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Dr. Paul G. Shewmon
Professor and Chairman of
Metallurgical Engineering Dept.
Ohio State University
Columbus, Ohio

re: Buckling Criteria and Application of Criteria to Design of Steel Containment Shell
International Structural Engineers, Glendale, CA 91206
March 1979.

Dear Professor Shewmon:

As indicated in my previous report of 16 April 1979, further action on my part was anticipated when the Final Report on this subject was to become available from International Structural Engineers. I did receive this Final Report from Dr. Hafiz and here are my observations.

The first 34 pages of the report do not address the question of Buckling Criteria at all, hence no contribution to the subject matter.

In Sections 4.1 to 4.4 the authors give a discussion of possible ways of qualifying structure under buckling loads with conclusions essentially as stated in Appendix A of my 16 April 79 letter.

Section 5 presents very good review of pertinent literature and demonstrates that buckling of cylinders under axial stress which varies linearly axially is conservatively represented by buckling stress resulting from application of uniform stress equal to maximum linearly varying stress. Similar conclusion is reached for circumferentially varying axial stress. This conclusion supports the simplified analysis practiced today where axisymmetric prebuckling state corresponding to maximum axial stress of the nonsymmetrical state of stress is used.

It is also found that for cylindrical shells with stress states that are predominantly circumferential the buckling stress is relatively insensitive to the circumferential distribution of the stress, and in general uniform maximum circumferential stress gives conservative buckling stress. No such simple conclusions are found for other more general stress distributions.

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The buckling of spherical shells has seen less attention. An interesting result showing that buckling pressure of ring reinforced cylindrical shell closed with spherical cap shows greater buckling strength to external pressure than the cylinder alone, indicates that cylinder controls the buckling load. This, however, is only a special case of one investigation and by no means representative of other designs.

It is noted that work reviewed by the authors of subject report is in general limited in scope due to analytical tools used. If a more general computer code were available (as recommended under Item 2 of my 16 April 1979 letter) authors conclusions could be made more definitive and simplified analysis methods of perfect structures could be developed with greater confidence. The transition from the ideal analytical to real structure buckling loads (knockdown factor, C_A) would still require further quantification.

The authors suggest a tentative method of stability analysis based on knockdown factors associated with uniform axial, circumferential and shear stress. These factors correspond in principle to C_A quoted in the Appendix to my letter of 16 April 79. However, here the factors are assumed to be different for each type of stress whereas C_A is a single factor for the entire state of stress. Authors choice of different factor for each type of stress is obviously related to the practical advantage in obtaining such a factor from rather simple tests. On the other hand, the disadvantage is that the resulting stress field (prebuckling stress) has no physical meaning and certainly is not in equilibrium with any applied load. I believe, however, that the idea is rather intuitively sound and it should be given further analysis. A set of reduction factors recommended by the authors is that earlier suggested by NASA. It is further noted that ASME recommended buckling reduction factor of 0.1 provides factor of safety of 3 or more for cylinders with radius/wall (R/t) thickness ratios of 550 or less. As shells get thinner, the ASME Code factor 0.1 represents factor of safety less than 3 as compared to NASA's lower bound for most test data. In fact this factor of safety goes as follows:

R/T	F.S.
500	3.21
550	3.07
600	2.94
700	2.71
800	2.53
900	2.37
1000	2.24
1100	2.12
1200	2.02

R/t	F.S.
1300	1.94
1400	1.86
1500	1.79
1600	1.73
1800	1.62
2000	1.54
2500	1.39

Free standing containment shells have most likely R/t $\simeq$ 500, hence ASME factor of safety is in excess of 3. However, for very thin shells ASME Code may permit too low a factor of safety.

In Conclusions section subject report makes recommendations to perform research needed to establish knockdown factors for combined loading which corresponds to Item 1 of my letter of 16 April 79.

As indicated before in this letter the use of different factors for different type of stress leads to prebuckling stress states which are physically meaningless in that they are not in equilibrium with any set of applied loads. While the approach is convenient from the point of view that such "pure" stress knockdown factors are available from MASA's work, the interaction of various stress fields is not represented by such an approach.

Further work is necessary to validate the method proposed by the authors or to develop factors such as C_A of my 16 April 79 letter.

Very truly yours,

Zenons Zudans
Senior Vice President
Engineering

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