Ramsay Maunder Associates
Finite Element Specialists and Engineering Consultants

Letter to Verulam (IStructE)

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Dear Editor of Verulam,

We would like to add to the discussion initiated by John Botterill (Verulam, 5th May 2010) on the width of slab to be considered to carry a concentrated load ("shear loads on slabs"), and the replies by Bill Wadsworth and Charles Goodchild (Verulam, 19th October 2010). The question of effective width raises interesting questions relating to the use of EC2, the use of elastic and limit analyses, and ductility.

EC2 is written as a general rather than a prescriptive code of practice, thus relying on the engineer to carry out appropriate structural analyses, or refer to standard solutions if they exist, rather than provide guidance rules for the concentrated load problem.

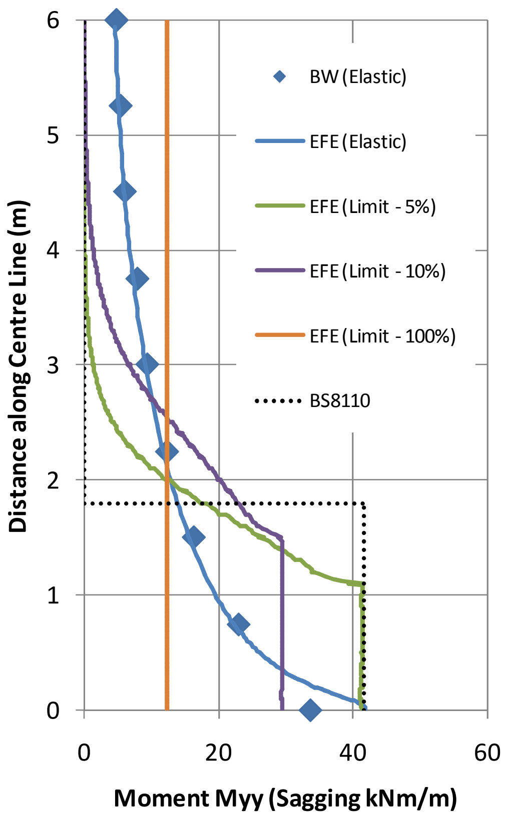

Figure 1: Bending Moments at Midspan

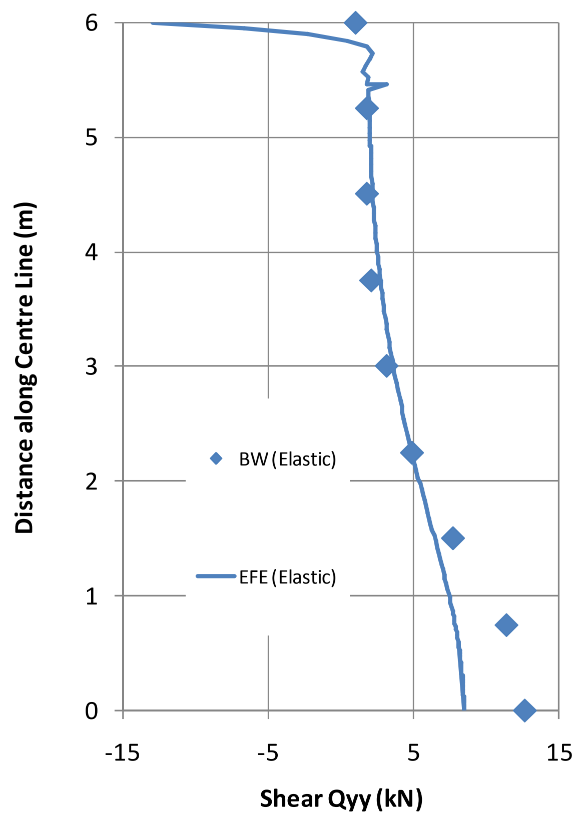

Figure 2: Reactions

Referring to the elastic analysis of the problem as defined by Bill Wadsworth, it would seem to us that finite element models can be used to provide reliably accurate distributions of moment and shear throughout the slab. We considered the case of a central concentrated load, and found that the distributions converged to values a little different from Bill's finite difference method based on a horizontal grid spacing of 0.75m parallel to the supports – Figures 1 and 2. We have confidence in our results since we have good agreement between both conforming and equilibrating finite element models (referred to as EFE in figures 1 and 2). We have assumed the load to be uniformly distributed over a square area of side length 0.2m which is also taken as the thickness of the slab. So the main difference in the moments occurs under the load, which might be expected, but a bigger difference occurs for the shear force at the centre of a support, and the finite element models recognise the concentrated downward reactions located at the ends of the supports.

So what moments and forces should be used in design, particularly if we want to justify designing for smaller moments in the neighbourhood of the load? EC2 allows us to exploit plastic methods and use limit analyses, although it doesn't appear to be prescriptive as regards ductility in this situation! We have carried out limit analyses based on the yield line method for upper bounds, and a method for lower bounds based on equilibrium finite element models (EFE), for various arrangements of orthotropic reinforcement (assuming equal top and bottom reinforcement for simplicity). Results from the yield line method indicate that a single circular fan mechanism is not the most critical mechanism, but rather some variation on the mechanism in Figure 3. The interesting feature of the lower bound results plotted in Figure 4 is that the region of slab that is fully utilised by yielding tends to form a well defined band for highly orthotropic reinforcement, and the width of this band agrees well with the dimensions of the corresponding yield line pattern. This gives us confidence in the limit solutions which agree as regards the limit load to within 10%. The results in figure 1 for bending moments across the 12m width of slab in Bill's example indicate the extent of moment redistribution from the elastic state.

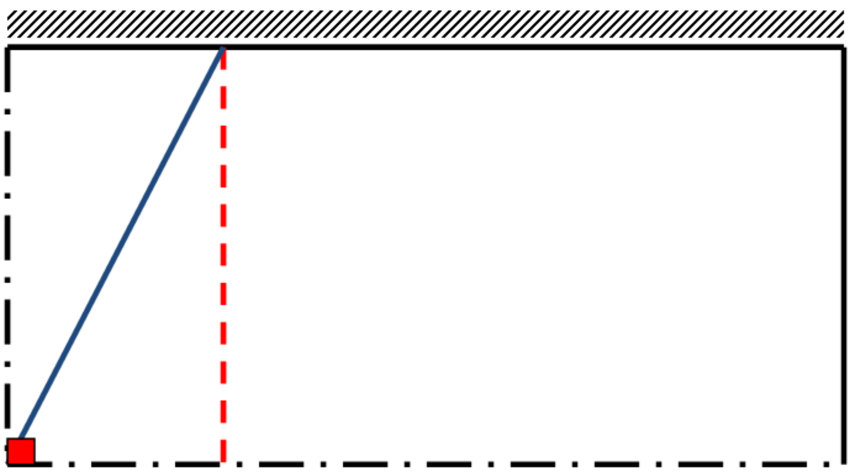

Figure 3: Yield-Line Pattern

So from the design point of view the limit analyses provide a rational way to redistribute moments throughout the slab, and this leads to much lower moments in the neighbourhood of the load. Can we safely base ULS design on these moments? This raises the question of ductility, as would a design based on a simple fan mechanism if this was appropriate, since with equal top and bottom reinforcement in the isotropic case this mechanism would imply the need for moment capacities of only some 8kNm/m (P/4π), instead of some 40kNm/m from the elastic analyses!! It would appear from Section 5.6 Plastic analysis in EC2 that rotation capacity needs to be checked, but do the same rules apply for slabs as in the current problem as for continuous beams? If so, how then is the value of a moment to be defined when we recognise that moment becomes a tensor quantity rather than a scalar?

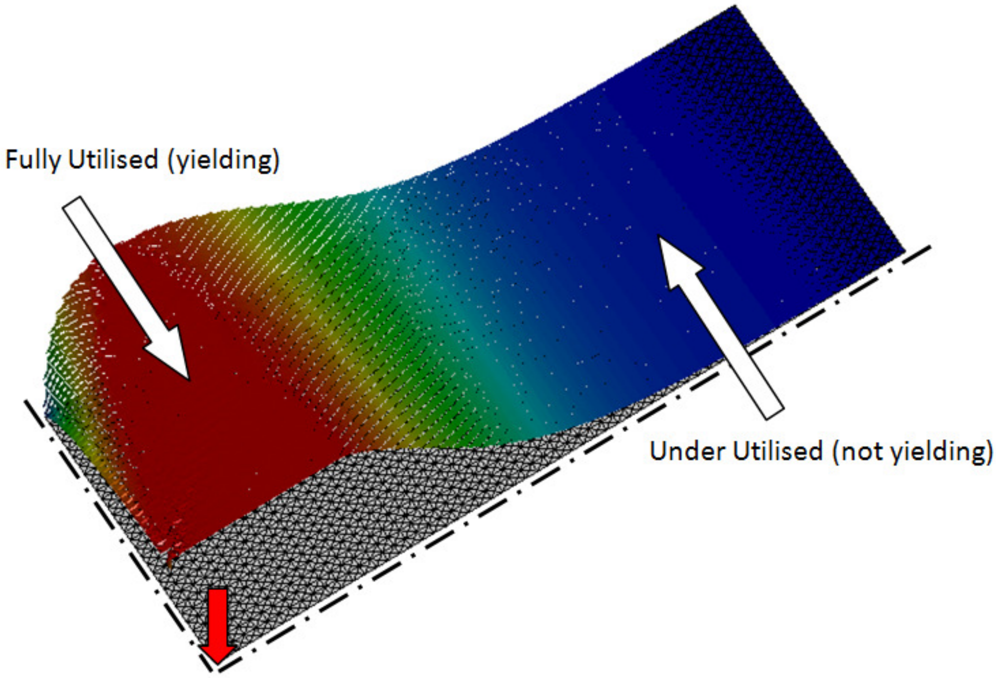

Figure 4: Contours of Utilisation from EFE

Further details of the equilibrium finite element models (EFE) used in this study and more comprehensive results may be seen at www.ramsay-maunder.co.uk.

Yours sincerely,

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