SAND97-0836C
CONF-970826--10

Preliminary Results of Steel Containment Vessel Model Test[1]

T. Matsumoto[a], K. Komine[a], S. Arai[a]

V. K. Luk[b], M. F. Hessheimer[b], and

J. F. Costello[c]

[a] *Nuclear Power Engineering Corporation, Tokyo, Japan*

[b] *Sandia National Laboratories, Albuquerque, NM, USA*

[c] *United States Nuclear Regulatory Commission, Washington, D.C., USA*

DISCLAIMER

Abstract

A high pressure test of a mixed-scaled model (1:10 in geometry and 1:4 in shell thickness) of a steel containment vessel (SCV), representing an improved boiling water reactor (BWR) Mark II containment, was conducted on December 11-12, 1996 at Sandia National Laboratories. This paper describes the preliminary results of the high pressure test. In addition, the preliminary post-test measurement data and the preliminary comparison of test data with pretest analysis predictions are also presented.[1]

1. Introduction

The Nuclear Power Engineering Corporation (NUPEC) of Japan and the U.S. Nuclear Regulatory Commission (NRC) have been co-sponsoring and jointly funding a Cooperative Containment Research Program at Sandia National Laboratories. The purpose of the program is to investigate the response of representative models of nuclear containment structures to pressure loading beyond the design basis accident and to compare analytical predictions with measured behavior. This is accomplished by conducting static, pneumatic overpressurization tests of scale models at ambient temperature. One of the tests was a test of a mixed scaled model with 1:10 in geometry and 1:4 in shell thickness of a steel containment vessel (SCV), representing an improved boiling water reactor (BWR) Mark II containment.

This paper describes the preliminary results of the high pressure test of the SCV model. The preliminary post-test measurement data for the gap between the SCV model and the contact structure and the preliminary comparison of test data with pretest analysis predictions are also included. The pretest preparations and the summary of the conduct of the tests are described in Reference 1.

[1] *This work is jointly sponsored by the Nuclear Power Engineering Corporation and the U.S. Nuclear Regulatory Commission. The work of the Nuclear Power Engineering Corporation is performed under the auspices of the Ministry of International Trade and Industry, Japan. Sandia National Laboratories is operated for the U.S. Department of Energy under Contract Number DE-AC04-94AL85000.*

2. Test Objectives

The SCV model test was intended to accomplish the following specific test objectives:

1) to provide experimental data for checking the predictive capabilities of analytical methods to represent some aspects of the static internal pressure response of a steel containment,

   a) beyond the elastic range, without consideration of contact with a surrounding shield structure or thermal effects, and

   b) after contact with a surrounding shield structure,

2) to investigate the failure mode of the SCV model, and

3) to provide experimental data useful for the evaluation of actual steel containments.

To meet these objectives, the high pressure test was conducted using a monotonic pressure rise and the cycle of unloading and reloading was not desirable.

3. High Pressure Test

The high pressure test of the SCV model was conducted on December 11-12, 1996 at Sandia National Laboratories. The actual conduct of the test was described in detail in Reference 1. Briefly, after approximately sixteen and a half hours of continuous monotonic increase in pressure by pumping nitrogen gas into the SCV model, the test was terminated when the pressure in the model dropped very rapidly, even with the pressurization system operating at its maximum flow rate of 1300 scfm (standard cubic feet per minute). The cause of failure of the SCV model was a tear resulting in leakage; the failure mode was not catastrophic. The maximum internal pressure achieved during the test was 4.66 MPa, which is 5.97 times the design pressure.

4. Preliminary Instrumentation Data

Post-test inspection of the SCV model revealed a large tear, approximately 230 mm long, along the weld seam at the edge of the equipment hatch reinforcement plate. The tear was found on the left side of the equipment hatch (from an interior view, as shown in Fig. 1a) and preliminary inspections suggest that the tear may have initiated at a point roughly 30 mm below the material change interface and propagated in both directions before it stopped. In addition, a small meridional tear, approximately 55 mm long, was found next to a semi-circular hole (situated at about 200°) in the stiffening ring above the equipment hatch. The cause of this tear has not been determined.

More than 97 % of the instruments on the SCV model survived the high pressure test and recorded information on deformation behavior of the model during the test. This paper provides a summary of the preliminary raw data from the test. These data have not been compensated for temperature variations. In addition, the strain data have not been adjusted for cross-axis compensation, and the displacement data for interior transducers have not been adjusted due to the movement of the central support column that was installed inside the model to anchor the displacement transducers.

4.1 Strain gage data around equipment hatch reinforcement plate

A network of strip, rosette, and single strain gages was installed around the equipment hatch. Some of these gages recorded very high strain readings. Figure 1a shows the locations of a few critical strain gages around the equipment hatch. The strip gage

(STG-I-EQH-16) installed adjacent to the upper end of the large tear registered 4.35 % strain and a rosette gage (RSG-I-EQH-12) slightly above it had a reading of 3.7 %. However, the highest strain reading of 8.7 % was recorded on the right side (an interior view), the non-torn side, by a strip gage (STG-I-EQH-37) above the material change interface. A strain reading of 1.53 % was recorded at the top of the equipment hatch (STG-I-EQH-2) and a very low strain reading of 0.10 % was found at its bottom (STG-I-EQH-28). Figure 1b shows the strain data recorded by these gages around the equipment hatch.

4.2 Free field strain gage data

Free field hoop strain data ranging from 1.8 to 2.1 % were recorded by the exterior strain gages at the upper conical shell section above the equipment hatch. The narrow range of strain variations around this section suggests that the SCV model experienced axisymmetric expansion there.

4.3 Horizontal and vertical displacement data

The interior displacement transducers in the middle conical shell section at the elevation directly above the material change interface recorded the highest horizontal displacements, ranging from 19 to 27 mm. A plot of these horizontal displacement data is shown in Fig. 2. The transducer at the top head region recorded a vertical displacement of 17.3 mm and that at the center of the equipment hatch had a vertical displacement reading of -2.8 mm at the end of the test.

4.4 Round Robin analysis output location data

A set of pretest analytical predictions, euphemistically referred to as a Round Robin analysis, was conducted by analysts from eight organizations in Germany, India, Italy, Japan and the U.S. The Round Robin analysis participants were requested to provide pretest analysis predictions at 43 strategically chosen standard output locations throughout the SCV model. Data were recorded at every one of these locations. The Round Robin pretest analysis predictions will be compared with the test data at a later date.

4.5 Acoustic emission data

There were twenty-four acoustic emission sensors installed on the model: eighteen interior and six exterior. The preliminary analysis of data collected by these sensors indicated two regions with high acoustic emissions during the test. One region was located just below the equipment hatch. It had most of the emission occurring at 4.25 MPa. The close proximity of this region to the equipment hatch suggests that the large tear might have initiated at this pressure. Another region had a significant increase of emission at 3.75 MPa. However, this region is not very close to the small tear, therefore it is not clear whether the initiation of the small tear is related to this pressure.

5. Post-Test Measurement Data

A steel contact structure was installed over the SCV model prior to the pressure tests to represent some features of the reactor shield building in the actual plant. There are 70 holes drilled on the contact structure in four arrays, 90^0 apart. The locations of these holes are shown in Fig. 3. The purposes of these holes were 1) to facilitate the positioning of the contact structure with respect to the SCV model during its installation, and 2) to provide access for installing the contact detection devices to monitor gap closing during the high pressure test.

The gap size at every hole location was measured before and after the high pressure test. Table 1 shows these measurements. The equipment hatch is situated at 90^0. As shown in Fig. 3, hole # 2 is located close to the bottom of the contact structure and hole # 19 is at its top. Holes # 7 and 8 are at the elevation of the equipment hatch. As seen from Table 1, the top of the contact structure came in contact with the SCV model, and the gap around the equipment hatch and the region above it closed during the test. In addition, pretest measurement data of the fabricated SCV model indicated that the local areas around the equipment hatch reinforcement plate were pulled inward during welding of this section onto the model. The extent of this out-of-roundness of the SCV model seemed to be decreased when the model underwent outward expansion under internal pressurization.

6. Comparison of Test Data with Pretest Analysis Predictions

There was a locally thinned section, very close to the large tear at the equipment hatch reinforcement plate, where reduced shell thickness was detected and measured before the pressure tests. Pretest analysis results [2] predicted that the SCV model would fail around this section at a pressure of 4.50 MPa. Test data indicate that the model failed at a pressure of 4.66 MPa during the high pressure test. Therefore, the pretest analysis gave a good prediction of the failure pressure, but was based on a different response mode.

Post-test inspection of the equipment hatch and the strain gage data around this area indicate that the model might have had a very steep strain gradient near the weld seam on the edge of the equipment hatch reinforcement plate where the large tear was detected. The pretest analysis results predicted much lower strains and strain gradients around the equipment hatch, and a higher strain at the locally thinned section, very close to the large tear, where thinner shell thickness was used in the analysis to simulate local shell thickness variations.

As mentioned in Section 4.2, the highest free field hoop strain data were recorded at the upper conical shell section, ranging from 1.8 to 2.1 %. The pretest analysis predictions on free field hoop strain data at this section are approximately 25 % below the test data. Close comparison between the two sets of plots indicate a reasonably good agreement at low pressure range, up to approximately 3.5 P_d, but the pretest analysis results on strains did not increase as fast as the test data at higher pressure ranges.

7. Conclusion

The high pressure test of the SCV model was conducted at Sandia National Laboratories on December 11-12, 1996. The cause of failure of the SCV model during the high pressure test was a tear in the model wall resulting in leakage; the failure mode was not catastrophic. The maximum internal pressure achieved during the test was 4.66 MPa which is 5.97 times the design pressure. Most of the instruments on the SCV model survived the test and recorded data that will be extensively analyzed to examine the deformation behavior of the model during the test.

A preliminary comparison of the test data with the pretest analysis predictions was performed. A detailed evaluation will be conducted to provide guidance for the post-test failure analysis and inspection. Metallurgical evaluation of the two tears is also planned.

8. References

1. Luk, V.K., et al. 1997. Testing of a Steel Containment Vessel Model Test. SMiRT 14, Lyon, France, August 17-22, 1997.

2. Porter, V.L., Carter, P.A. and Key, S.W. 1996. Pretest Analyses of the Steel Containment Vessel Model. NUREG/CR-6516, SAND96-2877, Sandia National Laboratories, Albuquerque, New Mexico.

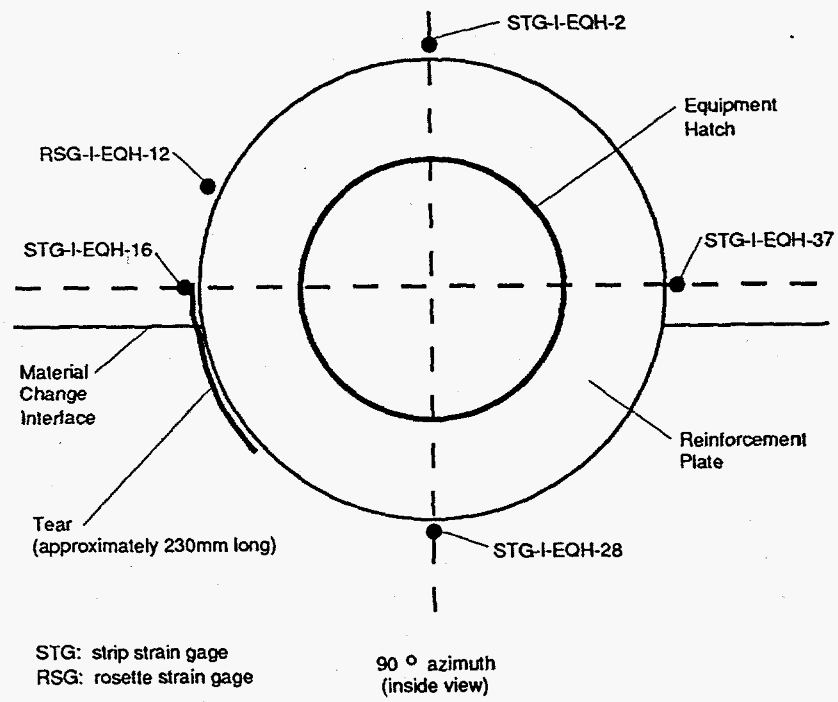

Fig. 1a Sketch of the equipment hatch from an interior view

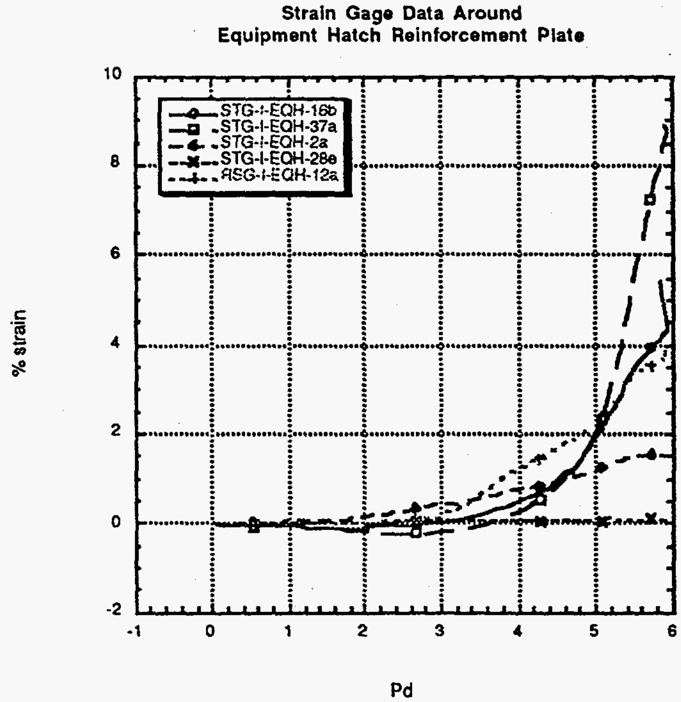

Fig. 1b Strain gage data around equipment hatch reinforcement plate

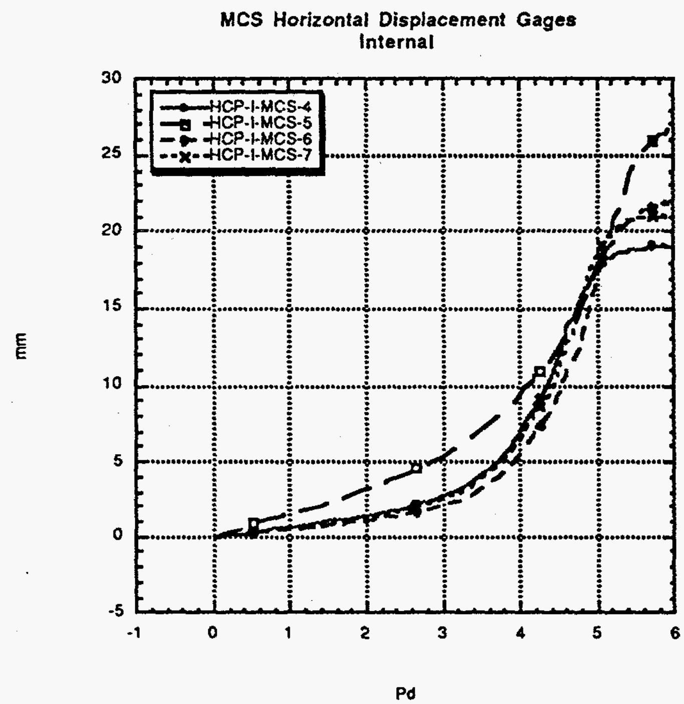

Fig. 2 Horizontal displacements recorded on four displacement transducers at the middle conical shell section, partitioned 90^0 apart

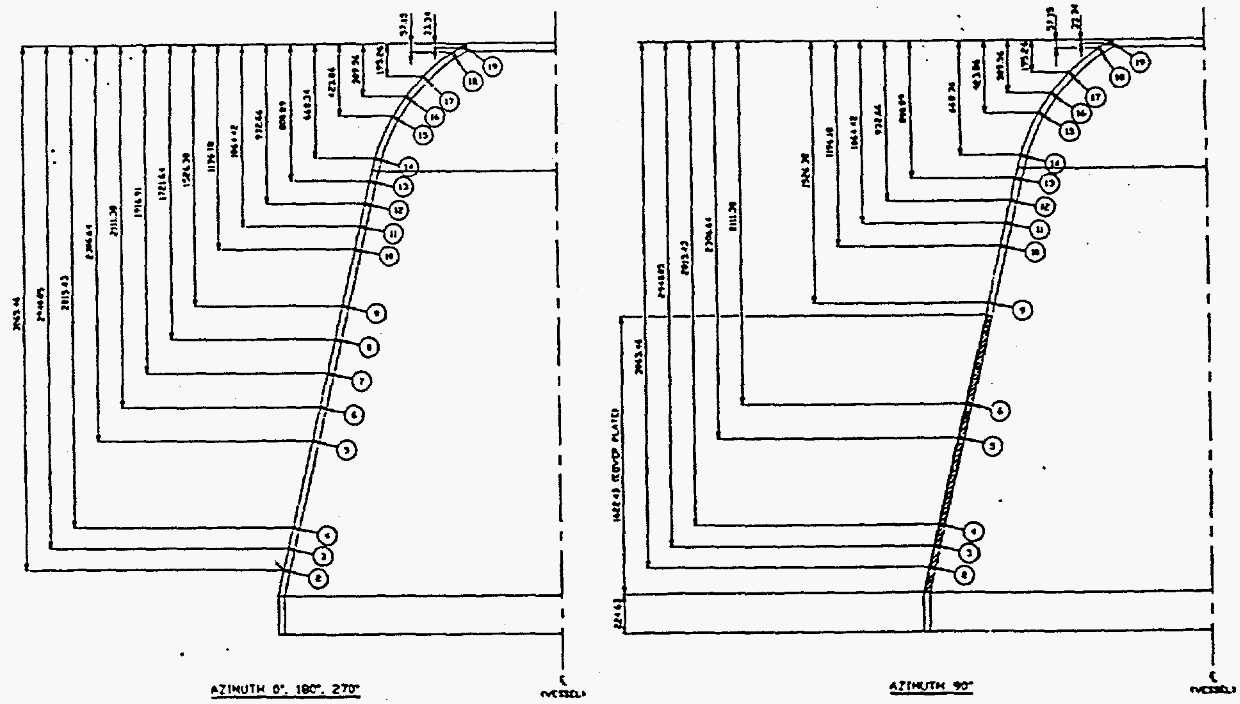

Fig. 3 Locations of measurement holes on the contact structure (dimensions in mm)

Table 1 Gap size measurements between SCV model and contact structure before and after the high pressure test

Measurement Hole #	0°		90°		180°		270°	
	A (mm)	B (mm)	A (mm)	B (mm)	A (mm)	B (mm)	A (mm)	B (mm)
2	130.71	130.20	124.38	123.75	136.88	136.73	140.13	140.06
3	99.29	98.68	94.26	92.99	104.91	104.29	108.31	105.16
4	69.62	69.39	66.15	65.05	74.45	73.66	77.47	76.50
5	19.05	17.45	13.36	9.65	22.00	21.03	24.61	23.06
6	18.39	15.60	20.37	7.47	20.55	18.34	22.99	20.19
7	18.80	11.28			21.11	13.31	22.73	13.49
8	20.98	2.62			22.81	3.51	23.77	4.01
9	19.81	2.08	29.39	3.43	21.64	1.50	22.43	3.33
10	20.17	4.32	24.71	5.89	23.27	5.38	23.80	6.30
11	22.35	2.59	23.47	3.15	22.96	2.92	23.54	4.57
12	22.48	3.07	20.65	3.02	24.33	3.48	22.25	3.30
13	21.28	6.68	19.38	7.21	24.00	7.92	22.78	7.11
14	25.42	20.09	18.24	14.15	24.18	18.39	23.62	17.98
15	22.63	23.19	19.63	19.20	22.23	22.40	21.31	21.21
16	20.14	20.50	18.23	17.81	19.76	19.99	18.49	18.34
17	19.69	20.19	17.12	16.97	18.01	18.44	17.10	17.15
18	19.66	12.37	15.78	10.06	16.03	11.73	15.39	10.46
19	24.77	1.28	27.18	1.66	27.69	1.91	24.00	1.81

Note: A = pretest gap size measurement B = post-test gap size measurement