Factors of Ignorance?

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A student of structural design could be forgiven for believing that in modern codes the 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?

Table 3 below compares the overall safety factors from the latest draught Eurocode 2 (reinforced concrete) with those in BS8110. As safety levels in both the proposed Eurocodes and existing limit state codes like BS8110 are both claimed to have been set by comparison with past practice, the safety factors from CP114 are also shown for interest. For overturning stability, CP114 gave no explicit recommendations, so the recommendations of the steel permissible stress code BS449 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 BS5950'.

The CP114 safety factor was 1.8 generally, with a 25% overstress allowed for load combinations including wind loads; BS449 required a safety factor against overturning of 1.2 (dead load) or 1.4 (imposed and wind loads). The BS8110 safety factors are summarised in Table 1. The safety factors recommended in the latest draft EC2 are summarised in Table 2.

Table 1 - BS8110 Safety Factors

Combination	DLmax	DLmin	LL	Water	Earth P.	Wind
1. DL+LL	1.4	1	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
Strength			
Permanent	1.35	1	_
Variable	1.5	0	0.7x1.5 = 1.05
Variable (wind)	1.5	0	0.6x1.5 = 0.9
Overturning			
Permanent	1.1	0.9	
Variable	1.5	0	0.7x1.5 = 1.05
Variable (wind)	1.5	0	0.6x1.5 = 0.9
Materials factor (reinforcement) = 1.15			

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In the comparisons made between the different codes, the combination (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, the table compares EC2 with BS8110 and CP114.

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	1.25	1.47	1.47	1.47
EC2	1.64	1.46	1.725	1.55	1.55/1.725*
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	1.4	
EC2	1.22	1.44	1.31	1.67	

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

Comparison

The comparison reveals some interesting differences between the codes.

1. The 'CP114' basic safety factor on strength is rather more conservative than the more recent codes but it gives results which are reasonably consistent and logical. However BS8110 and EC2 both show some rather odd anomalies.
2. For overturning stability, the old BS449 safety factors seem sensible. BS8110 is a bit of a mess: very conservative for dead load, reasonable for wind load acting alone but obviously unsafe for DL+LL+WL. EC2 give reasonable results for dead load and live load but very odd for wind loads - too low for DL+LL+WL and too high for WL acting alone.
3. In CP114 and BS8110 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 CP114, EC2 requires a *lower* safety factor for DL+LL but a *higher* safety factor for combinations including wind load - particularly where wind acts alone. The EC2 safety factors for combinations including wind load are much higher than BS8110. Do the draughters of EC2 know something we don't, or have they made a mistake?
5. BS8110 and EC2 specify a lower safety factor for structures which support DL+LL+WL than those which support only WL, yet the potential consequences of failure are potentially much more serious.
6. For laterally-loaded members, the differences between the codes are remarkable. In CP114 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 BS8110, the safety factor on earth pressure and water pressure is reduced to the same level as wind load. EC2 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

1. The variations in EC2 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.
2. Part of the problem is that EC2 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?
3. 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 EC2 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'.
4. 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?
5. 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'. 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 don't work out so well in practice.
6. How could such obvious errors have slipped through the draughting and assessment process? Part of the problem is that in Eurocodes the assessment of safety factors is a very fragmented process: 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 an answer is generated by combining rules and information from separate documents in this way, maybe we should not be surprised if the results are rather odd and irrational.

Today's draught Eurocodes are the product of a draughting process which began almost 50 years ago, in the work of the CEB. Are the proposed changes in safety factors and design requirements 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 'factors of ignorance' dressed up in fancy new clothes?