Conceptual Design of Double Steel Containment Vessels

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IN CONJUNCTION WITH nuclear plants, huge containment vessels for the enclosure of the pressure circuit, embracing reactor and heat exchangers, have already found acceptance. Inside of the containment vessel, surrounding the primary coolant loops, is a primary shielding wall which is a principal barrier against missiles resulting from internal explosion, affords protection to the vessel itself, and tends to protect the vessel from radiation damage, activation, and nuclear heating. Under normal operation the temperature of the containment is generally accepted as 150°F or less and is subject to only minor thermal stress effects; however, under maximum credible accident, or MCA, the temperature may rise to 300°F or more, depending upon engineered safeguards, free volume, and heat sinks provided in the vessel. Therefore, the vessel sustains a small thermal stress at normal operation but must withstand significant thermal deformation and interior pressure under MCA conditions. At the present time reinforced concrete and prestressed concrete vessels are generally designed for this type of containment, whereas a single steel vessel is considered economically unfeasible because of the large thickness of plate required.

CONCRETE VESSELS

A prestressed concrete containment vessel, or PCCV, is more acceptable than reinforced concrete vessels, since it increases the structural elasticity and safety against a catastrophic failure; however, it does not lessen the possibility of radiation leakage. Due to the lack of information about the properties of concrete at elevated temperature subjected to a permanent load, the structural behavior of a PCCV is quite difficult to predict realistically and is beset with greater uncertainties than the design analysis of conventional steel vessels. A mild steel liner plate, therefore, is utilized to render impermeable the interior surface of a PCCV, thus keeping the radiation within a finite amount not to exceed the tolerance set forth in 10 CRF 100 due to the cracking of the concrete. Even though the plate is provided solely to prevent leakage, it represents 20 to 25 percent of the total cost of the whole vessel. Additionally, due to the high thermal stresses in the liner plate in the event of MCA, and the low conductivity of concrete, plate buckling or overstressing and concrete cracking may result. As a result, the certainty of performance of the PCCV is questionable. In the absence of more predictable structural behavior of the PCCV, a double steel containment vessel, or DSCV, is proposed as an alternative type of structure. The DSCV is able not only to withstand catastrophic failure, but also to provide effective protection against leakage of radioactive materials.

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STEEL VESSELS

A DSCV could be constructed by using two concentric steel vessels separated and supported by a continuous frame. The spacing between these two shells would be determined by the clearance required for construction and not for the purpose of preventing radioactivity. For simplicity of geometry for construction and efficiency of free volume, semi-spherical domes with vertical shell walls, as shown in Fig. 1, may be desirable. At the bottom, a single elliptical shell with an edge stiffener for strength and to facilitate connection to the footing could be utilized.

Under normal operation neither shell is subject to forces except for a small thermal stress introduced by the differential of temperature between the inner and outer surfaces of the vessel. Even though under MCA condition the thermal stress increases with interior pressure, maximum forces act only for a very short time and then gradually decrease. The inner shell acts just as the liner plate in the PCCV and the outer shell acts as a conventional structure. Therefore, mild steel plate could be used for both shells and structural steel shapes could be used for the intermediate frame.

The vessel can be stress analyzed as an elastic structure, either at normal or MCA condition, by considering it as an isotropic structural shell with stiffening ribs. The thermal stress caused by the expansion of the inner plate may create buckling and overstressing problems similar to those in the liner plate of the PCCV. The interior pressure causes tension in the frame and the two shells, and causes an uplift force along the bottom of the shell wall. Since the uplift force on the bottom closure is

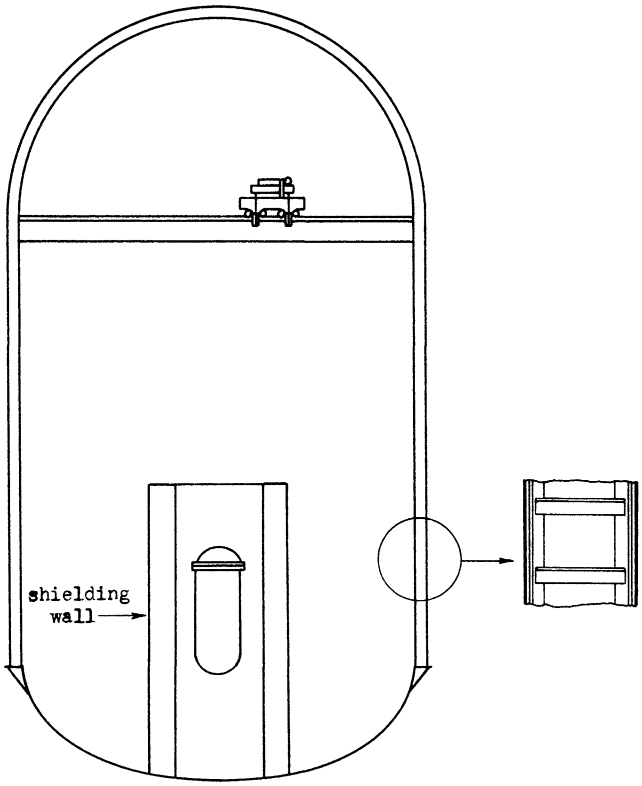

Fig. 1. Double Steel Containment Vessel

opposed by the dead load of the internal structure, a single steel shell at the bottom should be adequate. To minimize the effect of thermal deformation, thinner plates should be used for the inner shell. The total force should be assumed to be carried by the intermediate frame and both shells, acting together.

Since the stress analysis is always based upon homogeneous material and elastic theory, the behavior of a steel vessel will be more predictable than that of a concrete vessel. The behavior of a DSCV can be predicted to a high degree of accuracy and the radiation can be more reliably controlled. Due to the high thermal conductivity of steel, the DSCV reacts quickly as a heat sink. Accordingly, the maximum pressure as well as the temperature at MCA condition would be decreased, and the design load reduced. To provide a greater capacity to absorb heat, a circulated water system could be built within chambers between the shells. This would significantly increase the heat absorption capacity and reduce the maximum design pressure of a DSCV. Since the total DSCV weight is less than the weight of a PCCV, the size and thickness of the required footing would be smaller.

CONCLUSION

Various aspects of the designs considered herein are conceptual, and in order to implement them in actual design a more detailed and thorough study would be necessary. It is believed with the present knowledge and state of technology on steel vessels that a double steel containment vessel can be designed and constructed. It is believed that such a structure would provide superior protection and that its behavior under MCA conditions would be more reliably predicted than is the case for prestressed concrete containment vessels.

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