

DISCUSSION

Strengthening of Existing Composite Beams Using LRFD Procedures

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Mr. Miller has presented an excellent method for strengthening composite steel beams. His method requires that there is sufficient headroom below the beam to accommodate a small WT section, or at least a cover plate. If no headroom is available the beam can be strengthened by means of cables placed on each side of the web. (Figure 1) The author found that the existing beam has a capacity of 360 ft. kips, and the required capacity is 466 ft. kips. The cable tension must provide a counter moment of $466 - 360 = 106$ ft. kips.

To be conservative, only the portion of the concrete above the 3-in. deck is used. Locate the elastic neutral axis, using $n = 9$. The effective width of the slab is $120/9 = 13.33$ in. Referring to figure one:

$$\text{Area of concrete} = 13.33 \times 3.25 = 43.33 \text{ in}^2$$

$$\text{Area of steel} = 13 \text{ in}^2 \text{ for a W21} \times 44$$

$$\text{Total area} = 56.33 \text{ in}^2$$

Distance from N.A. steel section to N.A. composite section:

$$y = 14.96 \times 43.33 / 56.33 = 11.51$$

(Dimensions are in inches.)

The moment arm for the cables is

$$8.33 + 11.51 = 19.84$$

The required tension force in each cable is

$$T = 12 \times 106 / (2 \times 19.84) = 32 \text{ kips}$$

The Dywidag catalog shows that a $\frac{5}{8}$ -in. threadbar has a capacity of 26.1 kips. The next size up is a 1-in. grade 150 threadbar, capacity of 76.5 kips **o.k.** When live load is applied, the cable tension is increased. The cables and anchor-

ages must be designed for this additional tension. Hoadley¹ gives the following formula for the additional tension T' : $T' = \text{NUM}/\text{DEN}$.

$$\text{NUM} = wL^2e / 12 \quad \text{DEN} = e^2 + EI / (A_s E_s) + r^2$$

where

w = uniform load in kips/in.

L = span length in inches

e = distance from the cables to the centroid of the composite section in inches

E = modulus of elasticity of the steel beam

E_s = modulus of elasticity of the cables (both in kips/in.²)

I = moment of inertia of the composite beam in in.⁴

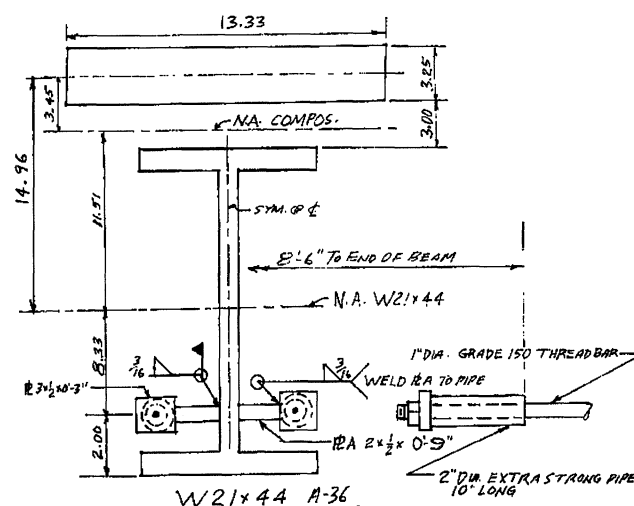


Fig 1. Cross section showing cables and anchorages.

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A_s = cross sectional area of the cables in in.²
 r = radius of gyration of the composite section in inches

Referring to Figure 1 the required properties are calculated.
 $E_s = E$. $I = 843$ in.⁴ for a W21×44.

$$I = 843 + 13 \times 11.51^2 + 43.32 \times 3.25^2 / 12 \\ + 43.32 \times 3.45^2 = 3,119 \text{ in.}^4$$

$$r^2 = 3,119 / 56.33 = 55.37 \text{ in.}^2$$

For a 1-in. dia. grade 150 threadbar,

$$A_s = 0.85 \text{ in.}^2$$

$$\text{Liveload} = 1 \text{ kip/ft.} = .0833 \text{ kips/in.}$$

$$L = 480 \text{ in.}$$

Substituting these values in the expressions for NUM and DEN yields $T' = 7$ kips/cable. The cables and anchorages must be designed for this additional load, or a total of $32 + 7 = 39$ kips. This additional load has no adverse effects on the W21×44 or the concrete, since it will only reduce but not overcome the dead and live load moments. As will be explained later, the cable anchorages are located 8 ft-6 in. from each end. With a dead load of 0.81 kips per foot, $M_{DL} = 108$ ft.kips. The cables provide an uplift moment of 106 ft/kips. Similarly, with $DL + LL = 1.81$ kips per foot, the total moment 8 ft-6 in. from each end is 241 ft/kips, while the uplift moment from the cables is $2 \times 39 \times 19.84 / 12 = 129$ ft/kips. Therefore, in no case will the cable tension overcome the gravity loads.

Hoadley's formula is based on the assumption that the cable is as long as the beam. Since the cable does not extend the full length of the beam (as will be shown later) the actual value of T' is less than seven kips. Part of T' will be lost due to some relaxation of the cable.

The cable tension is transferred to the pipe by bearing on the 3×3-in. plate. The pipe transfers its load to the 9-in. long plate through the $\frac{3}{16}$ -in. shop weld. The 9-in. plate transfers the load through shear to the $\frac{3}{16}$ -in. field weld, which in turn transfers the load to the web. Check each of the above items:

Cable

1-in. dia. 150 grade threadbar (Area = 0.85 in.²) allow 76.5 kips, actual tension, 39 kips **o.k.**

Bearing between 3×3-in. plate and 2-in. dia. extra strong pipe:

$$\text{Area pipe} = 1.48 \text{ in.}^2$$

$$\text{Bearing} = 39 / 1.48 = 26.4 \text{ kips/in.}^2$$

$$\text{allow } .9 \times 36 = 32.4 \text{ **o.k.**}$$

Weld size

For $\frac{1}{2}$ -in. plate, min. weld = $\frac{3}{16}$ -in. Using $F_w = 60$, $0.3 \times 60 \times .707 \times \frac{3}{16} = 2.39$ kips/in.

Length of weld reqd.

$$39 / (2.39) = 8.2\text{-in.}$$

Use 9× $\frac{1}{2}$ -in. plate welded to 10-in. long pipe and W21×44.

Shear in plate

$$39 / (9 \times 0.5) = 8.7 \text{ ksi.}, \text{ allow } .4 \times 36 = 14.4 \text{ ksi **o.k.**}$$

Anchorage location

The author found the unreinforced beam has a capacity of 360 ft-kips. A 40-ft span carrying a uniform load of 2.33 kips/ft will have end reactions of 46.6 kips. The distance from the support to the point at which the moment is 360 ft-kips is X ft.

$$46.6(X) - (0.5)(2.33)X^2 = 360$$

From which $X = 10.46$ ft from the end. Place anchorages 8 ft-6 in. from each end of the beam to provide a 2-ft development length (Figure 1).

LL Deflection

$$5 \times .08333 \times 480^4 / (384 \times 29,000 \times 3,119) \\ = .64 \text{ in.} = L/750 \text{ **o.k.**}$$

CONCLUSION

The author has presented a way to strengthen a beam when headroom is available. This discussion presents a solution for the case where there is no spare headroom. With one or the other of these methods virtually any beam (composite or non-composite) can be strengthened.

REFERENCE

1. Hoadley, Peter G., "Behavior of Prestressed Composite Steel Beams," *ASCE Journal of the Structural Division*, Vol. 89, No. ST3, Part 1, June 1963.