

Thermal Buckling Tests of Steel Plates in Concrete Secondary Containments

J.T. Julien, N.W. Hanson, D.M. Schultz

Construction Technology Laboratories, 5420 Old Orchard Road, Skokie, Illinois 60077, U.S.A.

Abstract

Two large scale specimens were designed, constructed, and tested to observe and evaluate behavior of liner plates of a secondary containment cylinder wall exposed to a thermal transient in the presence of internal pressure. Specimens were representative of reinforced and prestressed concrete design of secondary containment buildings for nuclear power plants. To perform the tests, a test fixture was designed and constructed which could apply surface pressures of 65 nsi (448 kPa) and shock the specimen with heated air up to 500F (260C). Specimens were tested, resulting in expansion of liner plate without buckling between anchors. Buckling strains were relieved when the concrete section cracked.

1. Introduction

Since the Three Mile Island (TMI) incident, scenarios with a potential for loss of coolant accident (LOCA) combined with hydrogen deflagration have become priority items. As a result, the need to evaluate behavior of nuclear containments under high internal pressures became apparent.

To investigate the behavior of containments subjected to overpressurization, the Electric Power Research Institute (EPRI) has undertaken a multi-phase research program at Construction Technology Laboratories (CTL).

The overall objective of the EPRI program is to provide the utility industry with a test-verified analytical method for making realistic estimates of actual capacities and leak rates of reinforced and prestressed concrete containments under internal overpressurization from postulated degraded core accidents. These estimates are needed to perform plant-specific probabilistic risk assessments. Results from the test program described in this paper are being used to confirm analytical models for predicting strength and deformations of containment walls in a separate parallel investigation sponsored by EPRI.

The overall test program being performed at CTL is described in Reference 1. Testing was initiated in 1981 and is currently scheduled for completion in 1985. Results of tests performed through mid-1984 are presented in detail in Reference 2.

2. Objective

It has been recognized that overpressurization in secondary containments may be

accompanied by a thermal transient. Engineers are aware of the potential for thermal transient situations. However, there is little experimental data upon which to verify current analytical methods. The objective of the tests described herein is to measure the behavior of a mechanically anchored curved steel plate/concrete composite when subjected to a combined thermal transient and applied air surface pressure. The plate represents the membrane liner of a secondary containment building for nuclear power plants. Two specimens were designed and tested. One specimen is representative of reinforced concrete design where the liner plate is attached to the concrete by headed studs. The other specimen is representative of prestressed concrete design where the liner plate is attached to the concrete by continuous angle anchorages.

3. Specimen Design

Each specimen was 9 ft (2.7 m) square and 2.5 ft (0.8 m) thick. Specimens were designed to be representative of elements from the cylinder wall of a secondary containment for nuclear power plants. Specimen 2.6 was representative of prestressed concrete design and Specimen 2.7 was representative of reinforced concrete design. Full size liner plate material, anchors, and reinforcement were used in both specimens. However, the concrete thickness was reduced for handling purposes. Specimen 2.6 utilized continuous 3x2x1/4-in. (75x51x6.4-mm) angles welded to the liner plate. Specimen 2.7 utilized 5/8-in. (16-mm) diameter, 6-1/2-in. (165-mm) long headed studs. The liner plate was rolled during fabrication to provide a curvature representative of the curvature in a typical cylindrical containment wall. Liner plate and reinforcement details for Specimens 2.6 and 2.7 are shown in Figs. 1, 2, and 3.

4. Testing Apparatus

The thermal buckling test frame was designed and constructed for use in determining the effects of thermal transients on mechanically anchored liner plate. The thermal buckling frame was designed to function in two different ways: (1) to apply a surface pressure of 65 psi (448 kPa) to the specimen and, (2) to subject the specimen to a thermal transient with a peak temperature of 500F (260C).

The test assembly is shown in Fig. 4. The test assembly system was comprised of the thermal buckling frame, the specimen, and the heating and pressure systems. The specimen was secured to the buckling frame by means of prestressed steel bars. A grout pad between the buckling frame and the specimen provided an air-tight seal.

The thermal system was made up of twenty electrical heating elements that had the capability of reaching a temperature of 2200F (1200C). Heat was stored in an assembly of steel bars. To build up and contain the heat in the system, the heating elements and the heat storage steel bars were placed in an insulated chamber.

An air moving system, which consisted of six blower units designed for moderate temperature use, was used to force air past the heated steel bars and across the specimen surface, as shown in Fig. 4. The blowers were powered by a motor externally mounted on the thermal buckling frame. When the heated steel bars reached a temperature of approximately 1000F (540C), the blower units were engaged, forcing air across the specimen surface.

5. Instrumentation

Specimen behavior was measured using external and internal instrumentation. Externally, temperatures were monitored with Type K thermocouples and lateral buckling of the liner plate was measured using linear potentiometers. Air surface pressure was measured with a pressure transducer. Internal instrumentation consisted of Type K thermocouples. Thermocouples and potentiometers were located in a grid about the specimen centerlines. Nine thermocouples were located on the plate, on both air and concrete faces, and within the concrete at 3 in. (76 mm) and 15 in. (381 mm) into the concrete from the liner plate. All temperature and displacement measurements were recorded by a digital data acquisition system. The instrumentation layout is shown in Fig. 5.

6. Results

No buckling of the liner plate was observed for either specimen. The thermal transient peak on the specimen surface was reached within 5 minutes after the blower units were engaged. There was a pronounced thermal gradient through the concrete section, with the peak liner plate temperature at the air surface/liner plate interface averaging 320F (160C) while the concrete 15 in. (381 mm) away from the liner plate remained at approximately room temperature. There also was a marked time lag effect between the peak temperatures for the different layers of thermocouples.

The average of the peak liner plate surface temperatures on the heated air side was approximately 320F (160C). The average of the peak temperatures on the liner plate/concrete interface was approximately 260F (127C). The maximum pressure reached during the test was 70 psi (482 kPa). When the heated air was released into the air plenum from the furnace the pressure increased dramatically from 50 psi (345 kPa) to 70 psi (482 kPa). Typical surface pressure and liner plate temperature versus time relationship is shown in Fig. 6.

During the initial heating time, there was some leakage of heat from the thermal system into the air plenum. The air near the liner plate increased from room temperature to a maximum of approximately 175F (79C). When the blower units were engaged, the air temperature near the liner plate increased to approximately 600F (315C) within 5 minutes and then began to decrease. Cavity depressurization occurred when corner cracks formed in each of the concrete specimens. Loss of air pressure was accompanied by loss of heated air.

7. Acknowledgment

This work is supported by the Electric Power Research Institute, Palo Alto, California, U.S.A., as part of Structural Integrity Research in the Nuclear Power Division's Risk Assessment Program. The project team would like to thank H. T. Tang, Y. K. Tang, R. K. Winkleblack, and G. E. Sliter of EPRI for overall guidance and technical input in this program. The project team would also like to thank J. Raschid and R. S. Dunham of Anatech International Corporation, La Jolla, California, U.S.A., for their analytical efforts and assistance in design of these specimens and Adolf Walser and Dr. Joseph Ucciferro for their assistance in the areas of prestressed and reinforced concrete containment design.

8. References

1. Schultz, D.M., and Hanson, N.W., "Full Scale Leak-Rate Tests on Concrete Containment Wall Elements," Proceedings Second Workshop on Containment Integrity, Washington, D.C., June 12-15, 1984.
2. Julien, J.T., Schultz, D.M., and Weinmann, T.L., Concrete Containment Structural Element Tests, Volume 1: "Half-Thickness Element Tests - Description and Results," Volume 2: "Half-Thickness Element Tests - Detailed Test Data," Volume 3: "Liner-Plate Tests," report to the Electric Power Research Institute, Palo Alto, California, submitted by Construction Technology Laboratories, a division of the Portland Cement Association, Skokie, Illinois, November 1984, 104 pp. Available through Research Reports Center, P.O. Box 50490, Palo Alto, California 94303, Document EPRI NP-3774.

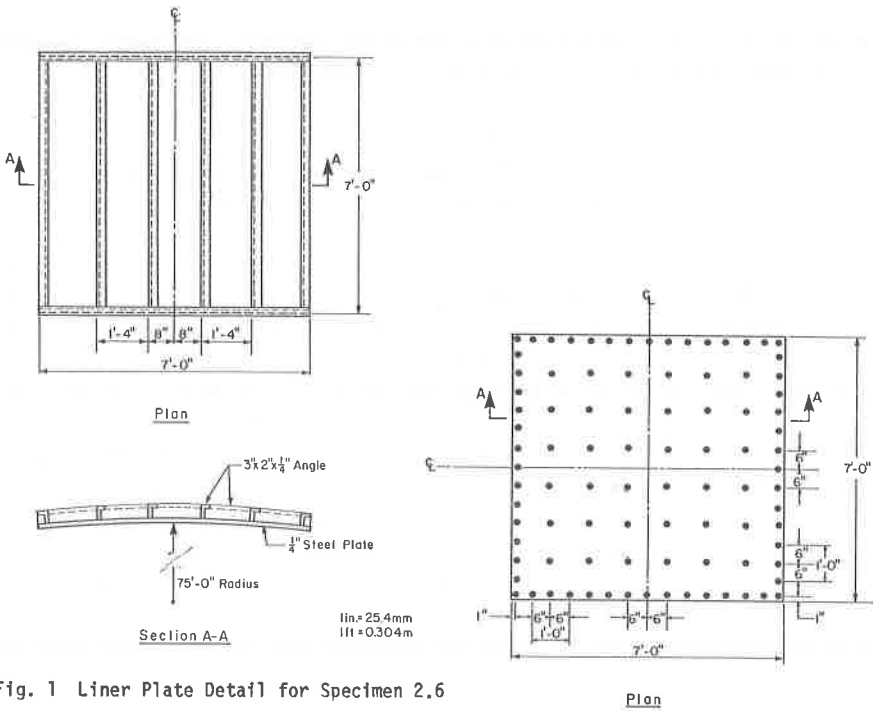


Fig. 1 Liner Plate Detail for Specimen 2.6

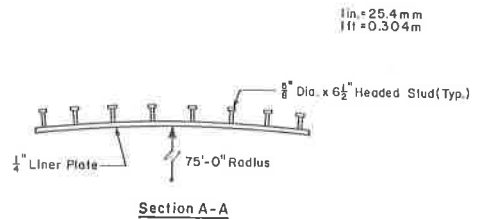
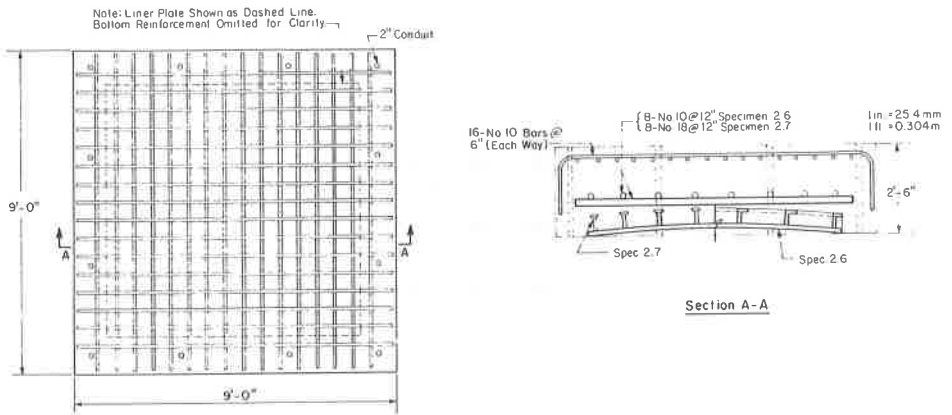


Fig. 2 Liner Plate Detail for Specimen 2.7



Plan

Fig. 3 Reinforcement Details for Specimens 2.6 and 2.7

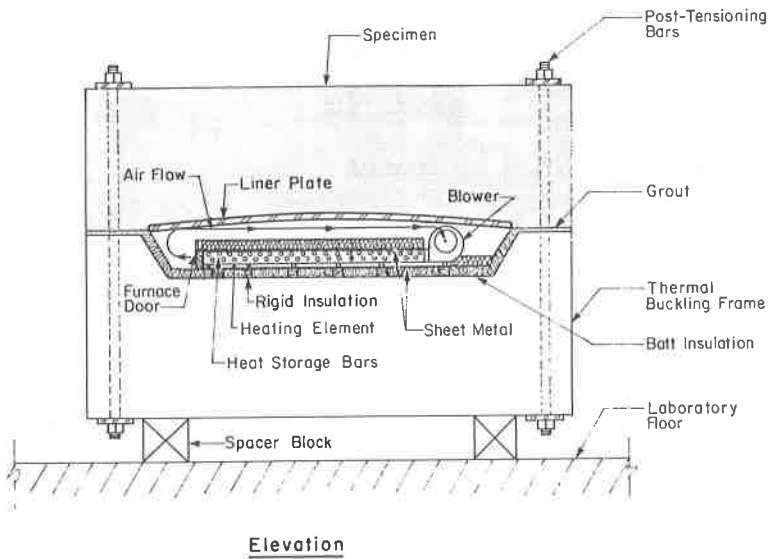
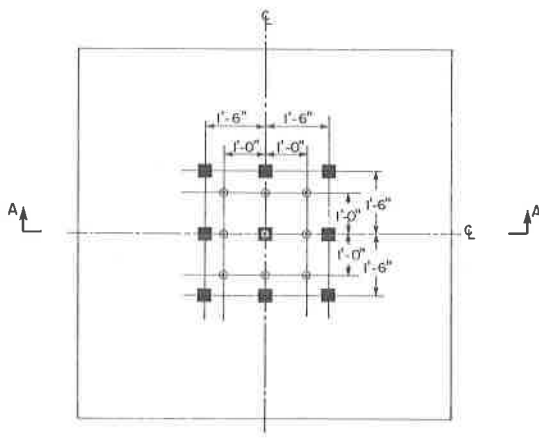
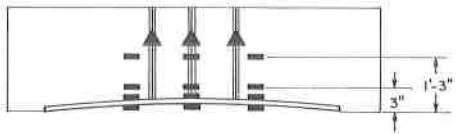


Fig. 4 Thermal Buckling Frame and Test Specimen Assembly



Plan

1 in. = 25.4 mm
1 ft = 0.304 m



Section A-A

- Thermocouple (T/C)
- ▲ Linear Potentiometer

Fig. 5 Instrumentation for Specimen 2.7

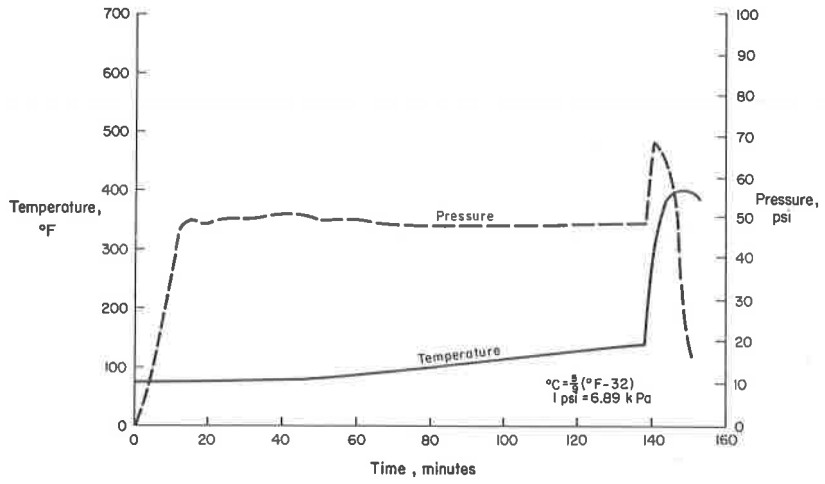


Fig. 6 Pressure and Liner Plate Temperature versus Time