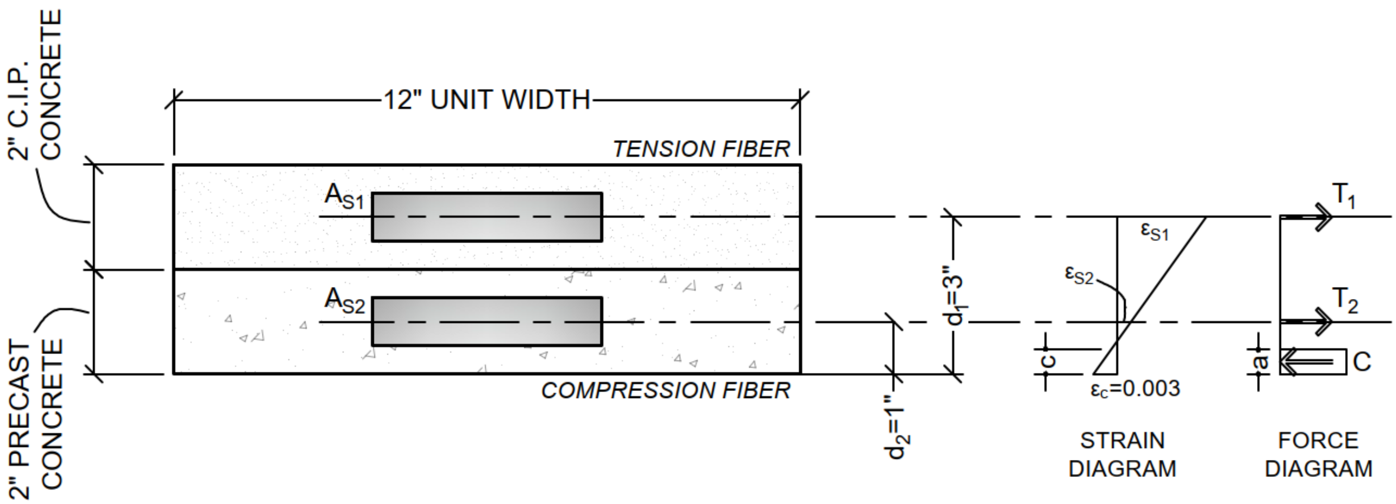
Dead Load P_{DL} = 150 pcf x 4" thickness x 1 ft / 12 inches x 4.98 ft x 2.552 ft = 636 lbs
Dead Load Moment M_{DL} = P x L/2 = 636 x 2.552 ft / 2 = 0.812 kip-ft

Live Load = P_{LL} = 3,000 lbs
Shared Live Load Moment $M_{LL,SHARE}$ = 3000/2 x 2.552 ft = 3.83 kip-ft

<u>Ultimate combined moment with load-sharing:</u>
$M_{U,SHARE}$ = 1.2(0.812)+1.6(3.83) = 7.1 kip-ft on a 4.98 ft distribution width
➔ **1.43 kip-ft on a 1-foot unit strip**

<u>Ultimate combined moment without load-sharing:</u>
$M_{U,NON-SHARE}$ = 1.2(0.812)+1.6(3.83 x 2) = 13.23 kip-ft on a 4.98 ft distribution width
➔ **2.66 kip-ft on a 1-foot unit strip**

For the field-topped DT, the cross-section, strain, and force diagrams are illustrated below:



WWR REQUIREMENT IN FIELD-TOPPED DT WITH LOAD-SHARING (Mu = 1.43 kip-ft / ft)

Calculations are carried out in accordance with ACI 318-19 using strain compatibility. Iteration was used to arrive at the "lightest" WWR solution. The representative iterations are summarized below, assuming a WWR yield strength of 80 ksi. A 1-foot unit strip of DT flange within the distribution width is analyzed. Field topping acts compositely with the DT precast flange.

CIP WWR PRECAST WWR	Strain in CIP WWR	Strain in PRECAST WWR	Neutral axis, c	ϕM_n
W1.4 @ 6" W1.4 @ 6"	0.079 in/in tensile	0.024 in/in tensile	0.1098 in	0.66 kip-ft
W2.9 @ 6" W2.9 @ 6"	0.037 in/in tensile	0.010 in/in tensile	0.2275 in	1.33 kip-ft
W4.0 @ 6" W2.9 @ 6"	0.030 in/in tensile	0.008 in/in tensile	0.2706 in	1.70 kip-ft
W4.0 @ 6" W2.1 @ 6"	0.035 in/in tensile	0.010 in/in tensile	0.239 in	1.62 kip-ft
W4.0 @ 6" W1.4 @ 6"	0.039 in/in tensile	0.011 in/in tensile	0.212 in	1.55 kip-ft

The selected reinforcement combination is shaded light green. Validation steps are shown below.

$$c = 0.212"$$

$$\varepsilon_y = \frac{80\ ksi}{29{,}000\ ksi} = 0.0028\ in/in$$

$$\varepsilon_{s1} = 0.003 \times \frac{d_1}{c} - 0.003 = 0.003 \times \frac{3}{0.212} - 0.003 = 0.0394\ in/in > \varepsilon_y$$

$$T_1 = A_s \times f_y = 0.08\ in^2 \times 80\ ksi = 6.4\ kips$$

$$\varepsilon_{s2} = 0.003 \times \frac{d_2}{c} - 0.003 = 0.003 \times \frac{1}{0.212} - 0.003 = 0.0111 \frac{in}{in} > \varepsilon_y$$

$$T_2 = A_s \times f_y = 0.028\ in^2 \times 80\ ksi = 2.24\ kips$$

$$C = 6.4\ kips + 2.24\ kips = -8.64\ kips\ (balancing\ compression\ force)$$

$$a = \frac{C}{0.85 \times f'_c \times 12"} = \frac{8.64}{0.85 \times 5 \times 12"} = 0.169"$$

$$M_n = C \times \frac{a}{2} + T_1 \times d_1 + T_2 \times d_2 = 20.71\ kip \cdot in = 1.72\ kip \cdot ft$$

$$\varphi M_n = 0.9 \times 1.72 = 1.55\ kip \cdot ft > M_u = 1.43\ kip \cdot ft$$

Finally, check minimum flexural steel per foot in accordance with ACI 318-19 Section 7.6.1.1:

$$A_{s,min} = 0.0018 \times A_g = 0.0018 \times 12 \times (2" + 2") = 0.0864\ in^2 < 0.08\ in^2 + 0.028\ in^2 = 0.108\ in^2\ \therefore ok$$

Note that because the DT is a prestressed concrete section, there is no explicit requirement for longitudinal shrinkage and temperature reinforcement.

Final selection:

- **6x6 W4.0/W4.0 (a commonly available “stock” size) in CIP topping**
- **6x6 W1.4/W1.4 (a commonly available “stock” size) in precast flange**

WWR REQUIREMENT IN FIELD-TOPPED DT WITHOUT LOAD-SHARING (Mu = 2.66 kip-ft / ft)

Calculations are carried out in accordance with ACI 318-19 using strain compatibility. Iteration was used to arrive at the “lightest” WWR solution (iterations are not shown here).

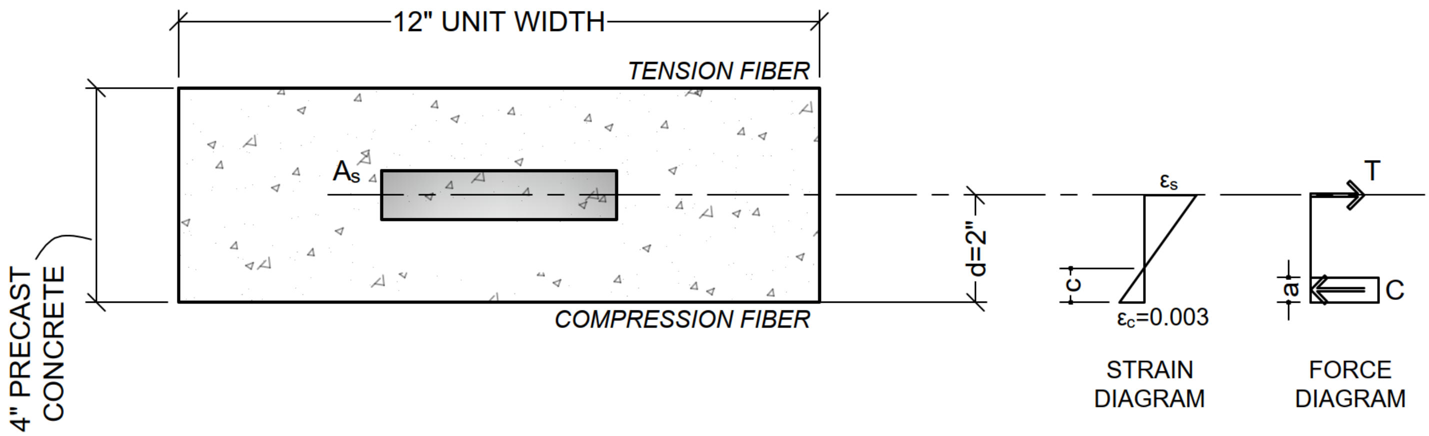
- WWR yield strength is 80 ksi.
- A 1-foot unit strip of DT flange within the distribution width is analyzed.
- Field topping acts compositely with the DT precast flange.

CIP WWR PRECAST WWR	Strain in CIP WWR	Strain in PRECAST WWR	Neutral axis, c	ϕM_n
W7.0 @ 6” W2.9 @ 6”	0.0202 in/in tensile	.0047 in/in tensile	0.388”	2.68 kip-ft

Final selection:

- **6x12 W7.0/W2.9 in CIP topping**
- **6x6 W2.9/W2.9 (a commonly available “stock” size) in precast flange**

For the pre-topped DT, which is characterized by the entire 4-inch flange thickness cast in the plant/yard and reinforced with one layer positioned mid-depth, the cross-section, strain, and force diagrams are illustrated below:



WWR REQUIREMENT IN PRE-TOPPED DT WITH LOAD-SHARING (Mu = 1.43 kip-ft / ft)

Calculations are carried out in accordance with ACI 318-19 using strain compatibility.

- WWR yield strength is 80 ksi.
- A 1-foot unit strip of DT flange within the distribution width is analyzed.

PRECAST WWR	Strain in PRECAST WWR	Neutral axis, c	ϕM_n
W7.0 @ 6”	.019 in/in tensile	0.275”	1.59 kip-ft

Minimum flexural steel per foot in accordance with ACI 318-19 Section 7.6.1.1 is satisfied.

Final selection:

- **6x12 W7.0/W2.9 in precast flange**

WWR REQUIREMENT IN PRE-TOPPED DT WITHOUT LOAD-SHARING (Mu = 2.66 kip-ft / ft)

Calculations are carried out in accordance with ACI 318-19 using strain compatibility.

- WWR yield strength is 80 ksi.
- A 1-foot unit strip of DT flange within the distribution width is analyzed.

PRECAST WWR	Strain in PRECAST WWR	Neutral axis, c	ϕM_n
W12.5 @ 6”	.009 in/in tensile	0.490”	2.70 kip-ft

Minimum flexural steel per foot in accordance with ACI 318-19 Section 7.6.1.1 is satisfied.

Final selection:

- **6x12 W12.5/W5.0 in precast flange**

The four DT design scenarios are shown below.

TYPE OF DT	DT LOAD-SHARING?	TRANSVERSE REINFORCEMENT AREA	TRANSVERSE REINFORCEMENT PROVIDED	ϕMn
FIELD-TOPPED	YES	0.108 in^2 cumulative	W4.0 @ 6" oc CIP W1.4 @ 6" oc PRECAST	1.55 kip-ft
FIELD-TOPPED	NO	0.198 in^2 cumulative	W7.0 @ 6" oc CIP W2.9 @ 6" oc PRECAST	2.68 kip-ft
PRE-TOPPED	YES	0.14 in^2	W7.0 @ 6" oc PRECAST	1.59 kip-ft
PRE-TOPPED	NO	0.25 in^2	W12.5 @ 6" oc PRECAST	2.70 kip-ft

Other considerations include:

- Only Negative flexure has been checked herein. A detailed design of double tee flange reinforcement should consider positive flexure in the "backspan" (i.e., that portion of the flange that spans *between* the stems) as well as in flanges that rely upon load-sharing and experience moment reversal due to propped cantilever behavior.
- Plain WWR is used in these examples, however deformed WWR is equally readily available.
- Selection of WWR style can vary on a case-by-case basis to suit the project and the designer. It is noteworthy that one of the most efficient methods of specifying flange WWR is to simply identify steel areas that are required by the design, in turn allowing the WWR detailer to furnish WWR styles that best balance structural design conformance with production-driven economy and availability.

For more information visit www.wirereinforcementinstitute.org.

References:

1. ACI Committee 318, "Building Code Requirements for Structural Concrete (ACI 318-19) and Commentary (ACI 318R-19)", American Concrete Institute, Farmington Hills, MI, 2019 (Reapproved 2022)

2. "2021 International Building Code", International Code Council, Inc., Country Club Hills, MI, 2020