Numerical layout optimization research at the University of Sheffield

Matthew Gilbert, Helen Fairclough & Linwei He

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In this session Matthew Gilbert, Helen Fairclough and Linwei He will present details of previous and current research in the area of numerical layout optimization undertaken at the University of Sheffield, with two specific research problems highlighted along with future research directions.

9:00-9:45 - Layout optimization research at the University of Sheffield (Prof. Matthew Gilbert)

Abstract: At the University of Sheffield over the last two decades the numerical layout optimization technique originally pioneered by Dorn and co-workers in the 1960s has been extended for use in a wide range of application areas. Specifically, the technique has been applied to truss and grillage design problems and also to engineering analysis problems involving identification of the critical layout of discontinuities in solid bodies at the point of collapse ('discontinuity layout optimization'). In each case mathematical programming techniques can be used to solve the underlying problems, with highly accurate solutions obtainable that often allow new insights to be drawn.

In this presentation Matthew will provide an overview of previous research carried out in the area and will highlight some of the tools that have been developed as a consequence of this, most of which are now publicly available. He will then discuss future research directions in the context of the current climate crisis, which places renewed emphasis on the need to extend the life of existing structures and to design new ones that are significantly more materially efficient (and possessing significantly lower embodied carbon) than their predecessors.

9:45-10:30 - Material-efficient forms for long-span structures (Dr Helen Fairclough)

Abstract: In structures containing long spans, a large proportion of the loading is caused by the self-weight of the structure itself. This presents the opportunity for significant benefits to be realised through the use of structural optimization methods – since any decrease in material usage is further amplified by reductions in supporting structural elements. Recent work has shown that the ubiquitous suspension bridge form uses up to 70% more material than a layout based on an optimized design. Furthermore, optimized structural forms have the potential to allow longer spans than are possible with current designs. With longer span bridges, an increased range of obstacles may be crossed; the associated increased connectivity can unlock economic and social benefits, also increasing the attractiveness of surface transport options.

However, applying structural optimization methods to long spans also comes with many challenges – identifying and addressing these will be the focus of this presentation. This will include recently developed methods to ensure accurate and conservative modelling of the self-weight of the structure. Issues relating to the provision of anchorages and foundations will also be addressed, as these parts of the structure often contain very large quantities of carbon-intensive materials (e.g. concrete). The influence of varying loadings and dynamic effects will also be discussed, as these too become more severe at longer spans. Furthermore, user-friendly tools employing these methods will be demonstrated.

This presentation will focus principally on application to bridge structures, as these are where the longest spans are typically found. Nonetheless, many of the methods outlined have wide ranging applicability. Thus, other long-span structures, such as canopy roofs and stadiums, will also be discussed where relevant. Overall, the approaches outlined in this presentation provide a powerful framework to minimise the embodied carbon associated with some critical and large-scale infrastructure projects.

10:30-10:45 - Q&A

10:45-11:00 - Comfort break

11:00-11:45 - Adaptive layout optimization of fail-safe truss structures (Dr Linwei He)

Abstract: Avoiding disproportionate and progressive collapse via 'fail-safe design' is a key consideration in the design of large buildings and other infrastructure. In this presentation the 'fail-safe' design requirement is considered in the context of numerical layout optimization, a powerful and highly efficient method to generate minimum volume truss structures. This allows an optimal balance to be struck between redundancy (i.e., inclusion of redundant material to guard against potential disproportionate and progressive collapse) and efficiency (i.e., least material usage).

In the proposed 'fail-safe' layout optimization procedure described, globally optimal solutions for various structural damage scenarios are presented, including the member-based damage scenario (i.e., any one member in a structure can be damaged and/or have zero strength without causing structural collapse). Following the 'ground structure' approach, it is evident that the full optimization problem contains a huge number of potential members and damage cases. Thus instead of directly solving the full problem, a novel adaptive solution scheme is utilized, permitting members and damage cases to be added iteratively to the problem, without affecting the optimality of the solution obtained. It is demonstrated that significantly more challenging problems than those found in the literature can now be solved rigorously and efficiently via the proposed method.

The availability of a procedure able to identify globally optimal solutions also allows new benchmarks for least-material designs of 'fail-safe' truss structures to be established. To demonstrate the efficacy of the proposed method, a number of example structures are considered in the presentation, along with different damage scenarios, including 'area damage' that can occur anywhere within a structure, in which multiple members are simultaneously damaged.

11:45-11:55 - Q&A

11:55-12:00 - Closure