8th. World Congress on Computational Mechanics (WCCM8)
5th. European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)
June 30 – July 5, 2008
Venice, Italy

ASSESSING INSTABILITY EFFECTS ON THE COLLAPSE OF THICK TUBES: THE ROLE OF NUMERICAL ANALYSIS

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Key Words: *Thick tubes, Plasticity-instability interaction, Numerical experiments.*

ABSTRACT

Some recent innovative nuclear power plant designs are characterized by integral configurations, all primary system components (pumps, steam generators, pressurizer and control rod drive mechanisms) being contained inside the reactor vessel. Some elements, such as steam generator tubes, are subjected to external, rather than internal, pressure and codes require very high thickness to face possible instability effects. As an example, for the IRIS (*International Reactor Innovative and Secure*) project [1], ASME Section III rules require an external diameter to thickness ratio less than 8.5, about twice the thickness that would be admitted if the same pressure acted from inside.

Since tubes so thick have found limited application so far, their collapse behavior was rarely studied and codes apparently react to the present lack of knowledge by assuming an extremely conservative attitude. In fact, ASME code does not consider imperfections explicitly when defining the failure pressure: provided that their entities are below a given threshold, imperfections are accounted for by means of a safety factor that is essentially slenderness independent. Obviously, the value required by the most demanding situations is unnecessarily severe in other instances.

Collapse of thick tubes is dominated by yielding. Instability plays a limited role but its effect cannot be neglected when safety is of primary concern. A precise assessment of it requires that the imperfection induced plasticity-instability interaction be studied, which can be done either experimentally or numerically. Within the framework of the IRIS project, an experimental study in this sense is being performed at the University of Pisa and first results show that the actual pressure bearing capacity is significantly higher than the vale predicted by codes [2].

From laboratory tests, however, it is difficult to single out the consequences of individual imperfections, which clearly is a must in view of establishing general sizing procedures. To this purpose, a thorough numerical study was undertaken. Large displacement, elastic plastic analyses up to collapse were performed by explicitly including different imperfections, either by themselves or combined with each other. The following have been considered

- Initial out of roundness (*ovality*);
- Non uniform thickness (*eccentricity*);
- Initial stresses.

The assumptions on which computations are based and the results obtained are described in detail in [3]. Results show that the effects of imperfections of different nature exhibit the same dependence on slenderness and that, among all of them, ovality most significantly affects the pressure bearing capacity of the tube and can be taken as representative of all effects of this kind.

For design purposes, it is proposed that a *reference failure pressure* be computed by considering ovality only (its entity is taken as the maximum value permitted by the code). An *allowable working pressure* is defined by reducing the reference value by a suitable safety factor, which is meant at facing other imperfections and all the sources of uncertainty not considered in computations. The safety factor is defined so as to reproduce ASME Section III sizing for medium-thick tubes, such as those currently employed in oil industry as pipes or casing. They belong to a range explored sufficiently well to ensure that codes consider the proper safety margin. If the same safety factor is used for thick tubes, significant thickness saving can be achieved without jeopardizing safety.

A proposal for a design formula has been advanced on this basis [4]. However, it is felt that the main interest of the results obtained rests on the assessment of the role played by different imperfections and on the identification of the one that most significantly affects the overall tube strength and that must be included in a numerical model when complete nonlinear analyses are required.

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