AD 346
Design actions during concreting for beams and decking in composite floors

The purpose of this AD Note is to clarify the design values of loading on decking and beams in a steel framed building with a composite floor during execution (the construction stage). The requirements of the Eurocodes are not always clear and reference has to be made to several Parts and their National Annexes. This AD sets out SCI's interpretation and recommendations for this situation.

The basis for structural design is set out in BS EN 1990. This is referred to by other Eurocode Parts dealing with the design of structural elements, including BS EN 1991-1-6, which covers actions during execution, BS EN 1993-1-1 for the design of steel structures, BS EN 1993-1-3 for the design of decking, and BS EN 1994-1-1 for the design of composite steel and concrete structures. All these Parts, together with their respective UK National Annexes, are needed to determine the value of the design effects due to combined actions.

Construction loads on profiled steel decking

Actions at the ULS

Construction loads applied during the casting of concrete

The construction loads (Q_c) during the casting of concrete are covered in BS EN 1991-1-6 clause 4.11.2 and the Standard shows the loads diagrammatically; the diagram, with text labels, is reproduced in Figure 1.

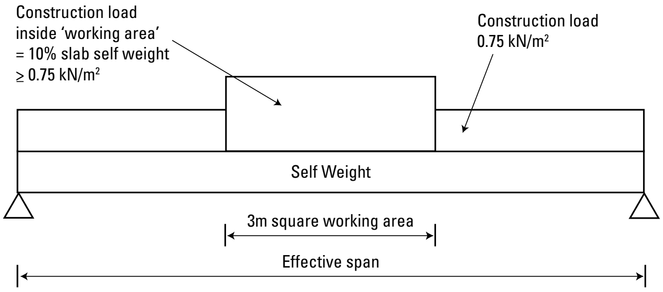

Figure 1 Construction loads during casting of concrete, according to BS EN 1991-1-6

The diagram implies that the load within the working area would be no greater than outside the working area unless the slab weight exceeds 7.5 kN/m², which is much greater than in normal composite decks. This further implies that there would be no allowance for heaping of concrete in the working area. SCI considers that the omission of an allowance for heaped concrete is unwise, and may not have been intended.

Consequently, SCI recommends the following construction loads during casting of concrete for a composite slab:

(i) 0.75 kN/m² generally

(ii) An additional load of 10% of the slab self weight or 0.75 kN/m², whichever is greater, over a 3 m × 3 m 'working area'. This area should be treated as a moveable patch load that should be applied to cause maximum effect.

This recommended loading is shown diagrammatically in Figure 2.

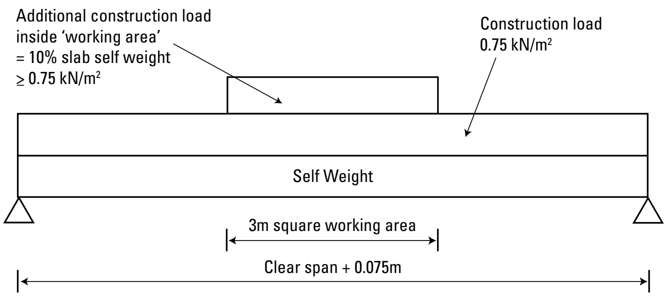

Figure 2 SCI's recommended construction loads on decking during casting of concrete

Allowance for the weight of the wet concrete and reinforcement

The densities and self weight of construction materials are given in BS EN 1991-1-1, and the data is informative. SCI believes that the increase in density of concrete due to the reinforcement of 1kN/m³ given in BS EN 1991-1-1, Annex A, Table A.1 is appropriate for reinforced concrete but not for composite floors, which have only a relatively light mesh. It is also noted that weight of the fresh concrete is to be treated as a variable action, which means that the partial factor γ_Q is applied, rather than γ_G.

For composite slabs, SCI recommends the following loads for weight of concrete and reinforcement:

(i) 24 kN/m³ for **dry** normal weight concrete and 19 kN/m³ for **dry** lightweight aggregate concrete

(ii) 25 kN/m³ and for **wet** normal weight concrete and 20 kN/m³ for **wet** lightweight aggregate concrete

(iii) The weight of the reinforcement for the specified mesh; the value should thus be determined on a case-by-case basis.

(iv) The self weight of the wet concrete is treated as a variable action for the construction condition

(v) The self weight of the reinforcement is treated as a permanent action.

Ponding:

The allowance for ponding of concrete during execution is given in BS EN 1994-1-1 clause 9.3.2. The clause states that, if the deflection of the steel decking is greater than 1/10 of the slab depth, the effect of ponding should be allowed for. It states that the deflection should be calculated under the self weight of the decking plus that of the wet concrete (it must be presumed that the weight of the reinforcement should be included, although it is not stated), calculated for serviceability (i.e. unfactored values of loads). The clause advises that ponding may be allowed for by considering an overall increase in thickness of concrete of 0.7 times the maximum deflection. It may be presumed that the extra weight of concrete from ponding should also be treated as a variable action.

It should be noted that where laser 'mass flood' levelling techniques are employed, the slab depth will be greatly influenced by the deflection of the beams, and this should be considered – see AD 344.

Expression for effects of actions on decking at the ULS:

The expression for effects of actions at the ULS is derived from consideration of the general expression 6.10 for the design combination of actions or the more onerous of expressions 6.10a and 6.10b, all set out in BS EN 1990 clause 6.4.3.2(3). These expressions may be simplified when there is only one variable action e.g. for the design of decking and beams subject to a single variable action (construction load) and permanent actions (self weight), which leads to the following expressions:

option (i)

$$E_d = E\{\Sigma\gamma_{G,j,sup}G_{k,j,sup} + \Sigma\gamma_{G,j,inf}G_{k,j,inf} + \gamma_{Q,1}Q_{k,1}\}, \quad (6.10)$$

option (ii)

$$E_d = E\{\Sigma\gamma_{G,j,sup}G_{k,j,sup} + \Sigma\gamma_{G,j,inf}G_{k,j,inf} + \gamma_{Q,1}\psi_{0,1}Q_{k,1}\}, \quad (6.10a)$$

$$E_d = E\{\Sigma\xi\gamma_{G,j,sup}G_{k,j,sup} + \Sigma\gamma_{G,j,inf}G_{k,j,inf} + \gamma_{Q,1}Q_{k,1}\}, \quad (6.10b),$$

It must be verified that $E_d \leq R_d$ [see BS EN 1990, 6.4.2(3)P].

However, because BS EN 1991-1-6, Annex A1 Clause A1.1 (1) recommends $\psi_0 = 1.0$ for construction loads (and the UK NA adopts this value), expressions 6.10 and 6.10a become identical. Also, expressions 6.10a and 6.10b then only differ by the ξ factor in expression 6.10b. A recommended value of ξ is given in BS EN 1990, Table A1.2.(B), but the UK NA Table NA.A1.2(B) gives a different value, $\xi = 0.925$. Consequently, the more onerous expression is 6.10a, and it has to be evaluated using the partial factors defined by Table NA.A1.2(B). In short, during concreting, all the self weight except that of the concrete is factored by 1.35 and all the variable actions are non-independent and factored by 1.5.

The following expression is therefore recommended for determining design effects during construction at the ultimate limit state:

$$E_d = E\{1.35G_{k,1a,sup} + 1.5Q_{k,1a} + 1.5Q_{k,1b} + 1.5Q_{k,1c}\}$$

where:

$Q_{k,1a}$ is the construction load for personnel and heaping of concrete in the 3m x 3m working area (at least 0.75 kN/m^2, as recommended above). [This construction loading covers the action defined in BS EN 1991-1-6 as Q_{ca}, which is 'personnel and hand tools', and Q_{cf}, which is defined as 'loads from parts of a structure in a temporary state'.]

$Q_{k,1b}$ is the construction load for personnel etc. across the full area (0.75 kN/m^2). [This general load is also stated in BS EN 1991-1-6 as covering Q_{ca}.]

$Q_{k,1c}$ is the weight of the wet concrete, applied across the full area, including additional concrete from ponding (where applicable). [This general load is stated in BS EN 1991-1-6 as covering Q_{cc}, 'Non-permanent equipment' and Q_{cf}, 'Loads from part of a structure in a temporary state'.]

$G_{k,1a,sup}$ is the self weight of the decking and reinforcement.

Actions at SLS

BS EN 1991-1-6, clause A.1.2, states that "for the verification of serviceability limit states [for actions during execution], the combinations of actions to be taken into account should be the characteristic and the quasi-permanent combinations as defined in EN 1990". For the construction stage of composite floors, these combinations may be expressed as:

$$E_d = E\{\Sigma G_{k,j} + Q_{k,1} + \Sigma\psi_0 Q_{k,i}\} \quad j \geq 1, i > 1 \quad (6.14b)$$

and

$$E_d = E\{\Sigma G_{k,j} + \Sigma\psi_{2,i} Q_{k,i}\} \quad j \geq 1, i > 1 \quad (6.16b)$$

BS EN 1990 states that the characteristic combination (6.14b) is normally used for irreversible limit states. SCI recommends that this combination, which is more onerous than the quasi-permanent combination (6.16b), should apply to verification of both deflection and inelastic deformation criteria at the SLS for decking.

SLS deflection limits

BS EN 1994-1-1, clause 9.6, notes that the limiting deflection under the weight of wet concrete and self weight of the decking may be given in the National Annex but recommends a limit of effective span/180. The UK NA recommends the lesser of the effective span/180 and 20 mm as the limit when loads from ponding are ignored, and the lesser of the effective span/130 and 30 mm when loads from ponding are included; these are the same as the limits given previously in BS 5950-4. SCI suggests that deflections should only be verified in the fully concreted state, i.e. with no patterned loading.

For actions associated with the concreting and the self weight, the recommended SLS design expression for deflections reduces to:

$$E_d = E\{G_{k,1a,sup} + Q_{k,1c}\}$$

SLS deformation limit

There is no requirement for verification of the deformation of the profiled sheeting as shuttering at the SLS in BS EN 1994-1-1, but BS EN 1993-1-3, clause 7.2, gives a deformation limit in terms of a limit on the combined effect of moment and reaction at the SLS at an internal support, when plastic global analysis is used at ULS. SCI considers it appropriate to include the construction loading within the 3m x 3m 'working area' together with the wet concrete and self weight loads for this verification. It is possible that this criterion will govern the design of the decking, but it will depend on the properties of the particular decking.

Based on the characteristic combination, and taking ψ_0 as 1.0, the recommended SLS design expression for verifying the deformation limit reduces to:

$$E_d = E\{G_{k,1a,sup} + Q_{k,1a} + Q_{k,1b} + Q_{k,1c}\}.$$

Construction loads on beams

Actions at the ULS

Construction loads applied during casting of concrete

As noted above, there are three components of construction load on the decking during casting of concrete, $Q_{k,1a}$, $Q_{k,1b}$ and $Q_{k,1c}$. In SCI's opinion, a uniform construction load of $Q_{k,1b}$ = 0.75 kN/m^2 would be difficult to achieve, let alone exceed, over the large area typically supported by a beam, especially when concreting operations are in progress, and the addition of $Q_{k,1a}$ = 0.75 kN/m^2 over the 3m x 3m working area would be excessive for design of the beams. With good site control, this allowance for heaping of concrete may be ignored because the application of partial factor for variable actions to the weight of the wet concrete is felt to be sufficiently onerous. Therefore, SCI recommends that designers take advantage of clause N.A.2.13 of the UK NA to BS EN 1991-1-6 to use "values of Q_{ca} and Q_{cc} … determined for the individual project". SCI recommends using $Q_{k,1a}$ = 0 and $Q_{k,1b}$ = 0.75 kN/m^2 for the design of the beams. The designer should make the contractor aware that good site practice in placing concrete has been assumed and that supervision is adequate to prevent undue heaping of concrete and concentration of men and tools.

Based on the above, SCI recommends the following design formula for actions on beams associated with concreting and self weight:

$$E_d = E\{1.35G_{k,1a,sup} + 1.35G_{k,1b,sup} + 1.5Q_{k,1b} + 1.5Q_{k,1c}\}$$

where $G_{k1a,sup}$ is the weight of the beam section.

Ponding:

BS EN 1994-1-1 does not mention allowance for ponding in the design of beams, but it is recommended that, if ponding has to be included in the design of the decking, consideration should also be given to including it in the design of the beams (in term $Q_{k,1c}$).

As noted for the design of decking, where laser 'mass flood' levelling techniques are employed, the slab thickness will be greatly influenced by the deflection of the beams. The slab thickness for the design of secondary beams is increased by up to 70% of its deflection, plus 70% of the deflection of the decking and up to 100% of the deflection of primary beams. For the design of primary beams, the increase is 70% of the combined deflections of the decking, primary and secondary beams.

However, if the levelling technique is known to be based on constant thickness rather than constant level, then it is considered that there is sufficient margin of safety to ignore the effect of ponding.

Actions at the SLS

The Principle stated in BS EN 1991-1-6, Clause 3.3(1)P, that "Operations during execution which can cause excessive cracking and/or early deflections and which may adversely affect the durability, fitness for use and/or aesthetic appearance in the final stage shall be avoided" is particularly relevant to the deflection of the supporting beams.

Where an assessment of deflection of beams is needed for this consideration, SCI recommends the following expression for determining the deflection of beams during concreting:

$$E_d = E\{1.0G_{k,1a,sup} + 1.0G_{k,1b,sup} + 1.0\ Q_{k,1c}\}$$

There is no requirement to limit stress at SLS unless verification of fatigue at ULS is required, or some form of prestressing is employed (see BS EN 1994-1-1, clause 7.2.2).

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