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Design Guidelines for Partially Composite Beams

In our review, it is assumed that the behaviour of the headed stud connectors welded within profiled steel sheeting is consistent with that which was assumed in the development of the design expressions for partial shear connection given in BS 5950-3: 1990[1] and BS EN 1990-1-1: 2004[2]; that is to say, the load-slip behaviour for the connectors is elastic-perfectly plastic, with a characteristic slip capacity of at least 6.0 mm. Uplift at the connectors is also assumed to be prevented.

Effective breadth of concrete slab

Rather than using the effective breadth rules given in BS5950-3: 1990, the guidance given in BSEN1994-1-1: 2004 is applied in the proposed design methodology given in the Arup report. In this case, the effective breadth of the concrete flange is taken as zero at the supports, which increases linearly with span up to a final breadth of $B_{\mathrm{eff}} = L/4$. However, for partially composite beams, the beam span L is reduced and replaced by the length of the composite section L_{comp}.

While the stiffness and theoretical bending resistance is reduced by the assumption of a narrower effective breadth, the other effect is that the amount of force that needs to transferred by the shear connectors is reduced. As a consequence of this, fewer studs are required to achieve full shear connection, thereby making it easier to satisfy the minimum degree of shear connection requirements for partial shear connection design. Whilst the narrower effective breadth appears to be based on engineering judgment rather than a detailed consideration of shear lag effects, from your memorandum dated 2 June 2004, it

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[1] BS5950-3: 1990 Structural use of steelwork in buildings: Part 3: Section 3.1: Code of practice for design of simple and continuous composite beams, London, BSI, 1990

[2] BS EN1994-1-1: 2004 Eurocode 4: Design of composite steel and concrete structures – Part 1.1: General rules and rules for buildings, London, BSI, 2004

would appear that the conservatism that exists in strength and stiffness calculations does not adversely affect the ductility of the shear connectors in that, for the five partially composite beam examples you have considered, a larger effective breadth (based on beam span/4) increases the demand for slip by only 10%.

Lateral torsional buckling

The top flange is partially restrained against lateral torsional buckling. The Arup report recognises this effect by taking an effective length of the non-shear connected length, which is reasonable. However, this will have little effect on the design of the beam.

Shear connection

The slip in the shear connectors will be dependent on elastic and plastic effects in the beam, and plasticity effects will dominate as the beam reaches its plastic limit. The same shear connection rules as in BS 5950-3: 1990[1] or BS EN 1994-1-1: 2004[2] may be applied, provided that the steel beam has not gone beyond its elastic resistance at any point in the span except close to the point of maximum moment.

Unless detailed calculations are made on the amount of slip demanded by the partially composite beam, the SCI agrees with the Arup report that the minimum degree of shear connection should conservatively be based on the actual span of the beam when considering the rules given in the current Standards.

In the Arup report it is proposed to use the partial shear connection rules given in Clause 5.5.2 of BS5950-3: 1990. It should be noted, however, that these rules are only appropriated for steel beams with equal flanges[3]. As a consequence of this, these rules would not be appropriate for partially composite beam number 4 given in the Arup memorandum dated 31 July 2003 (where the steel section consists of an asymmetric plate girder). For cases when asymmetric steel sections are considered, it is recommended that the rules given in clause 6.6.1.2 of BS EN1994-1-1: 2004 should be used.

Uniform distribution of shear connectors

In simple terms, it is necessary to ensure that sufficient bending resistance is provided at all points in the span. This theory is presented in the Appendix to this letter and the behaviour is illustrated in Figure 1. The critical point is generally at the first shear connector, where the steel beams must resist the applied moment. It is considered that the elastic resistance of the beam should be used at this point to avoid plasticity effects in the beam away from the point of maximum moment and associated local deformation at the shear connectors. Assuming that this point is approximately 20% of the span away from the support, it follows that the moment in the steel beam is 64% of the maximum moment, which means that the steel beam will be heavier than in fully utilized normal composite design.

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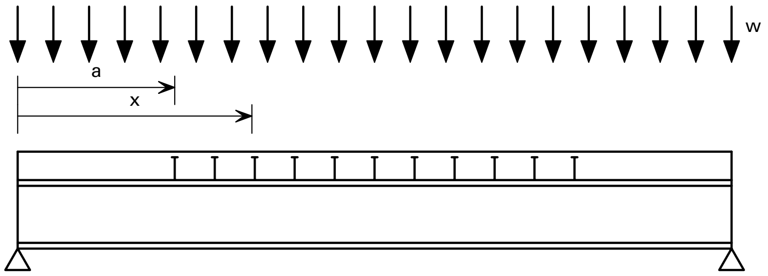
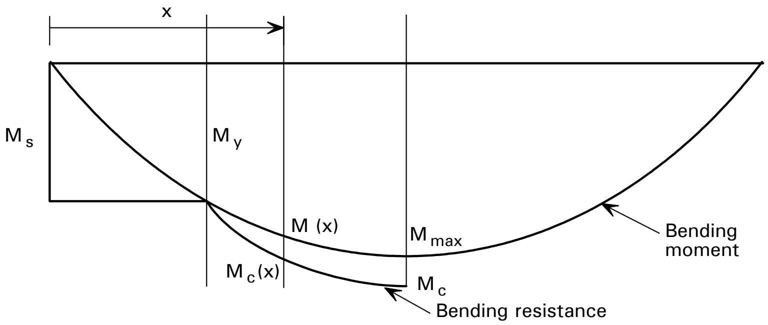
[3] AD266 Shear connection in composite beams (available on http://new-steel-construction.com)



Partially shear connected beam



Bending resistance envelope

Figure 1 *Bending resistance of partially composite beams*

The increase of composite bending resistance is then approximately linear (or slightly parabolic). In order to satisfy that the bending resistance is achieved at all points, the composite resistance should exceed the maximum moment by a significant amount. Although the Arup report suggests that the composite resistance should exceed the maximum bending moment by 10%, using the simple calculations given in the appendix, it is suggested that this should increase to 20%. However, for cases when the resistance is checked at all points along the span, the 20% limitation need not be considered.

Non-uniform distribution of shear connectors

For cases when a non-uniform distribution of shear connectors is provided, it may be possible to relax the requirement that the elastic resistance of the beam should be used at the first stud position. However, in this case, account should be taken of the shear connector deformation from the beam curvature.

Deflections

Deflections will increase due to the loss of composite action in part of the span. This effect may be calculated exactly by integration of the curvature along the span. Typically, for a 20% non-shear-connected zone, the increase in deflections of the composite beam will be about 30% irrespective of the shear connection provided (see Appendix).

Surface cracking

Although crack control is not considered directly, it is recommended that the requirements given in Clause 6.3 of BS5950-3: 1990 should be considered; particularly in the vicinity of the composite and non-composite zones due to the sudden change of beam stiffness.

I hope you find the above critique of some use in the development of your design rules for partially composite beams. Should you have any queries, please do not hesitate to contact me.

Yours sincerely

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Appendix

The following design process has been adopted:

Applied moment at point x in the span:

$$M(x) = M_{\max}\left(1-\left(\frac{L-2x}{L}\right)^2\right)$$

Composite bending resistance at point $x > a$:

$$M_c(x) = M_s + (M_c - M_s)\left[\frac{x-a}{L/2-a}\right]$$

where a is the location of the first shear connector from the support

Bending resistance at point $x < a$:

$M(x) \le M_s$

where M_s is the elastic bending resistance of the steel beam

Bending resistance at point $x > a$:

$M(x) \le M_c\,(x)$

Bending resistance at the point of maximum moment, $x = L/2$:

$M_{\max} \le 0.8M_c$

(This reserve in bending resistance will generally be satisfied by adoption of the minimum degree of shear connection rules).

For calculation of deflections, the approximate effective inertia of the fully composite beam is given by:

$$I_{eff} = I_{comp} - 0.5\,(I_{comp} - I_s)\,(2a/L)^2$$

This formula takes account of the loss of shear connection over length a. Deflections should also be increased by the effects of partial shear connection according to BS 5950-3.