SECTION D

DESIGN, CONSTRUCTION AND OPERATION OF THE EXPERIMENTAL FACILITY

by

C. R. Dudgeon and W. H. C. Swan.

SECTION D

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1. Introduction

The well simulation tank was designed and constructed specifically for use in studying the hydraulics of flow into wells and practical aspects associated with well drilling and development.

The immediate uses envisaged for the experimental facility were:-

(i) verification of the theoretical and numerical methods developed to study the pattern of flow through the aquifer in close proximity to wells and to predict flow rates and drawdowns:

(ii) verification of design graphs and tables to be prepared using a digital computer;

(iii) study of the flow phenomena in the well and in the vicinity of the well boundary (e.g. at screens);

(iv) study of the effects of drilling and development techniques on the hydraulic properties of the aquifer material near the well.

Future uses might include the testing of new types of commerical screens, pumps and other types of equipment.

It was considered that to meet current and future needs the facility should be designed:-

(i) to be as flexible in operation as possible;

(ii) to allow various types of instrumentation to be installed without difficulty or structural modification;

(iii) to allow confined and unconfined flows to be studied with velocities at the screen up to those met in high yielding wells in the field;

(iv) to allow model or small size prototype studies to be carried out for either -

(a) a full circle portion of a well and surrounding aquifer,

(b) a quadrant portion of a well and surrounding aquifer;

(v) to allow observation of flow along a radial plane for the quarter well case;

(vi) to be relatively maintenance free;

(vii) to minimise material handling problems;

(viii) to allow experiments to proceed regardless of weather conditions.

Because of scaling problems involved in non-linear flow through porous media, the larger the tank the better but the greater the problem in handling aquifer material. It was clear that as regards size, a compromise, governed mainly by the cost, materials handling and available space would be necessary.

2. Design Selected

2.1 General Layout

As a compromise between the conflicting requirements, a square tank in plan, with internal dimensions of 16' x 16' x 11' was selected. The general layout of the tank and associated structures is shown in Figures 2.1 and 2.2.

The square section was selected as it allowed tests to be performed either on a quadrant of an aquifer of 16 ft. radius with the well located in one corner of the tank or on a circular aquifer of 8 ft. radius with the well located in the centre of the tank. Provision of inspection windows in the wall of the tank common to the instrumentation annexe allow observation of flow along a radial plane for the quarter well case.

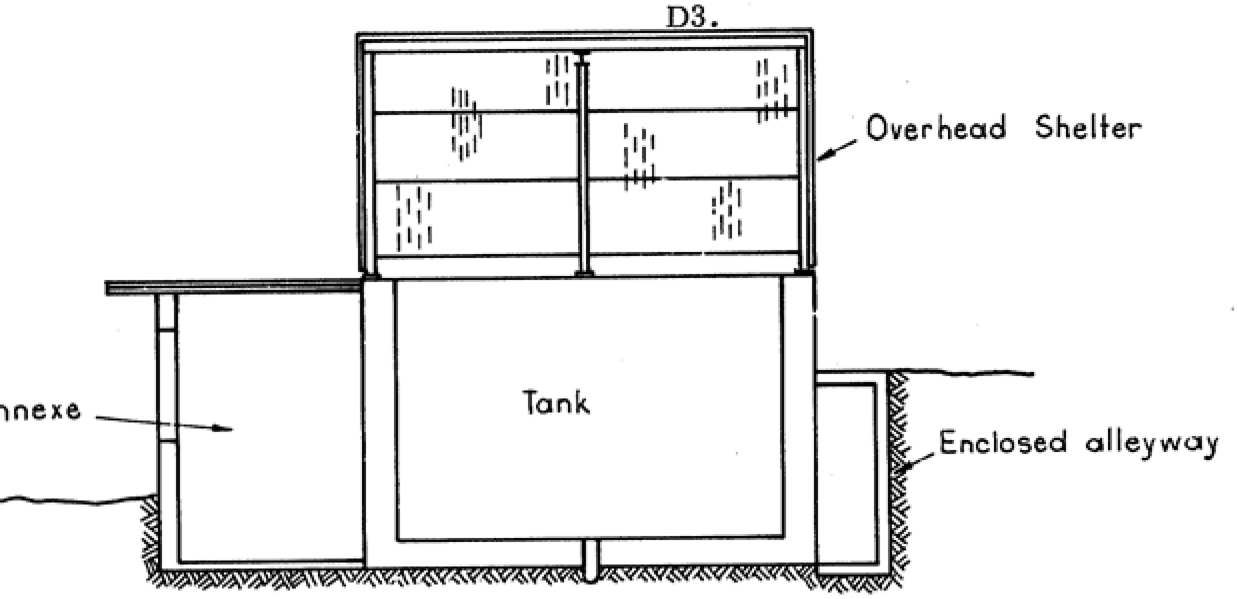
Other advantages of a square section were the ease of forming for construction, the existence of space for stilling areas at the corners and the ease of fitting a pressure resisting cover to allow confined flow cases to be studied under high flow rate conditions.

The pressure resisting cover was located approximately 5 ft. above the floor of the tank. The design head on the cover was 55 ft., applied through a recirculating pump with provision for damping pressure fluctuations.

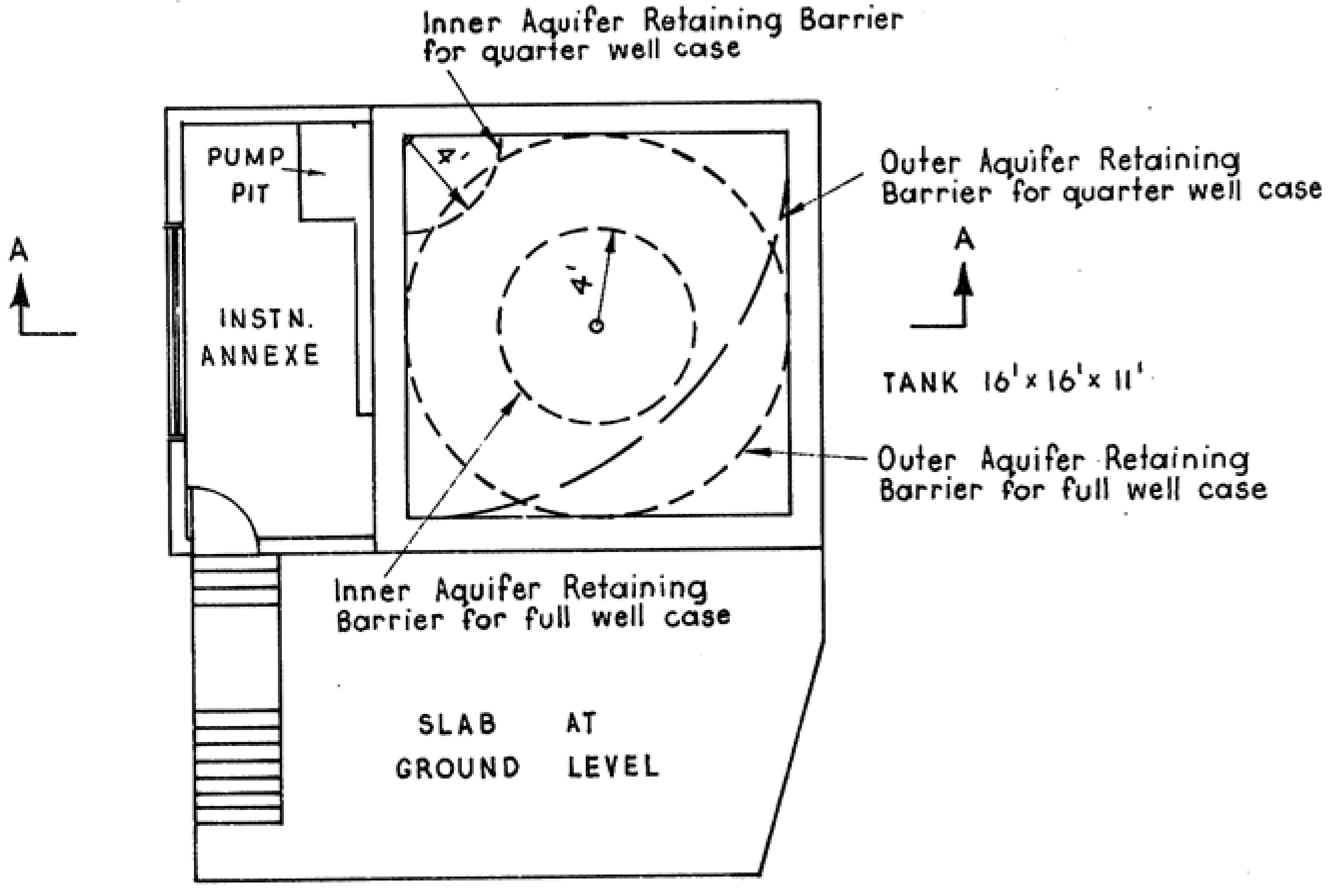
A major design problem was to allow for the transfer of the upthrust on this cover to the walls of the tank.

2.2 Location

The tank was sited in the grounds of the Water Research Laboratory on a rock ledge adjacent to a bank of convenient height.



ELEVATION A-A



FLOOR PLAN

Scale : ⅓" = 1' 0"

FIGURE 2·1 : WELL TESTING FACILITY

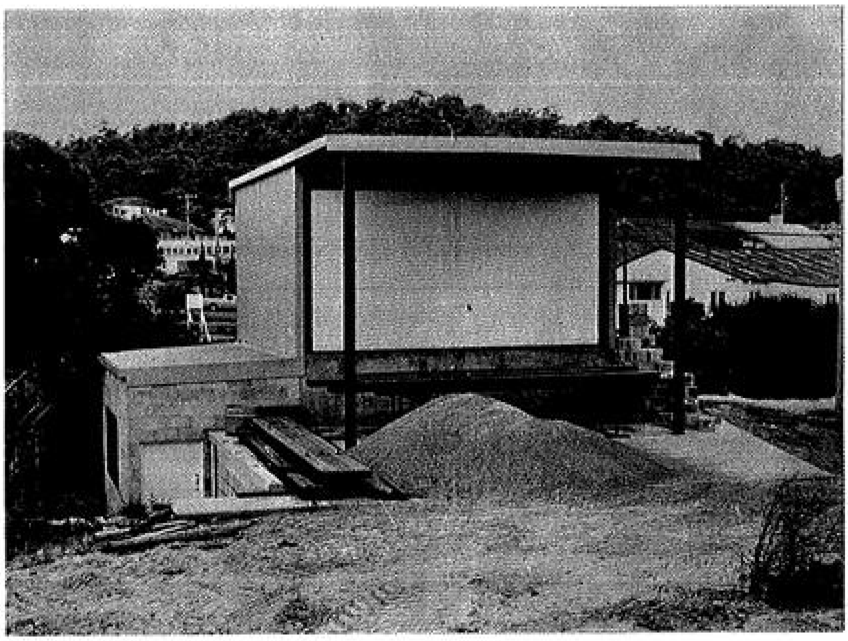


Figure 2.2: Well Testing Facility.

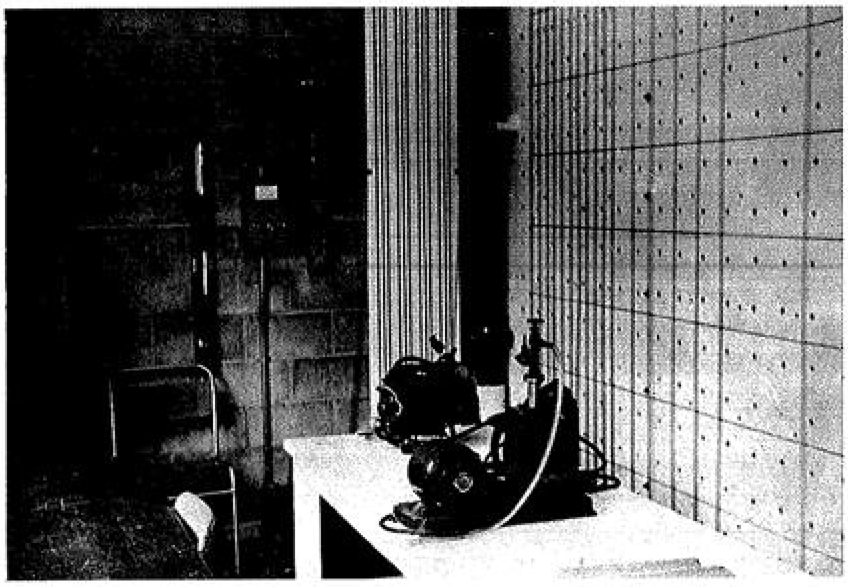


Figure 2.3: Internal view of Instrumentation Annexe showing Orifice Manometer Panel (centre) and Piezometer Tubes (right)

As can be seen from Figure 2.1 this allowed the base of the tank to be placed below the level of the adjoining working area. A covered walkway between the tank and the masonry wall retaining the bank allowed access to all sides of the tank and the pipe system. The concrete roof of the walkway formed part of a paved area approximately 4 feet below the top of the tank walls at the level of the main working area. The arrangement allowed easy access to the top of the tank for transferring materials and equipment and afforded a sheltered paved working area in front of the tank.

A large concrete bin for storing aquifer material was located immediately in front of the tank.

2.3 Structural Design

Design calculations for the confined case design head of 55 feet resulted in a base and wall thickness of 15 inches with heavy reinforcement in both floor and walls to resist the upward thrust on the confining lid.

It was initially intended to have the pressure cover at the top of the tank but because of the high shear stresses in the concrete the cover was placed nearer the bottom. A removable flange is provided around the inside of the walls to take the weight of the cover. Upthrust is transferred to the reinforced concrete walls by a system of steel beams and trusses. The lower level of the cover in no way hampers the operation of the tank for either confined or unconfined aquifer tests. To have increased the thickness of the tank walls to resist the shear with a full height cover would have increased the cost considerably and made the provision of access and inspection holes through the walls impracticable.

2.4 Instrumentation Annexe

An instrumentation annexe approximately 9 feet wide extends the full length of one side of the tank. Masonry block walls, a concrete floor and insulated roof prevent rapid fluctuations of temperature within the annexe.

2.5 Instrumentation and Inspection Holes

A mosaic of $\frac{1}{2}$ inch diameter holes at 1 foot centres left in the walls of the tank allow access for instrumentation wires and tubes. The holes were formed by P.V.C. tubes through which form tie bolts passed during construction. Each tube had its own waterstop cast into the concrete and can be plugged at its inner or outer end.

In the wall common to the tank and annexe, 1 inch diameter holes at 6 inch centres were provided in addition to the instrumentation holes. (Fig. 2 The P.V.C. tubes which lined these holes were fitted with transparent windows at their inner ends to allow flow through the aquifer material at the wall to be observed when a corner well was being tested. The diameter of inspection hole selected was considered the smallest which would allow scrutiny of typical zones of the coarsest aquifer material likely to be used. A small illuminating telescope was required for detailed observation.

Part of the interior of the instrumentation annexe with manometers and observation holes at the corner well position is shown in Figure 2.3.

2.6 Overhead Shelter

A portal frame enclosure was constructed over the tank and covered with steel sheeting to protect models in the tank from the weather. Double doors fitted to the accessible side of the enclosure opened out to combine with a roof extension to form a sheltered working area in front of the tank.

2.7 Water Supply and Pipework

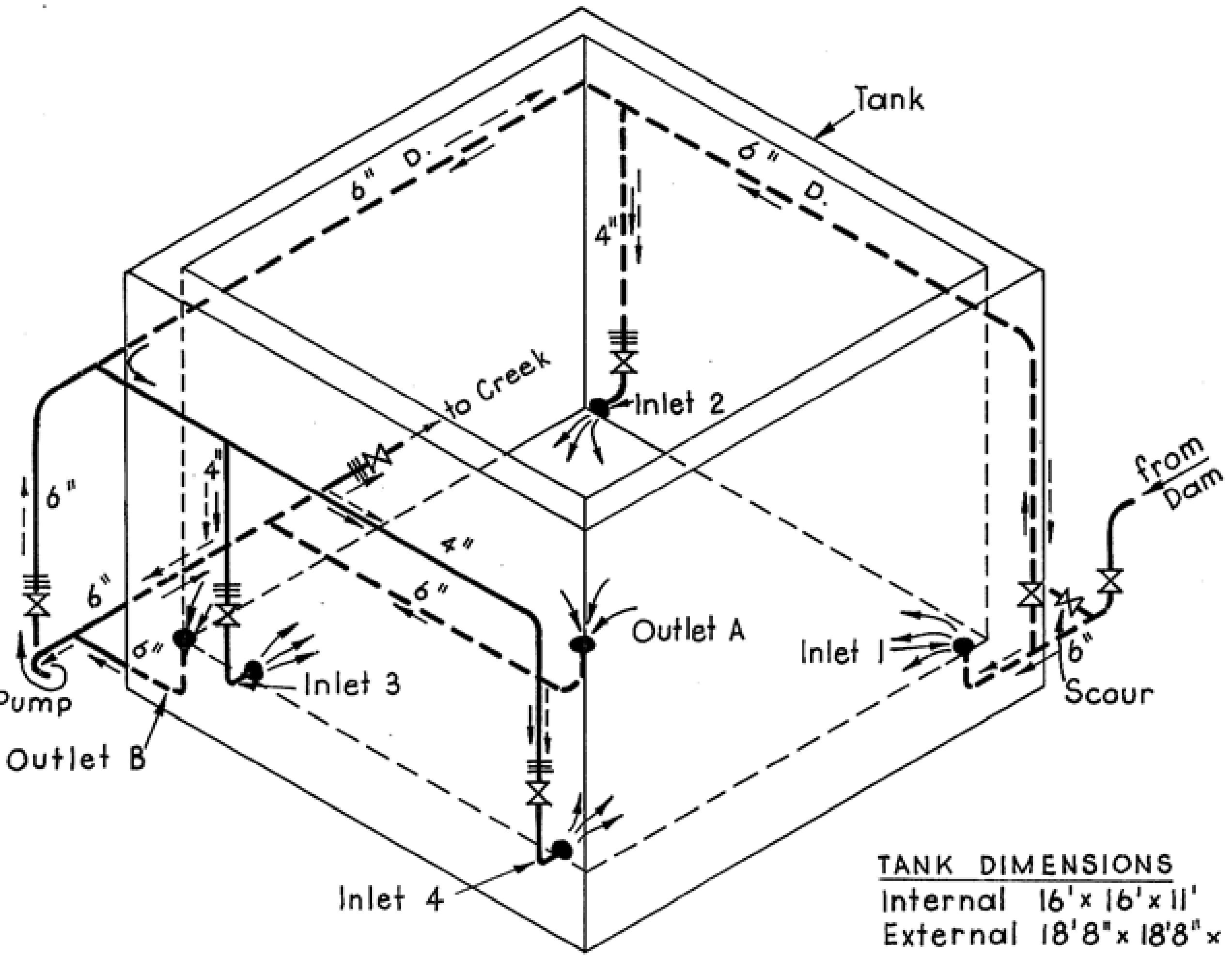
The flexible arrangement of 6 inch and 4 inch pipes selected allows gravity driven or pumped water supplies to be fed to and drawn from wells placed at the centre or corner of the tank. Figure 2.4 shows the layout in diagrammatic form. Gravity flows up to 2 c.f.s could be drawn from the laboratory's reservoir at inlet heads of up to 20 feet. A 6 inch centrifugal pump fitted with a 20 H.P. motor and capable of delivering 2 c.f.s. against a head of 60 feet was used to recirculate water through the tank. The head-discharge characteristics of the pump were such that the pump could be used to supply maximum discharge at the tank's design head.

2.8 Electric Hoist

With a view to easing the materials handling problem a movable hoist rail was hung from the overhead shelter structure. An electric hoist with a safe working load of 1 ton moving on this rail allows items of equipment, sections of the cover and aquifer material to be transferred to and from the tank.

2.9 Outer Aquifer Retaining Barrier

Initially it was intended to use only 16 gauge perforated steel sheets, joined together to form a circular barrier, to retain the aquifer material,



TANK DIMENSIONS
Internal 16' × 16' × 11'
External 18'8" × 18'8" × 12'3"

≡ Orifice Plates shown thus

1. With ¼ well under investigation Inlet 1 only to be used and Outlet A, to be blank flanged; valves on Inlets 2,3,4 to be enclosed.
2. With full well under investigation use all Inlets and blank flange outlet B
3. With pump in operation flow shown — — ►; gravitate ——►

FIGURE 2·4: EXPERIMENTAL FACILITY PIPEWORK AND FLOW DIAGRAM

Figure 2.5: Internal View of Observation Wall.

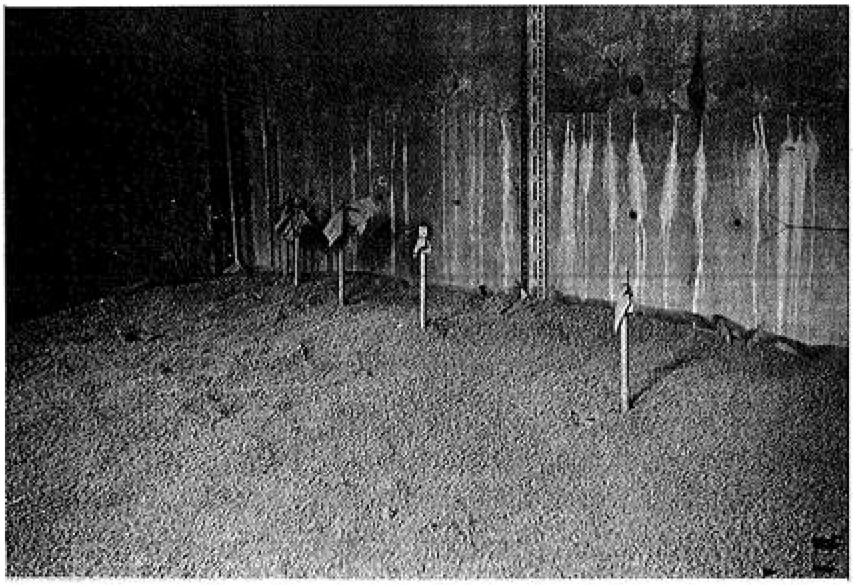


Figure 2.6: View of Aquifer Material in Tank showing Location of Inner Aquifer Retaining Barrier and Multiple Observation Wells.

allowing the load to be taken by the metal in hoop tension. However, difficulties arose in transferring the load between sheets, and to the tank wall in the case of a quadrant aquifer, as it was decided to limit the aquifer thickness to 5 feet until suitable connections could be developed. The solution adopted was to connect the sheets to prefabricated curved steel frames bolted together to form a cylindrical barrier. Connection of these frames together and to the walls by bolts can be done quickly and easily with the aid of the hoist.

2.10 Inner Aquifer Retaining Barrier

A 4 feet radius inner barrier was provided to allow aquifer material close to the well to be removed without disturbing the bulk of the aquifer. This allowed the task of changing screens and gravel pack material to be speeded up and the packing of the major part of the aquifer to remain unchanged. The barrier was made from perforated 16 gauge steel sheet, curved and corrugated to allow it to resist compressive loading without buckling. The open area of the barrier was 52% which was considered great enough to prevent additional flow resistance being introduced at this point. This view was confirmed by observation of the hydraulic grade line through the aquifer in the vicinity of the barrier.

A view of part of the interior of the tank showing the positions of the corner well and inner retaining barrier is shown in Figure 2.6.

3. Instrumentation

3.1 Piezometer Tappings

Copper tubes were set into the tank floor during construction on a radial line from the corner well outlet to the diagonally opposite corner. The spacing was varied as shown in Figure 3.1 to allow for the greater rate of variation of pressure towards the well locations. The tubes were led to the outer edge of the tank base, those originating between the corner and centre well positions terminating in the annexe, the remainder in the covered space on the opposite side. A screwed brass tee fitted to the end of each tube allowed permanent connections to be made to a bank of manometer tubes and additional connections to pressure gauges or transducers as required.

Additional piezometers can be inserted at any point required by taking advantage of the access holes in the walls.

3.2 Pressure Gauge and Transducers

A "Precision Pressure Gauge", Model 145, was purchased from Texas Instruments Inc., U.S.A. to allow rapid and accurate measurements of pressure to be made for both steady and unsteady flow conditions. It is also intended to use capacitance pressure transducers for unsteady flow work in future studies in the tank.

3.3 Orifice Plate Meters

Discharges were measured by D and D/2 orifice plate meters manufactured according to the specifications of the British Standard Code for Flow Measurement, B.S. 1042, Part I, 1964. The upstream and downstream lengths of adjacent straight piping specified by the code could not be provided because of the short piping runs but the deviations from the standard were not great. Calibration runs showed no significant differences between computed and actual discharge coefficients for all flow conditions.

Meters were provided on the discharge side of the pump and at each of the corner inlets so that the total flow and distribution of flow could be measured.

3.4 Contact Electrode Gauge for Measuring Water Levels

A relatively inexpensive stainless steel contact electrode using a low voltage battery, transistorised amplifying circuit and indicator light was developed for measuring water levels in the main and observation wells. It proved to be accurate and reliable and warrants development as a field instrument.

3.5 Multiple Observation Well

To allow measurement of piezometric heads to be made at various levels at a given point in the aquifer a multiple observation well was developed. This consisted of a length of P.V.C. tube with holes drilled at 1 foot intervals and a series of sliding valves which allowed the holes to be covered or uncovered as required without disturbing the piezometer tube or the surrounding aquifer material. The valves were operated by a rod inserted from the top of the well.

These observation wells were placed in the aquifer on a line radiating from the pumped well.

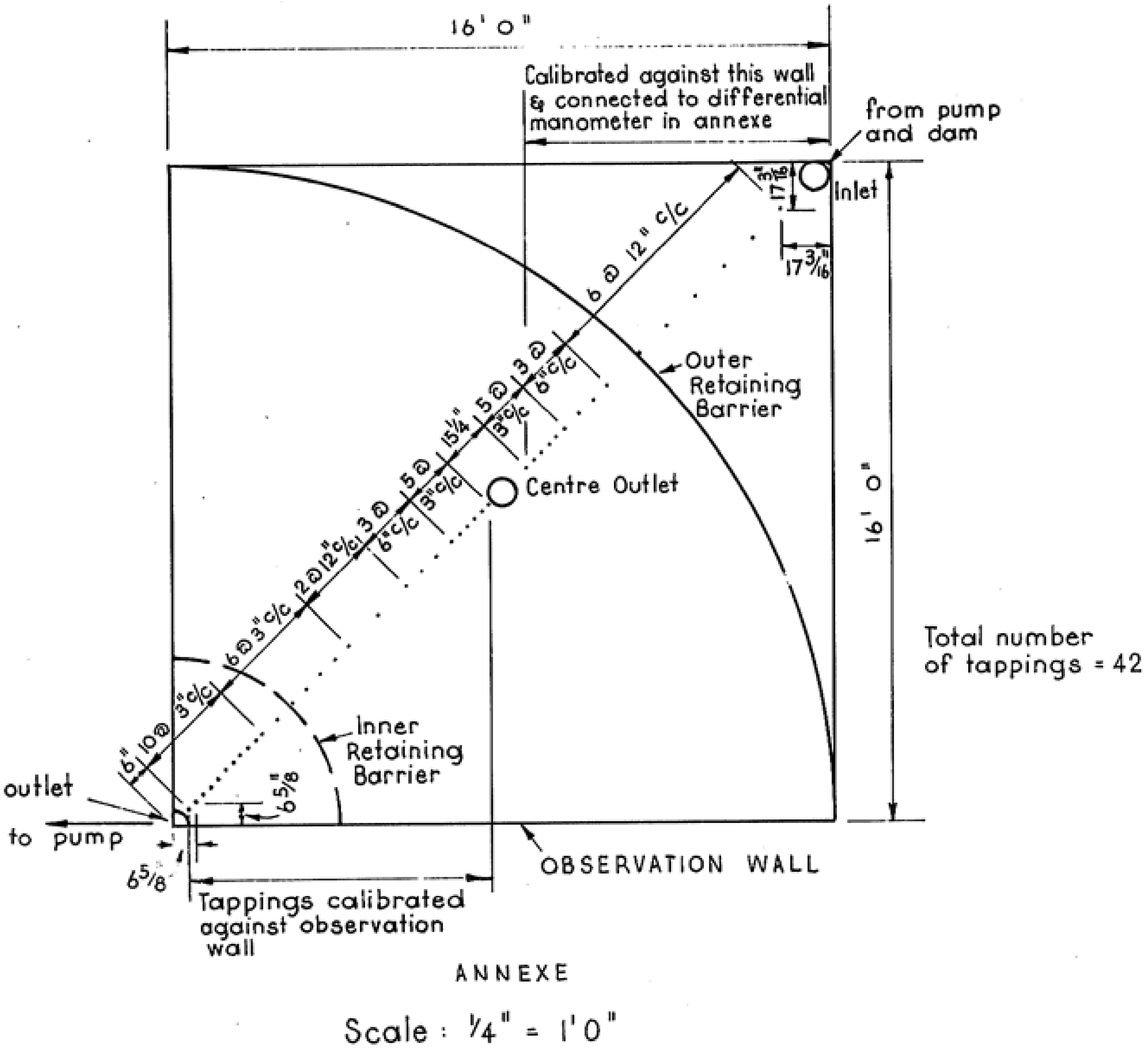


FIGURE 3·1 : LOCATION OF PIEZOMETER TAPPINGS AND AQUIFER RETAINING BARRIERS

4. Operation of Experimental Facility

4.1 Calibration

The manifolds which linked the manometer tubes on each side of the tank were joined through a connecting manometer so that levels on each side could be inter-related. Since the roofs of the instrumentation annexe and walkway were at different levels it was found necessary to depress the water levels in the manometer tubes in the walkway below the corresponding levels in the annexe. Horizontal lines at 1 foot vertical intervals were drawn on the tank walls behind the manometers to allow readings to be compared. Distances between calibration lines were measured with a 12 inch rule to an accuracy of 1/16 inch.

The tappings of the orifice plate meters were connected to a panel of manometers provided with scales graduated to 1/8 inch. Calibration runs using the best, worst and intermediate combinations of flow rate and orifice diameter showed that differential heads measured on these scales did not differ significantly from values computed according to the flow code B.S. 1042 despite the upstream and downstream pipe lengths being somewhat shorter than specified by the code. The tank served as a volumetric measuring tank for flow meter calibration. Water was run into or out of the tank through the meters over measured time and depth intervals.

4.2 Placement of Aquifer Material

Aquifer material was placed in the tank by tipping it from buckets carried by the hoist. Care was taken to avoid uneven compaction.

4.3 Flooding of Aquifer Material

The tank was filled slowly to allow time for air to escape in advance of the wetting front. There was no indication of appreciable volumes of air trapped between the aquifer particles.

4.4 Determination of Effective Porosity of Aquifer

After initial wetting, the aquifer was allowed to drain for a week. The tank was then re-filled slowly. The volumes of water required to fill the pores in the aquifer were determined over successive depth increments. Effective porosity values were calculated from the measured volumes of gross space occupied by the aquifer and water added.

4.5 Confined Aquifer Testing

Initial confined tests were made by covering a 5 feet thick aquifer with polythene sheeting held down by several inches of aquifer material and sealed to the edges of the tank. Water above the confining layer applied additional force to hold the sheeting down and at the same time provided head to drive water through the aquifer from the outer perforated metal boundary to the well which was left open to the atmosphere.

Because of the shortage of time between completion of construction of the tank and the completion of the current project it was decided to defer the use of the pressure resisting lid until experiments on development processes were performed in the succeeding project. Further confined tests at higher flow rates could be carried out at that time in conjunction with determining the effects of development on the hydraulic characteristics of the aquifer material near the well.

It was found that, even with the relatively small heads available with the open tank, non-Darcy flow occurred near the well, allowing sufficient data to be obtained for comparison with computed values.

4.6 Unconfined Aquifer Testing

Priority was given to confined aquifer tests as by far the greatest proportion of aquifers throughout Australia are of this type. However, by drawing down the water surface in the well sufficiently, the confined aquifer could be used for unconfined flows as the aquifer material was coarse enough to allow ready entry of air and make capillary fringe effects negligible. It was thus possible to obtain experimental data for comparison with computed values for unconfined flow. Measurements of the vertical variation in head at various distances from the well were also made for comparison with computed values.

5. Laboratory Tests

5.1 Objectives

The ultimate objectives of the laboratory tests in the experimental facility are to investigate under controlled conditions flow through well screens and the surrounding zone of the aquifer which is affected by construction and development of the well. Losses can then be identified, calculated and minimised and flow rates maximised.

In the laboratory tests performed to date, the objectives included verification of the steady state flow analysis postulated in the numerical studies for a confined aquifer , the determination of the coefficient of hydraulic conductivity 'k', the determination of the Forchheimer coefficients 'a' and 'b', the determination of the critical Reynolds Number $\mathbb{R}_{cr}$ for the transition from the linear flow regime to the nonlinear flow regime and the determination of the effect of the inner aquifer retaining barrier on the flow.

5.2 Test Procedures

Before the commencement of tests the experimental tank was allowed to fill slowly in order to allow the vast majority of the air in the pores of the aquifer to escape. Once the water level in the experimental tank had covered the top of the aquifer model the remainder of the volume of the tank was filled rapidly.

Careful examination of all piezometer and manometer tubes was carried out to ensure no airlocks were present. Any airlocks were subsequently removed by flushing.

The recirculating pump was then started and run for a period of approximately 15 minutes to ensure that all air trapped in the recirculating pump, pipeline and aquifer material near the well screen was removed as evident from the lack of air bubbles in the recirculated water entering the tank in the stilling area outside the outer aquifer retaining barrier. During this time the desired flow rate was set by means of a throttling valve on the opposite side of the tank to the instrumentation annexe.

When all air had been removed, the pump was shut off and the system allowed to settle down. This afforded time to recheck all the piezometer and manometer tubes.

The differential manometer levels for the orifice plate meter above the pump were then depressed and the pump started. Careful manipulation in depressing the levels of the manometer was required after the starting of the pump in order to keep the levels on scale. The depression of the manometer levels was accomplished with the aid of compressed air from a small cylinder.

Upon attaining steady state conditions the orifice manometer was then observed, followed by the observation of the connecting manometer between the piezometer manifolds, the well drawdown and then the piezometer tubes. Periodic checks were made of the levels in the orifice manometer, the connecting manometer of the piezometer manifolds and the well drawdown to ensure that steady state conditions were attained. Any major fluctuations resulted in the test being discarded and a new test re-run at the same discharge.

At the completion of the test, the throttling valve was reset to a new discharge and the test procedure repeated.

5.3 Experimental Results - Confined Aquifer

5.3.1 Laboratory Test Results

All results obtained from the laboratory tests were tabulated, and later prepared for inclusion as data into a Fortran IV computer programme for processing. A tabulation of the results from twentyone tests is given in Table 1. A semi-logarithmic plot of drawdown against radial distance from the well for six of these tests is shown in Figures 5.1 and 5.2.

5.3.2 Sieve Analyses

Sieve analyses were performed on the aquifer material used in the laboratory tests. The results of the analyses using the British standard sieve series are given in Figure 5.3.

5.3.3 Effective Porosity Measurements

The effective porosity of the aquifer material was determined by volume measurement during the slow filling of the tank and aquifer model. Results of the tests are tabulated in Table 2.

Table 1: Experimental Results - Confined Aquifer

Test	Discharge Q (cusecs)	Well Draw-down s_w	Drawdown at Radius r from Well, s(ft)							
			r=0.50	0.75	1.00	1.50	3.00	5.00	7.00	10.00
1	0.052	0.080	0.070	0.062	0.057	0.046	0.026	0.010	0.002	0.000
2	0.083	0.18	0.164	0.143	0.133	0.112	0.081	0.055	0.039	0.029
3	0.129	0.31	0.253	0.212	0.191	0.160	0.108	0.066	0.045	0.019
4	0.183	0.47	0.364	0.309	0.270	0.228	0.161	0.109	0.077	0.041
5	0.204	0.59	0.466	0.403	0.356	0.294	0.205	0.143	0.101	0.052
6	0.213	0.73	0.533	0.486	0.419	0.346	0.247	0.174	0.116	0.070
7	0.222	0.76	0.541	0.437	0.382	0.314	0.221	0.142	0.093	0.043
8	0.272	0.80	0.606	0.518	0.450	0.366	0.257	0.179	0.127	0.070
9	0.282	0.99	0.740	0.594	0.516	0.417	0.292	0.193	0.130	0.066
10	0.313	1.23	0.890	0.708	0.609	0.489	0.328	0.219	0.140	0.068
11	0.341	1.37	1.005	0.796	0.677	0.546	0.369	0.244	0.161	0.083
12	0.367	1.57	1.146	0.896	0.766	0.615	0.422	0.281	0.182	0.094
13	0.399	1.75	1.25	0.99	0.834	0.666	0.454	0.308	0.198	0.099
14	0.433	2.03	1.453	1.130	0.964	0.716	0.516	0.349	0.219	0.115
15	0.484	2.38	1.696	1.336	1.115	0.875	0.589	0.391	0.250	0.125
16	0.550	2.95	2.065	1.086	1.336	1.042	0.693	0.464	0.292	0.146
17	0.593	3.35	2.353	1.792	1.511	1.177	0.774	0.520	0.328	0.167
18	0.608	3.46	2.385	1.823	1.526	1.187	0.778	0.521	0.328	0.169
19	0.624	3.55	2.454	1.871	1.563	1.214	0.787	0.522	0.334	0.167
20	0.633	3.60	2.525	1.943	1.641	1.287	0.886	0.568	0.334	0.188
21	0.708	4.40	3.048	2.334	1.933	1.503	0.975	0.654	0.417	0.214

Table 2: Effective Porosity Measurements

Depth (ft.)		Effective Porosity (percent)
From	To	
0	0.5	33.75
0.5	1.0	31.36
1.0	1.5	32.40
1.5	2.0	30.80
2.0	2.5	30.50
2.5	3.0	30.50
3.0	3.5	36.75
3.5	4.0	38.68
		Mean Porosity 33.1 per cent

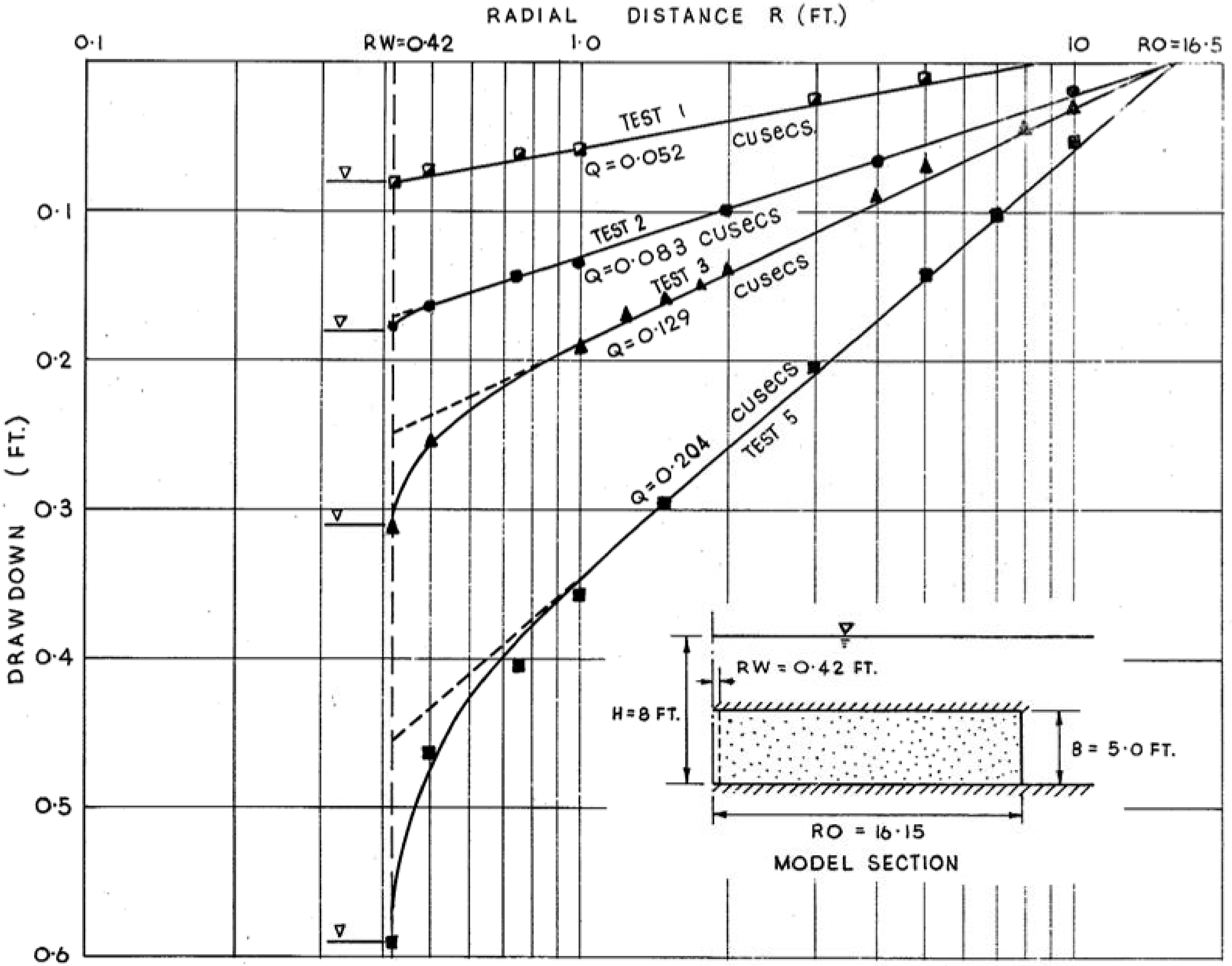


Figure 5.1: Typical Drawdown Curves - Confined Aquifer.

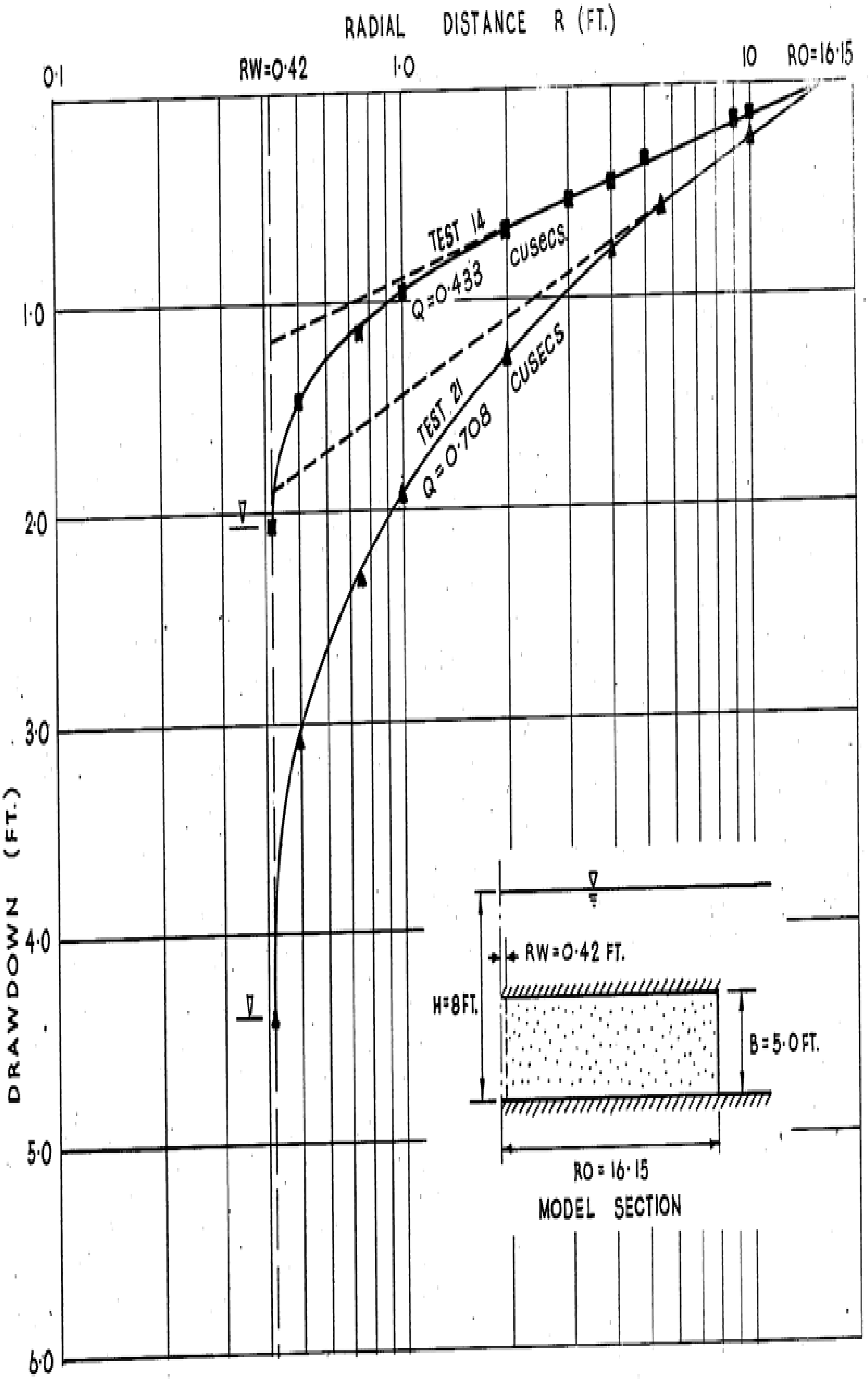


Figure 5.2: Typical Drawdown Curves - Confined Aquifer.

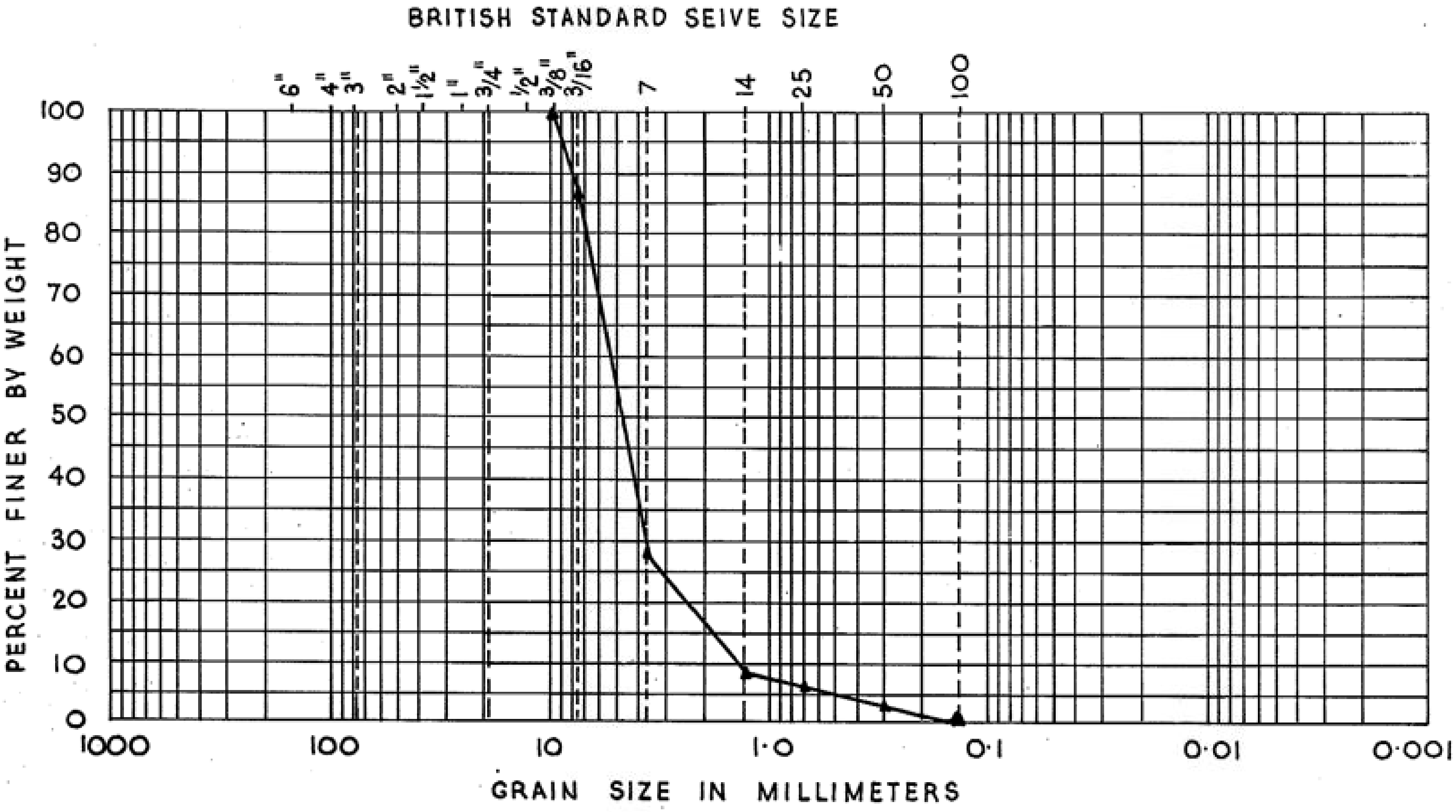


Figure 5.3: Size Grading Aquifer Material - Confined Aquifer.

5.4 Analysis of Experimental Results

5.4.1 Determination of the Coefficient of Hydraulic Conductivity 'K'

The value of the coefficient of hydraulic conductivity 'K' was determined from the slope of the straight line portion of the drawdown curves, in conjunction with the use of equation (5.1).

$$K = \frac{2Q}{\pi m \Delta s} \ln \left(\frac{r_2}{r_1}\right) \tag{5.1}$$

The results of the analysis are shown in Table 3. Test 21 was not included as there was some dewatering of the aquifer due to the water level in the well being below the top of the aquifer model.

Table 3: Coefficient of Hydraulic Conductivity 'K'

Test	Δs (ft)	$\ln \frac{r_2}{r_1}$	Q (cusecs)	K (ft/sec)
1	0.08	3.65	0.052	0.2437
2	0.17	3.65	0.083	0.2268
3	0.25	3.65	0.129	0.2397
4	0.345	3.65	0.183	0.2464
5	0.455	3.65	0.204	0.2083
6	0.52	3.65	0.213	0.1913
7	0.53	3.65	0.222	0.1946
8	0.56	3.65	0.272	0.2257
9	0.62	3.65	0.282	0.2113
10	0.75	3.65	0.313	0.1939
11	0.85	3.65	0.341	0.1863
12	0.93	3.65	0.367	0.1833
13	1.00	3.65	0.399	0.1854
14	1.15	3.65	0.433	0.1749
15	1.25	3.65	0.484	0.1799
16	1.50	3.65	0.550	0.1703
17	1.70	3.65	0.593	0.1620
18	1.75	3.65	0.608	0.1614
19	1.77	3.65	0.624	0.1638
20	1.80	3.65	0.633	0.1633

Mean value of linear hydraulic coefficient K = 0.1956 ft/sec.

5.4.2 Determination of Forchheimer Coefficients 'a' and 'b'

The calculation of the Forchheimer coefficients 'a' and 'b' was performed using the theory proposed in Appendix 1 of Section C. For the purposes of the calculation the relationship between the drawdown and the discharge is assumed to be of the form

$$\frac{s_w}{Q} = A + BQ \tag{5.2}$$

where

A = intercept on the $\frac{s_w}{Q}$ axis of the $\frac{s_w}{Q}$ versus Q plot

B = slope of the linear $\frac{s_w}{Q}$ versus Q plot

also $A = \left(\frac{a}{2\pi m} \ln \frac{r_c}{r_w} + \frac{1}{2\pi Km} \ln \frac{r_o}{r_{cr}} \right)$

$$B = \frac{b}{4\pi^2 m^2} \left(\frac{1}{r_w} - \frac{1}{r_{cr}} \right)$$

The significance of equation (5.2) is illustrated in Figure 5.4. The horizontal portion of the curve corresponds to linear flow regime existing up to the critical radius. The $\frac{s_w}{Q}$ value of this horizontal line will be denoted by D and is given by Equation (5.3).

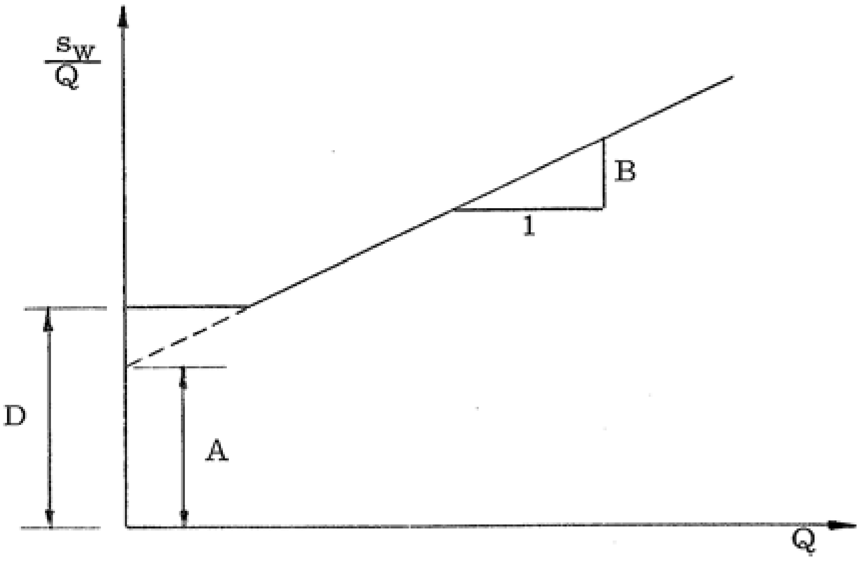


Figure 5.4: Significance of $\frac{s_w}{Q} = A + BQ$

$$D = \frac{1}{2\pi Km} \ln \left(\frac{r_o}{r_w}\right) \qquad (5.3)$$

It is assumed further that the ratio of a to 1/K is in the same ratio as A to D, consequently

$$\frac{D}{A} = \frac{1}{Ka} \qquad (5.4)$$

From the $\frac{s_w}{Q}$ against Q plot (Figure 5.5) for the aquifer model tested and the knowledge of the value of K

$$D = 0.593$$

$$A = 0.52$$

Hence $\frac{1}{Ka} = \frac{0.593}{0.52} = 1.14$

then

$$a = \frac{1}{1.14K}$$

$$= 4.475 \text{ sec/ft.}$$

$$= 0.075 \text{ min/ft.}$$

Also the slope $B = \frac{0.5}{4 \times 0.34} = 0.365$

and $b = \frac{C\,4\pi^2 m^2}{\frac{1}{r_w} - \frac{1}{r_{cr}}}$

For a typical test which lies close to the line of best fit, for example test 20, $r_{cr} = 3.7$ and,

$$b = \frac{0.365 \times {}^2 \times 5^2 \times 4}{2.1}$$

$$= 173 \text{ sec}^2/\text{ft}^2 = 0.048 \text{ min}^2/\text{ft}^2$$

A drawdown discharge curve for all test results has been included for the sake of completeness (Figure 5.6).

5.4.3 Determination of the Critical Reynolds Number $\mathbb{R}_{cr}$

The critical velocity V_{cr} was calculated from the knowledge of the coefficient of hydraulic conductivity 'K' and the Forchheimer coefficients 'a' and 'b' and relationship (5.5)

$$V_{cr} = \frac{1}{b} \left(\frac{1}{K} - a\right) \qquad (5.5)$$

For values of $K = 0.196$ ft/sec.
$a = 4.475$ sec/ft.
$b = 173\ \mathrm{sec}^2/\mathrm{ft}^2$

then $V_{cr} = 0.0037$ ft/sec.

The critical Reynolds Number $\mathbb{R}_{cr}$ was then calculated by relationship (5.6)

$$\mathbb{R}_{cr} = \frac{V_{cr}\ \bar{d}}{} \qquad (5.6)$$

Adopting a temperature of 68°F for the purposes of the calculation

$$= 1.94\ \mathrm{slugs/ft}^3$$

$$= 2.1 \times 10^{-5}\ \mathrm{lb\ sec/ft}^2$$

and $\bar{d} = d_{90} = 4.92 \times 10^{-3}$ ft.

$$\text{Hence } \mathbb{R}_{cr} = \frac{0.0037 \times 0.00492 \times 1.94}{0.000021} = 1.7$$

5.5 Discussion of Results

The drawdown curves obtained in Figures 5.1 and 5.2 provide verification of the two flow regime adopted in the theoretical analysis.

In the drawdown curves of Figures 5.1 and 5.2 there appears to be an additional drawdown in the well, over and above the formation losses which increases with increasing discharge. The additional drawdown is more than likely the result of screen losses although this has not been fully substantiated. At this point it should be noted that all of the computations performed neglected the existence of screen losses.

During the tests it was assumed that no increase in permeability resulted from development of the aquifer material surrounding the screen.

With regard to the coefficients, 'a', 'b', and 'K' it should be borne in mind that the values obtained from the experimental results are at best only approximate values. The degree of certainty that can be assigned the calculated value of K is reasonably high as this has been obtained directly from the slope of the straight line portion of the drawdown curve. However, the degree of certainty which can be assigned to the values of 'a' and 'b' is not as high. The values of 'a' and 'b' are estimated to be within 10 per cent of their correct values. It should be realised that this estimated error and the values of 'a', 'b' and 'K' require verification by permeameter tests on the aquifer material. This will be carried out shortly.

The values for 'K', 'a', 'b', and '$\mathbb{R}_{cr}$' obtained by the methods outlined, compare favourably with the values obtained for similar size materials tested and tabulated in Section C.

Finally, any effect of the inner aquifer retaining barrier upon the flow profile through the aquifer model from the drawdown curves appears to be negligible.

5.6 Conclusions and Further Work

The analysis of the experimental results presented shows that the flow of water towards a heavily pumped well is of a two flow regime nature, the two flow regimes being

(a) linear; governed by a hydraulic gradient velocity relationship

$$v = Ki \tag{5.7}$$

(b) non-linear; governed by a hydraulic gradient-velocity relationship

$$i = av + bv^2 \tag{5.8}$$

The extent of the non-linear flow regime can be specified indirectly by the critical Reynolds number $\mathbb{R}_{cr}$.

The existence of increasing screen losses appearing in the drawdown curves for increasing discharge warrants further investigation. Further studies will include the effects of partial penetration, well radius, drilling and development and different screen types under transient and steady state conditions for confined and unconfined aquifers.

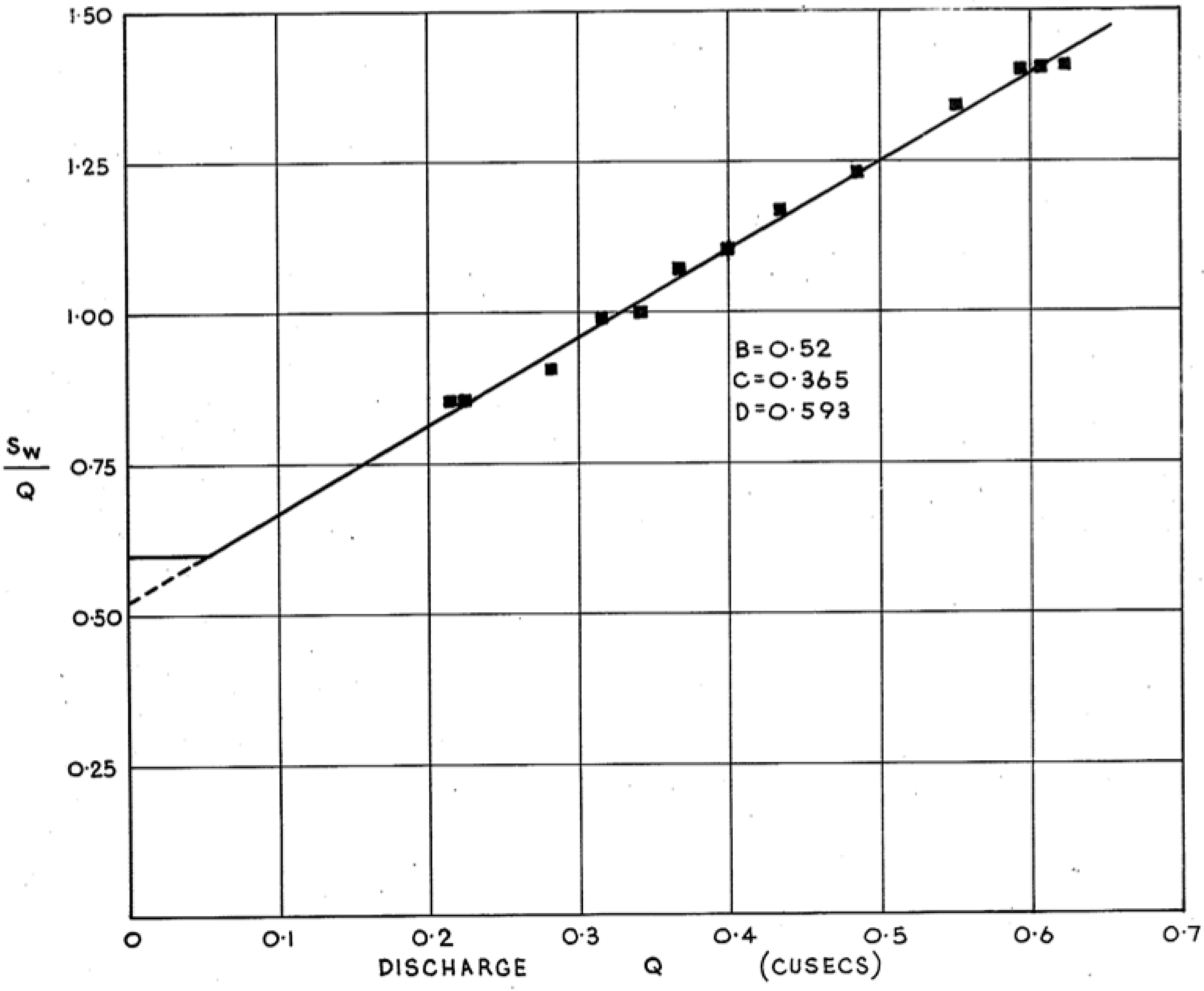


Fig. 5.5: $\frac{S_W}{Q}$ versus Q plot.

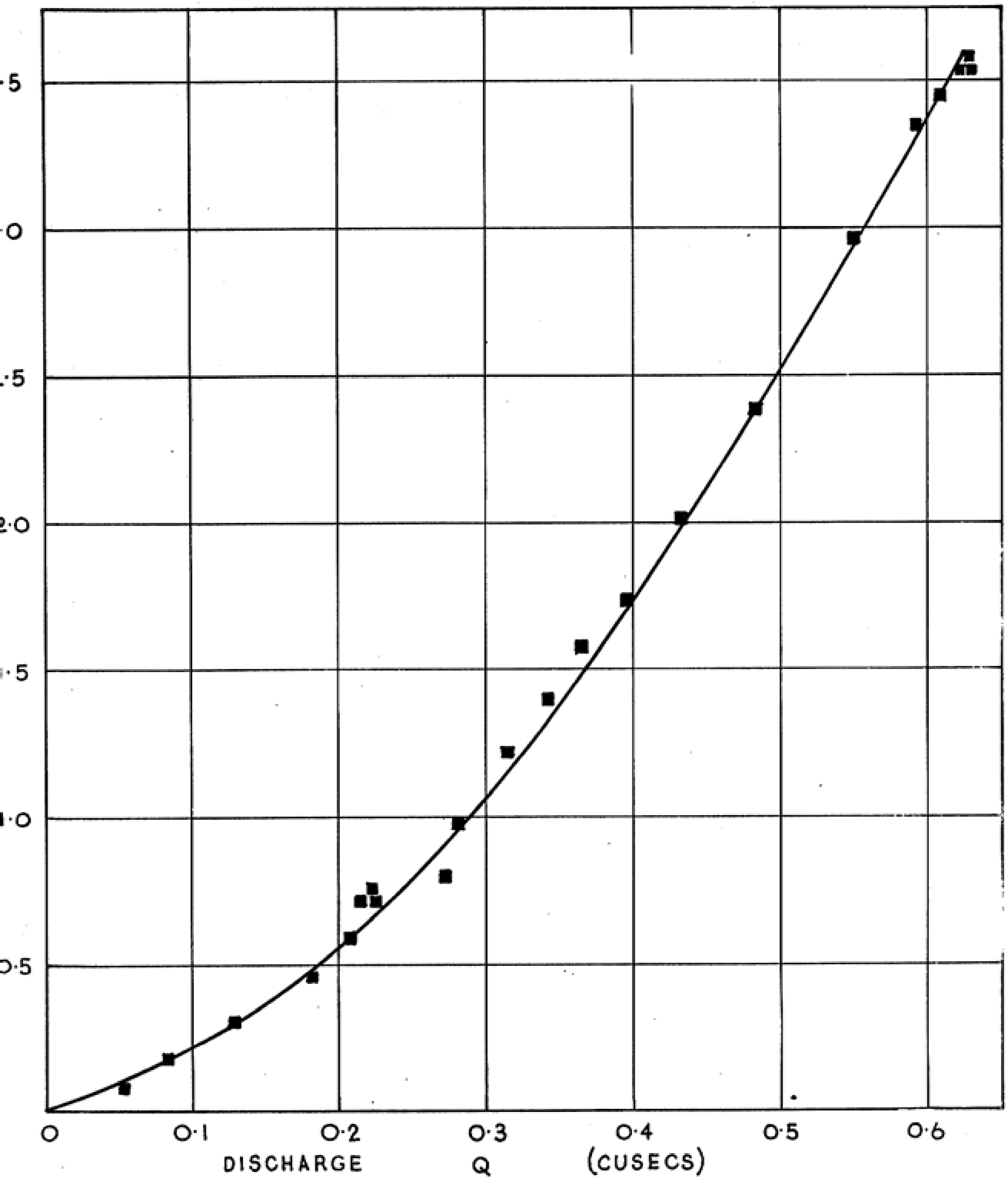


Fig. 5.6: S_W versus Q plot.