'middle third' criterion, it was based on the stability rule, following Jacques Heyman[1]. By deciding on a safety factor of 1.5, it can be demonstrated that this corresponds to a force vector diagram, in which stability is maintained if the resultant horizontal and vertical thrust sits within the central portion of a rectangular buttress split into three equal parts.

What seemed to be a neat solution, for first approximation, was clearly confusing to engineers familiar with the middle-third rule, e.g. with eccentric footings. Thilo Willems, Christina Scrivener, Donald Macleod and Mehdi Khabbazan (among others) justifiably pointed out this discrepancy. I stand corrected. Any reference to this method now has notes added for clarification, that it is a 'stability' check and not a 'stress' or 'bearing' check.

Peter Sparkes illuminates the buttress problem further, in pointing out that the real force diagram flows in a curved fashion towards the outside edge of a buttress. This is well illustrated in *Structures: Or Why Things Don't Fall Down*[2]. As Allan Mann opines, at the top of the buttress, where the flying buttress meets the top of the stabilising buttress, the problem has to assume implicitly that the vault thrust may be resisted without assistance from the self-weight of the stabilising buttress (whether in shear, mortar bond or friction; or combination thereof) – or 'all bets are off'.

Duncan Froggatt makes another good observation: that the thrust may be increased by some 20% if the vault is assumed to be an inverted catenary. I defer to Jacques Heyman[1], who reveals in far more detail vault thrusts.

The 'approximate' methods presented in 'And finally...' are all based on taking readily available equations, familiar to practising engineers (e.g. $WL^2/8h$ or $T = PR$ for cables with applied tension), and their use in solving conceptual problems. If this is combined with a careful listing of 'assumptions' (e.g. the thrust is horizontal; the buttress is rectangular; the pinnacle weight is ignored), then, at the next stage of analysis, the assumptions may be further considered and a more detailed assessment made. As Ove Arup might have asserted: 'the problem is defined' and the engineer is on the way to finding an appropriate solution.

And finally, back to the original question: 'Is the buttress stable?' Perhaps the answer should be: 'Yes, probably'.

REFERENCES

►1) Heyman J. (1995) *The Stone Skeleton*, Cambridge: Cambridge University Press, Chapter 9, Figures 8–10

►2) Gordon J.E. (1978) *Structures: Or Why Things Don't Fall Down*, London: Penguin, Section 5.3, Figure 5.3.

More on masonry arches

One of our international correspondents, Denis Camilleri, has pitched in on the issue of masonry buttress stability. Not so much on the 'And finally...' conundrum, but on wider ramifications.

I must say that the 'And finally...' question in the March issue aroused my interest. I also enjoyed the June follow-up (Comment & reply) and would like to further the discussion.

Besides Heyman's publication, *The Stone Skeleton*, I would also add the Institution's document, *Appraisal of existing structures* (1996).

The Institution's publication notes that if the engineer is satisfied that the structure has already been subjected to a high proportion of its design load without physical distress, then the structure should be assumed to be serviceable, even if it does not comply with the code requirements. The guiding principle should be: 'if it works, leave it alone'.

This document further notes that BS 5628, like all similar codes, is aimed at the design of new structures to be constructed with modern materials. It does, however, contain information which, if suitably interpreted, can provide the basis for appraisal, once the strength of the unit together with the mortar is known.

It is noted that the majority of these masonry buildings have given centuries of good use, with nominal crack patterns arising. Adequate performance is therefore to be expected, possibly further verified by the good weathertightness these building types offer.

Thus, it falls squarely on us engineers to devise a structural solution whereby the transmission of forces is directed safely to the foundations – more by engineering feel for the load path as dictated by the existing constructions!

So, why is the middle-third rule, together with developing tension as outlined in elastic design, still being considered part of a design suite? Stability will surely be obtained via the stability moment as calculated at the edge of the supporting pier, balanced out by a rectangular, not triangular, compressive stress block, as outlined in Eurocode 7, based on limit state.

Now, when referring to the factor of safety, for this situation reference has to be made to the EN 1990 EQU condition and guidance provided for checks to be undertaken for historic buildings. The EQU condition refers to loss of equilibrium of the structure whether considered for sliding, overturning or uplift. In the case of dead or permanent load, once the weight is a known quantity, should the 0.9 coefficient be upgraded to 1? In the case of the overturning force, should this be factored at 1.5, as for new structures, or is a reduced factor appropriate for historical constructions?

Denis, coming from Malta, must have more experience with stone buildings than all of us in the UK. Is there anything else there but limestone? The issue here is not really about the 'And finally...' question: that was just the spur. Quite rightly, Denis reminds us that when dealing with old structures, we have to be sensible. Simple rules help us understand how they 'stand up' and what their margins of safety are. But what those margins ought to be has to be tempered with experience of how the structure has performed.

And Bill Harvey has also sent us his own words of wisdom.

The flurry of notes on ancient masonry in the past couple of issues cannot go without comment. As an (ex)-teacher, I always worried about oversimplifying structural forms; and the more I learn (at 70), the more I worry.

When you are dealing with redundant hyperstatic structures in which all the parts have massive stiffness, it is often extremely difficult to assess load paths. The fact that stiffnesses are large doesn't mean that the differences between them are not. Jacques Heyman's frequently stated argument that if you can find a load path, so will the structure, is no help at all in anticipating the onset of damage (though it may well identify ultimate capacity for monotonically increasing load).

People talk about the '10-year rule'. Some say the '100-year rule'. But if the structure