Partial factors - obscure objects of desire?

Part Two: Alastair Hughes reviews the choices available in the Eurocodes and questions 'what next?'. Part One (in the Nov/Dec 2012 issue of NSC) has been a long preamble; in this second part we come to the point.

Design values of actions

'Design values of actions' means more or less the same as 'factored loads'.

Leave aside 'equilibrium' (EQU) verifications in which a factor less than 1 is applied to 'favourable' permanent actions (such as self weight that counters overturning). Leave aside accidental and seismic design situations, and geotechnical (GEO) verifications which have unique complications of their own. Different factors may apply in all of these, and of course in serviceability calculations, but in the remainder of this article our focus is on ordinary everyday strength (STR) verifications in which all the action is 'unfavourable'.

To evaluate 'STR' design values of actions we are referred to Table A1.2(B) of EN 1990. As first encountered in the Standard, this seems rather obscure, but some light is shed when the algebra is replaced with numbers in Table NA.A1.2(B). Further elucidation can be gained from Table A.1 of SCI publication P361 (reproduced below), in which the partial (γ) factors and their combination (ψ) factors are multiplied out as they would apply in a typical design situation.

Recall that all these numbers are NDPs, so this table and the remarks which follow are valid only for buildings in the UK.

The choice

The Table offers two alternative formats. Confusingly, the first is labelled 'Eq. 6.10' (or '6.10' for short) and the second is 'Eq. 6.10a and Eq. 6.10b'. The latter option might better be described as '6.10a/b' as it is one or the other; the more onerous is taken. Clearly the intention was that each nation should come down in favour of **either** 6.10 **or** 6.10a/b, because NOTE 1 of the EN declares that 'the choice…will be in the National Annex' – though neither is recommended over the other. The UK NA fails to oblige, and declares in a NOTE 1 of its own that 'Either expression 6.10, or expression 6.10a together with and 6.10b may be made, as desired' (sic). That sentence should have been intercepted by BSI's editorial team, but in other words 'you can choose whichever you like best'. Hence the title of this article.

Which option is to be the object of our desire? The key difference is that 6.10b introduces a modification factor ξ, 0.925 in UK, which reduces the factor on self weight (permanent action) from 1.35 to 1.25. This means that 6.10b alone would always be advantageous over 6.10, because they treat variable actions just the same: the #1 variable action is factored 1.5, with #2 and any others subject also to combination (ψ) factors. Combination factors are less than 1, to reflect the statistical improbability that

Table A.1 Partial, combination and reduction factors for the STR and GEO ultimate limit states for buildings in the UK

Expression	Unfavourable Permanent action: Self-weight	Unfavourable Variable actions: Imposed floor loads	Unfavourable Variable actions: Wind loads	Unfavourable Variable actions: Snow loads *
6.10	$\gamma_{G,j,sup}$ = 1.35	$\gamma_{Q,1}$ = 1.5	$\gamma_{Q,i}\psi_{0,i}$ = 1.5 × 0.5 = 0.75	$\gamma_{Q,i}\psi_{0,i}$ = 1.5 × 0.5 = 0.75
	$\gamma_{G,j,sup}$ = 1.35	$\gamma_{Q,i}\psi_{0,i}$ = 1.5 × 0.7 = 1.05	$\gamma_{Q,1}$ = 1.5	$\gamma_{Q,i}\psi_{0,i}$ = 1.5 × 0.5 = 0.75
	$\gamma_{G,j,sup}$ = 1.35	$\gamma_{Q,i}\psi_{0,i}$ = 1.5 × 0.7 = 1.05	$\gamma_{Q,i}\psi_{0,i}$ = 1.5 × 0.5 = 0.75	$\gamma_{Q,1}$ = 1.5
6.10a +	$\gamma_{G,j,sup}$ = 1.35	**$\gamma_{Q,1}\psi_{0,1}$ = 1.5 × 0.7 = 1.05**	$\gamma_{Q,i}\psi_{0,i}$ = 1.5 × 0.5 = 0.75	$\gamma_{Q,i}\psi_{0,i}$ = 1.5 × 0.5 = 0.75
	$\gamma_{G,j,sup}$ = 1.35	$\gamma_{Q,i}\psi_{0,i}$ = 1.5 × 0.7 = 1.05	**$\gamma_{Q,1}\psi_{0,1}$ = 1.5 × 0.5 = 0.75**	$\gamma_{Q,i}\psi_{0,i}$ = 1.5 × 0.5 = 0.75
	$\gamma_{G,j,sup}$ = 1.35	$\gamma_{Q,i}\psi_{0,i}$ = 1.5 × 0.7 = 1.05	$\gamma_{Q,i}\psi_{0,i}$ = 1.5 × 0.5 = 0.75	**$\gamma_{Q,1}\psi_{0,1}$ = 1.5 × 0.5 = 0.75**
6.10b	$\xi\gamma_{G,j,sup}$ = 0.925 × 1.35 = 1.25	$\gamma_{Q,1}$ = 1.5	$\gamma_{Q,i}\psi_{0,i}$ = 1.5 × 0.5 = 0.75	$\gamma_{Q,i}\psi_{0,i}$ = 1.5 × 0.5 = 0.75
	$\xi\gamma_{G,j,sup}$ = 0.925 × 1.35 = 1.25	$\gamma_{Q,i}\psi_{0,i}$ = 1.5 × 0.7 = 1.05	$\gamma_{Q,1}$ = 1.5	$\gamma_{Q,i}\psi_{0,i}$ = 1.5 × 0.5 = 0.75
	$\xi\gamma_{G,j,sup}$ = 0.925 × 1.35 = 1.25	$\gamma_{Q,i}\psi_{0,i}$ = 1.5 × 0.7 = 1.05	$\gamma_{Q,i}\psi_{0,i}$ = 1.5 × 0.5 = 0.75	$\gamma_{Q,1}$ = 1.5

Note:

All factor values given above are taken from the National Annex to BS EN 1990.

Shaded boxes indicate the 'leading variable action'.

Bold text indicates the 'main accompanying variable action'.

The remaining variable actions are the 'other accompanying variable actions'.

\+ The same values are obtained for each of the three variations of expression (6.10a) (i.e. when each variable action in turn is treated as the main accompanying action) because the UK National Annex specifies the same value for $\gamma_{Q,1}$ and $\gamma_{Q,i}$.

* $\psi_{0,1}$ and $\psi_{0,i}$ values for snow are for buildings at an altitude of less than 1000 m above mean sea level.

more than one independent variable action will simultaneously act in full. Each significant variable action (or group of actions, if they don't act independently) is ranked #1 in turn, and all the combinations include all the actions that can coincide.

But it cannot be taken for granted that 6.10b is always available. 6.10a might be more onerous. Its purpose is to prevent the overall average load factor getting too low in situations where the load is largely dead. 6.10a factors the permanent action by 1.35, just like 6.10, but applies the combination factors to **each and every** coincident variable action (with no influence of rank). 6.10a would become more onerous than 6.10b if self weight were to exceed 4.5 times payload, which is unlikely (but not impossible – a concrete roof slab for instance). Beware however of storage loads, which for obvious reasons are not reduced in combination. Also beware of constructional situations, such as the wet concrete condition in composite construction, for which EN 1991-1-6 and its UKNA prescribe $\psi = 1$. Expression 6.10a then becomes not only more onerous than 6.10b but also identical to 6.10, effectively denying the choice. Another trap for the unwary is that ψ must be taken as 1 when taking advantage of storey based live load reduction (though this Principle in EN 1991-1-1 3.3.2 (2) does not apply to area-based LLR, so α_A and ψ may apply together!). Can the interactions of all these rules have been reasoned out by a controlling mind?

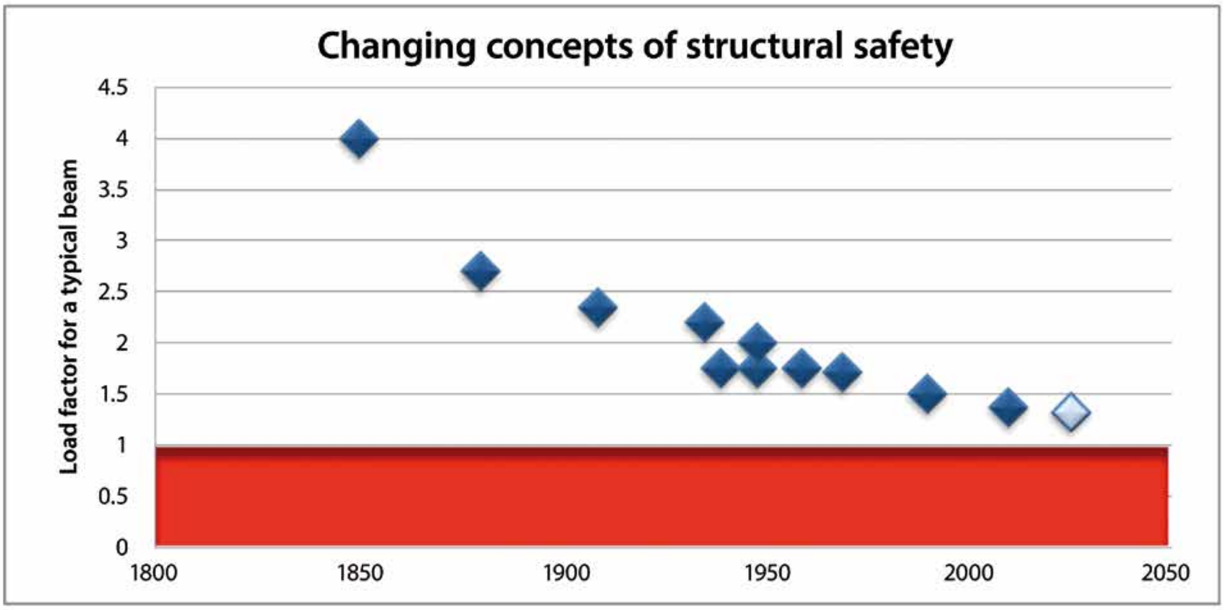
It tends to be assumed, in SCI publications and other guidance, that the automatic choice will be the 6.10a/b option because 6.10 can never be advantageous, even when 6.10a prevails over 6.10b. However 6.10 is relatively foolproof and straightforward to apply, which may be why the UK committee, like its European counterpart, sits on the fence. This author would be reluctant to criticise a designer who prefers 6.10 for its simplicity, or simply judges 1.35 to be quite low enough. You might be inclined to agree, if faced with an unpropped composite floor in which 'ponding' has increased the thickness of concrete at midspan by 20% - due to just an inch (25 mm) of deflection at the wet concrete stage.

Remarkably, the RV for ξ is only 0.85, reducing the 6.10b permanent load factor still further to 1.15 in a nation which adopts it. Conspiracy theorists might point a finger at the European concrete industry! (To be fair, it should be recognised that the lower ξ makes it slightly less unusual for 6.10a to prevail over 6.10b.)

But perhaps it is even more remarkable that the UK committee chose to leave a non-negligible component of the safety factor subject to the 'desire' of the designer. Typically the difference between the two options amounts to 3 to 4% in overall safety factor (on top of the circa 5% reduction previously identified). This latitude is highly unusual in Design Standards. We can only assume that 6.10a/b defines today's officially acceptable level of safety (see chart below).

Overall, the margin embodied in our structural safety paradigm for buildings has never been lower. Of course, a similar statement could have been made after most Code changes over the past century, and it is entirely proper to take a dividend in return for investment in better design. Nevertheless, as load factors decline below the psychologically important 1.5 level the question: 'how low can they go?' may pose itself. This article will not attempt an answer.

To conclude, a note of sympathy for the standardisers. Given the nature of the problem and its intractability, it may well be impossible to satisfy all the conflicting national traditions and interest groups. In an attempt to capture every nuance, and provide something for everybody, an all-embracing framework has been devised which is more complicated than anybody could have wished. For the time being nations can pick and choose, writing in their own numbers, but the force of destiny has some hard nuts to crack before true pan-European harmony can be proclaimed.



This chart is indicative of the refinement in load factor over a period which roughly corresponds to the existence of structural engineering as a profession. 19th century cast iron structures were designed to resist 4 times the load to which they would be subjected, partly to allow for hidden defects. In the permissible stress era (most of the 20th century) load factors are deduced for a mild steel beam of shape factor 1.15 (as in The Steel Skeleton Volume 2 Chapter 16). Permissible stresses progressed from 6.5 Tsi (101 MPa) at the time of the Forth Bridge to 7.5 Tsi (116 MPa) in LCC 1909 to 8 Tsi (124 MPa) in BS 449:1935, then 10 Tsi (154 MPa) in a 1939 emergency amendment which was adopted permanently after the war. (BS 449:1948 also prescribed a load factor of 2 for its 'fully rigid' design method.) The 1959 increase to 10.5 Tsi (162 MPa) reflected an increase in minimum yield stress from 15.25 Tsi (S236) to 16 Tsi (S247) in BS 15. Metrication nudged 10.5 Tsi up to 165 MPa cf BS 4360:Part 2:1969's S245 [actually a reduction from 16.5 Tsi (S255) in BS 4360:1968]. Post 1990, factors are explicit; equal live and dead load is assumed; hence 1.5 as the average of 1.4 and 1.6, and so on. The pale blue marker is speculative, to be inked in if the UK were to adopt RVs in the Eurocode by (say) 2025.