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MARK I CONTAINMENT PROGRAM 1/4 SCALE PRESSURE SUPPRESSION POOL TEST PROGRAM: DOWNLOAD OSCILLATION EVALUATION

TASK NUMBER 5.5.2

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MARK I CONTAINMENT PROGRAM

1/4 SCALE PRESSURE

SUPPRESSION POOL SWELL TEST PROGRAM: DOWNLOAD OSCILLATION EVALUATION

TASK NUMBER 5.5.2

This work was performed with the support of Nuclear Services Corporation and Aerotherm Division of Acurex Corporation under contract to General Electric.

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693 252

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

APPENDIXES

695 255

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF TABLES

ABSTRACT

This report documents the results of the Mark I Containment Program Task 5.5.2, Download Oscillation Evaluation. This pool swell test program conducted in the Mark I 1/4 Scale Test Facility (QSTF) both identified the causes of download oscillations previously observed in subscale pool swell tests and developed methods to prevent their subsequent occurrence.

The test and evaluation work established that download oscillations in the QSTF have two primary causes, neither of which are prototypical of full-scale conditions. These causes are:

1) *Fluid/structure interaction caused by the flexible yet massive end windows.*

2) *System flexibility introduced by the presence of air bubbles on the submerged facility surfaces.*

Download oscillations can be virtually eliminated in the QSTF by laterally stiffening the end windows and by removing the submerged surface air bubbles.

Since scaling of all parameters except peak download has been confirmed, and since the peak downloads were scalable for the full ΔP conditions where there were essentially no download oscillations, it can be expected that elimination of download oscillations will make peak downloads for the less than full ΔP conditions also scalable.*

**ΔP refers to the drywell-to-wetwell pressure differential used to depress the water level inside the downcomers.*

ACKNOWLEDGMENT

The Download Oscillation Evaluation program described in this report was conducted with the support of Nuclear Services Corporation and the Aerotherm Division of Acurex Corporation.

1. SUMMARY

This report documents the test and evaluation work conducted under the Mark I Containment Program Task 5.5.2 to evaluate the causes of download oscillation observed in previous 1/4 scale and 1/12 scale tests as reported in References 1 and 2. These download oscillations were of sufficient magnitude to prevent confirmation of the scaling laws for peak download at conditions other than full ΔP as reported in Reference 1. The small oscillations that were present at full ΔP did not prevent scaling confirmation of peak download at that condition.

The Download Oscillation Evaluation Program described herein and subscale tests by EPRI (Reference 3) have shown that the download oscillations were primarily attributable to test facility related phenomena which are not prototypical of full-scale plant conditions. The oscillations were primarily due to the flexibility of the test facility end windows and the presence of air bubbles on submerged test facility surfaces. Download oscillations have been virtually eliminated from the 1/4 scale data by stiffening the end windows and adding a surfactant, which has been observed to remove air bubbles from the submerged facility surfaces.

Comparable tests have not been performed at 1/12 scale with download oscillations removed for direct comparison with 1/4 scale data. However, the following arguments strongly suggest that failure to confirm the scaling law for peak download at less than full ΔP was caused only by the download oscillations:

- The scaling laws for all of the other parameters including download impulse (area under the download transient) were confirmed by the Task 5.5.1 data, in spite of the download oscillations.

- The scaling law for peak downforce at full ΔP, where the downforce oscillations were small, was confirmed by the Task 5.5.1 data.

Although the shell of the Mark I torus is more flexible than the test facilities used in subscale testing, tests run in the QSTF over a range of vertical natural frequencies from 20 Hz to 70 Hz have shown that changes in the vertical motion of the boundary do not significantly alter the acceleration corrected vertical force history.*

Elimination of the download oscillations from the subscale data, which are to be used to predict full-scale Mark I containment pool swell loads, is justified because the oscillations are sustained by phenomena which are related to the test facilities and are not prototypical of the Mark I Containment conditions as explained below.

- Window Stiffness

  End windows do not exist in the Mark I containment and, consequently, could not be a prototypical source of download oscillations. Stiffening the test facility windows is, therefore, fully justified to achieve proper simulation.

- Air Bubbles

  The following justifications are given for the elimination of air bubbles from the submerged test facility surfaces.

1. Vacuum Test Conditions

In the subscale test programs, water is introduced into the torus at atmospheric pressure. The pressure in the torus is then lowered to vacuum conditions (3.68 psia for 1/4 scale) to provide for proper scaling. As the vacuum is being drawn the dissolved gases reach super-saturated levels and begin precipitating out. Some of these bubbles become trapped on submerged test facility surfaces. The vacuum conditions which generate the air bubbles are not prototypical of the Mark I containment which is at atmospheric pressure.

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*Integrated torus pressure data acceleration corrected for water inertia to define the applied force on a non-accelerating boundary.

693 262

2. Large Surface Area

The wetted surface to water volume ratio is about 12 times greater in the QSTF than it is in a full-scale Mark I Containment due to the presence of the end windows in the test facility which are not a feature of Mark I. The wetted surface is about three times greater in the test facility than the scaling factor dictates, for the same reason. The end windows provide additional submerged surface area for trapping air bubbles.

3. Time Factor

Subscale test runs are made shortly after the introduction of water into the test facility. Under full-scale conditions the water would remain in the torus for extended periods of time allowing time for the pool and the free space above it to reach equilibrium.

Surfactant is added to the water in the QSTF to remove the air bubbles from submerged facility surfaces. Although similar results can be achieved through deaeration of the water by repeated facility blowdown, the use of surfactant was selected for the QSTF tests for operational simplicity, to achieve controlled test conditions and because the reduction of surface tension at subscale is more prototypical of full scale conditions.

Surface tension forces have not been scaled. Since scaling studies showed that surface tension forces are small compared to inertial forces, they were expected to have a negligible effect on the pool swell phenomena. The discovery of the effect of surfactant on subscale surface air bubbles does not change this conclusion. However if surface tension were scaled for a quarter scale test, it would be proportional to the square of the scaling factor ($\sim$1/16). Although commercial surfactants can only reduce the surface tension by factors of from 2 to 3, the surface tension reduction achieved by adding surfactant for the QSTF tests is in the right direction for proper scaling.

693 263

The presence of cylindrical window struts offers the potential for modifying the pool hydrodynamics by adding drag. Since the objective of the 5.5.2 work was directed at download oscillations, and since there is little pool motion at peak download, the ten strut configuration was selected to maximize window stiffness. Even so, the struts are largely removed from the regions of highest pool swell and constitute only a small fraction (less than 1%) of the pool volume. Based on the window accelerations measured with eight struts below the water, satisfactory window stiffness for future tests may be obtainable with fewer struts which would further minimize any concerns over window strut drag.

As a result of the test and evaluation work performed under Task 5.5.2, the causes of the download oscillations were found to be facility related. Their removal provides conditions under which download scaling would be expected to be confirmed. Download oscillations are essentially removed using the modifications described in this report. The QSTF load definition tests conducted under Task 5.5.3 will utilize surfactant and window stiffening struts to minimize download oscillations.

693 264

2. INTRODUCTION

The Mark I 1/4 Scale Test Facility (QSTF) was constructed and tests were conducted under Long Term Program Task 5.5.1 to evaluate the validity of the pool swell scaling relationships. These scaling relationships provide for small scale experimental modeling of the pool swell phenomena. Using the validated scaling relationships, full-scale loads for a postulated Loss of Coolant Accident (LOCA) can be determined from small-scale test results. During the Mark I Short Term Program, pool swell loads and load sensitivites were predicted on the basis of data from 1/12 scale 2D tests. During the Task 5.5.1 QSTF tests, a data base was established at 1/4 scale comparable to the Phase IV A tests conducted at 1/12 scale under Task 5.8 (Reference 2). These data were used to evaluate the validity of the scaling relationships.

Comparisons between 1/12 and 1/4 scale data were made for four test conditions—two drywell pressurization rates with both zero and full initial drywell/wetwell differential pressure (ΔP). These comparisons indicated that in general the hydrodynamic characteristics and their variation with drywell pressurization rate and initial ΔP scaled well between 1/12 and 1/4 scale. However, the download transients at both 1/4 and 1/12 scale exhibited significant oscillations at conditions less than full ΔP. For the 1/12 scale data base selected, the magnitude of the oscillations were significantly larger than the 1/4 scale oscillations. Consequently, the scaling relationships could not be confirmed for peak download at conditions less than full ΔP.

The Download Oscillation Evaluation was initiated to understand the causes of download oscillation and develop a basis for predicting full-scale downloads from subscale test data. The two test series conducted in Task 5.5.2 for download oscillation evaluation were:

Series 1 Facility Sensitivity

This test series was designed to evaluate the sensitivity of the facility response to vertical and lateral stiffness changes, define facility response modes and provide the capability for measurement of bubble pressure.

Series 2* Facility Fluid/Structure Interaction

This test series was specifically directed at fluid/structure interaction effects caused by end window flexibility, and the effects of excess dissolved air in the pool under vacuum test conditions.

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*This test series was originally defined as Series #3 in PAP, Rev. 2, 8/1/77 and is so designated in all test data.

3. BACKGROUND INFORMATION

3.1 TYPICAL DOWNLOAD OSCILLATIONS

Typical download oscillations which occurred during 1/4 and 1/12 scale pool swell transients are shown in Figures 3-1 through 3-3. The maximum peak-to-peak amplitude of the oscillations in the 1/4 scale tests was approximately 5600 lbf (25 kN) at about 157 milliseconds into the transient; the approximate frequency of the oscillations was 50 Hz. At this time, the air bubble has just cleared the downcomers. Thereafter, the oscillations continue in a damping mode to the end of the transient. Since the maximum peak-to-peak amplitude of the oscillations is of the same order of magnitude as the peak download on the torus, their effect on the interpretation of the test results is very significant.

Figure 3-3 shows that the 1/12 scale test data (when scaled to the 1/4 scale test) correlates well with the 1/4 scale test results when the oscillations are eliminated from the data by drawing a line through the midpoints of the oscillations. To assure that the shape of the download trace without oscillations is correctly represented in Figure 3-3 it was necessary to identify the causes of the oscillations and to then find means of preventing their occurrence in the tests.

3.2 POTENTIAL OSCILLATION MECHANISMS

The following is a list of the potential causes of download oscillations which were investigated in this program.

- Structural Stiffness of the Test Facility
    - Lateral Stiffness (Window/Frame Assemblies)
    - Vertical Stiffness

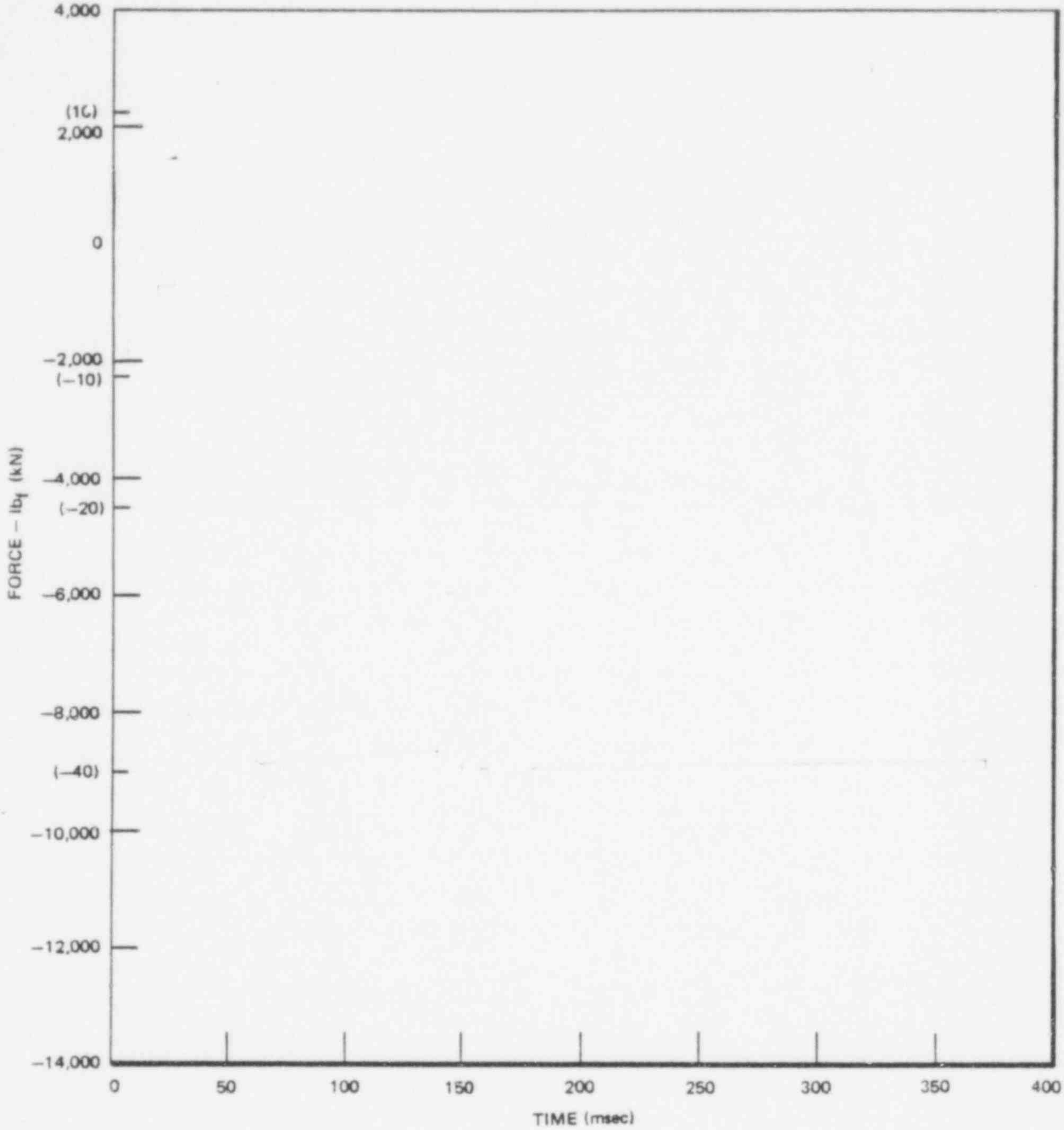

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Figure 3-1. Torus Vertical Force Transients for 1/12 and 1/4 Scale (Medium Orifice — Zero ΔP Test Condition)

*Proprietary information deleted

693 268

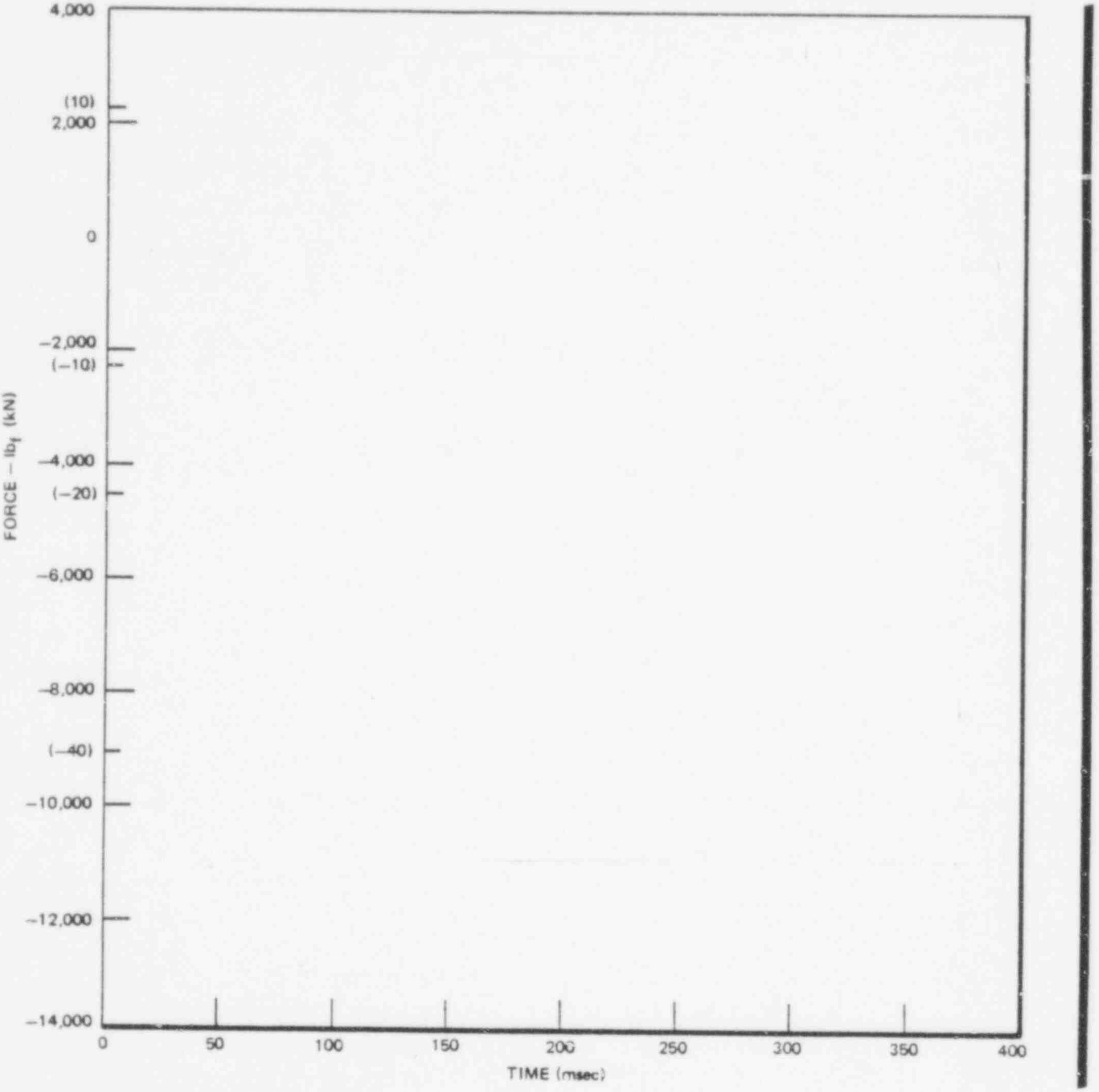

Figure 3-2. Torus Vertical Force Transients for 1/12 and 1/4 Scale (Large Orifice — Zero ΔP Test Condition)

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*Proprietary information deleted

693 269

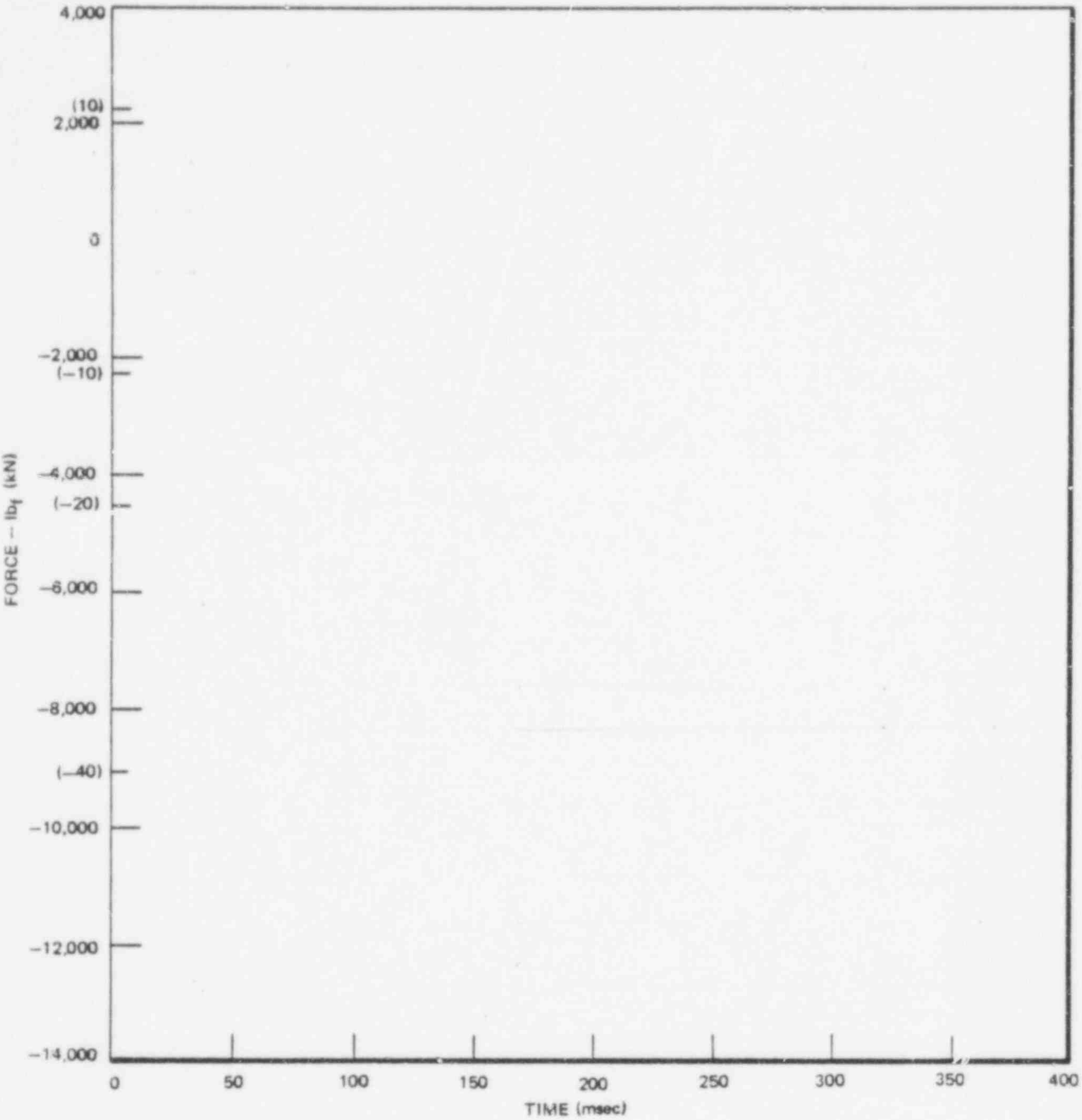

Figure 3-3. Ramp Representation of the Downforce

- Acoustic Effects
- Vent Clearing Hydrodynamic Effects
- Air Bubbles

The above phenomena and their potential for the initiation or maintenance of download oscillations are described briefly below.

3.2.1 Structural Stiffness of the Test Facility

Previous subscale tests (Reference 2) showed that the magnitude and frequency of download oscillations are sensitive to the test facility structural stiffness. In this investigation the vertical stiffness of the torus and its support structure were considered as was the lateral (window/frame assembly) stiffness.

The test facility flexibility was expected to be a major contributory factor to the download oscillations. As the pressure of the system rises, the fluid/structure interface moves due to the flexibility of the test facility. The structure in turn stores energy which can be later fed into the pool creating a spring/mass oscillator.

3.2.2 Acoustic Effects

Acoustic effects were investigated to determine whether they were casually linked to the download oscillations. Specifically, the presence of acoustic waves in the vent system was investigated.

As the vents clear, the rapid expansion of the bubble could potentially depressurize the downcomers sending a rarefaction wave upstream to the drywell. This wave, reflected back as a pressurization wave, could result in oscillation of the download. The sonic velocity in air and the dimensions of the test facility are consistent with such a postulation.

3.2.3 Vent Clearing Hydrodynamic Effects (Bubble Pressure Oscillation)

The hydrodynamics associated with vent clearing were considered to be a possible source of the download oscillations and were investigated. The study was oriented towards providing an understanding of the vent clearing mechanism to establish if pressure oscillations are an inherent part of this mechanism. The rapid bubble expansion when the air starts entering the quiescent torus pool, together with the restricting effect of the water still remaining in the vent, causes the bubble pressure to drop rapidly. As the events are cleared of water, the bubble pressure returns rapidly to near the drywell pressure. This one to one and a half cycle bubble pressure oscillation, caused by the vent clearing process, could be responsible for the initiation of the download oscillations if the test facility is sufficiently flexible.

3.2.4 Air Bubbles

Air bubbles formed on submerged test facility surfaces and/or suspended in the torus water were considered as a possible source of download oscillations. Submerged air bubbles are a potential source of download oscillations because the compressible air bubbles and the water mass form a spring/mass system which can oscillate in response to the download force transient.

The source of air bubbles could be the air dissolved in the water entering the torus and/or air bubbles trapped on the test facility surfaces as the torus is being partially filled with water.

3.2.4.1 Dissolved Air

At the initial test static pressure of the system, 3.68 psia, the dissolved oxygen content of normal tap water is at supersaturation levels. Air bubbles formed will rise to the surface, become entrapped on submerged test facility surfaces, and/or remain suspended in the water.

3.2.4.2 Surface Air Bubbles

As water is being introduced into the torus it displaces the air which is already there. It is likely that as the water level in the torus rises a certain portion of the air being displaced will become trapped on the submerged test facility surfaces. As the torus is evacuated these trapped bubbles would expand.

695 273

4. PROGRAM DESCRIPTION

This section describes the Download Oscillation Evaluation Test Program conducted under Task 5.5.2 and identifies the parameters which were evaluated.

4.1 DOWNLOAD OSCILLATION EVALUATION TEST PROGRAM DESCRIPTION

The Test Program consisted of two test series described as follows.

4.1.1 Series 1

A total of 26 test runs were made in January through April of 1977 in the 1/4 scale test facility under Task 5.5.2, Series 1: Facility Sensitivity Tests. The Series 1 tests were conducted to determine the effects of vertical and lateral test facility stiffness. In addition, instrumentation (pressure transducers) was added to the test facility in order to measure bubble pressures. This was done to further the understanding of the hydrodynamics of pool swell. In this series all tests, except Test 3, were at zero drywell/wetwell initial ΔP using the large orifice.* Test 3 was run at full ΔP (12" of water). Table 4-1 presents the test matrix for the Task 5.5.2, Series 1 test program.

4.1.2 Series 2

A total of 12 test runs were made in August and September of 1977, in the 1/4 Scale Test Facility under Task 5.5.2, Series 2: Facility Fluid/Structure Interaction. The tests were run to examine the effects of fluid/structure interaction, air bubbles either suspended in the pool or on submerged facility surfaces, and water surface tension on the vent clearing mechanism. All tests were at zero initial drywell/wetwell ΔP. Table 4-2 presents the test matrix for the task 5.5.2, Series 2 test program.

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*Large drywell flow orifice from Task 5.5.1 Scaling Law Tests (Reference 1).

Table 4-1

TEST CONDITIONS FOR TASK 5.5.2, SERIES 1
(Large Orifice all Cases)

Test No.	Valve	ΔP	Vertical Stiffness	Window Stiffness	Month	Day	Year
1	Double Disc	0	Original	Original	1	21	77
2	Double Disc	0	Original	Original	1	25	77
3	Double Disc	12"*	Original	Original	1	26	77
4	Double Disc	0	Original	Original	2	4	77
5	Fast Butterfly	0	Original	Original	2	7	77
6	Fast Butterfly	0	Spherical Load Cell Button Inserted	Original	2	10	77
7	Fast Butterfly	0	Spherical Load Cell Button Relapped	Original	2	11	77
8	Fast Butterfly	0	Button Relapped, Shim Stock Added	Original	2	18	77
9	Fast Butterfly	0	Dummy Load Cell	Original	2	22	77
10	Fast Butterfly	0	Torus Load Cell Reinstalled (Same as Test 8)	Original	2	23	77
11	Fast Butterfly	0	Same as Test 8	Original	2	23	77
12	Fast	0	Same as Test 8	One Brace Inserted Between Front and Rear Windows, 10" Below Centerline	2	25	77
13	Fast Butterfly	0	Same as Test 8	Same as Test 12	3	2	77

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*Full ΔP for scaled 4 ft submergence

Table 4-1 (Continued)

Test No.	Valve	ΔP	Vertical Stiffness	Window Stiffness	Month	Day	Year
14	Fast Butterfly	0	Variable Stiffness Beam Added with Rollers 75 3/4" Apart	Same as Test 12	3	4	77
15	Fast Butterfly	0	Same as Test 14	Same as Test 12	3	7	77
16	Fast Butterfly	0	Same as Test 14	Original (Brace Removed)	3	16	77
17	Fast Butterfly	0	Same as Test 14	Original	3	15	77
18	Fast Butterfly	0	Same as Test 14	Original	3	15	77
19	Fast Butterfly	(Window off, transient fL/D test)			3	21	77
20	Fast Butterfly	(Window off, transient fL/D test)			3	22	77
21	Fast Butterfly	0	Same as Test 14	Original	3	31	77
22	Fast Butterfly	0	Same as Test 14	Original	4	14	77
23	Fast Butterfly	0	Same as Test 14	Original	4	14	77
24	Double Disc	0	Same as Test 14	Original	4	7	77
25	Double Disc	0	Same as Test 14	Original	4	8	77
26	Double Disc	0	Same as Test 14	Original	4	8	77

Table 4-2

TEST CONDITIONS FOR MARK I, 1/4 SCALE TESTS TASK 5.5.2, SERIES 2

Test No.	Load Cell Button	Window/Frame Bracing	Pool Water Deaerated	Surfactant Added to Pool Water	Photographic Record	Test Date
1	Lapped Spherical	No	Yes	No	Downcomer Close-Up	8/20/77
2	Flat	No	Yes	No	↓	8/31/77
3	Flat	No	Yes	No	↓	9/2/77
4	Flat	No	Yes	No	↓	9/2/77
5	Flat	Yes (10 struts)	No	No	(None)	9/8/77
6	Flat	Yes (10 struts)	No	No	Downcomer Close-Up	9/9/77
7	Lapped Spherical	Yes (10 struts)	No	No	↓	9/9/77
8	Flat	Yes (10 struts)	No	Entire pool	↓	9/13/77
9	Flat	Yes (10 struts)	No	Entire pool	↓	9/14/77
10	Flat	Yes (10 struts)	No	Downcomer only	↓	9/15/77
11	Flat	Yes (10 struts)	No	Downcomer only	↓	9/16/77
12	Flat	No	No	Entire pool	Downcomer Close-Up and Overall Facility	9/20/77

Notes: 1. Surfactant concentration used is 1 part to 200 parts water, except in Test 11 when concentration increased to 1 part to 100 parts water.

2. LOCAM camera speed is 500 frames per second. A Bolex camera at 64 frames per second was used for overall view of Test 12.

4.2 PARAMETERS EVALUATED

The QSTF Tests evaluated the following parameters identified in Section 3.0 as potential causes of download oscillation.

- Structural Stiffness
- Acoustic Effects
- Vent Clearing Hydrodynamic Effects
- Air Bubbles

This section describes modifications to the test facility, test procedures and instrumentation which were used to determine the effects of the above parameters on the magnitude of the download oscillations. Descriptions of the test facility and the test instrumentation are given in Appendices A and B, respectively.

4.2.1 Structural Stiffness

4.2.1.1 Lateral Stiffness (Window/Frame Assemblies)

The QSTF has two large plexiglass windows which are built into the ends of the test facility as shown in Figure 4-1. The window/frame assemblies are more flexible than the remainder of the structure. To determine if the structural flexibility introduced by the windows contributed significantly to the occurrence of download oscillations, it was necessary to greatly stiffen the window assemblies. The test results using the stiffened window/frame assemblies could then be compared with the results of prior tests to determine if the magnitudes of the download oscillations were significantly reduced.

Alternative means of stiffening the windows were considered including both internal and external devices. Internal struts were selected because of their ability to achieve a relatively high degree of stiffness with minimum facility impact in terms of added weight and reduced visibility of the phenomena. When

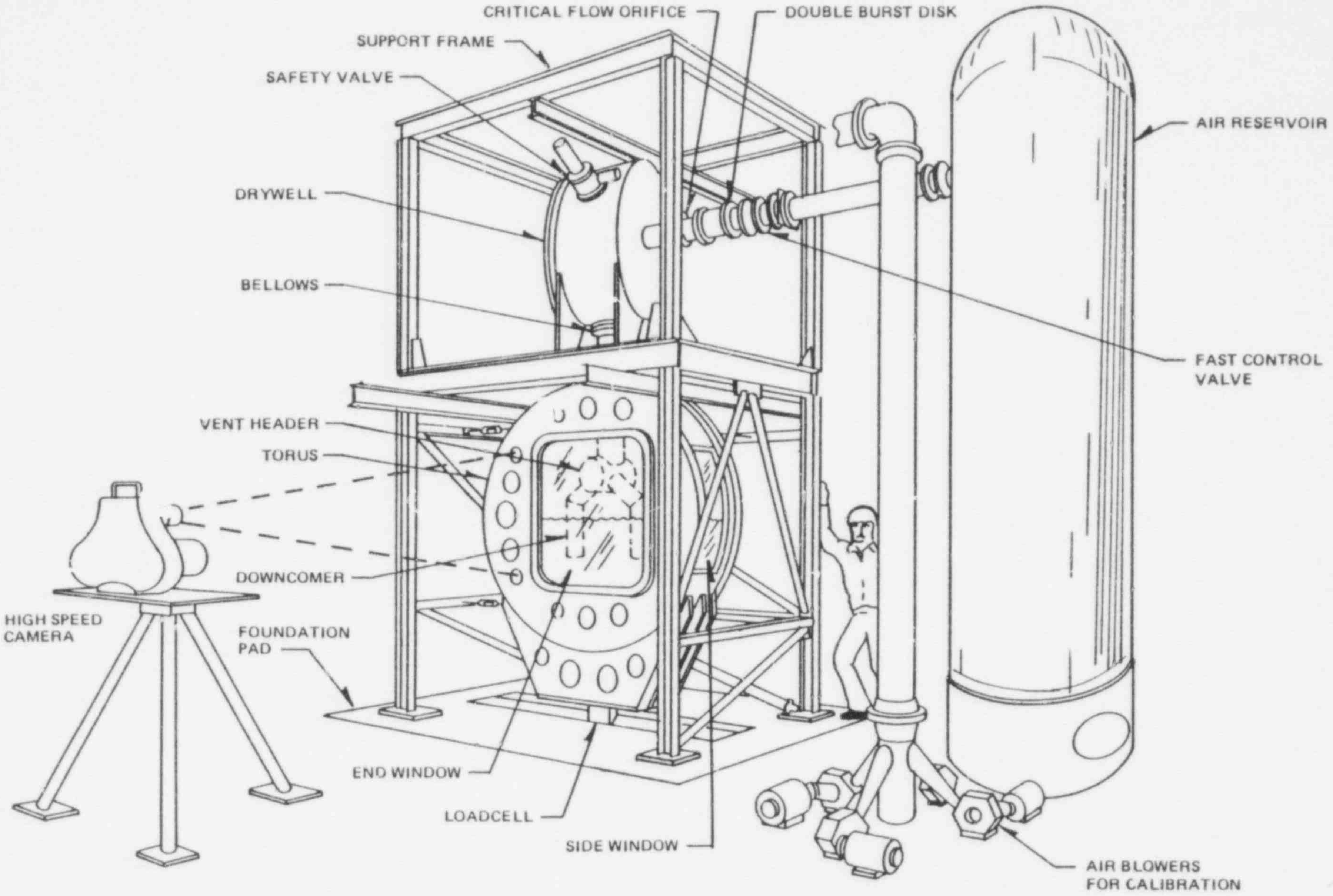

Figure 4-1. Mark I BWR Containment Pool Swell 1/4 Scale Test Facility - Perspective

693 279

the facility is evacuated to the initial test pressure of 3.68 psia, the struts become loaded and remain loaded until the internal pressure is raised back to near atmospheric.

The strut design selected is shown in Figure 4-2. Detailed 3-D finite element calculations were performed to determine the strut arrangement that would produce window frame natural frequencies far above the observed frequency (∿50 Hz) of the download oscillations. The first and second mode window/frame natural frequencies for various numbers of lateral struts, derived from the analysis, are given in Table 4-3. The ten strut arrangement shown graphically in Figure 4-3 and in a photograph in Figure 4-4 was selected for the investigation. A finite element static stress analysis was performed and a vibration test program was conducted in support of the analysis. Lateral stiffness was examined in Task 5.5.2, Series 1, Tests 12 through 15 and Task 5.5.2, Series 2, Tests 5 through 11 as described in Tables 4-1 and 4-2.

4.2.1.2 Vertical Stiffness

In the Task 5.5.2, Series 1 tests two modifications were made to the QSTF which affected vertical structural stiffness. They were:

- Change in the Load Cell Contact Button Design
- Addition of a Variable Stiffness Support Beam

Modification of Load Cell Contact Button Design

Figure 4-5 shows the contact point between the torus load cell and the torus structure as originally designed and as used throughout the Task 5.5.1 tests. The support button had a flat, hardened bottom surface that mated with the hemispherical top of the load cell. This was according to the load cell manufacturer's specifications to avoid potential side loads being transmitted to the load cell. Review of the design revealed that this created a potential soft spot, i.e., the curved surface would elastically indent the flat surface. A modified button was designed, fabricated and installed after Task 5.5.2,

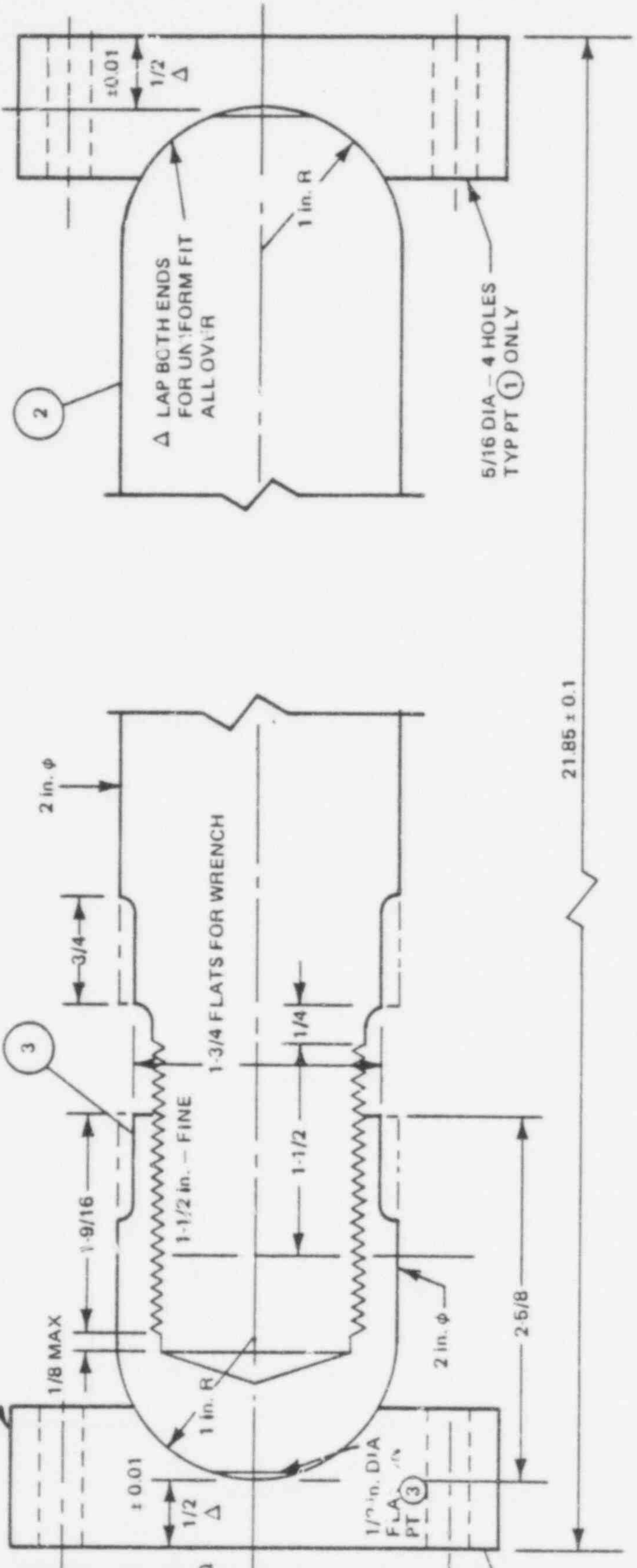

Figure 4-2. Window Strut

Table 4-3
CALCULATED WINDOW FREQUENCIES FOR VARIOUS NUMBERS OF STRUTS

Number of Struts	Frequencies 1st Mode	2nd Mode
0	37 Hz	95 Hz
1	91	107
8	93	191
10	164	209

Series 1 Test 5. That button had a concave lower surface to fit the 8 inch radius dome of the load cell. To avoid transmission of side loads, the threaded shaft of the original button was omitted so that the button and the bottom plate of the torus support structure could have relative lateral movement.

Additional alterations were made during the Task 5.5.2, Series 1 and 2 test programs as described in Tables 4-1 and 4-2.

Variable Stiffness Support Beam

To provide test data at low torus vertical frequency, the solid steel block that supports the torus load cell was removed and replaced with an I beam approximately 10 feet long resting on two rollers. The wider the separation of the two rollers, the lower the vertical natural frequency of the supported torus. The rollers of this "variable stiffness beam" were set at a spacing of 75-3/4 inches to achieve a vertical first mode natural frequency of 20 Hz.

The variable stiffness support beam was used in Task 5.5.2, Series 1, Tests 14 through 26 excepting Tests 19 and 20 as described in Table 4-1. The variable stiffness beam was not used for the Task 5.5.2, Series 2 tests.

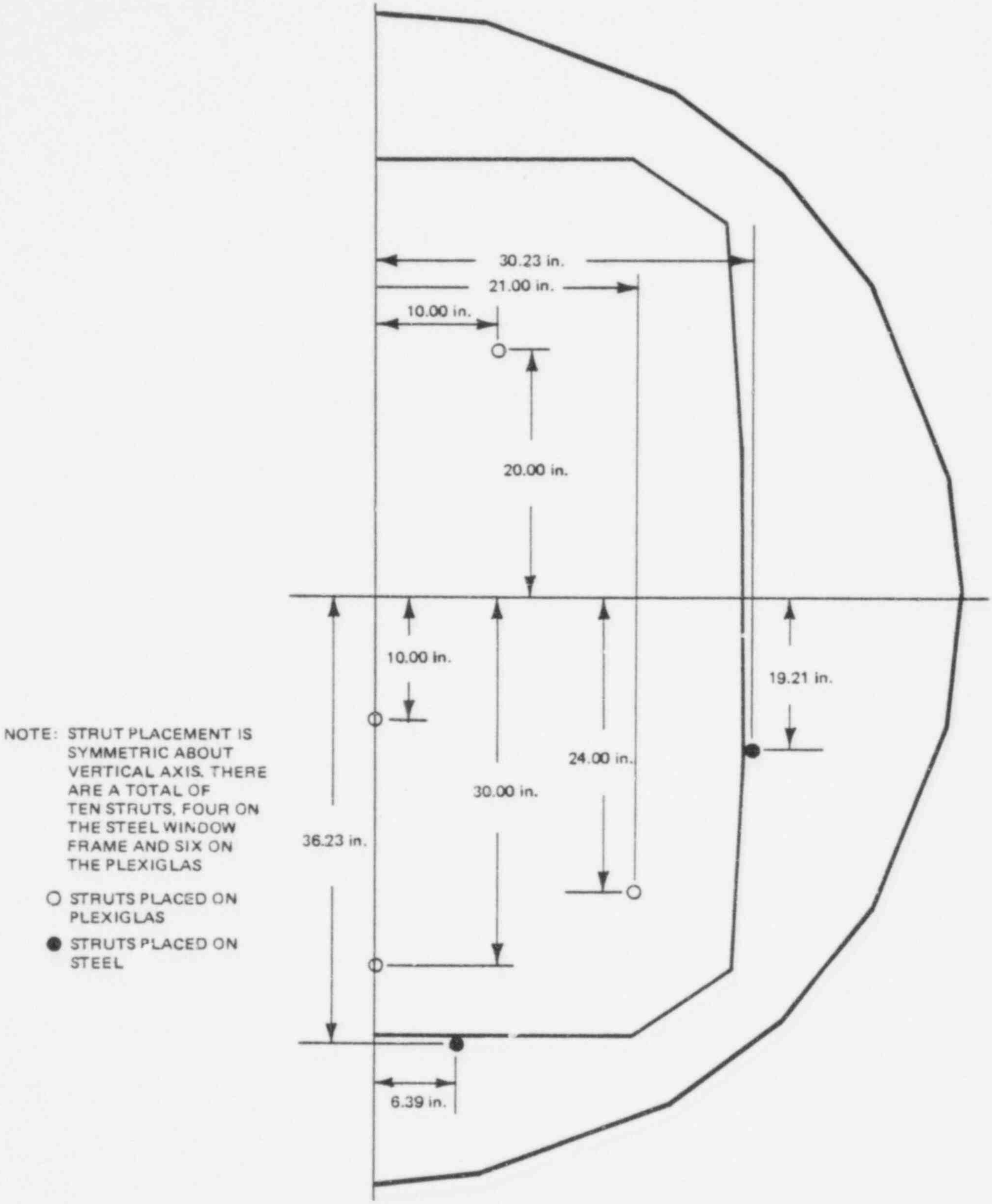

Figure 4-3. Window Strut Placement

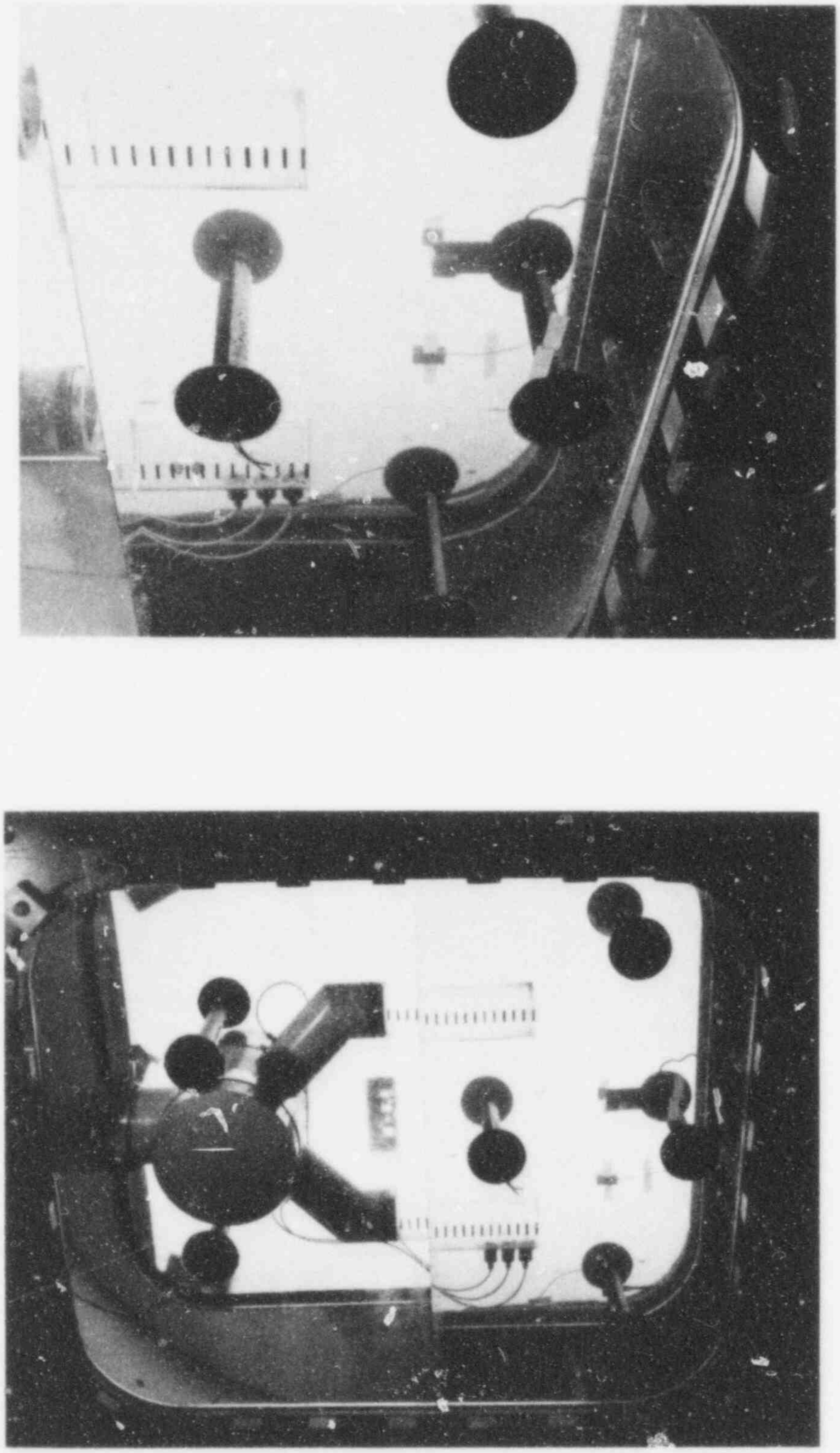

Figure 4-4. Struts Bracing Window and Frame

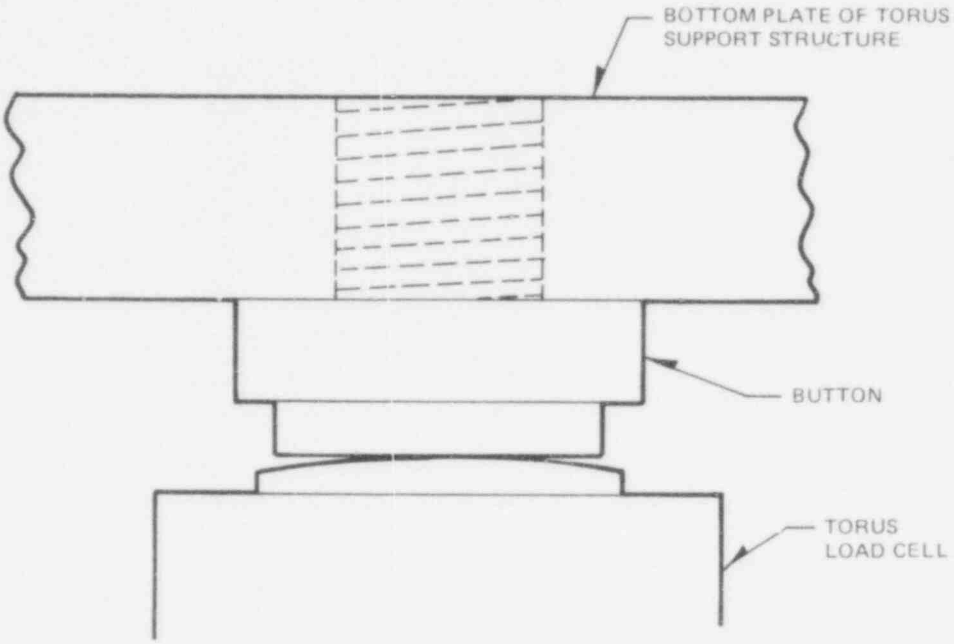

Figure 4-5. Torus Load Cell and Contact Button

Instrumentation

The following instrumentation was used specifically to measure the fluid/structure effects as they related to window/frame vibrations:

1. Pressures were measured at three locations (Instruments 9-11 in Appendix B) in the pool adjacent to the lower portion of the window.

2. Lateral accelerations of the window/frames were measured directly adjacent to the locations identified in item 1 above (Instruments 15-17 in Appendix B). The location of a fourth accelerometer used for the same purpose varied from test run to test run.

4.2.2 Acoustic Effects

To determine the effects of vent acoustics on download oscillations it was necessary to monitor the pressure histories in the downcomer and vent.

Instrumentation

The instrumentation consisted of a pressure transducer inside the vent system (shown in Figure 4-6) to measure any acoustical signals which might be generated during the transient. Additional pressure transducers described in Section 4.2.3 were placed in the downcomer. The locations of the remaining instrumentation are identified in the test facility instrumentation description given in Appendix B.

The instrumentation described above was installed prior to the first run of Task 5.5.2, Series 2 and was monitored throughout the test series on analog tape.

4.2.3 Vent Clearing Hydrodynamic Effects (Bubble Pressure Oscillations)

The phenomenon of vent clearing is described in Appendix C. To determine if vent clearing was the cause of the download oscillations it was necessary to determine the downcomer internal pressure history. If vent clearing was indeed the cause of the download oscillations then oscillations in the downcomer and vent pressure measurements could be expected.

Instrumentation

Three pressure transducers, shown in Figure 4-7, were placed in the downcomer to measure the internal pressure history of the downcomer, in addition to the vent pressure transducer discussed in Section 4.2.2.

4.2.4 Air Bubbles

Regardless of the original source of air and whether the bubbles are suspended in the water or cling to the submerged test facility surface, they can be a

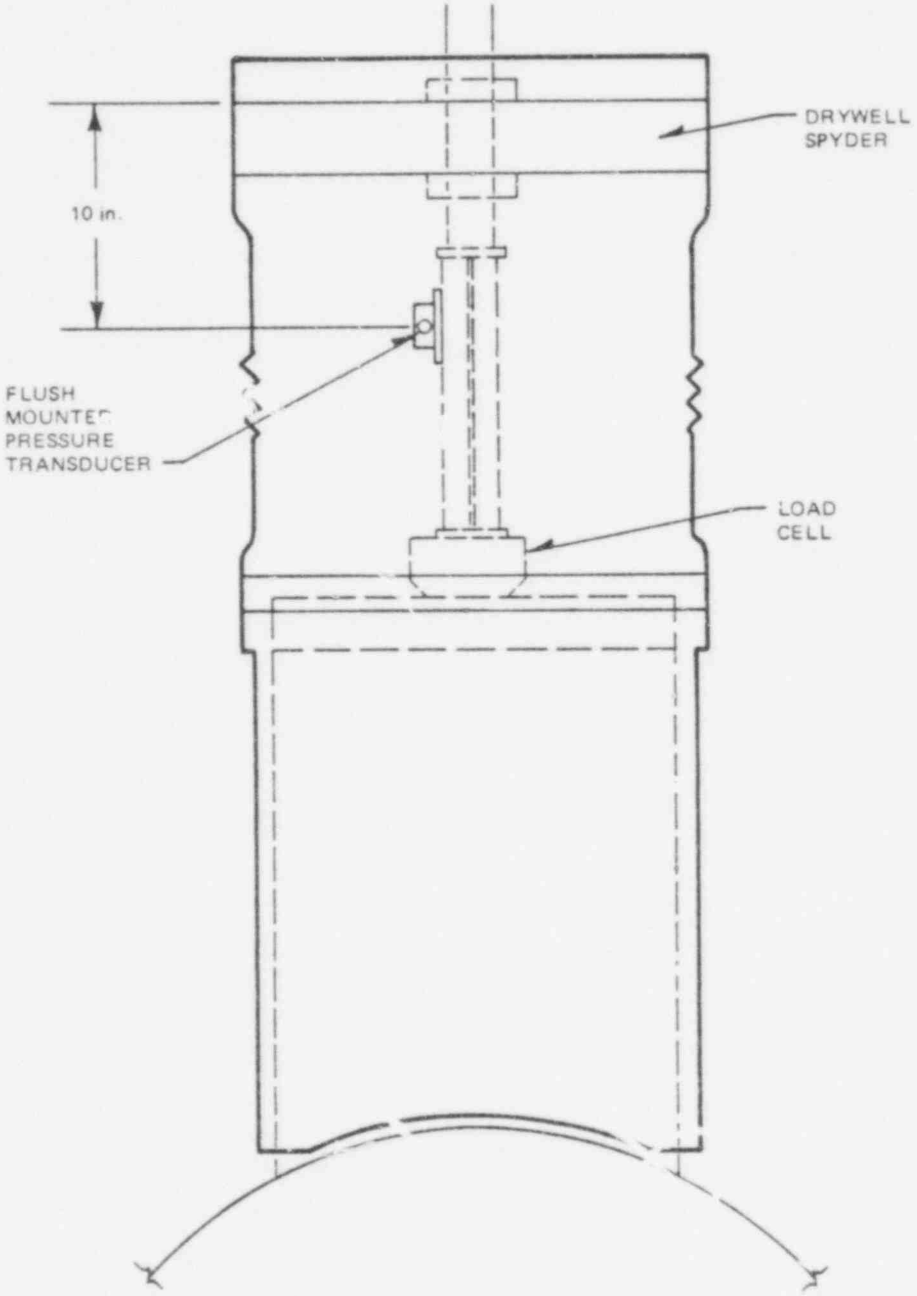

Figure 4-6. Vent Pressure Transducer

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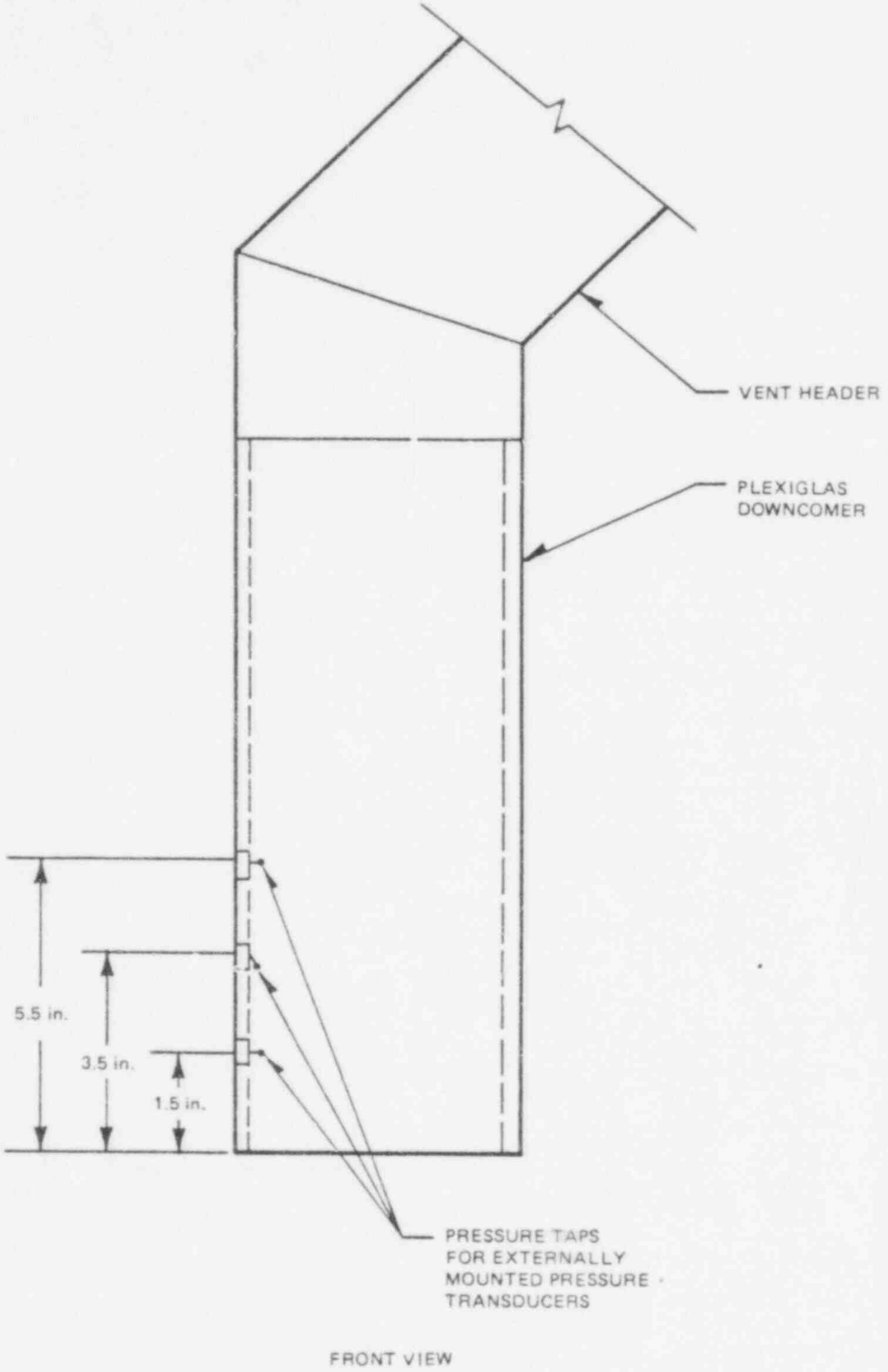

Figure 4-7. Downcomer Internal Pressure Measurements

source of download oscillation because air is compressible and, therefore, contributes flexibility to the spring/mass system consisting of the bubbles and the test facility.

Two aspects of this phenomena were studied, dissolved air content and air bubbles clinging to submerged facility surfaces.

4.2.4.1 Dissolved Air

To determine the effects of dissolved air content on the download oscillations it was necessary to provide, in the test facility, a means of deaerating the water as it was introduced into the torus. This was accomplished by installing an air atomizing spray nozzle and sampling chamber as shown in Figure 4-8. The torus was evacuated and water was introduced into the torus through the nozzle. The air was released from the water as it separated into a fine mist. The air was continuously removed from the torus by the vacuum pump. After filling under vacuum, samples of water were drawn from the torus and measured for oxygen content. The effectiveness of the spray nozzle system in deaerating the entering water is shown in Table 4-4 where the dissolved oxygen content (normally about 7 ppm at ambient pressure) was actually reduced to below the equilibrium level for the 3.68 psia (1/4 atmosphere) test pressure. Figure 4-9 presents two photographs of the facility window showing the effects of deaeration. The numbered scale is in inches. No surface bubbles are visible with deaerated water. Task 5.5.2, Series 2 test runs 1 through 4 were conducted with deaerated water.

Instrumentation

The only instrument added was the water sampling chamber and its auxiliary equipment.

4.2.4.2 Surface Air Bubbles

To determine the effects on download oscillation of the air bubbles formed on the submerged test facility surfaces as water is being introduced into the

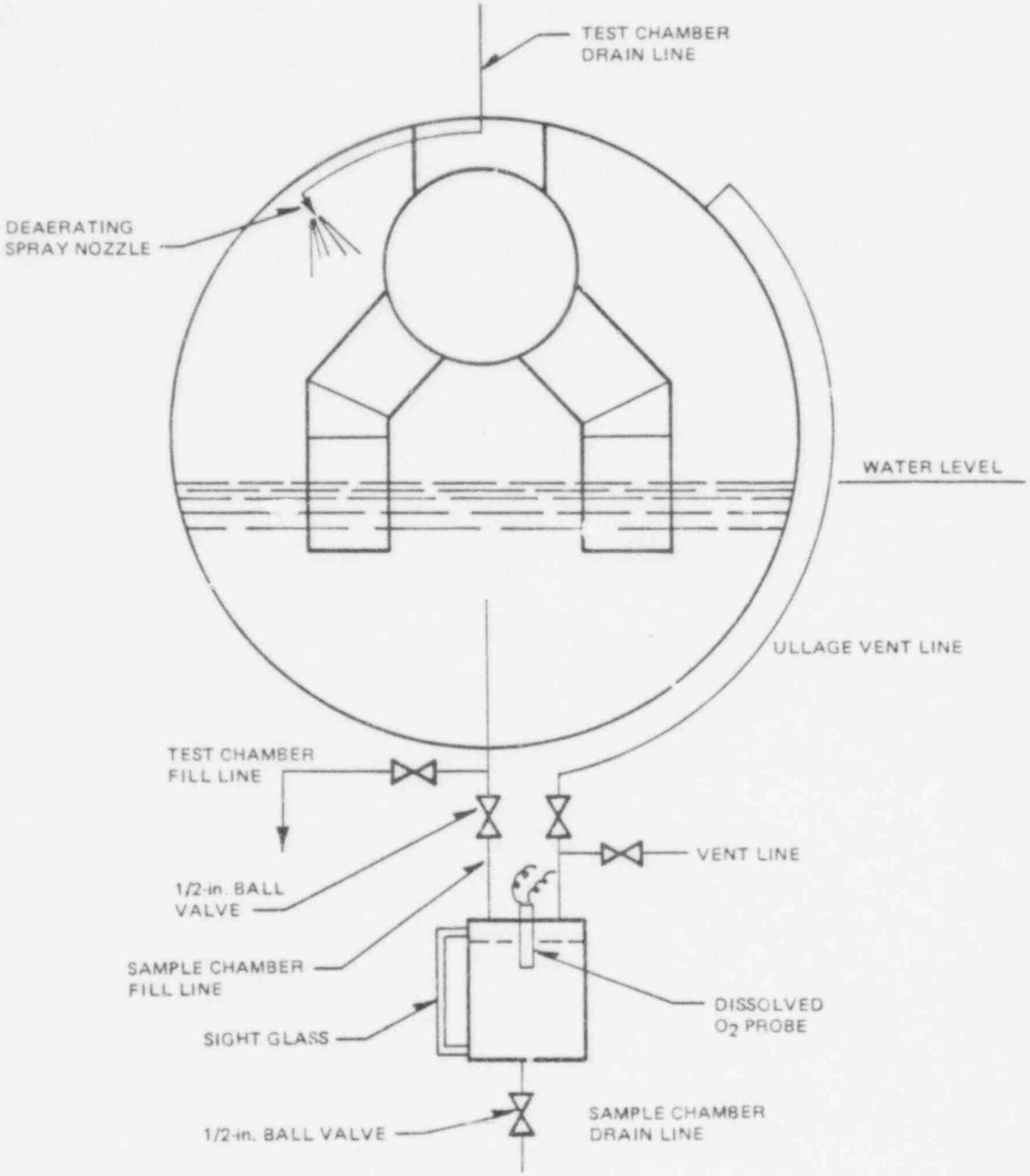

Figure 4-8. Deaeration System

Table 4-4

DEAERATED WATER OXYGEN CONTENT MEASUREMENTS
TASK 5.5.2, SERIES 2

Test No.	Dissolved Oxygen* (ppm) Pre-Test	Post-Test
1	1.0	3.0
2	1.5	2.9
3	1.5	3.2
4	1.5	3.2

---

*Normally about 7 ppm at ambient pressure.

torus and/or from air released from the water, it was necessary to find a means of removing these air bubbles from the test facility. This was accomplished by adding a surfactant (Kodak Photo Flow) to the water entering the torus in the concentration of one part surfactant to 200 parts of water, as recommended by the manufacturer. Addition of surfactant was observed to remove visible air bubbles, from the submerged facility surfaces (see Figure 4-9). The effectiveness of the surfactant in reducing the surface tension of water is given in Table 4-5. Since the surfactant achieves a minimum surface tension of about 32 dynes/cm at concentrations several times weaker than the 200:1 concentration used, uniform surface tension throughout the pool can be assumed. Surfactant was used in Task 5.5.2, Series 2, Tests 8 through 12 as described in Table 4-6.

Instrumentation

No additional instrumentation was needed for this phase of the investigation.

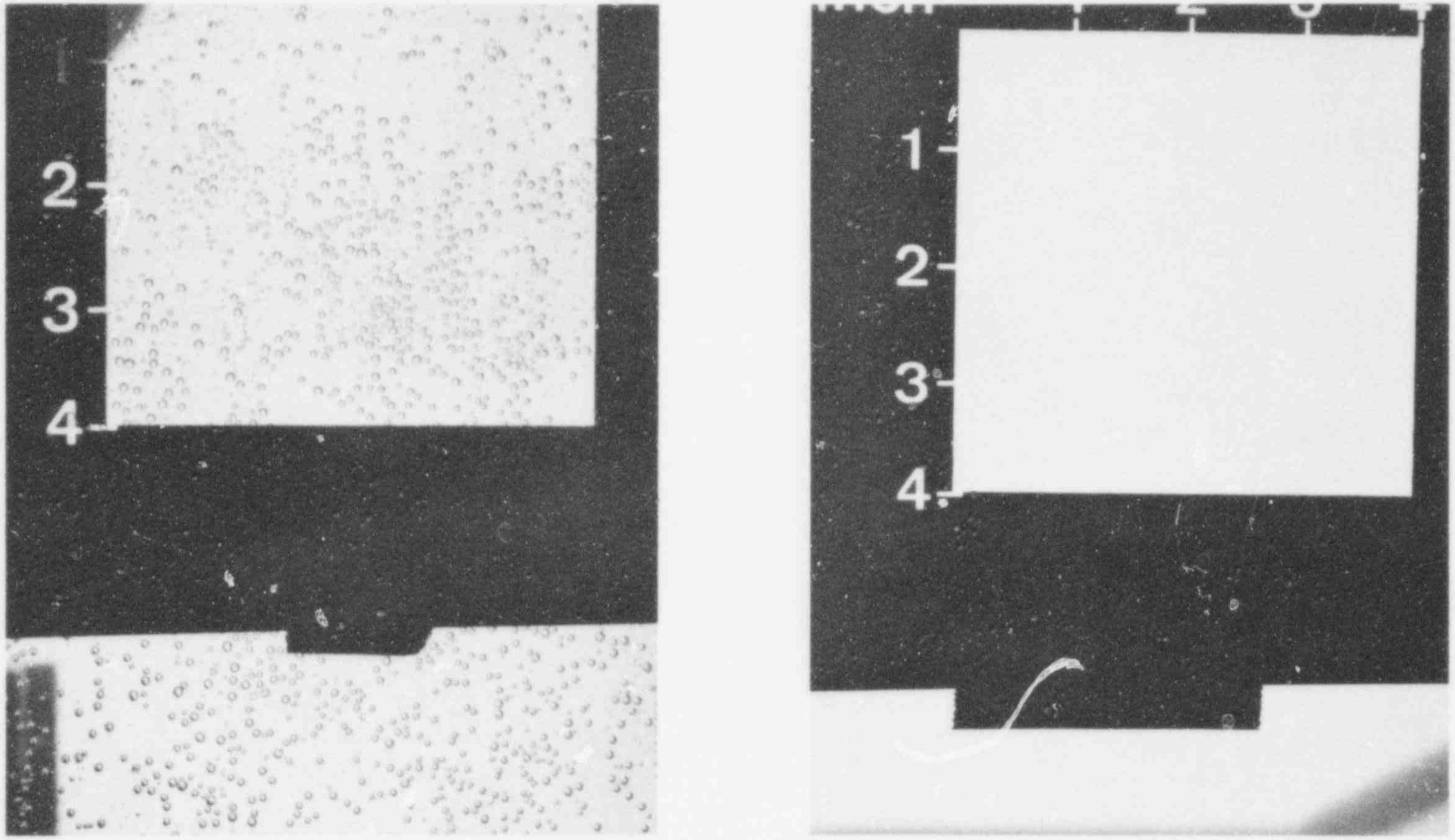

Figure 4-9. Surface Air Bubbles on End Window-With Tap Water Standard Method (left), with Deaeration During Filling (right)

693 292

Table 4-5

SURFACTANT CONCENTRATION VS. MEASURED SURFACE TENSION

Surfactant Concentration	Capillary Rise (inches)	Surface Tension (dynes/cm)
100% Surfactant	0.35	30.8
1 part to 40 parts water	0.32	28.2
1 part to 80 parts water	0.37	32.6
1 part to 160 parts water	0.38	33.5
1 part to 320 parts water	0.35	30.8
1 part to 640 parts water	0.42	37.0
1 part to 1280 parts water	0.38	33.5
100% Pure Water	0.84	72

Note: Surfactant is Kodak Photo Flow 200.

Table 4-6

SURFACE TENSION MEASUREMENTS FOR TESTS WITH SURFACTANT TASK 5.5.2, SERIES 2

Test No.	Surface Tension (dynes/cm) Pre-Test	Surface Tension (dynes/cm) Post-Test
8	30.6	
9	30.6	
10	68.5	
11	70	35
12	34	

Notes:
1. Same pool water used in Test 9 as in Test 8.
2. Samples for surface tension measurement taken from pool (surfactant added only in downcomers for Tests 10 and 11)
3. Surface tension of pool water is nominally 72 dynes/cm with no surfactant

5. TEST RESULTS

In this section test data, primarily from the two Task 5.5.2 Download Oscillation Evaluation test series, are compared to determine the degree to which each of the parameters considered contributes to the download oscillations.

All downloads presented in this section are derived from spatially integrating the pressure distribution (∫PdA) inside the torus with a correction added for the inertial effects of the pool mass.

5.1 STRUCTURAL STIFFNESS

5.1.1 Lateral Stiffness (Window/Frame Assemblies)

Figure 5-1 compares the window/frame lateral acceleration between Task 5.5.2, Series 2, Test 3 without struts and Test 5 with struts bracing the window and frame. Location of the struts and accelerometers are shown schematically in the figure. As can be seen, the struts effectively remove the lateral vibrations of the window/frame assemblies.

The effect of window stiffness on net torus forces is presented in Figure 5-2. Task 5.5.2, Series 2 Test 5 with ten struts bracing the windows is compared with Test 8 with no struts and Test 12 with one strut the latter two from Task 5.5.2, Series 1. In all of these three tests, the vertical natural frequency was about 57 Hz and fresh pool water was used, i.e., there were no previous blowdowns. (Repeated blowdowns with the same water have been shown to remove surface air bubbles and, therefore, reduce download oscillations. See Section 5.4)

Peak Download

Stiffening the windows did not appear to have a major effect on the amplitude of the first peak download as shown in Figure 5-2 and in Table 5-1.

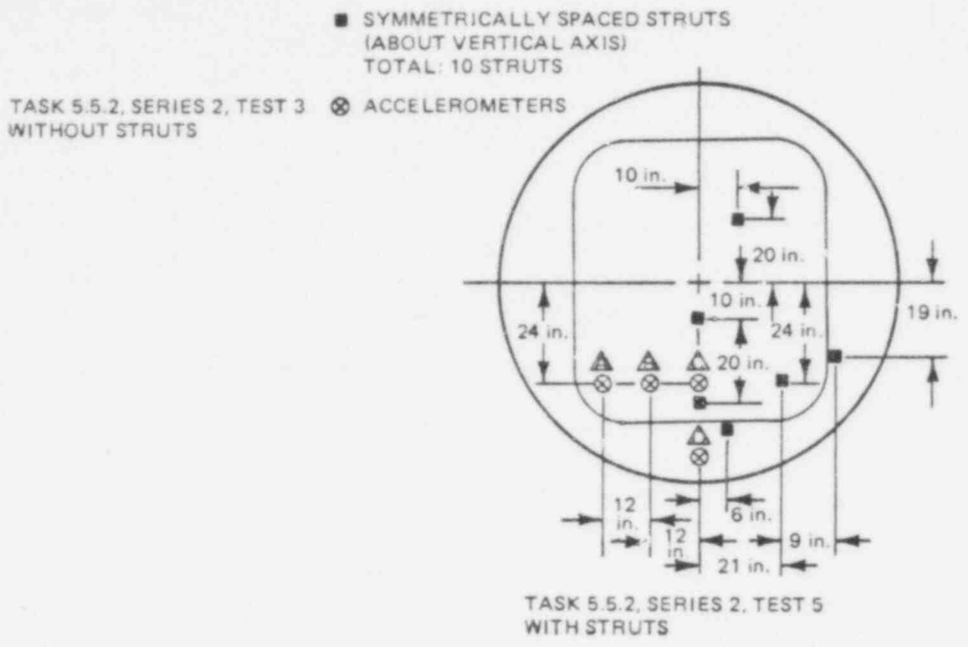

Figure 5-1. Effect of Window Stiffness on Torus Window/Frame Acceleration

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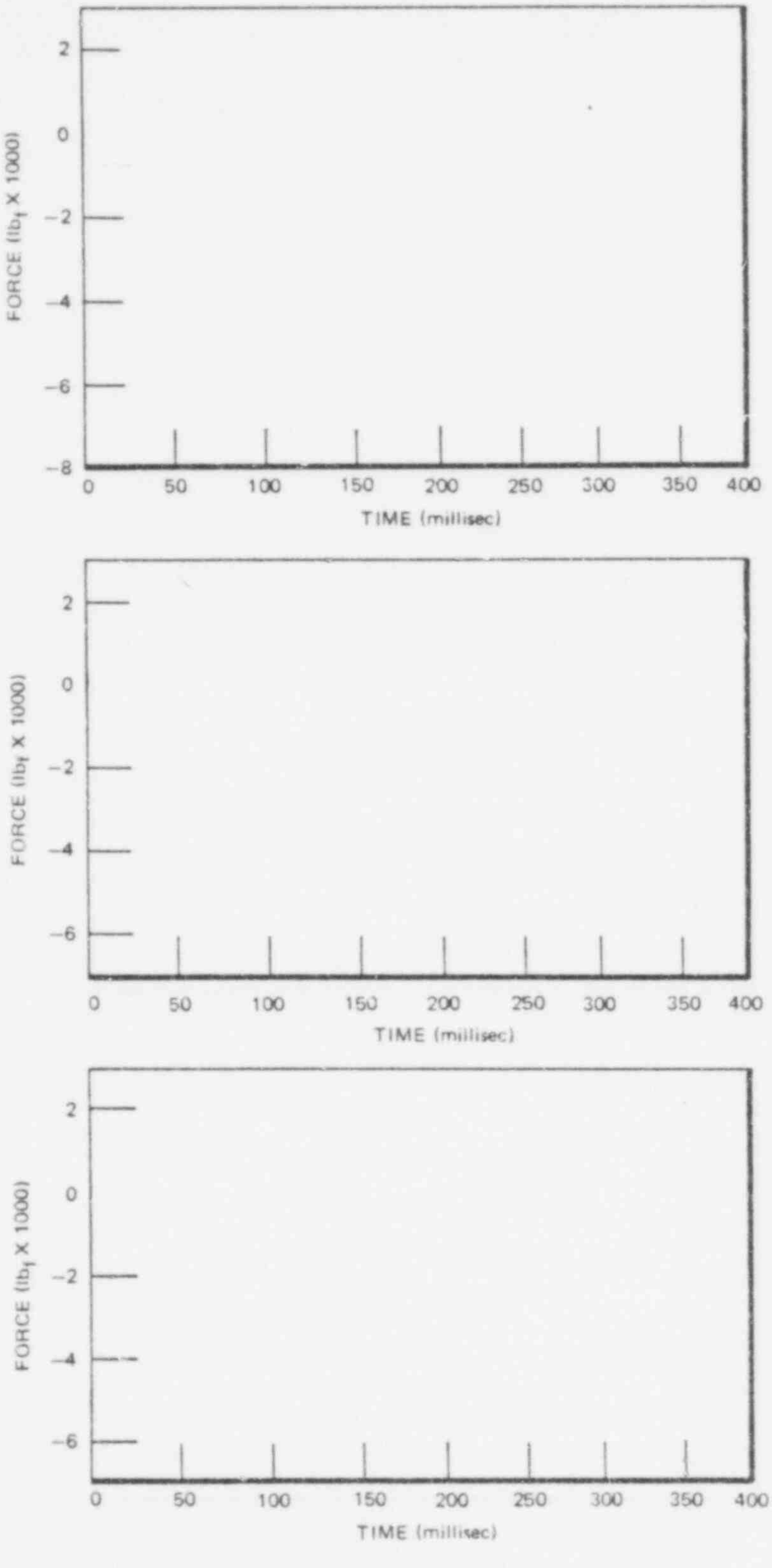

Figure 5-2. Effect of Window Stiffness on Net Torus Force History

Table 5-1
EFFECT OF WINDOW/FRAME STIFFNESS ON PEAK DOWNLOAD

Window/Frame Stiffness	Test Run	Peak Download ~lbf
No Lateral Support Added (Reference Case)	Task 5.5.2 Series 1, Test 8	
One Lateral Strut Added	Task 5.5.2 Series 1, Test 12	
Ten Lateral Struts Added	Task 5.5.2 Series 2, Test 5	

Download Oscillations

Figure 5-3 illustrates a method for quantitatively comparing the severity of download oscillations using the peak-to peak amplitudes and the time of download peaks relative to the first peak. This method was used to compare the oscillations of Figure 5-2, as presented in Table 5-2.

Stiffening the windows/frames greatly dampens the download oscillations as shown in Table 5-2 and Figure 5-2. However, stiffening the windows only does not completely eliminate them, implying that another mechanism(s) is also responsible for causing the download oscillations. Increasing the window/frame stiffness beyond a single strut does not appear to affect the amplitude of the first oscillation but does somewhat dampen subsequent oscillations without, however, altering their period.

5.1.2 Vertical Stiffness

Torus natural vertical frequency was varied in Task 5.5.2, Series 1 testing to evalute what effects such variations have on measured loads. Three frequencies were obtained: 20, 51 and 57 Hz. See Section 4.2 1.2, for the modifications made. The 51 Hz configuration existed throughout Task 5.5.1 and in the Task 5.5.2 Series 2 Tests.

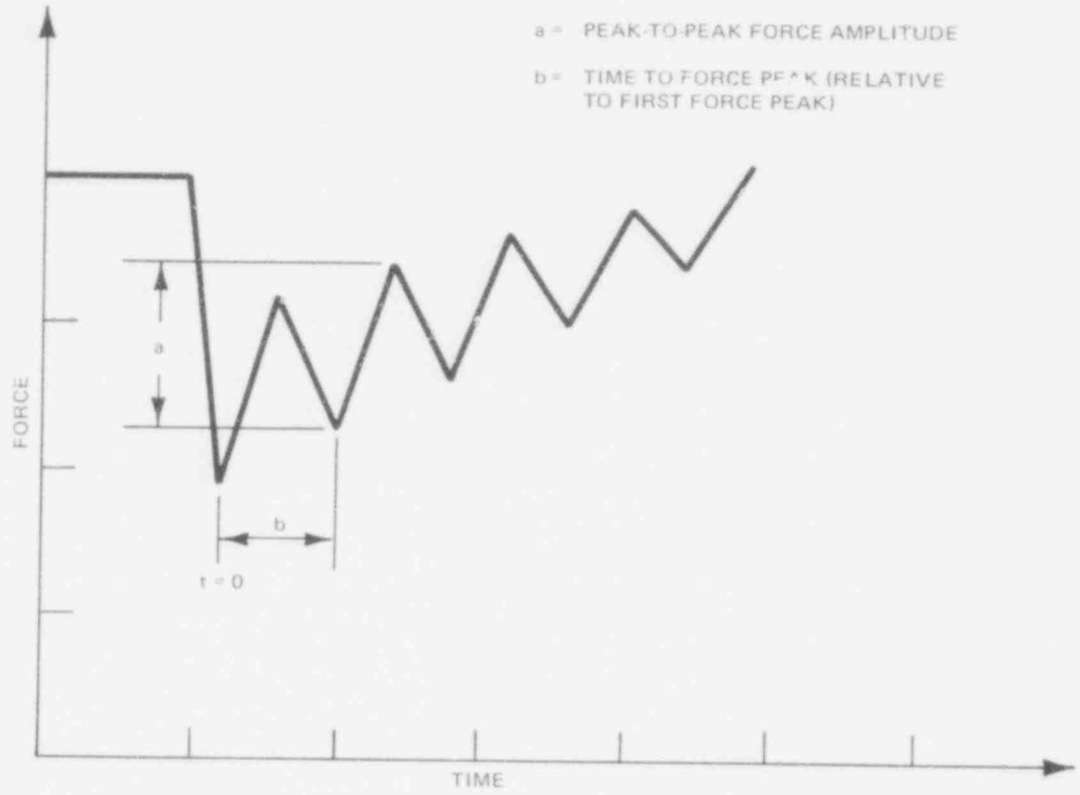

Figure 5-3. Characterization of Downforce Oscillations

693 298

Table 5-2

EFFECTS OF WINDOW/FRAME STIFFNESS ON DOWNLOAD OSCILLATIONS

		No Lateral Support Added (Reference Case) Task 5.5.2 Series 1, Test 8		One Lateral Strut Added Task 5.5.2 Series 1, Test 12			Ten Lateral Struts Added Task 5.5.2 Series 1, Test 5		
Oscillation No.	Direction	Amplitude Peak-to-Peak of Oscillation ~lbf	Time From First Peak Download ~msec	Amplitude Peak-to-Peak of Oscillation ~lbf	% Dampened From Ref. Case	Time From First Peak Download ~msec	Amplitude Peak-to-Peak of Oscillation ~lbf	% Dampened From Ref. Case	Time From First Peak Download ~msec
1st									
2nd									
3rd									
4th									
5th									
6th									
7th									
8th									

Peak Download

Changing the test facility vertical stiffness had little effect on the first peak download achieved during the transient. See Figure 5-4.

Download Oscillations

The amplitude of the download oscillations are roughly the same over the range of the tested natural vertical frequencies when the integrated pressures are corrected for water inertia. However, the oscillations appear to be somewhat more severe at 57 Hz, probably due to the fact that the second mode natural frequency of the windows (68 Hz) is being approached.

5.2 ACOUSTIC EFFECTS

If acoustic pressure waves passing through the vent system between the drywell and the downcomer exit were responsible for the downforce oscillations, these pressure oscillations would be picked up by all the vent header pressure transducers. Although the lower pressure transducer on the downcomer exhibits an oscillation (see Section 5.3) as shown in Figure 5-5, the pressure transducer in the vent pipe shows no evidence of a similar pressure oscillation. Therefore vent acoustics do not appear to be a significant cause of pool swell download oscillations.

5.3 VENT CLEARING HYDRODYNAMIC EFFECTS

The vent clearing hydrodynamics are complex and are described in detail in Appendix C. In summary, air bypasses the water slug at the downcomer walls as the slug is accelerating downward and a Taylor instability of the upper surface of the resulting central water column appears to develop. The dynamics of these phenomena as the bypass air and the unstable water column exit the downcomer result in the pressure histories for the three downcomer pressure transducers as shown in Figure 5-6. A significant pressure transient occurs near the vent exit. However, the figure shows that for all three elevations there are no sustained downcomer pressure oscillations that could be the source of sustained torus download oscillations.

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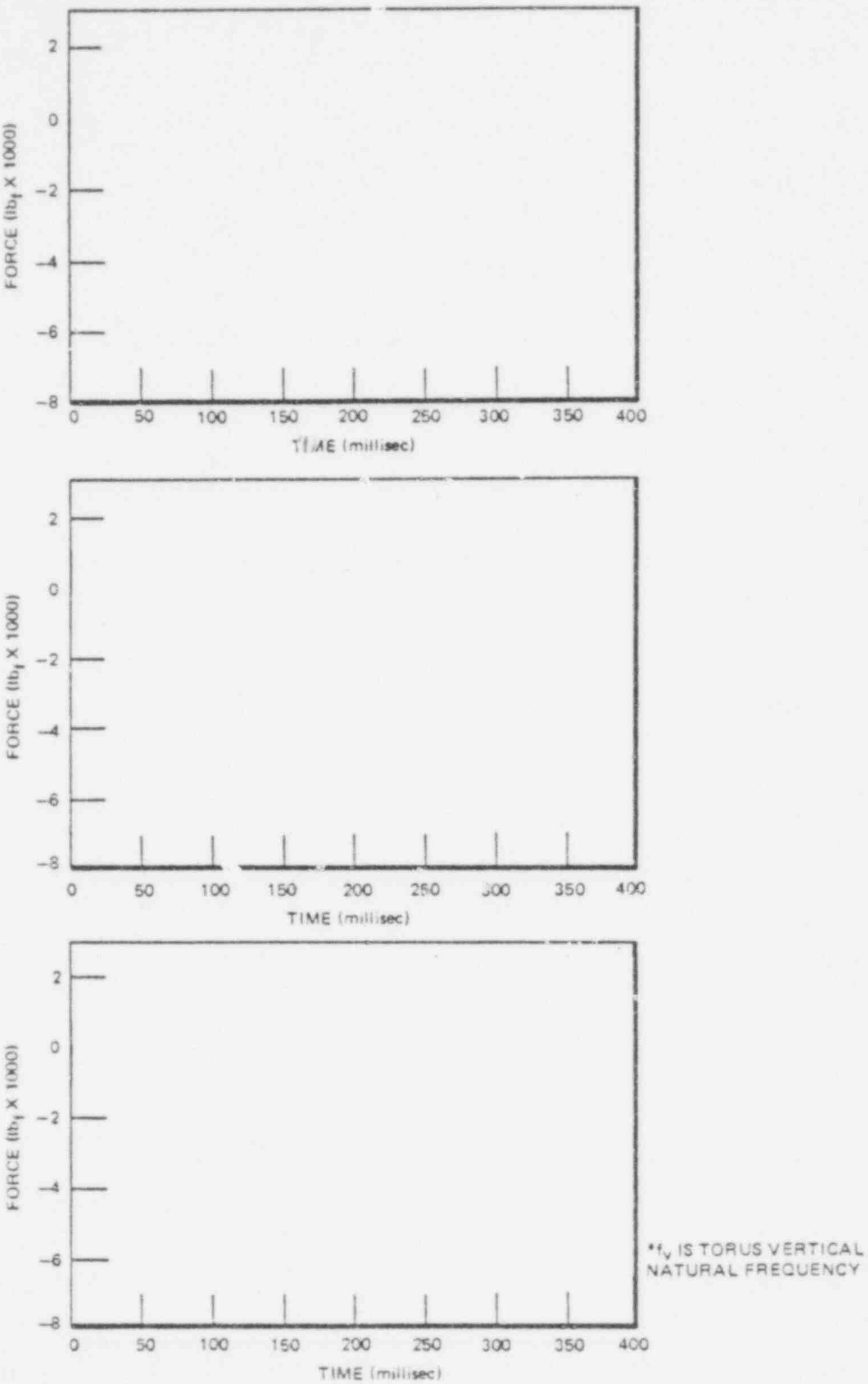

Figure 5-4. Effect of Vertical Stiffness on Torus Vertical Load History – Based on the Spatial Pressure Integral Corrected for Torus Vertical Acceleration

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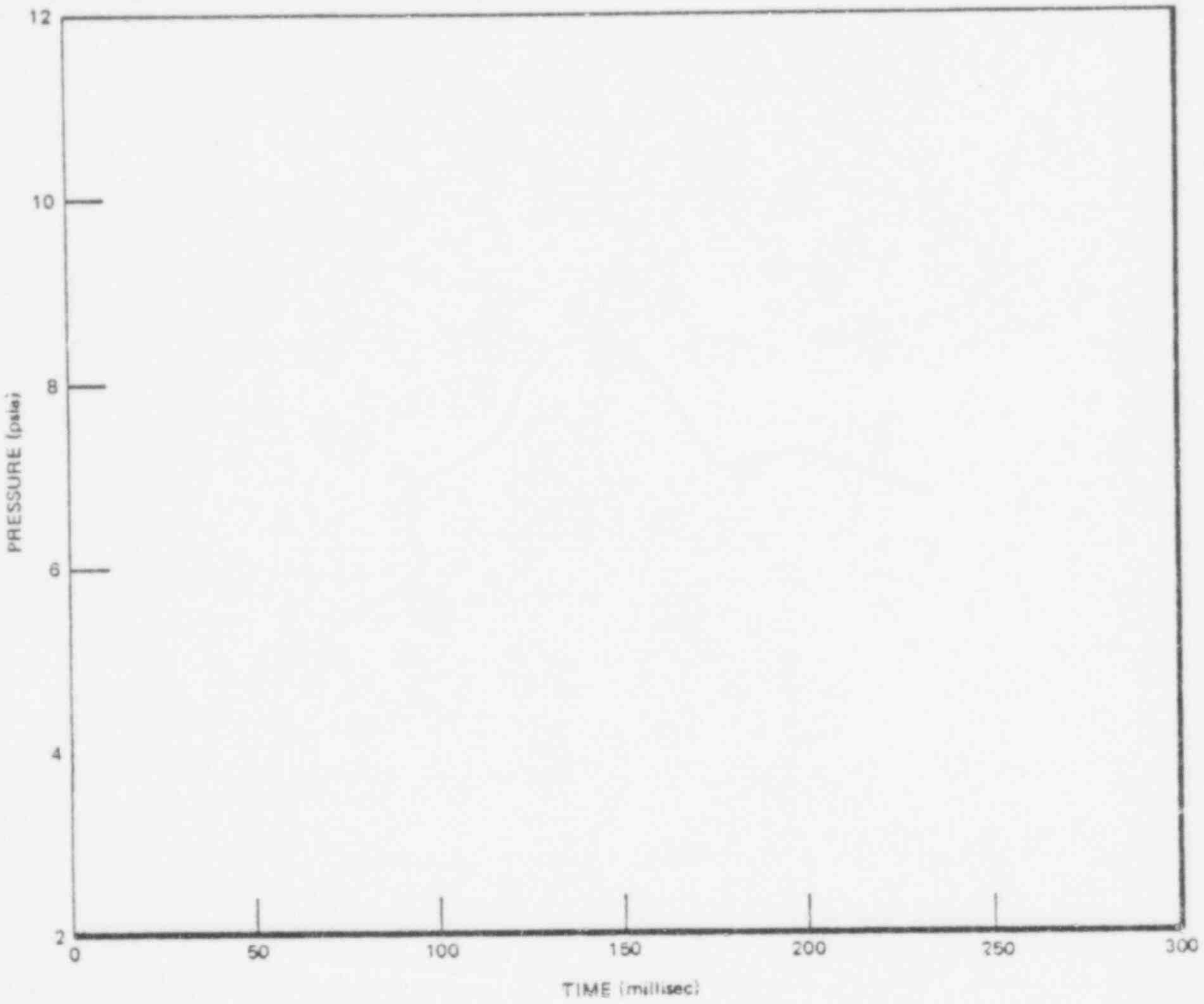

Figure 5-5. Vent and Downcomer Internal Pressures

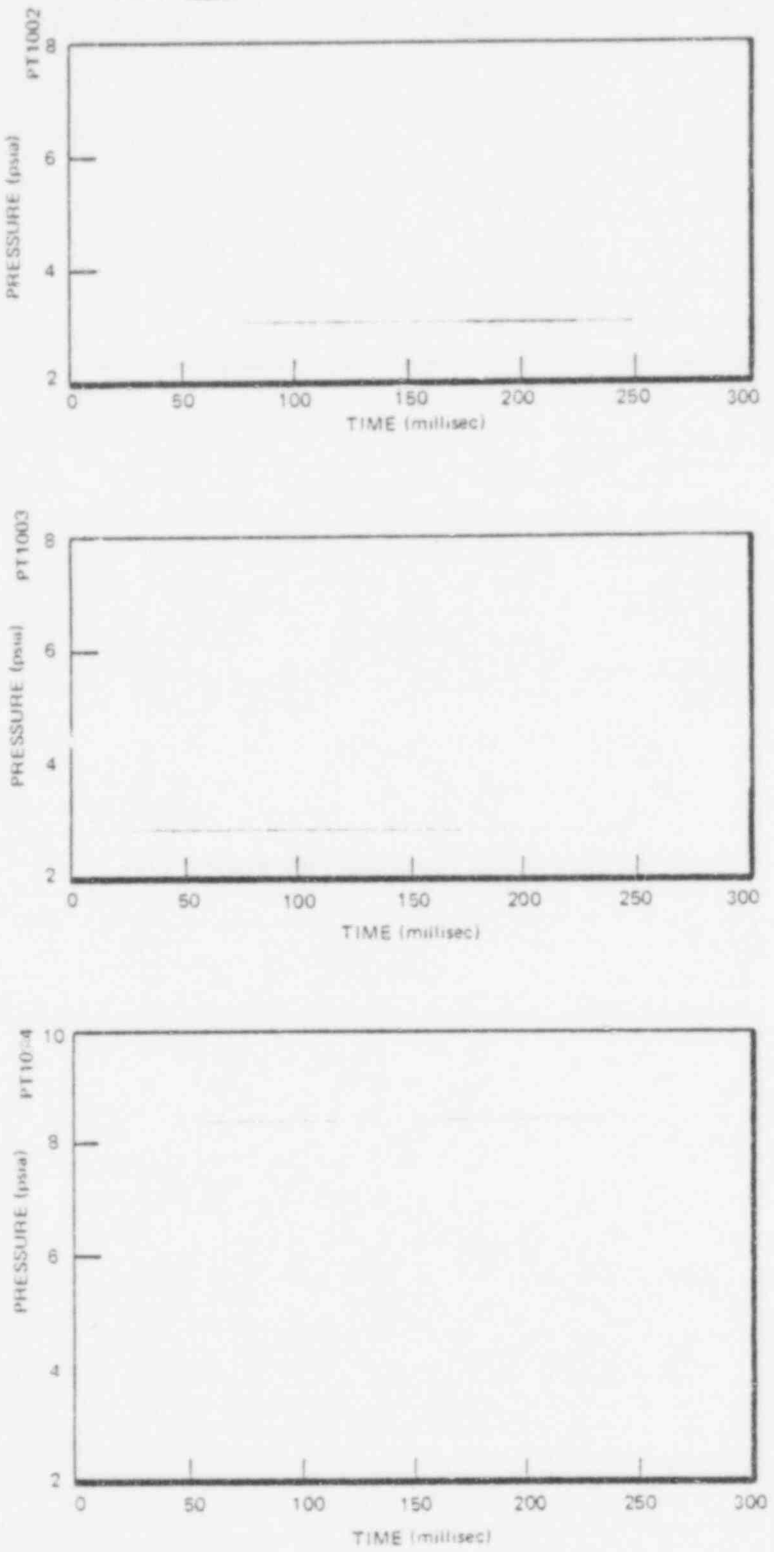

Figure 5-6. Downcomer Internal Pressures During Deaerated Pool Test
Task 5.5.2, Series 2, Test 3

693 303

Figure 5-7 compares downloads with and without surfactant added only in the downcomer water slugs. The windows are stiffened in both cases. The figure shows that the basic oscillatory nature of downloads is not significantly changed by such a change in downcomer water properties, further substantiating that the vent clearing hydrodynamic effects are not the source of sustained download oscillations.

5.4 AIR BUBBLES

The effect of air bubbles on the submerged surfaces of the test facility was investigated by removing the bubbles with three different techniques, as discussed below.

5.4.1 Repeat Blowdowns

It was observed that when the facility is prepared for a test with fresh water the windows are blanketed with air bubbles. As a blowdown occurs these air bubbles are swept off the submerged facility surfaces. The effect of this removal is shown in Figure 5-8 for a sequence of four identical tests, using the same water repeatedly. The decreasing peak-to-peak force amplitude implies that download oscillations are significantly decreased. The decreasing time interval in time to force peak shows increasing frequency, indicating an effective stiffening of the spring/mass system sustaining the oscillation.

5.4.2 Surfactant

The effects of surfactant in the pool water are shown in Figure 5-9. No lateral struts were present. As can be seen, removal of most of the air bubbles from the submerged test facility surfaces, caused by the surfactant, significantly dampens the oscillations.

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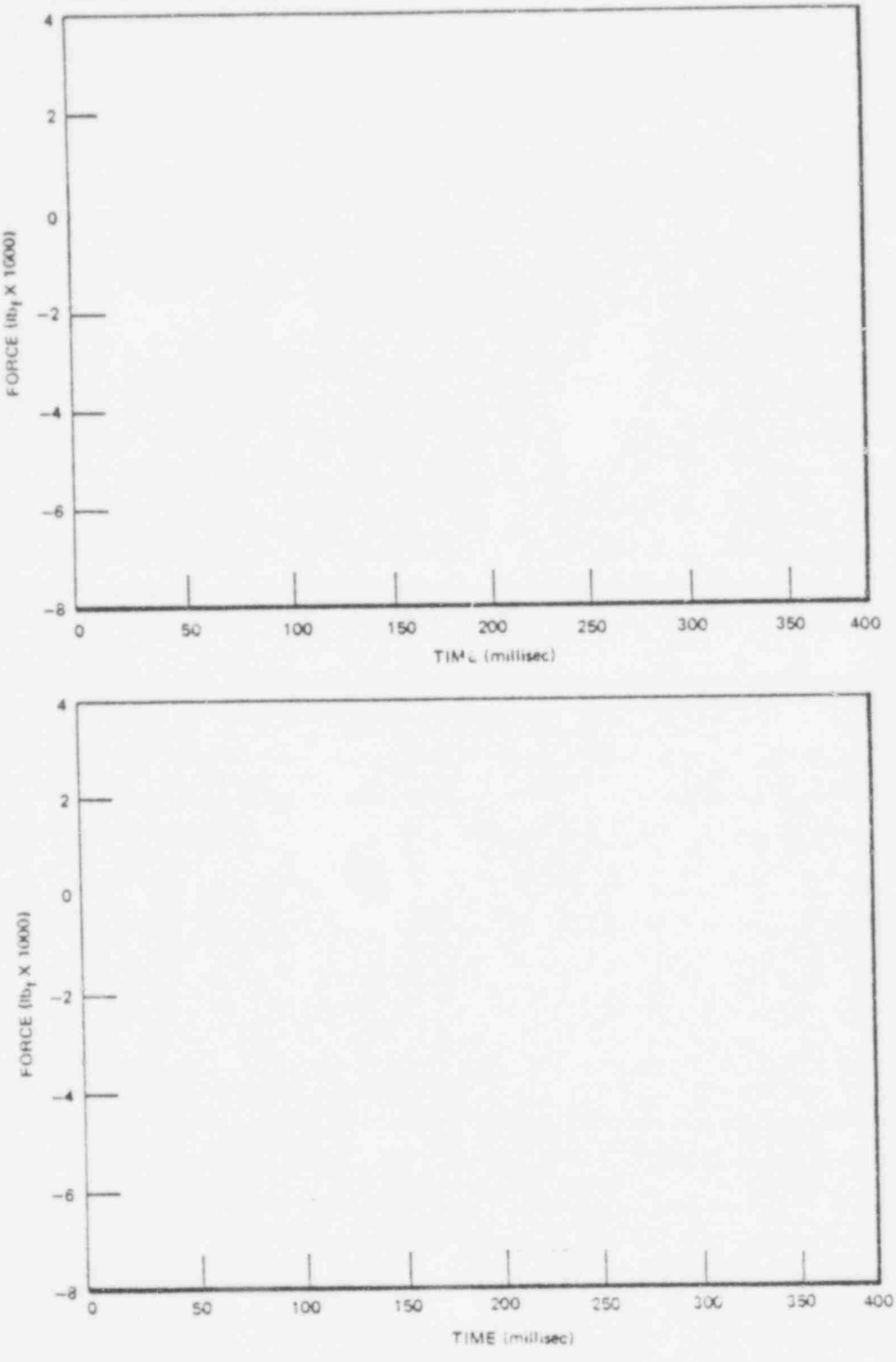


Figure 5-7. Effects of Surfactant in Downcomers Only and Stiffened Window on Net Torus Forces Pressure Integral + MA

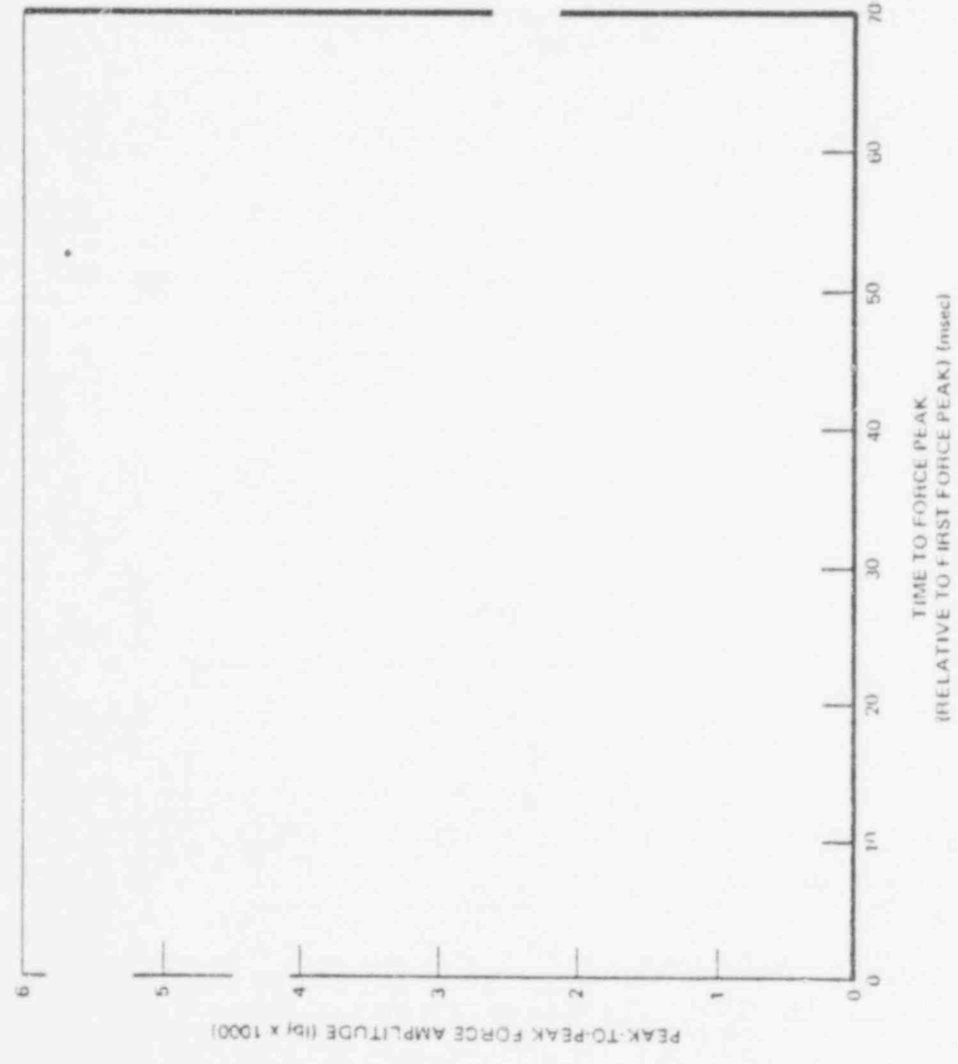
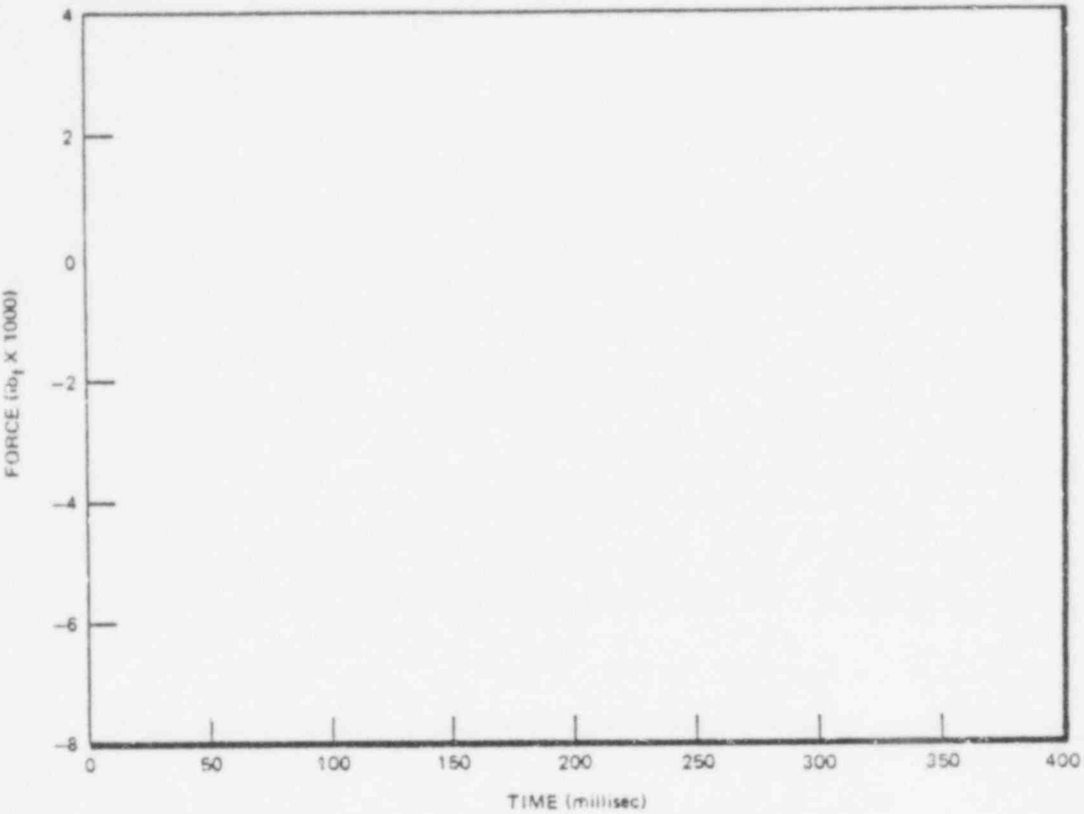


Figure 5-8. Character of Downforce Oscillations for Consecutive Blowdowns with Same Pool Water in 1/4 Scale Tests



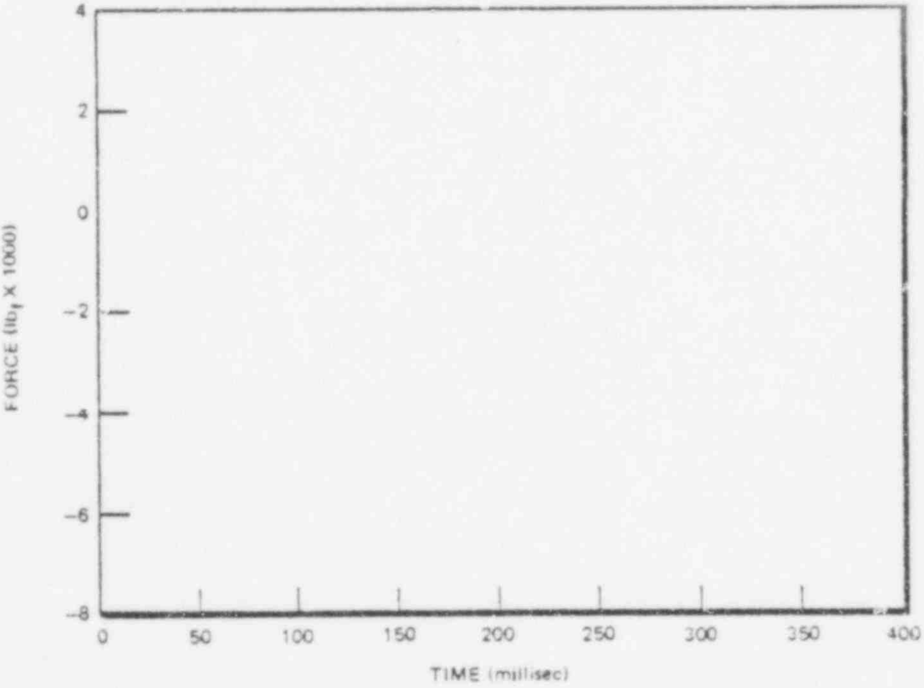


Figure 5-9. Effect of Surfactant in Pool on Net Torus Force History

693 307

5.4.3 Deaeration

Figure 5-10 shows the effect of deaeration on download oscillations compared to repeated blowdowns and to addition of surfactant. All three techniques of surface bubble removal result in similar reductions in download oscillations Deaeration appears somewhat less effective than the other two but not significantly different. This is also illustrated in Figure 5-11 where results of the three methods of surface bubble removal are compared with results of a fresh water test with surface air bubbles present.

5.4.4 Summary of Air Bubble Effects

The presence of air bubbles on the submerged facility surfaces was a significant cause of the download oscillations. However, removal of the air bubbles alone is not sufficient to eliminate the download oscillations.

5.5 COMBINED EFFECTS OF WINDOW STIFFENING AND AIR BUBBLES REMOVED

In Figure 5-12 is a comparison of the net torus force histories for the following conditions:

Figure No.	Window Stiffening	Surfactant Added To Pool Water
5-12a	no	no
5-12b	yes	no
5-12c	no	yes
5-12d	yes	yes

5.5.1 Window Stiffening Only

It can be seen by comparing Figure 5-12b to the reference case in Figure 5-12a (no window struts, fresh water) that window stiffening alone nearly dampened out all but the first one and a half oscillations. The amplitudes of those oscillations were somewhat reduced.

693 306

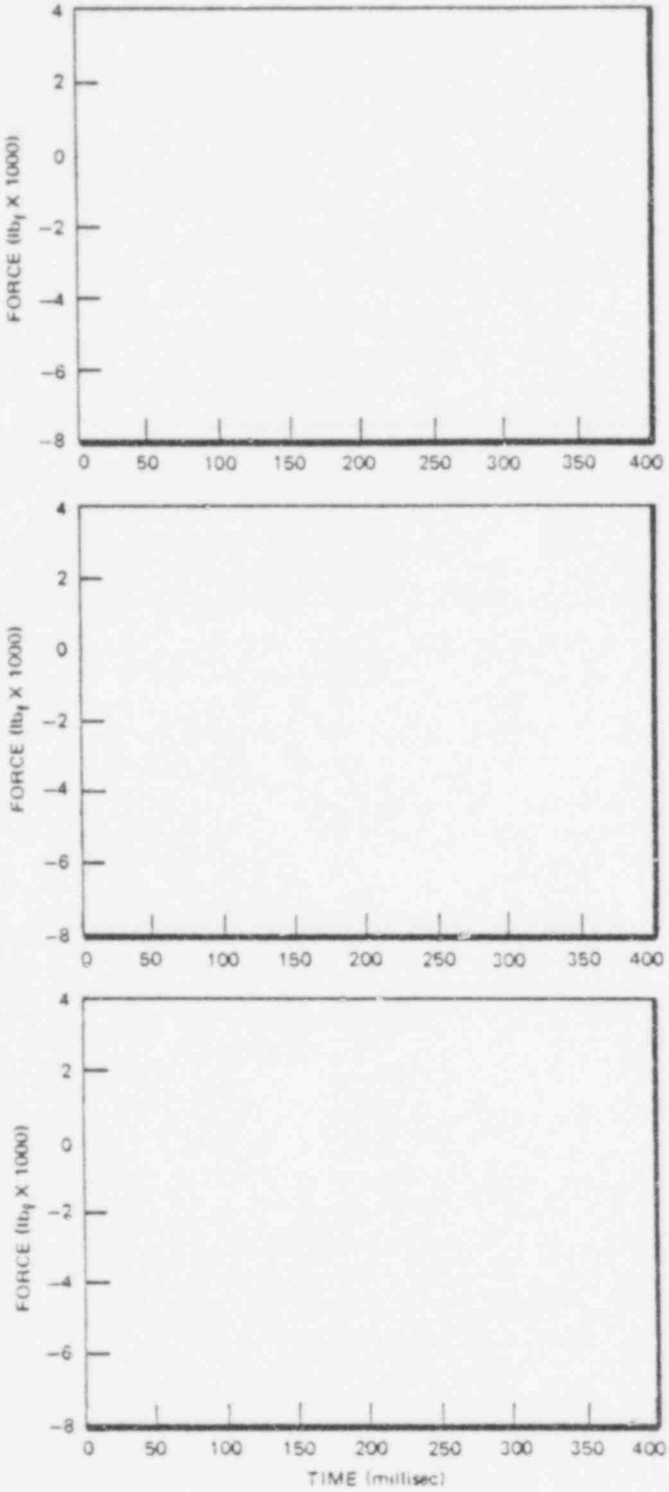


Figure 5-10. Effect of Pool Water Condition on Net Torus Force History

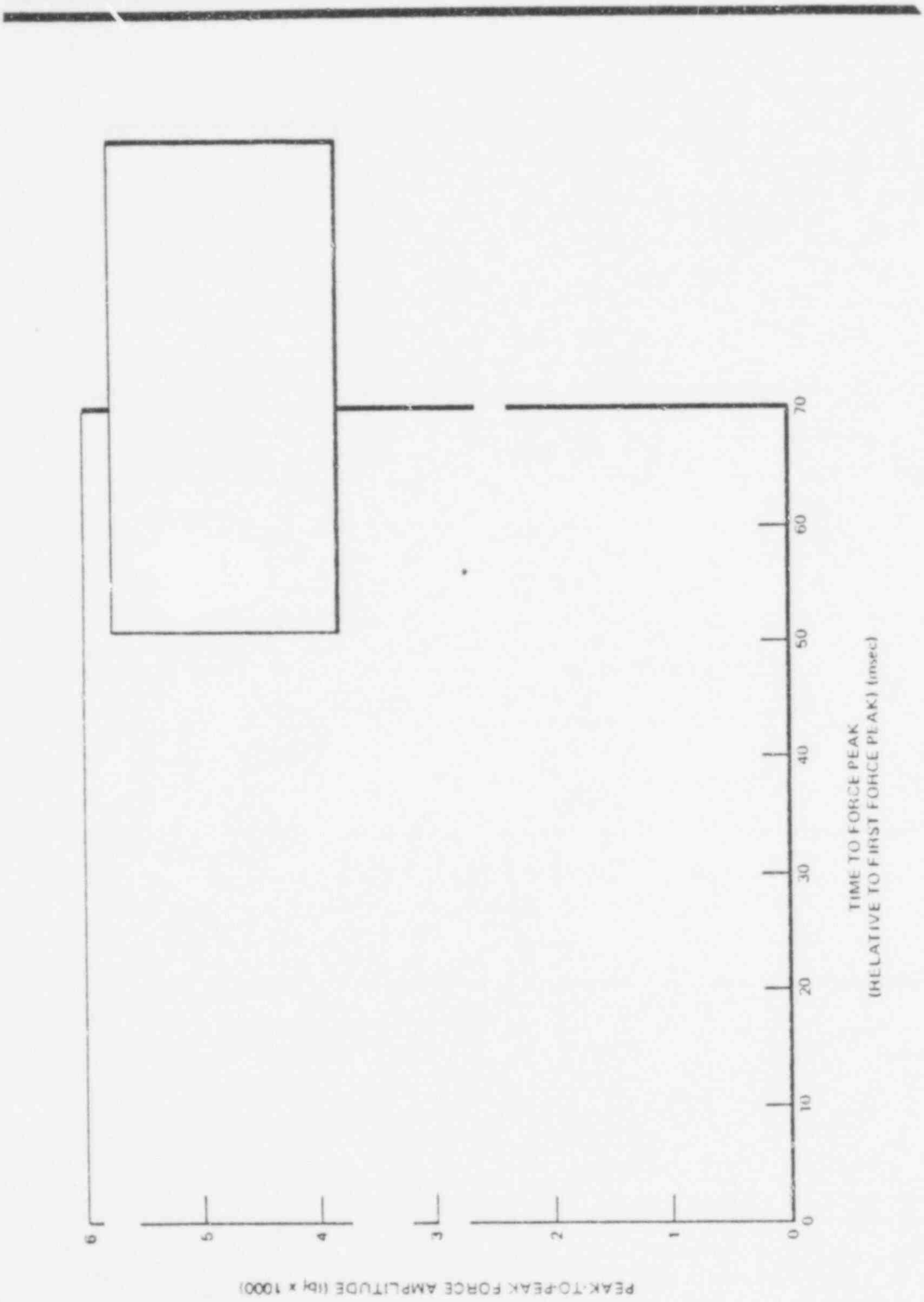
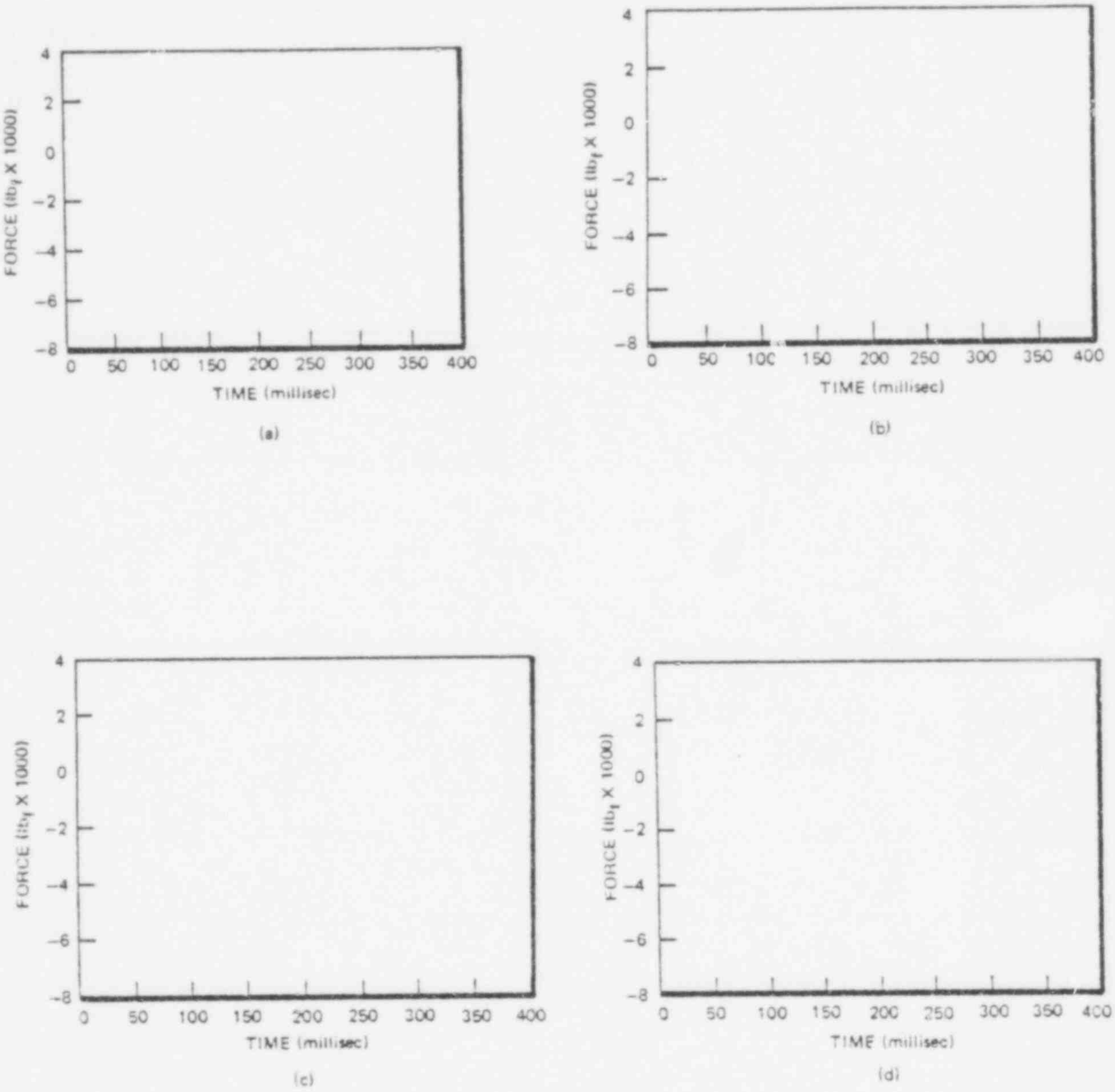


Figure 5-11. Comparison of Downforce Oscillations for Test with Air Bubbles Removed by Repeated Blowdowns, Deaerated Pool and Surfactant Added



(a)

(b)

(c)

(d)

Figure 5-12. Effects of Lateral Stiffening and Air Bubble Removal on Net Torus Forces History Pressure Integral + MA

5.5.2 Bubble Removal Only

It can be seen from Figure 5-12c that adding surfactant to the pool (with no window stiffening) significantly reduced the amplitude of the oscillations but did not eliminate them. The amplitude of the first oscillation was reduced by more than was accomplished by window stiffening but the subsequent oscillations did not damp out as quickly.

5.5.3 Combined Effect

If the test facility windows are stiffened and the air bubbles are removed from the submerged test facility surfaces, the download oscillations with the exception of the first half oscillation are virtually eliminated as shown in Figure 5-12d. The amplitude of the first half oscillation is reduced by nearly 80%.

5.6 SUMMARY OF RESULTS

The amplitude of the first peak download was probably amplified by up to 20% by the presence of download oscillations in the Quarter Scale Test Facility. Both window flexibility and the presence of air bubbles on submerged test facility surfaces were the causes of the download oscillations. The former was the primary cause and the latter a significant contributing cause. The event which initiated the oscillctions was the initial discharge of air into the torus as the vents were cleared. If the test facility windows are stiffened and the air bubbles are removed from the test facility surfaces, the download oscillations are virtually eliminated.

6. CONCLUSIONS

The following conclusions about peak downloads and download oscillations are drawn from the Task 5.5.2 Download Oscillation Evaluation work.

- Download oscillations in the QSTF affected the amplitude of the initial download peak by 10% to 20%
- Download oscillations can be virtually eliminated by
  - Increasing the lateral stiffness of the test facility and
  - Removing the air bubbles from submerged test facility surfaces.
- The download oscillations were initiated by the discharge of higher pressure air into the torus as the vents are cleared.
- With download oscillations removed, peak downloads without ΔP would be expected to scale.

These conclusions are discussed in more detail below.

6.1 PEAK DOWNLOAD

Elimination of the download oscillations in the QSTF reduced the peak downloads by approximately 20% (from 7,000 lbf* to 5,600 lbf**) from the values obtained with fresh water and with either window struts or surfactant.

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*Mean $\int$ PA + MA for Task 5.5.2, Series 1 tests 6 through 11

**Mean $\int$ PA + MA for Task 5.5.2, Series 2 tests 8 and 9

6.2 DOWNLOAD OSCILLATIONS

The two parameters which were found to be the major causes of the download oscillations were:

- Lateral Stiffness of the Test Facility

- The Presence of Air Bubbles on the Submerged Test Facility Surfaces

None of the other parameters considered contributed significantly to the download oscillations.

6.2.1 Lateral Stiffness of the Test Facility

One cause of the downforce oscillations was the relative flexibility of the end windows/frames which produced low natural frequency modes in the torus. As the torus was loaded by the sudden discharge of air from the downcomers, the fundamental mode of the unstiffened windows/frames was excited and as a consequence download oscillations occurred. The end windows are a feature of the test facility and are not a part of the Mark I containment.

To remove this cause of downforce oscillations from the test, it was necessary to increase the lateral stiffness of the test facility. This was achieved by the addition of lateral struts to the test facility as described in Section 4.1.

6.2.2 Air Bubbles on Submerged Test Facility Surfaces

The other major cause of the download oscillations was the presence of air bubbles on the submerged test facility surfaces. The air bubbles increase the apparent flexibility of the test facility and consequently their presence supports download oscillations. The number of air bubbles present can be greatly reduced by the addition of a surfactant to the water in the torus or by agitating the water by conducting a number of blowdowns before a test run is made.

6.3 INITIAL PULSE

The Task 5.5.2 Download Oscillation Evaluation tests indicated that the discharge of air into the torus at less than full ΔP provided a rapid loading pulse to the spring/mass system of torus structure, bubbles, and water mass which then reverberated causing downforce oscillations. The tests have indicated that the oscillations can be virtually eliminated (Figure 5-12d) by stiffening the test facility. The discharge of air as the vents are cleared instigate the download oscillations but further introduction of air into the torus does not act to sustain the oscillations.

6.4 DOWNLOAD SCALING

Previous work (reference no. 1) showed that at full ΔP conditions, there were no significant download oscillations and scaling was confirmed for both peak download and download impulse as well as for other parameters investigated. At zero ΔP conditions, scaling was confirmed for all parameters (including download impulse) except peak download. Download oscillations were observed in both 1/4 scale and 1/12 scale facilities at zero ΔP.

The present investigation has established that download oscillations are test facility related and non-prototypical of full scale conditions. Since download impulse and the times of peak download and peak upload have been shown to scale, peak downloads at zero ΔP with the oscillations essentially removed would be expected to scale as was previously confirmed for peak download at full ΔP.

7. REFERENCES

1. Galyardt, D.L. et al., "Mark I Containment Program 1/4 Scale Pressure Suppression Pool Swell Test Program: Scaling Evaluation", Task No. 5.5.1, NEDE-21627-P, GE Proprietary, January 1978 (G.E. Report)

2. Galyardt, D.L., "Mark I 1/12-Scale Pressure Suppression Pool Swell Test Program Phase IV Tests", NEDE-21492-P GE Proprietary, Mark 1977 (G.E. Report)

3. Final Report on the Dynamic Modeling of a Mark I Suppression System EPRI Report *________, Sept/Oct 1978.

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* Report number not available at time of printing.

APPENDIX A. TEST FACILITY DESCRIPTION

TEST FACILITY DESCRIPTION

This appendix describes the standard test facility and facility capability requirements. A description of the modifications to facility hardware and test conditions used to determine the effects of the various postulated causes of downforce oscillations is provided in Section 4.

A.1 TEST FACILITY

A sketch of the 1/4 Scale Test Facility (QSTF) is shown in Figure 4-1. The 1/4 scale configuration is generally based upon a typical Mark I BWR pressure suppression containment. However, the dimensions are scaled from the earlier GE 1/12 scale facility rather than any specific plant.

A narrow segment (about 8°) of the torus, including one pair of downcomers, is modeled; the segment is approximated by parallel faces rather than a pie shape. The test torus is 7.75 feet in internal diameter and 21.8 inches in internal width.

Drywell pressurization is modeled by using a large compressed air tank which discharges on command into a simulated drywell volume (which is volumetrically, but not geometrically, modeled) through a very fast-acting valve and a metering orifice. The drywell orifice upstream pressure is increased to 55 psia, the air supply pressure, from its initial pressure of 3.68 psia in about 0.030 sec. The large air source results in a very small change in supply pressure and temperature during a simulated LOCA transient so that the incoming enthalpy flow is nearly constant (decreases by less than 7 percent in 0.75 sec). Transparent end and side ports allow visual observation of the phenomena from two directions. High speed photography is utilized to examine fine details of the one-second event and to measure surface velocities during the pool swell. Transparent downcomers make the vent-clearing phenomena visible.

The drywell and wetwell are isolated structurally and connected only by a flexible bellows. The vent header was designed to be structurally isolated from the wetwell so that vent header impact can be separately measured with a load cell.

A.2 TEST CONDITIONS AND TOLERANCES

The test conditions and tolerances used in the program were based upon the scaling law requirements for quarter scale pool swell simulation. A list of the test conditions is provided in Table A-1.

Table A-1
TEST CONDITIONS

Initial Test Conditions	Value and Tolerance
Reservoir Pressure	55 ± 1 psia
Reservoir Temperature	70 ± 10° F
Drywell Pressure	3.7 ± 0.1 psia
Wetwell Freespace Pressure	3.7 ± 0.1 psia
Drywell/Wetwell ΔP	12, 0 ± 0.2 in H_2O
Downcomer Submergence	12.0 ± 0.1 in.
Water Temperature	70 ± 10° F
Dissolved Oxygen Content	1.5 ± 0.5 ppm*
Drywell Orifice	2.668" Diam.

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*For deaeration tests Task 5.5.2, Series 3 (Tests 1 through 4)

693 318

APPENDIX B. TEST INSTRUMENTATION DESCRIPTION

B.1 TEST INSTRUMENTATION

The facility was instrumented with fourteen pressure transducers, six accelerometers, one thermocouple and two load cells as shown in Figure B-1. Transducer ranges, sample rates and low pass filter settings for each of the instruments are given in Table B-1. Seven channels were recorded on analog tapes.

Functionally, the instrumentation falls into two categories. The first category consists of standard reference instrumentation. The primary purpose of this instrumentation group is to quantify the gross aspects of pool swell. Included in this group are measurements of the pressure upstream of the drywell orifice, drywell pressure, differential pressure across the downcomer orifice, air temperature upstream of the downcomer orifice, wetwell pressures (freespace and three submerged location 180°, 210°, 240°) and the torus loads.

The second functional group of instrumentation consists of measurements specifically designed to investigate fluid/structure interaction, vent acoustics and vent clearing hydrodynamics. The objectives and types of measurements for this functional group are discussed below.

Fluid/Structure Interaction - Instrumentation related to fluid/structure interaction was to provide a better understanding of the basic phenomenon. The instrumentation is specifically oriented towards fluid/structure effects as they relate to window/frame vibrations. Pressures were measured at three locations in the pool adjacent to the lower portion of the window/frame. Lateral accelerations of the external surface of the window/frame assembly were measured directly adjacent to the three internal pool pressure measurements.

One other accelerometer was used to measure lateral window/frame accelerations. The location of this accelerometer was varied from test to test. In addition to the above measurements, the vertical acceleration of the wetwell was measured.

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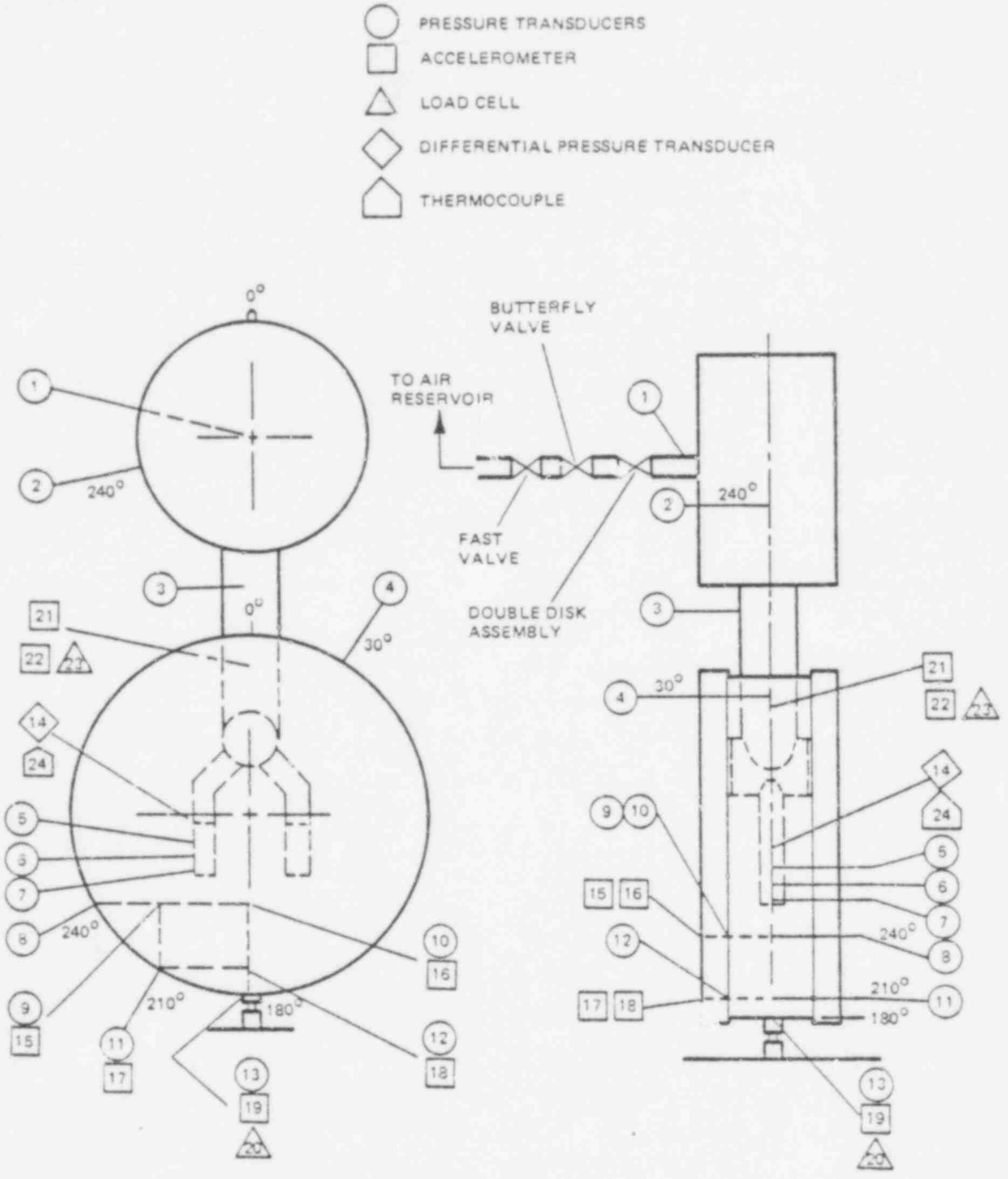

NOTE: NUMBERS CORRESPOND TO TABLE B-1

Figure B-1. Test Instrumentation

Table B-1
TEST INSTRUMENTATION

Ref. No.*	Measurement	Instrument No.	Transducer Range	Sample Rate (Hz)	Filter Frequency (Hz)	Analog Record
1	Orifice Upstream Pressure	PT-1022	0-50 psia	500	300	
2	Drywell Pressure	PT-1014	↓	↓	300	
3	Upper Vent Pressure	PT-1015	↓	↓	10K	X
4	Torus Air Pressure	PT-1001	↓	↓	10K	
5	Downcomer Pressure	PT-1002	↓	2,000	10K	X
6	Downcomer Pressure	PT-1003	↓	500	10K	X
7	Downcomer Pressure	PT-1004	↓	↓	10K	X
8	Torus Water Pressure	PT-1006	↓	↓	10K	X
9	Torus Water Pressure	PT-1012	↓	↓	300	
10	Torus Water Pressure	PT-1005	↓	↓	10K	X
11	Torus Water Pressure	PT-1009	↓	↓	10K	
12	Torus Water Pressure	PT-1010	↓	↓	300	
13	Torus Water Pressure	PT-1011	↓	↓	10K	X
14	Downcomer Diff. Pres.	DP-1020	0 to 10 psid	500	300	
15	Window Lateral Accel.	AT-3000	±25g	↓	Unfiltered	
16	Window Lateral Accel.	AT-3001	±5g	↓	↓	
17	Window Lateral Accel.	AT-3002	±5g	↓	↓	
18	Window Lateral Accel.	AT-3003	±5g	↓	↓	
19	Torus Vertical Accel.	AT-1017	±5g	1,000	↓	
20	Torus Load	LC-1016	50,000 lb_f	2,000	↓	
21	Vent Header Vert. Accel.	AT-1018	±25g	2,000	1,000	
22	Vent Header Vert. Accel.	AT-1018	±25g	2,000	Unfiltered	
23	Vent Header Load	LC-1021	10,000 lb_f	2,000	1,000	
24	Downcomer Air Temp.	TE-1019	0 to 500°F	500	300	

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*Refer to Figure B-1 for instrument locations.

693 321

Vent Acoustics; Vent Clearing - The objectives of this instrumentation were (1) to identify if acoustic waves in the vent system can be causally linked to the download oscillations and (2) to further investigate vent clearing phenomena. To meet the above objectives, five pressure transducers were located in the vent system; four of these vent transducers and three pool pressure transducers were recorded on analog tape. The locations for three pressure transducers in the downcomer are shown in Figure 4-7. An additional pressure transducer was located on the support inside the vent connecting the drywell and vent header, as shown in Figure 4-6, with the diaphragm oriented parallel to the flow direction.

High-speed movies were taken of each test. Camera setup was such as to provide a close-up view of the plastic downcomer instrumented for internal pressure measurements for the first 11 tests of Task 5.5.2, Series 2. Black and white film was used for the close-up photographic records because of its better resolution. A standard LOCAM was used at 500 frames/second operating speed and was positioned so that the above field of view was achieved with a 50mm objective lens. Task 5.5.2, Series 1 tests and Test 12 of Task 5.5.2, Series 2 were photographed using color film and a full facility view.

B.2 DATA ACQUISITION AND REDUCTION

Test data are recorded utilizing a high-speed data acquisition system (20,000 values per second recorded) that converts the electrical signals to engineering units and produces plots within minutes of each test.

Seven channels were recorded on analog tapes. The data recorded on the FM tape recorder was played back through the standard Analog to Digital system (used for all normal data recording) at a sampling rate of 4000 samples/second. The recorder used was a Honeywell 5600c, 14 channel FM tape recorder. The input and output sensitivites are 0-2 volts (peak-to-peak) with a frequency response of 5 kilocycles per channel.

APPENDIX C. VENT CLEARING PHENOMENON

C.1 VENT CLEARING MECHANISM

The movie stills of vent clearing are shown in Figure C-1 and C-2 for Task 5.5.2, Series 2, Test 3, in which the pool was deaerated. Selected frames of the downcomer close-ups depict various stages of vent clearing. Three pressure transducers, which measure internal pressures in the downcomer, can be seen in these closeups. Each frame is identified by time from reference time (T_o).

By 100 msec, the water level in the downcomer has dropped about 5 inches, and a central water slug is beginning to form. Development of the central water slug, which appears as a column, can be seen in the photographs. Simultaneously, an annular air pocket forms between the downcomer inside wall and the central water slug. Formation of the central water slug is possibly due to a higher pressure gradient along the walls and development of a Taylor instability. Inspection of the movie originals clearly shows a vortex region appearing at the end of the downcomers. By 128 msec, the peripheral air in the annular pocket has cleared the downcomer bottom and started to form a toroidal air bubble in the pool near the downcomer exit.

Figure C-3 presents the time history plot of measured downcomer pressures in Task 5.5.2, Series 2, Test 3. The points identified as t_1 through t_6 relate to Figure C-4 and the following description of the vent clearing process. Similarly, the events which are identified by time t_1 through t_7 in the downcomer close-ups of Figures C-1 and C-2 are identified in Figure C-4. The vent clearing mechanism is illustrated in Figure C-4. At time "t_1", as the air clears the vent near the wall, a toroidal bubble is formed at the vent exit. By this time, all of the three downcomer internal pressure readings have just passed their peaks; for the lower two downcomer internal pressures, their first peaks. Exposure of high pressure air from the drywell to the low pool pressure and the momentum of the water ejected from the vent causes this bubble to overexpand, as shown at time "t_2". This results in

693 323

Figure C-1. Vent Clearing Through Downcomer, Task 5.5.2, Series 2, Test 3

693 324

Figure C-2. Vent Clearing Through Downcomer (Continued)
Task 5.5.2, Series 2, Test 3

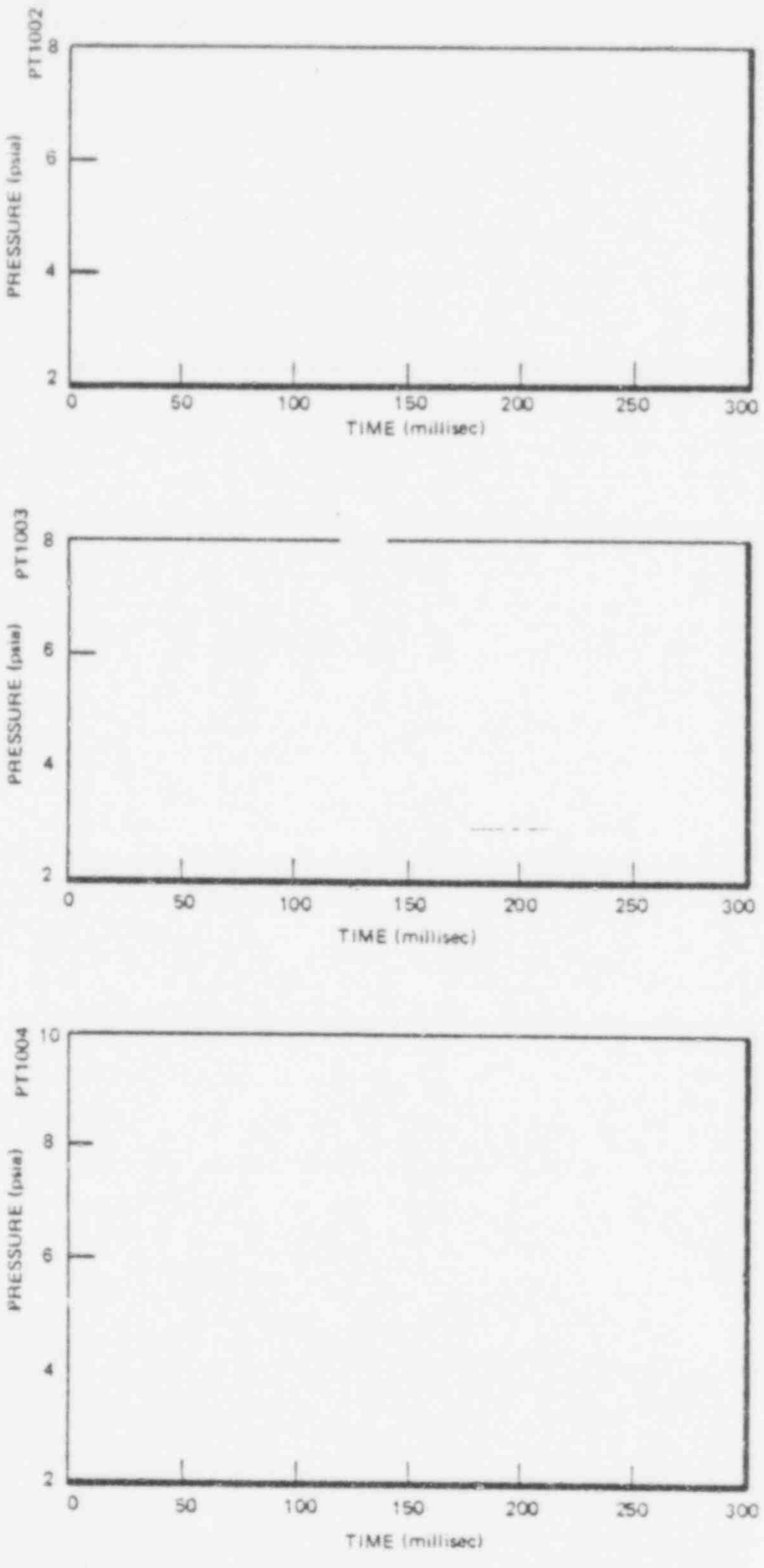

Figure C-3. Downcomer Internal Pressures During Deaerated Pool Test
Task 5.5.2, Series 2, Test 3

Figure C-4. Vent Clearing Mechanism

acceleration of the air flow with an accompanying drop in pressure in the air space between the downcomer inside wall and the central water column. These events can be identified in Figure C-1.

This causes the cup-shaped top of the central water column to impact on the inside wall at time "t_3". Appearance of a dark band in the movies of the downcomer close-up at 132 msec in Figure C-2 is the result of this impact of the top water layer on the downcomer wall. The impact occurs at a location between the upper and middle pressure transducers. The pressure read by the lower two pressure transducers then drops as the annular region is isolated from the vent pressure above the water level. The toroidal bubble continues to expand, primarily due to water inertia. As the occlusion and the central water slug are pushed down, at time "t_4", the middle downcomer internal pressure shows a sharp spike at the second peak due to the top layer of water impacting on the pressure transducer diaphragm (see also Figure C-3).

As the occlusion and central water slug are pushed further out of the vent, at time "t_5", the middle pressure transducer is again exposed to the high air pressure above the water level. The lower pressure transducer continues to drop as the transducer is still isolated by the occlusion, and the bubble continues to expand. As the occlusion moves over the lower pressure transducer at time "t_6", a sharp spike is observed because of the top layer of water impacting on the pressure transducer (see also Figure C-3).

Finally, "true" vent clearing occurs as the central water slug breaks up and the high pressure air breaks through into the toroidal bubble at time "t_7". This results in formation of the characteristic oval air bubble around the downcomer bottom, as shown at time "t_8" in Figure C-4.

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SUMMARY

This report documents the results of the Mark I Containment Program Task 5.5.2, Download Oscillation Evaluation. This pool swell test program conducted in the Mark I 1/4 Scale Test Facility (QSTF) both identified the causes of download oscillations previously observed in subscale pool swell tests and developed methods to prevent their subsequent occurrence.

This work was performed with the support of Nuclear Services Corporation and Aerotherm Division of Acurex Corporation under contract to General Electric.

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693 330