3.Lean design

Structural safety when designing lean in the climate emergency

The IStructE Safety, Health and Wellbeing Panel considers the safety implications when aspiring to a lean design.

The Institution of Structural Engineers' Safety, Health and Wellbeing Panel finds itself in a difficult position when considering the relationship between safety and steps to mitigate climate change. Simplistically, if you put less material in a structure, then the level of risk increases as there is less 'redundancy'. While no one should increase member sizes to guard against design inadequacies, there are clearly risks with going too far the other way.

In addition to the life-safety impacts of failure, emissions due to demolishing, removing and rebuilding only add to the original emissions related to the structure. Therefore, in a time where we are all being urged to minimise and optimise our designs, getting it right has never been more important.

In this article, the Panel, which is made up of a disparate group of people drawn from all types of practice around the world, describes some of the topics it regularly debates – a summary of members' shared experiences of close calls and dangerous situations – and their relationship to the climate emergency. Where possible, we also make recommendations for mitigating dangers, striving to create structures that are both safe and sustainable.

Conservativism

We start with the topic of conservativism, or 'overengineering'. Material strengths are generally well-understood and well-defined; and codes deal with the remaining uncertainty through partial safety factors on materials and loading.

There should, therefore, be no need to add a further 'factor of safety' by increasing member capacity. However, the Get It Right Initiative[1] highlights that 23% of the industry's turnover is spent on correcting errors, which might suggest that it would be prudent to add some redundancy, 'just in case'.

Our experience indicates that a few percentages of over-stress (or a slight erosion of factors of safety) is rarely the primary cause of failure, and that unnecessary overdesign like this is misguided.

Codes, loads and liability

Similarly, the thoughtless application of design codes has been shown time and again to result in either overdesign (which is wasteful) or underdesign (which is dangerous). The importance of understanding each code clause and where it needs to be applied must not be underestimated.

On the subject of codes, while we agree that industry-accepted loadings are rarely achieved in office buildings[2], we highlight the regularity with which loads are increased above code, often driven by the 'added value' perceived by clients.

Work by the SEI in the USA[2] has indicated that, in buildings examined that were designed by engineers using codes, most were 'overdesigned' (though it should also be noted that 25% of the buildings tested were significantly below strength).

Decreasing loading below code allowances is difficult if we wish to avoid being liable for redesign or rebuilding our work, but clearly we should also avoid this deliberate and unnecessary overspecification of loads.

Moving to a performance-based design approach can also allow a more accurate assessment of building performance – thus reducing the amount of material used to resist the codified imposed loads (even if the loads themselves have not been reduced).

Increasing utilisation without understanding failure

Increasing utilisation is not always a safe solution. We regularly see situations where small member sizes have led to impossible connection designs. Similarly, failure of connections themselves is often overlooked, with several tower crane collapses resulting from pull-out failure of the bolts at the bottom of the mast. In such cases, the marginal carbon cost of bigger bolts would have been trivial, and this sudden failure mode could have been avoided if the engineer had considered how their design might fail.

Avoiding sudden and brittle failures is

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FIGURE 1: It is preferable to avoid sudden failure, such as that of the Pipers Row car park in Wolverhampton in 1997

always preferable **(Figure 1)**. In beams and slabs, this means ensuring failure in bending occurs prior to shear – and then ensuring ductility by verifying that the rebar yields before the concrete crushes (incidentally, this means that the concrete can never be 'fully utilised'). Considerations like this make sure that if failure does occur, the risk is minimised. If an engineer is to push their designs to the limit, it is even more important to think about failure.

Finally, we are aware of many dramatic failures resulting from lack of durability (a possible cause of the collapse of the Ponte Morandi in Italy in 2018). Getting the detailing right is important in terms of both safety and carbon – meaning appropriate cover, free-draining steel connections, and dry timber. Rebuilding a structure due to poor detailing is an inexcusable waste of resources.

Reuse

Where possible (and where this is a lower-carbon option), adapting and reusing structures is to be favoured. The challenge is to persuade others of the acceptability of a structure when either 'it doesn't meet modern codes' or 'there are no records'. It takes a competent engineer to look at the evidence and agree that 'it's good enough', taking responsibility for the durability and structural behaviour of the reused structure.

The assessment techniques of existing buildings proposed by the SEI[2] would allow an examination of an existing structure to be undertaken to ascertain its strength, and to understand whether any deterioration had taken place – allowing a confident assessment of a building's suitability for reuse to be made.

Allowing for future adaptability is equally important – and designing structures in a manner that will allow them to be safely reused in the future is as important as the safe reuse of our existing building stock. Appropriate consideration should be paid to the future durability, inspectability and adaptability of the structure.

Material choices

We should not lose sight of why steel and concrete have become the mainstream building materials of choice. With the use of timber increasing in response to the climate emergency, we must stress that the industry's understanding of timber is still developing in many areas, most notably fire[3–5].

In fact, designing with any 'new' material (which is what engineered timber is) carries risks that must be considered by the engineer. Acknowledging the 'unknown unknowns' might be a good place to start.

> **“ IF WE INCREASE THE SOPHISTICATION OF OUR DESIGNS TO REDUCE OUR CLIMATE IMPACT, WILL CONTRACTORS ACQUIRE THE SKILLS TO BUILD THEM?**

Changes in loading resulting from climate change

What should we do with the structures that we are designing now to account for the different forces that climate change is going to impose on them? We know that global heating is making the weather more extreme: increased rainfall and snow, leading to increased loading; hotter and colder weather, leading to more thermal movement; colder weather, leading to more icing, leading to more use of salts as well as more ice accretion on lattice structures.

As loads increase in the future, we may need to strengthen certain structures, highlighting the need to allow for safe future adaptability in our designs. One might consider increasing the capacity today, but the certain increase in carbon emissions from this needs to be balanced against the possible savings in the future. Is this 'carbon investment' worth it?

Upskilling in response to our new philosophy of design

Much of the response to the climate emergency requires a new approach to structural design. Structural arrangements optimised for carbon rather than buildability, the use of novel materials, and designing to the limits of the codes are all examples of changes that require the design team to embrace this new approach.

We know that there are many safety implications associated with this new philosophy of design. Perhaps this highlights the need to agree more design time (and fees) to check our work more thoroughly and avoid costly mistakes.

It certainly highlights the need to avoid relying on finite element analyses with little respect for the overall structural performance or an understanding of its true behaviour. A better understanding of what makes a structure safe, or where a safety margin variation is tolerable, might be a good start.

We should also remember that while some clients may see this new approach as beneficial, others will want to quantify the value it adds to the project – is it worth the risk? Similarly, if we increase the sophistication of our designs to reduce our climate impact, will contractors acquire the skills to build them?

And how will (traditionally conservative) insurers approach these structures? They will need to be reassured that the structural integrity and durability are not compromised, proven to a recognised standard. Not a safety risk, but a project risk nonetheless.

Summary

There is no argument that we need to adapt our structural designs to limit the adverse impact of the built environment on the living environment. It is a fearful crisis that we must tackle, starting now.

But the solution is not as simple as designing everything to work to the maximum to minimise the upfront embodied carbon. The process is much more sophisticated, certainly in terms of safety. And if we lose one structure through minor safety mistakes (which happens), we will have thrown a lot of embodied carbon away.

To exercise any influence, engineers need to understand the issues, be involved in the design process at concept stage, and take a positive lead on the solutions that minimise the overall impact on the climate. To achieve this, we need to strive to be better designers, a little more outgoing and communicative, and a little less buried in the numbers.

Plenty to think about!

REFERENCES

1) Get it Right Initiative (2020) [Online] Available at: https://getitright.uk.com/ (Accessed: November 2020)

2) Task Committee on Performance-Based Design (2018) *Advocating Performance-Based Design. Report to the ASCE Structural Engineering Institute of Board of Governors* [Online] Available at: www.asce.org/uploadedFiles/Technical_Areas/Structural_Engineering/Content_Pieces/2018-sei-advocating-for-performance-based-design-report.pdf (Accessed: December 2020)

3) Law A. and Hadden R. (2020) 'We need to talk about timber: fire safety design in tall buildings', *The Structural Engineer*, 98 (3), pp. 10–15

4) Law A. (2019) *Fire safety design: we need to talk about timber* [Online] Available at: www.istructe.org/resources/training/fire-safety-design-we-need-to-talk-about-timber/ (Accessed: November 2020)

5) Deeny S., Lane B., Hadden R. and Lawrence A. (2018) 'Fire safety design in modern timber buildings', *The Structural Engineer*, 96 (1), pp. 48–53