

Study on Mechanical Properties of Steel-concrete Composite Beams with Web Opening with Stiffening Ribs

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Abstract:

Opening holes in the web of steel-concrete composite beams reduces the load carrying capacity and stiffness of composite beams, and by setting stiffening ribs near the holes is a commonly used reinforcement method in engineering. On the basis of existing tests, the mechanical property research is carried out by using ABAQUS to set different distances of stiffening ribs in the hole area, to derive the effective stiffening rib setting position, and to put forward a new type of hole-opening method to improve the load carrying capacity of composite beams and the hole-opening space.

Keywords:

Combined Beam, Web Opening, Stiffening Rib, Finite Element Analysis

1. Introduction

Due to the advantages of steel and concrete, steel - mixed structure can effectively reduce the height of the structure, improve structural rigidity, reduce the structure under live load deflection [1], in recent years in China's bridges and high-rise buildings in the rapid development. In the high-rise building web open hole steel - mixed combination beam has a convenient pipeline through, increase the headroom height, and reduce deadweight, and increase economic benefits and other advantages, so in the field of construction industry has a broad application prospects. The shear performance of the combined beams is assumed by the concrete slab and the web of the steel girder. The opening of the web plate affects the stress performance of the steel-concrete combined beams, so that its load-bearing capacity is significantly reduced, and the reasonable installation of stiffening ribs in the hole area is a common method of reinforcement in the project. The location of the stiffening rib from the hole will change the force form of the hole, so setting the appropriate location of the stiffening rib can effectively improve the force performance of the combined beam, increase the space of the web opening, and improve the economic efficiency. At present, the research on the web opening combined beams mainly focuses on the different hole shapes and the setting of stiffening ribs at the hole location, but the

specific location of the stiffening ribs is less researched. Based on the damage mechanism of hollow web truss, Wang Peng et al. [2] established four sub-moment functions of the opening according to the plastic stress distribution in the opening area of the web-opened beam in the limit state. A method of calculating the ultimate load carrying capacity of the web-open-cavity composite beams with stiffening ribs is proposed, and the results show that the installation of stiffeners at the opening can effectively improve the bending and vertical shear capacity of the web-open-cavity composite beams and the vertical shear capacity increases with the increase of the area of the stiffeners. Liao Wenyuan et al. [3] carried out an experimental study on open-cell combined beams in the negative moment zone, and concluded that the concrete shear effect in the hole region in the negative moment zone is larger than that in the positive moment zone; and the reinforcement method was also investigated. Wang Peng et al. [4] investigated the vertical shear performance of web opening combination beams under static load, and a total of 5 web opening combination beams and 1 comparison combination beam were carried out. The experiments were carried out under concentrated loads, and the specimens were all fully sheared connections, with the main variation parameters being concrete slab thickness and reinforcement ratio. The loading method is monotonic static, the loading method is monotonic static loading, for the parameters such as slab thickness and reinforcement ratio of the concrete wing slab. The conclusions are drawn for the variation of parameters such as slab thickness and reinforcement ratio of the concrete wing plate. The openings in the web of the steel-concrete composite beams significantly reduced the stiffness and bearing capacity of the composite beams. The stiffness and load carrying capacity of the combined beams were significantly reduced. In addition, the deformation capacity of the beam was also significantly reduced after the opening of the web, due to the fact that most of the shear force was borne by the concrete wing plate above the opening and the T-shaped cross-section steel beam on the opening, face steel beams above the opening take up most of the shear force. When the shear capacity of steel-concrete beams in the web opening is insufficient, it should be considered to take reinforcing measures in the concrete wing plate above the opening and around the opening. At present, there are fewer studies on the stiffening ribs reinforcing the holes in the web-opened steel-concrete beams, and there is a lack of specific data to support the effect of the change of the setting position of the stiffening ribs relative to the opening area on the force performance of the beams. Therefore, this paper selects two variables, namely, the distance of the stiffening ribs from the opening and the number of openings, and conducts finite-element simulation analyses on the web-opened steel-concrete beams to study the force performance and the bearing capacity of the beam. The study of steel-concrete composite beams with web openings with stiffening ribs is very necessary.

2. Finite Element Analysis Mode

In order to study the stress performance of steel-concrete composite beams with open holes in the web, numerical simulation analysis was carried out by using the finite element program ABAQUS, and six composite beam specimens numbered A1~A4 and B1~B2 were designed, of which A1 was a composite beam without holes as a comparison specimen, and the remaining five were composite beam specimens with open holes in the web. The strength of the concrete wing plate is C40; the reinforcement of the concrete wing plate is HRB235; the material of the specimen steel beam is Q235B, and the steel beams are all of I-beam section; the diameter of the pegs is 19mm, the length is 80mm, and the spacing is 100mm, which are evenly

arranged along the length of the beams. Based on ABAQUS finite element software to establish a foot-scale web open hole steel-concrete beam model for calculation, the concrete using Solid 65 unit, while considering the concrete crushing and cracking, the concrete slab reinforcement is simulated using the LINK180 unit, do not take into account the bond slippage between the reinforcement and concrete. The upper and lower flanges of the steel girder are simulated by SOLID45 unit. The web of the beam is simulated by PLANE42 unit, and the bolts are simulated by beam188. The longitudinal and transverse slips between the reinforced concrete slab and the beam, as well as the vertical lifting, are simulated by bolts through the connecting unit composed of three orthogonal spring units COMBIN39, and the bolts nodes are Boolean-operated with the surrounding concrete nodes, which can be easily inserted into the interface of the composite beams. The connecting units at the interface of the combined beams are located at the same spatial point in the unstressed condition, but they are two nodes of the steel beam and the concrete slab respectively, and the reinforcement cage is coupled with the concrete slab.

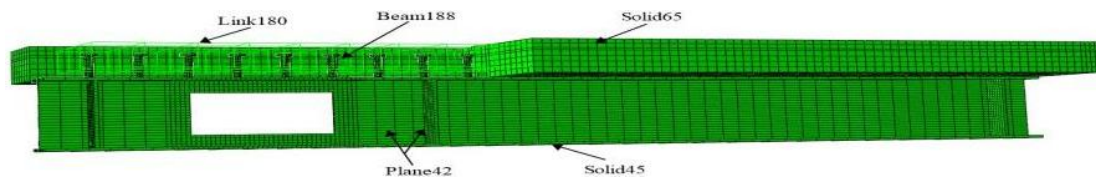


Figure 1. Finite element simulation unit.

The Willan-Warke five-parameter damage criterion was adopted for the concrete damage criterion, the constitutive relationship of concrete in uniaxial compression is shown in equation (1), the ascending section is a quadratic parabola, the compressive strength of the concrete $f_c=26.8\text{MPa}$, ultimate strain is 0.0038 the modulus of elasticity $E_c=3.25\times 10^4\text{MPa}$, Poisson's ratio=0.2, the peak strain is 0.002. The steel beam, stiffener plate, pegs and reinforcement are all adopted in the bilinear isotropic strengthening model, using VonMises yield criterion, the yield strength of steel f_y is 235MPa; elasticity= $2.06\times 10^5\text{MPa}$; Poisson's ratio=0.3. ϵ_y is the yield strain of steel, ϵ_h is the reinforcing strain of steel, and the reinforcing modulus of steel $E'_s=0.01E_s$. and the mathematical expression of the stress-strain relationship is shown in equation (2). The load-slip relationship was modeled using a mathematical model obtained by regression analysis by Oll-gaard [5] on the basis of roll-out tests, as shown in Eq. (3).

$$\sigma = \begin{cases} f_c \left[2 \frac{\epsilon}{\epsilon_0} - \left(\frac{\epsilon}{\epsilon_0} \right)^2 \right], & \epsilon \leq \epsilon_0, \\ f_c \left[1 - 0.15 \frac{\epsilon - \epsilon_0}{\epsilon_u - \epsilon_0} \right], & \epsilon_0 \leq \epsilon \leq \epsilon_u. \end{cases} \quad (1)$$

$$\sigma = \begin{cases} E_s \epsilon, & \epsilon < \epsilon_y \\ f_y, & \epsilon \geq \epsilon_y \end{cases} \quad (2)$$

$$\begin{cases} P_x = N_v^C (1 - e^{-0.71s_x})^{0.4}, \\ P_y = \frac{E_s A_{sd}}{L_s} s_y, \\ P_z = N_v^C (1 - e^{-0.71s_z})^{0.4}. \end{cases} \quad (3)$$

$$N_v^C = 0.43 A_{sd} \sqrt{E_c f_c} \leq 0.7 A_{sd} \gamma f$$

Where: s_x, s_y, s_z is x, y, z direction of the relative slip; L_s for the length of the peg; A_{sd} for the cross-sectional area of the peg; N_{cv} for a single peg shear capacity; f for the design value of the tensile strength of the peg; γ for the minimum value of the tensile strength of the material pegs and the ratio of yield strength.

3. Calculation Results

3.1. Abbreviations and Acronyms

In order to analyze the effect of the relative distance of the stiffening ribs from the holes on the stresses of the combined beams, the number of holes and other parameters were kept unchanged, and only the longitudinal distances from the stiffening ribs to the holes were varied to be 0mm, 100mm, and 200mm, respectively, the results of the calculations are shown in Figure 2. The results show that the load carrying capacity of the combined beam specimen A2 with open holes decreased by 56.38% and the deformation capacity decreased by 55.21% compared with that of the combined beam specimen A1 without open holes with the same plate thickness and the same number of holes. It can be seen that the opening of the hole leads to a large decrease in the load carrying capacity and deformation of the combined beam. When a hole was opened in the web of the composite beam, and the stiffening ribs were arranged near the hole with the same size of the hole, and the distance from the hole was changed, the load carrying capacity of specimens A4 and A3 increased by 63.92% and 54.85% compared with that of specimen A2 due to the reduction of the distance from the stiffening ribs to the hole by 200 mm and 100 mm, respectively. It shows that the closer the stiffening rib arrangement is to the hole, the more effective it is to improve the load carrying capacity of the combined beams with open hole. The reason is that the different positions of the stiffening rib arrangement from the hole will make the web of the beam in the area of the hole to change the form of the stress, and most of the stresses will be borne by the stiffening rib when the stiffening rib directly bears the concentration of the stress in the hole on the side of the open hole, the height of the stiffening rib is same as that of the web plate, and the length of the beam along the flange direction is much longer than that of the beam web plate. Therefore, the stress performance is improved. Distance of stiffening ribs has a significant effect.

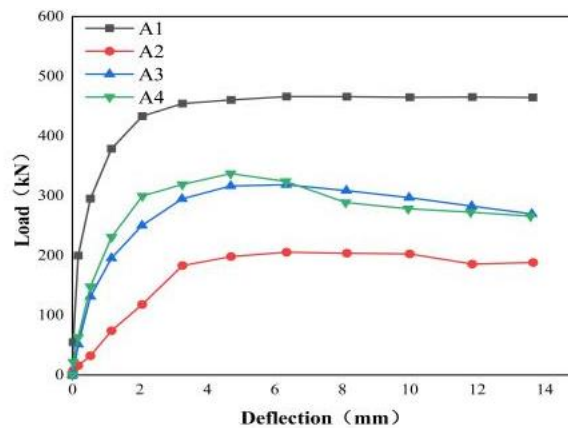


Figure 2. Effect of stiffening rib position.

3.2. Change in number of openingss

Under the condition that the relative position of the stiffening ribs from the holes remains unchanged, the number of holes in the web of the combined beam is changed, and the holes are arranged according to the location of the stiffening ribs from the holes in the center of the through-length, and the results of the calculations are shown in Figure 3.

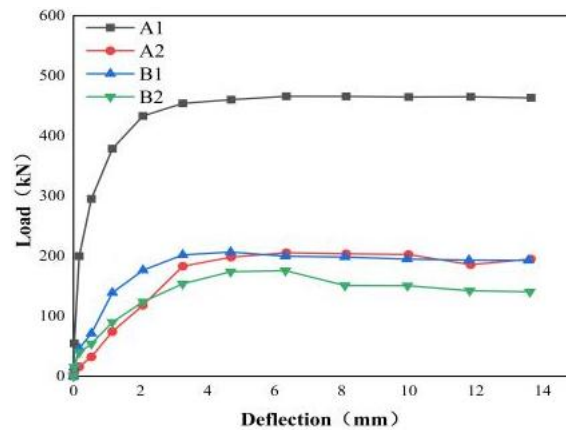


Figure 3. Effect of number of holes.

The results show that: In the case that the relative position of the stiffener from the hole and the size of the hole are the same, compared with the specimen A2, although the B1 specimen is through-length opening, the bearing capacity of the two specimens is very close by nonlinear finite element analysis, and the deformation capacity of the B1 specimen is increased by 40.57%. Compared with specimen A2, the nonlinear finite element analysis bearing capacity of the steel-concrete composite beam of the web opening is reduced by 14.43%, but the deformation capacity is increased by 13.33%, indicating that the through-length opening of the steel beam web will not significantly reduce the mechanical performance of the composite beam compared with the conventional opening, and increasing the distance between the stiffener of the through-length opening composite beam and the opening can make the force of the opening around the web more uniform, and the bearing capacity can be slightly improved.

4. Conclusions

(1) The location of stiffening ribs in the hole opening area significantly affects the load carrying capacity of the combined beam when a single hole is opened in the web opening, and the arrangement of A4 significantly improves the load carrying capacity and doubles the opening space compared with that of the traditional web opening combined beam; (2) The through-length opening of the web opening steel-concrete composite beam has more opening space than that of the traditional web opening composite beam, but the load carrying capacity is not significantly reduced, which can be selected in the engineering practice by combining with the actual working conditions such as the opening demand and the force performance.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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