Study on the Influence of the Height of Steel Beam on Creep Effects of Composite Beams

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Abstract. The height of steel beam is an important parameter in the design of structure. The effects of increasing the steel height of composite beam are quite different from that of the pure steel beam because of composite and creep effects. To reveal the influences of this critical parameter Rüsch constitutive equation of creep is used to obtain the exact results. With the increase of the steel height and after a limiting value is reached, the rate of the increase of the whole section stiffness becomes smaller, the rate of the increase of the compression zone of steel web becomes larger, yet the axial force and redistributed moment of concrete slab become almost constant. The deflection increases almost linearly and keeps a large slope with the increase of the steel height. Local buckling risk of the web must be considered.

1. Introduction
For composite beams the variation of the dimension of concrete slab is limited, and the size of steel beam (especially the height) is normally chosen in design to change to meet the requirement of different spans of structures. Normally for pure steel beam the bending stiffness increases with its height. Whether is it the same norm for composite beam? Moreover, compared with RC structures creep effects of composite beams are significantly larger [1-8]. And so far the problem of the deflection increase (especially for large span bridge) still bothers structural engineers, and its one main reason is creep of concrete. Therefore it is necessary to reveal the relationship between the steel height and creep effects of composite beams.

2. Parameter analysis
Creep of concrete increases the deformations of cross section, which is equivalent to reduce the elastic modular or stiffness of concrete. Therefore the creep-transformed area and stiffness of concrete slab can be used to represent the creep effects. With the reduction of the transformed area, the whole centre of gravity will move downwards, along with the neutral axis of the steel beam. Then it influences the height of compression zone of the steel beam that is important for local buckling analysis. The internal forces and stresses of cross-section changes great consequently. All these negative effects are strong correlation with the height of steel beam according to the following analysis.

Simply-supported composite beam is considered and cross-section is shown in Figure 1. The variation of the height of steel beam (hst) is assumed from 25 to 200cm. The section is assumed to be...
subjected to a constant bending moment. For creep analysis the internal forces of the two individual sections (shown in Figure 1) include axial force $N_0$, $N_r$ and $N_t$ (subscript '0' denotes initial time $t_0$, 'r' denotes redistribution and 't' denotes time $t$), bending moment $M_{c0}$, $M_{cr}$, $M_{ct}$, $M_{s0}$, $M_{sr}$ and $M_{st}$ (subscript 'c' and 's' denote concrete slab and steel beam respectively). The redistributed internal force is equal to the difference between the internal force at time $t$ and $t_0$, which is caused by deformation incompatibility of the two individual sections (concrete creep and steel doesn’t).

$$M_{c0} - N_0 = M_{cr} - N_r = M_{ct} - N_t$$

$$M_{s0} = N_0 + M_{sr} = N_r + M_{st}$$

Elastic modular of concrete slab $E_c = 30$ GPa
Elastic modular of steel beam $E_s = 210$ GPa
Area of concrete slab $A_c = 7500$ cm$^2$
Second moment of area of concrete slab $I_c = 3.91 \times 10^4$ cm$^4$
Creep coefficient $\varphi = 3$
Bending moment $M = 3000$ kN m

Figure 1. Cross-section and internal forces

Rüsch constitutive equation of creep [9] is used to establish the classical system of two simultaneous differential equations [10]. In this paper exact solutions of the system are obtained by using MATLAB programs of the authors.

2.1 Influence of the steel height on creep-transformed stiffness of cross-section

Just as shown in Figure 2a the composite stiffness between the two individual sections $S_d$ contributes the major part of the whole $I_t$ and that of concrete slab $I_{cr}$ is very small. If the stiffness coefficient $j_s$ [10] is considered, the influences of $h_{st}$ can be divided into two kinds (Figure 2b). First, when $j_s < 0.2$, the influence is significantly large (the slope is large and nonlinear). Second, when $j_s > 0.2$, the influence is small (the slope is small), which means that $I_t$ increases little with $h_{st}$ when $h_{st}$ reaches a limiting value (about 80 cm in this example). In other word it will be uneconomic in the design if the method is used by increasing the steel height to obtain the bending stiffness when $h_{st}$ is high enough.

Figure 2. Influence on creep-transformed stiffness

2.2 Influence of the steel height on the height of compression zone of steel web

The height of compression zone of steel web $x$ need be used to judge the classification of section, which represents local buckling susceptibility. The larger the height of compression zone, the more susceptible the local buckling of the web, and the less bearing capacity the cross section. Figure 3 shows that creep almost doubles the height of compression zone, the increase ratio becomes larger
with the increase of \( h_{st} \), and both \( x_0 \) and \( x_t \) are linear to \( h_{st} \). It means that in view of local buckling control the steel height must be limited.

![Concrete slab and Steel beam diagram](image)

Figure 3. Influence on the compression height of the steel web

2.3 **Influence of the steel height on the internal forces**

As previously analysed, the whole bending stiffness \( (I_t) \) is far larger than the superposition of the two individual sections \( (I_s + I_{cr}) \) because of their composite effects. In other word for composite beam the axial force of individual section is considerably large. However with the development of time creep of concrete reduces their composite effects by the redistributed axial force \( (N_r) \), and the other internal forces and stresses as well, shown in Figure 4.

![Steel height vs. Axial force](image)

(a) Axial force of individual section

![Steel height vs. Bending moment](image)

(b) Bending moment of individual section
Figure 4. Influence on the creep-induced redistribution of internal forces

Figure 4a shows some interesting phenomenon that is the influence of $h_s$ on $N_r$ is almost bilinear. The slope of line ① is large that means composite effects is reduced greatly by creep with the increase of $h_s$. The slope of line ② is almost zero that means $N_r$ becomes constant. Figure 4b shows $M_{cr}$ tends to be zeros after the limiting value of $h_s$ reaches. And similar phenomenon can also be observed for the stresses (Figure 4c and 4d). In one word after the limiting value is reached the steel height has little influence on $N_r$, $M_{cr}$ and stresses, and then some variables become constant.

Unlike these phenomena $M_{sr}$ is almost linear to $h_s$ and keeps a large slope. And curvature and deflection are proportional to $M_{sr}$ because modular or stiffness of steel is time-independent. Therefore the value of $h_s$ must be controlled in view of the control of deflection.

3. Conclusions

Different from the pure steel beam, the bending stiffness of composite beam is not always increase with the increase of the steel height because of the composite effects between two individual sections. When the steel height reaches a limiting value, two things must be kept in mind for designers of structure. Firstly the increase of bending stiffness of whole section becomes small with the increase of the steel height (shown in Figure 2), and then the method of increasing the steel height is uneconomic. Secondly the increase of compression zone of steel web becomes large with the increase of the steel height (shown in Figure 3), which increases local buckling risk of the web.

After the height of steel beam reaches a limiting value, the axial force between individual section and redistributed moment of concrete slab becomes constant with the steel height, and the same with the extreme stresses of the two individual sections (shown in Figure 4). These almost constant values benefit the practical calculation. The higher the steel height, the larger deflection (can be represented by the steel redistributed moment, shown in Figure 4b). The steel height must be limited in view of the control of deflection.

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