Ultimate Capacity of Two Free-Standing Containments

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ABSTRACT

A set of analyses has been performed by EMPRESARIOS AGRUPADOS to determine the ultimate capacity of two free-standing steel containments corresponding to the Mark III type of GE reactors. The two containments are very similar as regards their basic dimensions, but they present certain differences: The first was designed with a lower thickness in the upper cylindrical portion and a highly stiffened 2:1 torispherical dome, while the second has an even thickness in the cylindrical portion and a 1.5:1 torispherical dome with a slight meridional stiffness.

The ultimate capacity of the first containment was determined from plastic collapse of the cylindrical area located below the polar crane girder. In the second containment, it was determined by plastic collapse of the dome knuckle. The ultimate capacity pressure values were similar: 97 and 91 psi. Failure due to dome instability is not a determining factor as, in one case, the strong stiffness and, in the other, the greater curvature radius, considerably increase critical buckling pressure.

INTRODUCTION

When considering the measures to be taken in the case of a severe accident, it is of crucial importance to know, as precisely as possible, the ultimate capacity values of the containment subjected to extreme load conditions. In view of the wide range of severe accident scenarios which could possibly be produced today, and for lack of any general agreement as to which are the most probable, evaluation of the containment ultimate capacity under all these conditions is not feasible and should be restricted to evaluation under simple load conditions.

This paper contemplates only the actuation of internal pressure applied statically. It therefore deals with the determination of ultimate capacity as specified in the American regulatory standard (SRP-3.8.2).

The failure modalities are those associated with non-cyclic loads: failure due to plastic collapse and failure due to instability. The failure modality due to brittle fracture in local critical areas (with a high usage factor in the fatigue analysis) is not considered, since this circumstance could only arise during the final phase of plant life and would require an estimate of the final size of flaws.

An important criterion is that of establishing what exactly is considered as an ultimate state. The most realistic way to tackle this would be to associate it with the appearance of breaks which either involve the leak before break due to their local and stable nature, or have a general and catastrophic nature. It is clear that an analysis of these conditions would be difficult, because of both unpredictable material behaviour and the high cost involved. This paper has selected the criterion which considers plastic collapse as the ultimate state, as defined in the ASME Code (NB-3213.25).

CONTAINMENT GEOMETRY

The two containments are free-standing, of the GE MARK III type, with the same radius in the cylinder of 685 in. Figure 1 shows the upper cylindrical portions and the domes with stiffening (the stiffeners are drawn at half-scale).

In the first containment, referred to as C1 from now on, the thicknesses of the cylindrical area decrease with the height, beginning with 1.5" at the anchorage and reaching 1.181" below the polar crane and 1.102" between the polar crane and the commencement of the dome. This reduction of thicknesses is justified by the design loads, as the seismic and hydrodynamic actions are maximum at the base and decrease with the height. The dome is torispherical, with a radius/height ratio of 2:1 and thicknesses of 1.417" in the knuckle and 1.339" in the center. The stiffening is very strong, in both circumferential and meridional directions.

In the second containment, C2, the cylindrical area as well as the dome have a constant thickness of 1.5". The dome is torispherical, with a radius/height ratio of 1.5:1 and with a strong stiffening in the circumferential direction, but a lesser one in the meridional direction.

The remaining details, such as base anchorage, polar crane girder, personnel airlocks, equipment hatches, penetrations, etc. are similar in both containments.

SELECTION OF CRITICAL ZONES

Critical zones for plastic collapse failures have been selected from elastic design analyses, using the membrane stress maximum value as a basic selection criterion. This criterion is suitable for curved areas, in view of the negligible importance of secondary bending stresses in the collapse mechanism of a component. As regards flat areas, it is well known that, although primary bending stresses are developed initially, large deformations produce curvatures which finally lead to a high collapse load; therefore these areas are not usually critical.

In the case of C1, the bigger general membrane stresses are produced in the cylindrical area situated between the final circumferential stiffener and the polar crane. The area situated above the polar crane, although with a lower thickness, is not so critical, because of the proximity of the crane and the stiffener situated at the commencement of the dome. In the case of C2, the bigger general membrane stresses are produced in the dome knuckle.

In both containments, the bigger local membrane stresses are produced at the joint of the steel plate to the local reinforcement of the personnel airlock. As it is the case with secondary stresses, these stresses are mainly due to deformation incompatibilities and do not normally affect the collapse mechanism. This area has, nevertheless, been considered as critical.

As regards failure due to instability, under internal pressure only membrane stresses of compression are produced in the dome knuckle (in the circumferential direction), in the sleeves and expansion joints of some penetrations, and in the airlock and hatch barrels. Out of all these areas, we can only consider the dome knuckle and expansion joints as slender. As joint instability pressure is quite high, the critical area selected from the point of view of instability failure is the dome knuckle.

PLASTIC COLLAPSE ANALYSIS

The analysis of the area of interaction of the personnel airlock with the cylindrical envelope, which is identical for C1 and C2, was done through an spatial model, using the ANSYS program, version 4.3. The finite element used was the triangular shell (STIFF 48). Figure 2 shows the model which has been reduced to one-fourth of its size by symmetry, and includes a bracket and circumferential stiffener near the airlock. Non-linear analysis was selected only for the material, as large displacements were not expected, due to the strong stiffening in the area. Pressure was applied progressively, with a first step near to the first plastification (55 psi) and succesive progressively lower increments, in such a way that the calculation process would converge. The final pressure was 124 psi.

The analyses of the cylindrical zone of C1 and of the knuckle zone of C2 have been performed through axisymmetrical models, using as well the ANSYS program with the finite element plastic axisymmetric conical shell (STIFF 51). The size of the models has been determined in such a way that the boundary conditions would be known and independent of the behaviour of the studied zone. In this case, however, the geometric non-linearity was taken into account similarly to the material non-linearity, as big displacements were expected. Like in the previous model, pressure was applied progressively, with a variation range covering from 80 to 100 psi for C1 and from 70 to 120 psi for C2. Figure 3 shows the increase in the deflection for the C1 cylindrical zone model; the tendency to a constant bending in the meridional direction can be appreciated.

The most significant results of the analyses are included in figures 4 and 5, where the variation of the maximum displacements and the maximum strain, respectively, have been depicted as a function of the pressure. It can be seen that the determinant zones of the ultimate capacity in both containments are not the airlock zones, but the general zones, for which values of 97 psi in C1 and 91 psi in C2 are obtained.

STABILITY ANALYSIS

With the aim of studying the stability under internal pressure of the dome knuckles, linear bifurcation analyses were performed, using axisymmetrical models, wide enough, of the zones. To be able to represent the buckling modes in circumferential waves, the finite element axisymmetrical conical shell with non-axisymmetric load (STIFF 61) of the ANSYS program was used. As a pre-load status, a pressure of 10 psi was applied to both models.

Figure 6 represents the variation of the first buckling eigenvalue with the number of waves. Minima are 65.9 for C1 and 39.2 for C2, with which the corresponding critical pressures are 659 and 392 psi, respectively. These values are, obviously, ideal theoretical values, since the real component conditions were not considered in the analyses: Dimensional tolerances, residual stresses, etc., nor material plastifications. To get the real critical pressures, the reduction factors of the Code Case N-284 were applied, with the exception of the safety factor for service level, obtaining in both cases values bigger than 100 psi. The instability of the knuckles arises hence later than the plastic collapse of the above analyzed zones, and it is therefore non determinant to the ultimate capacity pressure of the containment.

CONCLUSIONS

The plastic collapse analysis in the interaction zone of the airlock has evidenced, once more, the little importance of local stresses in the non-linear behaviour, when we deal with the application of non-cyclical loads. The results of the plastic collapse analysis in the general zones of both containments have been very similar: 97 and 91 psi. Both are in the same magnitude order than other containments of the same kind.

In regard to the dome instability failure, it has been verified that it is not a determining factor as, in one case, the strong stiffness and, in the other, the greater curvature radius, considerably increase the critical buckling pressure.

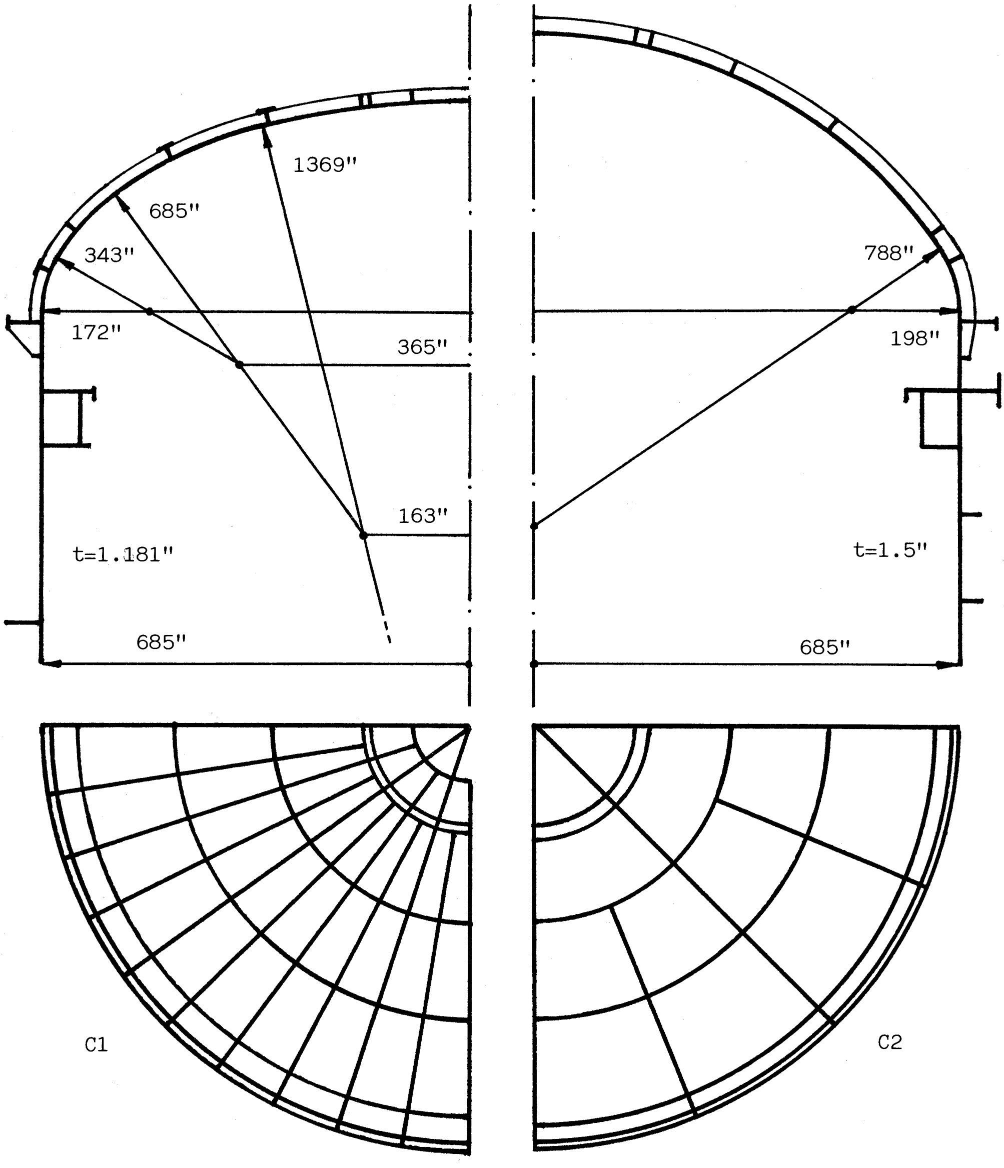


Figure 1

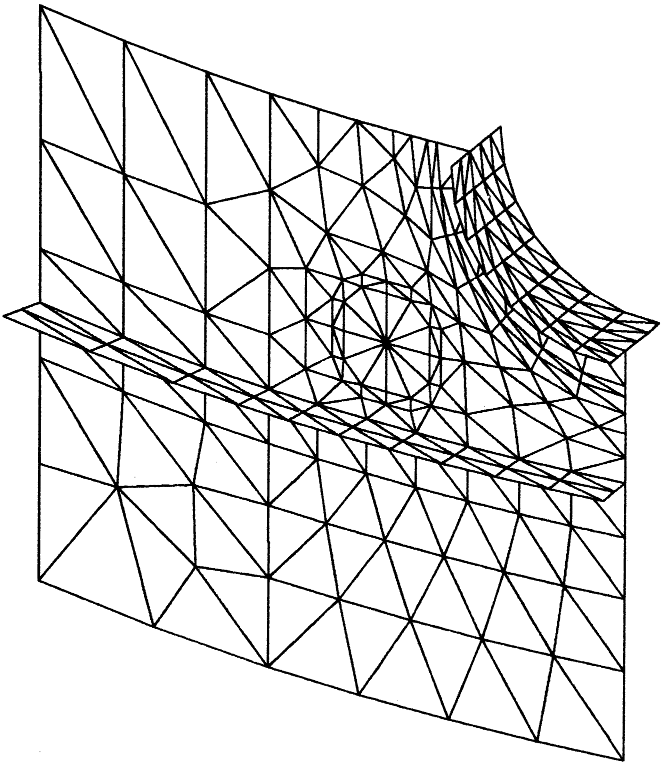


Figure 2

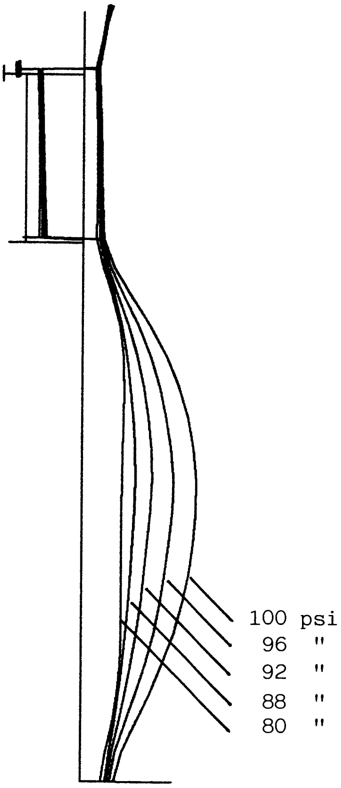
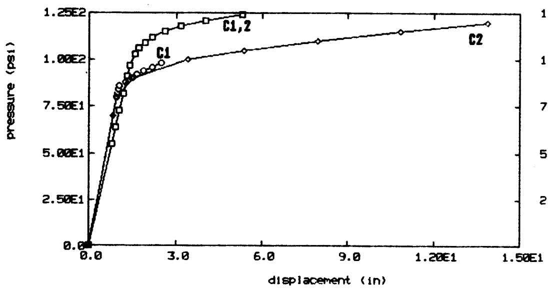


Figure 3



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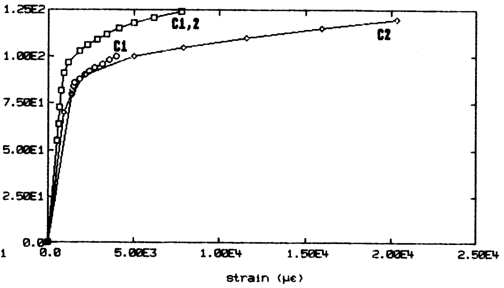

Figure 5

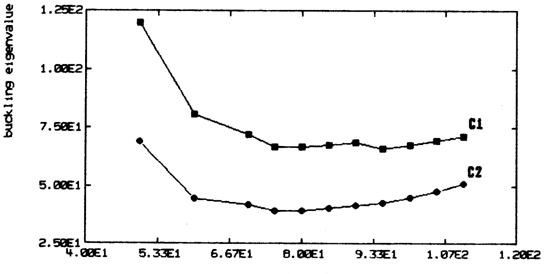

Figure 6