vision, which makes it difficult to control, particularly in storage tanks with no light.

We have also adapted techniques from the medical profession to 'see inside' critical elements to detect corrosion and other problems concerning electrical equipment. All these are designed to be used while the vessel is on hire, on station and in operation, so avoiding shutdowns or out-of-service periods, the consequential costs of which are horrendous.

We can all learn from each other, so having an open mind and sharing problems with colleagues from other industries and professions is the key to making ground-breaking discoveries. I understand that it was only when a structural engineer and surgeon got together that the modern hip joint was developed.

Over one lifetime, developments in metrology have revolutionised the way we survey, giving faster, cheaper and more accurate surveys. Drone surveys have also been found useful in situations from inspecting facades to penetrating fire-damaged buildings. Hence, positive feedback is to be encouraged and *The Structural Engineer* will welcome input of practical experience.

Safety factors

Readers always seem to enjoy a puzzle on safety factors. Barry Franchi offers us his views on the safety margins against foundation base overturning.

The following views are based on traditional foundation design; that is, the overturning moment is the working moment, and W, a working load.

It is customary to obtain a factor of safety on overturning of a foundation base by taking moments about the base edge and dividing the stabilising moment by the overturning moment. This factor of safety is often called a notional one (F_n below) because it is difficult to imagine the base rotating about an edge, unless it is founded on very hard rock. In reality, we know that the ground will fail first. The Eurocode is also quite clear about this.

So, out of interest, I have calculated alternative factors of safety. For the traditional approach, the pressure under the base is assumed to be a triangular shape, while, when computing a condition at failure, the distribution is presumed rectangular. I have also presumed that the ground fails near the base edge at a pressure equal to three times the safe or permissible pressure. The foundation is assumed to be square, with the overturning moment acting at right angles to one edge. Also, the vertical load, W, is assumed to act at the centre of the base. The differing factors of safety for a defined notional factor (F_n) and a factor based on ground failure (F_g) are as follows:

$F_n = 3.0$ « « $F_g = 2.5$
$F_n = 2.5$ « « $F_g = 2.12$
$F_n = 2.0$ « « $F_g = 1.75$
$F_n = 1.5$ « « $F_g = 1.38$

Please note the following:

Generally, $F_n = WL/2M_w$ where L = the base side dimension and M_w = the working overturning moment, so $M_w = WL/2F_n$. Thereafter, the arithmetic follows a traditional route of balancing eccentric pressure under the base against the forces applied to the base top. When $F_n = 2.0$ for example (and based on a triangular stress block), the maximum working ground pressure = $8W/3A$ where A = the area of the base. So, the failure ground pressure = $8W/A$.

Using the same approach for a ground failure condition, but using a rectangular stress block and the same working loads, the width of the stress block = $L/8$, the failure moment $M_f = W(L/2 – L/16)$. So, $M_f = 0.438WL$ and $M_w = W(0.5L – 0.75L/3)$, so $M_w = 0.25WL$ and $F_g = M_f/M_w$, which equals 1.75.

In the case of a square crane base, where the overturning moment can also act along the base diagonal, for $F_n = 2$, F_g increases to 1.8. On comparing the results, it is comforting to see that F_n is not that far out.

It is probable that many engineers of my generation have already made this comparison. For those who haven't, I hope that this exercise is of interest.

Barry seems to have concluded that the differing approaches to computation based on differing assumptions can suggest differing safety margins, but that the margin based on his suggested (true) failure mode is not that much below one calculated traditionally.

Design life of bridges

Denis Camilleri writes from Malta inspired by a recent article on bridge design.

Having undertaken my last bridge designs in the early 1980s, Simon Bourne's double bridge technical feature was very instructive ('An introduction to bridges for structural engineers', parts 1 and 2, January and March 2019). As quoted, bridge engineering is not the same kettle of fish as designing building structures.

Back in the 1980s, a good backing in strength of materials, together with bridge codes that were still in a convenient and easy-to-use format, led towards a clear design methodology, whether it was for the strength or the member vibration characteristics. Finite element analysis was not much in vogue back then, although some load distribution tables were available.

This double feature outlined nine issues, delving even into the Roman Vitruvian principles, reminding us that sustainability is not such a modern issue after all! But it is the design lives of bridges that aroused my further interest. So, a bridge is designed for a lifespan of 100 years, while normal structures have a 50-year design life. What does this higher design life imply? In concrete works, higher covers are specified, while higher strand losses are probably catered for in prestressed concrete.

Is anything else implied in these higher design lives, such as higher live loadings, enhanced factors of safety, higher characteristic wind speeds? How do the three consequence classes, as highlighted in Annex B: Table B3 of EN

"IS ANYTHING ELSE IMPLIED IN THESE HIGHER DESIGN LIVES, SUCH AS HIGHER LIVE LOADINGS, ENHANCED FACTORS OF SAFETY, HIGHER CHARACTERISTIC WIND SPEEDS?"

1990, impact on bridge design?

Perhaps members of the bridge design community can enlighten Denis over the practical implications of extended design lives?

Engineering in the domestic sector

There are enough matters of engineering interest in domestic housing, and their extensions, to worry engineers, David Wilson observes – and asks a question.

In modern house design, I frequently see two features (usually in the front elevation) that significantly impact racking stability. These are:

- single-storey front door vestibules with a large opening below the external wall from first-floor level to the roof to create the hall
- part of the external wall from first-floor level to the roof set back from the ground floor wall.

I would be interested to hear from others how Building Regulations Diagram 14 should be applied in such situations.

With the trend for adding basements, roof extensions and general 'opening up', there are dangers of creating instability. Who else has views or experiences?

Soft skills are essential for success

Finally, David Brett takes up a theme from our President's Inaugural Address with some considerable enthusiasm.

Our President, Joe Kindregan, made a very important comment in his inaugural address earlier this year:

'The education of structural engineers for the future may have to involve less technical depth, instead training people to have a complete perspective of problems, most of which are non-technical.'

I couldn't agree more. In order to attract and retain the most talented students we need to improve the profile of engineers to a similar status as our Victorian ancestors. They were the rock stars of their age and understood the 'soft skills' required to promote their designs to the investors concerned. They must have also inspired a new generation of engineers to follow in their footsteps.

We are entering an era of 'lifetime learning' through the education of engineers and Continuing Professional Development (CPD) courses. As the pace of change increases, this will probably be the only way to maintain the professional standards expected of our members.

We need to excite the ambitions of talented students to follow in the example of our distinguished members who have produced some of the most iconic structures in the world. As a young engineer I was attracted to join Arup for exactly that reason.

It was exciting to be working on 'cutting edge' designs and to work for, with, and be inspired by such talented engineers as Sir Ove Arup, and some of our distinguished former presidents, Peter Dunican, Peter Campbell, and Sir Edmund (Ted) Happold, etc. It was only when I went on to study as a postgraduate at the London School of Economics, to learn some of the 'soft skills', that I changed direction and went on to a career in marketing – again for engineering companies.

It was important to understand the language and motivations of investors, politicians and civil servants, as they rarely understand the engineering challenges involved. Market research, cost–benefit analysis, discounted cash flow, working capital requirements, return on capital, interest charges, etc. all needed to be mastered and understood in order to negotiate authoritatively with them.

I could count my counterparts on one hand as it was rare for engineers to move into marketing at the time. We need an army of charismatic and articulate engineers with the so-called 'soft skills' to promote the profession to talented young students, so that they can experience that supreme sense of achievement in creating iconic structures.

I still get a kick out of seeing structures I designed many years ago – some of which are now listed – every time I pass by them. We are fortunate that our designs are usually visually impressive, unlike a microelectronics engineer producing a brilliant silicon chip which only their peers can appreciate.

"IT WAS IMPORTANT TO UNDERSTAND THE LANGUAGE AND MOTIVATIONS OF INVESTORS, POLITICIANS AND CIVIL SERVANTS"

However, 'soft skills' can be equally satisfying, as I was able to help promote and export British designed and manufactured structures to over 125 countries throughout the world and license the technology to a dozen other countries where exporting was not possible. We received the Queen's Award for export achievement as a result. I also led the market research for a new method of construction for offices, schools, hospitals and hotels, etc., which went on to complete over 1000 projects throughout the UK, and received the Queen's Award for technological achievement.

Our President is to be congratulated in highlighting this issue and others in his address. Let's hope that his words are heeded and the challenge taken up in the direction of engineering education and CPD courses in future.

From a lifetime in engineering, Verulam can certainly empathise with the President that day-to-day problems more often arise from dealing with people than dealing with technology. After all, technology normally does as it's told and doesn't have emotions. However, we must observe balance: there are many dedicated engineers who just want to stick to building safe structures and that's hard enough. Whatever the demands, there is room for everyone, not just 'the brightest and the best'. Nonetheless, for us all, an increased understanding of costs and skills in communication would not go amiss.

Safety factors for overturning and design life of bridges

Paul Jackson responds to two letters published in the May issue.

1) Safety factor for overturning. I also note that some codes or specifications I have worked with, notably for wind turbine bases, specify 'notional' overturning factors which are less than the ratio of adverse wind load factor to relieving dead load factor. This makes it impossible for them to ever be critical, as structure and ground have to be checked for a more onerous case. It is not clear why they have the notional factor: presumably a hangover from earlier documents.

2) Design life of bridges. The longer design life (actually 120 years in the UK) also affects fatigue calculations, and it was for fatigue calculations that explicit design life was first introduced (by Idris Price, I think). Highway live loads are not explicitly altered for it, although the derivation of UK loads does include a contingency factor for future increases. The wind and temperature actions are explicitly increased for increased return periods (the UK National Annex to the Eurocode enabling you to do this by changing either nominal action or factor), but not as yet for any increased climate change effect.

In reliability terms, whether the effect of the increased life should be applied is debatable. It depends whether you think the required reliability should be expressed as 'target risk of structure failing per year' or 'target risk of structure failing over design life'. I think it was Chris Hendy who suggested the latter was morally questionable, as it implicitly valued the life of construction workers who spend their working lives on temporary structures with a short design life lower than that of those of us who work mainly in permanent offices!

Regarding 'overturning', it may be the case that for large bases subject to dynamic loads, structures respond by 'rocking' rather than (complete) 'overturning'. It might also be the case that a decision has to be made over whether base edge lifting is tolerable or not. In some circumstances, repeated edge lift is not considered desirable even if the structure as a whole cannot credibly 'overturn'. Neither of these considerations is explicitly considered for routine foundations.

Regarding 'design life of bridges', if we target sustainability and proper use of scarce resources, it seems eminently sensible to design for longer lives if the marginal construction costs are small. If we design properly for durability, rather than least first capital cost, we are also minimising the exposure risk of maintenance workers who might thereby not be needed during the structure's life.

In extending a bridge's life, fatigue is an undoubted design issue. Increases in environmental factors (wind and temperature) seem unlikely to be critical. Experience suggests that attention should be focused on learning lessons from the factors that actually limit life: salt being one. Perhaps we should worry less about the mathematics and concern ourselves more with traditional detailing and 'maintainability'?

Which way now for codes and standards?

Alasdair Beal responds to Stuart Matthews' recent Viewpoint (May 2019) about performance-based codes versus prescriptive codes.

It is unfortunate that Stuart Matthews confuses discussion about the form of codes of practice by setting up a false debate about 'performance-based codes' versus 'traditional prescriptive codes'. If he looks at BS 449 (which I would recommend to any modern code-writer), he will find that its recommendations are in fact generally performance-based: maximum allowable stresses and minimum safety factors are defined and engineers are largely left free to do as they wish within these limits. Prescriptive/standard/'recipe' requirements are only introduced in a few situations when necessary, which is as it should be.

Traditional codes may be simple and clear (and what's wrong with that?) but portraying them as anachronistic 'prescriptive solutions' and rules of thumb that hamper progress is setting them up as a 'man of straw' in the debate – a caricature that is easy to knock down but bears little relationship to reality. In reality, good codes have always been based on 'performance-based' standards, but with prescriptive requirements introduced where necessary on a 'horses for courses' basis.

"HOW TO GET CODES THAT ARE SIMPLE, CLEAR AND EASY TO USE?"

So, what is the debate about? While engineers debate 'performance-based' codes versus 'prescriptive codes', there are others in the background with a rather more sinister, politically-driven agenda which views regulations (particularly national regulations) as 'barriers to free trade' which should be stripped down and minimised as far as possible. In this view, governments should only set minimum performance standards and leave businesses free to comply with these in any way that they wish.

However, rules which are only defined in abstract theoretical terms may be open to endless debate about interpretation and difficult to police and enforce. It can be easier to be sure of getting what you want by saying, 'I want a spade', than by listing all the performance parameters the desired implement should have and then leaving the supplier free to supply anything they wish that they believe complies with these.

In the aftermath of Grenfell Tower, it is hard to escape the conclusion that if the Building Regulations Approved Documents had been more 'prescriptive' and less 'enabling', tragedy might have been averted and a large amount of money saved.

A serious debate about the form and content of modern codes is long overdue. However, arguments about the relative merits of 'performance-based rules' and 'prescriptive rules' are not the point, as both have their roles. What we should be debating is how to get codes that are simple, clear and easy to use – and how to establish and enforce building regulations that will ensure public safety.

Stuart's Viewpoint ended with: 'So, what do you think: prescription or performance-based or what?' Surely, this is the invitation to 'a serious debate' that Alasdair endorses in his last paragraph?

Alasdair writes as well about the choice: 'both have their roles'. True – and BS 449

deformation is surely 'settlement' (under applied stress) plus longer-term increase (consolidation) in some soils.

Time to declare a climate emergency?

David Knight issues a call to action on the climate.

All the winners of the Stirling Prize, the UK's foremost prize for architecture, have taken the bold step of collectively declaring a climate emergency and committing to a series of principles that will govern their work in the future (www.architectsdeclare.com). As structural engineers, I believe that we have a responsibility to join them, and show leadership in the construction industry by refusing to carry out work that does not hold sustainable design principles at its core.

As we know, almost 40% of energy-related carbon dioxide emissions are due to buildings and construction. The twin crises of climate breakdown and biodiversity loss are the most serious issues of our time. We can no longer continue to pretend that 'business as usual' is an adequate response – we must all make a step change in our behaviour.

I would like to call on the Institution's Supreme Award winners to show a similar commitment, and hope that they are joined by all practices that are serious about dealing with the crisis in climate and biodiversity. We should seek to:

1) Raise awareness of the climate and biodiversity emergencies and the urgent need for action amongst our clients and supply chains.
2) Advocate for faster change in our industry towards 'circular economy' design practices and a higher governmental funding priority to support this.
3) Establish climate and biodiversity mitigation principles as the key measure of structural engineering's success: demonstrated through awards and prizes.
4) Share knowledge and research to that end on an open-source basis.
5) Evaluate all new projects against the aspiration to contribute positively to mitigating climate breakdown, and encourage our clients to adopt this approach.
6) Upgrade existing buildings for extended use as a more carbon-efficient alternative to demolition and new build whenever there is a viable choice.
7) Include lifecycle costing and whole-life carbon modelling as part of our basic scope of work, and encourage the use of post-occupancy evaluation by our clients to reduce both embodied and operational resource use.
8) Collaborate with architects, contractors and clients to further reduce construction waste.
9) Accelerate the shift to low-embodied-carbon materials in all our work.
10) Minimise wasteful use of resources in the work that we do, both in quantum and in detail.

As structural engineers, we have a duty to question every job that we receive on these principles. A collective statement and commitment about this urgent issue would send an important message.

Design life of bridges

Alan Hayward responds to a letter we published in June about the design life of bridges.

Taking up the comment by Paul Jackson, the 120-year design life originated, in my view, from British Railways (BR) in the 1960s. I was then an engineering trainee with BR.

In 1962, the fatigue requirements in BS 153 were revised. Until then, fatigue in bridges was unrelated to design life, only to an arbitrary endurance limit of 2×10^6 cycles of maximum design stress range (f_{min}/f_{max} = -1 to +1) which took no account of variable load spectra. The 1962 revision to BS 153: Parts 3B and 4[1,2] used the considerable research into fatigue of welded structures. It now catered for a variable loading spectrum, but would need a specified design life.

The basis of the spectrum for railway loading was outlined in an ICE discussion in 1963[3]: *'The total numbers of stress cycles were computed for a period of 120 years, which had been assessed as the average life of steel bridges of modern design before they required renewal due to corrosion and other forms of deterioration.'*

Thus, the design life was being defined from a consideration of long-term deterioration rather than fatigue. Berridge[4] also confirms that 'the average life period is taken as 120 years'.

The revision to BS 153-3A:1954 in 1966[5] included the spectra for BR (and London Transport), confirming the period of 120 years. One of the first designs to the revised fatigue clause was the reconstruction of Grosvenor Bridge[6]. The designers established a specific load spectrum taking account of the absence of freight traffic. In the discussion on BS I53[3], P.J. Clark (Freeman Fox) stated: *'They had been asked to produce a bridge with a life expectancy of 100 years; and had finally achieved one of 200 years. This had seemed to offer a reasonable margin, in case the embryo code was altered before the bridge was built'.*

In 1978, BS 5400[7] adopted a 120-year design life throughout. Until then, the design life for UK concrete bridges was taken as 100 years, and in the USA it is normally 75 years. In the Eurocode (BS EN 1990:2002) the 'indicative design life' is 100 years, amended to 120 years by the UK National Annex.

Although apparently originating from fatigue, it seems that the period of 120 years was actually based on the estimate of bridge life to replacement from long-term deterioration.

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We are grateful to Alan for his explanations. As so often if the origin of rules is lost, that later leads to misconceptions about their importance. It is worth taking this point further to make some observations:

All code committees should be required to define the origin of rules so that informed decisions can be made later.

Given that the spectra Alan describes were developed in the 1960s, and traffic has changed enormously since then, the question of their current validity must arise.

Alan makes the point that, in reality, life is more likely governed by long-term deterioration. Those decisions on 120 years were made back in 1978 and we have learned a great deal about durability since then. So, is an economic reappraisal required?

We also publish a letter on climate change, cutting waste, etc. in this issue. Surely as part of this drive we must seek a reappraisal of the design life of all structures. If the marginal cost of life extension is low, then wouldn't it be sensible to require current designers to assure that their structures are capable of surviving much longer than is the norm?

What do other readers think?

Safety factors

It was predictable that someone would write in about the 'safety factors' letter published in the May issue. Yul Tammo's letter (along with another) highlights interesting aspects about interpreting equations.

Barry Franchi's letter on safety factors was quite interesting and I found it an illustrative exercise. However, I did not come up with the same conclusion as he did.

I agree that, in the traditional method, the factor of safety against overturning is $F_n = WL/2M_w$, and that for $F_n = 2$, the overturning moment $M_w = 0.25WL$ and the ultimate ground pressure = $8W/A$. Using this ground pressure for the Eurocode method gives an effective width of the stress block of $L/8$, i.e. an eccentricity $e = 7L/16$ and a moment $M_f = 0.438WL$, but after this we differ.

Using the same approach as for the traditional method, the Eurocode method gives the factor of safety against overturning $F_g = 0.5WL/0.438WL = 1.14286$, to be compared with $F_n = 2.0$ and then $F_w/F_g = 2.0/1.14286 = 1.75$. Hence, 1.75 is not the Eurocode factor of safety against overturning when the traditional factor is 2.0, as Barry claims; it is the ratio between them.

Similarly, when $F_n = 3.0$, $F_g = 1.2$ and $F_n/F_g = 2.5$ etc., as stated by Barry.

Barry himself defines F_g as = M_f/M_w, which equals 1.75 on his assumptions. So F_g isn't really the safety margin (as Yul points out). If we define the 'safety factor' as vertically applied load × $L/2$ / applied moment, then at working load (W) and with Barry's premise on ground failure under a triangular stress distribution, and taking, for example, $F_n = 2$, the ground pressure at failure is $8W/3A$ (a point to note is this arithmetic only works if the width of (triangular) base pressure is less than the base width).

The question now being asked is 'what alternative answer would we get if we assumed that the base pressure was not triangular but was instead a rectangular stress block starting from the base edge?' Continuing from the earlier example, the assumption is that the pressure value is $8W/A$, just as Barry writes and Yul agrees. It is now possible to back calculate a corresponding applied moment (M_f) which corresponds to the ground failure pressure. This is $0.438WL$ (both Barry and Yul agree). If the definition of the safety factor remains as 'applied load × $L/2$ / M', then instead of being 2 (as in this example), it looks as if it reduces to 1.143, which looks alarmingly less than 2.

However, this is reduction is deceptive because the 'M' in the separate computations differs. Verulam's comments on the following letter will make that clearer.

Alastair Hughes is also intrigued by Barry Franchi's algebra.

Barry's comparisons are thought-provoking and deserve to be taken further. They are presented in quite an abstract way; it may help to substitute realistic numbers for the algebra. Suppose the base is 2m square and the axial force W is 200kN. It follows that the overturning moment M in the first example ('notional' factor of safety $F_n = 3$) must be 67kNm, and in the last example ($F_n = 1.5$) M must be 133kNm.

In the first example, the triangular stress block occupies the full area of the base, varying from 0 at one edge to 100kPa at the other. If this represents a safe or permissible pressure, the corresponding rectangular block stress is assumed to be 300kPa, so its centroid is 1 – (200 ÷ 300 ÷ 2 ÷ 2) = 0.833 m from the centre, whence Barry has calculated a realistic factor of safety F_g of 200 × 0.833 ÷ 67 = 2.5. Less than the optimistic presumption of 3, but still more than adequate.

"LET'S HOPE THAT LATER THIS YEAR A REVISED ANNEX A FOR EN 1990 EMERGES THAT IS EASIER TO FOLLOW, UNDERSTAND AND BELIEVE IN"

However, the last example's triangular stress block only occupies half the base area, from 0 at the centreline to 200kPa at the edge. In other words, the soil must be twice as resistant as before. The centroid of the corresponding rectangular 600kPa stress block is 1 – (200 ÷ 600 ÷ 2 ÷ 2) = 0.917 m from the centre, whence Barry has calculated F_g = 200 × 0.917 ÷ 133 = 1.38, for comparison with F_n of 1.5. But in practice the soil is a given. If the rectangular stress block is limited to 300kPa, it remains as before and F_g is more realistically calculated as 200 × 0.833 ÷ 133 = 1.25. Not such a comforting conclusion!

How does all this relate to Eurocode design? According to BS EN 1990:2002, in 'EQU' verifications variable action is factored 1.5; permanent action is factored 1.1 when unfavourable and 0.9 when favourable (stabilising). Both W and M can be a mixture of permanent and variable, so it is difficult to generalise, but clearly the target overall factor of safety can vary, widely, between 1.22 (in a design situation with no variable action) and 1.67 (if 100% variable were countered by 100% permanent).

The latter may be unlikely in practice; in Barry's crane base, 100% of M will indeed be factored 1.5, but part of W (arising from load on the hook and weight of moving parts) is also factored 1.5 – which effectively dilutes (disguises?) the target overall factor.

Let's hope that later this year a revised Annex A for EN 1990 emerges that is easier to follow, understand and believe in. Meanwhile, what is apparent is that present-day practice extrapolates below the range covered by Barry's examples. Sailing closer to the wind? Maybe the way to win races, but it does demand attention at the helm.

Incidentally, a square crane base with moment acting about a diagonal will lose its lever arm advantage as the stress block (now triangular on plan) grows inwards (in