Some Economic Considerations for Composite Floor Beams

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To the discerning structural engineer, changes in specification rules always offer an economic opportunity to find new and better ways to implement savings in material or labor costs. In a subtle manner, a 1978 AISC Specification rule change for partial composite design of steel flexural members strongly improved the opportunity to make important economic savings in optimizing the floor system costs. The change was simply the introduction of a square-root power instead of a linear relationship in Specification Eq. (1.11). The revised equation now reads:

$$S_{eff} = S_s + (V'_h/V_h)^{1/2}(S_{tr} - S_s)$$

where

S_{eff} = effective section modulus of transformed composite section referred to its bottom flange, in.^{3}

S_s = section modulus of steel beam referred to its bottom flange, in.^{3}

S_{tr} = section modulus of transformed composite section referred to its bottom flange, based upon maximum permitted effective width of concrete flange (Sect. 1.11.1), in.^{3}

V_h = horizontal shear to be resisted between the point of maximum positive moment and the point of zero moment for full composite action

V'_h = horizontal shear to be resisted between the point of maximum positive moment and the point of zero moment for partial composite action

As shown in Fig. 1, the new rule permits partial composite action when the effective horizontal shear force between the beam and the concrete slab is between 25% to 100% of the full composite horizontal shear value. With the new formula, a broader selection of more economical design alternatives is now possible. There remains only the problem of examining those available beam shapes that, when combined with a given concrete slab, will render the least-cost selection.

Because of the deterministic nature of the properties of available steel beams to be selected, the solution can best be described in a graphical manner. In order to develop a convenient investigative tool for examining partial composite design alternatives, advantage can be taken of selecting certain standard design conditions for the materials. The selected conditions are:

1. Structural steel: ASTM A36
2. Concrete: Normal weight f'_c = 3.0 ksi
3. Headed stud shear connectors = 3/4 in. dia.
4. Uniformly loaded simply supported beam
5. Assume steel stress controls horizontal shear, V_h

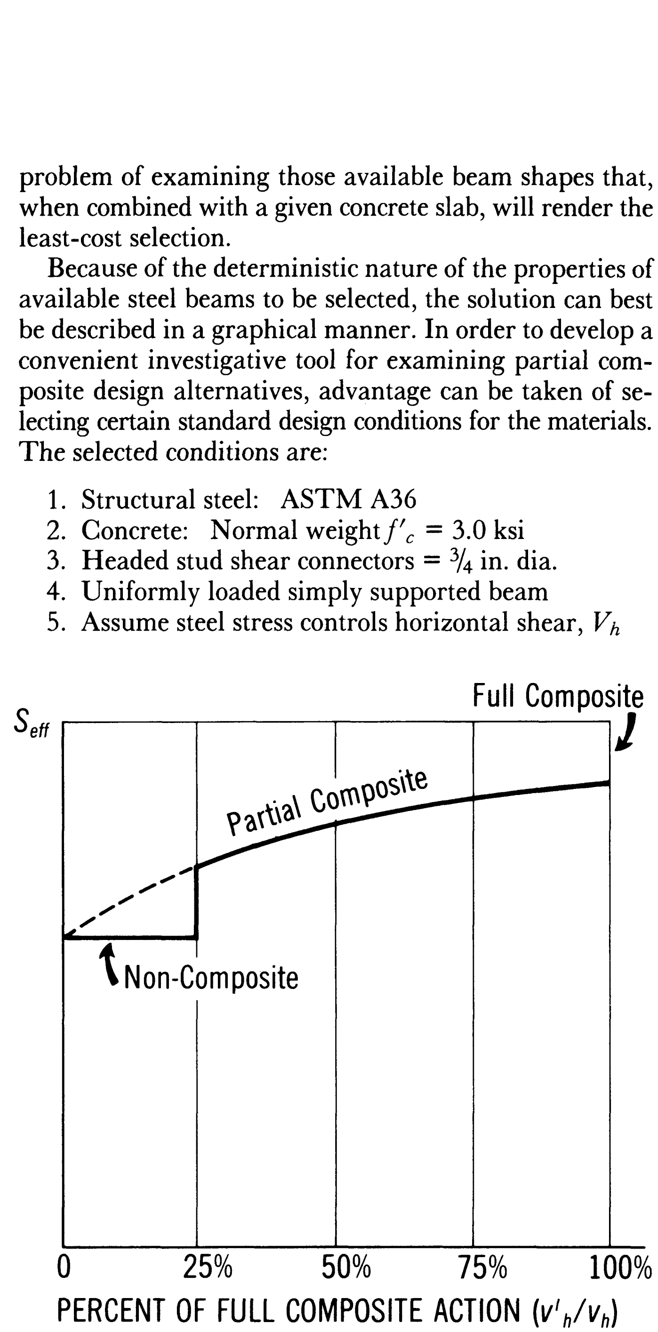

Figure 1

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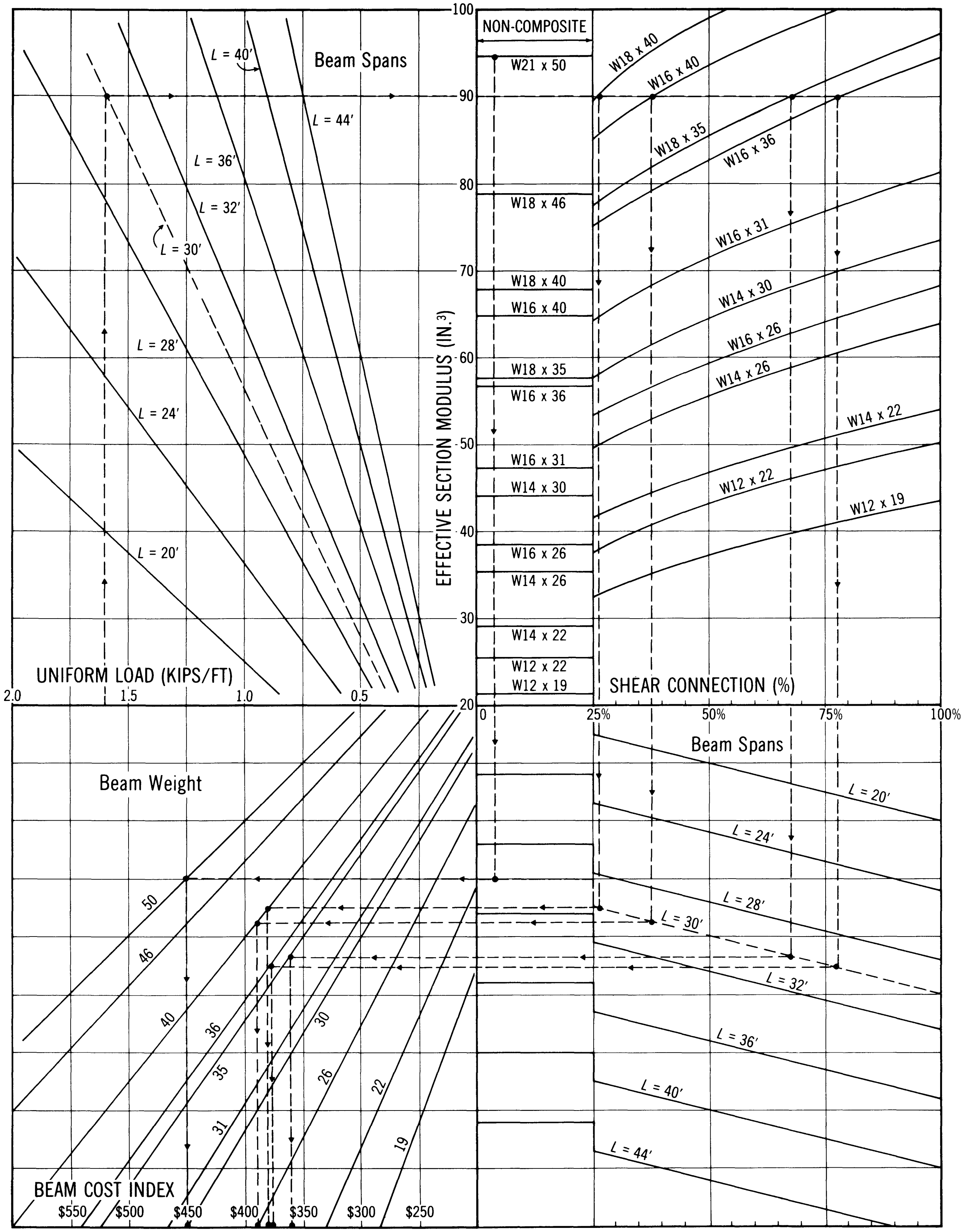

Fig. 2. Partial composite beam economy chart; $F_y = 36$ ksi, $f'_c = 3.0$ ksi, $5^1/_2$-in. normal weight concrete

By manipulation of the above design criteria, it can be shown that for the full composite action, the above conditions yield:

$$N_s = 0.928\ W_s$$

where

N_s = number of stud shear connectors per beam
W_s = weight of the beam in pounds per foot

For a more conservative approach, which accounts for usual rounding-up design procedures, we can state:

$$N_s = W_s$$

From this we can set up the following cost relationship:

$$\text{Cost index} = W_s(LC_b + vC_s)$$

where

L = Beam span (ft)
C_b = Mill cost of steel ($/lb)
C_s = Cost of installed headed stud shear connector ($/stud)
$v = V'_h/V_h$ = percentage shear connection

Armed with this relationship for the above mentioned standard conditions, realistic cost estimates of several beam selections can be made. These will vary from the heaviest beam (non-composite) through several intermediate selections (partial composite) down to the theoretical lightest beam (full composite).

For a given external design condition of loading, beam spacing and span, it is obvious that there is a decreasing need for shear connectors as the beam weight increases. In other words, a trade-off between beam weight and shear connector requirements is created. From a cost point of view, only a knowledge of the mill price of the structural steel and the average price of an installed shear connector is required to develop convenient equations for accurate cost relationships.

A nomogram can be developed to graphically illustrate how to select the low-cost choice for a series of beam-connector combinations. By inputting load and floor geometry, an array of design possibilities may be charted as shown in Fig. 2. In this case, it has been assumed that C_b = $0.30/lb and C_s = $2.00/stud are currently typical cost factors and that the normal weight plain concrete slab has a thickness of 5½ in. The transformed section modulus S_{tr} has been taken directly from the Composite Beam Selection Table as found in the AISC Manual.[1]

By the utilization of such an economy chart, each partially composite beam that meets the design load and geometry conditions can be compared economically, and the beam with the lowest cost index should be chosen as the optimum selection. Variations from the assumed conditions can be developed in the same manner, although it would introduce slightly more complex relationships. Also, adjustments for variation in actual regional cost factors should be considered when applying the proposed procedure.

EXAMPLE PROBLEM

Assume the following conditions for a composite floor beam system using ASTM A36 steel:

Beam Span:	30 ft
Beam Spacing:	10 ft
Concrete Slab:	5½ in. normal weight concrete; f'_c = 3.0 ksi
Shear Connectors:	¾ in. dia.
Loads:	
Construction:	48 psf
Superimposed:	112 psf
Total	160 psf
Required Section Modulus:	90 in.³

Selections that meet the design requirements are listed in Table 1.

The obvious selection is indicated by the minimum cost index, and a W18x35 with 22 shear connectors shows a savings of $21 compared to the W16x36 selection. It is interesting to note that the most economical selection is not represented by the beam utilizing the most shear connectors.

Using conventional composite design practices, a *full* composite design would suggest a W16x36 using 34 shear beam connectors, which would have a cost index of $392. This would be a $33 premium cost per beam over the more optimum selection indicated above.

The use of the nomogram offers an even more convenient and time-saving method, as well as providing the designer with a large-canvas approach to the problem. As shown in Fig. 2 (dotted lines), the preliminary selection can be quickly made without calculations.

A study of the design alternatives indicates that the most economical selection usually is the fully composite lowest beam-weight with shear connector requirements reduced just enough to meet the design requirements. The basic reason that the W18x35 was the optimum selection in the example was that it initially represented a more economical bare steel section over the W16x36. This realization provides one with an easy short-cut approach. However, in some cases, it is possible that a heavier beam-weight with fewer studs may be even more economical, and this could be checked by means of the optimization procedure.

Table 1

Beam	V'_h/V_h	V_h	V'_h	N_s	Cost Index
W21x50	0	—	—	0	$450
W18x40	0.26	212	53	10	381
W16x40	0.38	212	83	16	390
W18x35	0.67	185	122	22	359
W16x36	0.78	191	153	28	380
W16x36	1.00	191	191	34	392

Thus, a general rule that can be followed to minimize composite beam cost is to:

1. Select the most economical steel beam (least weight) which has a fully composite bending capacity greater than or equal to the design requirement; the AISC *Manual* Composite Beam Selection Table and Moment of Inertia Selection Table can help in this regard.
2. Reduce bending capacity to meet the actual design requirements by specifying partial composite action with less shear connectors.
3. Check several heavier beam-weights with even fewer shear connectors that may show further improved economy.

Once selected, the optimized beam then can be investigated for further secondary checks for shear, deflection, buckling, etc.

Because economy in selection of members is always an important task for the structural designer of structural steel floor systems, the use of the alternatives offered by the partial composite concepts should be utilized with such economical objectives in mind. The method shown in this paper provides a simple and quick approach that offers a cost-conscious dimension to the designer.

REFERENCES

1. Manual of Steel Construction, 8th Edition *American Institute of Steel Construction, Chicago, 1980.*