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Structural Assessment: Making the Most of What You Have

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This paper is inspired by the safe theorem as expressed by Professor Heyman, and the recognition that structural engineers need to be able to demonstrate that the loads applied to their structures can be transmitted by stresses, or stress-resultants, that lie within bounds set by the strengths of the materials of construction. When this need is set in the context of structural assessment, it is likely that the engineer will wish to push the structure to its limits, i.e. to assess the maximum level of load capacity that can be justified.

We propose an efficient computational method for use in limit and shakedown analyses, which also provide safe lower bound solutions when the theorems of plasticity are valid. These methods of analysis have been implemented for plates in a new software tool EFE, and enable us to make the most of limited resources whilst conforming with elastic and plastic design methods permitted within the less prescriptive Eurocodes.

With both limit and elastic shakedown analyses in mind, a brief summary of the formulation of appropriate hybrid equilibrium macro plate elements for both membrane and bending behaviours is presented together with an efficient method for the direct construction of hyperstatic, or residual, fields of stress-resultants in local subdomains of the finite element model. When imbued with linear elastic material properties, the equilibrium finite element model leads to linear elastic solutions appropriate for elastic shakedown analyses. Although yield surfaces can be linearised in order to use a linear programme (LP), the applications presented involve conic surfaces for which second order cone programming (SOCP) is most suitable, and has been used so as to exploit the high level of sparsity which follows from the choice of hyperstatic fields.

Illustrative numerical examples will be presented for plate structures in the forms of:

- Reinforced concrete slabs with orthotropic reinforcement subjected to concentrated loads and/or supports, using the Nielsen yield criterion;
- Steel floor plates, using the von Mises yield criterion;
- Masonry walls/arches subjected to in-plane loading, using an homogenised material model with limits on the values of tensile and compressive principal stresses.

EFE Equilibrium Finite Elements

for safe structural analysis

and design optimisation