EUROMECH Final Report Date:

Please send this report to the Secretary of the European Mechanics Council, Professor Bengt Lundberg, School of Engineering, Uppsala University, Box 534, S-751 21 Uppsala, Sweden, within one month after the Colloquium.

General

Euromech Colloquium No: 317

Title: BUCKLING STRENGTH OF IMPERFECTION-SENSITIVE SHELLS.

Co-Chairmen: Prof. G.D. GALLETLY
Prof. J. ARBOCZ

Place and country: LIVERPOOL, ENGLAND

Dates: 21-23 MARCH 1994

Finance

The conference fee £120. included 2 conference dinners 1 welcoming reception, 3 lunches, 6 coffee/tea breaks

Funding: SELF

Accomodation (type and cost): £18/night (B and B) in a hall of residence

Meals: in Reg. Fee except for breakfast £35/night (B and B) at Britannia Adelphi Hotel

Participation

Total number of participants: 59

Distribution of participants by country:

Code	Country	Number	Code	Country	Number
A	Austria	5	IRL	Ireland	0
B	Belgium	0	LT	Latvia	0
BG	Bulgaria	1	LV	Lithuania	0
CH	Switzerland	2	N	Norway	1
CS	Czechoslovakia	1	NL	Netherlands	3
D	Germany	18	P	Portugal	0
DK	Denmark	3	PL	Poland	5
E	Spain	0	R	Rumania	0
EE	Estonia	0	S	Sweden	2
F	France	3	SF	Finland	0
GB	Great Britain	8	YU	Yugoslavia	
GR	Greece	0	CIS	CIS Ukraine	2
H	Hungary	1	-	Others Israel	1
I	Italy	0		Croatia	1
				USA	2

Is there need of another colloquium on the same subject? Which year? Yes. In 2-3 years time.

Please turn

Scientific Report

See attached report.

Please use additional pages if needed and sign at the end.

Scientific Report

EUROMECH COLLOQUIUM 317

Buckling strength of Imperfection - Sensitive Shells

The University of Liverpool, 21-23 March, 1994

The topic of this colloquium received wide interest in the scientific community working in the field of shell stability. With the exception of Ghent University (Belgium) and the University of Metz (France) all the major European Research Groups accepted the invitation of the organizers and attended the conference. They also 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 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, as an alternative to the currently used design curves, which are based on lower bounds to all currently available experimental results?"

In summary 40 papers were presented, 6 of which were from U.K. Universities. There were 8 papers from East-European countries, 1 paper from Israel and 2 from the U.S.A.

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

"Causes of Imperfection-Sensitivity in the Buckling of Thin Shells"

"The Role of the Imperfection-Sensitivity Concept in Civil Engineering Structural Design"

and

"The Development of Shell Imperfection Measurement Techniques"

leading up to the final round table discussion entitled "Towards Improved Shell Design Procedures".

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 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 significant number of papers which dealt with the derivation of relatively simple-to-use buckling formulas based on analytical solutions. The imperfection sensitivity of the critical buckling load was accounted for by one of Koiter's asymptotic formulas. 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 patterns and some isolated papers dealing with special problems such as the postbuckling behavior of locally loaded cylindrical shells, the effect of imperfections on wind-loaded cylinders, the stability of silos containing granular solids and the effect of imposed displacement at the base on the stability of a cooling tower.

Turning now to **new developments**, there were two papers presented which reported on attempts to simulate numerically the experimentally observed collapse behavior of axially compressed cylindrical shells. The first paper covered the theory behind the novel approach of mode-jumping, which consists of a standard path-following algorithm up to the limit point followed by a transient time integration method representing the dynamic process of buckling that occurs very suddenly. Finally, once the transient response settled down a switch back to the path-following technique allows the computation of the stable postbuckling path observed in experiments. In a second paper this novel approach was used for the numerical simulation of the postbuckling behavior of a composite cylinder in compression. It was shown that the transient analysis algorithm made it possible to continue the solution beyond the critical point with solutions of a diamond wave form similar to those observed during the test.

There were three papers dealing with Stochastic Stability Analysis using random initial imperfections, one paper describing a shape and thickness optimization for elastic shell structures taking the imperfection sensitivity of the critical buckling loads into account and one paper reporting on a very sophisticated approach to carry out detailed imperfection surveys on large shell structures such as storage bins and silos.

Finally the differences between the two approaches to the design of buckling sensitive shell structures, namely the Lower Bound Design vs the Imperfection Sensitivity Design was highlighted by a well-attended Round Table Discussion during the closing session. After a lengthy and lively discussion there was a general agreement that in order to support innovative shell design the carrying out of imperfection surveys on representative full scale shell structures must be further stimulated and supported. The prevailing opinion was that an International Project supported within the EUROCODE activities of the EC in Brussels may 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 including the initial geometric imperfections are available. However, the experimental/theoretical correlation for externally pressurized spun steel hemispheres was not as good as one would have expected and more work needs to be done on this problem. Further, for large civil engineering structures, such as off-shore drill-platforms, for reliable collapse load predictions material nonlinearities must also be modelled accurately. The establishment of an International Imperfection Data Bank containing imperfection surveys on representative shell structures, the development of Reliability Based Design Procedures and the appearance of new computational algorithms including mode jumping are very promising techniques and ~~shall~~ 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, where the new results obtained with these techniques could be discussed in more detail.

Liverpool, May 10, 1994

Prof.dr. G.D. Galletly

Delft, May 10, 1994

Prof.dr. J. Arbocz