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A Study on Shear Resistance of Stud Connectors Used with Profiled Steel Sheeting

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Summary

A formula, considering the main effective factors, is proposed for predicting the shear resistance of the studs used with sheeting perpendicular to the steel beams in this paper. This was done by analyzing the mechanical behaviour of the head stud connectors used with profiled steel sheeting. The proposed formula is applicable to both the stud connectors welded through holes in the sheeting and the stud connectors welded through the sheeting. The theoretical predictions are in good agreement with the test results.

1. Introduction

The use of mechanical connectors is essential for ensuring composite action in composite beams. The head stud is the most widely used type of connector in composite construction, especially in composite floor system with profiled steel sheeting. The direct shear strength of connectors may be evaluated by using a representative model test known as the push-out test. In 1970, Fisher[1] conducted through-deck push-out tests and found that specimens that included the profiled steel sheeting had reduced strength and stiffness of the connection for several profiles. He modeled the reduction in shear capacity by the following formula:

$$P_t = kP_s \qquad (1)$$

where P_t is shear strength of a connector used with profiled steel sheeting; P_s is shear strength of a connector in a solid concrete slab; k is a reduction factor for resistance of the shear connector. Fisher's[1] reduction factor for sheeting that spans perpendicular to the beam, denoted by the symbol k_g, is

$$k_g = 0.35 b_a / h_p \qquad (2)$$

where b_a is the breadth of the rib to be used in calculation , and taken as the mean rib breadth for open profiles, and the minimum breadth for re-entrant profiles; h_p is the over all depth of the profiled sheeting.

Eq.(2) was modified by Grant, Fisher and Slutter[2] in 1977. They observed that besides the rib width-height radio b_a/h_p, the height of the rib and the embedment of the connector must be taken into account to correctly predict the resistance of the shear connectors used with profiled sheeting. The modified equation of k_g was given as follows:

$$k_g = (0.85/\sqrt{N_r})(b_a/h_p)[(h/h_p)-1]\leq 1 \quad (3)$$

where N_r is the number of studs per rib; h is the height of the stud connector.

Eq.(3) was adopted in many codes of practice. However, the evaluation of all the available tests revealed that the reduction factors given by Eq.(3) do not give safe results over the whole range of possible applications. Therefore the coefficient 0.85 in Eq.(3) was reduced to 0.7 in recently revised EC4[3] and limitations are given for the rib height, the rib breadth and the number of studs per rib. That is

$$k_g = (0.7/\sqrt{N_r})(b_a/h_p)[(h/h_p)-1]\leq k_{max} \quad (4)$$

with $h_p \leq 85$mm, $b_a \geq h_p$, $N_r \leq 2$, $k_{max}=1$ for $N_r=1$, and $k_{max}=0.8$ for $N_r=2$.

Several researchers[4~6] have shown that the reduction factor k_g given by Eq.(4) is unreliable and , in some conditions, it overestimates the strength of a ribbed-deck connection, although the coefficient 0.85 was reduced to 0.7. Besides, there are no such equations for the studs welded through holes in the sheeting in EC4. In this paper, the behaviour of the headed studs used with perpendicular profiled steel sheeting is analyzed, and main effects on the shear strength of the head stud connectors used with perpendicular profiled sheeting are identified. A formula is proposed to predict the shear strength of the stud connectors used with perpendicular profiled steel sheeting.

2. Development and Verification of Shear Strength Formula

2.1 Roik and Lungershausen's Formula

In composite beams with profiled steel sheeting, the horizontal shear is transferred from the steel beam to the concrete slab through the rib that can be taken as connecting members between the steel beam and the concrete slab. But in composite beams with solid slabs, the horizontal shear at the interface can be directly transmitted through the studs and the welding. Therefore the failure mechanisms of the shear studs in these two distinct types of composite beams are different. By analyzing the test data in Germany, a formula was given by Riok and Lungershausen for calculating the shear resistance of the studs used with perpendicular profiled steel sheeting (see Fig.1)[7]. According to Fig. 1 the ultimate shear resistance of the studs used with Perpendicular profiled steel sheeting P_t can be obtained as follows:

$$P_t = 2M_u/a = 2M_u/(\alpha/d) \quad (5)$$

with

$$M_u = f_u d^3 / 6 \tag{6}$$

$$\alpha = a / d \tag{7}$$

where M_u is the plastic resistance moment of the stud cross-section, a is the distance between two plastic hinges, α is a/d ratio.

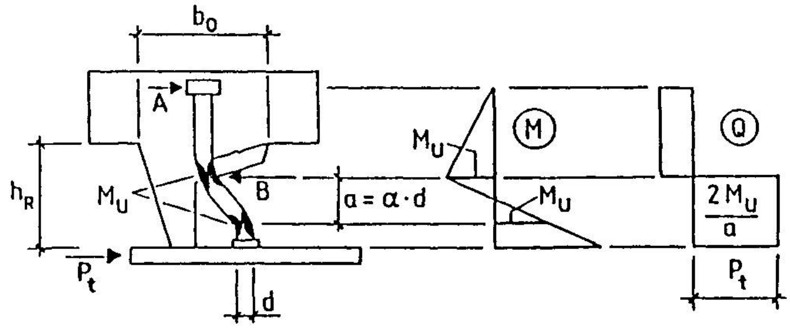

Fig.1 Failure Mechanism of stud used with profiled steel sheeting

Roik and Lungershausen have found that the coefficient α depends mainly on the geometry of the ribs. They proposed the following equation for α to take the effect of the geometry of the ribs into account:

$$\alpha = 0.6 + 0.8(h_p / b_o)^2 \tag{8}$$

where b_o is the top breadth of the rib.

In addition, they have introduced two coefficients β and $(N_r)^{-0.5}$, where β is taken as 1 for open profiles and 1.1 for re-entrant profiles and N_r is the number of studs per rib. Thus Eq.(5) becomes

$$P_t = \frac{\beta}{\sqrt{N_r}} \frac{f_u d^3}{0.6 + 0.8(h_p / b_o)^2} \tag{9}$$

2.2 Proposed Formula

There is a difference in the welding process of the studs used with profiled steel sheeting between in Germany and in USA, Canada, UK and some Member States of the European Union. In Germany, the holes are cut out in the decking before the studs are welded, and the stud connectors are welded through the holes to the beam underneath, while in USA, Canada, and UK the through-deck welding technique are usually used during the welding course of the stud connectors.

Test results have shown that the shear resistance of the studs welded through holes in the sheeting is lower relative to the studs welded through the sheeting to the steel beams[8]. In the push-out tests analyzed by Roik and Lungershausen, all studs were welded to the steel beams through holes in the sheeting, therefore, Roik and Lungershausen's formula is only suitable for the predictions of the stud connectors used with sheeting in which holes are cut out.

Test results of Roik and Lungerhausen[7] indicate that the resistance is independent of the cube strength of the concrete f_{cu}, but the dependence on f_{cu} is evident in the tests carried out by Bode and Künzel[8], Mattram and Johnson[9]. By analyzing the test data, it can be found that the shear resistance appears to be related to the tensile strength of the studs, the concrete strength and the geometry of the ribs. It is also to be noted that the stud weld transfers the partial shear force directly from the sheeting to the steel beam. This effect is obvious for studs welded through the sheeting.

According to the above analysis, the coefficient α in Roik and Lungershausen's formula should be reconsidered. To derive reasonable expression for the strength of the studs used with perpendicular profiled sheeting, the data from previous investigations which subjected to statistical analysis to determinate the importance of the variables involved, because a theoretical analysis considering the above effective factors is extremely difficult. From Eq.(5) α may be written as:

$$\alpha = (1/3) f_u d^2 / P_e \tag{10}$$

where P_e is the experimental shear resistance of the stud connectors used with perpendicular profiled steel sheeting. An alternative formula for calculating α is proposed through a multi-variable linear regression analysis on 69 push-out test specimens with one stud per rib reported in references [8]~[14].

$$\alpha = \left(0.424 + 0.775\sqrt{f_u d^2/(f_c b_m)}\sqrt{h_p/b_m}\right)\alpha_t \tag{11}$$

where f_c is the cylinder compression strength of the concrete; b_m is the mean breadth of a rib of the profiled sheeting; $\alpha_t = 1$ for studs welded through holes in the sheeting, and $\alpha_t = 1+0.6 b_u t/d^2$ for studs using through-deck welding technique; b_u is the bottom breadth of the rib, t is the thickness of the sheeting.

Additionally, the number of the studs in rib also affects the shear resistance. To consider this effect, the authors have carried out regression analysis using the test specimens with two studs per rib from references [8]~[14] and obtained an equation that fitted all sets of data well.

$$\alpha_n = 0.29[1 + (h - h_p)/d]/\sqrt{N_r} \tag{12}$$

Based on the above arguments, various cases are considered and the formula for calculating the shear resistance of the stud connectors can be written as follows:

$$P_t = \frac{A_s f_u}{1 + 1.82(d/b_m)\sqrt{f_u/f_c}\sqrt{h_p/b_m}}\alpha_t \alpha_n \tag{13}$$

where α_t and α_n are given by Eq.(11) and Eq.(12) , respectively. Eq.(13) is to be used with the following restrictions:

$d \leq 22$ mm

$t = 0.75$~1.2 mm

$h\text{-}h_p \geq 50$ mm

$h_p \leq 140$ mm

$N_r \leq 2$

Fig.2 is a diagram to verify the accuracy of the proposed formula with respect to experimental data. A total of 91 test specimens were available in the literature to compare with the proposed theory. They were reported in [8]~[14]. Using the ratio of calculated shear strength to test shear resistance as an indicator, the mean and standard deviation of this ratio for 91 data were 1.006 and 0.096, respectively. The coefficient of correlation of experimental versus predicted results were 0.959.

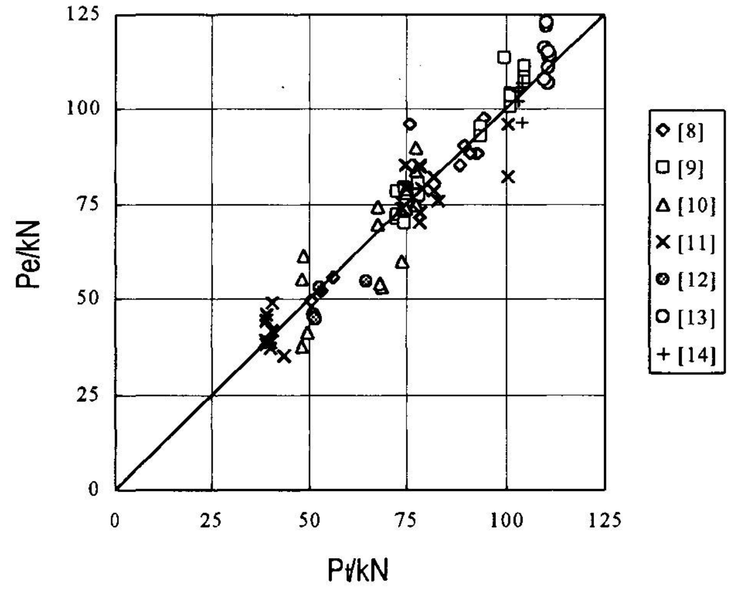

Fig.2 Comparison of calculated and experimental shear resistance

3. Conclusion

It is shown that the formula proposed in EC4 for calculating the shear strength of the head stud connectors used with perpendicular profiled steel sheeting can be unconservative, compared with the results of the push-out tests. In addition, the EC4 formula is not applicable to the specimens with studs welded through holes in the sheeting, because the shear strength of the studs with pre-holed deck is lower relative to the studs using through-deck welding technique.

Considering the main effective factors, a formula is proposed for predicting the shear resistance of the studs used with perpendicular profiled steel sheeting. This formula has taken the effects of the tensile strength of the stud material, the size of the stud, the compressive strength of the concrete, the geometry of the profiled sheeting and the welding process into account. The study has demonstrated that the proposed formula is applicable for modern composite beams with many different kinds of profiled steel sheeting and the different welding processes. Comparison of results indicates that the proposed calculation formula gives a much better fit to the test data.

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