Design Guidelines for Partially Composite Beams

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Methodology to be adopted when using Resotec: Vibration Damping System for Steel Deck Composite Floors from Richard Lees Steel Decking

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1. OVERVIEW

This document describes a design methodology for a simply supported partially composite beam. A partially composite beam is a composite beam which only has shear studs along a potion of its length. Figure 1 shows a schematic drawing of such a system. Only simply supported beams are considered here.

Where possible, the design procedure follows Part 1 (Rolled and welded sections) and Part 3 (Design in composite construction) of the British Standard Steel Code BS 5950. Procedures for dealing with aspects of the design that are not covered by the codes are proposed in this document and the basis of these explained.

The scope of the design methodology is discussed in section 2. Section 3 outlines general assumptions for the design of a partially composite beam. Section 4 describes the specific design checks that are required for a partially composite beam where these differ from those already covered in BS 5950.

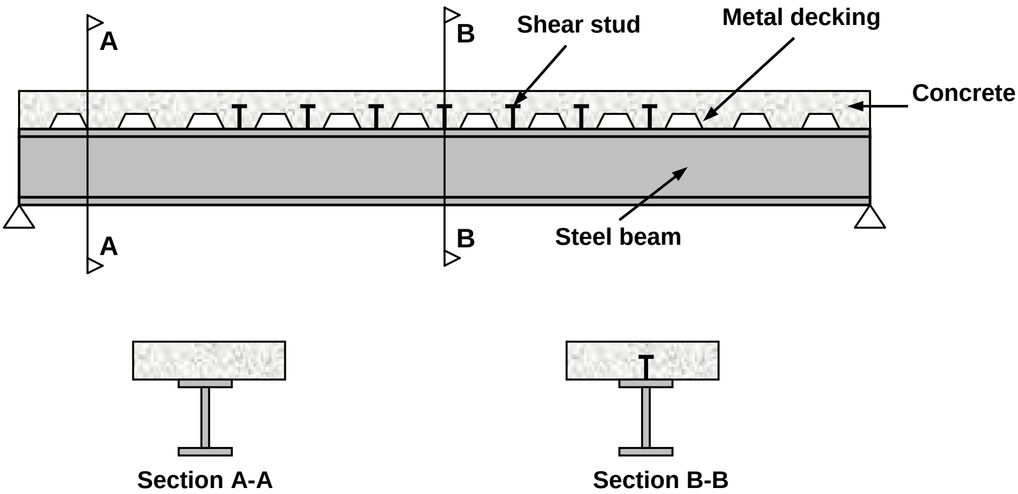

Figure 1 Partially Composite Beam

2. INTRODUCTION/ BACKGROUND

2.1 Scope

The scope of this document is the static design of partially composite beams, as described above. In particular, it is intended that these procedures be used to assess the minimum length of the fully composite section for a particular composite floor configuration. This document does not cover the following aspects, which are covered adequately in the existing codes:

- Transverse reinforcement in the concrete slab
- Exact arrangement of the stud layout (grouping etc.)
- Detailed design of the concrete slab in the non-composite part of the partially composite beam
- Shear buckling of the web and design of stiffeners

The dynamic performance is also not discussed.

2.2 Design Codes

The following codes have been used for the design methodology:

- BS 5950-1:2000 Code of practice for design – Rolled and welded sections
- BS 5950-3.1:1990 Design in composite construction

2.3 Terms and Definitions

The following terms are used in this document:

Partially composite beam	A steel beam and concrete slab, which act compositely in the central portion of the beam only. See Figure 1
Composite section	The portion of the partially composite beam in which the concrete slab and steel beam act compositely. The shear connection is provided by shear studs. (Section B-B, figure 1).
Non-composite section	The portion of the partially composite beam in which the concrete slab and steel beam do not act compositely, with no shear connection between the two. (Section A-A, figure 1).
Percentage Composite (pc)	The ratio of the length of the composite section to the length of the beam.

3. GENERAL DESIGN ASSUMPTIONS

This section summarises the assumptions made during the design process relating to:

- Contribution of concrete slab to the capacity and stiffness of the composite beam
- Stiffness of partially composite section, which varies along the length of the beam
- Design of the steel beam

The methodology for stiffness and capacity calculation applies to the completed composite section. During the construction stage, the steel beam alone provides strength and stiffness.

3.1 Contribution of Concrete Slab to Capacity and Stiffness

3.1.1 Full and Effective Breadth of Concrete Slab

For the partially composite beam, the effective width is calculated based on the length of the composite section L_{comp} instead of the beam length L. Furthermore, the effective breadth of the concrete is ramped, assuming a zero breadth at the interface with the non-composite section, a stress spreading angle of 45^o and a final breadth B_{eff} (Figure 2).

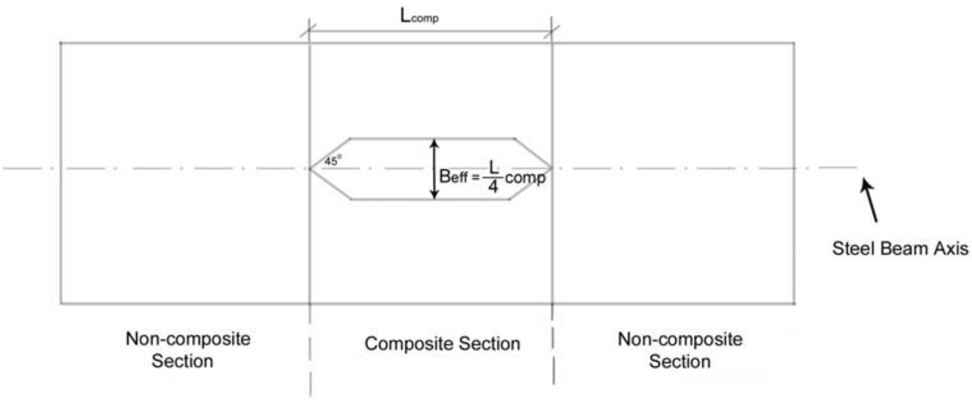

Figure 2 Effective Breadth of Concrete along the Composite Section of the Beam

For both stiffness and capacity calculations, the concrete within the depth of the ribs and the metal decking is neglected (BS 5950-3.1:1990 4.4.1).

3.1.2 Section Properties, Stiffness and Strength for the Non-Composite and Composite Sections

In the composite section the width of the concrete slab contributing to the composite section is limited to the value given in section 3.1.1. This applies to both SLS and ULS calculations. The effect of a partial shear connection on stiffness and capacity in the composite section is considered in sections 4.3 and 4.4. The second moment of area of the composite section is calculated using the formula for an uncracked section given in BS 5950-3.1:1990 4.2.2, B.3.1., with the exception that a reduced width of slab at the end of the composite section is used (as described in section 3.1.1.).

In the non-composite section, the stiffness is the sum of the individual stiffnesses of the steel beam and the concrete above the ribs. The full width of the slab is considered. It is assumed that the concrete above the ribs remains uncracked.

4. STATIC CHECKS

The following design checks for a partially composite beam differ from, or are additional to those normally performed for composite beams.

- Capacity of steel beam in non-composite section
- Lateral-torsional buckling of steel flange in compression
- Capacity of composite section
- Deflection and irreversible deformation
- Checks for construction stage

The design checks are described in turn below.

4.1 Capacity of Steel Beam in non-composite section

4.1.1 Moment Capacity

The steel beam section is classified according to BS 5950-1:2000 3.5.2, Table 11, assuming an axial force of zero. The moment capacity is calculated according to BS 5950-1:2000 4.2.5.

4.2 Lateral Torsional Buckling of Steel Flange in Compression

For simply supported beams only the top flange is in compression and thus only this needs to be checked for lateral torsional buckling. In the composite section, the top flange is restrained from buckling by shear studs. In the non-composite section, however, lateral torsional buckling of the steel flange in compression might be possible.

The effective length of the top flange in the non-composite section is determined by the end conditions. It is assumed that the end at the interface with the composite section (End 1, Figure 3) is fully restrained against rotations, while the other end (End 2, figure 3) is free to rotate. Based on factors given in BS 5950-1:2000 4.3.5.1, the effective length is calculated as (BS 5950-1:2000 4.3.5.1):

End 1: Compression Flange fully constrained against rotation

$$L_{eff,1} = 0.75\ L_{nc}$$

End 2: Both Flanges free to rotate

$$L_{eff,2} = 1.00\ L_{nc}$$

The final effective length is calculated using the average of the two factors:

$$L_{eff} = 0.875\ L_{nc}$$

where $L_{eff,\,1}$ and $L_{eff,\,2}$ are the effective lengths based on end connections 1 and 2, L_{nc} the length of the non-composite section and L_{eff} the effective length of the non-composite section.

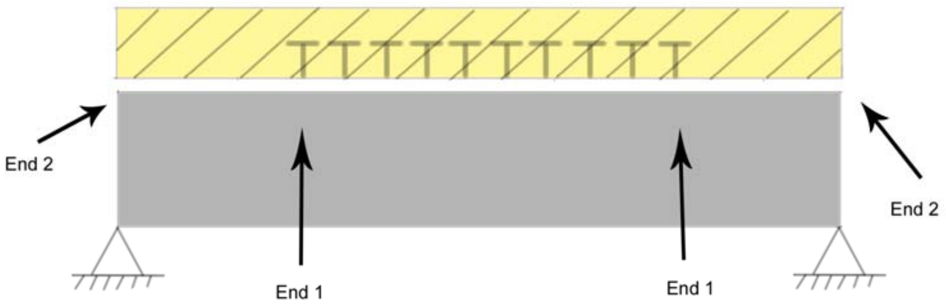

Figure 3 End conditions for lateral torsional buckling of the steel flange in compression in the non-composite section

If the composite length is zero, i.e. if the entire beam is made non-composite, the effective length L_{eff} is equal to the beam length L.

4.3 Capacity of Composite Section

4.3.1 Shear Capacity

It is assumed that the steel beam only contributes to the shear capacity of the composite section. Hence, the shear capacity of the composite section is the same as the shear capacity of the non-composite section.

4.3.2 Moment Capacity

The presence of the concrete slab in a composite beam offers additional compressive capacity to the top of the steel beam, increasing its bending moment capacity. It is assumed that the metal decking spans onto the beam and that “effective attachment” to the slab is provided (BS 5950-3.1:1990 4.5.2). Hence, compared to the non-composite section, the compression flange is “upgraded” by one class (Class 3 → Class2, Class 2 → Class1).

4.3.3 Shear connection

Shear connection between the slab and the concrete will normally be provided by studs. The capacity of the studs is dependent on the size, concrete grade and deck profile.

The maximum shear connection that is useful is such that the force in the concrete slab at midspan is equal to the lesser of the slab and beam capacity. For a fully composite beam this shear connection is normally uniformly distributed over the length of the beam and does not follow the shear flow requirements. This implies some yielding of the connection at the ends of the beam and redistribution of the connection forces towards midspan. The yielding will give some slip between the concrete and the steel at the end of the beam. In many cases the beams are designed for partial interaction i.e. the shear connection is less than the maximum mentioned above, the amount of interaction is the ratio of the actual shear connection to that required to give the maximum force in the slab. This can be economic but means that the slip between the concrete and steel is increased. To limit the slip to that provided by the ductility of the shear connection the decrease in the amount of interaction required is also limited and rules are given in BS 5950-3.1:1990 5.5.2; these rules relate the amount of interaction to the span of the beam.

For partially composite beams it is intended that the same level of interaction is used as that required for the fully composite beam i.e. based on the total span of the beam; not just the composite length. However, typically the effective width of the slab in the partially composite beam is less than that of the fully composite section. In this case the slab force capacity is less, hence the maximum shear connection is also less, and less shear connection is required for the same interaction.

When a uniform shear connection has been provided studies have shown that in many cases the slip at the end of the partially composite section is greater than that at the end of a fully composite beam. However it is also clear that the amount of slip decreases if either unpropped construction is used and/or the moment capacity of the section is not fully utilised. If these two criteria are met a uniform shear connection is considered adequate. Where either of these criteria is not met a non-uniform shear connection is proposed. The following two cases are therefore proposed:

Case 1: $M_{demand}/M_{capacity} < 90\%$ and unpropped construction

The amount of interaction is calculated according to BS 5950-3.1:1990 5.5.2 based on the full length of the beam and shear connection is provided in the partially composite length to achieve that interaction. The shear connection can be uniformly spaced over the length of the partially composite section although where possible increased shear connection should be provided at the beginning of the partially composite length.

Case 2: $M_{demand}/M_{capacity}$ > 90% and/or propped construction

The amount of interaction is calculated according to BS 5950-3.1:1990 5.5.2 based on the full length of the beam and shear connection is provided in the partially composite length to achieve that interaction. The shear connection should be non uniform and based on matching the degree of interaction for the fully composite beam. The degree of interaction at a point along the beam is defined as the ratio of the sum of the shear connection from the end of the beam (or composite length) to the force required at midspan The shear connection in the partially composite beam should be such that the degree of interaction matches that of the fully composite beam at a distance of an eighth of the distance into composite length (see Figure 4)

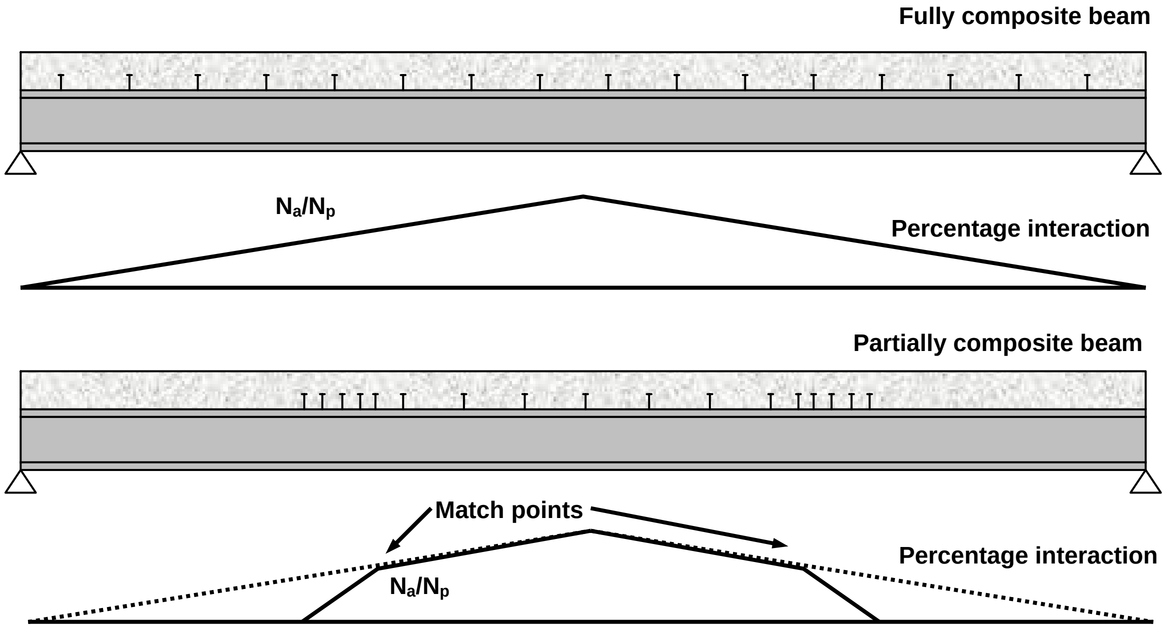

Figure 4 Case 2 ($M_{demand}/M_{capacity}$ > 90%): Matching percentage interaction of partial composite and fully composite beams with match points at quarter distance into composite half span.

The longitudinal shear strength of the concrete slab and the potential requirement for transverse reinforcement is checked according to BS 5950-3.1:1990 5.6. The increased number of studs towards the ends of the composite section in partially composite beams results in an increased shear demand that is resisted by the concrete slab, decking and, if required, transverse reinforcement.

4.4 SLS Checks

The SLS checks comprise 3 checks:

- Check of deflection due to imposed loads (IL)
- Check of deflections due to dead loads (DL)
- Irreversible deformation check

4.4.1 Stiffness values for calculation of deflections

The deflection is calculated exactly by integration of the curvature along the span with stiffness values based on the assumptions described in section 3.1 with further modifications in the composite section as shown below.

a) Propped Construction

In case of partial shear interaction, the stiffness of the composite section is decreased by a factor equivalent to that given in BS 5950-3.1:1990 6.1.4 for propped construction:

$$I_{equ} = I_{comp}/(1+(I_{comp}/I_{steel} - 1)*0.5*(1-N_a/N_p)$$

where I_{equ} is the second moment of area of the section with partial shear interaction, I_{comp} the second moment of area of the composite section and I_{steel} the second moment of area of the steel beam alone.

b) Unpropped Construction

In case of partial shear interaction, the stiffness of the composite section is decreased by a factor equivalent to that given in BS 5950-3.1:1990 6.1.4 for unpropped construction:

$$I_{equ} = I_{comp}/(1+(I_{comp}/I_{steel} - 1)*0.3*(1-N_a/N_p)$$

4.4.2 Deflection due to imposed loads

The deflection due to imposed loads (point load and UDL) are calculated using the stiffness values for the non-composite and composite section as described in section 4.4.1 and a load factor of unity.

4.4.3 Deflection due to total load

For the deflection calculation for total load a distinction is made between propped and unpropped construction:

a) Propped construction

- *DL* and *IL* are applied to the partially composite beam (with stiffness as described in section 4.4.1)

b) Unpropped construction

- *DL* applied to the steel beam only
- *IL* applied to the partial composite beam (with stiffness as described in section 4.4.1)

4.4.4 Irreversible Deformation

The irreversible deformation check is a stress check to ensure yielding does not occur under SLS loads given in BS 5950-3.1:1990 6.2. In the non-composite section, the maximum extreme fibre stress σ_{max} is calculated as

$$\sigma_{max} = BM_{nc,max} / Z$$

where $BM_{nc,max}$ is the maximum bending moment in the non-composite section and Z the elastic section modulus.

4.5 Construction Stage

It is assumed that capacity and deflection during the construction stage are only critical if the beam is not propped. Hence, the following checks are only required if an unpropped construction is specified.

The capacity during the construction stage is the capacity of the steel beam alone. Hence, shear capacity and bending moment capacity are calculated as described in section 4.1.1. The effective length L_{eff} for the lateral torsional buckling check is taken as the length of the non-composite section ($1.00\ L_{nc}$).