Discussion

Conceptual Design of Double Steel Containment Vessels

Paper presented by CHEN HWA WANG (April, 1967 issue)

Discussion by **Howard W. Wahl**

The recent article presents a very interesting concept for steel containment vessels, especially in view of the large number of nuclear power plants presently being designed and built. It is a very timely subject and deserves considerable attention. The following points of discussion appear to be in order after reviewing the article:

(1) The comparison made between the predictability of a double wall steel vessel and a prestressed concrete containment structure does not seem valid. The double steel containment vessel proposed in the article appears to have considerable stiffening and framing between the two concentric shells. Certainly this type of vessel would fall under the category of a stiffened thin shell. The predictability of such a vessel being based on a "homogeneous material and elastic theory" as stated in the article is seriously questioned.

The large amount of testing that has been done in Europe, the United Kingdom, and the U. S. on prestressed concrete reactor vessels has been done primarily to evaluate the predictability of these structures. Apparently all of the models built to date have indicated very good predictability. This is due primarily to the relatively sophisticated methods of analysis such as finite element computer programs and consideration of thermal stresses and long term properties of the concrete such as creep.

(2) The point regarding the high thermal stress in the liner plate of a prestressed concrete containment structure is very well taken. For this reason, conservative criteria have been established relative to the attachment of the liner plate to the structure, and strain limitations have been imposed to prevent progressive buckling failure of the liner plate. Here again the testing of the prestressed concrete reactor vessel liner plate has indicated adequate performance of the liner plate, in spite of local strains due to high temperatures. The significant point regarding the high temperature strains is that any buckling would partially relieve the thermal stress.

(3) The problem of thermal stress in a double wall steel containment vessel is quite significant for the thermal gradient associated with accident conditions. The inside shell will act more as an expansion membrane than a tensile membrane. This thermal expansion should therefore result in the outer shell carrying essentially all of the internal pressure. Preliminary calculations for a double shell vessel indicate a theoretical differential thermal stress between the two shells of approximately 40,000 psi regardless of shell thickness ratios. These stresses must be superimposed on the membrane stresses due to internal pressure. Such a superposition results in the outer membrane being subjected to significant additional tension. This somewhat invalidates the use of double shells to reduce the tensile stress.

(4) The stiffening frame used between the two shells would appear to promote large scale deflections of the inner shell between stiffeners because of the thermal stresses and the pressure. It is very hard to accept a stress analysis being based on homogeneous material and elastic theory and the statement that it results in a high degree of accuracy for the predictability of such a double membrane. Perhaps the predictability of the vessel or its performance can be improved as Prof. Wang suggested by circulating water within chambers between the shells.

However, it is normally considered that a containment vessel should be a passive system not relying on such a cooling system to prevent failure. The plants under construction today already have a significant number of redundant systems of reactor core cooling and containment atmosphere cooling to remove the internal heat. In spite of these redundant sys-

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tems, the containment is still required to function with only partial core cooling available during the accident. A containment concept requiring cooling of the shell in order to function structurally would not satisfy the criterion of being a passive system.

(5) While the weight of the double steel containment vessel would be significantly less than a concrete structure, the concrete structure also serves the function of a radiation shield. Indeed, the shielding requirement actually determines the concrete thickness. Such a shield would still be required for the double steel containment vessel and would rest on the same footing. Therefore, the total weight of the double steel containment vessel plus the radiation shield would slightly exceed that of a concrete structure.

Perhaps a better solution for providing a welded steel containment is the use of thicker plates and field stress relieving. This would result in a steel vessel that could be designed and fabricated in accordance with the existing ASME Code, Section III, "Nuclear Vessels." Thick walled steel pressure vessels have been successfully built and field stress-relieved for the petroleum industry and these techniques are now being used for the field assembly of reactor vessels. It is felt that such techniques would result in a vessel whose performance and reliability would be much more acceptable than a double walled welded stress vessel.

Discussion by **CHEN H. WANG**

The author wishes to express his appreciation of Mr. Wahl's comprehensive review and his several suggestions. In reply, the author feels that certain clarifications may be useful.

The internal pressure on Double Steel Containment Vessels (DSCV) is resisted not only by the inner and outer shells but also by the stiffening frame, resulting in greater economy since structural shapes are less expensive than plate. The stress distribution in the shells and stiffening frame will depend on the variation of shell thickness and frame structural sections.

The liner plate provided in Prestressed Concrete Containment Vessels (PCCV) serves only to prevent leakage of radioactive materials; it does not contribute to the strength of the vessel but, on the contrary, introduces considerable thermal stress under a Maximum Credible Accident condition. It is used because steel is a homogeneous material whose performance is presently more predictable than the behavior of prestressed concrete. If this were not so, a 1-in. concrete shell would have at least equal capability for radiation shielding. The behavior of prestressed concrete is unpredictable only because information is lacking concerning such long-term properties as creep temperature loading, shrinkage temperature loading, relaxation temperature loading, E_c temperature mixing, etc. Mr. Wahl indicated that the Prestressed Concrete Reactor Vessel (PCRV) models built to date do reflect consideration of concrete creep but no reference is offered to show such models had been accurately designed for creep, shrinkage, etc. A conservative assumption may substitute for lack of knowledge but it does not necessarily foster economy.

The structure should be designed for safety but it is equally important to design for economy. Conservative criteria should be employed only if the structural stress or behavior under design load cannot be determined due to the lack of knowledge of the properties of materials or the methods of accurate analysis.

In regard to thermal stress in a DSCV the discusser stated that, regardless of shell-thickness ratio, a theoretical differential thermal stress approximately equal to 40,000 psi existed between the two shells. This is seriously questioned. From the basic and necessary equilibrium conditions and kinematic relation, thermal stress is directly proportional to temperature, radius of containment vessel, thickness of inner plate and/or part of the stiffening frame, depending on the actual structure, but inversely proportional to the cross section of the outer shell and the unheated frame.

Although the outer shell stress results from superposition of stresses due to internal pressure and thermal expansion, it is not necessarily or ordinarily the sum total of these two stresses. The stresses carried by the inner shell and the stiffening frame, and also the deformation of the shells, will affect the resultant stress in the outer shell. The assumed constant thermal stress of 40,000 psi might be a particular, but not a general, solution. The discusser's assumption could be misleading in the structural analysis of a DSCV.

Admittedly, the inner shell of a DSCV will undergo larger deflection than the liner plate in a PCCV. However, by applying the Split Rigidity Concept, or other rigorous and sophisticated methods, exact analysis of the stresses and buckling in the shells and stiffening frame can be expected. Since steel is a homogeneous material, and because stresses and deformation of DSCV's are always held within the elastic range, behavior of a DSCV, compared to a PCCV, can, unquestionably, be predicted with greater accuracy.

If part of the containment vessel must serve as a radiation shield (which is not necessary for all such vessels) this function can be satisfied by insulation between the shells using less expensive materials regardless of their

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strength. However, use of such material can be avoided by rearranging the inside structure of the vessel to thicken the secondary shielding wall for increased resistance to leakage of radioactive materials. Since this rearrangement is generally possible, the dead weight of the structure could be considerably reduced.

From the discusser's point of view, thick-walled steel pressure vessels would be much more acceptable than DSCV's. How this can be justified, however, is not clear to the author based on the following considerations: thermal gradient in the wall, necessary reduction of allowable stress in the thickened wall, unfavorable economy compared with PCCV and DSCV, and its inferior performance and reliability if his doubts about homogeneity of the material and elastic theory in DSCV's persist.

It seems clear that a DSCV as an alternative is a more economical and reliable structure than a PCCV with a liner plate, at least until the structural behavior of prestressed concrete under high temperature and loading is better known and necessity of a liner plate removed.

ADDITIONAL REFERENCES

4. *Johns, P. J.* Thermal Stress Analysis, *Pergamon Press, New York, 1965.*
5. *Buchert, K. P.* Stability of Doubly Curved Stiffened Shells, *Ph.D. Dissertation, U. of Missouri at Columbia, January 1964.*
6. *Allentuch, A., Brady, K. and Kepener, J.* Long Cylindrical Shell Under Loads Applied to a Reinforcing Ring, *AIAA Journal, Vol. 5, No. 10, October 1967.*
7. *Buchert, K. P.* Stiffened Thin Shell Domes, *presented at the AISC National Engineering Conference, Omaha, Neb., May 1964.*