AD 450: Resistance of composite slabs to concentrated loads

EN 1994-1-1[1] clause 9.4.3 is entitled *effective width of composite slabs under concentrated point and line loads*. It has been the cause of much confusion, as explained below. We are now confident about our interpretation of this clause, and in particular the limits of 7.5 kN and 5.0 kN/m² quoted in its part 5).

The purpose of EN 1994-1-1 9.4.3

For design purposes composite slabs are, not unreasonably, assumed to be one-way spanning. Span is in the direction of the ribs, which add significantly to the depth of the slab and make its stiffness in this direction considerably greater than its transverse stiffness. A question that then arises is what width of slab can be assumed to be active in supporting a concentrated load?

A typical composite slab might span 3.5 m, and could be anything from 6 m to 12 m or more 'wide' (i.e. transverse to the assumed spanning direction). Clause 9.4.3 tells the designer how much of this width can be assumed to carry a concentrated load, acting as a beam. Figure 1 below is taken from EN 1994-1-1:

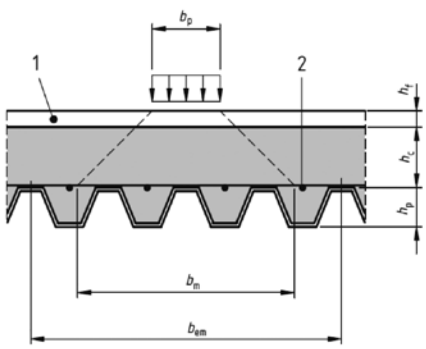

Figure 1: Widths associated with a concentrated load (1 indicates topping)

A load with a physical width b_p distributes at 45 degrees through the depth of slab (and any finishes) above the decking. It then distributes further, to a total width b_{em}, which is the width of slab assumed to carry the load (acting as a beam). The total width b_{em} is a function of the span type (internal or end), the load position within the span, and what physical behaviour is being verified (bending moment and longitudinal shear, or vertical shear resistance). Reference should be made to EN 1994-1-1 equations 9.2, 9.3 and 9.4.

The need for the limits given in 9.4.3 (5)

In 5) of this clause it is noted that 'nominal transverse reinforcement may be used without calculation' (i.e. assumed to be adequate) provided the following maxima are not exceeded for the 'characteristic imposed loads':

- Concentrated load 7.5 kN
- Distributed load 5.0 kN/m²

It is worth noting that, although EN 1994 1-1 clearly states these are limits for imposed loads, given the purpose of this clause other types of point and line loads should also be included in the verification.

It has long been assumed by many – including ourselves in P359 – that the inclusion of a 'squared' in the second of these limits was a 'typo', given that clause 9.4.3 concerns itself with point and line loads (not distributed loads). The wording in ECCS publication 087 (dated 1995) Design Manual for Composite Slabs[2] seemed to confirm this assumption. Some software has also, conservatively, misinterpreted this clause – for example using the defined contact area of a point load to determine a value per metre squared, to check against the second criterion.

The key to understanding what 5) is about is to consider the context. As noted above, it falls within a section of EN 1994-1-1 concerned with calculating the effective width of slab that may be assumed to support a concentrated load. That part of the width b_{em} that goes beyond b_m is a function of the transverse slab stiffnesses, and the definitions of b_{em} given in EN 1994-1-1 are for a typical slab. A slab that was subject to a very high concentrated load might not be typical – it could be designed to be appropriately strong and stiff in the direction of the ribs (its assumed span direction), but might then be relatively more flexible than 'typical' in the transverse direction (for which no explicit design is normally carried out). That relative flexibility would result in the concentrated load being carried over a narrower strip of slab.

So the intent of checking against the two limits defined in 5) is to ensure that the slab is not subject to excessive concentrated loads, so that it remains 'typical'. To do this the designer should consider all the loads on a given area of slab (between the supporting beams on all four sides), be they UDL, point loads or line loads, and check that:

- The heaviest concentrated load does not exceed 7.5 kN
- The sum of all the loads divided by the area of slab does not exceed 5.0 kN/m²

Unless both of these criteria are satisfied the slab should be designed considering the effects of transverse bending moments under the concentrated loads, with appropriate transverse reinforcement provided (see below). Alternatively, the effective width could be limited to b_m, so that no transverse distribution is assumed (or transverse slab stiffness needed). This option was explicitly stated in the ENV (so-called pre-standard) version of Eurocode 4[3].

It is important to recognise that these are 'rule of thumb' limits, so particularly unusual situations are worthy of more detailed analysis. For example, a combination of small UDL combined with a significant line load (the sum of which satisfied the 5.0 kN/m² limit), would result in very different behaviour from a large UDL combined with a small line load (also less than 5.0 kN/m²). The former situation would place greater demands on the ability of the slab to distribute load effects transversely. To avoid such situations a third limit that line loads should not exceed 5.0 kN/m was proposed in ECCS 087[2]. An alternative line load limit is given in Reference [5].

The fact that the UDL limit of 5.0 kN/m² does not allow significant concentrated loads to be supported in addition to the uniformly distributed loads typically present, is an indication that composite slabs are not well suited to carrying large concentrated loads.

Designing the slab for transverse bending

As noted above, if the stated load limits are exceeded then the slab must be designed explicitly for transverse bending, and appropriate transverse reinforcement provided. Whereas EN 1994-1-1 9.4.3(6) simply gives a general reference to EN 1992-1-1[4] for guidance, Reference [5] proposes a simple way of determining the transverse bending moment that can then be used in the standard design of a reinforced concrete beam strip that passes under the load.

By analogy with the load width b_m, the load length a_m is assumed to be given by:

$a_m = a_p + 2(h_f + h_c)$

Where h_f and h_c are the thickness of any finishes and depth of concrete above the deck, respectively, and a_p is the contact length of the load.

The transverse bending moment due to the load Q_{Ed}, per metre length (in the direction of the slab span) is then given by:

$$M_{Ed} = \frac{Q_{Ed}\,(b_{em}-b_m)}{8 \cdot a_m}$$

As a footnote it is worth remembering that software tends to consider one metre wide strips of slab – there is no facility to input the width of slab. Some post-processing of outputs in order to verify compliance with this clause may therefore be necessary.

References:

[1] BS EN 1994-1-1:2005, Eurocode 4 - Design of composite steel and concrete structures - Part 1-1: General rules and rules for buildings, BSI, 2005.

[2] ECCS 087 – Design Manual for Composite Slabs; Technical Committee 7 - Cold Formed Thin Walled Sheet Steel; Technical Working Group 7.6 - Composite Slabs, 1995.

[3] DD ENV 1994-1-1:1994, Eurocode 4. Design of composite steel and concrete structures. General rules and rules for buildings (together with United Kingdom National Application Document), BSI, 1994.

[4] BS EN 1992-1-1:2004+A1:2014, Eurocode 2: Design of concrete structures. General rules and rules for buildings, BSI 2004.

[5] Johnson, R. P, Wang, Y. C., Composite Structures of Steel and Concrete, Fourth edition, 2019; Wiley Blackwell.

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