

# Factors of ignorance?

A student of structural design could be forgiven for believing that in modern codes safety factors are determined with great precision by a complex process far removed from the 'factors of ignorance' which engineers relied on in days gone by. In place of simple 'global' factors, codes now specify complex arrays of partial safety factors which combine to adjust overall safety factors up and down to get precisely the correct value for each type of loading or design situation.

The latest draft Eurocodes are the culmination of decades of international effort and they introduce a number of innovations. They give detailed recommendations for load factors, materials factors and load combination factors — and their supporting documents discuss elaborate statistical calibration techniques based on target notional probabilities of failure and B-factors.

In the face of such sophistication, it seems almost churlish to question the results. However in structural engineering, as in so many things, 'the proof of the pudding is in the eating'. How do the safety factors in the latest draft Eurocodes compare with the codes we have used up to now? Have the results been worth the wait?

The BS 8110 safety factors are summarised in Table 1. The safety factors recommended in the latest draft Eurocode 2 are summarised in Table 2.

Table 3 compares the overall safety factors from the latest draft Eurocode 2 (reinforced concrete) with those in BS 8110. As safety levels in both the proposed Eurocodes and existing limit state codes like BS 8110 are both claimed to have been set by comparison with past practice, the safety factors from CP 114 are also shown for interest. For overturning stability, CP 114 gave no explicit recommendations, so the recommendations of the steel permissible stress code, BS 449 are shown; in the interests of historical accuracy, the figures quoted are those which it recommended before it was revised to 'bring it into line with BS 5950'.

The CP 114 safety factor was generally 1.8, with a 25% overstress allowed for load combinations including wind loads. BS 449 required a safety factor against overturning of 1.2 (dead load) or 1.4 (imposed and wind loads).

In the comparisons made between the different codes, the combination

*Alasdair Beal asks how the safety factors in the latest draft Eurocodes compare with the codes we have used up to now. Have the results been worth the wait?*



(Dead Load+Live Load) is assumed to comprise 50% DL+50%LL. (Dead Load+Live Load+Wind Load) is assumed to comprise 35%DL+35%LL+30%WL. For member design, Table 3 compares EC 2 with BS 8110 and CP 114.

## Comparison

The comparison reveals some interesting differences between the codes, as follows:

1. The 'CP 114' basic safety factor on strength is rather more conservative than the more recent codes but it gives results which are reasonably consistent and logical.
2. For overturning stability, the old BS 449 safety factors seem sensible. BS 8110 is a bit of a mess: very conservative for dead load, reasonable for wind load acting alone but obviously unsafe for DL+LL+WL. EC 2 gives reasonable results for dead load and live load but is very odd for wind loads — too low for DL+LL+WL and too high for WL acting alone.
3. In CP 114 and BS 8110 the critical load combination for design is usually DL+LL. However in Eurocodes, the critical load combination is DL+LL+WL, making design more complicated.
4. Compared with CP 114, EC 2 requires a lower safety factor for DL+LL but a higher safety factor for combinations including wind load — particularly where wind acts alone. The EC 2 safety factors for combinations including wind load are much higher than BS 8110. Do the drafters of EC 2 know something we don't, or have they made a mistake?
5. BS 8110 and EC 2 specify a lower safety factor for structures which support DL+LL+WL than those which support only WL, yet the

TABLE 1: BS 8110 safety factors

Combination	DLmax	DLmin	LL	Water	Earth P.	Wind
1. DL+LL	1.4	1.0	1.6	1.4	1.4	-
2. DL+WL	1.4	1.0	-	1.4	1.4	1.4
3. DL+LL+WL	1.2	1.2	1.2	1.2	1.2	1.2

TABLE 2: Draft Eurocode 2 safety factors

Load	Max.	Min.	Combination: reduced value
<b>Strength</b>			
Permanent	1.35	1.00	-
Variable	1.50	0	0.7_1.5=1.05
Variable (wind)	1.50	0	0.6_1.5=0.90
<b>Overturning</b>			
Permanent	1.10	0.90	-
Variable	1.50	0	0.7_1.5=1.05
Variable (wind)	1.50	0	0.6_1.5=0.90

Materials factor (reinforcement) = 1.15

TABLE 3: Comparison of safety factors

Safety factors on strength					
Loading	DL+LL	DL+LL+WL	WL	Earth P.	Water P.
CP114	1.8	1.44	1.44	1.8	1.8
BS8110	1.575	1.26	1.47	1.47	1.47
EC2	1.64	1.46	1.725	1.55	1.55/1.725*

\*the lower figure applies if the water pressure is permanent, the higher if it is variable.

Safety factors on overturning				
	DL	DL+LL	DL+LL+WL	WL
(BS449)	1.2	1.4	1.4	1.4
BS8110	1.4	1.5	1.0	1.4
EC2	1.22	1.44	1.31	1.67

potential consequences of failure are potentially much more serious.

6. For laterally-loaded members, the differences between the codes are remarkable. In CP 114 the safety factor was constant for dead load, live load, earth pressure and water pressure and a lower safety factor was allowed for load combinations including wind load. In BS 8110, the safety factor on earth pressure and water pressure is reduced to the same level as wind load. EC 2 also reduces the safety factor for earth pressure (because it is a 'permanent' load) but it increases the safety factor on both water pressure and wind load (because they are 'variable' loads).

### Comments

The variations in EC 2 safety factors for member strength for different situations do not make sense as they stand and there are obvious practical objections to making DL+LL+WL the critical load combination for general design.

Part of the problem is that EC 2 classifies load factors on the basis of whether loads are 'permanent' or 'variable'. However, these classifications are a poor guide to the predictability of a load. Water pressure may be variable but it is known more precisely than any other load, whereas earth pressure may be permanent but it is often the least accurately known loading of all. Then consider the differences between ordinary

imposed load and the theoretical loading from extreme wind gusts – both are 'variable' loads but they are hardly of equal importance. Does it really make sense to give them both the same safety factor?

The 'correct' values to give safety factors for each situation are to some extent a matter of opinion. However what are we to make of EC 2 when it reduces the safety factor for DL+LL but increases it for wind load, or when it reduces the safety factor for earth pressure but increases it for water pressure? It is hard to escape the conclusion that it is 'just plain wrong'.

It is often claimed that partial safety factor systems are better than traditional 'global' safety factors because they allow safety factors to be increased or decreased for different loadings. However, for this approach to be credible, the adjustments need to be rational and well worked-out. Simply allocating higher and lower values of safety factor on the basis of whether loads are 'variable' or 'permanent' is crude and arbitrary, so maybe the poor Eurocode results should not come as a surprise. However, what is the point of a complex partial factor code which produces less consistent, less rational results than a traditional permissible stress code?

Eurocodes apply the 'Turkstra principle' to load combinations: when two types of imposed load are present, the load factor on one is reduced by a 'combination factor'. It sounds

like a nice idea, but does it make sense to have a lower safety factor on a structure supporting DL+LL+WL than on one which supports only WL? Is it right to specify a lower safety factor for a major building than for a garage signpost? Sometimes ideas that sound nice in principle do not work out so well in practice.

How could such obvious errors have slipped through the drafting and assessment process? Part of the problem is that in Eurocodes the assessment of safety factors is very fragmented: materials factors are defined in the design code, load factors for different load classes are defined in a different code, and the rules for allocating real loads to the load classes are in yet another code. When answers are generated by combining rules and information from separate documents in this way, perhaps we should not be surprised if the results are rather odd and irrational.

Today's Eurocodes are the product of a drafting process which began almost 50 years ago, in the work of the CEB. Are the proposed changes in safety factors the result of research which shows that past practice is wrong, or are they simply the result of committee decisions without an underlying technical logic? Are the proposed new safety factors the product of technical breakthroughs, or are they just more 'factors of ignorance' dressed up in fancy new clothes? SE

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