Partial factors - obscure objects of desire?

In a two part article, Alastair Hughes, formerly of the SCI, delves into the UK's structural safety culture, remarks on an uncharacteristic permissiveness and questions 'what next?' Part One sets the scene.

Introduction

This is an article about load factors which are set by EN 1990 and its UK National Annex. They apply to all buildings, whatever they are made of.

Load factors ought not to be considered in isolation. They are only part of the overall safety margin – hence the name 'partial factor'. Resistance factors, by which the material strength is divided, provide the other part. Known as 'material' factors, they depend on the type of design situation as well as material and are given in EN 1992, 3, 4 etc and respective National Annexes.

γ-factors of both kinds are in the range 1 to 1.5 or thereabouts. Committees determine their values by juggling statistics, reliability theory and experience.

In principle the effect of the action multiplied by the load factor must not exceed the resistance divided by the resistance factor. The load factor allows for a degree of overload and the material factor for a degree of understrength and/or undersize. Both these degrees are sufficient to make the 'design' (factored) values highly improbable, though statistical improbability knows no bounds and a line has to be drawn, usually at the 95% level. If there is a 5% probability that each is beyond the line, there is a negligible probability that both will be.

Routinely, but unconservatively, neglected - some examples:

- Minor second order effects
- Minor dynamic magnification
- Sub-'significant' orography
- Underweight sections: ±4% rolling tolerance could lead to 6% shortfall in bending resistance

Typically these are taken into account only when above 10% or thereabouts. Below this threshold, our factors are expected to cover them.

But that's an oversimplification, because the overall safety factor has other things to account for: routine approximations (maybe shading into minor errors?) in design and execution, the possibility that the statistical edifice may not be quite as soundly based as is supposed, the ravages of time and a general feeling that something ought to be kept in reserve for the unforeseen. A case can therefore be made for a third factor, dedicated neither to load nor to resistance, and quantified solely from wise judgement and experience. Although EN 1990 provides a framework to allow this possibility (a 'model uncertainty factor') it is not widely adopted. In the UK the load and material factors together have to generate the margin of safety that is right for society. The balance between them does matter, because load factors act alone in non-strength-related situations such as overturning. This was the motive for abandoning the pre-1970 permissible stress approach, which was equivalent to a material factor alone.

The subsequently introduced load factors differentiate between live and dead load. Given the way we arrive at design loads for buildings, it is debatable whether that complication has added to the sum total of structural safety, but it is here to stay, having been retained and elaborated in EN 1990. (In fairness, it should be pointed out that Eurocodes are not just for buildings and anyone tasked with bridging the Strait of Messina would be very much in favour of differential load factors.)

Material factors vary greatly, for a variety of reasons – not all connected with variability of material, as a few examples can demonstrate. Steel is an interesting case because ostensibly its strength is unfactored, with γ_{M0} of 1.0. It might appear that the only safety factor is the load factor, which would be worrying, but in fact there is a concealed material factor, or margin, in that the yield strength is a 'guaranteed minimum' rather than a truly characteristic value. There is, in some situations, a further hidden reserve from strain hardening. Rebar attracts a γ_M of 1.15, which may reflect that it has been strain hardened in the manufacturing process.

Concrete is given a material factor of 1.5, seemingly generous even for an inherently variable material, but in reality part of it represents a conversion factor between the strength of a properly made cylinder (crushed after 28 days under water) and that of concrete in the actual structure (cast, compacted and cured under site conditions).

Bolts are factory products, precise in dimensions and relatively consistent in strength, yet they are given a γ_{M2} of 1.25, which might be to allow for unequal sharing of load between bolts in common jointing situations. Or might it be a reflection that these small but important components warrant an extra dose of safety on cost-benefit or consequences-of-failure grounds? Perhaps it doesn't help to probe; for one reason or another it just seems sensible.

So let us conclude this preamble with the observation that in reality overall safety factors probably, and rightly, owe as much to custom and common sense as to reliability theory and statistics. Indeed the statistical edifice can be undermined, e.g. by sheeting suppliers who deliberately, and legally, roll down to the lower end of the rather generous thickness tolerance allowed by their product standard. Design methods based on the nominal thickness lose their validity. That's not a bad example of the kind of unforeseen which our overall safety factors get called upon to cover. On the other hand, we routinely overdose on safety (or make prudent provision, if you prefer) when we declare a 'characteristic' office occupancy loading greater than the standard 2.5 kPa, itself a figure which only begins to approach the 95% level after it has been subject to 50% Live Load Reduction (LLR) in a column more than ten floors down.

What matters is that enough of an overall safety margin is there when it is needed. In that event, the manner in which it is built up, or broken down, seems pretty secondary.

National differences

The Eurocode system allows individual nations to set their own partial factors, either because it was felt that some are more risk-averse than others or because they couldn't agree. Perhaps mainly the latter, in view of the intricate and arguably somewhat self-defeating subdivision of these factors, only part of which is touched upon above. What the Eurocode system does dictate is a format, and a nomenclature, within which the subdivision takes place. Partial factors are 'Nationally Determined Parameters' (NDPs), for each of which a 'Recommended Value' (RV) is given, but nations remain at liberty to substitute their own. In theory, NDPs allow for differences in climate or 'way of life'. The latter could, presumably, embrace structural safety culture and expectations of execution quality. The intention is that a time will come when the system will no longer tolerate such differences (other than the climatic ones) and standard values will apply from Aberdeen to Zagreb. The UK has a treaty obligation to progress towards this vision of harmony.

By and large current UK partial factors have been set by a process of 'calibration' designed to give outcomes similar to the previous British Standards. But it has to be conceded that in the limit calibration is antithetical to progress, and that if Eurocodes are more advanced, scientific and accurate, it is safe to trim the partial factors a little. That will reward users, clients and society at large for the extra design effort, and lubricate the changeover. In fact it is the load factors rather than the material factors that have been trimmed. Substituting 1.35 and 1.5 for the familiar 1.4 and 1.6 lowers the overall average factor by something in the order of 5%, and that's not the end of the story. This truly political decision is applicable to all buildings, regardless of material, and is communicated in NA.2.2 of the NA to BS EN 1990:2002.

In Part Two next issue: permutations and combinations in everyday strength verifications.