STRUCTURAL OPTIMIZATION OF AUTOMOTIVE COMPONENTS FORMED FROM THIN SHEET

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ABSTRACT: *The pressure of an increasingly competitive market is encouraging a widespread cost-cutting and weight reduction policy. For many structural automotive components, these two factors are linked to the thickness of the sheets of materials from which they are formed. This situation means that stability criteria form determining factor more important than strength or mere stiffness.*

The mechanical behaviour of components made from thin sheet is markedly non-linear, so that the problems posed for design of this type of parts often escapes from the designer's intuition. The objective of this paper is to outline the physical bases of the behaviour of this type of components, and to draw attention to the hazards involved in an over-simplistic analysis.

INTRODUCTION

The current trend towards cost reduction means that new criteria are brought to the design of automotive components formed from thin sheet. When it comes to conceiving this type of structural components, designers must be aware that the usual strength or stiffness criteria may prove insufficient given the marked complexity of their structural behaviour. This complexity results, on one hand, from their propensity to present notably non-linear phenomena and instability (crippling) under service loads, and on the other hand from their sensitivity to factors associated with the physical reality of each particular part (initial imperfections, prior stresses, etc.). As a consequence of this, calculations are often incomplete, ambiguous or, at the very least, with a high degree of uncertainty, which makes it advisable to combine analytical and experimental approaches.

The object of the present paper is to highlight some of the peculiar features of the structural behaviour of this type of components, especially with respect to instability phenomena. It is addressed to design engineers not familiar with this type of questions.

PRIOR CONSIDERATIONS

The phenomenon of instability or buckling basically consists in a disproportionate increase in displacements resulting from a small increase in the applied load. This change arises due to a sudden change in the distribution of internal stresses in the part when a critical load value is reached. The compressive membrane stresses, uniform throughout the thickness, are suddenly replaced by flexural and/or torsion stresses of very much higher values. This change of behaviour can be either reversible, remaining within the elastic field, in which case its immediate effects can disappear, or it irreversible leading to permanent plastic deformation. Instability is therefore associated with compressive membrane stresses whose critical value depend on the intrinsic stiffness of the material and the geometry of the part. Designers must therefore pay special attention to this situation.

Instability can be either overall or local. Where overall, the component presents overall strength failure, while local instability only leads to partial failure. A typical example of overall instability would be the collapse of a bar under compression, while an example of local instability would be the crippling of the zone between two spot welds that are spaced too far apart.

The instability point can be reached without existing any prior non-linear behaviour, or it can arise after a zone of high non-linear behaviour. The calculations to be applied in each case are considerably different.

When perfect components are statically analysed, there can be found two phenomena usually referred to as buckling: the collapse at the maximum point of the load-displacement curve or equilibrium path and the bifurcation of the equilibrium.

Figure 1a shows several options for equilibrium paths. Following an initial behavioural phase which may be linear or non-linear, a point of bifurcation (λ_B) is reached at which a geometrically perfect component can evolve in two ways: either towards a maximum of the initial equilibrium path (collapse load λ_P) or according to a second equilibrium path which can be stable or unstable. Where this secondary path is stable, the component will present a post-critical strength reserve, while if it is unstable it will show collapse. In this second case the component is said to be sensitive to imperfections.

A real component, which has imperfections, presents a reduced collapse load (λ_I), lower than the bifurcation load of the perfect component (λ_B), as can be seen in figure 1a.

The difference between the bifurcation load of a perfect component (λ_B) and the reduced collapse load of a real component (λ_I) will depend on initial imperfections and on the shape of the secondary equilibrium path of the perfect component

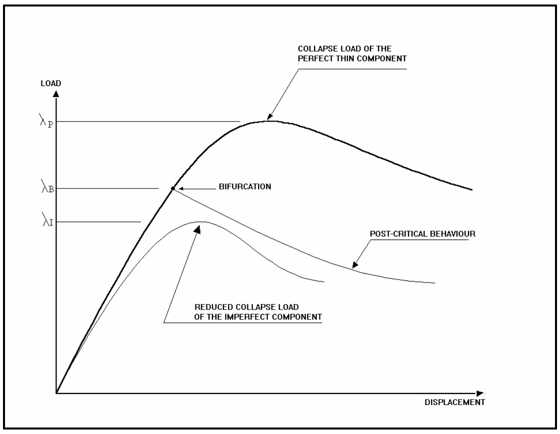

Figure 1a

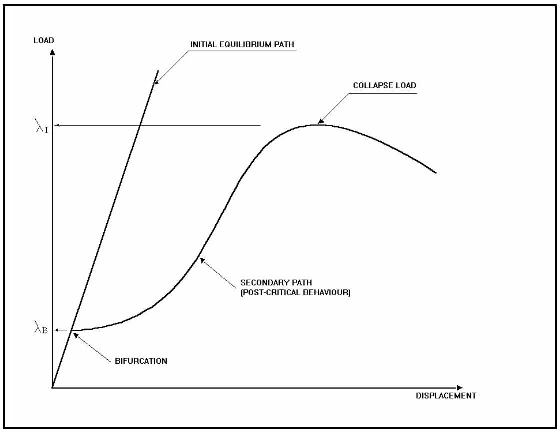

Figure 1b

Figure 1b presents another possible form of behaviour of a component: after an initial linear phase, two possible equilibrium paths arise at the bifurcation point. A real component would follow the secondary path, which in this case is stable due to its positive slope. In this case the bifurcation load λ_B characterises a local buckling with little effect on overall strength. The collapse load λ_I is finally reached.

When weight plays a fundamental role, the several parts of a structure are allowed to exceed the local buckling loads, in order to take advantage of their post-critical strength. (Note here that if this capacity is to be taken into account in the optimisation process of a design, the utmost caution must be taken when making physical simplifications or component behavioural models - when, for example, geometrical imperfections are brought into calculations).

Another equally risky approach lies in designing so that overall and local instabilities arise simultaneously (the load capacity of structures with simultaneous local and overall buckling can be especially sensitive to initial imperfections).

On components submitted to cyclical loadings in which plastic fields arise, instability can appear in a delayed manner due to the progressive accumulation of plastic deformation, possibility to be taken into account when determining the lifetime of the component. It should be noted here that the appearance of parasitic or secondary stresses during crippling can give rise to fatigue fracture even in the elastic field.

As an of example of the stated above, a simulation of the stability behaviour of a profile formed from thin sheets, is presented below in order to show the importance of considering this concept when designing components.

SIMULATION OF THE STABILITY BEHAVIOUR OF A THIN PROFILE

An I profile formed from thin sheets with hinged ends and submitted to a vertical load is analysed. For this purpose, a half-profile Finite Elements model has been developed (figure 2), and a dynamic non-linear calculation has been carried out taking into account large displacements. As the aim of the study is the stability of this profile, it has been necessary to introduce an initial imperfection in the compressed flange with the dual purpose of activating its instability and reproducing reality.

Figure 3 shows in an exaggerated way the deformation obtained 10 seconds after the start of load application. Local instabilities in the compressed flange can be clearly observed, though there is no overall instability under the applied load.

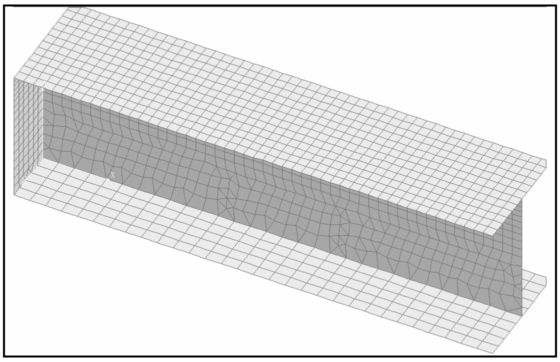

Figure 2

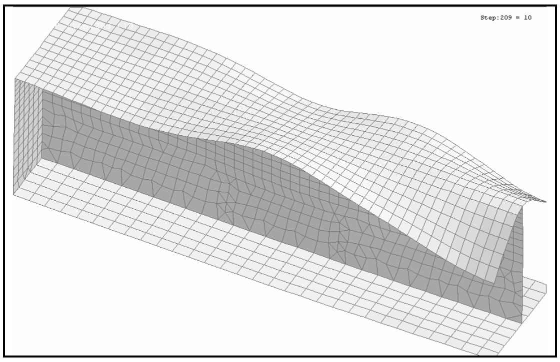

Figure 3

With regard to the stress state of the profile it might noted that, in case a mere strength calculation had been carried out, without analysing its local stability, it would not have been possible to evaluate the local flexural stresses which appear in the compressed flange zones with instabilities, the real behaviour of the profile differing markedly from the simulated. It is also remarkable that the level and nature of the imperfections initially considered within this simulation have a notable influence - as happens with the analytical calculations - on the stable behaviour of the profile, so it is important that said imperfections are as close as possible to reality.

This fact means that in structural component tests and simulations in which several local buckling modes may appear simultaneously, such as vehicle crash or even the usual dynamic behaviour of components formed from thin sheet, the prediction of the strength and stability behaviour needs several hypotheses as far as imperfections are concerned (within the expected limits) and an analysis of sensitivity of the results to this factor.

CONCLUSIONS

When conceiving components formed from thin sheets, the designer must take cautions such as the following ones:

- Take instability as an ultimate state condition to be checked systematically.

- Limit the distance between supports of compressed components.

- Take control of the free length of compressed members between restrictions such as spot welds. The designer must take in consideration enabling formal or added stiffeners on compressed members prone to local buckling under service loads.

- Check the imperfections level within final product and its material quality.

- Reduce as much as possible compressive load eccentricities.

- Take into account possible stress redistributions that may overload compressed components in case of appearing local yielding.

- Check the possible generation of cyclic cripplings that may produce increasing strains or fatigue fracture.

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