Some practical considerations on the postcritical behaviour of structures

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Some Practical Considerations on the Postcritical Behaviour of Structures

Quelques remarques pratiques sur le comportement des structures dans le domaine post-critique

Praktische Bemerkungen über das Verhalten der Konstruktionen im überkritischen Bereich

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In the following the postcritical behaviour of structures would be dealt with from the viewpoint of their practical applications.

Basically, three different types of postbuckling behaviour can be distinguished. The load-bearing capacity of the structure can be - after exceeding the critical load P_{cr}^{lin} of the classical /linear/ theory - either increasing, or constant, or decreasing. Plotting the load P against some average value of the buckling deformation w, these three cases can be represented by the diagrams of Figs. 1a,b,c. Here, in addition to the perfect /centrally compressed/ case, some curves corresponding to initially imperfect structures have been represented too.

Structures with increasing postbuckling load-bearing capacity /Fig. 1a/ are insensitive to initial imperfections and/or creep because their diagrams have no peak which could be influenced by these two factors. On the other hand, structures with decreasing diagrams /Fig. 1c/ are extremely sensitive to initial imperfections and creep as well, for the peak value of their P/w/-curves depend markedly on the magnitude of both. /The influence of creep is similar to that of initial imperfections because creep increases buckling deformation, thus it augments the influence of the imperfection./ We can thus choose a much smaller safety factor for structures corresponding to Fig. 1a than to those of Fig. 1c.

Structures corresponding to Fig. 1c form a case of transition between the two other groups. Its importance comes mainly from the fact that it can be treated theoretically in a simple way, but it also describes, at least approximatively, the behaviour of some structures /e.g. buckling of bars/.

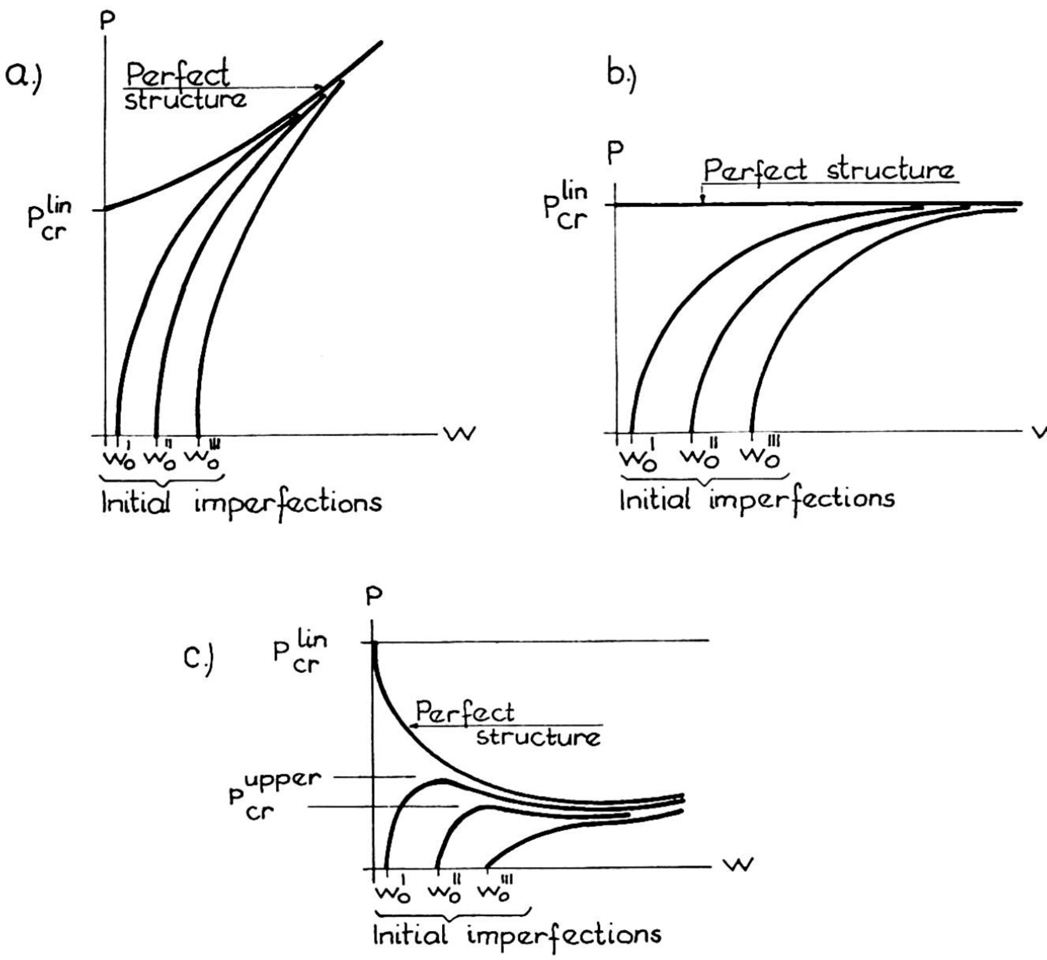

Fig. 1.

From all that has been said follows that when designing a structure, it is most important to know whether its postbuckling load-bearing capacity increases or decreases. For some structures we know this from theoretical investigations to be found in the literature. But if we have to design a structure the postbuckling analysis of which has not yet been made, some simple criteria to determine the kind of its postbuckling behaviour could be of great value. In the following some such criteria will be shown.

<u>Theoretically</u> it can be said [2], [3] that a structure has an increasing postbuckling load-bearing capacity if the following two conditions are fulfilled:

a/ The structure must have some parts which can bear more load, even without the other, more buckled /weaker/ parts, than the whole structure.

b/ The redistribution of stresses that is necessary for condition a/ must be physically possible in the structure itself as well as at the supports.

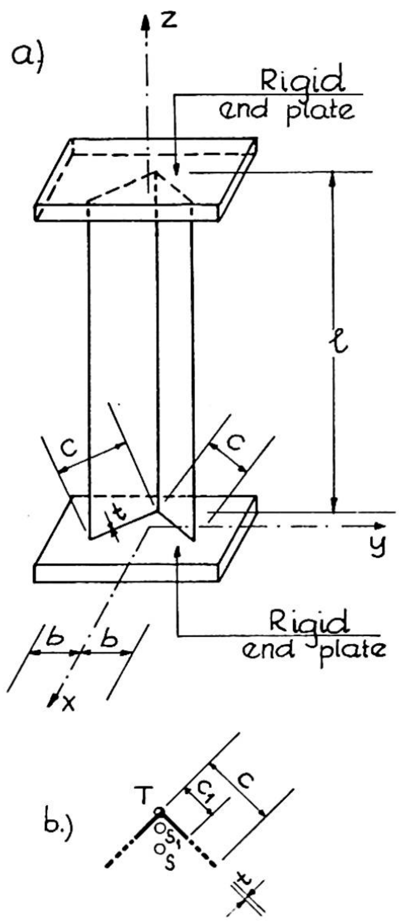

Fig 2.

Let us illustrate this on the pure torsional buckling of a straight bar with the cross section of an angle /Fig. 2a/. When the critical load is exceeded, the angle begins to buckle with the rotation of the cross sections around their shear centre T /Fig. 2b/. We can assume, as an approximation, that the free ends of the cross sections cease to bear any load. Thus, instead of the original flange width c of the angle only a part of it, of width c_1, will be effective. This part, however, can carry more load than the original whole structure. This can be seen in the formula for the critical load of torsional buckling for an angle with built-in ends 5 :

$$P_{cr} = 2 \frac{G t^3}{c} .$$

Since P_{cr} is inversely proportional to flange width c, the smaller c, the greater the critical load will be. Condition a/ is thus fulfilled.

In this case the redistribution of stresses means that the point of action of the load must shift from the original centroid S to the centroid S_1 of the smaller cross section. If the end conditions make this possible /e.g. in case of rigid end plates/, then condition b/ is also fulfilled, thus we obtain an increasing postbuckling load-bearing capacity.

Essentially the same considerations can be made in relation to the torsional buckling of shell-arches 1 , 3 , plate buckling 5 etc., i.e. in all cases where the critical load is inversely proportional to some dimension of the structure, and even in some other cases. Sometimes it is also possible to establish a simple upper bound for the maximum value of the postbuckling load the

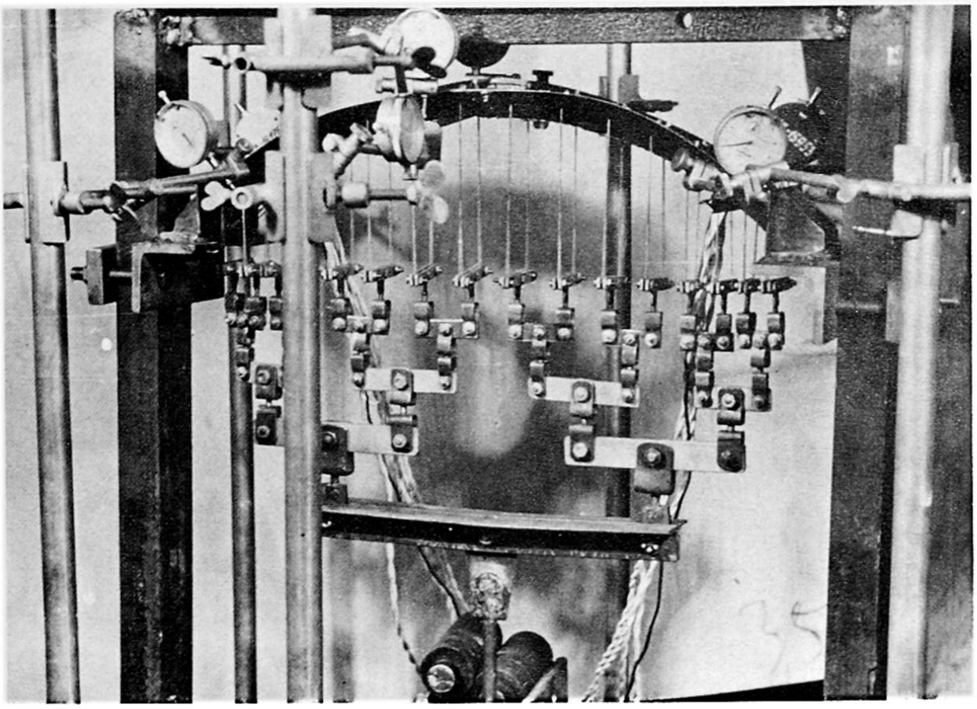

Fig. 3.

structure can carry [2] . For illustration, Fig. 3 shows a steel model of a shell-arch with built-in ends under centrical compression. The rotation of the middle cross section, as characteristic for the torsional buckling, is plotted in Fig. 4. After exceeding the linear critical load P_{cr}^{lin} = 512 kp, the load-deflection curve has a markedly ascending character, represented in Fig. 1a.

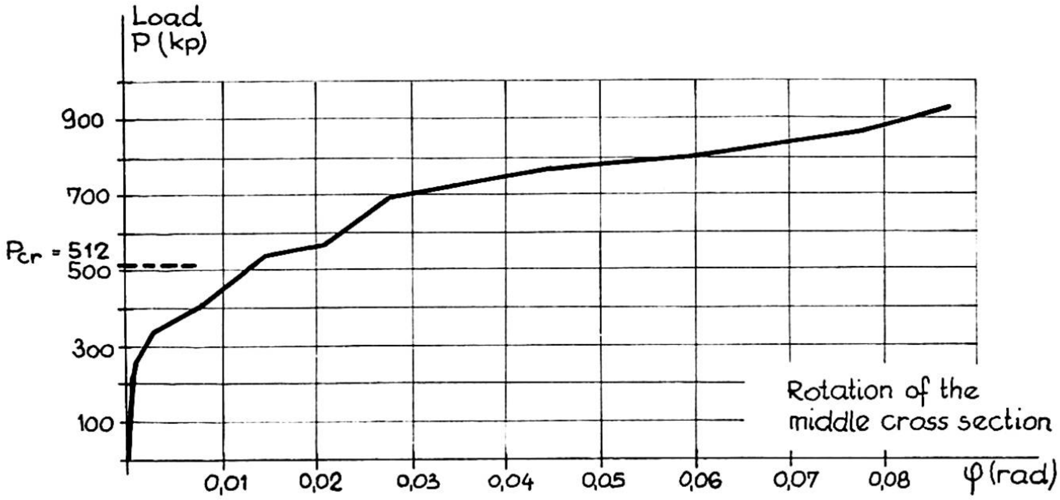

Fig. 4.

In cases, however, when these theoretical considerations cannot be applied, there is another possibility to predict postbuckling behaviour from <u>non-destructive model tests.</u>

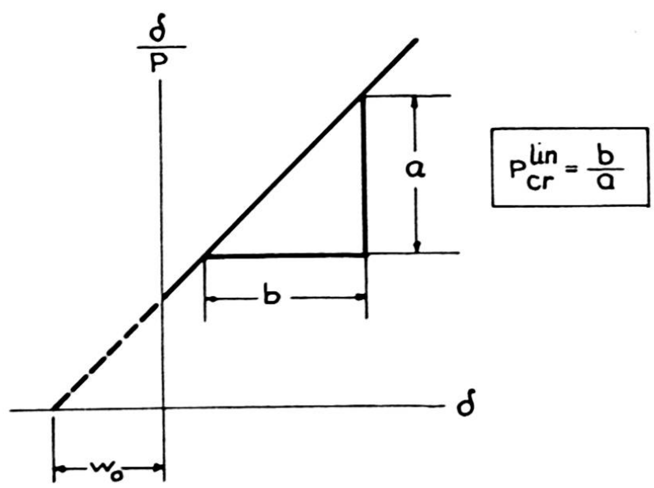

Fig. 5.

It is well known [5] that for structures corresponding to Fig. 1b, the asymptotic curves for the imperfect cases can be made straight by plotting the ratio δ/P against the buckling deformation $\delta = w - w_o$, measured from the initial /imperfect/ state w_o /Fig. 5/. The inverse slope of this line gives the critical load. This procedure, called Southwell's plot, greatly facilitates the determination of this latter since it would be much more uncertain to determine the asymptotic value of the curves in Fig. 1b by extrapolation.

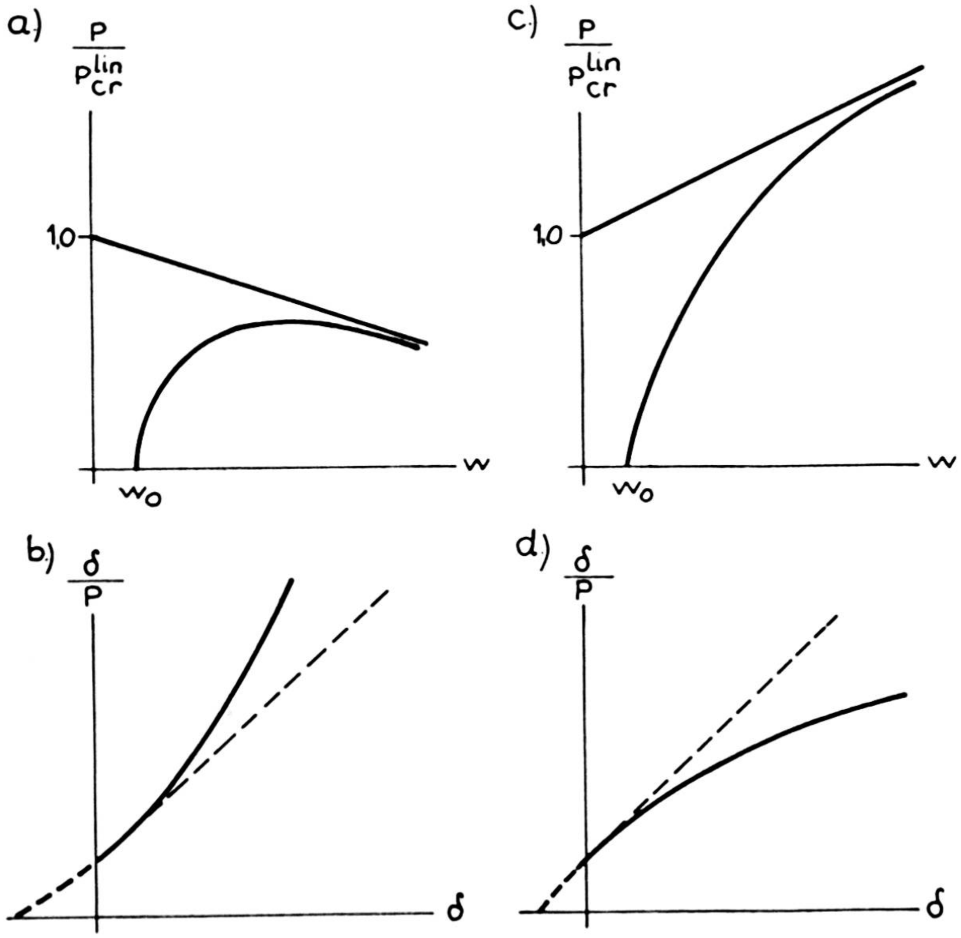

Fig. 6.

It can be easily shown [2], [4] that in case of increasing or decreasing

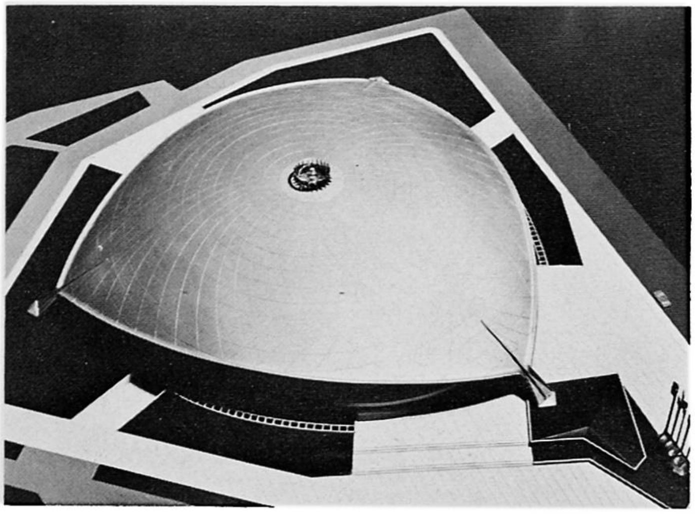

Fig. 7.

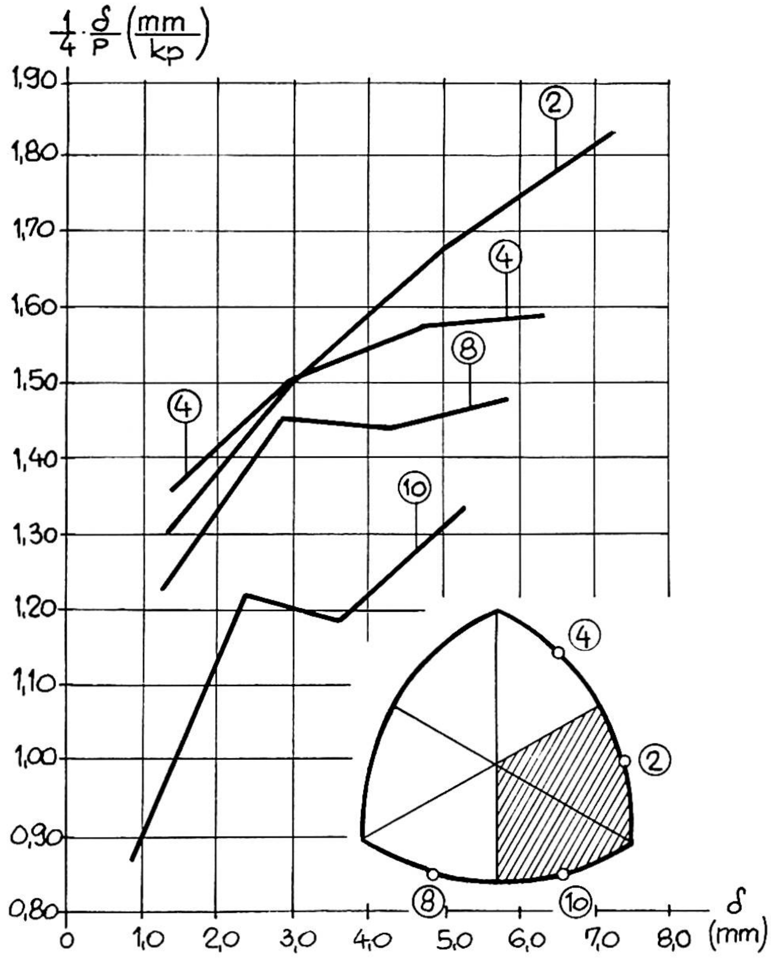

Fig. 8.

postbuckling load-bearing capacities, the Southwell diagram becomes curved downwards or upwards, respectively /Fig. 6/. Thus, measuring the buckling deformations of the model and plotting δ/P against them, we can decide at once and without destructing the model whether it has a constant /Fig. 1b/, an increasing /Fig. 1a/ or a decreasing /Fig. 1c/ postbuckling load-bearing capacity.

For illustration we show some results of the model test of the new Budapest Sports Hall, designed recently /Fig. 7/. Its structure is a reticulated steel shell without stiffening edge arches, supported by three points at a distance of 112,80 m.

For the stability of the structure only rough estimates could be made in the course of design. Thus we had to resort to a model test. Since we intended to study its behaviour under several loading cases, it was desirable to clear up postbuckling characteristics by a non-destructive model test in order to avoid costs of several models. Fig. 8 shows the Southwell diagrams of four edge points for the loading indicated by hachure. All diagrams show a definite downward curvature. The ensuing increasing postbuckling load-bearing capacity has been confirmed by the final test when we loaded the model with total load up to failure.

I hope these viewpoints might be of some use for designers.

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Summary

After description of the three main types of postbuckling behaviour of structures two conditions, necessary for the increasing postbuckling load-bearing capacity, will be established. For determination of postbuckling behaviour from non-destructive model tests, the generalized Southwell plot will be presented.

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