Scientific Report

EUROMECH COLLOQUIUM 424

Buckling Predictions of Imperfections Sensitive Shells

ROLDUC, The Netherlands, 2-5 September 2001

The topic of this colloquium received wide interest in the scientific community working in the field of shell stability. Nearly all the major European Research Groups accepted the invitation of the organizers and attended the conference. They presented at least one paper covering the topics of the meeting. In addition, quite a few additional proposals were received, so that an interesting programme (see annex) could be arranged serving as a basis for the discussion of the main question raised at the conference:

> "Is it possible to devise an improved shell design procedure, which makes full use of the concept of imperfection sensitivity and the new generation of nonlinear computer codes, as an alternative to the currently used design curves, which are based on lower bounds to all currently available experimental results?"

In summary 39 papers were presented including 5 papers from East-European countries, 1 paper from Israel and 1 from the USA (the papers by M. Jamal et al (Morocco) and J. Naprstek (Czech Repubic) were withdrawn in the last minute for various reasons).

There were a number of survey type lectures covering such topics as

> "On the Imperfection Sensitivity of Shells"
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> "Substitute Geometrical Imperfections for the Numerical Buckling Assessment of Cylindrical Shells under Combined Loading"
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> "Nonlinear Shell Buckling Design: Examples coming from Nuclear Industry and Application to Other Industries"

and another review paper dealing with the different mathematical approaches that have been used to elucidate the perplexing buckling behavior of thin-walled shells.

That the use of assumed or measured initial imperfections has become a standard procedure whenever stability analysis is carried out, was vividly demonstrated by the large number of papers dealing with the evaluation of the load carrying capacity of different shell geometries under various external loads. In all cases the imperfection sensitivity of the critical buckling loads was investigated either by using a variety of numerical approaches based (e.g. based on Koiter's asymptotic imperfection sensitivity theory), or by employing advanced nonlinear shell codes to calculate the nonlinear collapse behavior of the imperfect shell structures.

There were a number of papers which dealt with the derivation of relatively simple-to-use buckling formulas based either on analytical solutions or on numerical simulations based on the fully nonlinear theory. Some authors attempted to validate the predictions by comparison with experimental results, others by comparison with the results of refined finite element collapse load calculations.

There were a few papers dealing with plastic buckling and localization of buckling patters, and with dynamic buckling. Some other papers dealt with special problems such as the buckling behavior of foam-filled circular cylindrical shells under axial compression, creep buckling of cylindrical shells under axial and radial loads, neural predictions of buckling loads of cylindrical shells, buckling behavior of high performance concrete shells, the use of buckling and postbuckling characteristics of thin strips to estimate residual stresses and delamination growth analysis of axially compressed composite panels.

Four papers presented reported on an approach often called "high-fidelity analysis", where the uncertainties involved in a design are simulated by refined and accurate numerical models. Two papers used a "hierarchical approach" to investigate the possible detrimental effects of a whole series of factors such as effects of stiffener and load eccentricity and prebuckling deformation caused by the edge restraints, besides the influence of initial imperfections and of the boundary conditions. The other two papers presented the results of a combined experimental and analytical study of the buckling response of unstiffened thin-walled graphite-epoxy cylindrical shells. It was shown that, by including besides the traditional initial geometric shell-wall imperfections also other nontraditional forms of imperfections such as shell-wall thickness variations, shell-end imperfections, variations in loads applied to the ends of the shell, variations in boundary conditions and boundary stiffness and the effects of manufacturing anomalies caused by small gaps between adjacent pieces of graphite-epoxy tape in a shell-wall layer, the high-fidelity nonlinear shell analysis procedure will predict the response of the shells quite accurately. Preliminary results of this comparison suggest that the nonlinear analysis procedure can be used for determining accurate, high-fidelity design knockdown factors for predicting shell buckling and collapse in the design process.

It was unfortunate that the only paper dealing with Stochastic Stability Analysis using random initial imperfections had to be withdrawn in the last minute because of personal reasons.

The differences between the two popular approaches to the design of buckling sensitive shell structures, namely the Lower Bound Design based on an empirical knockdown factor versus the Imperfection Sensitivity Design based on worst shape or measured initial imperfections was highlighted by many discussions not only at the sessions but continuing during the common meals, and also until late hours in the friendly bars of the Monastery Congress-Center Rolduc. After lengthy and lively discussions there was a general agreement that from the results presented it became clear that if one wants to achieve a reliable prediction of the buckling or collapse load one must work with measured initial imperfections. There was an unanimous support for continuing and intensifying imperfection surveys on representative full scale structures. The prevailing opinion was that International Projects supported within the EUROCODE activities of the EC in Brussels should be the appropriate way to proceed with this undertaking.

In conclusion, the Colloquium made it clear that the present level of nonlinear shell theories and their numerical implementations offer ways to model the collapse behavior of shell structures accurately, if the appropriate input data is available. Here it must be stressed that besides the initial geometric imperfections also shell end imperfections, variations in loads applied to the ends of the shell and other nontraditional imperfections may be needed for a reliable and accurate buckling load prediction.

Further, in certain applications such as large off-shore drilling-platforms for reliable collapse load predictions material nonlinearities must also be modeled accurately.

The establishment of an International Imperfection Data Bank containing imperfection surveys on representative shell structures and the development of reliability Based Design Procedures will become more important in the coming years. They could also be the topics for a further colloquium on shell stability analysis in, say, three more years, when the new results obtained with these techniques could be discussed in more detail.

Delft, December 18, 2001

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