T H E S I S

on

THE FLOW OF WATER THROUGH CERTAIN TYPES OF WATER BEARING MATERIAL AS AFFECTED BY WELL CASING PERFORATIONS

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by

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APPROVED:

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Introduction

The increasing demand for groundwater for irrigation, together with the recent development of drainage by means of pumping has lead to the extensive use of the "California" or "Stovepipe" type of well casing. This type of casing is particularly adapted to the deepwell turbine type of pump. The stovepipe casing originated in California over thirty five years ago (5), and its use is becoming general over the irrigated areas of the west.

The stovepipe casing is made up of short joints, two to four feet in length. These joints are constructed of eight to sixteen gauge sheet of steel, rolled into shape, and riveted or welded at the seam.* There is an inside and an outside joint of such size that they will telescope tightly together. The casing is made up as it is driven. The inside and outside joints are added alternately and are telescoped together so that two outside joints join together midway of an inside joint, and two inside joints join together midway of an outside joint. Thus, a continuous string of double thickness casing is formed.

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* Welded casing was used in the well recently put in under supervision of the Oregon Experiment Station at Gervais, Ore.

The stovepipe casing, made in this manner, has many specific advantages. Large diameter wells, up to thirty six inches in diameter, may be cased at a comparatively low cost. The short joints make it easy to handle, and lower the cost of transportation. It may be driven as the well is drilled which will prevent caving while drilling through unconsolidated material. The sheet steel of which the casing is made may be perforated from within the well without serious difficulty. For these reasons the stovepipe casing is generally used for irrigation and drainage purposes.

The success or failure of the stovepipe casing, granting an adequate supply of water, is dependent upon the perforations. The casing may be perforated in place or the factory perforated casing may be used. If the factory perforated casing is used it is necessary to have an accurate knowledge of the strata of material penetrated so that the perforated sections may be added at the proper points as the casing is made up. When perforated in place, the depths at which to perforate are determined from the log of the well as it is drilled.

At the present time well drillers follow various "thumb rules" in providing perforations. Some drillers say that there should be a definite ratio of the total area of the openings to the area of the cross section of the well, such as eight or ten to one. Other drillers prefer to provide as many perforations as possible. This seems to be the safest method to follow.

Though these methods of perforating are generally and successfully used, oftentimes serious troubles occur. If the perforations are too large, sand may enter the well and reduce its efficiency by filling up the lower portion of the well and by causing excessive wear on the moving parts of the pump. There are cases where enough sand has been pumped out to completely undermine and destroy the well. When the casing is perforated from within, there is grave danger of greatly weakening the casing by having an excessive number of large size holes adjacent to each other or by having the perforator strike on a row of rivets.

If the area of the perforations is too small or if there is not enough of them the efficiency of the well will also be impaired. There is a possibility that the supply of water would be insufficient or the drawdown for a given quantity of water would be excessive. If the perforations are so small that they hold back all of the sand, the well cannot be properly developed (5). Occasionally the individual openings may be of such size and shape that with use they gradually plug up, resulting in the necessity of reperforating or redeveloping, or both (3).

It is evident that if the well driller could be sure of what type of casing perforation to use before doing the actual perforating, the chances for failure would be greatly reduced.

The work, as reported in this paper, was undertaken to study various types of well casing perforations and their relation to the water bearing material. It was intended to study the effect of the size and shape of the openings upon the yield of water, upon the removal of separates from the water bearing material, and on the "drawdown" curve of the water outside of the casing.

Review of Literature

In the work so far contributed on groundwater hydrology there is very little reference to the effect of casing perforations or well screens upon the yield of water. King (1) studied the influence of screen well points upon the yield of water from sand, and reached the conclusion that the resistance offered to the flow of water was greater from the sand than from the screen. Slichter (7), in studying the operation of some pumping plants, figured the yield of water per unit area of well screen exposed. His work was with screw casing and special screens, and his findings would hardly be applicable to the stovepipe type of casing.

A comprehensive study of the drilling of wells by the stovepipe method was made by Schwalen (5). He described the different methods of perforating, but gave only a general idea of the yield of water to expect from the different types of perforations. Weir (10) studied a group of stovepipe type wells, and the effect of pumping from them upon the general water table of an area, but he did not go into the effect of the perforations in an individual well.

Materials and Method

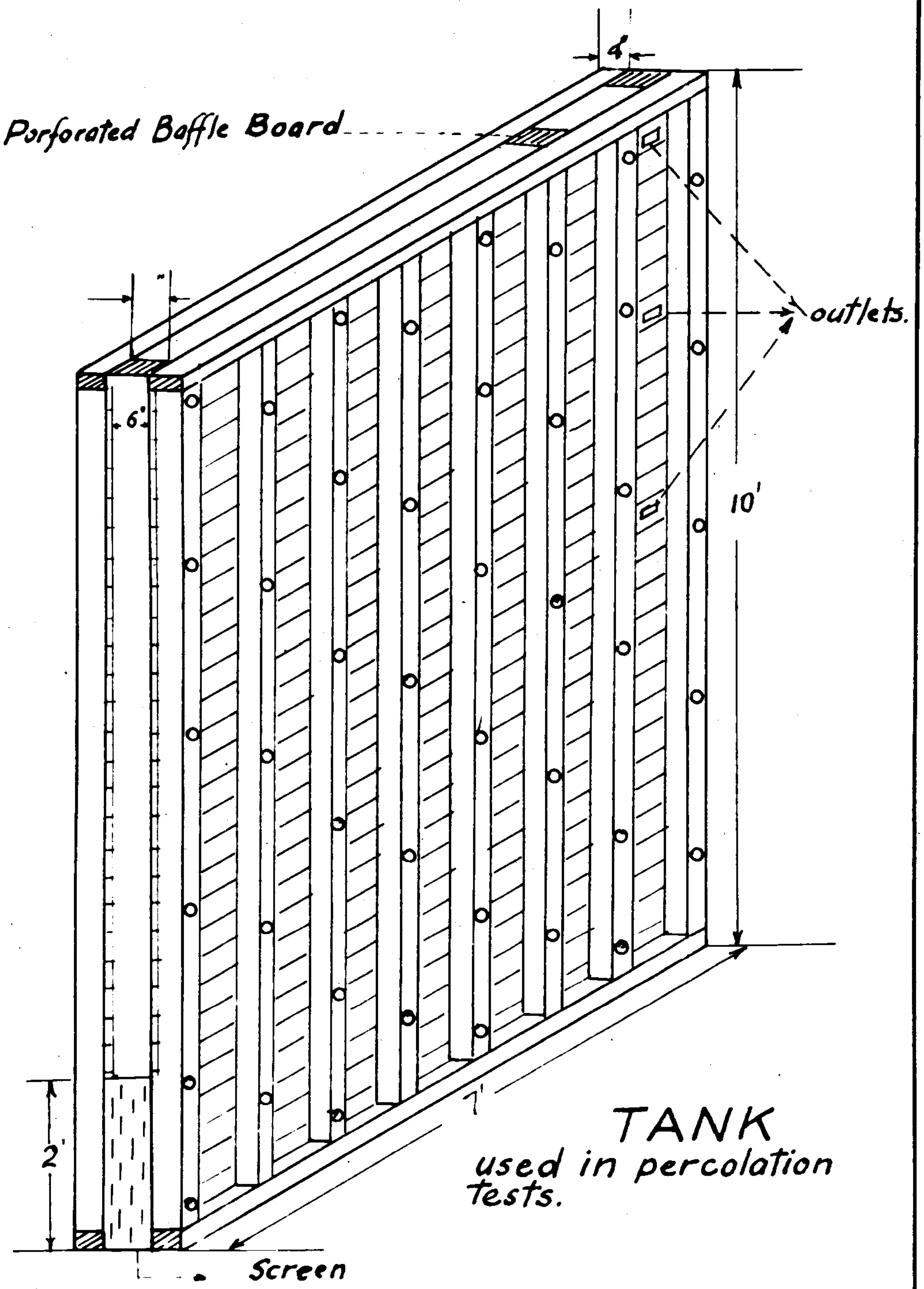
For this group of experiments a tank was constructed after general ideas taken from King (1), Schlick (4), and Norling (2) in studying drainage curves, and Slichter (7) in studying the distribution of electrolytes in ground-water. While using the general ideas of the above workers, the apparatus was enlarged and modified so as to more nearly duplicate a section of well casing with the adjacent water bearing stratum.

This tank was constructed as shown in Figure 1. The material used was 1" by 4" flooring for the sides; 3" by 6" planks for the ends and bottom; and 2" by 4" pieces for nail ties. The tank was ten feet high, seven feet long, and six inches wide. It was made rigid by running ½" by 16" bolts through opposite pairs of nail ties.

An opening was provided at one end to which, by means of stove bolts and a rubber gasket, a section of well casing could be securely fastened. The area of casing exposed on the inside was six inches wide and two feet high.

On the opposite end from the casing a reservoir was constructed so the water could have access to the full height of the material tested. This reservoir was constructed by placing a perforated baffle board one foot from the end as indicated in Figure 1. Three outlets were provided so that a constant head could be maintained at 5.0', 7.5', and 9.6' from the bottom of the inside of the tank. The water

FIG. 1



TANK
used in percolation tests.

Scale 1" = 2'

supply was taken from the city main by means of a three inch canvas hose.

The rest of the tank, a space of nine feet nine inches high, five feet six inches long, and six inches wide was for the material to be tested.

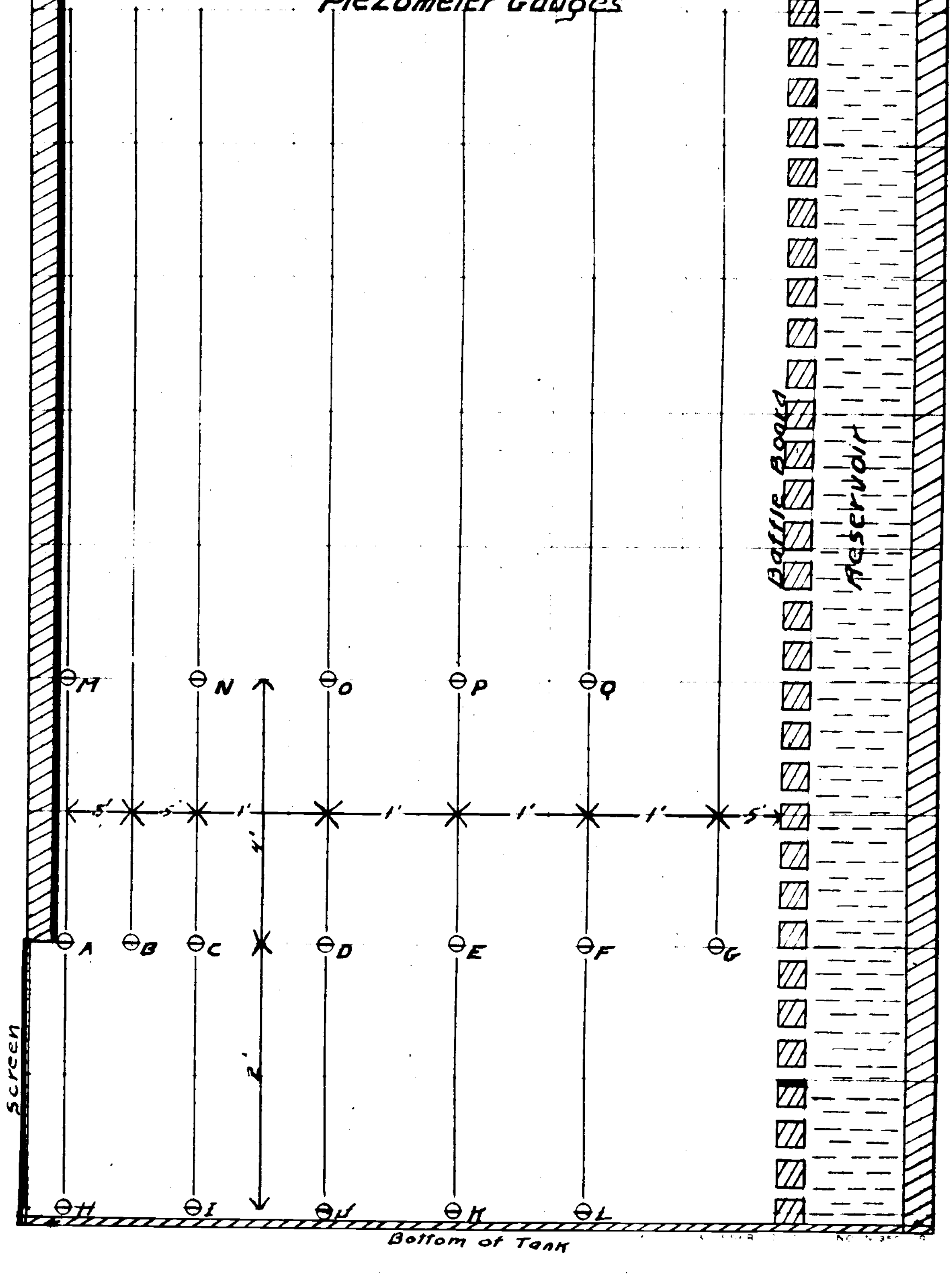
Piezometer gauges were placed on the outside of the tank as indicated by the diagram, Figure II. These gauges consisted of a piece of one-half inch pipe, sic inches long, with a brass petcock screwed in one end. These pipes were inserted through auger holes in the side of the tank so that the open end reached the middle of the tank. A piece of three-eights glass tubimg was connected to the petcock on each pipe by means of a rubber tube. These glass tubes extended to the top of the tank making it possible to read the exact pressure on the point where the gauge was inserted.

The series of gauges, A, B, C, D, E, F, and G, (Figure II) placed on a line across the tank at the top of the casing, two feet from the bottom of the inside of the tank, was the series of gauges used during the experiment in observing the movement of the drawdown curve. The other two series of gauges were added to compare the pressures taken at different heights on the tank.

When completed, the tank was placed in the weir channel of hydraulic engineering laboratory. This was merely a matter of convenience as it made it easy to catch all of the water coming out of the screen and conduct it

FIG. 2

Diagram Showing Location of Piezometer Gauges



to the settling tank which was a square tank of two hundred gallons capacity. The overflow from the settling tank dropped directly onto the scale. Plates I and II give a general idea of the set-up, although the scales are not visible. The scales, part of the regular equipment of the hydraulics laboratory, School of Engineering, Oregon State College, were built especially for weighing large quantities of water, having a balanced tank of two thousand gallons capacity for catching the water. The scales were accurate to five pounds.

The samples of casing used in these tests were two feet by six inch sections of standard, factory perforated stovepipe casing. They were prepared by the Montague Steel Pipe Company of San Fransisco, California on regular factory equipment. These sections are shown in Plate III, and the numbers given them here will be used in referring to the separate sections or screens throughout this paper. The No. 3 screen is not shown, but it is constructed the same as the No. 1 screen with the edges turned out. Table 1 compares the different screens as to area, width, length, and number of openings and the total area of openings.

Two types of material were tested, one was a fine sand, and the other was a bank run gravel. The original analysis of the sand is shown in Table II, and gravel is shown in Table VI.

In making the tests the tank was filled with the sand or gravel. In order to get a uniform distribution, the material was settled in water by gradually filling the tank with water as the material was shoveled in. Before the outlet was opened to start the test, the tank was completely filled with water in order to see that all of the gauges were clear.

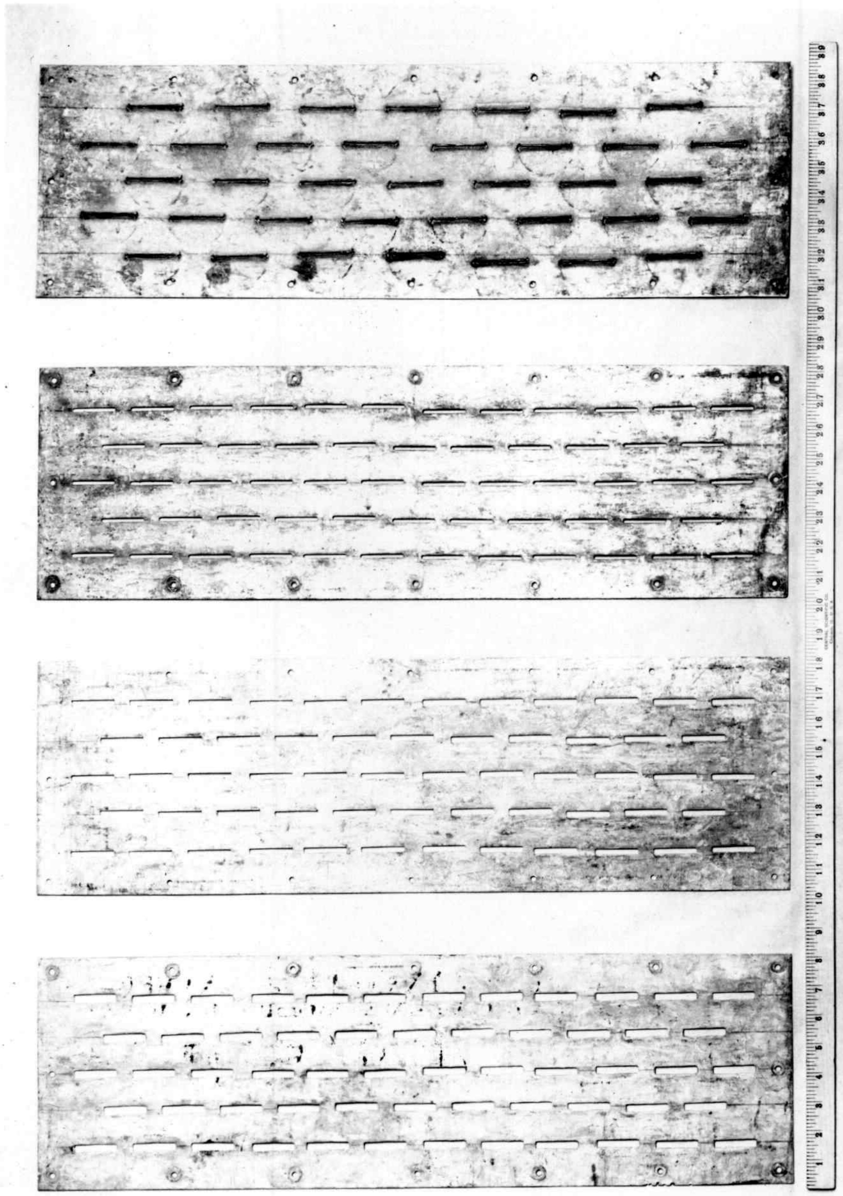
When starting a test on a particular screen, the water was first maintained at the five foot level. As soon as the water began to percolate through, the time was checked and the scales were set. After running one hour the weight and the time were recorded, the temperature of the water was taken at the inlet and the outlet, and the readings of the gauges were recorded. This was repeated every half-hour for the first two hours, and then every hour until the discharge and the gauge readings were fairly constant. At intervals during the test the readings in the other two series of gauges were recorded, and the free water surface was located. The free water surface was checked by spacing three-sixteenths inch holes vertically above the same stations where the gauge readings were taken. These holes were fitted with plugs, and the water surface was taken to be the point where the water barely ran out. The duration of the test for a particular head was twenty four hours.

After the completion of the test for the five foot head, the screen was removed and enough sand was taken out through the hole to cause a complete shift of the material

Plate III

CASING SECTIONS USED IN EXPERIMENT

Numbered from left to right, the casing sections are designated as Screens No. 5, No. 4, No. 2, and No. 1 The No. 3 screen, which has the same type of perforation as the No. 1, is not pictured.



in order to destroy any structure of the material built up by the previous run. The test was then repeated on the other two heads. At the end of the test on the 9.60' head, the screen was removed and samples of the material were taken at 0.0', 0.25', 0.50', 1.00', and 2.00' back from the screen. A mechanical analysis was made of these samples to get some idea of the shift of the material. All material collected in the settling tank was dryed, weighed, and analyzed. This included only material from the test on the 10' head.

For the sand, duplicate 100 gram samples were taken for analysis. 1000 gram samples were used for the original analysis of the gravel, and 100 gram samples were taken of the material caught in the settling tank. The sand and the material from the settling tank with the gravel were analyzed by the U. S. Bureau of Soils method. The original analyses of the gravel were made by the sieve analysis method employed by the Department of Mechanics and Materials, Oregon State College, except that the portion below 5 mm. was analyzed by the Bureau of Soils method in order to determine the portion below .005 mm.

Results of Tests on Sand

The results of the tests on the sand are shown in Tables I, II, IV, and V, and in Figures 3, 4, 5, 6, 7, 8, 9, 10, and 11. Tables II, III, IV, and V show the analyses of the sand back of the screen before and after the twenty four hour test of the different screens with the 9.60' head. They also show the analyses of the sand caught in the settling tank during the test.

Readings of the gauges at the 2.0' level are shown in Figures 3, 5, 7, and 9 as taken at different times during all of the tests on the different screens. The rate of descharge for each set of gauge readings is shown. Figures 4, 6, 8, and 10 show the relation of gauge readings taken at different heights on the tank to the free water surface. Figure 11 shows the relation of the 2.0' gauge readings, taken after twenty four hours of continuous run, on the different screens and different heads, to each other.

The relation of the size of the individual perforations to the size of the various separates washed out to those retained is shown by comparing Table I with Tables II, III, IV, and V. These tables bring out the fact that there is a relation between the size of particles retained and the size of the openings. This is not an exact relationship. Table II shows that the No. 1 screen having perforations averaging 1.35 mm. wide effectively retains all material above .50 mm; Table III shows that the No. 2 screen having an average perforation width of 2.02 mm. retains all material above 2.00 mm.; Table IV shows that the No. 3 screen having an average perforation width of 1.90 mm. retains all material above 1.00 mm.; and Table V shows that the No. 4 screen having a perforation width of 5.85 mm. retains all material above 2.0 mm. The No. 5

screen was not tested with the sand, because the perforations were so large that none of the sand was retained.

The footnote under each of the tables shows the quantity of material washed through. These quantities and the corresponding analysis are not exact, because very little of the fraction below .005 mm. would settle in the settling tank, and it is probable that a large portion of the fraction between .005 mm. and .01 mm. was carried on through the tank. It is interesting to note that material washed through was greater in the case of either the No. 1 or the No. 3 screen than for the No. 2 screen, although in the two former screens the perforations were not so wide, the total area was less. This is probably due to the fact that the No. 1 and the No. 3 screens had the edges of the perforations turned out toward the sand, thus reducing the tendency of the sand to wedge in the opening. Otherwise, the amount of material washed through seems to be proportional to the size and area of the openings.

From the gradation of the analyses back from the screen, it would seem that most of the material which was washed out came from the first foot of material back of the screen. This is probably not true as the amount of material collected was too great for the No. 3 and No. 4 screens. Most of the material was collected during the first two hours of the test, and it is possible that there

TABLE I

COMPARISON OF CASING SECTIONS

No. of Screen	No. of openings	Total area of opening	Ave. length openings	Ave. width openings	Ave. area openings	Type edge
1	37	21.46 sq. cm.	4.30 cm.	.135 cm.	.580 sq. cm.	Turned out
2	58	36.656	3.33	.202	.632	Smooth
3	37	31.635	4.25	.190	.856	Turned out
4	58	127.51	3.76	.585	2.195	Smooth
5	58	190.24	3.75	.877	3.288	Smooth

TABLE II

MECHANICAL ANALYSIS OF SAND BEFORE AND AFTER

TEST ON NO. I SCREEN

Size Separates	Original* Analysis	From Settling Tank	Distance back from Screen 0.0'	0,25'	0.50'	1.0'	1.50'	2.0'
.005 mm.	1.54%	3.47%	--	--	0.76%	3.99%	1.84%	1.31%
.005 to .01	3.23	16.37	0.93%	1.46%	1.93	7.53	3.99	2.98
.01 to .1	6.45	41.44	1.00	3.37	4.80	8.60	6.75	6.00
.1 to .25	16.33	34.16	6.88	12.19	14.15	16.21	15.45	19.12
.25 to .50	28.95	4.56	25.35	28.06	27.60	26.93	29.04	29.99
.50 to 1.0	26.67	--	36.44	28.96	28.13	21.74	27.11	25.27
1.0 to 2.0	13.35	--	21.40	15.10	16.72	11.84	14.05	13.13
2.0 to 5.0	2.50	--	8.78	9.42	4.31	1.98	.97	1.11
Above 5.0	.96	--	3.14	1.53	1.55	1.15	.76	1.06

*Total weight material washed through--18.57 pounds.

TABLE III

MECHANICAL ANALYSIS OF SAND BEFORE AND AFTER TEST ON NO. 2 SCREEN

Size Separates	Original Analysis	Settling* Tank	Distance back from screen					
			0.0'	0.25'	0.50'	1.00'	1.50'	2.00'
Below .005 mm.	1.54%	2.51	--	0.38	0.47	4.11	1.72	1.64
.005 to .01	3.23	14.45	0.40	0.89	2.16	8.68	4.17	3.10
.01 to .15	6.45	30.76	4.75	5.01	3.85	12.32	7.95	6.34
.1 to .25	16.33	29.26	12.23	18.85	16.03	17.40	15.41	17.08
.25 to .50	28.95	15.98	16.64	19.35	33.00	23.56	27.86	28.46
.50 to1.0	26.67	4.03	17.27	20.11	29.71	20.34	25.70	26.50
1,0 to2.0	13.35	3.00	24.09	19.49	18.86	10.87	13.01	12.87
2.0 to5.0	2.50	--	15.83	10.18	3.12	2.34	2.10	2.32
Above 5.0 mm.	.96	--	8.77	4.81	1.78	.25	2.05	1.56

*Total weight material washed through--4.64 pounds.

TABLE IV

MECHANICAL ANALYSIS OF SAND BEFORE AND AFTER TEST ON NO. IV SCREEN

Size Separates	Original* Analysis	Settling Tank	Distance from screen					
			0.0'	0.25'	0.50'	1.00'	1.50'	2.00'
Below .005 mm.	1.54	4.69	--	--	0.40	3.91	1.50	1.28
.005 to .01	3.23	18.01	--	2.33	2.01	8.57	4.07	3.37
.01 to .1	6.45	38.46	2.38	1.87	5.08	15.14	5.34	7.05
.1 to .25	16.33	33.91	9.71	11.55	13.22	14.96	16.33	15.98
.25 to .50	28.95	3.22	24.16	29.36	26.62	24.30	28.06	26.32
.50 to 1.0	26.67	1.69	35.05	30.45	29.93	20.47	29.21	28.30
1.0 to 2.0	13.35	--	20.42	14.70	15.82	11.74	13.41	17.48
2.0 to 5.0	2.50	--	8.18	7.58	4.81	0.87	1.61	0.17
Above 5.0	.96	--	2.08	3.13	2.29	--	0.62	--

*Total weight material washed through--38.48 pounds.

TABLE V

MECHANICAL ANALYSIS OF SAND BEFORE AND AFTER TEST ON NO. 4 SCREEN

Size Separates	Original Analysis	Settling* Tank	Distance from Screen					
			0.0'	0.25'	0.50	1.00'	1.50'	2.00'
.005, Below	1.54%	5.80%	--	--	0.21%	2.81	1.32	1.31
.005 to .01	3.23	6.38	--	--	1.88	4.58	3.01	3.01
.01 to .1	6.45	9.02	--	--	5.13	6.97	7.48	7.48
.1 to .25	16.33	12.57	--	1.58%	9.61	13.11	15.14	15.14
.25 to .50	28.95	26.67	3.43%	8.03	25.44	29.03	27.35	27.35
.50 to 1.0	26.67	28.18	11.18	19.42	27.37	26.37	26.84	26.84
1.0 to 2.0	13.35	12.36	12.45	26.30	28.09	12.31	15.98	5.98
2.0 to 5.0	2.50	--	29.16	32.33	2.13	3.30	3.40	3.40
Above 5.0	.96	--	33.75	12.31	.10	1.47	2.45	2.45

*Total weight material washed through--58.85 pounds.

was a shift of material during the other twenty two hours of the ~~test~~.

It may be noticed in the table of analyses for each screen that there is an accumulation of fime material one foot from the casing. It is peculiar that this should occur at about the same point for each screen. There seems to be no logical explanation for this accumulation. Theoretically the velocity of the water should increase as it nears the screen as the cross sectional area of the stream of water through the sand becomes less, and, since the carrying capacity of the water increases with the velocity, there should be no opportunity for the deposition of the material.

A study of Figures 3, 5, 7, and 9, brings out the fact that, for this particular sand, as time progresses, the discharge decreases and the pressure curve of the gauges rises with a given screen and a given head. The maximum rise of the pressure curve was reached, in practically all instances, after twelve hours of run. Except in Figure 9 (No. 4 screen), the discharge and the curve after twenty four hours of run are not significantly different from the curve and the discharge after twelve hours of run. With the No. 4 screen the discharge increased in the interval between twelve and twenty four hours, and the curve dropped.

It will be noticed in all cases that the discharge is not proportional to the head, but that the rate of discharge increases more than the increase in head would indicate. The average discharge after twenty four hours for the 9.60' head was nearly five times as great as the average discharge taken at the same time for the 5.00' head.

The decrease in the rate of discharge with time seems to be a characteristic of the percolation of water through this sand. It was thought that possibly the decrease was caused by biological growth within the sand, but this theory was proven erroneous by draining out the water after finishing a test for a particular head, and then starting the test over for that same head. Whenever this was tried, the discharge was increased over that for the end of the previous test, and practically the same rate of decrease in discharge occurred with time. If the decrease were due to biological growth, the effect should have been accumulative.

The most plausible explanation for the decrease in rate of discharge with time is to assume that, for a particular head, the water seeks certain definite channels through which it percolates, and, as time goes on, these channels gradually "silt" up causing the decrease in the rate of flow. This theory is substantiated by the fact that, whenever the flow of water was stopped and then started again at the same head, the new discharge was laden with material washed out of the sand. Whenever the tank was jarred while the water was flowing through, the discharge would become turbid, and there would be an increase in the rate of flow. This would indicate that the "channels of flow" had been disturbed enough to cause some of the time material to be washed out.

The coincidental rise of the curves with the decreasing rate of discharge tends to confirm the above theory, since a silting up of the channels would cause a greater resistance which would cause a rise in the curves.

The irregularities in the curves from the five foot heads are caused from the fact that the readings for lower portion of the curve were taken from a lower set of gauges.

When the test was run on the No. 4 screen, (Figure 9) the rate of discharge began to increase and the discharge became turbid after eighteen hours. This indicates that the pressure built up within the sand finally became great enough to force the material out through the openings in the screen which were larger than for the other three screens.

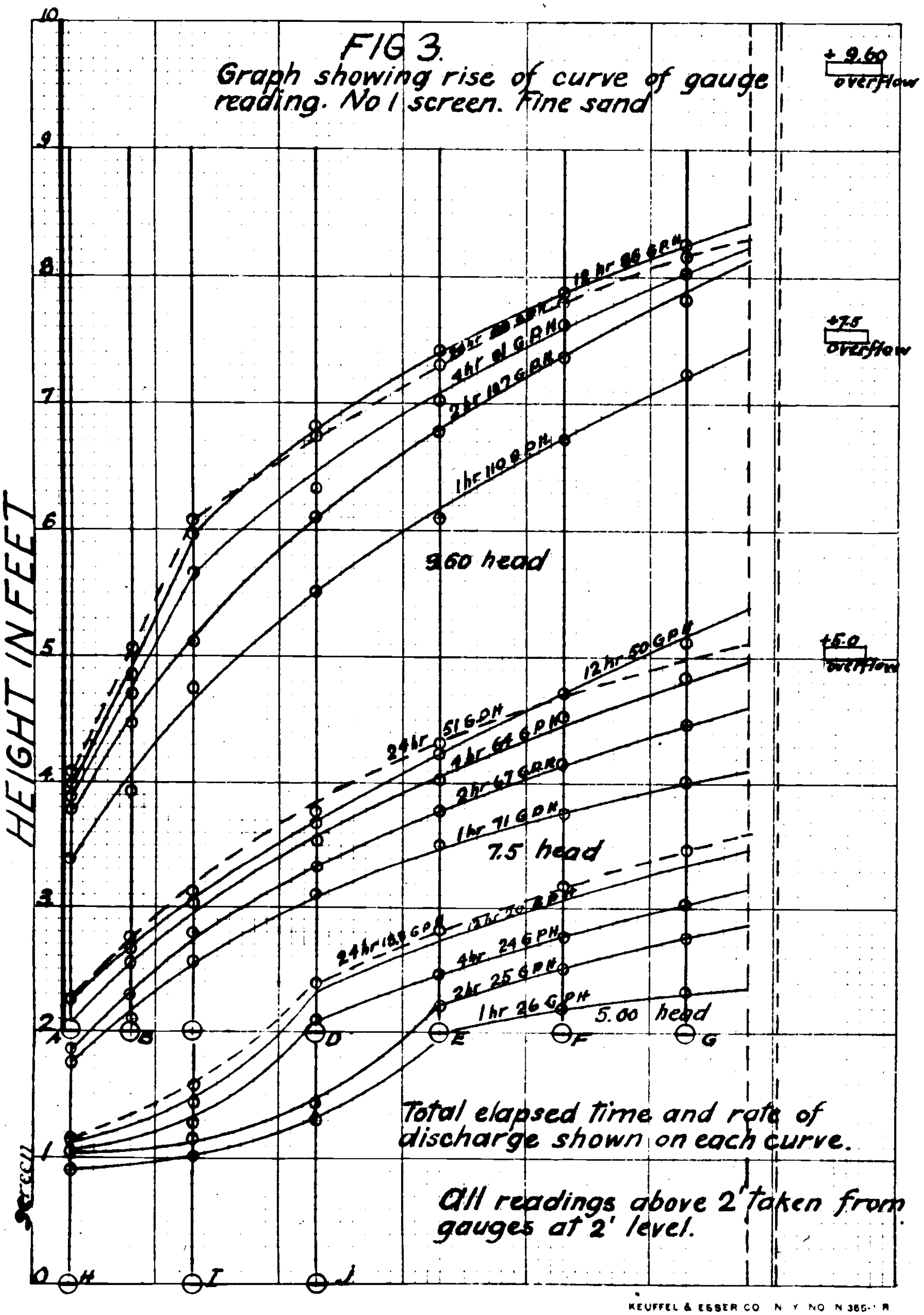
It was thought at the start of the experimental work that the gauge reading would correspond to the water surface, but, when some preliminary curves were plotted, some irregularities occurred which could not be explained unless the gauge readings, taken at different elevations, were different. Gauges above and below the original series were added to check on this. Figures 4, 6, 8, and 10 bring out conclusively that a gauge reading taken at a given height on the tank would not mean that the elevation of the water surface had been determined.

There is a tendency for the pressure curves taken at the 0', 2', and 4' levels to diverge as they approach the screen. This is more clearly shown with the No. 4 screen (Figure 10) than in the others. This is an indication that the differences in gauge readings taken at different elevations above the same point would increase with an increase in velocity.

The gauge readings after twenty four hours and the discharge for the different heads and the different screens are compared in Figure 11. Except for the No. 4 screen, the effect of the different sizes of perforations on the drawdown curves was negligible. The No. 4 screen which had larger perforations than the other permitted more fine material to be washed out which increased the discharge resulting in a lower drawdown curve.

While the temperature was checked on all the tests, it was disregarded as a factor, since for any particular test, the variation was not over 2 degrees F.

In these tests the resistance to flow offered by the sand was so great that the effect of the different perforation was not clearly brought out. It is safe to conclude that any one of the screens, 1 to 4, would be satisfactory for this type of material, but that the perforation in the No. 5 screen would be too large.



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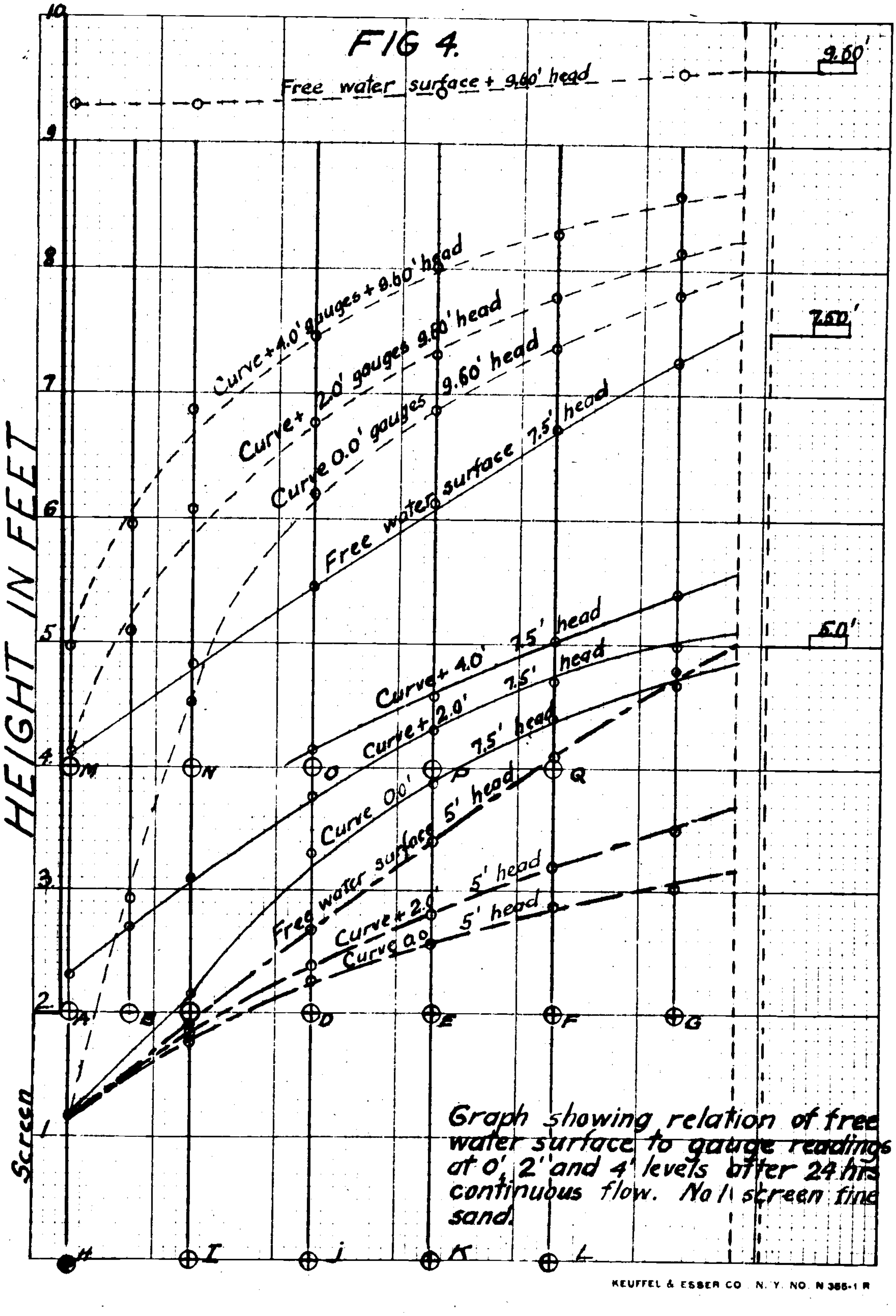

Graph showing relation of free water surface to gauge readings at 0', 2' and 4' levels after 24 hrs continuous flow. No 1 screen fine sand.

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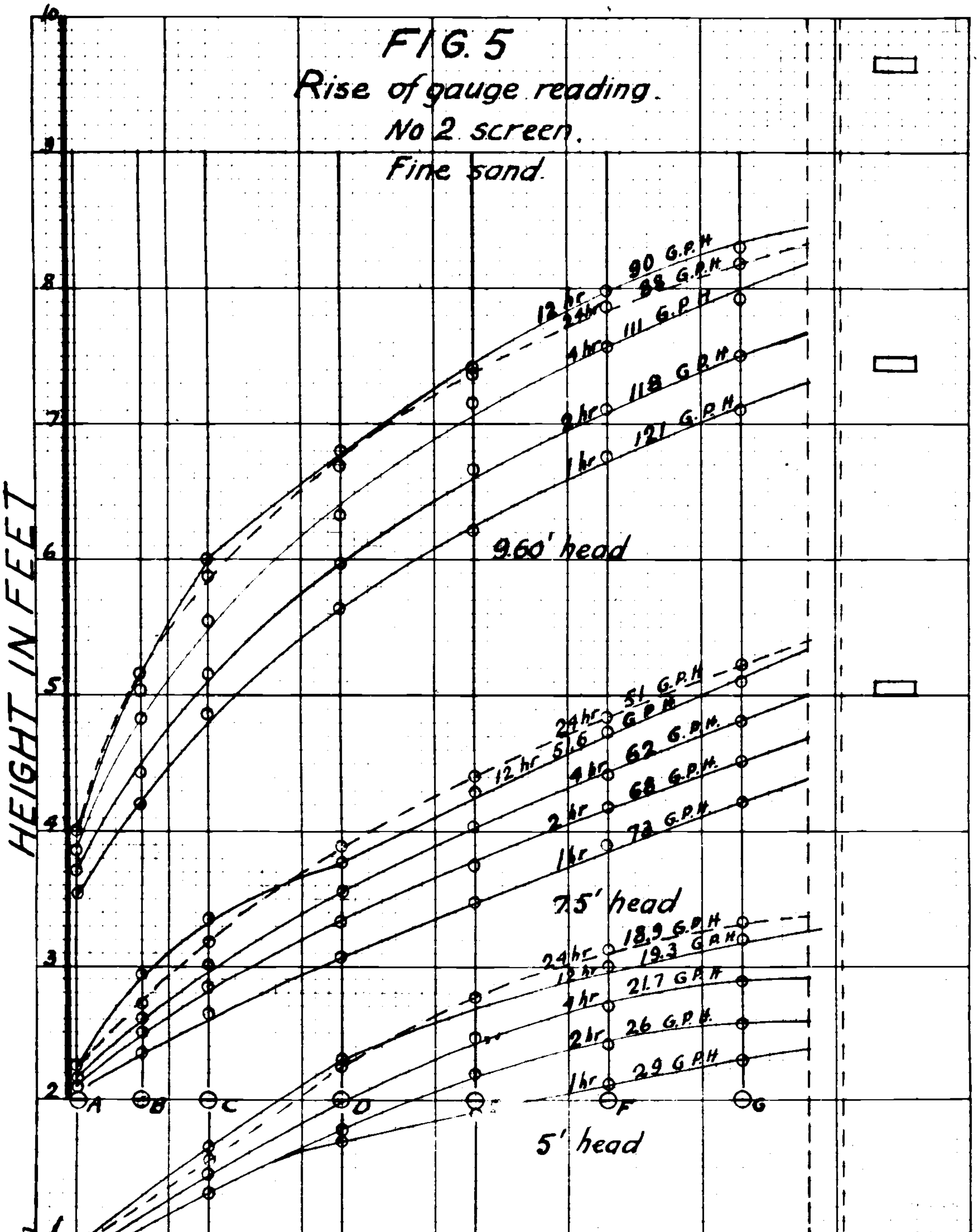

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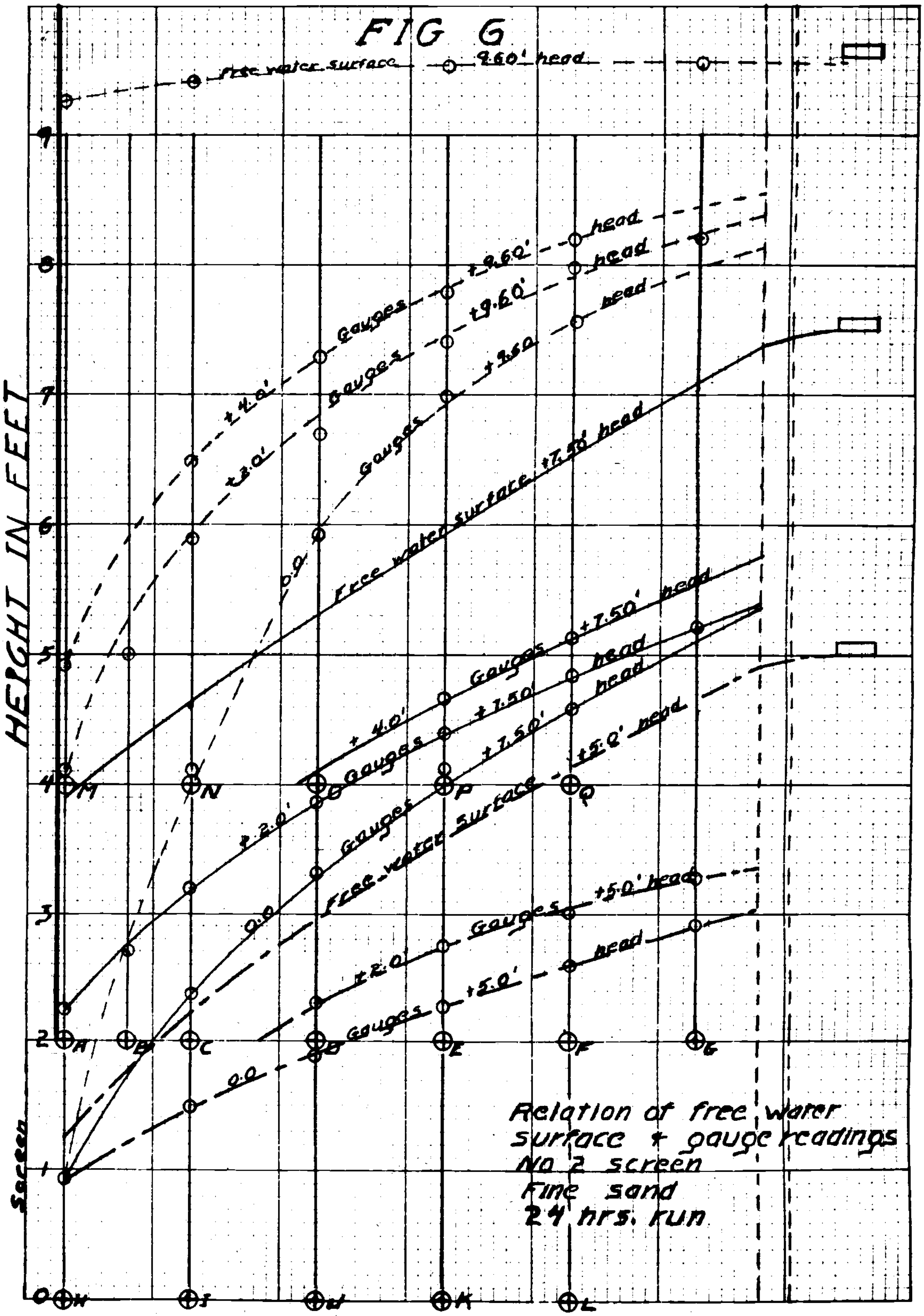

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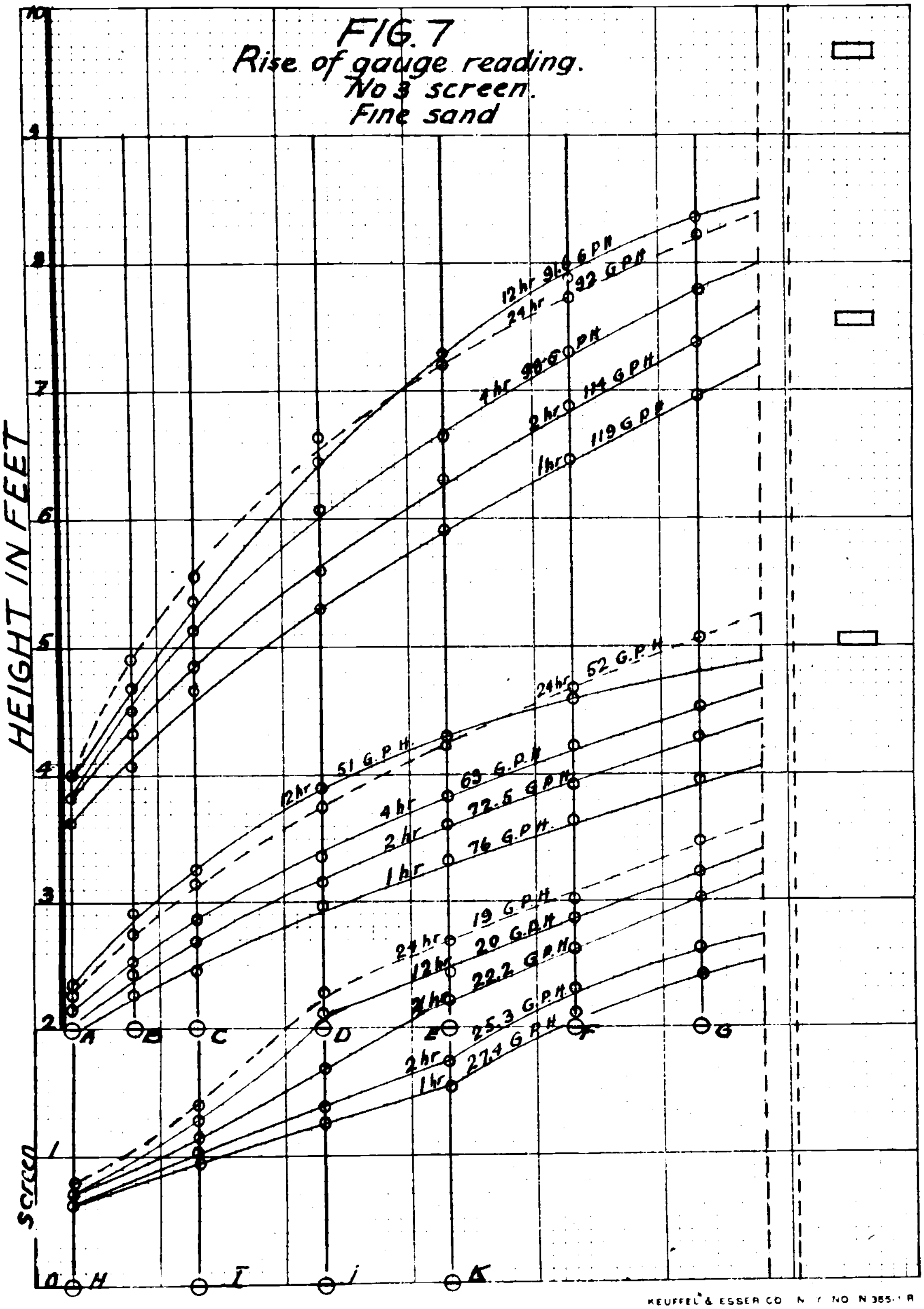

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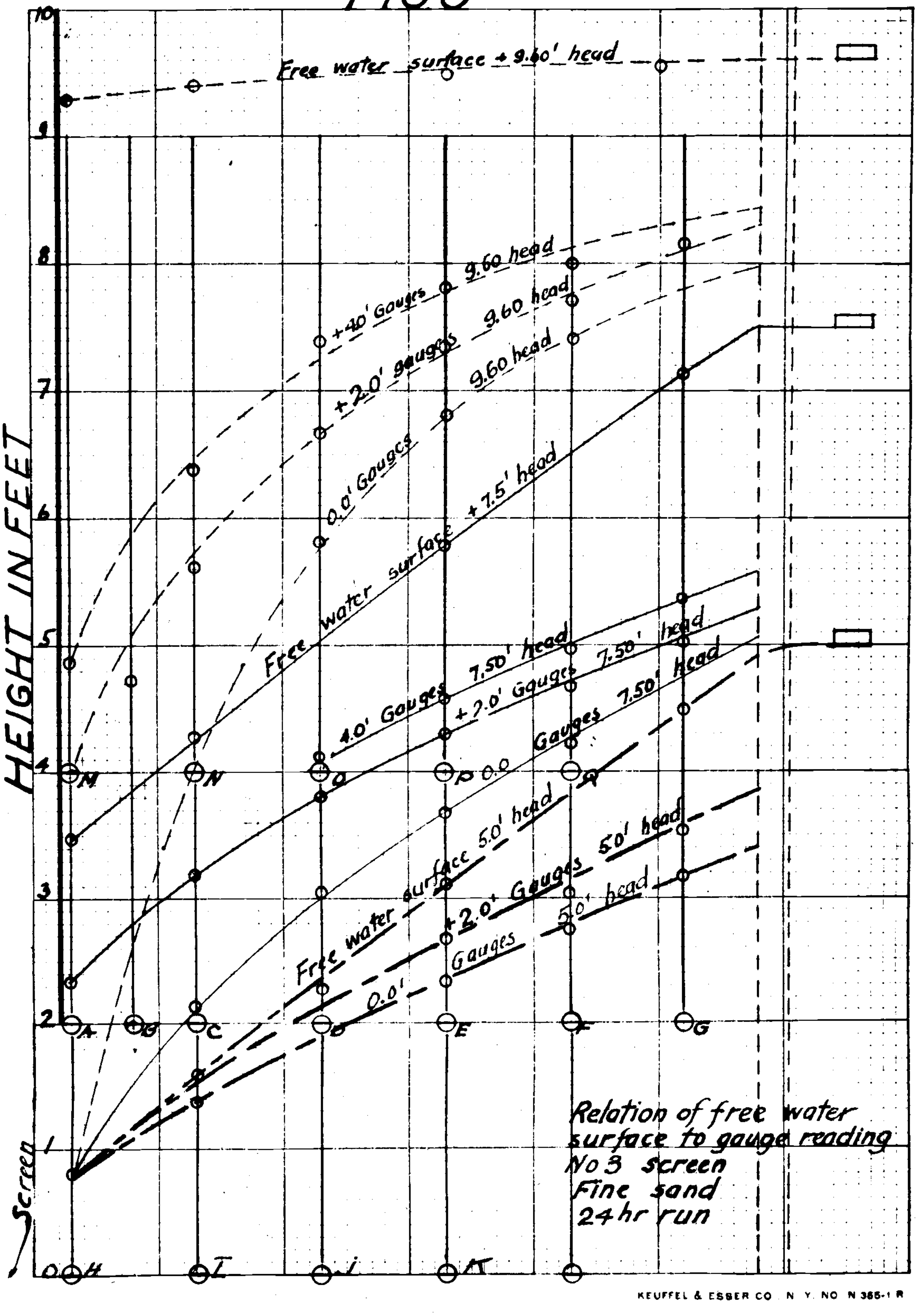
FIG 8



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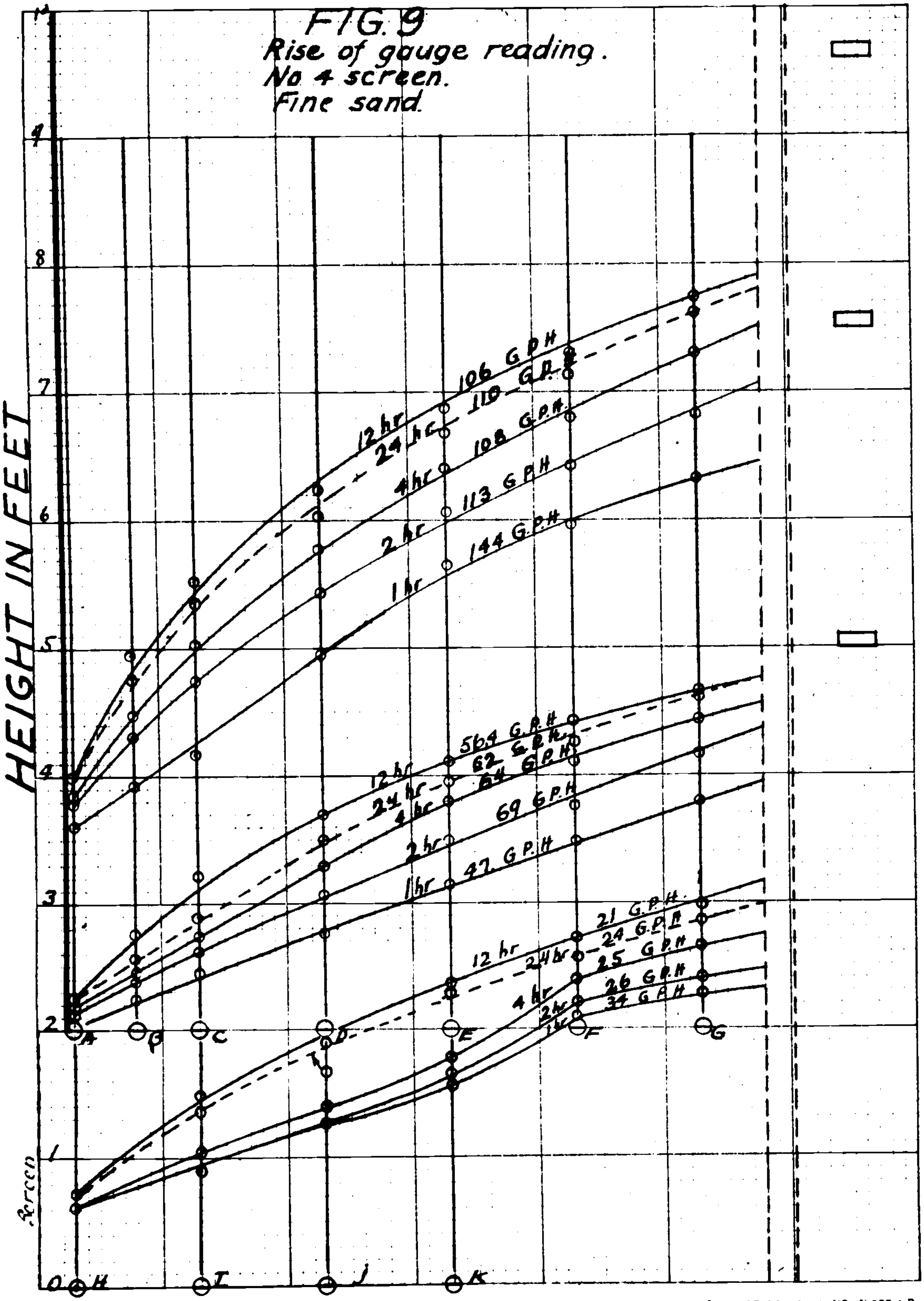

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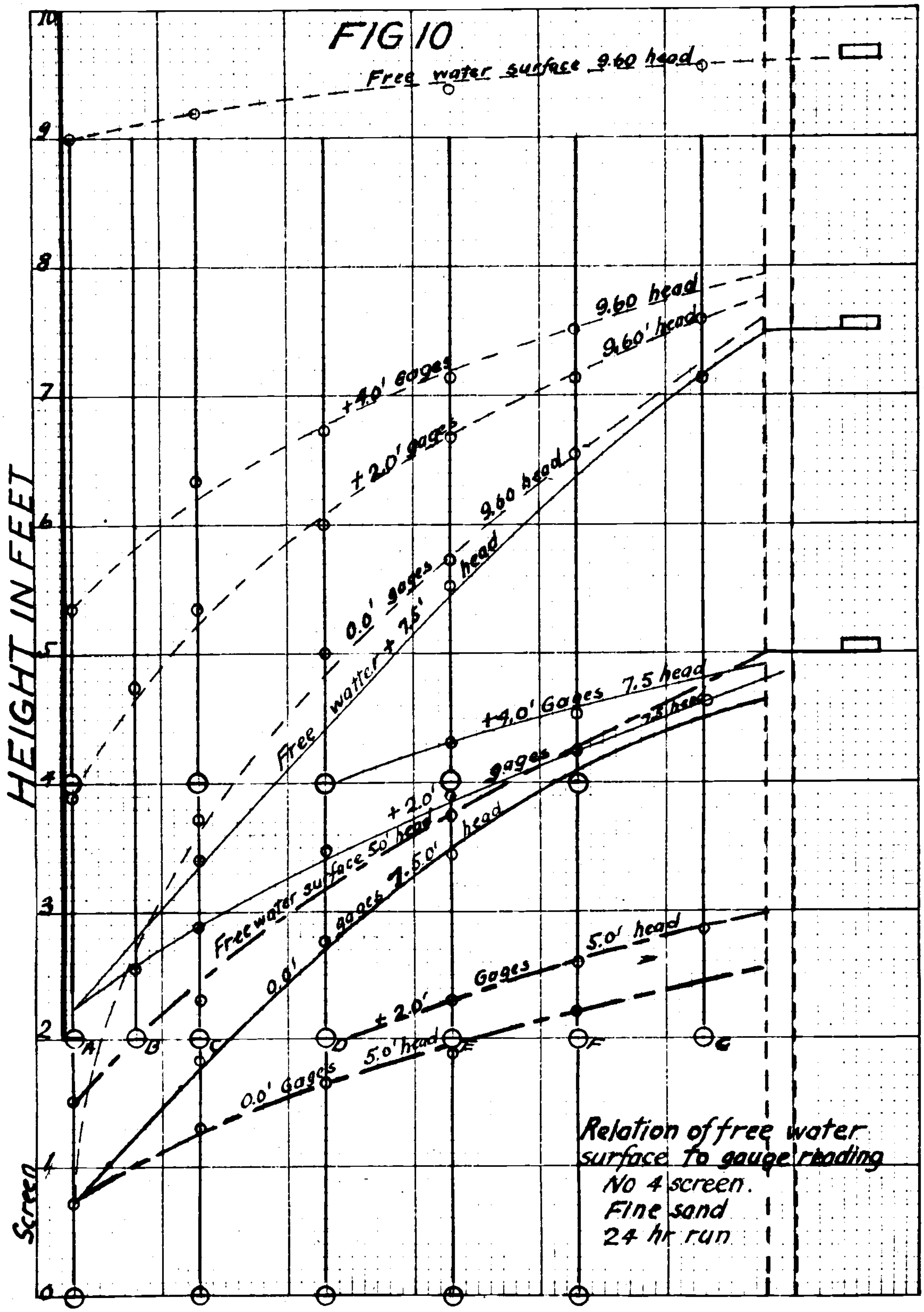


FIG 10
Free water surface 9.60 head
9.60 head
9.60' head
+4.0' Gages
+2.0' gages
9.60 head
0.0' gages
Free water + 7.5' head
+4.0' Gages 7.5 head
7.5 head
+2.0' gages
Free water surface 5.0' head
0.0' gages 7.5.0' head
5.0' head
+2.0' Gages
0.0' Gages 5.0' head
A
B
C
D
E
F
G
HEIGHT IN FEET
Screen
Relation of free water surface to gauge reading
No 4 screen.
Fine sand
24 hr run.
KEUFFEL & ESSER CO. N. Y. NO. N 358-1 R

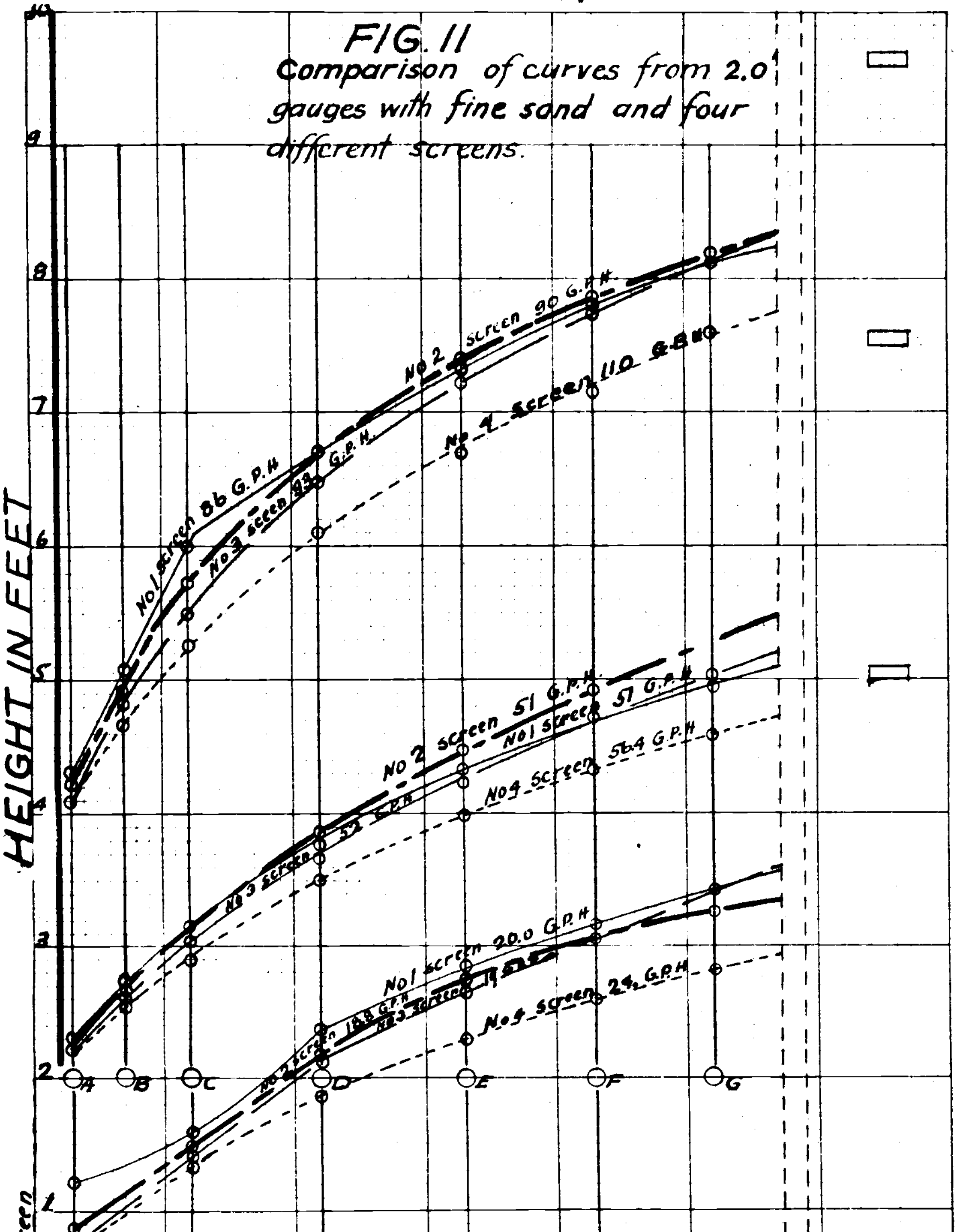


FIG. 11
Comparison of curves from 2.0 gauges with fine sand and four different screens.

KEUFFEL & ESSER CO. N.Y. NO. N 355-1 P

RESULTS OF TESTS ON GRAVEL

The results of the test on the gravel are shown in Tables VI and VII and Figures 12 to 20. Tables VI gives the original analysis of the gravel. Table VII gives the quantities and the analyses of the material accumulated in the settling tank. Figures 12, 14, 15, 16, and 18 show the gauge readings and rates of discharge for each head on each screen. Figures 13, 17, and 19 show the relation of the gauge readings to the free water surface for each screen. The curves of the gauge readings after twenty four hours for each screen and each head are compared in Figure 20.

The analyses on the gravel are not nearly so complete as those for the sand. This was caused by the fact that it was impossible to secure a representative sample of the material after the screen was removed. The relation between the amount and size of material removed and the size of the perforations is brought out by comparing Table I and Table VII. Slightly larger particles passed through each size of perforation with the gravel than passed through with the sand. In all cases, with the gravel, the largest material which passed through approached the width of the perforation, but with the sand each perforation was effective in retaining sizes smaller than the width of the perforation. This is probably caused by the fact that the rate of discharge was greater from the gravel than from the sand, and that, with the sand, the individual particles were sharp and angular while in the gravel they tended to be smooth and round.

That most of the material caught in the settling tank was between .25 mm. and .50 mm. in size is shown in Table VII. The reason for this is that the original gravel was high in this size of separates as shown in Table VI.

The effect of having the edges of the perforations turned out is clearly shown in Table VII. Both screens, No. 1 and No. 3, have the edges of the perforations turned out. The No. 2 screen has a smooth edge. The total area and average width of the perforations was greater in the No. 2 screen than in either the No. 1 or the No. 3. Nevertheless, the amount of sand which passed through each of the latter two screens was greater than that which passed through the No. 2 screen. Figure 20 shows that the discharge for the No. 3 screen was greater than that for the No. 2 screen, and that the No. 1 screen with one-third less area in perforations had practically the same discharge as the No. 2 screen. This shows that the perforations having the edges turned out allow more sand to go through and therefore permits a greater discharge.

ORIGINAL ANALYSIS OF GRAVEL

Size of Grains	Per cent
Above 18.85 mm.	36.19
9.42 to 18.85 mm.	14.63
5.0 to 9.42	5.20
2.0 to 5.0	6.10
1.0 to 2.0	4.63
.50 to 1.0	4.69
.25 to .50	20.00
.1 to .25	7.77
.01 to .1	.49
.05 to .01	.20
.001 to .01	.12

Table VII

Analyses of Material Washed from Gravel

Screen No.	1	2	3	4	5
Amount in Pounds	19.61	8.42	24.36	84.50	127.30
Size Separates below .005 M.M.	.36	.28	.17	.44	.56
.005 to .01	4.44	5.06	4.71	4.17	3.72
.01 to .1	8.36	7.91	7.82	5.81	5.15
.1 to .25	10.46	9.83	10.08	8.32	7.34
.25 to .50	68.08	65.77	61.54	60.19	50.52
.50 to 1.0	8.30	6.22	10.07	11.64	10.46
1.0 to 2.0		4.53	5.61	13.09	11.71
2.0 to 5.0				6.34	7.88
5.0 to 9.42					2.66

The behavior of the pressure curves as determined by the series of gauges at the two foot elevation is shown in Figures 13, 14, 15, 17, and 19. For screens number 1, 2, and 3, the curves continue to rise during the first twelve hours, much as they did for the sand, although the curves are flatter. The rate of discharge for these screens also decreases up to twelve hours. All of the material removed from the gravel by the water was removed during the first two hours, for these screens, which shows that the decrease in discharge was due to an accumulation of fine material either in the channels of flow or just back of the screen.

The effect of stopping and starting the flow at the same head was not the same for screens 1, 2, and 3 in this test as it was with the sand. Here, it caused only a small amount of material to be washed through the screen, a slight drop in the gauges, and the rate of discharge was not changed.

The behavior of the drawdown curves for the No. 4 screen is different from any yet studied. With this screen the maximum rise of the curve occurs at four hours, and at this time, the rate of discharge is the least. During this test, material was washed through the screen for the first two hours after which the discharge water cleared up. After about four hours of run, the discharge again became turbid, indicating that more material was being removed. As soon as this started, the rate of discharge began to increase and the curve began to drop down. The discharge continued to be turbid, the rate of discharge to increase, and the drawdown curve to drop until about the eighteenth hour of the run. The discharge then cleared up, and the rate and curve remained constant until the end of the run. This sequence was the same for all three heads, and must have been due to natural course of flow, since the tank was not disturbed in any way.

The results of the test on the No. 5 screen (Figure 19) present still a different study. Here, there was the same rise in the drawdown curve that occurred with the No. 4 screen, but the rate of discharge showed a gradual increase up to sixteen or eighteen hours after which both the rate of discharge and the drawdown curves were constant. Material was washed through the screen up until the time that the rate of discharge became constant.

The results of the test on the No. 4 screen may be explained by assuming that, after the first two hours of the test, the screen and the channels of flow began to plug up which slowed down the rate of discharge and raised the drawdown curve until a sufficient head was built up to again force the fine material out through the screen. At first thought, this explanation does not seem to apply to the No. 5 screen where rate of discharge gradually increased.

The area of the perforations of the No. 5 screen was nearly fifty percent greater than of those of the No. 4 screen. Since there were the same number of openings for each, the resistance offered to the flow of water must have been greater for the No. 4 screen. The shape of the curves for the No. 4 screen indicates that the major portion of the resistance built up during the first four hours was near the screen since the maximum rise of the curve occurred near this point. The curves for the No. 5 screen indicate that at no time during the test was there any resistance built up at the screen, but there is an indication that there was a resistance built up farther back since the maximum rise in the curves occurs one foot back from the screen.

The fact that the discharge gradually increased while the drawdown curves were rising for the No. 5 screen could be explained by assuming that there was a resistance built up within the body of the material which caused the rise in the curves. At the same time, the increase in head was great enough to keep the rate of discharge gradually increasing, and, after a period of time, force out the accumulated fine material.

The effect of starting and stopping the flow was different with the No. 4 screen than for the No. 5 screen.

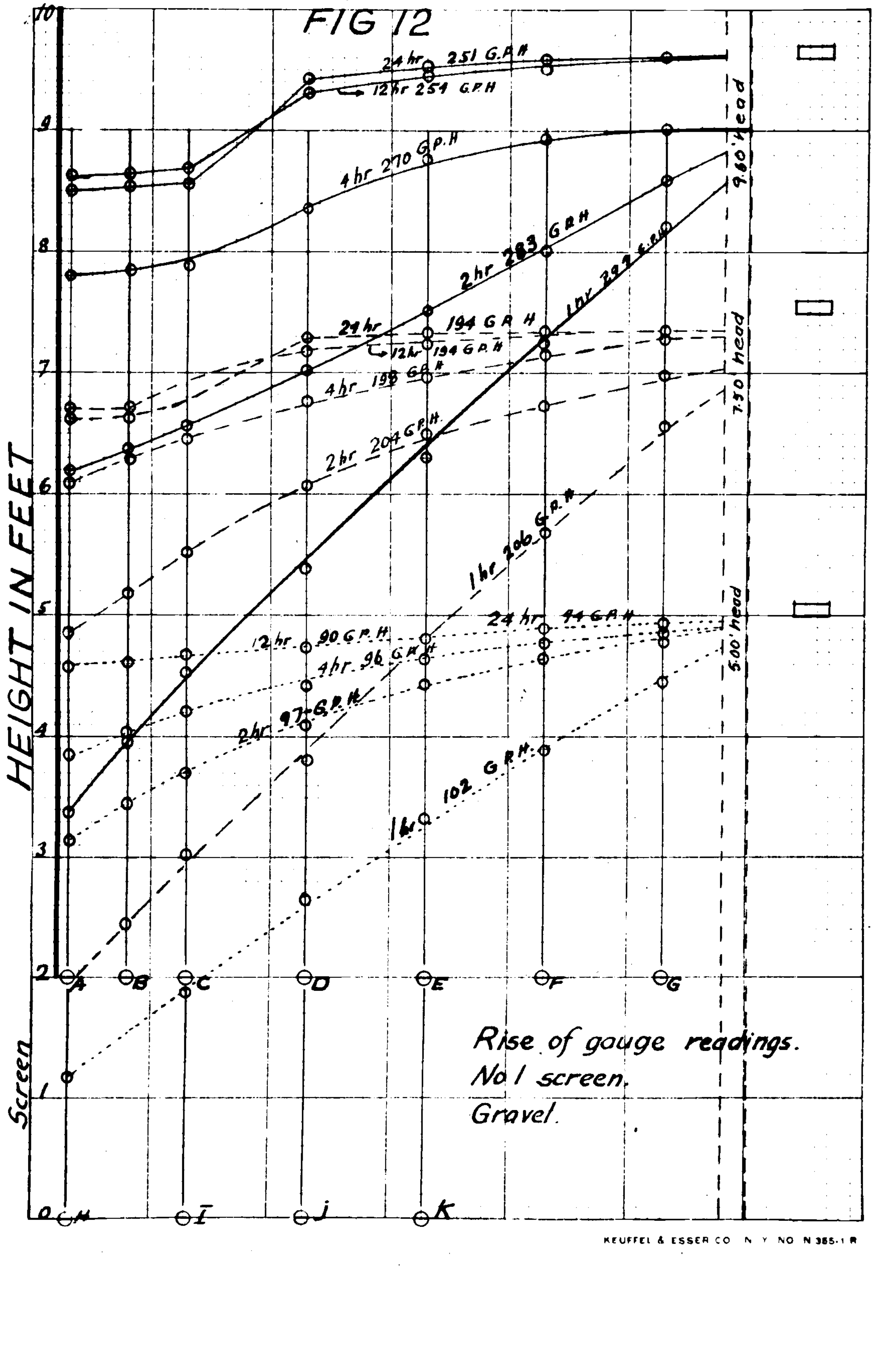
With the No. 5 screen, the rate of discharge increased, the drawdown curve dropped, and more material was removed each time the flow was stopped and started. With the No. 4 screen the behavior was much the same as for screens 1, 2, and 3.

It is possible that stopping and starting the flow had no effect on screens 1 to 4, because fine material was lodged back of the screen while the perforations in the No. 5 screen were large enough to prevent this. The rise in the curves (Figures 12, 14, 15 and 16) indicates that any resistance built up was just back of the screen since the maximum rise of the curves with time occurs here.

Continued starting and stopping the flow had no effect on screens 1 to 4, but with the No. 5 screen each time this was done resulted in an added amount of sand removed and a further increase in discharge. This shows that in order to properly develop a well, the perforations must be large enough to allow a certain amount of fine material to pass through.

The gauge readings taken at the three different levels and the free water surface for screens No. 1, 4, and 5 , are compared in Figures 13, 17, and 19. This comparison is not made for the other two screens, because they were almost identical with the No. 1 screen. These curves show that the difference between pressure readings taken

FIG 12



Rise of gauge readings.
No 1 screen.
Gravel.

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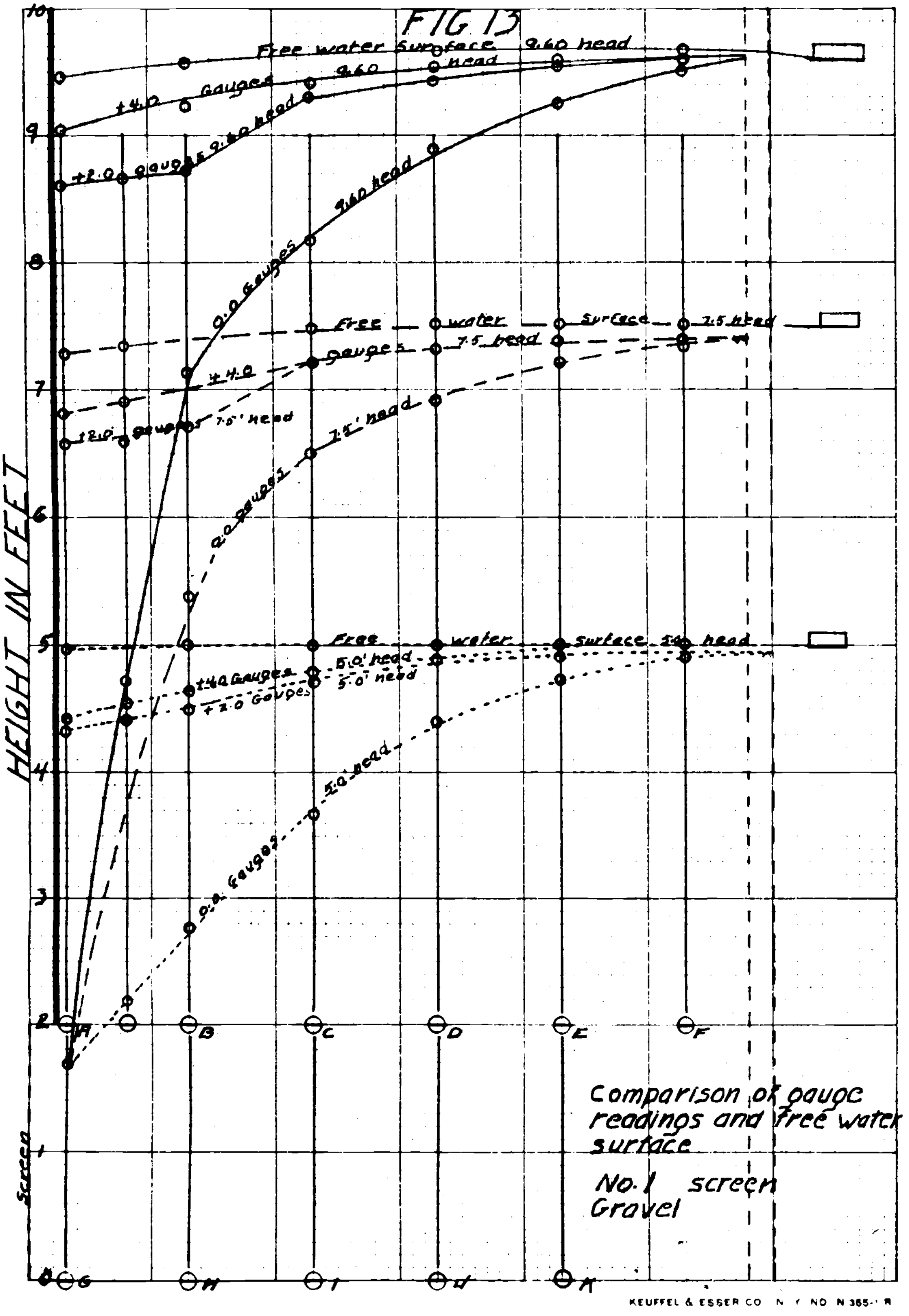

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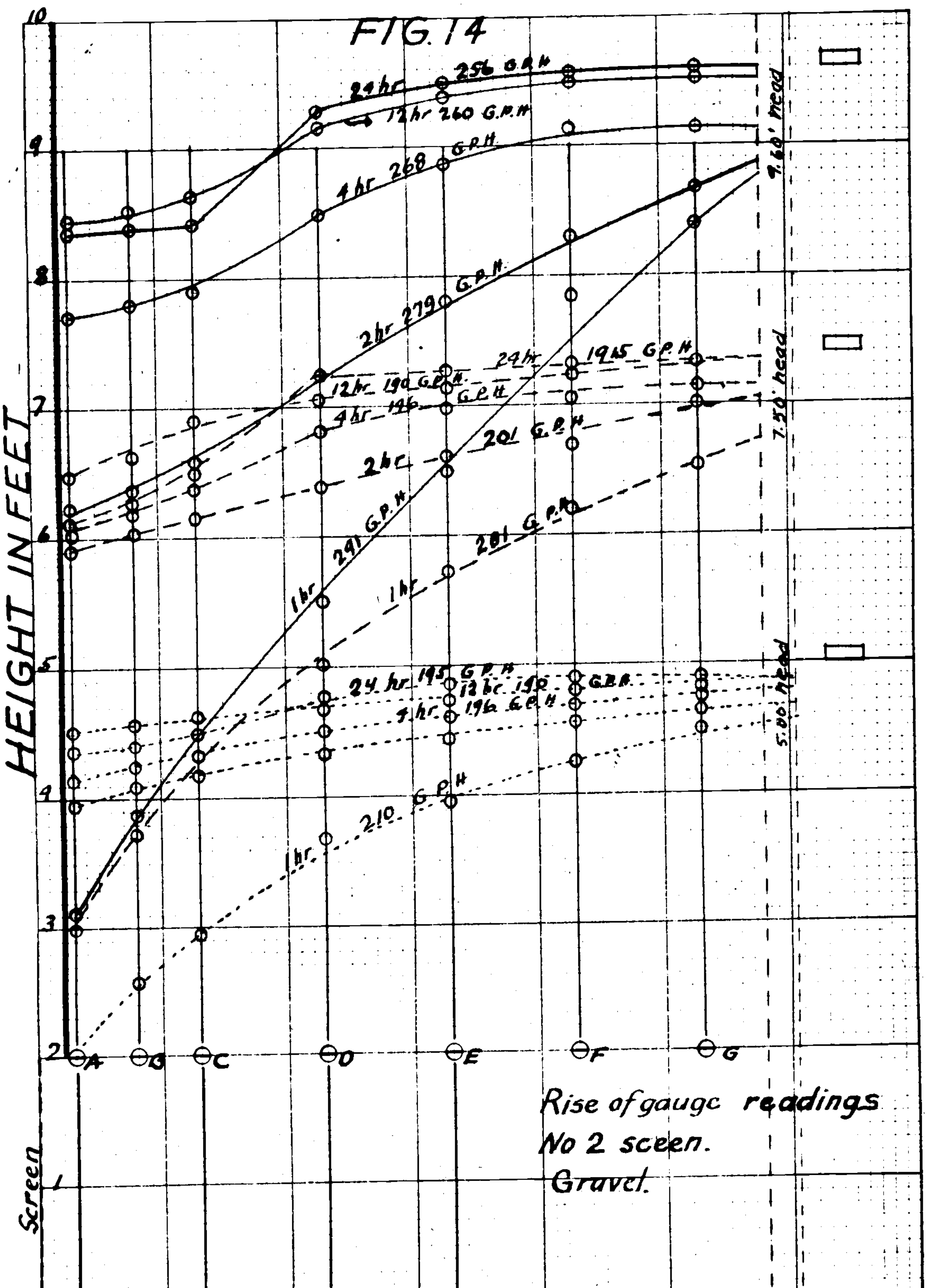

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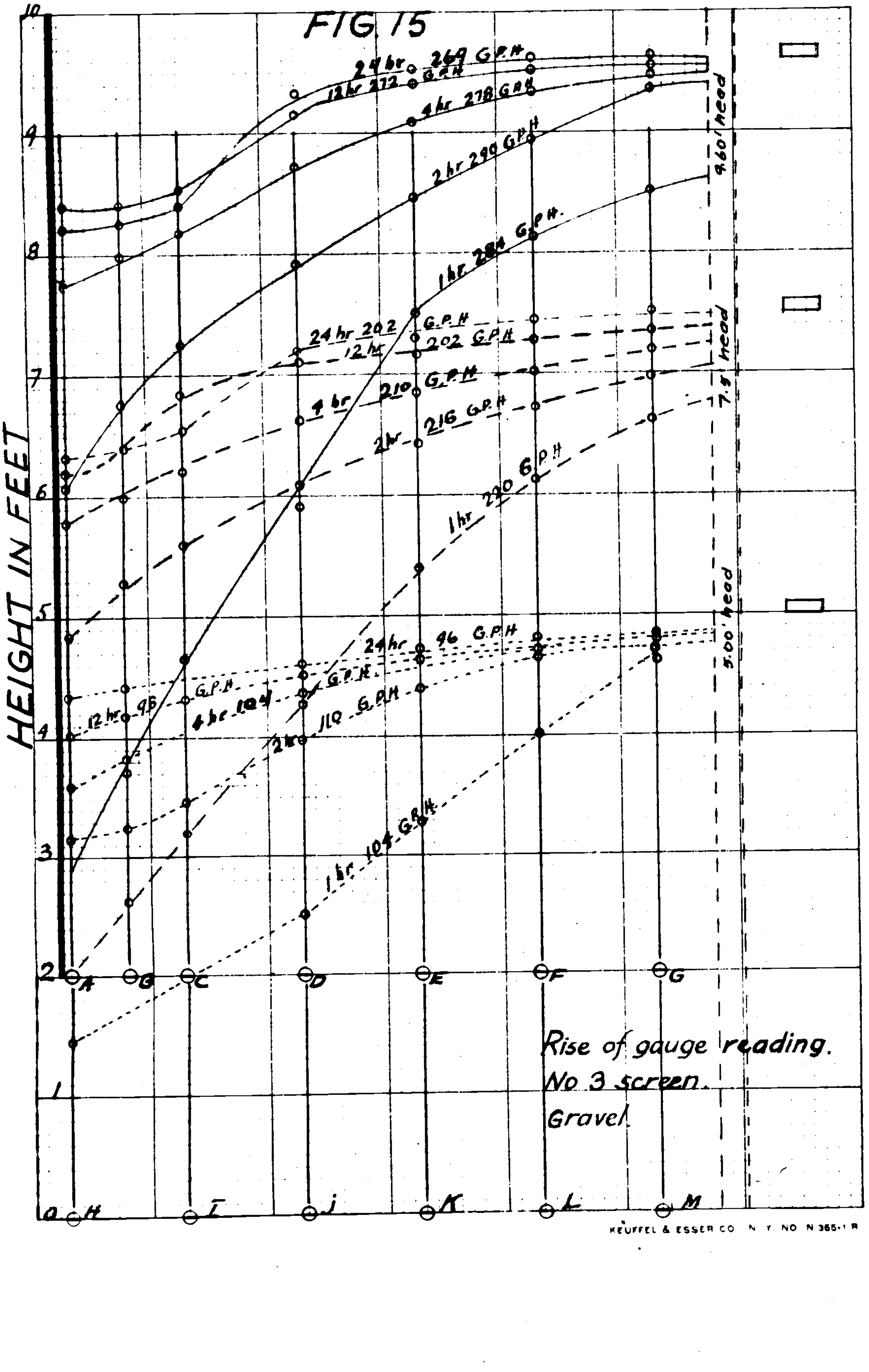
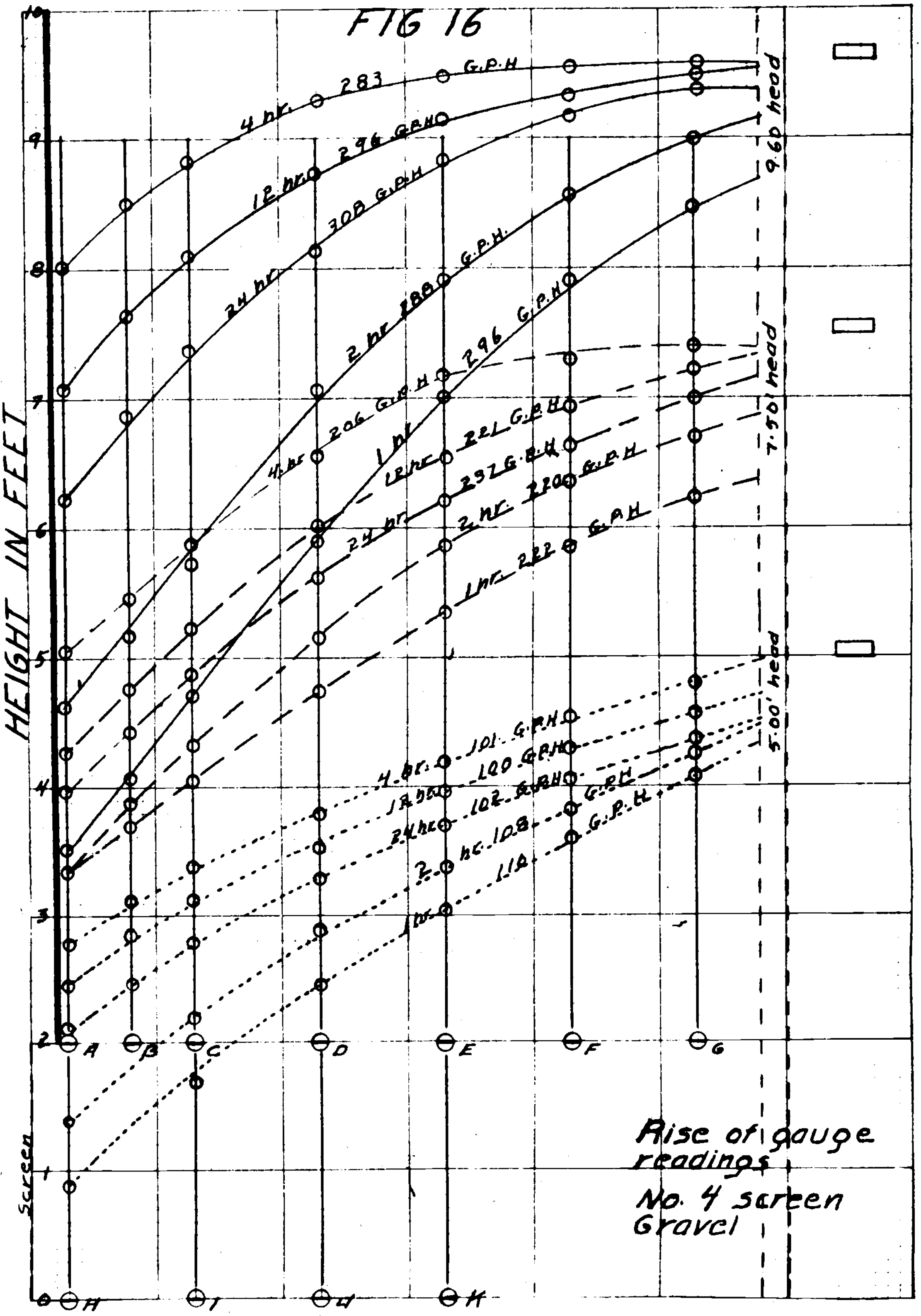


FIG. 15
HEIGHT IN FEET
10
9
8
7
6
5
4
3
2
1
0
24 hr 269 G.P.H.
12 hr 272 G.P.H.
4 hr 278 G.P.H.
2 hr 290 G.P.H.
1 hr 284 G.P.H.
24 hr 202 G.P.H.
12 hr 202 G.P.H.
4 hr 210 G.P.H.
2 hr 216 G.P.H.
1 hr 220 G.P.H.
24 hr 96 G.P.H.
12 hr 98 G.P.H.
4 hr 104 G.P.H.
2 hr 110 G.P.H.
1 hr 104 G.P.H.
9.60' head
7.5' head
5.00' head
A
B
C
D
E
F
G
H
I
J
K
L
M
Rise of gauge reading.
No 3 screen.
Gravel
KEUFFEL & ESSER CO. N. Y. NO. N 365-1 R



Rise of gauge readings
No. 4 screen
Gravel

KEUFFEL & ESSER CO., N.Y. NO. N 355-1 R

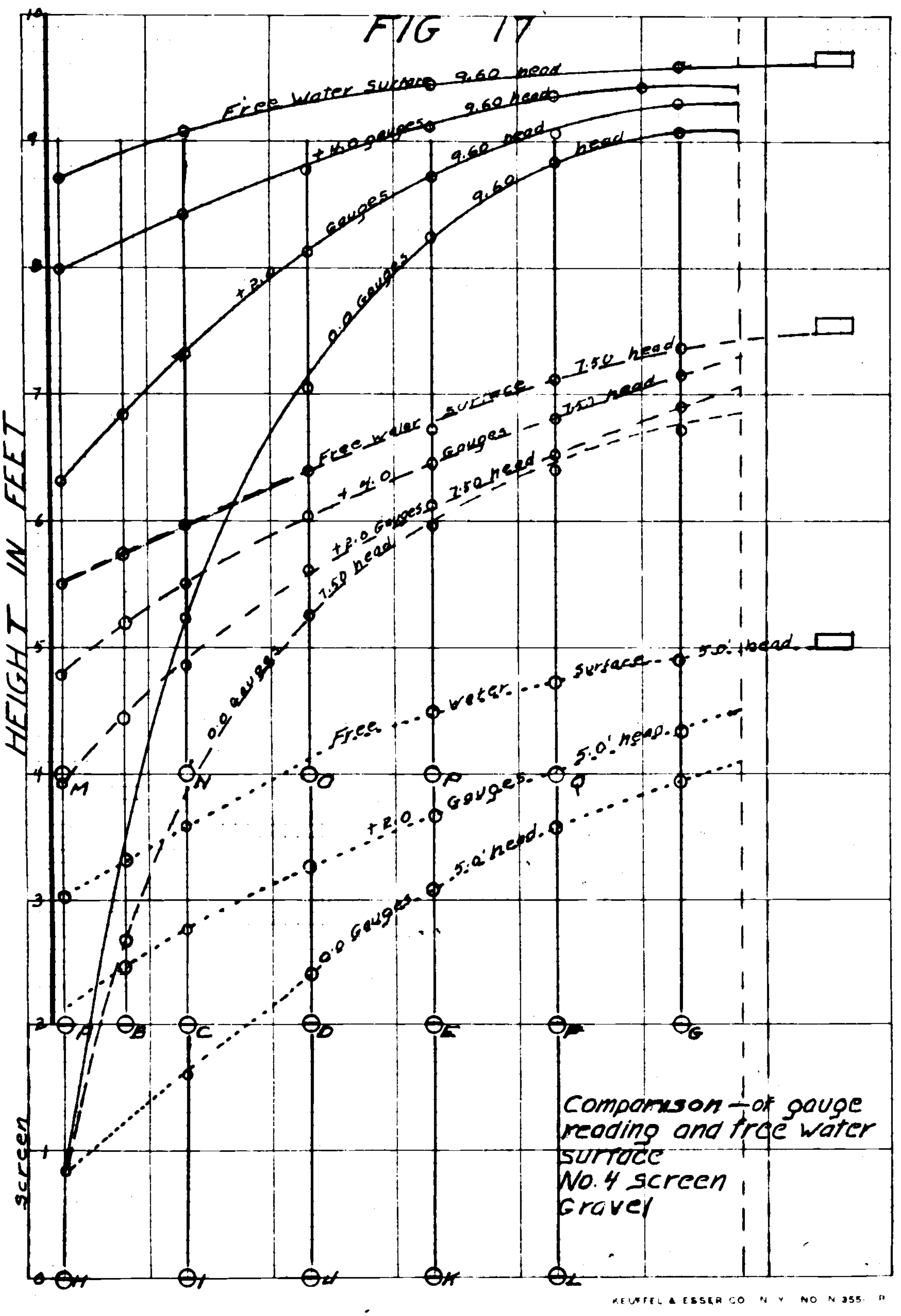


FIG 17
HEIGHT IN FEET
Free Water Surface 9.60 head
+4.0 gauges 9.60 head
+2.0 Gauges 9.60 head
0.0 Gauges 9.60 head
Free water surface 7.50 head
+4.0 Gauges 7.50 head
+2.0 Gauges 7.50 head
0.0 gauges 7.50 head
Free water Surface 5.0' head
+2.0 Gauges 5.0' head
0.0 Gauges 5.0' head
Screen
M
N
O
P
Q
A
B
C
D
E
F
G
H
I
J
K
L
Comparison of gauge reading and free water surface
No. 4 screen
Gravel
KEUFFEL & ESSER CO. N.Y. NO. N 355

FIG 18

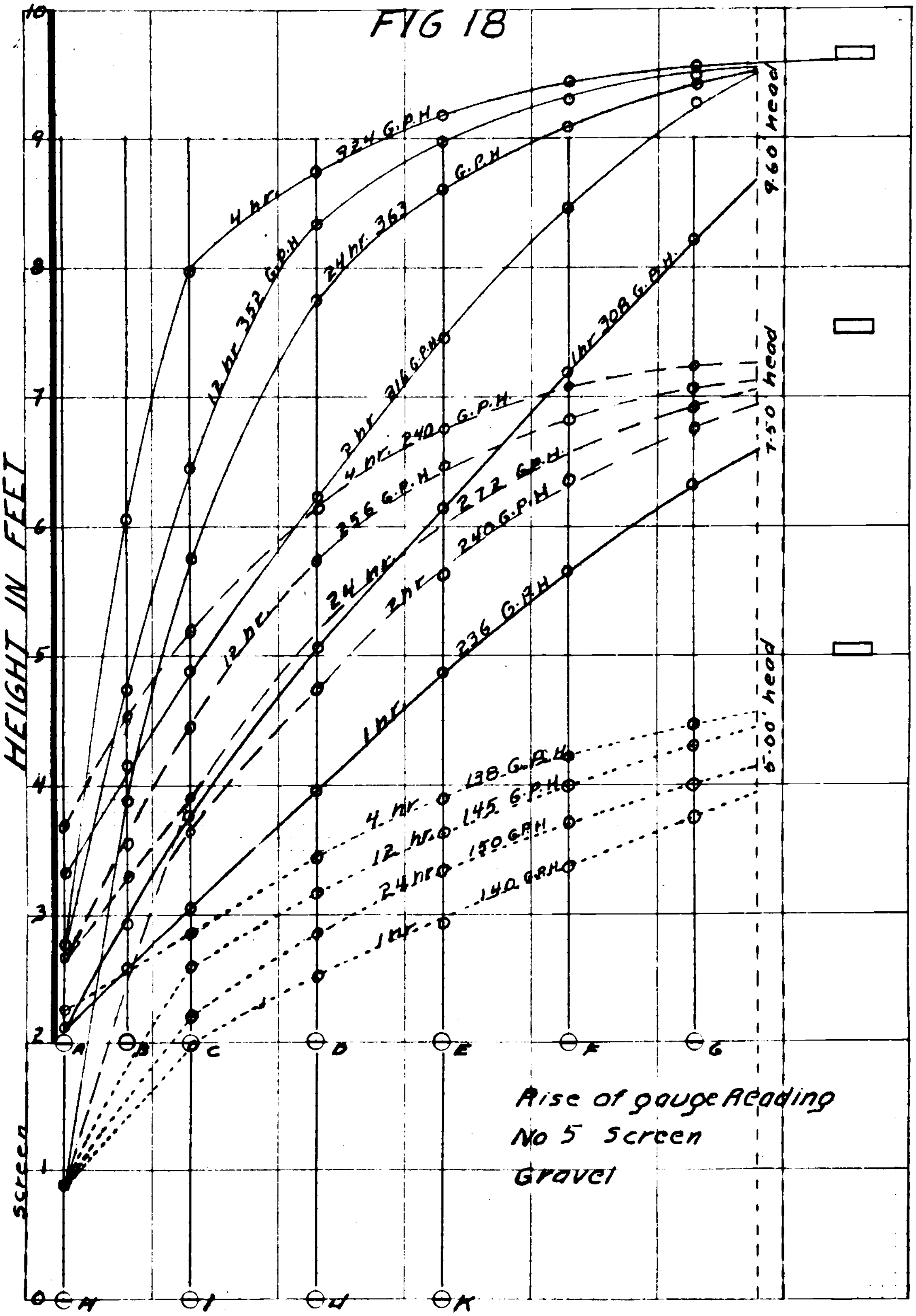

HEIGHT IN FEET
Screen
9.60 head
7.50 head
5.00 head
4 hr. 324 G.P.H
12 hr. 352 G.P.H
24 hr. 363 G.P.H
1 hr. 308 G.P.H.
2 hr. 316 G.P.H
4 hr. 240 G.P.H.
12 hr. 256 G.P.H
24 hr. 272 G.P.H
2 hr. 240 G.P.H
1 hr. 236 G.P.H
4 hr. 138 G.P.H
12 hr. 145 G.P.H
24 hr. 150 G.P.H
1 hr. 140 G.P.H
A B C D E F G
H I J K
Rise of gauge Reading
No 5 Screen
Gravel
KEUFFEL & ESSER CO. N.Y. NO. N 355

FIG 19

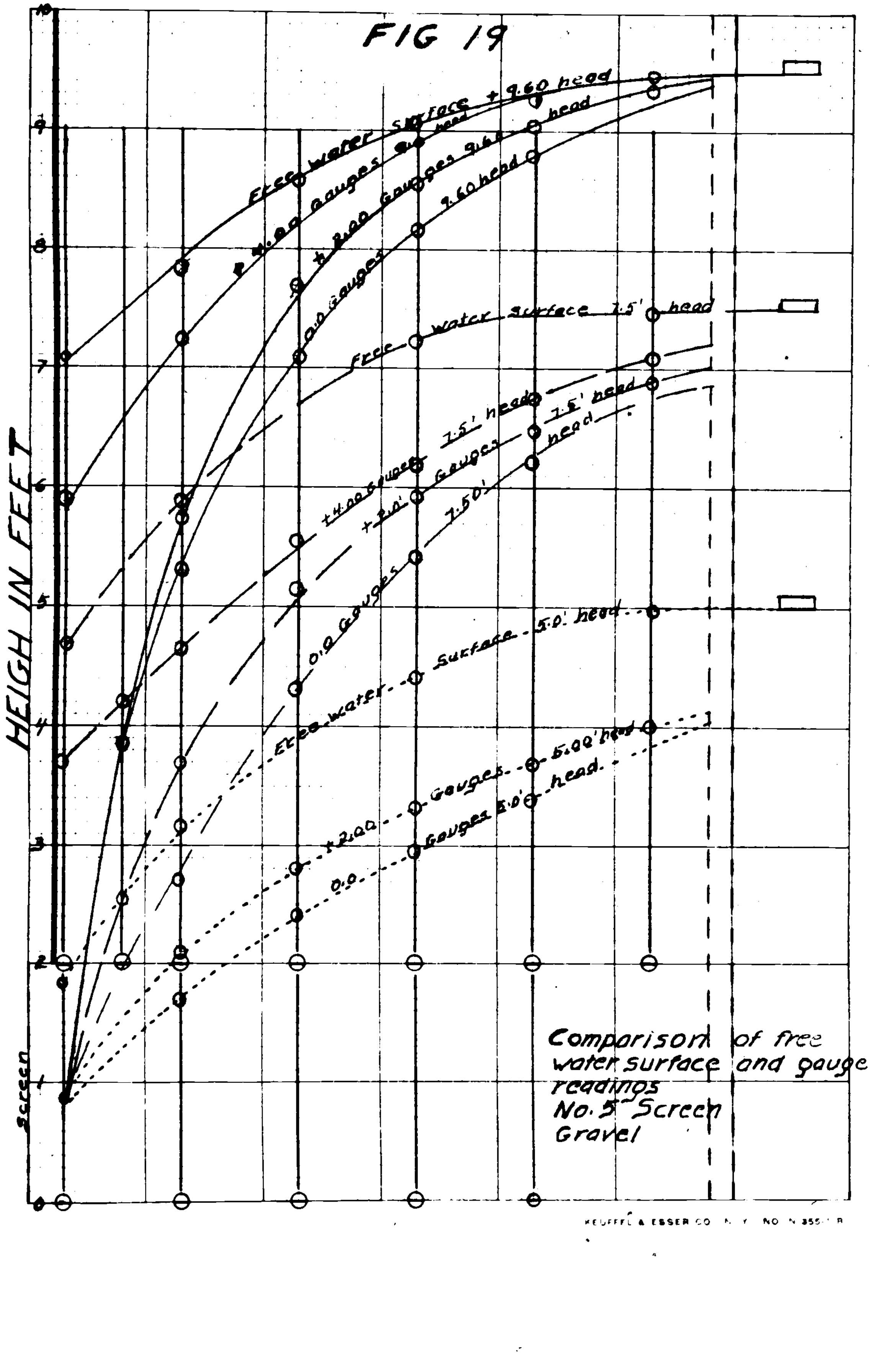


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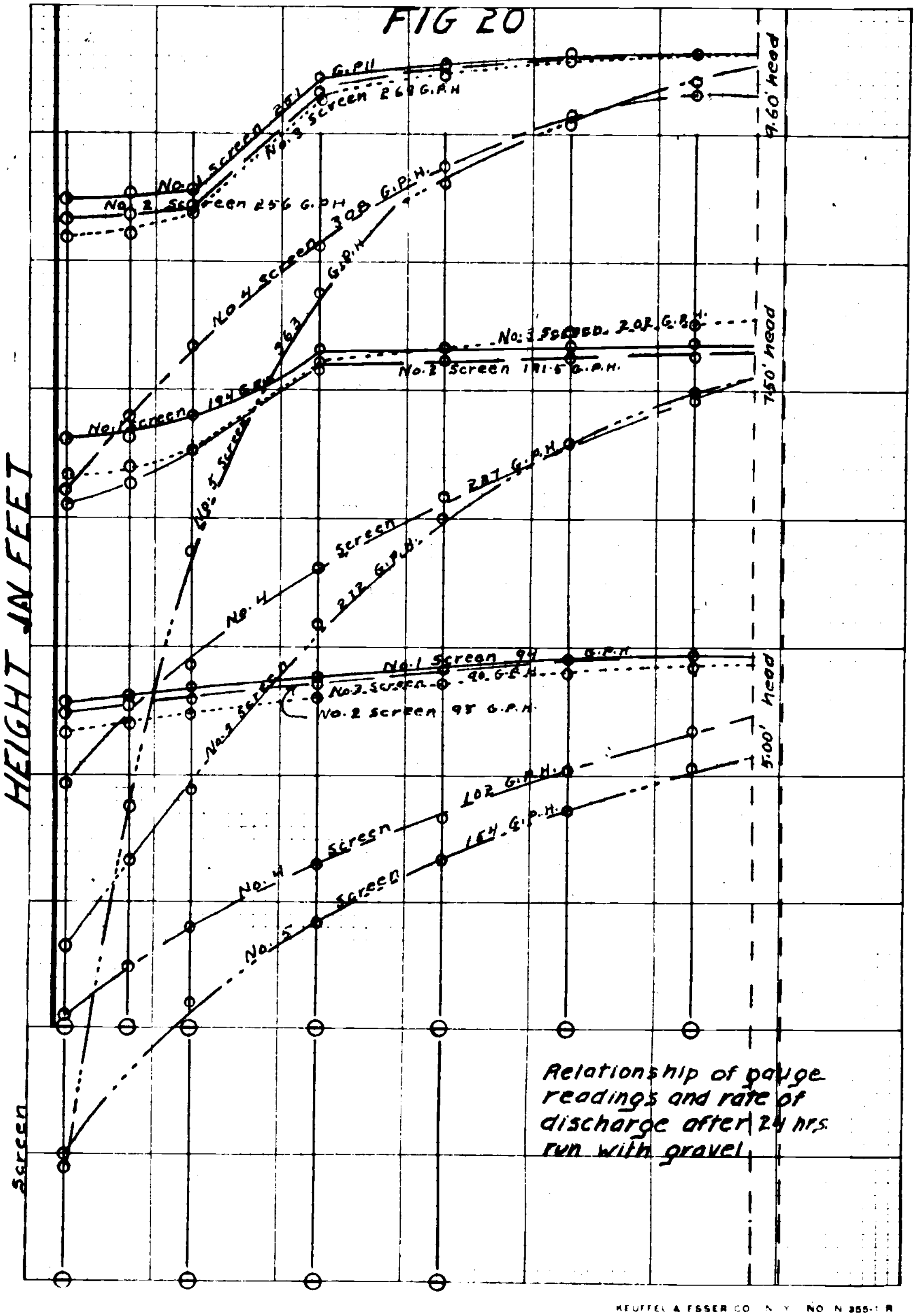
FIG 20



Relationship of gauge readings and rate of discharge after 24 hrs. run with gravel

KEUFFEL & ESSER CO. N.Y. NO. N 355-1 R

at different heights tend to be greater as the velocity of flow increases.

The drawdown curves and the rate of discharge for the different screens and heads after twenty four hours of run are compared in Figure 22. This figure shows that there was a great resistance offered to the flow of water by screens No. 1, 2, and 3, that this was not so great for the No. 4 screen, and that there was very little resistance offered by the No. 5 screen. The perforations in the No. 5 screen probably approached the proper size to use for this particular material.

DISCUSSION

Several points brought to light in the results of the tests previously reported warrant further consideration either because they apply to both the materials used, or because they have a bearing on work previously reported.

The tendency of the pressure curves to rise with continued flow unless material was being removed is characteristic of both the sand and the gravel. This was undoubtedly caused by the silting up of the channels of flow in the material, or by the plugging up of the perforations in the screen.

King (1) and Slichter (7) both noted the tendency of the discharge to decrease with time. Slichter attributed this to biological growth, and overcame the effect by the use of formalin. For the experiments herein reported, the decrease must have been due to a "silting up" process in the voids or at the screen, since biological growth was shown to be an unimportant factor.

The generally accepted practice in figuring the flow of water through a given material is to use Darcy's law (9), that the rate of flow is directly proportional to the head. In these experiments, it was found that the rate of discharge increased faster than the head, although this was not so marked with the gravel as with the sand. King also found this to be true in working on the flow of water through sand.

King and Norling (2) used piezometer gauges on the side of a percolation tank to determine the curve of the free water surface back from a tile. The curves presented with the sand and gravel experiments show that a pressure gauge at any point does not necessarily represent the water surface when the water is moving. Slichter (7) pointed out that differences in pressure at different elevations were possible. His theoretical curves divirged from eachother as the velocity increased which is as occurred with the experiments previously described.

The fact that merely changing the head caused more material to be washed out through the screen is analagous to well development. When a well is being developed, the greatest amounts of sand are removed just after the pump is started, at which time the greatest changes in head occur outside of the casing. Many times after the pump has ceased to discharge sand, stopping and then starting to pump causes sand to be discharged. This substantiates the theory that, after the head becomes constant, the movement of water is through definite lines of flow, and anything which would affect the direction or velocity of flow disturbs these lines of flow and causes more fine material to be moved by the water.

It is interesting to note the effect of having the edges of the perforations diverge outward on both the sand and the gravel. In both cases this type of perforation allowed more material to pass through per unit of area than perforations having a smooth edge. In both cases, the perforations with the edges turned out allowed a greater discharge of water per unit of afea. This substantiates a popular belief among well drillers that perforations diverging outward offer less resistance to the sand, which permits a greater flow of water.

From these experiments, it would seem that a certain amoung of material must be removed in order to prevent a decrease in the rate of discharge, and that an increase in the rate of discharge must be accompanied by the removal of material. After a certain length of time, an equilibrium is reached with the water at a certain lead where the discharge is constant, and no sand is removed.

The conditions of the experiment were different in several respects from the conditions in a well. An analagous condition would be a section of perforated casing, two feet high and six inches wide, in the side of a well. The water would approach such a screen in directions corresponding to radii of a circle centered in the middle of the well. As a result, the cross sectional area of the water as it approaches the screen becomes increasingly smaller in horizontal dimension as well as in the vertical dimension caused by drawdown of the water surface. In the tanks, as the water approached the casing, the cross sectional area of the water was reduced only in the vertical dimension. Assuming that a head was maintained at the same height and the same distance back from the screen for the well and for the tanks, and that the pressure curves were determined on a line at the same elevation, the curves so obtained would be steeper for the well than for the tank. The reason for this is that, with the well, the acceleration of the water is greater as it approaches the casing, because of the more rapid decrease in the area of the cross section of the water.

In a well, the discharge would not always drop freely away from the casing as it did in these experiments. It is not certain whether or not this would affect the results in any way.

With well development, when the pump is stopped there is a reversal of the direction of flow through the sand. This did not occur in these experiments, and it would undoubtedly affect the amount of material removed.

CONCLUSIONS

1. Continued flow through the material caused a decrease in the rate of discharge, unless some of the material was removed with the water.

2. The rate of discharge increased faster than the head.

3. A decrease in the rate of discharge was accompanied by a rise of the gauge readings.

4. Perforations with the edges diverging outward offered less resistance to fine material than perforations with smooth edges.

5. For fine material offering a great resistance to the flow of water, the type of perforations is not a determining factor in the rate of discharge, although

the perforations must be small enough to retain the body of the material.

6.In order to get an increasing rate of discharge, the perforations must be large enough to allow a portion of the finer material to pass through.

7. A gauge reading taken at a given point on the side of the tank does not determine the actual water surface for moving water within the tank.

SUMMARY

Tests were made on the percolation of water through typical water-bearing materials in a tank, roughly ten feet high, seven feet long, and six inches wide, as affected by different types of well casing perforations. The rate of discharge, changes in pressure taken at different elevations on the tank, and the amount of material removed were noted. It was found that a decrease in discharge was accompanied by a rise in pressure; that the size and shape of perforations affected the amount of material removed; that an increase in discharge was dependent on the removal of material, and that continued flow caused a decrease in the rate of discharge unless material was removed with the water.

oOo

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Plate I

APPARATUS USED IN EXPERIMENTS ON

WELL CASING PERFORATIONS

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The scales and settling tank are not shown, but they are directly below the end of the flume.

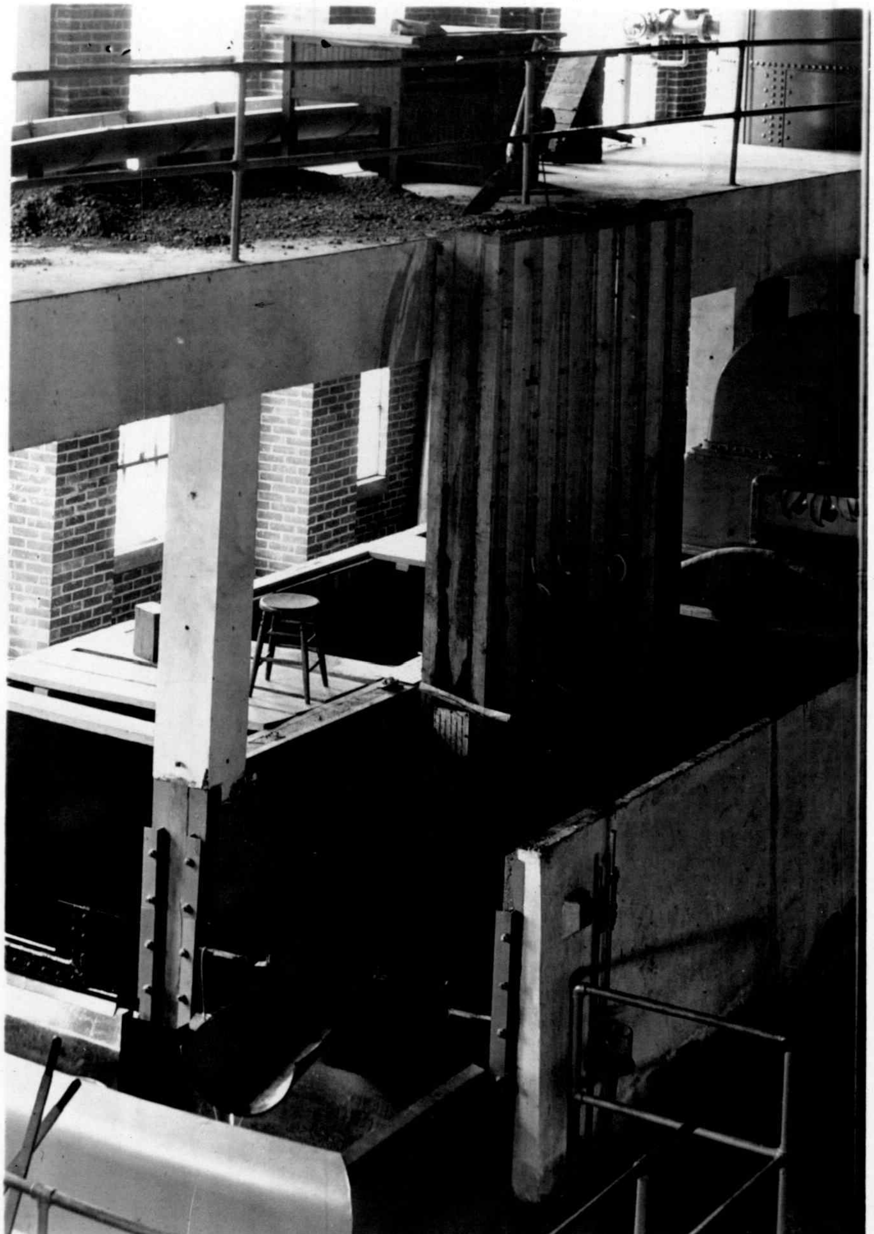

Plate II

VIEW OF CASING SECTION IN PLACE