FINAL REPORT

ON THE

DAVIS-BESSE NUCLEAR POWER STATION UNIT 1

ECCS EMERGENCY SUMP AND PUMP SUCTION LINE TESTING

December 15, 1976

TABLE OF CONTENTS

1.0 PURPOSE OF THE TESTING

1.1 Purpose of the Model Testing

The purpose of the hydraulic model test was to document that the ECCS emergency sump screen-grating design shown in Figure 5 will not develop unacceptable flow-reducing or air-entraining vortices.

1.2 Purpose of the Containment Spray and Decay Heat Removal Pump Suction Line Testing

The purpose of the suction line testing was to verify that the predicted head loss from the ECCS emergency sump to the containment spray and decay heat removal pump suctions is conservative.

2.0 INTRODUCTION TO THE MODEL TEST

2.1 General

The Davis-Besse Nuclear Power Station Unit 1 is under design for the Toledo Edison Company and Cleveland Electric Illuminating Company by Bechtel Company. Western Canada Hydraulic Laboratories Ltd. was retained by Bechtel Company for Toledo Edison to perform a hydraulic model test of the Davis-Besse Unit 1 ECCS emergency sump.

The sump structure for the emergency cooling system consists of two pipe inlets located horizontally in a sump about 14 feet long with average width of 4 feet. The diameter of each inlet is 18 inches with the center line at elevation 561 feet, and the inlets are separated by a distance of 5 feet 9 inches. The floor around the sump is at elevation 565 feet.

A screen, consisting of a top and three vertical sides (Figure 5), supported by a grating structure of 1.5-inch by 0.25-inch bars on 4.75-inch centers, surrounds the intake sump. The screen cloth consists of 0.0909-inch wire with an effective opening of 53 percent. Further to preclude the possibility of vortex action, the original design has been supplemented by adding six levels of 1-inch by 2-inch by 1-inch gratings, one of which is inside the sump. The other five are above the sump screen. The calculated minimum and maximum water levels in the containment are El. 567 feet and 572 feet, respectively. The total flow rate is 11,000 gpm (5500 gpm for each inlet - decay heat pump at 4000 gpm and the containment spray pump at 1500 gpm), and the maximum water temperature is 251 F at a pressure of 34.7 psig.

The flow reaches the sump from three paths (see Figure 1): Q_1, through and from under the instrumentation tunnel cover plate; Q_2, through the large opening between the containment wall and the secondary shield wall; and Q_3, through the narrow opening between the containment wall and the secondary shield wall. Because of the complex flow paths, the flow rate through each path cannot be predicted analytically. However, based on the system layout and postulated accident condition, the flow through the narrow opening Q_3 is expected to be from 10 to 35 percent of the total flow. The flow Q_1 is estimated to vary from about 5 to 75 percent of total flow and Q_2 to vary from about 15 to 75 percent of total flow.

2.2 Potential Vortex Problems

Of major concern is the occurrence of vortices near or in the intake sump of the emergency cooling system which could result in loss of pumping capacity or pump failure due to vibration. Pumping capacity could be reduced due to air entrainment and/or unacceptably high intake head losses. Nonair-entraining vortices should not affect the pumping capacity other than through affecting intake head losses. Air entrainment could produce unbalanced pressures on the pump impeller and cause pump failure due to vibration. Therefore, the intake design should be free of air-entraining vortices and should have acceptable intake loss coefficients.

The complex flow patterns approaching the intakes, the effect of the grating and screen, and the relatively low viscosity of the heated water precluded analytical or empirical predictions as to whether the intake configuration, as designed, would be free of flow-reducing vortices. A scaled hydraulic model was required to evaluate the adequacy of the intake design. The plant configuration does not lend itself to an in-place test which could demonstrate that under all conditions a vortex will not form in the intake.

This report presents the results of the testing. The report does not attempt to deal extensively with model scaling and test data.

3.0 THE MODEL

3.1 Model Scale

The model has been constructed at an undistorted scale of 1:2 (Figure 3). The unprecedented nature of these tests and the importance of reliable predictions of prototype performance, together with some considerations discussed briefly below, dictated the use of a large scale for the model.

The following considerations led to the choice of the 1:2 scale which was adopted to minimize scale effects.

The current practice for modeling intakes for wet-well vertical pumps is to use a scale of 1:10 to 1:15 and conduct tests with velocities up to prototype values. The use of prototype velocities is an empirical technique to increase circulation in an attempt to compensate for scale effects. There are, however, important differences between typical wet-well sumps and the intakes, namely:

a. Wet-well sumps are generally of simple plan form to develop uniformity of approach flow.

b. The approach channels for wet-well sumps are usually designed to be free of protuberances and configurations that could generate vortices or swirls.

c. The screens are usually further removed from the pump intake.

d. Water temperatures are usually lower.

These differences warranted an examination of factors currently known to affect vortex formation and an assessment of the adequacy of current modeling practice.

The degree of vorticity at an intake without protuberances depends on:

a. The geometry and characteristic dimensions of the intakes, sump, and approach channels.

b. The driving and retarding forces acting on the fluid, including surface tension, viscous shear, and pressure gradients.

To study the effects of these parameters on vortex formation and the effect of vortices on discharge coefficients, investigators have grouped variables into dimensionless numbers which include:

a. Weber number, $\frac{\rho V^2 D}{\sigma}$, which is a ratio of surface tension to inertia forces.

b. Froude number, $\frac{V}{\sqrt{gD}}$, which is a ratio of gravity to inertia forces.

c. Reynolds number, $\frac{VD}{\nu}$, which is a ratio of viscous to inertia forces.

d. Circulation number, $\frac{2\pi RVr}{Q}$, or the similar Kolf number, which characterizes circulation.

e. Strouhal number, $\frac{f_e D}{V}$, which characterizes the frequency of eddy shedding.

The parameters identified in the preceding dimensionless numbers are:

- r - radius of inlet, ft
- D - characteristic length, ft, e.g., depth or diameter
- R - radius of tank or perhaps flow streamline, ft
- Q - discharge, cfs
- V - characteristic velocity, fps
- f_e - frequency of eddy shedding, sec^{-1}
- g - gravity, ft/sec^2
- σ - surface tension, lbs/ft
- ν - kinematic viscosity, ft^2/sec
- ρ - density, $slugs/ft^3$

To reproduce exact dynamic and kinematic similarity on a geometrically similar model would require the value of each dimensionless number to be the same in model and prototype. This restriction would require a 1:1 scale of all parameters. Departing from the 1:1 scale, it is possible to maintain equality in one or more of the dimensionless numbers, but scale effects are introduced due to inequalities between model and prototype of the remaining numbers.

The choice of the length scale ratio then depends upon the acceptability of the scale effects introduced. In some cases, compensation can be made for a scale effect by a modeling technique, for example, adjusting the slope of a free surface tunnel model to compensate for the difference in friction between the model and the prototype.

The results of investigations by others indicated that scale effects on free vortices caused by failure to maintain equality of the Weber number are not significant, particularly at a model scale greater than 1 to 10.

Reproduction of the Froude number between model and prototype is common practice for free-surface models. The importance of maintaining Froude similarity increases with increasing Froude number if the flow pattern, or kinematic similarity, is to be maintained. For low Froude numbers (i.e., low velocity heads), the Froude number of the model may be increased over the prototype value without significantly distorting the flow pattern. In some instances the model Froude number can be increased to develop increased circulation without significant scale effects on Froude-related flow phenomena.

Dagget and Keulegan (18)*, Zielinski and Villemonte (55), and others have examined the effect of viscosity, that is, Reynolds number, and circulation on the formation and effect of vortices. Their tests were conducted in simple circular tanks with an orifice centrally located in the bottom of the tank. Circulation was controlled by flow vanes which could introduce the flow at various angles around the circumference of the tank. Their results indicated that the effect of viscosity became of decreasing importance with increasing intake pipe Reynolds number. The results of these studies lead to the conclusion that circulation is an important parameter for prototype situations with large Reynolds numbers.

The definition of circulation in circular tanks is $2\pi RV_o$, where R is the radius of the tank and V_o is the initial tangential velocity. The circulation in the circular tank can be varied by adjusting the flow vanes. Circulation is not amenable to a simple mathematical definition in a complex flow situation since it must of necessity include rotational tendencies due to nonuniform velocity distributions, eddies, turbulence, and swirls.

The velocity distribution of the flow approaching the sump in a geometrically scaled model is affected by frictional resistance of flow surfaces and form drag of pipes, valves, and restraints. Fractional and form drag coefficients are normally independent of Reynolds numbers provided the Reynolds number is sufficiently large. Circular cylinders are exceptions. This allows some leeway in the choice of a model scale to reproduce resistance effects on flow distribution.

Unlike conventional wet-well sumps of simple plan configurations, the flow in the vicinity of the emergency cooling system intake will be nonuniform

---

* Numbers refer to references listed at the end of this report.

and locally unsteady. Therefore, the choice of the 1:2 scale for the intake model was made to minimize scale effects in reproducing circulation effects associated with unsteady, nonuniform flow. This scale assures that scale effects due to surface tension are minimum and the model Reynolds number will be sufficiently high with heated water so as not to introduce significant scale effects on friction, form drag, and screen loss. Furthermore, on the basis of the work of Dagget and Keulegan, the model was operated at discharges greater than Froude-scaled values to increase circulation and Reynolds numbers. It was not expected that inertia-generated flow patterns would have been unduly distorted by departing from Froude-scaled discharges.

Last, the Strouhal number characterizing eddy shedding is constant for flat plates for Reynolds numbers greater than 10^3 and is constant for circular cylinders for Reynolds numbers between 10^3 and 2×10^5. This indicates that there will be kinematic similarity between eddy shedding and flow patterns as long as the velocity approaching circular members in the model does not exceed the values given below for a Froude-scaled discharge.

Model diameter (feet)	Velocity not to be exceeded during Froude discharge (fps)
0.15	1.25
0.25	0.75
0.5	0.38
0.75	0.25

The above Strouhal conditions were met.

3.2 Screen Selection

A section (2 feet by 4 feet), of the model screen and prototype screen was tested separately in a flume to measure head losses and determine discharge coefficients over the range of expected approach velocities. The prototype and model screens' dimensions are tabulated below:

	Prototype Screen	Model Screen
Wire size, inches	0.0909	0.0459
Opening size, inches	0.2437	0.1156
Percentage free area	53.1	51.8

Parallel block walls were built in an 80-foot flume to provide a 1.87-foot wide rectangular channel 30 feet long (Figure 4). The screens were placed 20 feet from the upstream end of the channel. Six stilling wells were installed to measure the hydraulic grade line, three of which were located at distances of 5.2, 7.8 and 10.4 feet upstream from the screen position. The others were located at distances of 2.6, 3.9, and 5.2 feet downstream from the screen position. Water levels in the stilling wells were measured with point gauges. The flume discharge was measured by calibrated orifices.

The upstream and downstream hydraulic gradelines were projected to determine the head loss across the screens. The discharge coefficients of the screens, C_D, were calculated as follows:

$$C_D = \left[\frac{1}{\Delta h} \quad \frac{1}{\alpha^2} \quad \frac{V^2}{2g} \right]^{1/2}$$

where:

h = measured head loss, ft

α = fractional projected free area of screen

V = approach velocity, fps

The discharge coefficients for the model and prototype screens are tabulated below:

Prototype Screen				Model Screen			
Approach Velocity fps	Δh ft	R_e	C_D	Approach Velocity fps	Δh	R_e	C_D
1.966	0.068	6300	1.77	2.052	0.096	3380	1.71
1.556	0.035	4980	1.95	1.492	0.047	2450	1.78
1.064	0.019	3410	1.82	1.017	0.023	1670	1.73
0.724	0.009	2320	1.78	0.655	0.010	1080	1.70
0.463	0.004	1480	1.71	0.457	0.005	750	1.69
		Average	1.81			Average	1.72

The test results indicated the head loss characteristics of the prototype screen were modeled satisfactorily.

The work of Bachelor and Townsend and others indicates that the scale and intensity of turbulence behind geometrically similar screens will scale with the linear dimensions of the screen. The model screen was both geometrically similar and close to a 1:2 scale of the prototype screen. Therefore, it was concluded the scale and intensity of turbulence was modeled adequately by the model screen.

4.0 THE MODEL TESTING PROGRAM

The test program consisted of eight series. These were broken into two phases. The Phase 1 series was used to develop test procedures and to determine the basic flow characteristics of the system including tests without screens and grating and tests with the original design of screens and grating. The Phase 2 tests were run to determine the exact elevation at which additional grating plates needed to be placed and to verify that the modified screen and grating design would be free from any objectionable vortex action.

In performing these tests, vortices that developed in the vicinity of the intakes were classified as Types A and B. Type A vortices were characterized by a depression of the water surface at the eye of the vortex but did not develop a continuous air core. Type B vortices developed an air core.

4.1 Phase 1 Testing

4.1.1 Series 1

Series 1 tests were conducted to determine the general flow characteristics with and without the intake screen and grating in place to determine whether objectionable vortex action developed.

The desired flow distributions were first set at ambient temperature, and static pressures of the approach flow, of the intake sump, and of the intake pipes were recorded. Flow patterns were observed and behavioral characteristics noted, including the type of vortices with and without the screen and grating.

These tests were repeated for temperatures of approximately 100, 140, and 170 F.

4.1.1.1 Series 1 Model Test Results Without Screen and Grating

The initial tests were undertaken to examine the performance of the system over a range of flow distributions and water temperatures.

Some general observations were noted:

a. With a water surface elevation of 572.0 feet and at ambient temperature, the surface was very calm and model surface velocities were less than 4 to 6 inches per second. Surface eddy shedding was weak and was limited to areas away from the intake sump. Occasional Type A vortices formed, but no air-entraining vortices developed. The intake loss coefficient for the pipe intake had an approximate value of 0.5.

b. At elevation 567.0 feet, the surface velocities were much higher and there were air-entraining vortices. The intake loss coefficient for the pipe intake remained approximately at 0.5.

c. An increase in the source flow from Q_2 increased the number of occurrences of vortices.

d. An increase in water temperature also increased the number of occurrences of vortices.

e. Increased vortex occurrences were noted when the water surface was raised from El 567.0 feet, which is immediately below the top tunnel plate, to El. 567.5 feet, which is slightly above the plate.

f. Under no condition did sustained air-entraining vortices persist for more than 20 to 30 model seconds. The eddy shedding and swirl production responsible for establishing a short-duration, air-entraining vortex was also disruptive and contributed to breaking an air-entraining vortex by disorganizing the flow.

4.1.1.2 Series 1 Model Test Results With Screen and Grating in Place

A series of tests was conducted with the original design grating and screen in the model. The grating was constructed on a scale of 1:2, and the model screen was very close to a 1:2 scale, with a wire diameter of 0.0459 inch and percentage opening of 51.8.

The model was tested at water levels of 567.5 and 569 feet with temperatures of 70 to 160 F. The flow splits Q_1, Q_2, and Q_3 were tested as follows:

Flow Condition	Percent		
	Q_1	Q_2	Q_3
1	5	75	20
2	75	15	10
3	35	30	35

Blockage configurations B and C, Figure 2, were tested. The following observations were made:

a. Occasionally a vortex would form which had an air core large enough to allow air to be drawn through the screen and grating. The air was broken into small bubbles by the screen. The small bubbles dispersed within the screen area and rose to the surface.

b. No organized vortex-type flow developed inside the screen structure.

c. The intake loss coefficient remained at approximately 0.5 for all tests.

4.1.2 Series 2 Testing

Series 2 was used to determine the period of time required to allow flow conditions to become established in the model and the length of observation time required to obtain data for comparison of various flow conditions.

Series 2 tests were carried out at ambient temperature, using Froude-scale discharges without the screen and grating structure, with the following flow distribution:

Q_1 - 15%

Q_2 - 60%

Q_3 - 25%

The occurrence of both type A (or nonair-entraining vortices) and type B (or air-entraining vortices) was recorded during sequential 15-minute intervals. In addition, a record was kept of the duration of the air-entraining vortices. Observations were continued for 2 1/2 hours.

4.1.2.1 Series 2 Test Results

The results of the Series 2 tests indicate that at least 30 minutes must be alloted for flow to stabilize before a reasonable degree of consistency can be expected in the number of nonair-entraining type A vortices and the number and duration of air-entraining type B vortices occurring per unit time.

Furthermore, the data suggested that an observational period of 1 hour after the flow has stabilized is sufficient to characterize flow conditions.

4.1.3 Series 3 Testing

Series 3 was developed to determine the effect of temperature and flow rate on the type, frequency, and duration of vortex formation.

Series 3 tests were carried out without screens and gratings at temperatures of approximately 60, 100, 140, and 170 F at 1.0, 1.2, and 1.4 times Froude-scale discharges with the following flow distribution:

Q_1 - 15%

Q_2 - 60%

Q_3 - 25%

After 30 minutes allowance for flow stabilization, all static and differential pressures were observed and recorded for each test. All type A and B vortices were counted and recorded for one hour. In addition, the duration of type B vortices was noted and recorded.

4.1.3.1 Series 3 Tests Results

a. The frequency of type A vortices increased with temperature and discharges.

b. The frequency of type B vortices increased with both an increase in temperature and an increase in discharge.

c. There was no observable trend in the average duration of air-entraining vortices with changes in discharge or temperature as long as the water level in the sump remained constant.

d. The trend in frequency of type B vortices, with changes in kinematic viscosity and discharge, suggested that the frequency of vortex formation is Reynolds-number dependent.

e. There was no trend in the variation of the intake loss coefficient, k, as a function of either total discharge or kinematic viscosity.

4.1.4 Series 4 Testing

Series 4 tests were developed to determine whether conditions at the intake are sensitive to the direction of Q_2 flow lines entering the model.

Series 4 tests were carried out at approximately 100 F for three water levels without screens and grating at 1.4 times Froude-scale discharges with the following flow distributuion (Figure 1):

Q_1 - 15%

Q_2 - 60%

Q_3 - 25%

The tests were run at Q_2 approach angles of 80, 110, and 140 degrees. Ninety degrees was parallel to, and 140 degrees directed toward, the outer containment wall. After a 30-minute flow stabilization period, all type A and B vortices were counted and recorded for one hour. In addition, the duration of type B vortices was noted and recorded.

4.1.4.1 Series 4 Tests Results

The results indicated that vortex generation is sensitive to approach conditions from Q_2, particularly the formation of air-entraining, type B vortices. The increase in the number of type B vortices was significant for a vane angle increase from 90 to 110 degrees and less significant for the increase from 110 to 140 degrees. This suggested that further testing should be conducted with a vane angle of 110 degrees.

4.1.5 Series 5 Tests

Series 5 tests were conducted to determine whether conditions at the intake were sensitive to the split in flow between the instrument tunnel and the adjacent access tunnel, Figure 1. This split in flow cannot be calculated, due to lack of data relative to losses across the in-core instrument tube support plates. Tests were run at a water surface elevation of 567.5 feet with the flow distribution of Q_1 = 15%, Q_2 = 60%, and Q_3 = 25%. The Q_1 flow was varied as follows:

%Q_1 in Access Shaft	% Q_1 in Instr. Tunnel
0	100
50	50
100	0

4.1.5.1 Series 5 Tests Results

Analysis of the test data did not indicate any definite trend in vortex formation with a variation in flow distribution between the instrument tunnel and the inspection tunnel. Therefore, testing was conducted with the instrument tunnel and inspection tunnel flow distribution approximately equal.

4.2 Phase 2 Testing

4.2.1 Series 6 Testing

Series 6 tests determined the areal extent and spacing of the additional 1-inch by 2-inch grating which was designed to prevent the development of organized circulation immediately outside of the screen, which could lead to vortex formation.

The procedure adopted in the development of stacked gratings was as follows:

a. While testing at the minimum sump water surface elevation of 567.0 feet, the areal extent and elevation of the grating required to eliminate any tendency of organized circulation was determined.

b. Testing was done at 140 F for the following three flow distributions:

Q_1	Q_2	Q_3
75	15	10
35	30	35
5	15	20

and with the five blockage conditions, A through E, Figure 2.

c. The sump water level was then raised until an organized circulation developed or until eddies having surface depressions in excess of 1/2 inch were observed. Another grating was installed at this water level.

d. The procedure in c was repeated until satisfactory operation was developed for all possible operating levels.

4.2.1.1 Series 6 Test Results

At the lowest sump operating level, the flow velocities were high and the flow was generally disorganized. The high-velocity flows caused eddy shedding downstream from structural members such as conduits, pipes, valves, railing, restraints, etc. To ensure that circulation of any eddies was not carried through the screen, the first grating platform (additional to the original design) was fixed on top of the sump screen, which, itself, is at El. 567.0 ft.

At operating levels just above El. 567.0 feet, a tendency developed for type A vortices to form outside the areal limits of the grating. A layer of grating surrounding the entire screen cage at El. 566.5 feet (Figure 5) eliminated these vortices.

With the 566.5 and 567.0 foot gratings in place, organized circulation developed at a sump water level of 568.0 feet, particularly for blockage conditions B and C. A grating was installed at this level. Similarly, a grating was installed at El. 569.0 feet. At water surface elevations above 569.0 feet, the flows were tranquil for all conditions, and eddy shedding was considerably reduced because most restraints, pipes, conduit, etc., were submerged. Above the grating at 569.0 feet, only one additional grating, at 570.05 feet was required to ensure adequate elimination of circulation. A solid plate will be placed above the maximum water surface to prevent falling objects from blocking the grating.

4.2.2 Series 7 and 8 Testing

The performance of the intake design was examined for single-train operation in Series 7 and with both trains operating in Series 8. Both series were run with and without screen blockage.

The purpose of Test Series 7 and 8 was to observe whether, with the modified design, organized circulation developed in the vicinity of the intake which could develop into air-entraining vortices.

The intake was tested over a sufficient range of operating conditions to make prototype operation predictable.

The tests covered the following:

a. The three flow distributions presented in Section 4.2.1

b. No blockage and 5 different blockage conditions, Figure 2

c. Sump water levels of 567.0. 567.9, 568.9, 570.3, and 572.0 feet.

The gratings associated with the intake were designed to eliminate circulation and preclude the formation of vortices irrespective of temperature (viscosity). However, advantage was taken of the heaters available to run the tests at water temperatures of 130 to 240 F. Higher temperatures resulted in the water surface being obscured by steam.

To add conservatism, the tests were conducted at a discharge of 1.41 times Froude-scaled values.

The data recorded for each test included:

a. A written description and sketch of the flow pattern

b. Five manometer readings to establish the flow distributions

c. Piezometric levels inside and outside of the screen area

d. Piezometric pressures within each intake pipe, 2.5 feet downstream of the intake

e. Water temperature.

4.2.2.1 Series 7 and 8 Test Results

There was no organized circulation observed in any of the conditions tested that could lead to organized vortices near the screen structure. Under no condition was air drawn into the intake sump.

The external grating effectively eliminated any circulation associated with eddies shed from pipes, supports, handrails, etc. Furthermore, the 1-inch by 2-inch grating at floor level El. 565.0 feet within the screen precludes the formation of air-entraining vortices within the screened area. Such action could develop if a free surface were to develop due to air being trapped as the water level rises in the containment or due to air coming out of solution.

The difference in piezometric pressures between the containment area and 2.5 feet into the intake pipes was measured for all flow conditions tested. The maximum pressure drop obtained from the model was 1.510 feet, prototype equivalent, for blockage condition B, a sump water level of 567.0 feet, and with both trains operating. This loss was composed of a 0.195-foot pressure drop associated with intake conditions, screen, and grating, and a 1.313-foot pressure drop associated with the pipe entrance loss and pipe velocity head.

The percentage of blockage for case B was 54 percent compared to 50 percent blockage required for design. Furthermore, the velocity head in the model was 0.83 foot compared to the expected maximum value of 0.81 foot in the prototype, and the percentage of the area of the model screen was 51.8 compared to 53.0 for the prototype. Corrections were made to the maximum piezometric level drop recorded, on the basis that:

a. The screen and grating loss varies as the square of the approach velocity, that is, the unblocked screen area, and inversly as the square of the percent free flow area through the screen.

b. The pipe intake loss varies as the pipe velocity head.

These corrections indicated that the maximum piezometric level drop to be expected for the prototype installation is 1.44 feet and would occur under the condition of 58 percent screen blockage. The intake loss calculated by Bechtel project engineers and incorporated in the design of the system was 1.442 feet.

4.3 Other Testing

Circulation is not easily controlled and, guantified in a complex flow situation such as that of the ECCS emergency sump, some tests were conducted with various sizes of screens and grating with various flow conditions to determine their effect on vortex suppression. Results of the study are presented in Appendix A.

To summarize the results, the testing conclusively demonstrated that grating and, in some cases, screens are an effective deterrent to the formation of vortices. The grating eliminates the flow circulation that is essential to vortex formation by acting as a flow straightener.

5.0 THE CONTAINMENT SPRAY AND DECAY HEAT REMOVAL SUCTION LINE TEST

5.1 General

In the event of an accident, the decay heat removal and containment spray pumps initially take suction from the BWST. When the BWST volume has been depleted, the suction is automatically switched to the ECCS emergency sump. The test outlined below was accomplished to verify that the predicted values for piping head losses from the ECCS emergency sump to the pumps were conservative with respect to the actual losses experienced in operation (Ref. letter from L. E. Roe to W. R. Butler dated May 7, 1976).

5.1.1 The Suction Line Test

The test was accomplished by installing a temporary pipe between the two inlet lines in the ECCS emergency sump. Flow was initiated from the BWST to one inlet and into the suction of the other train through the temporary pipe.

The test was conducted at the maximum flow rate capability for one train at a time (i.e. 4000 gpm for the decay heat pump and 1500 gpm for the containment spray pump). Once the flow rate was established, using the pump discharge flow indicators to verify the flow rate, the pressures at the decay heat pump suction pressure connection (located on the pumping flange), the containment spray pump suction pressure connection (located on the pump inlet flange), and at connections on the temporary piping between the sump suction lines were obtained. Using these pressures, the piping head loss minus the sump entrance loss has been calculated using the formula below:

$$h_L = P_{conn} - P_{suct} + E_{conn} - E_{suct}$$

Where h_L = suction piping head loss minus the entrance loss

P_{conn} = average pressure at the connections on the temporary pipe, ft

P_{suct} = pressure at the pump suction pressure connection, ft

E_{conn} = elevation at the instrument on the temporary pipe, ft

E_{suct} = elevation at the pump suction pressure instrument, ft

During the test, the BWST water temperature was recorded. Using this temperature, the head losses have been calculated.

5.1.2 Suction Line Test Results

The predicted and actual head loss values are presented in the table below.

	Head Loss from Test at ( ) F	Predicted Head Loss at ( ) F
Decay heat removal pump 1-1	3.41 ft. (85)	5.33 ft. (85)
Containment spray pump 1-1	3.11 ft. (85)	4.32 ft. (85)
Decay heat removal pump 1-2	4.42 ft. (89)	6.65 ft. (89)
Containment spray pump 1-2	4.72 ft. (89)	5.18 ft. (89)

Note: Test temperatures are different due to the time interval between running the test for each train.

6.0 SUMMARY AND CONCLUSIONS

The Phase 1 model tests demonstrated that, over the range of the variables tested, a single layer of screen and grating effectively prevented any vortex from penetrating the screen and therefore from reaching the intake.

It is the opinion of Bechtel and Western Canada Hydraulic Laboratories Limited, and supported by the applicant, that the original design of the screen and its supporting grating would have effectively precluded air-entraining vortices, originating outside the screen area, from entering the intake.

However, circulation was present outside the screen and grating, and no consistent correlation between vortex strengths, circulation, and viscosity could be derived from the test results to permit a positive, reliable extrapolation to 251 F.

Circulation is an essential and necessary feature of a vortex. Radial or vertical velocity components alone cannot develop the centrifugal force required to maintain a core of low pressure. Therefore, an intake design which eliminates organized circulation in the vicinity of the intake sump eliminates a feature essential to vortex formation. Viscosity affects the rate at which energy is used or dissipated within a flow field. For a given circulatory shear imposed by external forces in a free surface flow, a loss viscous fluid will develop higher tangential velocities and have a greater depth of circulation than a more viscous fluid. However, irrespective of viscous effects, and hence irrespective of temperature effects, a vortex cannot develop without circulation.

The Phase 2 model tests demonstrated that the intake design with stacked gratings, Figure 5, will operate so that no circulation will occur that could lead to organized vortices near or at the screen structure. Without circulation, the intake design will operate free of flow-reducing and/or air-entraining vortices irrespective of temperature.

A layer of grating was also placed at El. 565 feet to preclude the possibility of air-entraining vortices from being formed within the screen area should air be trapped under blockage on the screen.

The Phase 2 model tests deomonstrated that the maximum value of screen, grating, and intake loss was essentially the same as the value used in designing the emergency core cooling system.

With respect to the testing completed on the decay heat removal and containment spray pump suction lines, the values obtained for head loss minus entrance loss during the test were compared with those calculated using the test water temperature. The predicted values presented are considered verified since they are in all cases greater than the actual values, which is conservative with respect to proper operation of the decay heat removal and containment spray systems.

In conclusion, the report has presented the pertinent facts which demonstrate that the ECCS emergency sump operation is vortex free and that there is adequate NPSH available to assure that the system will operate as intended.

LIST OF SELECTED REFERENCES

1. Addison, H. 1948; "Centrifugal and Other Rotodynamic Pumps." (Chapman and Hall, London.)

2. Akers and Crump, "The Vortex Drop," *Journal*, Institution of Civil Engineers, August, 1960, p. 443.

3. Al'Tshul, A.D., and Margolin, M.S., "Effect of Vortices on the Discharge Coefficient for Flow of a Liquid Through an Orifice" (translation), *Gidrotekhnieheskoe Stroitel'stvo*, No. 6, June, 1968, p. 32.

4. Anwar, H.O. "Flow in a Free Vortex," *Water Power*, April, 1965.

5. Anwar, H.O. "Formation of a Weak Vortex," *Journal of Hydraulic Research*, vol. 4, No. 1, 1966.

6. Anwar, H.O., "Vortices at Low Head Intakes," *Water Power*, Nov. 1967, p. 455-457.

7. Anwar, H.O. "Prevention of Vortices at Intakes," *Water Power*, Oct. 1968, p. 393.

8. Anwar, H.O., discussion of "Effect of Viscosity on Vortex-Orifice Flow," by Paul B. Zielinski and James R. Villemonte, *Journal of the Hydraulics Division*, ASCE. Vol. 95, No. HY 1. Proc. Paper 6323, Jan., 1969, p. 568-570.

9. Berge, J.P., "Enquete sur la Formation de Vortex et Autres Anomalies d'ecoulement dans une enceinte avec ou sans Surface Libre," Societe Hydrotechnique de France - Section Machines - Group de travail No. 10, Nov., 1964.

10. Berge, J.P. "A Study of Vortex Formation and Other Abnormal Flow in a Tank With and Without a Free Surface," *La Huille Blanche*, Grenoble, France, No. 1, 1966, p. 13-40.

11. Binnie, A.M., and Hockings, G.A., "Laboratory Experiments on Whirlpools," Proceedings, Royal Society, London, Series A, Vol. 194, Sept., 1948. p. 398-415.

12. Binnie, A.M., and Davidson, J.F., "The Flow under Gravity of a Swirling Liquid Through an Orifice Plate," *Proceedings*, Royal Society, London, Series A, Vol. 199, 1949, p. 443-457.

13. Brewer, D. "Vortices in Pump Sumps," *The Allen Engineering Review*, March, 1957.

14. Denny, D.F., 1953 British Hydromechanics Research Assoc. Report, R.R. 430, Preliminary Report on the Formation of Air-entraining Vortices in Pump Section Wells.

15. Denny, D.F., 1953, British Hydromechanics Research Assoc. Research *Report R.R. 465, "Experiments with Air in Centrifugal Pumps."*

15. Denny, D.F., 1953, British Hydromechanics Research Assoc. Research Report R.R. 465, "Experiments with Air in Centrifugal Pumps."

16. Denny, D.F., and Yound. G.A.J. "The Prevention of Vortices and Swirl and Intakes," *Proceedings*, IAHR 7th Congress, Lisbon, 1957.

17. Denny, D.F., "An Experimental Study of Air Entraining Vortices in Pump Sumps," *Proceedings of Inst. of Mechanical Engineers*, Vol. 170, No. 2, 1956.

18. Daggett, L.L. and Keulegan, G.H., "Simulitude Conditions in Free Surface Vortex Formations," *Jounral of the Hydraulics Division*, ASCE, Vol. 100, No. HY11, Nov. 1974, pp. 1565-1581.

19. Donaldson, C. du p., and Sullivan, R.D., "Examination of the Solutions of the Navier-Stokes Equations for a Class of Three-dimensional Vortices, Part I: Velocity Distribution for Steady Motion," *Proceedings*, Heat Transfer and Fluid Mechanics Institute, Stanford University Press, Calif., 1960, p. 16-30.

20. Einstein, H.A., and Ki. H., "Steady Vortex Flow in a Real Fluid," *La Houille Blanche*, Vol. 10, No. 4, Aug.-Sept. 1955, p. 483-496.

21. Folsom, R.G. 1940 University of California, Pump Testing Laboratories, Technical Memo. No. 6, HP-14, "Some Performance Characteristics of Deep-well Turbine Pumps."

22. Fraser, W.H. 1953 Trans. A.S.M.E., vol. 75, No. 4, p. 643, "Hydraulic Problems Encountered in Intake Structures of Vertical Wet-Pit Pumps and Methods Leading to Their Solution."

23. Gordon, J.L., "Vortices at Intakes," *Water Power*, April 1970, p. 137-138.

24. Guiton, P., "Caviation dans les Pompes," *La Houille Blanche*, Nov. 1962, No. 6.

25. Haindl, K., "Contribution to Air-entrainment by a Vortex," Paper 16-D, *International Association for Hydraulic Research*, Montreal, 1959.

26. Hattersley, R.T., "Hydraulic Design of Pump Intakes," *HY 2*, March 1965, p. 223-249.

27. Hattersley, R.T., "Factors of Inlet Channel Flow affecting the Performance of a Pumping Plant," *Report No. 23*, Water Research Lab., University of New South Wales, Australia, Sept. 1960.

28. Holtorff, G., "The Free Surface and the Conditions of Similitude for a Vortex," *La Houille Blanch*, vol. 19, No. 3, 1964, p. 377-384.

29. Iversen, H.W., "Studies of Submergence Requirements of High Specific Speed Pumps," *Transactions*, ASME, vol. 75, 1953.

30. Kaufman, *Fluid Mechanics*, McGraw-Hill, p. 265 and 279.

31. Keulegan, G.H., and Daggett, L.L., "A Note on Gravity Head Viscometer," Miscellaneous Paper H-74-3, United States Army Engineer Waterways Expermient Station, Corps of Engineers, Vicksburg, Miss., Mar. 1974.

32. Kolf, R.C., "Vortex Flow from Horizontal Thin-Plate Orifices," thesis presented to the University of Wisconsin, at Madison, Wis., in 1956, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

33. Kolf, R.C., and Zielinski, P.B., "The Vortex Chamber as an Automatic Flow-Control Device," *Jounral of the Hydraulics Division*, ASCE, vol. 85, No. HY12, Proc. Paper 2310, Dec. 1959.

34. Lawton, F.L., "Factors Influencing Flow in Large Conduits," Report of the Task Force on Flow in Large Conduits of the Committee on Hydraulic Structures. *Transactions*, ASCE, Paper 4543, rol. 91 HY6 - November 1965.

35. Lennart, R., "Flow Problems with Respect to Intakes and Tunnels of Swedish Hydro Electric Power Plants," *Transactions*, of the Royal Institute of Technology, Stockholm, Sweden, NR 71, 1953.

36. Lewellen, W.S., "A Solution for Three-Dimensional Vortex Flow with Strong Circulation." *J. Fluid Mechanics*. vol. 14, 1962.

37. Long, R.R., "A Vortex in an Infinite Fluid." *Journal of Fluid Mechanics*, vol. 11.

38. Marklund, E. and Pipe, J.A., "Experiments on a Small Pump Suction Well, with Particular Reference to Vortex Formations." *Proceedings*, The Institution of Mechanical Engineers, vol. 170, 1956.

39. Marklund, E., discussion of "Effect of Viscosity on Vortex-Orifice Flow," by Paul B. Zielinski and James R. Villemonte, *Journal of the Hydraulics Division*, ASCE, vol. 95, No. HY1, Proc. Paper 6323, Jan. 1969, p. 567-568.

40. Messina, J.P., "Periodic Noise in Circulating Water Pumps," *Power*, Sept. 1971, p. 70-71.

41. McCorquodale, J.A., discussion of "Effect of Viscosity on Vortex-Orifice Flow," by Paul B. Zielinski and James R. Villemonte, Journal of the Hydraulics Division, *ASCE, vol. 95, No. HY1, Proc. Paper 7323, Jan. 1969, p. 567-568.*

42. McCorquodale, J.A., "Scale Effects in Swirling Flow," *Journal of the Hydraulics Division*, ASCE, vol. 94, HY1, Disc. by Marco Pica, HY1, Jan. 1969.

43. Pickford, J.A., and Reddy, Y.R., "Vortex Suppression in s Stilling Pond Over-flow," *Journal of the Hydraulics Division*, ASCE, vol. 100, No. HY11, Nov. 1974, pp 1685-1697.

44. Quick, M.C., "A Study of the Free Spiral Vortex," thesis presented to the University of Bristol, England, in 1961, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

45. Quick, M.C., "Scale Relationships between Geometrically Similar Free Spiral Vortices," *Civil Engineering and Public Works Review*, Part 1, September 1962, Part II. October 1962, p. 1319.

46. Quick, M.C., "Efficiency of Air Entraining Vortex Formation at Water Intake," *Journal of the Hydraulics Div.*, ASCE, vol , No. 96, HY7, July 1970, p. 1403-1416.

47. Reddy, Y.R., and Pickford, J.A., "Vortices at Intakes in Conventional Sumps," *Water Power*, March 1972, p. 108-109.

48. Rouse, H., and Hsu, H., "On the Growth and Decay of a Vortex Filament," *Proceedings*, 1st National Congress of Applied Mechanics, 1952, p. 741-746.

49. Richardson, C.A., 1941 Water Works and Sewerage Reference and Data, Part 1, *Water Supply*, p. 25, "Submergence and Spacing of Suction Bells."

50. Stepanoff, A.J., 1948 "Centrifugal and Axial-flow Pumps," p. 963 (Chapman and Hall, London).

51. Stevens, J.D., discussion of "The Vortex Chamber as an Automatic Flow-Control Device." by R.C. Kolf and P.B. Zielinski, *Journal of the Hydraulics Division*, ASCE, vol. 86, No. HY6, Proc. Paper 2525, June 1960.

52. Stevens, J.C., and Kolf, R.C., "Vortex Flow Through Horizontal Orifices," *Journal of the Sanitary Engineering Division*, ASCE, Vol. 83, No. SA6, Proc, Paper 1461, Dec. 1957.

53. Weltmer, W.W. 1950, *Power Engineering*, vol. 54, No. 6, P. 74. "Proper Suction Intakes Vital for Vertical Circulating Pumps."

54. Young, C.A.H., "Swirl and Vortices at Intakes," *Report No. SP 726*, British Hydro-Mechanics Research Association, April 1962.

55. Zielinski, P.B. and Villemont, J.R., "Effect of Viscosity on Vortex-Orifice Flow," vol. 94, HY3, May 1968, p. 745-751. Disc. on above in Jan. 1969. by Marklund, E., McCorquodale, J.A. and Anwan, H.O.

APPENDIX A

Testing to determine the effectiveness of screens and grating as Flow Straighteners

Circulation is not easily controlled and quantified in a complex flow situation such as that of the emergency core cooling sump intake. Some experiments were therefore carried out in a model of a diversion tunnel with submerged inlet in which the circulation could be varied by means of baffles. It was easily shown that an increase in the strength of circulation correlated with an increase in the size of the stationary vortex produced. Stationary vortices could be produced with air cores varying in size from 3/16 to 3/4 inch at the throat.

Various sizes of screens and grating were placed above the intake to determine their effectiveness in suppressing or eliminating the vortex. The gratings substantially reduced the circulation above the intake and completely eliminated the air core. The effectiveness of the screens decreased with an increase in the opening size and an increase in vortex size. The test results are summarized below:

Size of Air Core Surface to Throat	Grating		Screens		
	1/2" x 1/2"	1" by 2"	D_w = .0459" D_o = .1156"	D_w = 0.0909" D_o = 0.2437"	D_w = 0.01" D_o = 0.5"
1" - 2" to 1/16" - 3/16"	Core severed	Core severed	Core severed	Core severed	Core reformed under screen
1 1/2" - 2 1/2" to 3/16" - 5/16"	Core severed	Core severed	Core severed	Core severed	Core reformed under screen bubbles pass through two consecutive screens
2" - 4" to 1/2" - 3/4"	Core severed	Core severed	Passed some air bubbles	Passed some air bubbles	Core nearly continuous

D_w = wire diameter

D_o = opening size

Additional experience on the effectiveness of screens and gratings in eliminating air-entraining vortices was obtained using another intake facility. A flow situation developed outside of the test area, which created a stationary air-entraining vortex above a horizontal 14-inch diameter intake. The center line of the intake was submerged 8.0 feet. The vortex developed for an intake flow of approximately 2500 gpm. The core of the vortex was well organized, developing an air core at the surface of approximately 1 to 1.5 inches.

Several screens and gratings were lowered into the water away from the vortex and then moved slowly into the core. The screens tested had 1/8-, 1/4-, and 1 1/4-inch openings. The gratings were 1/2-inch flat plates forming 1/2-inch by 1-inch openings on edge and 1 1/4-inch flat plates on edge at 1 1/4-inch centers crossed by 1 1/4-inch twisted rods at 2-inch centers.

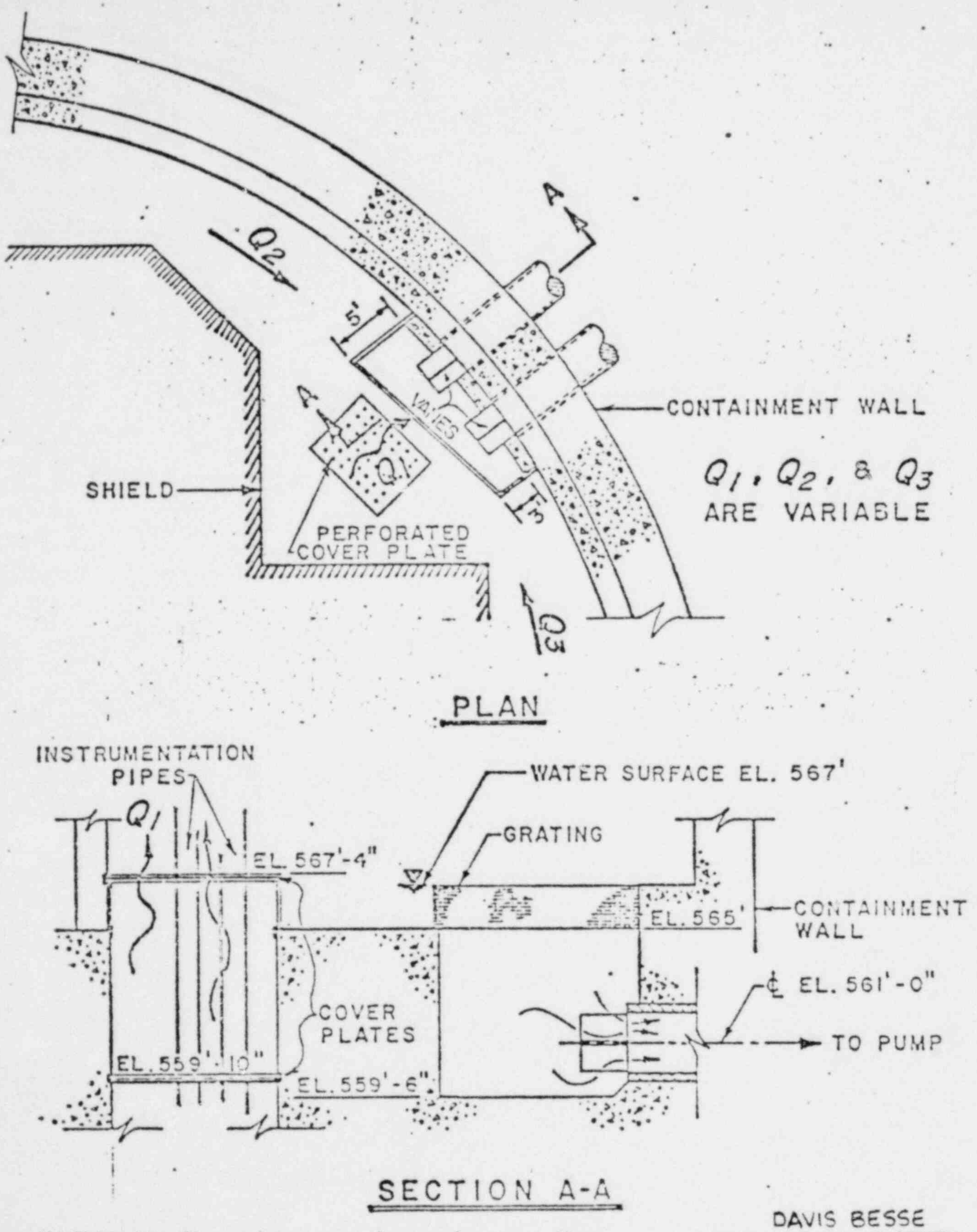
All screens and gratings, except the 1 1/4-inch screen, severed the air cores and eliminated the high circulation associated with the eye or core of the vortex when placed from 6 inches to several feet below the water surface. The 1 1/4-inch grating, but not the screens, was tested above the intake, 7 feet below the water surface, and rapidly severed the air core and disrupted the circulation.

The effectiveness of grating close to the intake in eliminating air-entraining vortices was demonstrated on the same facility, using a different intake. A 14-inch diameter intake extends 1.0 foot above the floor and is capped with a 13-inch-high, 20-inch-wide cruciform. The intake was surrounded by screen and grating, but the top of the cover, immediately above the intake, was covered by a plate. The distance between the top of the cruciform and the plate was 6 inches. The water depth above the cruciform was 53 inches.

Air was forced into the intake area for demonstration purposes and was trapped by the cover plate above the intake. With an intake flow varying from 3,000 to 6,000 gpm, the trapped air was drawn into the intake by vortices. A pocket of air could be partially or completely exhausted, depending on the duration of the vortex.

A 1 1/4-inch grating was placed over the cruciform and extended beyond the edge of the cruciform by approximately 3 inches. This grating completely eliminated the formation of air-entraining vortices. The air pockets moved randomly and laterally under the cover plate with no organization of the movement. Adding additional air resulted only in the air being exhausted through the adjacent screens.

In summary, the support testing conclusively demonstrated that gratings, and, in some cases screens, are an effective deterrent to the formation of vortices. The grating eliminates the flow circulation that is essential to vortex formation by acting as a flow straightener.



NOTE: All Dimensions are Approximate. Use Project Drawings for Exact Dimensions.

DAVIS BESSE
NUCLEAR POWER STATION
UNIT 1

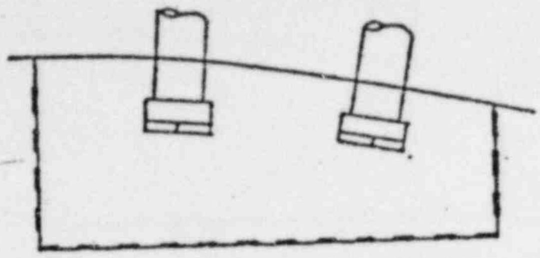
Schematic - ECCS Emergency Sump

NOT TO SCALE

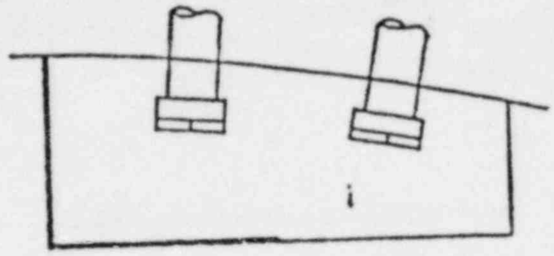
Rev. 1
5/24/76

Fig. 1

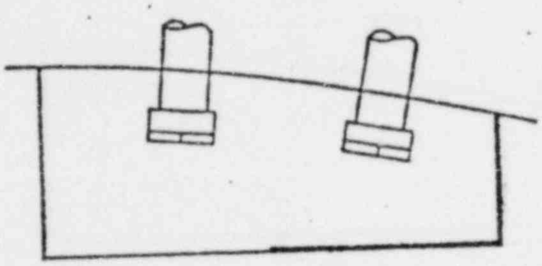
FIGURE 2



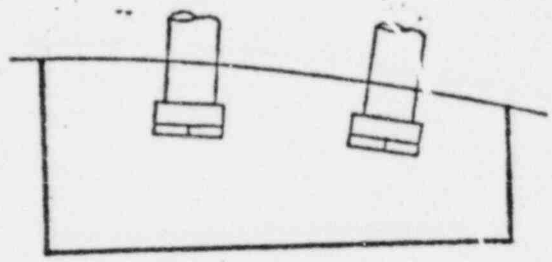
(A) TOP BLOCKED 100 %
VERTICAL SCREEN BLOCKED 50 %
OVER FULL HEIGHT BY ALTERNATE
3" WIDE OPEN AND BLOCKED STRIPS.



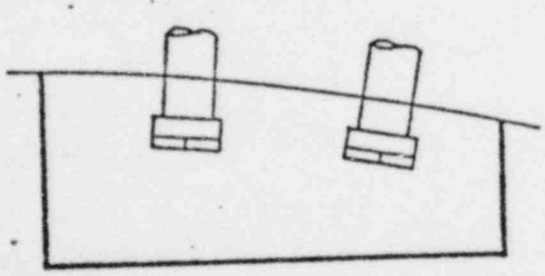
(B) TOP BLOCKED 100 %
VERTICAL SCREEN BLOCKED OVER
FULL HEIGHT OVER PORTION OF
HEAVY LINE.



(C) TOP BLOCKED 100%
VERTICAL SCREEN BLOCKED OVER
FULL HEIGHT OVER PORTION OF
HEAVY LINE.



(D) TOP BLOCKED 100%
VERTICAL SCREEN BLOCKED OVER
LOWER ONE - HALF AROUND PERIPHERY.

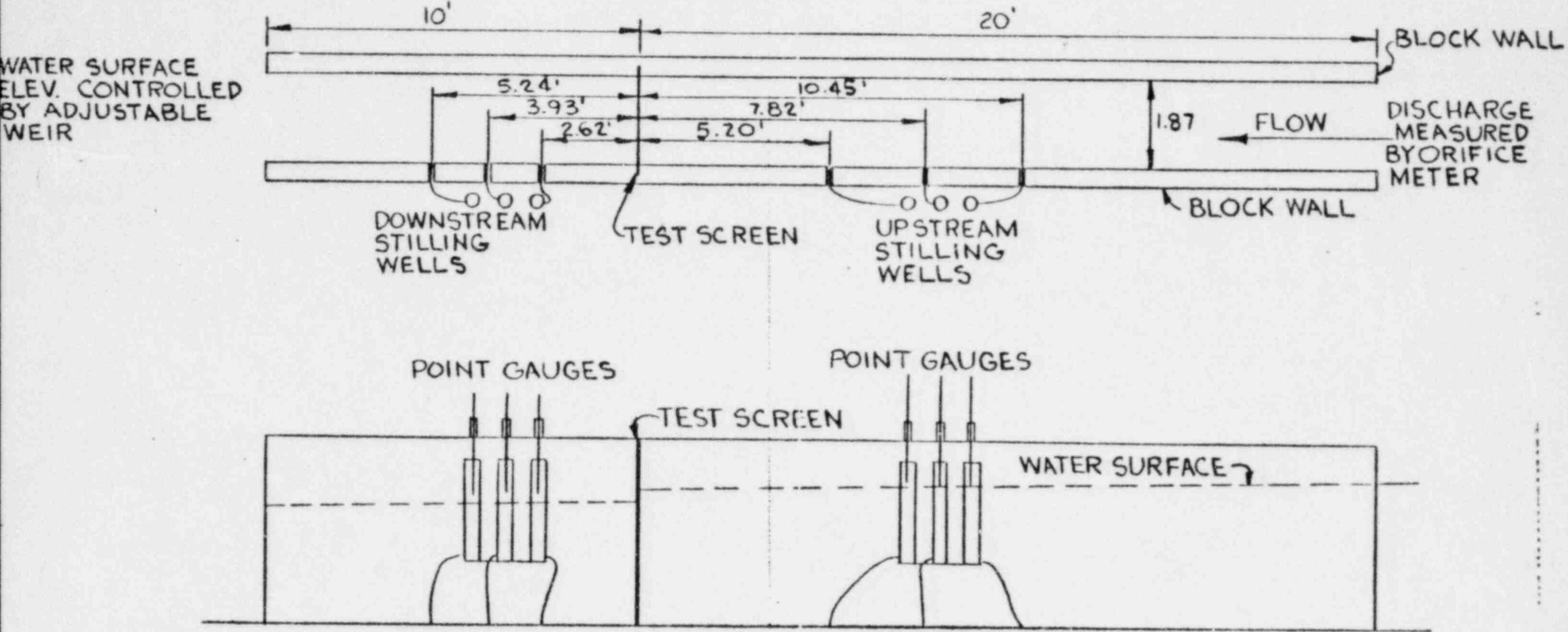


(E) TOP BLOCKED 100 %
VERTICAL SCREEN BLOCKED OVER
UPPER ONE - HALF AROUND
PERIPHERY.

DAVIS BESSE NUCLEAR POWER STATION
UNIT 1
HYDRAULIC MODEL STUDIES
ECCS EMERGENCY SUMP

CONFIGURATIONS FOR
SCREEN BLOCKAGE TESTS

BCIE SAR7A-WCH

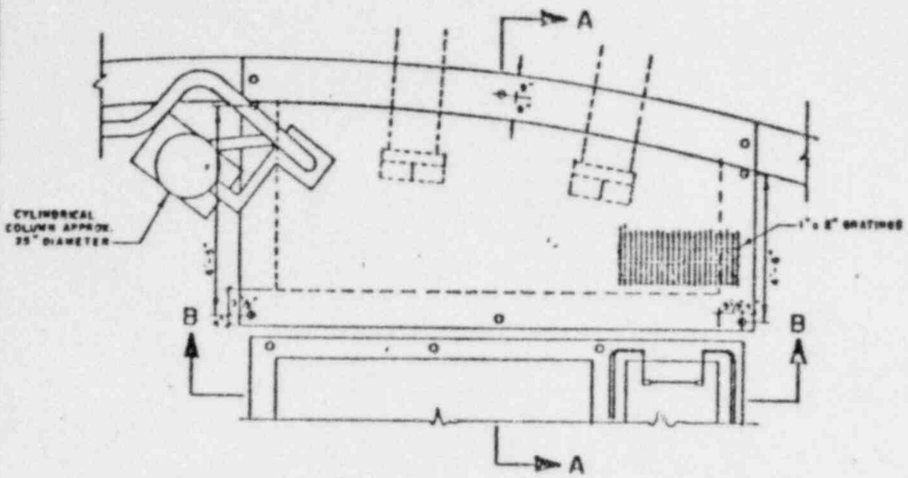


DAVIS BESSE NUCLEAR POWER STATION
UNIT 1
HYDRAULIC MODEL TEST
ECCS EMERGENCY SUMP

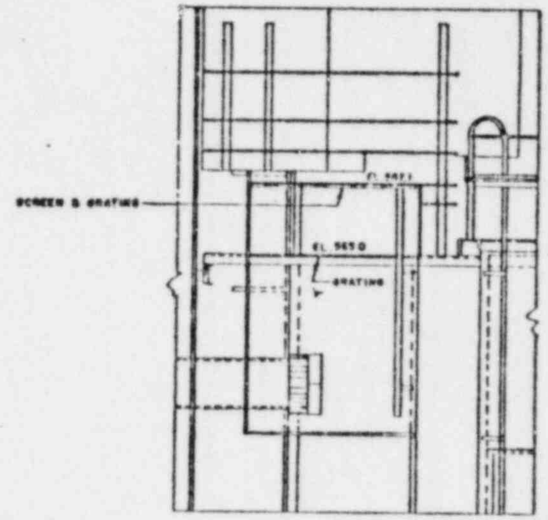
SCREEN TESTING FACILITY

FIG. 4

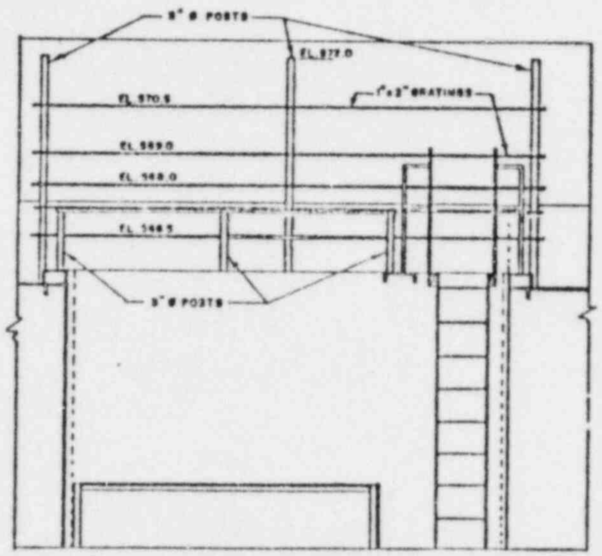
FIGURE 5



PLAN



SECTION A - A



SECTION B - B

NOTE: ALL DIMENSIONS ARE PROTOTYPE VALUES

DAVIS BESSE NUCLEAR POWER STATION
UNIT I
HYDRAULIC MODEL STUDIES
ECCS EMERGENCY SUMP

MODIFIED DESIGN OF
INTAKE SUMP