FLEXURE DESIGN

In the past, conventional analysis of composite beam sections has been linearly elastic. Concrete and steel stresses have been determined by transforming the composite section to a section of one material, usually steel, from which stresses are then determined with the familiar formula, $f = My / I$, and then compared to some limiting values which have been set to ensure an adequate level of safety. Although this procedure is familiar to most engineers, it does not predict the level of safety with as much accuracy as does an ultimate strength approach which is based on the actual failure strengths of the component materials.

It is now known that the flexural behavior at "ultimate" failure stages of composite concrete/steel beams and joists is similar to that of reinforced concrete beams - the elastic neutral axis begins to rise under increasing load as the component materials are stressed into their inelastic ranges. The typical stress-strain characteristics of the concrete and steel components are shown in fig. 5.

The various loading stages of the Hambro composite joist are indicated in fig. 6. As load is first applied to the composite joist, the strains are linear. The "elastic" neutral axis, concrete and steel stresses can be predicted from the conventional transformed area method. Generally speaking, the Hambro composite joist behaves in this "elastic" manner when subjected to the total working loads. With increasing load, failure always begins initially with yielding of the bottom chord. In (a), all of the bottom chord has just reached the yield stress, F_y. The maximum concrete strains will likely have just progressed into the inelastic concrete range, but the maximum concrete stress will still be less than $0.85 f'_c$.

With a further increase in load, large inelastic strains occur in the bottom chord and the ultimate tensile force, T_u , remains equal to $A_s F_y$. The strain neutral axis rises, as does the centroid of the compresssion force. Part (b) depicts the stage when the maximum concrete stress has just reached $0.85 f'_c$. At this stage, the ultimate resisting moment has increased slightly due to a small increase in lever arm.

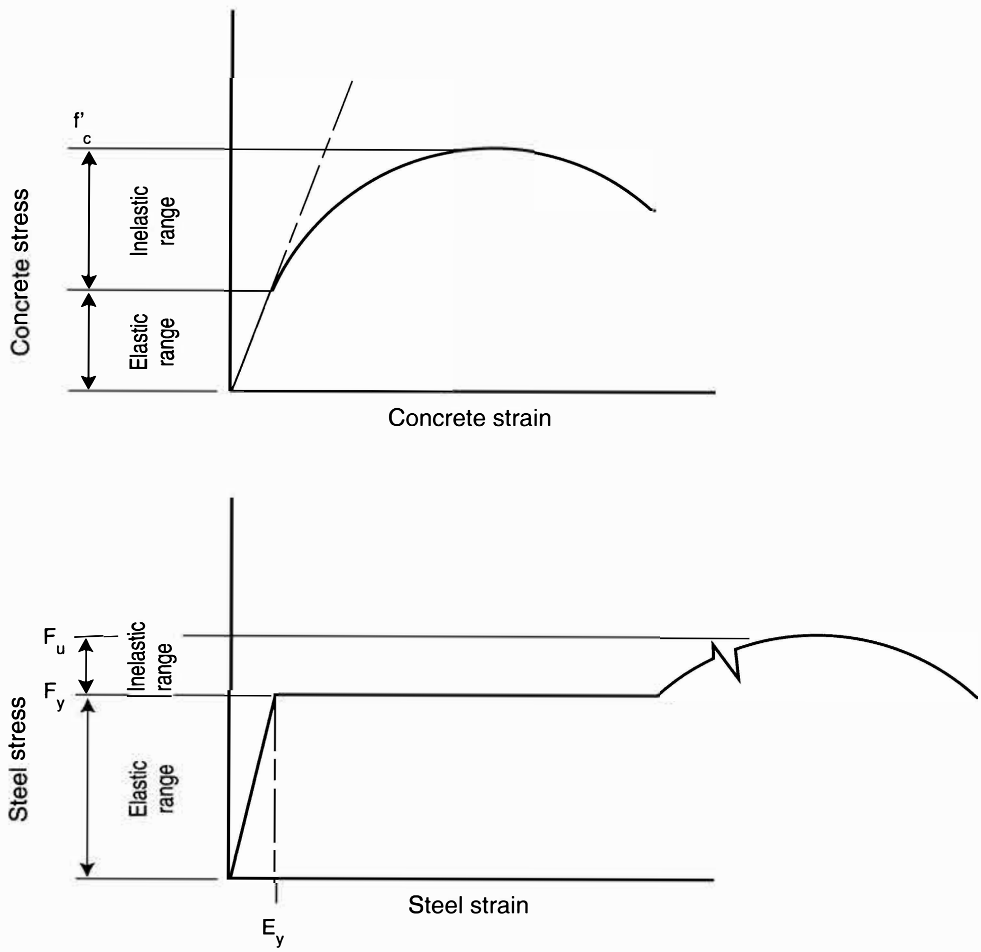
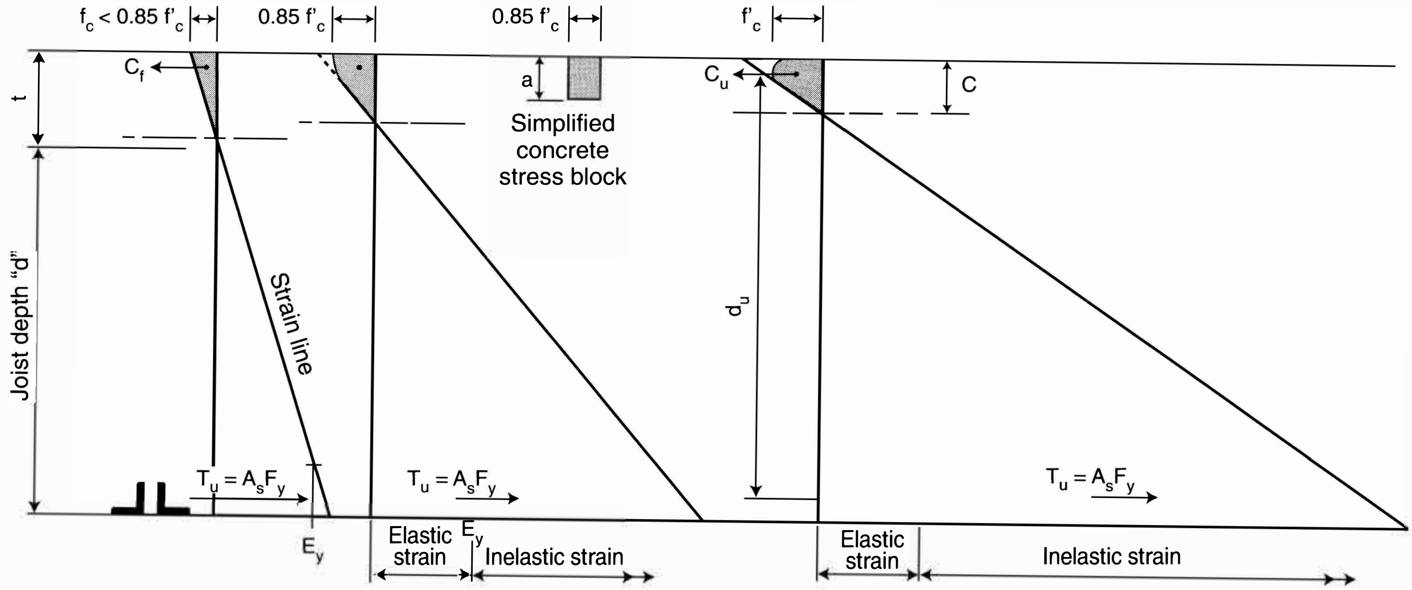


Fig. 5
Concrete and Steel Stress - Strain Curves

Various Flexural Failure Stages



(a) Initial steel yield

(b) Secondary yield stage

(c) Ultimate stage

Fig. 6

Upon additional load application, the steel and concrete strains progress further into their inelastic ranges. The strain neutral axis continues to rise and the lever arm continues to increase as the centroid of compression force continues to rise. In (c), final failure occurs with crushing of the upper concrete fibers. At this point, the maximum lever arm, du, has been reached. In load capacity calculations, the simplified concrete stress block as shown in (c) is universally used.

It is a simple matter to calculate the ultimate moment capacity of any Hambro composite joist, knowing the bottom chord size.

$$T_u = A_s F_y \quad \text{.........} \quad (7)$$

Also, C_u must equal T_u. Using an additional 0.9 concrete stress factor

$$C_u = 0.9 \times 0.85 f'_c ab \quad \text{.........} \quad (8)$$

Where b = lesser of span / 4, joist spacing, or $16\,t;\ f'_c = 3{,}000\ psi$

Equating (7) and (8) results in "a" becoming the only unknown and is easily calculated by the expression:

$$a = \frac{T_u}{0.9 \times 0.85 f'_c b} \quad \text{.........} \quad (9)$$

The lever arm, d_u, can now be determined and the ultimate moment capacity, M_u, is calculated from the expression:

$$M_u = T_u\, d_u \quad \text{.........} \quad (10)$$

Now M_u also $= M_u = \dfrac{W_u L^2}{8}$ .... (11)

Equating (10) and (11), $W_u \equiv \dfrac{8\, T_u\, d_u}{L^2}$

Using a load factor of 1.7, the working load capacity (total dead and live load) of the composite joist per unit length,

$$W_s = \frac{W_u}{1.7}$$

For a more exact analysis, factored loads will be considered.