Techniques and Results from the Internal Pressurization of a 1/8 Scale Steel Containment Model

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Abstract

A 1/8 scale model of a steel containment building was tested to failure using nitrogen gas. An extensive data base of the models response was generated that can be used to qualify methods used to predict response of containments. The test techniques and data acquisition and control systems are described and the experimental results for key areas of the model are discussed.

1. Introduction

A 1/8 scale model of a steel containment building was slowly pressurized to failure using nitrogen gas. This test was part of a U. S. Nuclear Regulatory Commission sponsored program on Containment Safety Margins* that has been described in several reports, most recently in [1].

The objective of the large steel model test was to generate a data base of model response to high pressure loading that could be used to qualify analytic codes. To this end the fabrication techniques and materials of an actual U. S. steel containment building were replicated as closely as possible. Features such as the equipment hatches, personnel locks, constrained penetrations, and the thickened sections were heavily instrumented.

2. Description of the Model

The 1/8 scale model of a steel containment was designed and built by Chicago Bridge and Iron Company using the American Society of Mechanical Engineers (ASME) codes. It had a design pressure of 40 psig and included a number of penetrations and other features

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*This work supported by the United States Nuclear Regulatory Commission and performed at Sandia National Laboratories which is operated for the U.S. Dept. of Energy under contract number DE-AC04-76DP00789.

present in an actual containment building. These included five piping penetrations ranging in size from 1 9/16 inch to 6 7/8 inch in diameter, a constrained pipe penetration, two personnel lock representations, and two operable equipment hatches.

Two personnel locks were located at 1/3 of midheight and slightly above midheight respectively, and approximately 150 degrees apart. The two operable equipment hatches which were 30 inches in diameter, were located just above midheight and approximately 120 degrees apart. Due to fabrication limitations, the hatch doors were stiffer than those in an actual containment and, therefore, had a higher buckling pressure. Two diametrically opposed piping penetrations were constrained by welding an internal pipe to the penetrations. This was done in order to simulate a constrained piping penetration. All penetrations were reinforced by thickened plate sections. The exterior of the shell was reinforced with circumferential stiffening rings. The interior of the model contained a structure consisting of three levels of floor grating, a ladder and supporting columns and bracing. This structure was fixed to the bottom head of the structure and did not contact the model. The bottom head is a stiff test fixture and not part of the model. More details of the model are given in figure 1 and in [2].

3. Instrumentation and Data Acquisition

The test data was taken with a data acquisition system which consisted of a central computer to control the data scanners and to record data, an acoustic detection system for the detection and location of leaks, and a theodolite based triangulation system for displacement measurements. A schematic of the data acquisition system is shown in figure 2.

Strains were measured with approximately 700 high elongation strain gages which were scanned and recorded by the main data acquisition computer. Strains were compensated for bridge nonlinearities, temperature effects, cross axis sensitivity, and lead wire resistance. Temperatures for thermal compensation of the strain gages were measured by 36 thermocouples mounted near concentrations of gages. Three different techniques were used to measure displacements. Nineteen cable actuated large displacement (0-12 inch) linear varying potentiometers were used to measure displacements inside the model. Thirty-two other small displacement (0-.5 inch) potentiometers were used to measure displacements around the equipment hatches. The theodolite based triangulation system measured displacements on the exterior surface of the model and photographs of the model's silhouette can be digitized to provide additional displacement data. All data, with the exception of the displacements from the photographs and the theodolite readings, were reduced to engineering units in real time and were available for making decisions during the conduct of the test.

4. Pressure and Temperature Control

The pressure and temperature were monitored and controlled by an Analog Devices Macsym II measurement and control system. Gas was piped from a liquid nitrogen supply, where it was gasified, to a valve gallery. The Macsym computer monitored gas supply pressure, fill valve pressure, model pressure, and model temperature. Gas temperature was monitored with four resistance temperature detectors (RTD's) located inside the model at different elevations. Ambient temperature was measured with two RTD's outside the model. Gas temperature inside the model was maintained at a level slightly above ambient (68° F) by means of three 25 kilowatt forced air electric heaters which were controlled by the Macsym through a proportional voltage controller. Using these inputs, the computer responded to the test conductor's commands to increase, decrease, or hold pressure through a system of three fill and four bleed valves in the valve gallery. A separate electrically actuated isolation valve and bleed valve were placed between the model and valve gallery for leak rate measurements and safety purposes respectively. During leak rate testing, the isolation valve was closed to prevent back leakage through the bleed and fill valves. The safety bleed valve was larger than those in the valve gallery and provided a means of rapidly depressurizing the model in the event of an emergency.

5. Conduct of the Test

Pressurization of the model began in late September 1984. After preliminary tests were completed and all systems checked, final testing of the model began on November 15 and concluded on November 17.

Preliminary testing of the model included a structural integrity test at 15% above design pressure and an integrated leak rate test at design pressure. During final high pressure testing, the model was pressurized incrementally at a constant temperature to 195 psig at which level the model ruptured. Strain and displacement data was recorded after each pressure step once the model stabilized. Stabilization was determined by continuously monitoring selected strain gages and displacement transducers. When no significant change was detected in the measurements, data was recorded.

Leak rate measurements were made during specified hold periods according to the ANSI/ANS-58.6-1981 containment system leakage testing requirements. Had a large leak developed, the pressure control system would have maintained pressure in the model and the leak rate could have been calculated from the mass flow into the model.

6. Experimental Results

Instrumentation was provided to record the response of the various penetrations and features throughout the model. Of interest in this test were the global response of the model and the response of the equipment hatches, constrained penetrations, and thick/thin section interface. Inside and outside views of the instrumentation on the cylindrical shell of the model are shown in figure 3. Instrumentation of the details, on and around penetrations, is not shown.

At 190 psig the cylinder wall deformed a maximum of 1.8 inches radially at midheight while the hatches moved radially outward 2 1/2 inches. Free field (away from penetrations) strains ranged from 1.50% at the spring line, to over 2.7% one third up the cylinder, to 1.22% near the dome. Most of the strains in the dome were elastic except near the apex where strains approached 0.3%. The dome had lower strains than the cylindrical wall as expected, because the same thickness of material was used for both.

Figure 4 is a typical plot of maximum and minimum principal strain in the free field between stiffeners 7 and 8 from the bottom. The curve shows that unlike a typical uniaxial curve, no distinct yield plateau was exhibited. Also evident in figure 4 is the "creeping" of the model once the yield plateau is exceeded. At 140 psig, below yield, three data scans were taken over a time span of 20 hours. No significant growth is evident. Above yield, multiple scans were taken at 165, 170, and 180 psig.

Figure 5 is a plot of radial and tangential strains at the 6 o'clock position in the equipment hatch sleeve .58 inches out from the shell interface. By 100 psig yielding was exceeded and, thereafter, continued to increase rapidly with each increase in pressure. At 190 psig, bending strains of 4 and 5 percent were measured at the 6 and 12 o'clock positions respectively.

Displacement transducers measured an ovaling near the sleeve/shell interface of 0.7 inches in the horizontal direction and less than -0.1 inch in the vertical direction at 190 psig. The equipment hatch door did not deform significantly. The relative sliding of the door sealing surfaces are shown in figure 6. Relative movement began noticeably at 150 psig and increased rapidly with each pressure step thereafter. The separation and rotation of the sealing surfaces were small compared to the relative sliding and are not shown in the figure.

In the thickened area surrounding the equipment hatch, strains were lower than free field and ranged from 1.75% at the sleeve/shell interface at 12 o'clock to less than 0.3% at 9 o'clock.

A combined bending/membrane strain of 2.7 or 1.3 times free field was measured in the shell material adjacent and horizontal to the reinforced material around equipment hatch 1. Strains decreased and became primarily membrane away from the hatch.

Combined bending/membrane strains in the shell around the constrained penetration ranged from 4.5% adjacent to the penetration at 12 o'clock to .69% at the edge of the reinforced material in the vertical direction. Maximum combined bending/membrane strains outside the reinforced material were 1.96% and 2.28% vertically and horizontally respectively over 6 inches away from the interface. Figure 7 shows a plot of displacement horizontally away from the constrained penetration. The effectiveness of the constrained pipe in limiting radial growth of the shell locally is evident in the figure.

Strain gages were mounted adjacent to each other on thick/thin shell interfaces to measure possible strain discontinuities. Strains in the reinforced section tended to be elastic, while significant plastic strains occured in the surrounding material. A strain concentration of 1.3 times free field was measured near equipment hatch 2. No larger strain concentrations were measured around thickened sections execpt near personnel lock 2 where a strain 1.7 times free field was measured. However, different stiffening patterns in this area may have contributed to the high strains.

After the pressure was increased to 195 psig, the model ruptured. Details are described in [1].

7. Ongoing Work

A large steel model of a typical U.S. steel containment building was tested and a large data base of strains and displacement histories of the models response to overpressure was gathered. In particular, displacement and strains around penetrations were recorded. Comparisons with analytical predictions have already been made and are discussed in [4]. A data report is presently being prepared which will include all data gathered during the test and will be available for comparisons with analytic predictions.

8. References

/1/ BLEJWAS, T.E. "Internal Pressure Experiments with Steel and Concrete Containment Models", Proceedings 8th Intl. Conf. on Structural Mechanics in Reactor Technology, Brussels, Belgium, August 19-23, 1985, Paper J 2/3.

/2/ REESE, R. N., and HORSCHEL, D. S., "Design and Fabrication of a 1:8 Scale Steel Containment Model," NUREG/CR-3647 SAND84-0048, Sandia National Laboratories, Albuquerque, NM, 87185 (February 1985)

/3/ CHANEY, W. S. Jr., "Gas Control System for the Large Scale Tests of the Containment Integrity Program Operation and Maintenance Guide," EGG-10282-6011 (September 1984)

/4/ CLAUSS, D. B., and HORSCHEL, D. S., "Comparison of Analytical and Experimental Results from Pressurization of a 1:8 Scale Steel Containment Model," Proceedings 8th SMiRT Conf., Brussels, Belgium, August 19-23, 1985, Paper J 2/5.

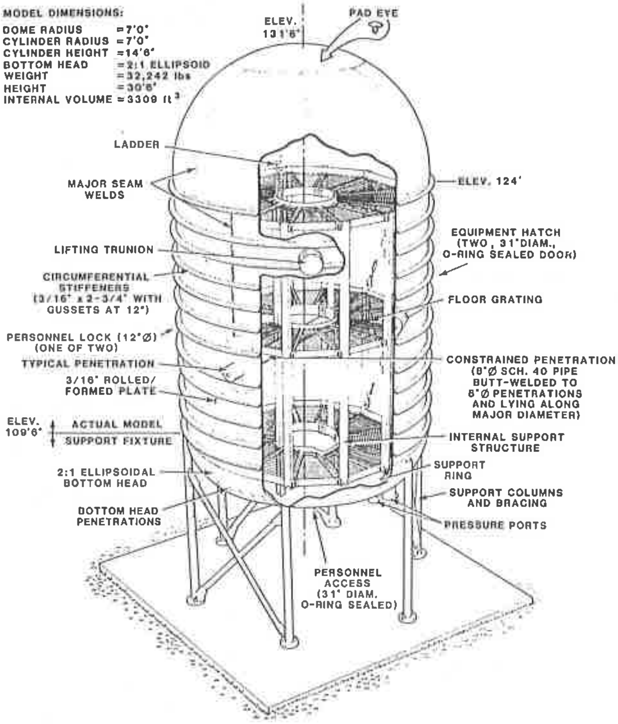

Figure 1 Large Steel Model

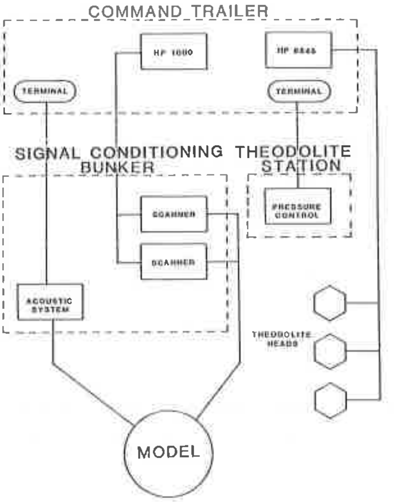

Figure 2 Data Acquisition System

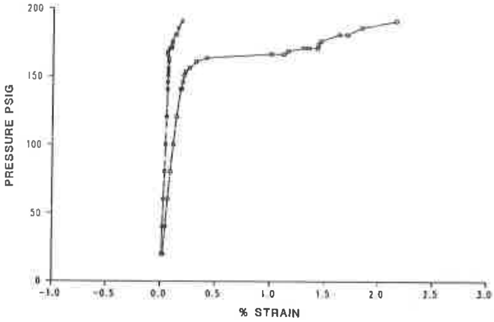

Figure 4 Typical Free Field Principal Strains 190 psig

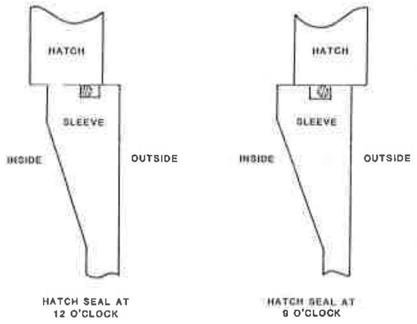

Figure 6 Equipment Hatch Seal at 190 psig

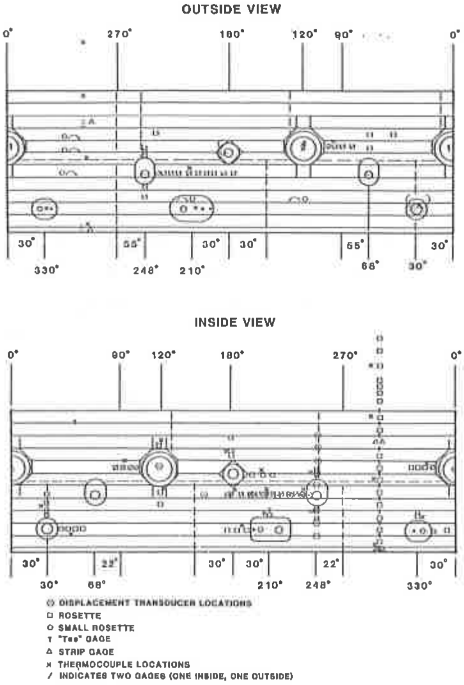

Figure 3 Instrumentation Locations

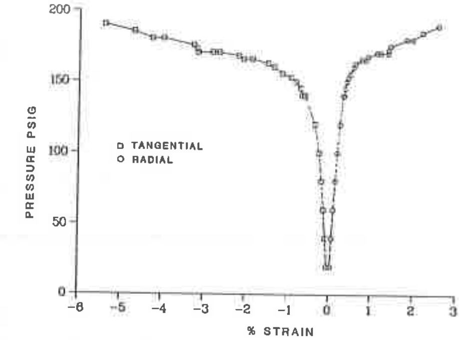

Figure 5 Radial & Tangential Strains in Hatch Sleeve at 190 psig

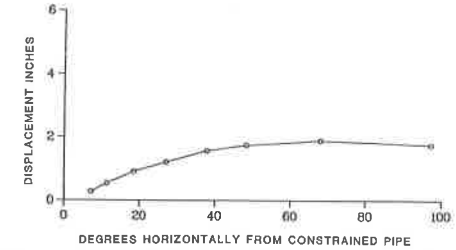

Figure 7 Radial Displacement of Shell Near Constrained Penetrations