Imperial College London

# Investigation into Web Optimisation for Slender I Sections in Major Axis Buckling

**MSc Graduate:** Wenxuan Hong [a] **Supervisors:** Prof. Leroy Gardner [a], Ben Weber [a]

[a] *Department of Civil and Environmental Engineering, Imperial College London, London, UK*

## Project objectives and goals

In the past two decades, additive manufacturing (AM) has gained popularity in multiple industries and academia, offering a great opportunity to manufacture parts with complex geometry and/or varying material properties. The possibility of structural optimisation with varying cross-sections and demand-oriented opening patterns is presented, benefiting from the flexibility of AM [1]. This study aims to increase the structural efficiency of a 3D printed thin-walled steel I section column in major axis buckling, by investigating the effects of creating web openings to increase material utilisation under compression using both parametric studies and nonlinear topology optimisation (TO). By investigating an efficient structural layout, this work makes contributions to meeting the growing demands of sustainable development.

## Description of method and results

The design and assessment of thin-walled steel I-shaped columns of grade S550 with varying cross-section and different web opening patterns were carried out based on a reference column design using a sinusoidal shape [2] with a nominal length of 1500 mm and a volume of 825000 mm³. The concept of optimisation by removing material from less stressed regions and redistributing it to locations with higher stress, thus keeping the total volume of the column constant, is investigated. A series of parametric studies focusing on (a) constant height ratio web openings and (b) tapered web openings, as shown in **Fig 1**, were performed in the commercial finite element package ABAQUS, where the parameters of opening length ($L_{hole}$), opening height ($H_{hole}$), spacing (S) and width of cross-bracings (w) were investigated.

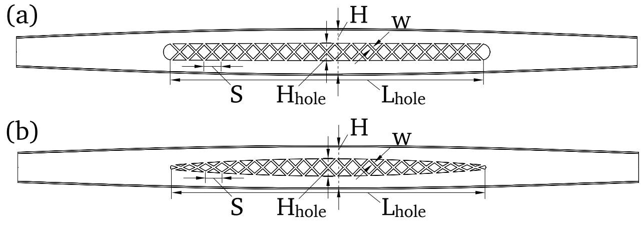


**Fig 1:** General layouts of column with web openings

Moreover, topology optimisations with different volume constraints and penalty factors were performed, in which the capability of nonlinear TO in improving the structural performance was investigated.

The maximum resistance from the constant height ratio opening models was 275.15 kN, whilst the maximum resistance from columns with the tapered opening was 277.68 kN. These correspond to a respectively 4.1% and 3.2% drop when comparing with the maximum resistance of the benchmark column without openings (286.90 kN). The reduction of the collapse load is attributed to local buckling at the connections between the cross-bracings and the web, accompanied by global buckling failure, as shown in **Fig 2.** The strongest column presented in this study had a tapered opening with a length of 1050.0 mm and a height of 26.01 mm.

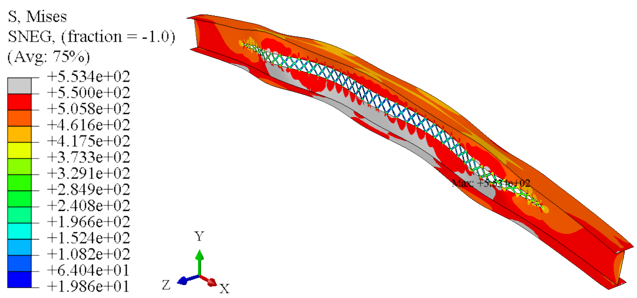


**Fig 2:** Von Mises stress plot at collapse (GMNIA)

Furthermore, the normalised resistance from columns using topology optimisation was 207.25 kN, where a 27.8% strength reduction was reported, which shows the significance of local buckling on the performance of the optimised columns, as this was not possible to be simulated using the topology optimisation algorithm.

## Conclusions

Within this study, all the proposed columns with web openings from both parametric studies and nonlinear TO were weaker than the benchmark column. No benefits from removing web material were obtained when comparing to the benchmark column with varying cross-section. Global buckling interacting with local buckling at the connections between cross-bracings and the web dominated the column failure, which indicated that for thin-walled steel I-sections in major axis buckling, the web plays an essential role in stabilising the structure, even though it is not fully utilised.

## References

[1] Buchanan C, Gardner L. Metal 3D printing in construction: A review of methods, research, applications, opportunities and challenges. *Engineering Structures.* 2019;180(2): 332-348.

[2] Ruocco E, Wang C, Zhang H, Challamel N. An approximate model for optimizing Bernoulli columns against buckling. *Engineering Structures.* 2017;141: 316-327.