The future of live load reduction – part two

In Part One (in the previous issue - NSC Vol 21, No 3) Alastair Hughes examined how the new regime of EN 1991-1-1:2002, together with its National Annex, makes provision for live load reduction (LLR) in UK buildings designed to the Eurocodes. Some anomalies and questions of interpretation were identified. In Part Two he proposes a way forward for the future.

Unlike Part One, Part Two is a proposal by Alastair Hughes which is aimed not at the designer but at the committee responsible for the standards.

Where next?

The UK committee decision to retain traditional LLR rules for the time being will, sooner or later, have to be reviewed. We have an obligation to progress in the direction of harmonization.

One possibility, which can be presented both as politically correct and as a simplification, is to integrate storey-based LLR into area-based LLR for all members including columns. A slight drawback is that the reduction factor α could vary from one column to another at the same level, but that is manageable.

For this course to be taken, it would be necessary for us in the UK to reconsider our approach to area-based LLR, in particular the 25% limit ($\alpha_A \geq 0.75$). There is surely no argument, except perhaps locally in crowd loaded areas, against the traditional 50% as a limit to be approached as the area increases; any debate would concern the rate of approach.

That rate of approach is exceedingly rapid if the recommended values are adopted: for instance, a column supporting just 50 m^2 of floor at each of two qualifying levels would enjoy α_A of 0.6 (40% LLR). This compares with the current 10%. To look at it another way, 40% LLR would become available just two floors down instead of the current five. Most of us would side with the UK committee and regard the European formula as sailing too close to the wind.

On the other hand, current UK area-based LLR is unduly handicapped by its 25% limitation. So here is a **suggestion** to the Code committee(s):

$$\alpha = 1 - na/1000$$
$$\geq 0.5$$

in which n is the number of qualifying ('occupied', non-storage) levels, a is the total area supported at each, in m^2, and α can be shorn of any subscript.

This eliminates the artificial distinction between two kinds of LLR. Of course A, the total area supported by the member in question, could substitute for na to make it obvious that this is simply an extension of the traditional UK formula for area-based LLR beyond its traditional 25% limitation.

If this suggestion were to be adopted, a column supporting 100 m^2 at each of five qualifying levels could earn the maximum 50% LLR, and successive stages of the same column would get 40%, 30%, 20%, 10%, more or less as now except that the supported area per level, as well as the number of levels, would enter the calculation – which seems entirely rational. The same formula, with n = 1, would apply to beams, and to the length of column just below the topmost qualifying level (which could be the roof if it is an occupied one, such as the top deck of a multi-storey car park).

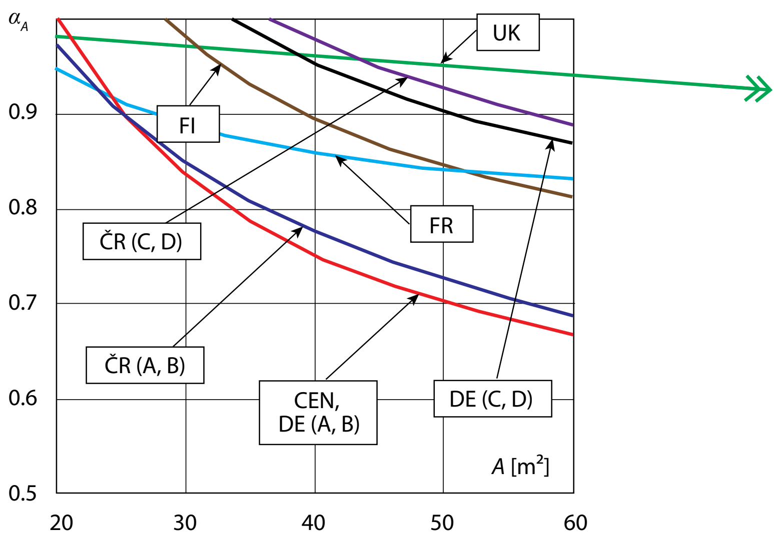

Figure 1 Area-based LLR

What's '*A*', exactly?

A point that needs clarifying in this context is whether or not it is intended that A (or na) in the formula is equal to the 'tributary' area customarily used to assess the load in the column (or beam). The Eurocode refers variously to 'loaded area' and 'area supported' which, taken literally, must be interpreted as the **total** supported area – the area whose load adds to the effect being designed against. A typical interior column is only fully loaded if all four complete panels of floor that surround it are fully loaded; that's four times the tributary area, so the distinction is important. Which is correct? Arguably, the answer is 'whichever the committee had in mind when formulating the rules'. We haven't been told, and the same criticism could be levelled at BS 6399. Could lack of a common understanding have exaggerated the national differences so evident in Figure 1?

For practical purposes it is simpler to base the rules on total supported area, as defined in Figure 2, opposite, which unlike tributary area is the same for the beam as for the reactions at its ends. Moreover it isn't always possible, with complex beam arrangements and/or cantilevers in play, to outline tributary areas in the normal way.

Whatever the intention, it deserves to be spelt out unambiguously in any future revision.

The harmonization challenge

We could also reflect that the scope for LLR is not unconnected with any generosity in the assessment of design imposed load. Nobody told the office floor whether it was designed for 2.5 or 5 kPa, and the load it actually experiences is, on average, rather less than 1 kPa regardless. This is no secret; every survey there has ever been has reported the same conclusion. Some examples of load intensity survey results can be found, amid much theorizing, in a recent report from which Figure 3 (over the page) is extracted. Graphs like these present the case for LLR cogently, and make the UK's straight line formula (the green line on Figure 1) look rather conservative. However these are surveys of normal occupancies in normal use. What the occupants might occasionally get up to is another matter, not so amenable to statistics but not to be disregarded. For example, think back to the seventies, when the office party actually took place in the office. Furniture was stacked against one wall, old Rolling Stones records were played and the cleared area of floor was subjected to energetic load testing by the people whose weight had, earlier in the day, been distributed around the rest of the building. Even if Facilities Management wouldn't allow this nowadays, it may explain and, to a considerable extent, justify the UK's relative caution towards area-based LLR. If you prefer a more up to date example, think of the recent pop-up café-bar phenomenon.

Historically, BS 6399's approach was even more grasping; until 1996 area-based LLR began at $A = 40$ m^2, with a straight line to $\alpha_A = 0.75$ at $A = 240$ m^2. In practice, for most designers most of the time, self-denial probably extends well beyond 40 m^2 to this day, as percentage reductions remain in single figures until A reaches 100 m^2.

In future, which occupancy categories should qualify for LLR? The current rules (discussed in Part One) are confusing. Common ground is that categories A to D should qualify and that non-occupied roofs (category H, accessible only for maintenance and repair) should not.

Category E includes both storage, traditionally denied LLR for good reasons, and plant/industry, whose floor loadings are commonly project-specific. Will any of us rise in protest if this category is excluded?

Category F is currently a victim of neglect, but in principle LLR seems applicable to multi-storey car parks. Seven 20 kN cars per 15.6 × 7.5 m bay equates to just 1.2 kPa, and the average car with occupants weighs less than 20 kN. Unless the client is a distributor of 'Chelsea tractors', why hesitate?

Although category G is similarly neglected, there is little to be gained from LLR in areas frequented by vehicles heavier than 30 kN.

It seems reasonable that an 'occupied' roof (category I) should be granted associate membership of its corresponding floor category, if that would qualify.

Here is how the table in Part One might recast:

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

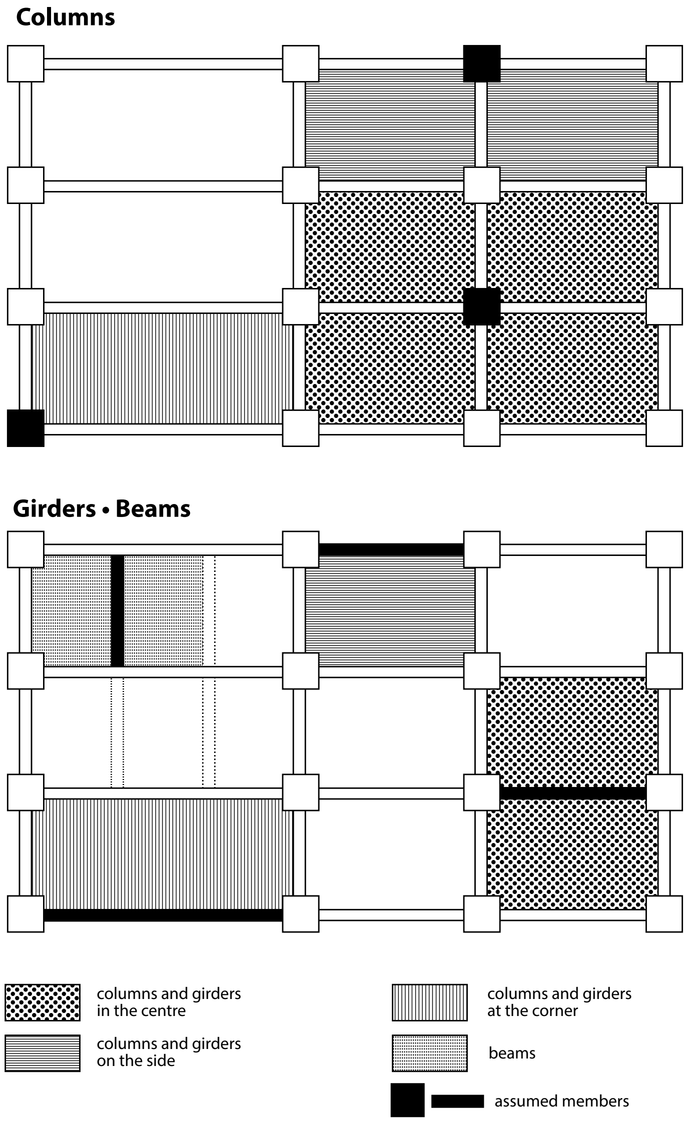

Figure 2 Definition of A

Finally, should the 50% maximum LLR ($\alpha \geq 0.5$) be varied for some categories, as EN 1991-1-1 recommends? The categories picked out are C (areas where people may congregate) and D (retail). For these it sets a 40% limit ($\alpha \geq 0.6$). So if, for example, q_k is 4 kPa for a retail floor this could not be reduced below 2.4 kPa.

No reason is given for the 40% limit. We may speculate that it is to allow for some degree of occasional crowd loading, but if so is it fit for purpose? Based on the current UKNA, $0.6q_k$ may vary between 1.2 kPa (for communal dining rooms) and 3 kPa (for bars, dance halls etc) or even 4.5 kPa (for stages), all within category C. At the lower end of this range, the safety factor would struggle to defend against overcrowding. Restricting LLR to $0.6q_k$ does not make enough of a difference, whereas a thoughtful designer will – by anticipating the possible uses to which the area may be put.

With the formula suggested here, 40% LLR corresponds to $A = 400$ m^2, which would require 600 people (average weight 0.8 kN) at 1.2 kPa or 1500 people at 3 kPa. These are comforting figures, in view of the unlikelihood of such large crowds concentrating their action effect on any one member supporting such a large area. [By contrast, the European formula grants 40% LLR at $A = 100$ m^2 so the same level of overloading could be generated by one quarter the number of people occupying a relatively modest area. This is much more plausible, prompting the observation that the restriction may have been a reaction (a misdirected one, arguably) to the generosity of the formula.]

In practice, of course, designers of assembly buildings will commonly design against unreduced load. In most of the buildings which are

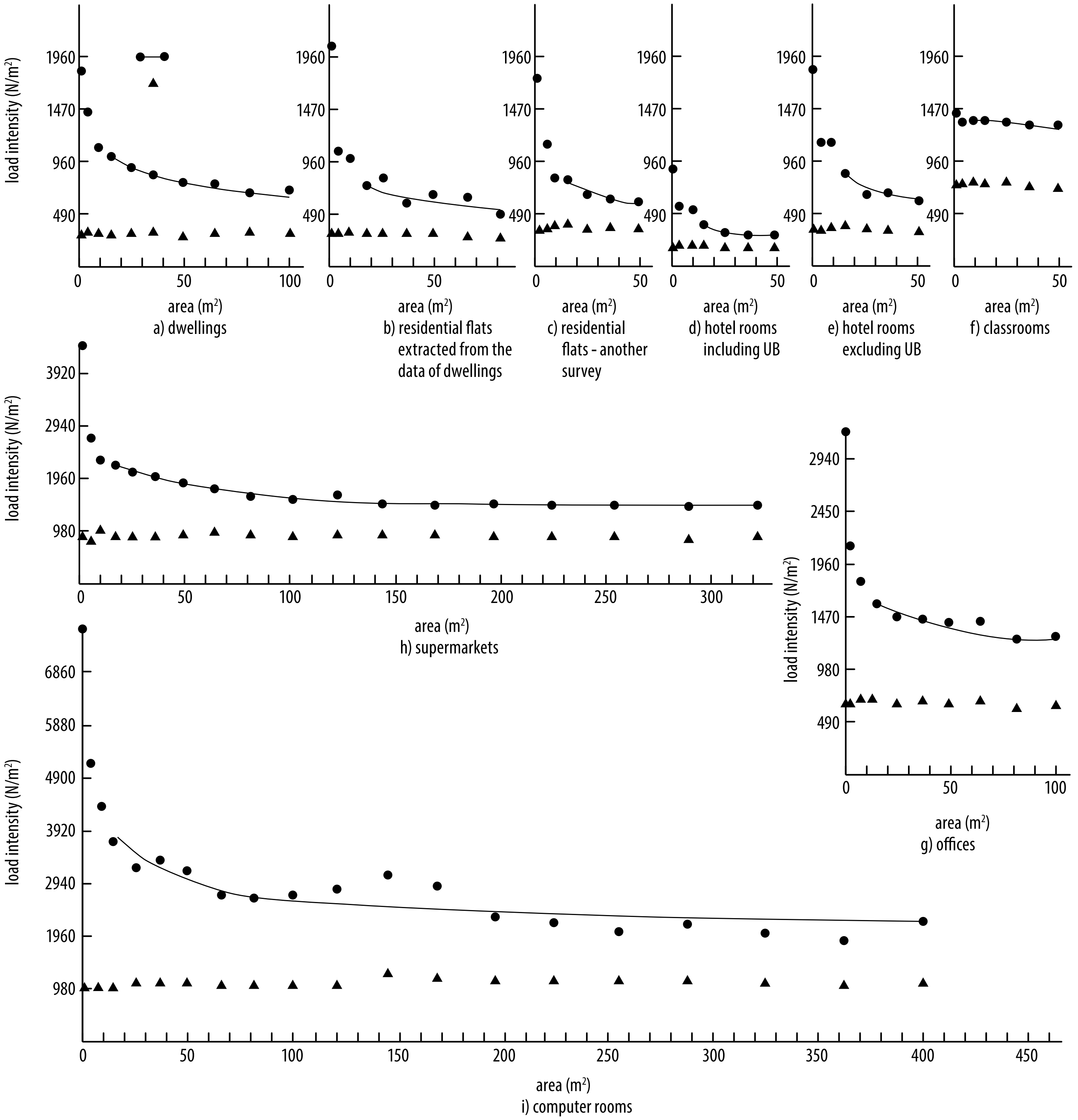

Figure 3 Load intensity surveys

candidates for LLR (and certainly those with most to gain) categories A/B will predominate, and the occasional floor of C/D could safely be allowed to participate in LLR on the same basis as all the rest. The people crowding into the 10th floor restaurant can't be in two places at once.

Whatever the original motive for the 40% limitation, it should be re-examined and, perhaps, substituted by an advisory 'floor' value of (say) 3 kPa where the area is all at one level and might, conceivably, be subject to serious crowd loading. More importantly, it has to be recognized that EN 1991-1-1's 'recommended' α_A formula, seemingly modelled on graphs like those of Figure 3, does not admit the very real possibility of exceptional local patterns of use (or abuse) which can be decidedly influential on individual members, even if unnoticed at the feet of the columns. What is called for is a drastic reduction in the rate at which LLR is initially dispensed. The straight line labelled UK in Figure 1, whose relative conservatism was remarked upon at the start of this article, now seems to offer as good a solution as any.

This article must stop short of any detailed discussion of the actual values set for q_k, but readers are invited to take a glance at EN 1991-1-1 Table 6.2, with its credibility-stretching ranges for national choice. A couple of examples: office areas, 2 to 3 kPa; railway station forecourts, 3 to 5 kPa. Until a consensus is reached on what the imposed loads should be in the first place it may be unrealistic to attempt to harmonize their reduction.

Terminology

Should it be 'variable action reduction' from now on? Surely not. Long live LLR!