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DESIGN OF STEEL TRUSSES BY GMNIA WITH CSM STRAIN LIMITS

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INTRODUCTION

Recently, design by second order analysis has become a practical design method for structural engineers due to its ability to capture the second order effects during analysis. Models employing shell elements are known as the most comprehensive analysis. However, as the process of modeling structures directly using shell elements is cumbersome, the majority of these methods use beam elements, which are unable to capture the effect of local buckling. This means the cross-section classification is still required along with the conservative cross-section (C-S) checks that will typically lead to an underestimated ultimate capacity prediction.

To overcome the shortcomings of traditional cross-section classifications, a deformation-based structural design approach, known as the Continuous Strength Method (CSM) was developed by Gardner (2008). The idea behind CSM is to present a continuous relationship between the deformation capacity and the cross-sectional slenderness. Recently, a geometrically and materially nonlinear analysis with imperfections (GMNIA) based design approach, also refered to as advanced analysis, has been developed that utilises these CSM strain limits, fewer design checks are thus required.

The focus of this thesis is to validate the applicability of steel truss design using advanced analysis with CSM strain limits, and evaluate the accuracy of the studied advanced analysis by comparing to other alternative steel truss design methods. Furthermore, a systematic worked example of steel truss design using the studied advanced analysis is also provided for illustration purpose.

DESCRIPTION OF METHOD AND RESULTS

The accuracy of using shell FE models to capture the full load-deformation behaviour has been successfully validated against experimental results for the cases of individual structural member by Fieber, Gardner, and Macorini (2019). Therefore, analysis methods directly modelling plasticity, residual stress and geometric imperfections using shell finite elements were adopted in this study as the benchmark results for steel truss analysis.

The advanced analysis design methods used beam FE models, and the effect of residual stress and geometric imperfections were accounted using equivalent bow imperfections which depend on the type of analysis adopted. For the GMNIA analysis, the quad-linear material model developed by Yun and Gardner (2017) was employed to define the full stress-strain response including the strain-hardening behaviour and yield plateau length.

For the benchmark shell analyses, the ultimate resistance is simply taken as the maximum load when the load deformation response decreases, while the ultimate resistance generated from the proposed design approach using beam FE model with strain limit check is taken as the lower of (1) the peak load at which the maximum load is reached at structure failure or (2) the load when the averaged longitudinal compressive strain ε_{Ed} over the elastic local buckling half-wavelength $L_{b,cs}$ has reached the determined CSM strain limit ε_{csm} or $\rho_{csm}\varepsilon_{csm}$. Meanwhile, the ultimate resistance for the simplified beam FE models (GMNIA) with C-S check are taken as the lower of the peak load or the load when the section capacity check can no longer be satisfied. The types of analysis used in this study are listed below:

- GMNIA with CSM Strain Limit (M4)
- EC3 Traditional Steel Design Approach (M2)
- GMNIA with C-S Check (M4)
- GNIA with elastic C-S Check (M4)
- GNIA with plastic C-S Check (M4)

Overall, the ultimate capacity predicted by the studied advanced analysis with CSM strain limit method using beam FE model has a consistent 10% to 15% capacity increase comparing to the traditional design approach, with the ultimate capacity prediction always remaining within 4% on the safe side of the reference shell FE model. Additionally, the proposed method of geometrically and materially nonlinear analysis with imperfections with CSM strain limits is successfully able to capture the correct failure mechanism during the analysis. The following Fig 1 shows an example of the predicted ultimate resistance using different design methods, and the load-deflection path for beam and shell FE models.

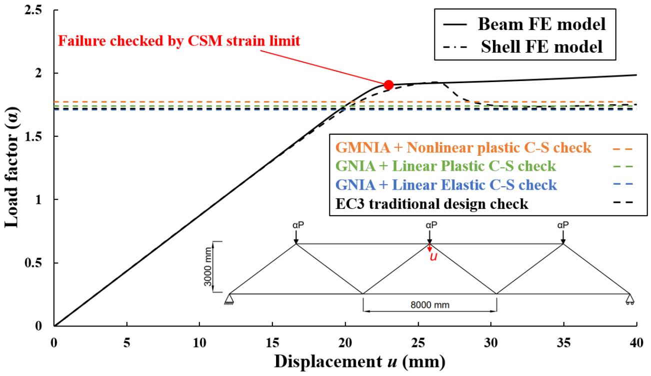

Fig 1: Load-deflection paths and predicted ultimate resistances for a S355 three span Warren truss using 6 different design methods.

POTENTIAL APPLICATION OF RESULTS

The applicability of GMNIA-based design with CSM strain limits for warren truss design has been successfully validated. The increased capacity predictions using advanced analysis with CSM strain limits will lead to a material saving for large scale design, and this feature satisfies the requirement of being a sustainable structural design approach. Additionally, as a practical design approach, this study has shown that the design efficiency can be significantly increased by using fewer design checks and employing computationally-efficient beam FE elements. The application of the design approach for larger and more complicated structures will be made in further investigations.

REFERENCES

Fieber, Andreas, Leroy Gardner, and Lorenzo Macorini (2019). “Design of structural steel members by advanced inelastic analysis with strain limits”. In: *Engineering Structures* 199, p. 109624.

Gardner, Leroy (2008). “The continuous strength method”. In: *Proceedings of the Institution of Civil Engineers-Structures and Buildings* 161.3, pp. 127–133.

Yun, Xiang and Leroy Gardner (2017). “Stress-strain curves for hot-rolled steels”. In: *Journal of Constructional Steel Research* 133, pp. 36–46.