INTERIM REPORT

ON THE

DAVIS-BESSE NUCLEAR POWER STATION UNIT 1

ECCS EMERGENCY SUMP MODEL

TESTING TO INVESTIGATE VORTEXING POTENTIAL

TABLE OF CONTENTS

1.0 PURPOSE OF THE STUDY

The purpose of this hydraulic model study is twofold:

1. To determine whether flow-reducing or air-entraining vortices will develop in the sump inlet of the emergency core cooling system.

2. If necessary, to develop modifications in the current design to eliminate flow-reducing or air-entraining vortices.

The purpose of this interim report is to present the results of the study to date and to outline what testing remains to be completed.

2.0 INTRODUCTION

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. The plant is a P.W.R. capable of generating 906 M.W.E. and is located near Toledo, Ohio.

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 and the center line elevation is at 561 feet, and the inlets are separated by a distance of 5 feet 9 inches. The floor around the sump is at el 565. Grating is provided on three sides (the back side consists of the containment vessel wall) and the top consisting of 1.5 inches by 0.25 inch bars spaced 4.75 inches on centers. The grating is covered by a wire mesh screen with a wire diameter of 0.092 inch and an effective opening of 53.4 percent.

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 train - decay heat pump at 4000 gpm, containment spray pump at 1500 gpm) and the maximum water temperature is 251°F at a pressure of 34.7 psig.

The flow is expected to reach 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 percent 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 can be reduced due to air entrainment and/or unacceptably high intake head losses. It is unlikely that non-air entraining vortices could affect the pumping capacity other than through affecting intake head losses. Air entrainment can 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 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, preclude analytical or empirical predictions as to whether the intake configuration, as designed, will be free of flow reducing vortices. A scaled hydraulic model was required to evaluate the adequacy of the present intake design and develop modifications, if necessary, since 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 interim report presents the results of the studies to date and outlines the testing which remains to be done. The report does not attempt to deal extensively with model scaling and test data, but seeks only to identify the major characteristics of flow conditions at the intake, trends in the data, and whether it appears possible to eliminate flow reducing vortices without major modifications to the present design.

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 lead to the choice of the 1:2 scale and the technique envisaged to compensate for scale effects.

The current practice for modelling intakes for wet-well vertical pumps is to employ a scale of 1:10 to 1:15 and conduct tests with velocities up to prototype values. As discussed later, the use of prototype velocities is an empirical technique to increase circulation in an attempt to compensate for scale effects. There are, though, important differences between typical wet-well sumps and the intakes for the emergency cooling system. 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 presently known to affect vortex formation and an assessment of the adequacy of current modelling practice.

The degree of vorticity at an intake depends upon:

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, $\frac{2\ RVr}{Q}$, 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 preceeding 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 acceptable degree of scale effects introduced, which in turn depends upon the effect of the forces characterized by the dimensionless number on the phenomena under study. In some cases compensation can be made for a scale effect by a modelling technique, for example, increasing the slope of a diversion tunnel model to compensate for relatively greater friction in the model, if the scale is such that the model is relatively rougher than 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. The effect may be limited only to the persistence of a vortex and to a lesser degree on the inception of a vortex.

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, or 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 then, 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

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

results indicated that the effect of viscosity became of decreasing importance with increasing Reynolds number. At large values of Reynolds number the coefficient of discharge was independent of the Reynolds number and thus of viscosity and/or velocity. However, their results indicated that the effect of circulation on the discharge coefficient increased with increasing Reynolds numbers and at large Reynolds numbers of discharge was a function of circulation. Examination of the results of the studies by Dagget and Keulegan and others leads to two possible conclusions with respect to modelling intakes:

a. Circulation is an important parameter for prototype situations with large Reynolds numbers.

b. Any scale effects due to lack of Reynolds similarity may be offset by increasing the circulation.

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 in the flow inherent in the flow approaching the sump due to nonuniform velocity distributions, eddies, turbulence, and swirls.

The velocity distribution of the flow approaching the sump is in a geometrically scaled model affected by frictional resistance of flow surfaces and form drag of pipes, valves, and restraints. It is well known that fractional and form drag coefficients are independent of Reynolds numbers, provided the Reynolds number is sufficiently large. Circular cylinders are exceptions. This normally allows some leeway in the choice of model scale to reproduce resistance effects on flow distribution. However, unsteady flow associated with turbulence and swirls limits the scale reduction if these characteristics are to be reproduced in the model with a minimum of scale effects.

Unlike conventional wet-well sumps of simple plan configurations, the flow in the vicinity of the emergency cooling system intake will be non-uniform and 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, non-uniform flow. This scale assures that scale effects due to surface tension are minimum and the model Reynolds number will be sufficiently high with water heated to 170-180°F so as not to introduce significant scale effects on friction, form drag, and screen loss coefficients. Furthermore it is expected that these minimal scale effects can be offset by increasing circulation through conducting the tests at discharges greater than Froude scaled values. Because of low velocity heads involved, it is not expected that inertia-generated flow patterns will be unduly distorted by departing from Froude scaled discharges.

Lastly 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

Provided the above criteria are met, the model velocities can be increased by a factor of 4.11 for 180°F degree water temperature in the model without destroying kinematic similarity of eddy shedding. The factor 4.11 is the product of model length scale, Froude velocity scale, and the ratio of kinematic viscosities at 180° and 251°F. The test program presently envisaged proposes increasing the velocity by a factor of only 1.4.

4.0 THE TESTING PROGRAM

The test program developed after preliminary tests on the 1:2 scale model consists of eight series of tests: Series 1 through 5 have already been conducted. The program can be modified, as necessary, if test results show that a change is required. Series 2 through 5 are conducted without screens and grating and series 6 through 8 are conducted with screens and grating.

Vortices that developed in the vicinity of the intakes were classified as Type '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 Series 1 was conducted to determine the general flow characteristics with and without the intake screen and grating in place to determine whether objectionable vortex action develops and, if necessary, to determine whether minor modifications to intake design could eliminate such vortices.

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

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

4.1.1 Series 1 Test Results

4.1.2 Model Tests Without Screen and Grating in Place

The initial tests were undertaken to examine the performance of the system over a range of flow distributions and water temperatures, and to identify behavioral characteristics of the flow for the various conditions. The testing accomplished without screens and grating were accomplished in order to gather data for prototype flow and temperature correlations.

Some general observations were noted:

a. With a water surface el 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 was a general tendency for air-entraining vortices to form. The intake loss coefficient for the pipe intake did not appear to have changed appreciably.

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

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

e. The presence or absence of the perforated steel plate at elevation 558.0 feet, in the instrument tunnel, noticeably affected the flow pattern in the sump area. In the absence of the plate, less flow emerged from the ladder access tunnel and more came from the tunnel itself causing the flow to "spill" into the intake sump, thereby preventing the flow above the sump from organizing.

f. A tendency for increased vortex formation was noted when the water surface was raised from elevation 567.0 feet, which is immediately below the top tunnel plate, to elevation 567.5 feet which is slightly above the plate.

Under no condition of flow distribution, water level, or temperature did an air-entraining vortex persist for a prolonged period of time. 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.

In summary, Series 1 tests indicated that without the screen and grating there is a general tendency for vortex formation for all temperatures and water levels with air-entraining vortices being developed at lower water levels. The frequency of air-entraining vortices increased with increased percentage of flow from Q_2. Under no condition did sustained air-entraining vortices persist for more than 20 to 30 model seconds.

4.1.3 Model Tests With Screen and Grating in Place

A series of tests were conducted with grating and screen in the model. The grating was constructed at a scale of 1:2 and the model screen was very close to a 1:2 scale with the wire diameter of 0.059 inch and percentage opening of 51.8.

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

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

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

a. Whereas without screens and grating in place there was a tendency for air-entraining vortices to develop for low water levels; with the screen and grating in place no air-entraining vortices established an air cord to either intake, with or without blockage.

b. Type 'A' nonair-entraining vortices did develop and occasionally a pocket of air would be drawn through the screen. This pocket of air would be broken into small bubbles by the screen. The small bubbles generally dispersed within the screen area and rose to the surface.

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

4.2 Series 2 is 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. This test was required specifically for Test Series 3.

Series 2 tests were carried out at ambient temperature using Froude scale discharges 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 were recorded for 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.

4.2.1 Series 2 Tests Results

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

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

4.3 Series 3 is to determine the effect of temperature and flow rate on the type, frequency, and duration of vortex formation. This series was designed to facilitate extrapolation of model results to predict prototype conditions.

Series 3 tests were carried out at temperatures of approximately ambient, 100°, 140°, and $170^{\circ}F$ 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, motor voltages, and currents 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.

4.3.1 Series 3 Tests Results

a. The frequency of type 'A' vortex increased with temperature at a given discharge. The rate of increase in vortex frequency with increase in temperature is less for discharges greater than the Freude scale discharge.

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

c. However, there is 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 remains constant.

d. The trend in frequency of type 'B' vortices when kinematic viscosity and discharge suggest that the frequency of vortex formation is Reynolds number dependent.

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

4.4 Series 4 tests are to determine whether conditions at the intake are sensitive to the direction of Q_2 flowlines entering the model.

Series 4 tests were carried out at approximately 100°F and 1.4 times Froude scale discharges with the following flow distirbution (figure 1):

Q_1 - 15%

Q_2 - 60%

Q_3 - 25%

Each test was carried out for three different directions of the Q_2 approach flow controlled by guide vanes. The angles were 90, 110, and 140 degrees with 90 degrees being 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.

4.4.1 Series 4 Tests Results

Series 4 tests were conducted to examine the influence of approach conditions of Q_2 on the formation of vortices. The test was conducted at three water levels and temperatures with a total discharge of 1.4 times Froude scaled prototype discharge.

The results indicate 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 is significant for a vane angle increase from 90 degrees to 110 degrees and less significant for the increase from 110 to 140 degrees. This suggests that Test Series 6, 7, and 8 should be conducted with a vane angle of 110 degrees.

4.5 Series 5 determined 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.

Tests were completed in which the flow split between the instrument tunnel and inspection tunnel were investigated. Tests were run at water surface elevation of 567.5 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

4.5.1 Series 5 Tests Results

Analysis of the test data does not indicate any definite trend in vortex formation potential with a variation in flow distribution between the instrument tunnel and the inspection tunnel. Therefore future testing will be conducted with the instrument tunnel and inspection tunnel approximately equal.

4.6 Series 6 tests determine that no tendency for vortex action develops when the intake screen is blocked. Five blockage conditions will be tested (Figure 2). If any tendency toward vortex formation is noted further modifications or additions will be made to the screen and grating design to eliminate this tendency.

4.7 Series 7 tests will examine the performance of the intake, modified as described for single intake operation with and without screen blockage.

4.8 Series 8 tests will examine the performance of the intake without screen blockage and with both intakes operating.

The results of the test data from Series 1 through 5 will be incorporated in Series 6, 7, and 8 which document intake flow characteristics in detail over sufficient range of operating conditions to make prototype operation predictable. The Series 6 to 8 tests are designed to prove the adequacy of the final screen and grating configuration.

As described below a modification has been developed and will be tested. Tests in Series 6, 7, and 8 will be documented to verify that both single and combined intakes operate free from objectionable vortex action over the range of operating conditions, with and without screen blockage.

Screen tests will be conducted concurrently to determine the head loss characteristics of the prototype and model screens.

4.9 Support Testing

4.9.1 Screen Tests

Sections of both the selected model and prototype screens were tested in 80 ft long flume. The screens are located 40 ft downstream from flow straightening baffle. Screens dimensions are tabulated below:

	Model	Prototype
b, inches	0.0495	0.0909
M, inches	0.1638	0.3346
S, %	48.2	46.95

Where b is wire diameter, M is mesh spacing, i.e., centerline spacing between wires, and S is solidity ratio defined as the ratio of blocked area to total area.

Six stilling wells were installed to measure hydraulic gradeline. Three were located 5.2, 7.8, 10.4 ft up stream from the screen. Three were located 2.6, 4.1 and 5.6 ft downstream from the screen. Water levels were measured with point gages tied to a datum.

A range of discharges was established to vary the approach flow velocity. Discharges were measured by orifice meters.

5.0 SUMMARY AND CONCLUSIONS

The 1:2 scale model that is being used to examine and develop an intake configuration for the emergency cooling system pump intakes has been described, and the test procedures and the test results to date have been presented. The pertinent results of the study are:

1. Without the screen and grating in place, there is a tendency toward vortex formation for all of the combinations of water level and temperatures used in this investigation. Air entraining vortices developed at some lower sump water levels, the frequency of which increased with an increase in discharge or water temperature.

2. Preliminary tests conducted with model screen and grating in place showed that the screen and grating prohibited penetration of any air cord vortices at temperatures up to 170°F. Under some conditions with blockage above 50%, a stationary air entraining vortex could be formed outside of the screen and grating. If the air core penetrated the screen and grating, it was broken into small bubbles which would rise to the top of the screen and pass upward through the screen.

These results indicate that the screen and grating may be sufficient to prevent vortices from affecting the pump performance, provided that these results can be extrapolated to prototype conditions.

For the following reasons extrapolation of these results is tenuous:

1. Although the screen and grating effectively prevent the vortices from reaching the intake in the model, the tendency toward vortex formation is still apparent in the flow outside the screen. On the basis of these tests it is difficult to predict positively that a decrease in viscosity, due to an increase in water temperature from 170°F to 251°F, would cause changes in the flow pattern which in turn would lead to formation of vortices that penetrate the screen.

2. Even though other investigations have found that the characteristics of an air entraining vortex are independent of surface tension effects, it is not likely that the passage of air through a screen is also independent of this effect. Because the surface tension of

water decreases as the temperature increases, the model is probably not a conservative estimator of the effect of the screen on an air entraining vortex.

In view of the uncertainities involved in extrapolating the results of this study to prototype conditions, the program of model tests presented in the next section is recommended to complete the investigation of vortices at the emergency cooling water system intake.

6.0 REMAINING STUDY ACTIVITIES

The results of the present investigation show that the screen and grating prevents the air core from extending to the intake pipes. The tendency toward vortex formation and the effects of a screen on an air core are apparently influenced by Reynolds Number and Weber Number as discussed previously. Consequently, some means of preventing the formation of vortices altogether that will operate independent of Reynolds and Weber Number effects is required.

A simple grating will fulfill this requirement. Floating gratings have been used effectively to prevent surface vortices at many installations. However, it is difficult to develop a design that will float all of the time. For this application, a series of fixed gratings is proposed. This approach eliminates the disadvantages of a floating grating and has the advantage that the grating is really most effective when submerged slightly below the free surface.

Flow through horizontal grating elements will create a flow pattern that is essentially independent of Reynolds Number. Because there will be no air entraining it is not necessary to consider Weber Number effects. Consequently, the model can be used to determine the number and spacing of the gratings required to prevent any tendency toward vortex formation, and the result can be extrapolated to the prototype with confidence.

The general approach to the development of a satisfactory set of gratings is as follows:

1. Beginning at the minimum sump water level, determine the practicable aerial extent and elevation of the grating required to eliminate the tendency toward vortex formation.

2. Raise the sump water level until a tendency toward vortex formation appears. Then install another grating and determine its location as required to eliminate the tendency toward vortex formation.

3. Repeat the procedure in 2 above, for the next grating and use this spacing to create a stack of gratings up to elevation 572. A check of effects of water temperature on the flow pattern would also be made.

4. Conduct test Series 6, 7, and 8 to demonstrate that the tendency toward vortex formation has been eliminated for all anticipated sump flow conditions. Make modifications to the grating configuration if necessary.

The tests used to establish the initial grating configuration would be based upon the studies to date. Series 6, 7 and 8 would be conducted at a water temperature of 140°F which provides a low viscosity with reasonable practicability in conducting the model tests. This temperature is selected to facilitate model operation. The tests will be made at 1.4 times Froude scale discharges.

The complete set of gratings, together with the original screen and supporting gratings will provide an extremely conservative approach to the prevention of vortices at the emergency cooling water intake. Rather than decide what degree of vortexing is permissible, the vortexing and indeed the tendency toward vortexing, will have been eliminated altogether. Should some operating condition result in formation of a vortex, the present series of tests shows that the existing screens and gratings will prevent deleterious effects from reaching the intake and affecting the pump performance.

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."

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 Califormia, 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.B., and Daggett, L.L., "A Note on Gravity Head Viscometer," *Miscellaneous Paper H-74-3*, United States Army Engineer Waterways Expermient Station, Crops 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).

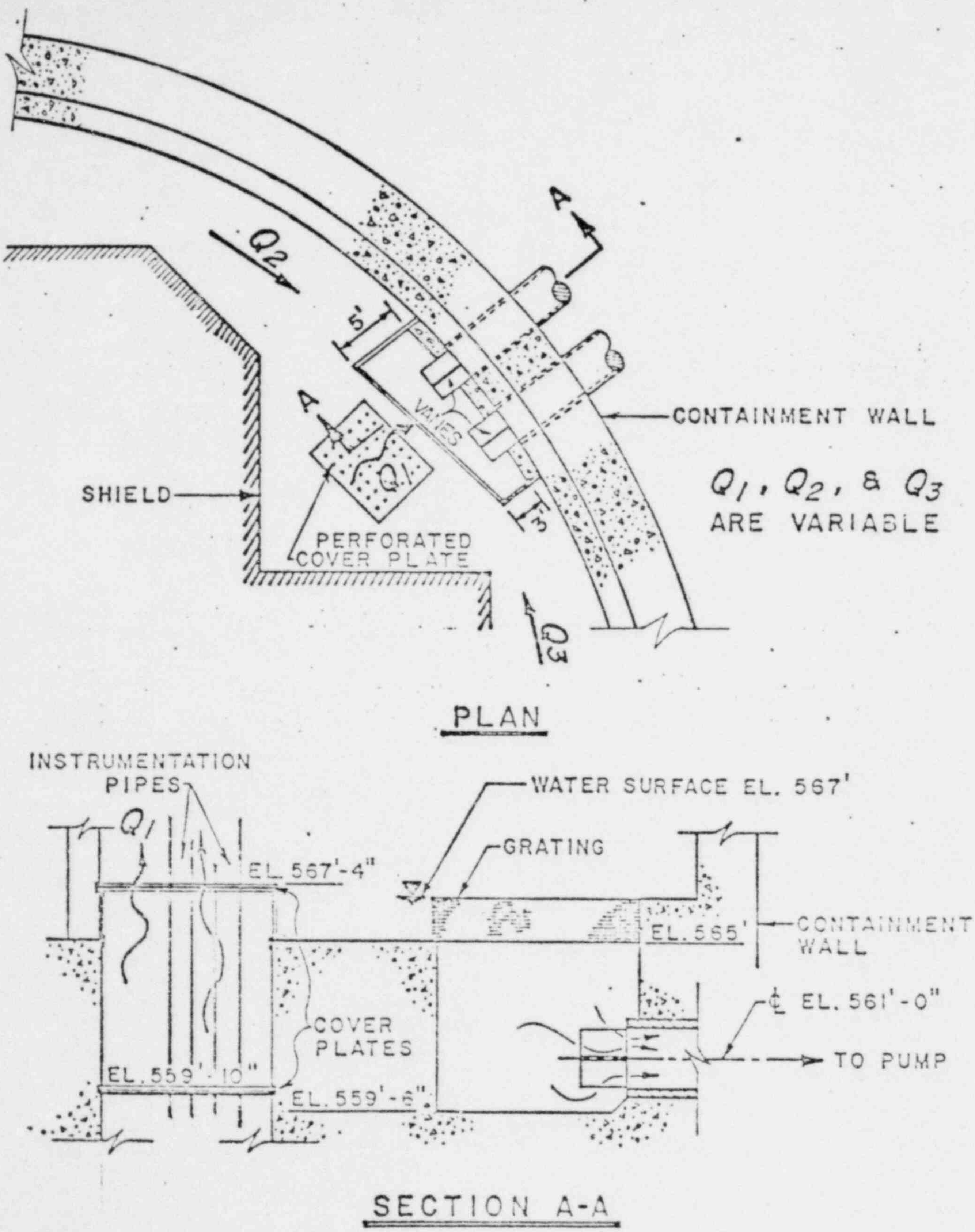
51. Stevens, J.D., discussion of "The Vortex Chamber as an Automatic Flow-Control Device." by R.C. Kolf and P.B. Zielinski, *Journal of the Hydraulics Division*, ASCE. vol. 86, No. HY6, Proc. Paper 2525, June 1960.

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. Zelinski, 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.



Q1, Q2, & Q3 ARE VARIABLE

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

DAVIS-BESSE NUCLEAR UNIT #1

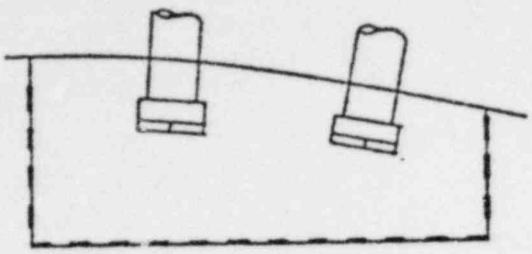
Schematic of the Pump Intake

NOT TO SCALE

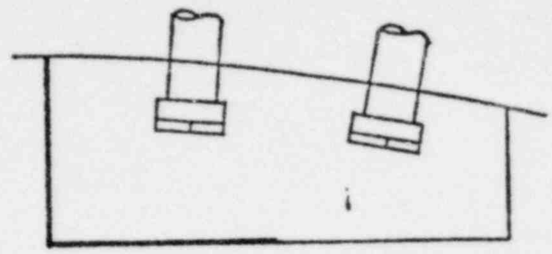
Rev. 1
5/24/76

Fig. 1

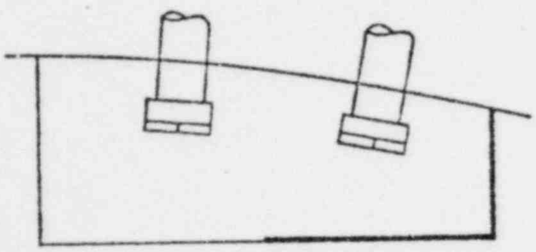
FIGURE 2



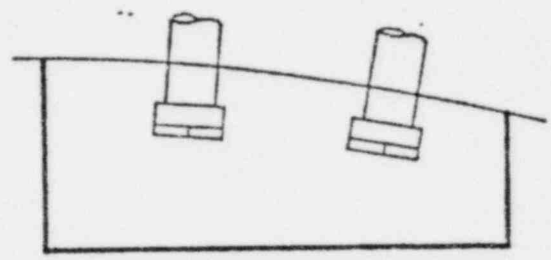
(A) TOP BLOCKED 100 %
VERTICAL SCREEN BLOCKED 50 %
OVER FULL HEIGHT BY ALTERNATE
3" WIDE OPEN AND BLOCKED STRIPS.



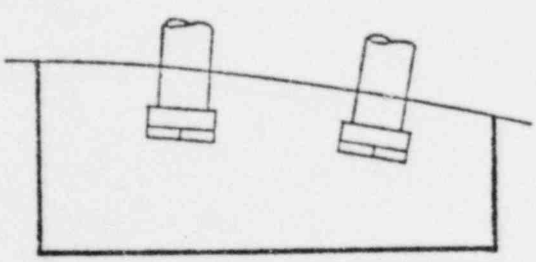
(B) TOP BLOCKED 100 %
VERTICAL SCREEN BLOCKED OVER
FULL HEIGHT OVER PORTION OF
HEAVY LINE.



(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
HYDRAULIC MODEL STUDIES
EMERGENCY COOLING SYSTEM INTAKES

CONFIGURATIONS FOR
SCREEN BLOCKAGE TESTS

BCIL 5687A - WCH