Primary Containment Structural Integrity Test at the Laguna Verde Station

Tiburcio Zazueta, Augusto Vera
Comisión Federal de Electricidad, Veracruz, Mexico

INTRODUCTION.

The Laguna Verde Station is the first Nuclear Project of Mexico. It consists of two General Electric BWR units of 654 MW. each with a Mark II type Primary Containment. The Unit 1 is expected to reach commercial operation during 1989 and Unit 2 has a 52% progress by January 1989 with a scheduled fuel load by 1993.

As part of the Testing Program, the Unit 1 Primary Containment had to undergo a Structural Integrity Test (SIT). This test was successfully completed and the purpose of this paper is to present an assessment of the overall performance of the Primary Containment in connection with the design basis, applied loads and analytical methods used to determine the reinforcement of the structure.

The primary containment is a reinforced concrete structure analysed and designed in accordance with the ASME Code Section III - Division 2. (Mexican Nuclear Regulation requires as a minimum, full compliance with the regulation of the NSSS supplier country of origin). The figure 1 shows a cross section of the Primary Containment, which rests on a 4.2 m. thick foundation mat that supports also the Reactor Building Secondary Containment.

The shape of the primary containment structure is a combination of a right cylinder and a frustum of a cone, with the drywell located in the top section of the cone and the suppression chamber in the bottom of the right cylinder. The drywell is separated from the suppression chamber by the diaphragm floor, which is a structural reinforced concrete floor supported on a structural steel beams. The walls of the primary containment have a minimum thickness of 1.5 m. - - - (4.91 ft) as determined by radiation shielding requirements.

The Containment has a steel liner plate utilized as primary leakage barrier. The steel liner plate is anchored to the inside face of the walls and floors for containment leak tightness. It has a minimum thickness of 3/8" at walls and - 1/4" at the floor. The liner plate is not used as a strength element.

The Primary Containment has a total of 206 penetrations being the most important ones the equipment and personnel hatch into the drywell and the acces hatch into the suppression chamber.

The Unit 1 Laguna Verde Primary Containment is designated as prototype, considering the specific Laguna Verde Design, the unique structural properties as well as the site specific characteristics.

ANALYSIS AND DESIGN OF THE PRIMARY CONTAINMENT

The code used for the design and construction of the primary containment, is the ASME Boiler and Pressure Vessel Code, Section III, Division 2 (ACI Standard 359). "Code for Concrete Reactor Vessels and Containments"; January 1, 1975, edition: Subsection CC-3000.

The Reactor Building Mat was analyzed as a rectangular slab using the finite element technique. Nastran Computer Program was used to determine internal stresses and deformations of the mat under different loading conditions. The stiffening effect of the RPV Pedestal, Primary Containment and the Reactor Building were considered.

From the Mat model, spring constants in the interphase with the Primary Containment were obtained and used as boundary conditions for the Containment Analysis. The finite element model includes the cylindrical and conical section and considers also the equipment hatch. The Nastran Program was used in the analysis.

The equipment hatch model is shown in Figure 2.

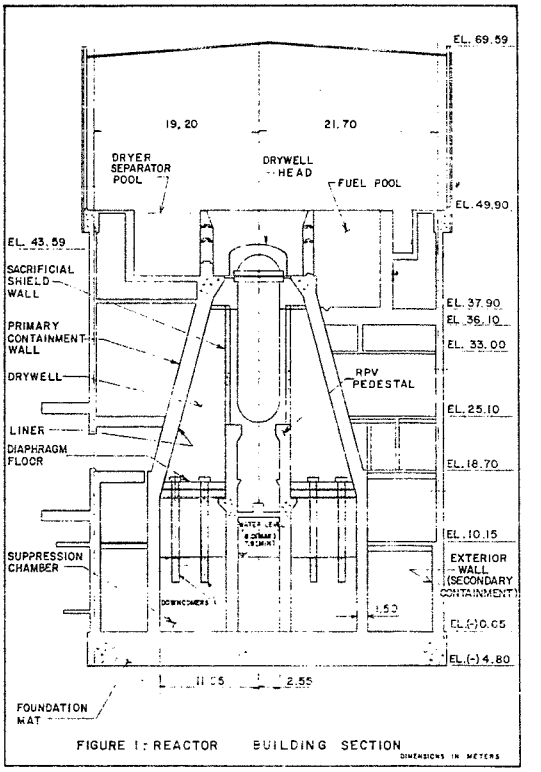

FIGURE 1: REACTOR BUILDING SECTION

DIMENSIONS IN METERS

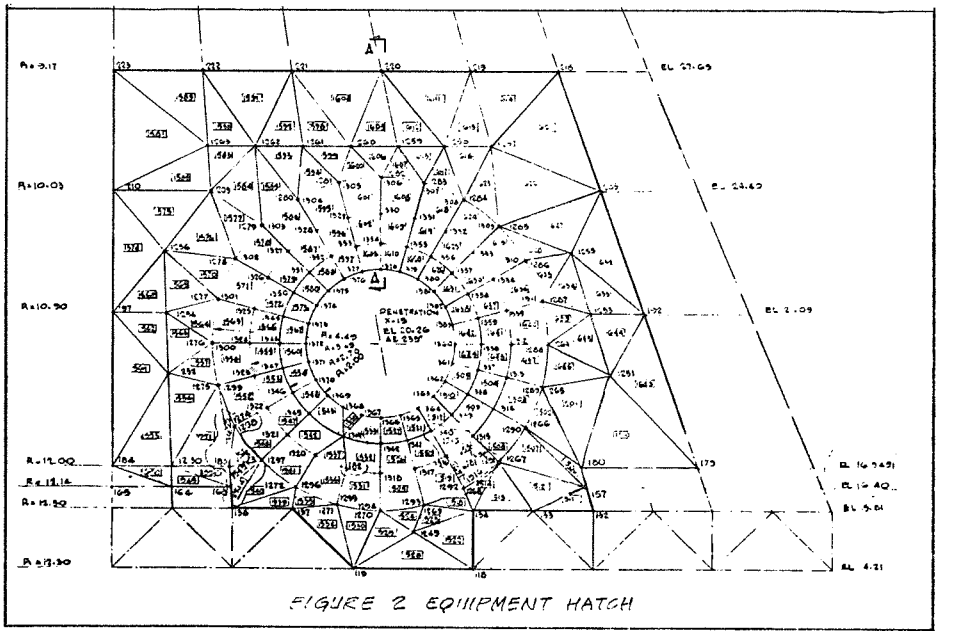
FIGURE 2 EQUIPMENT HATCH

The basic loads and combinations of the concrete containment, steel liner and liner anchors are based upon Section III of the ASME B&PV Code, Division 2.

In addition, an assessment of the containment design was performed to demostrate that the Laguna Verde containment can accomodate the hydrodynamic load

phenomena associated with SRV discharge and LOCA conditions in the Mark II containment in accordance with the requirements of NUREG 0487.

The Primary Containment Wall was reinforced vertically and circumferentially at inside and outside faces. Diagonal bars were provided for tangential and radial shear stresses.

The materials specified for the structure are concrete with f'c=300 kg/cm^2 for the mat and f'c=350 kg/cm^2 for the primary containment and reinforced steel ASTM A615, with minimum yield strength of 60,000 psi. For the containment wall, reinforcing bar size is # 10 and # 18 and the carbon steel for floor and wall liner plates conform to ASME SA516 grade 60.

STRUCTURAL INTEGRITY TEST.

The Primary Containment was tested in accordance with the requirements, conditions and acceptance setforth in the Article CC-6000 of the ASME Code Section III, Division 2. 1980 Edition, also including addenda for Winter 1980.

The acceptance requirements established for Laguna Verde Test are as follows:

a).- The measured maximum deflections at points of maximum predicted deflection do not exceed predicted values by more than 30%.

b).- The deflection recovery at the points of maximum expected deflection within 24 hours after complete depressurization is 70% as a minimum.

c).- Yielding of reinforcement does not develop as determined from the analysis of cracks and as indicated by the strain gage data and deflection measurements.

d).- No permanent damage occurs to the concrete structure.

In addition to the ASME Code, the structural acceptance criteria meets the requirements of USNRC Regulatory Guide 1.18 "Structural Acceptance Test for Concrete Primary Containment" (1972) and the USNRC Regulatory Guide 1.136. "Materials, Construction and Testing of Concrete Containments" Rev. 2 (1981).

As part of the preparation for the test, several activities were performed. For the purpose of this paper, the most important are as follows:

a).- Calculation of predicted deflections in the structure. The finite element model of the primary containment described above was used to predict the maximum expected deflections for the test.

b).- Primary Containment Inspection. The inner and outer surface of the Primary Containment Wall were carefully inspected prior to the testing. No abnormal condiction, liner deformation or cracks in the concrete were recorded for further use during the structural behavior evaluation.

c).- Instrumentation. The instrumentation and data acquisition system selected for the test were properly installed, and calibrated.

The Figure 3 identifies the location of the strain gages, the crack mapping areas and the points where deflections were measured during the test.

During the Structural Integrity Test, a total of 57 deflection sensors were monitored including 42 radial deflections, 12 vertical deflections, and 3 deflections in the equipment hatch (one tangential and 2 radial).

In addition to these deflections, 20 strain gages were used, the thermal gradient in the wall was measured with 6 thermocouples and 5 crack mapping areas were monitored.

Strains in the containment walls are measured by gages attached to sister bars. Sister bars are placed in a vertical position parallel to the inside vertical reinforcing bar; and in a horizontal position parallel to the inside horizontal reinforcing bar, and parallel to the outside horizontal reinforcing bar.

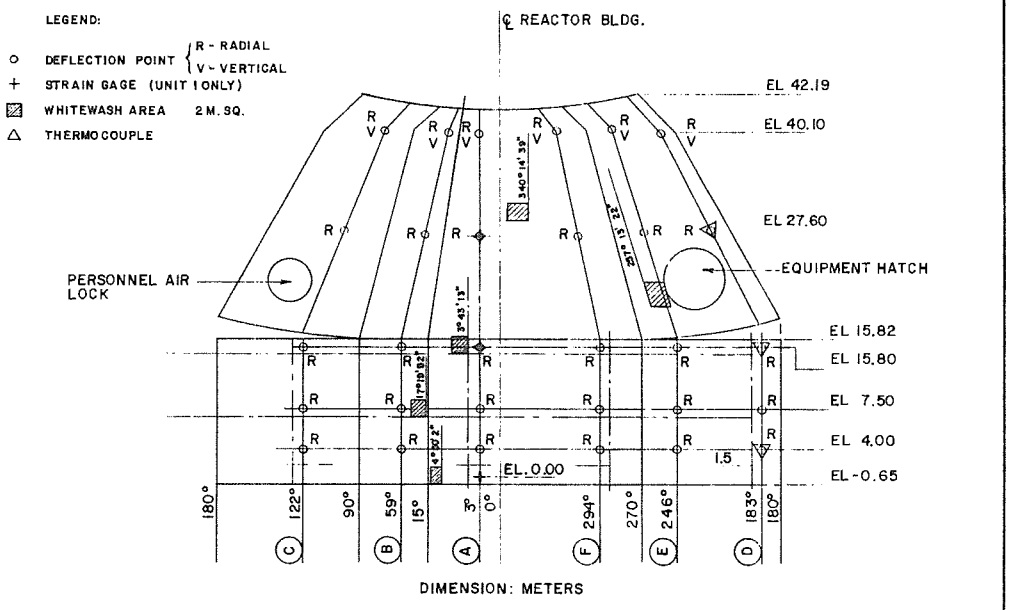

FIGURE 3 - DEVELOPED VIEW OF PRIMARY CONTAINMENT TEST GAGE LOCATION

DESCRIPTION OF THE TEST.

After the containment had been properly sealed, including openings through the drywell floor, and before being pressurized, all cracks in the mapping areas were noted and photographed and all instrument readings recorded to 0 kg/cm^2.

The structure was then inspected visually to locate any unusually severe crack in the remainder of the exposed concrete surface.

Pressurization of the containment proceeded in accordance with the pressure time history indicated in Figure 4, and readings and measurements were taken at each step. The pressurization of 3.64 kg/cm^2 (51.75 psig) corresponds to 115 percent of the design load.

During the test, Quality Assurance Personnel and Quality Control Personnel were verifying the compliance with the test procedures and the measurements and inspections performed during the test.

TEST RESULTS.

A summary of the test results is as follows:

a).- Strain Measurements.- The maximum strain gage data measured was 0.076×10^{-3}, well below the strain yielding value of 2×10^{-3}. Therefore, no permanent elongation ocurred.

b).- Crack mapping.- In the 5 crack mapping areas the initial crack pattern was maintained without change throughout the pressurization.

c).- Permanent Damage.- At the end of the test, the Primary Containment was thoroughly inspected. No damage to the liner or other structure occurred during the test.

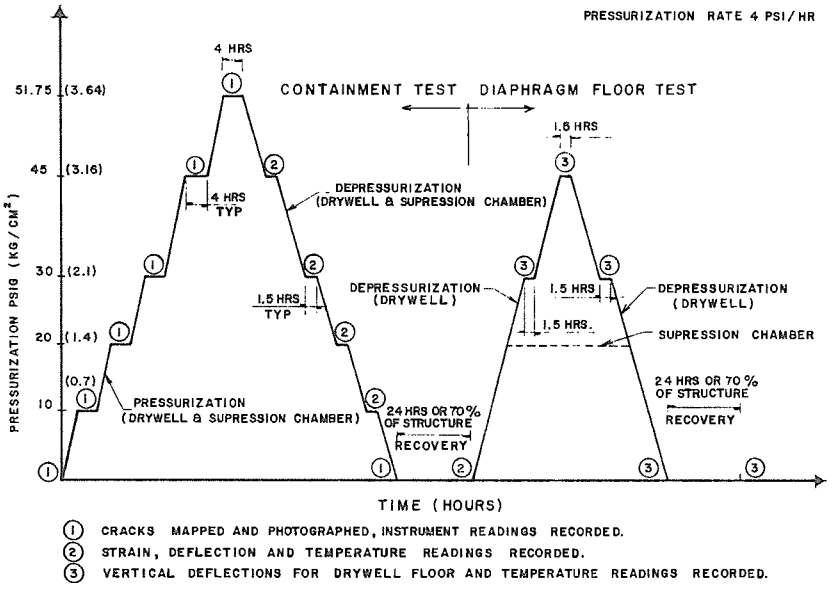

FIGURE 4.- TEST SCHEDULE

d).- Deflections.- Throughout the test all the measured maximum deflections were always below the maximum predicted values. The following table summarizes some of the results.

STRUCTURAL INTEGRITY TEST
PREDICTED STRUCTURAL RESPONSE, MEASURED VALUES AND RECOVERY PERCENTAGE VALUES

TEST GAUGE	MAXIMUM PREDICTED VALUES (MM.)	MAXIMUM MEASURED VALUES (MM.)	END OF THE TEST VALUES (MM.)	RECOVERY PERCENTAGE VALUES
DR-4	0.90	0.414	0.049	88
PR-11	3.96	0.326	0.028	91
DR-30	3.49	0.322	0.022	93
DR-42	4.66	0.784	0.137	82
DV-1	5.26	0.853	0.0	100
DV-5	5.12	0.879	0.0	100
DV-6	5.20	0.818	0.0	100

e).- Deflection recovery.- The deflection recovery, 24 hours after depressurization was 70% or more in all cases. The Figure 5 shows the curve pressure- deflection at two test gages.

The test results show a deformation of the structure in the elastic range and a full compliance with the established acceptance criteria.

CONCLUSIONS.

The results obtained during the test indicated that the actual behavior of the structure is in accordance with the analysis output. However, it also shows the existence of built-in safety factors in the different stages of the engineering and construction process.

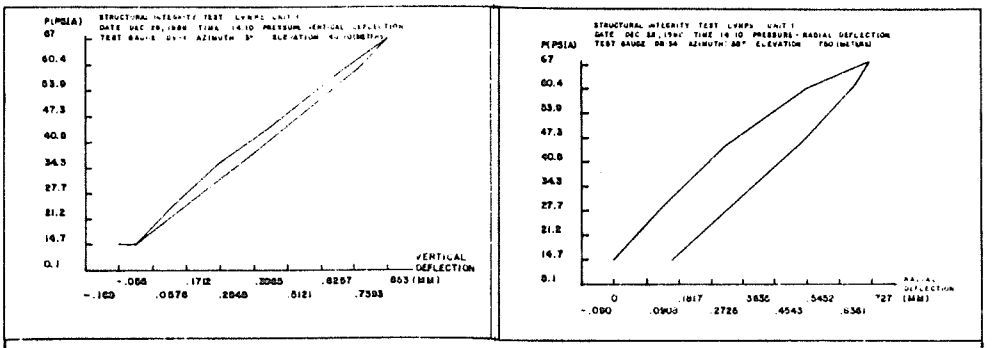

FIGURE 5.- DEFLECTION RECOVERY AT TWO LOCATIONS

Some of the concepts that should be noted are:

a).- The tensile strenght of the concrete, which is not considered in the analysis and design.

b).- The contribution of the steel liner plate to the overall structural behavior of the Primary Containment.

c).- The additional capability of the structures that results of using materials with actual strengths higher than the specified construction values.

It is concluded that the Primary Containment is capable to withstand the postulated internal pressure, maintaining its structural integrity.

REFERENCES.

1.- Specification CFE-LC-17 Rev. 4 "Especificacion de la Prueba de Integridad Estructuras del Contenedor Primario y del Diafragma".

2.- Procedure CFE CPP-13.1.17 Rev. 0 "Procedimiento de Prueba de Integridad Estructural del Contenedor Primario y del Diafragma".

3.- US NRC Regulatory Guide 1.18 Rev. (1972) "Structural Acceptance Test for Concrete Primary Reactor Containments"

4.- US NRC Regulatory Guide 1.136 Rev. 2 (1981) "Materials, Construction and Testing of Concrete Containments".

5.- ASME B & PV Code Section III, Division 2 Subsections CC-3000 and CC-6000, 1980 Edition including addenda for Winter 1980.

6.- US NRC Standard Review Plan.
NUREG-0800 Rev. 1 (1981).

9.6.1. Section 3.8.1. "Concrete Containment"
9.6.2. Section 3.8.2. "Steel Containment"
9.6.3. Section 3.8.3. "Concrete and Steel Internal Structures of Steel or Concrete Containments".