The future of live load reduction – part one

Although EN 1991-1-1:2002's recommendations for live load reduction are somewhat neutered by its UK National Annex, there remain subtle differences from BS 6399-1. In Part One Alastair Hughes examines how the new regime operates today for a UK building designed to the Eurocodes. Part Two will propose a way forward.

Introduction

Live load reduction (LLR) is familiar to all UK structural designers. It's an acknowledgement that prescribed occupancy loads per square metre (q_k), which need to represent dense local gravity loading imposed on a short span slab or beam, are well in excess of the truly characteristic loading averaged over a large extent of floor. The very densest concentrations are represented by separately applied roving point loads (Q_k) but in practice nearly all steel frame members are sized to resist the effects of q_k. This represents the combined action of feet, furniture, equipment and everything else that is imposed on a floor, treated as if uniformly distributed.

Currently designers can choose either storey-based LLR, which can generate up to 50% reduction (for a member or foundation supporting 11 or more storeys), or area-based LLR, which allows a relatively modest reduction, up to 25% (for a member supporting 250 m² or more) – but not both. And there is always the option of ignoring LLR completely, either for simplicity (if the benefits are not worth pursuing) or because it is judged prudent for the particular building or floor in question.

Virtually all tall building designs take advantage of storey-based LLR, but use of area-based LLR is much less routine. It can, nevertheless, deliver worthwhile reductions for long span beams and the columns which support them.

Eurocode 1 retains both these approaches. Its reduction factors are Nationally Determined Parameters (NDPs) for which it offers Recommended Values (RVs). For the time being, the UK National Annex (UKNA) declines the RVs. Familiar formulae still prevail, therefore, but all is not as before.

European background

A comparison between the pre-existing national formulae for LLR might be said to present the European harmonization challenge in microcosm. Figures 1 and 2, extracted from *http://eurocodes.jrc.ec.europa.eu/doc/WS2008/EN1991_2_Malakatas.pdf*, graphically portray the variety of national practice. In these graphs n = number of qualifying stories supported, A = area supported, in m², and the reduction factor $\alpha = 1 - [\%LLR]/100$. Some countries made a distinction between occupancy categories A/B and C/D, treating the latter much less generously.

At this point a summary of the occupancy categories may be helpful: (see table at bottom of page)

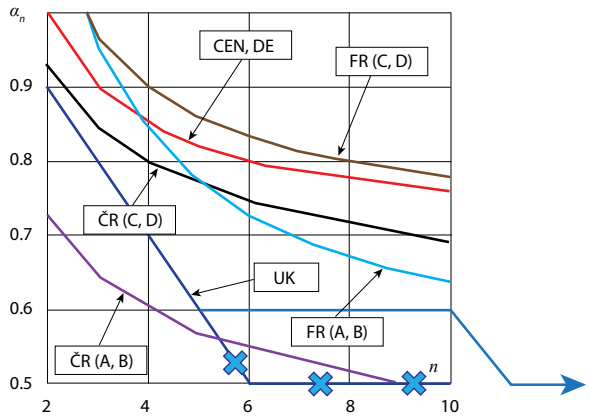

Figure 1 Storey-based LLR

Note the correction to the lowest part of Figure 1's blue line; for the UK α_n remains at 0.6 for n = 5 to 10, only dropping to 0.5 for n = 11+, beyond the right hand edge of the original graph. Even with this correction the UK looks relatively generous with storey-based LLR, but quite the opposite where area-based LLR is concerned. Figure 2 is a little deceptive in this respect, as it does not extend beyond 60 m² of supported area. In practice, many members collect load from a greater floor area.

	CATEGORY	OCCUPANCY	QUALIFYING FOR AREA-BASED LLR?	QUALIFYING FOR STOREY-BASED LLR?
FLOORS	A	Residential	Yes	
	B	Office	Yes	
	C	Assembly	Yes*	Yes
	D	Retail	Yes*	Yes
FLOORS AND ROOFS	E	Storage, industry, plant	No	
	F	Parking (cars)	No mention	No
	G	Fire appliances etc	No mention	No
ROOFS	H	(maintenance and repair only)	No	
	I	As A, B, C or D above	Yes (* if C or D)	No
	K	Helicopters	N/A (point loads)	

* EN 1991-1-1 (RV) restricts area-based LLR to 40% (instead of 50%) for these categories; UKNA limit is 25% regardless.

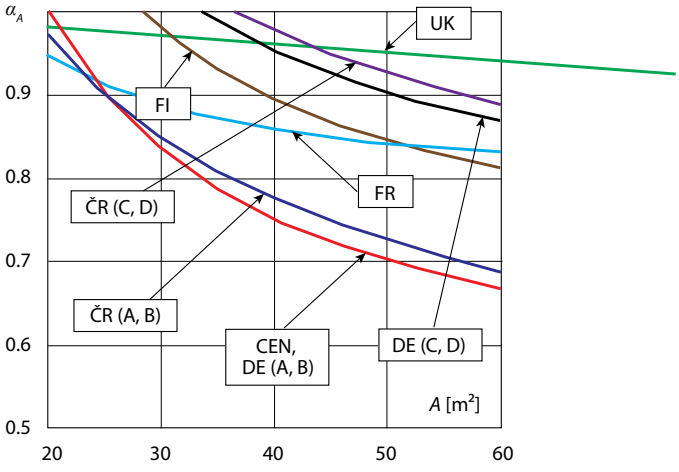

Figure 2 Area-based LLR

The UK's lower limit to α_A of 0.75 (a maximum reduction of 25%) ensures that storey-based LLR is advantageous if $n > 3$. For $n = 3$, area-based LLR becomes advantageous if the area at each level exceeds 67 m²; for $n = 2$, area-based LLR becomes advantageous with 50 m² at each level. For $n = 1$, and for beams, only area-based LLR is available.

European recommendations

The European committee's own formulae, which can be found in notes to EN 1991-1-1 6.3.1.2, look rather obscure at first sight because they involve the combination factor ψ_0. However ψ_0 (found in EN 1990 Table A1.1) is equal to 0.7 for occupancy categories other than E. For the categories to which LLR may apply, the formulae can therefore be simplified as follows. [NB If referring to EN 1991-1-1, make sure you have the 2009 version to hand. Its predecessor is seriously incorrect.]

For storey-based LLR:

$\alpha_n = 0.7 + 0.6/n$ (for $n > 2$)

This is the red line labelled CEN in Figure 1.

Under this regime, only 20% LLR is available 6 stories down, and only 29% 60 stories down. However area-based LLR is likely to be more advantageous:

$\alpha_A = 0.5 + 10/A$ (A in m²)

≥ 0.6 for categories C and D

This is the red line labelled CEN in Figure 2, which seems remarkably generous: for example 30% LLR for a beam supporting 50 m², compared with 5% (probably ignored) in UK practice. Restricting LLR at 40% for categories C and D presumably recognizes the potential for crowd loading in assembly and retail areas.

There is no rule against using area-based LLR for columns, so if a column supports 84 m² of offices per level the reduction available 6 stories down is 48%, and even directly below the top floor 38% can be taken. Given these RVs, it would be difficult to see a future for storey-based LLR, and this may be a deliberate policy; it is arguable that the total area matters more than the number of levels it is distributed over. However we need to remind ourselves that the RVs have not been adopted in the UK, where our relatively unproductive area-based LLR formula remains just as in BS 6399-1:1966:

$\alpha_A = 1 - A/1000$ (A in m²)

≥ 0.75

This is the green line labelled UK in Figure 2.

Some questionable provisions and interpretations

There is a further provision in EN 1991-1-1 3.3.2 (2) which is hostile to storey-based LLR: ψ must be taken as 1 when taking advantage of α_n. That is to say: no combination factor on floor loads that have been reduced by αn in design situations where wind or snow is the #1 variable action. It is difficult to fathom what this rule is intended to guard against, or why it should apply to α_n but not to α_A. But there it stands, not just an application rule but a 'Principle', anointed with a special kind of immutability! Leaving aside this subtlety, readers might (or might not) appreciate a reminder that this tedious and easily overlooked requirement is normative, not for national choice, and therefore applies already to Eurocode design for buildings in the UK.

Could it have been the intention of the European committee that both α_n and α_A can apply simultaneously to (e g) a column supporting 60 stories

(which might then enjoy over 60% LLR)? Surely not, but the only stipulation to the contrary is in the UKNA.

[It might be argued, by connoisseurs of Eurocode clause headings, that α_A is for beams and α_n is for columns, exclusively, but that interpretation would deny columns the reductions available to the beams they support – illogical, and contradicted by the UKNA's explicit permission to use α_A for columns.]

For mixed use buildings (such as 20 stories of hotel over 40 of offices) code literalists will note that EN 1991-1-1 6.2.1 (4) states that imposed loads '**from a single category** may be reduced … by α_A'. Some might infer that the LLR calculation has to start afresh downwards of level 40, or even that you cannot reduce the office component if you have reduced the hotel. Both these interpretations seem unduly cautious. Perhaps the European committee had in mind storage or plant zones within office floors, whose areas (and loads) should be excluded from the LLR calculation. The corresponding words '…**from the same category**' under the α_n formula are even more definite, but as they appear in a NOTE they are non-normative and common sense may be applied; helpfully, the UKNA redefines *n* with those words conspicuously absent.

Exclusions

No LLR is taken for storage occupancy, for the obvious reason that a warehouse floor can be expected to receive something close to its declared payload over its full area. Indeed the UKNA excludes all loads that have been 'specifically determined from knowledge of the proposed use of the structure', which would also apply to many industrial and plant occupancies. Presumably the word 'specifically' implies that the actual weights, or weight limits, have been added up, or will be controlled, for the floor in question. Might it now, therefore, be permissible for a plant floor with an 'allowance' of 7.5 kPa or more to participate in LLR (which would have been ruled out by BS 6399)? Maybe - but many will opt out of debate by continuing to leave plant levels out of the calculation.

A similar simplifying view could be taken for roofs, which don't qualify for LLR unless in category I, 'accessible with occupancy according to categories A to G'. If so, the roof is treated as if it were a floor of the relevant category – but only for **area**-based LLR. No roof (or plant floor) can ever **actually** be categorized A to D, and EN 1991-1-1 6.3.1.2 (11) stipulates that only categories A to D qualify for storey-based LLR. So where storey-based LLR is concerned the roof must always be disregarded (as with BS 6399 post-1996). It doesn't even count towards *n*, defined in the UKNA as 'the number of storeys with loads qualifying for reduction'.

For area-based LLR the question that now arises is whether α_A may be applied to q_k values not in Table 6.2. This table is for categories A to D and, by extension, category I. Would it be correct to interpret this as disqualifying all other categories? If so the exclusions would be as for α_n with the one exception that was discussed above: an occupied roof is allowed to participate in area-based but not in storey-based LLR.

But where does this leave multi-storey car parks? It seems almost as if category F has been overlooked. EN 1991 introduces α_A and α_n in clause 6.2 under the general heading of 'Load arrangements' but its numerical formulae come under 6.3.1: 'Residential, social, commercial and administration areas'. Does this mean that only loads in Table 6.2 qualify? There is no great desire to apply LLR to category E, but it does seem reasonable to pursue properly considered LLR for category F. That would have to be **area**-based, as 6.3.1.2(11)'s restriction is unambiguous and normative, but it could include the top deck of the car park as an 'accessible' roof. However there is a lack of positive guidance, without which some designers might prefer not to proceed. Category G, for example a podium designed for 10 kPa because it is accessible to fire appliances in emergency, is in a similar predicament.

The UKNA cannot fill the vacuum, as NAs are only allowed to pronounce on matters referred to them by the Code. In this uncomfortable territory between what is ruled in and what is ruled out, the SCI view is that responsible designers should feel free to exercise judgement. That might mean applying LLR in the design of the columns and foundations of a multi-storey car park; equally it might mean forgoing LLR in a category C assembly building.

In the next issue: Part Two will break the mould of technical articles for NSC by putting forward an evolutionary proposal which seeks to influence, rather than interpret.