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DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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Technical Memorandum No. 389

SATURATION OF EXISTING EARTH DAMS

by

R. C. HAVEN, JR., JUNIOR ENGINEER

Denver, Colorado
June 25, 1934

UNITED STATES

DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

MEMORANDUM TO CHIEF DESIGNING ENGINEER

SUBJECT: SATURATION OF EXISTING EARTH DAMS

By R. C. HAVEN, JR., JUNIOR ENGINEER

Undor diroction of

E. W. LANE, RESEARCH ENGINEER

TECHNICAL MEMORANDUM NO. 389

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SATURATION LINES
IN
EXISTING EARTH DAMS

INTRODUCTION

This memorandum represents an attempt to gather together what meagre information is available on the extent of saturation observed in some existing earth dams.

The extensive program of dam construction being undertaken by the Federal Government may require a more thorough understanding of the subject of percolation through and under and around the ends of earth embankments than the data at hand has to offer. A study of the subject is contemplated and the material shown here together with that which may subsequently be brought to light will form the necessary background to such work.

While this is not a theoretical treatise, intimate contact with literature on the subject suggested certain concepts of the interrelationship of various factors affecting position of the saturation surface.* These factors are thought worth presenting because it is felt that only with a fair idea in mind of the scope of the problem can an intelligent evaluation of the available data be made and a basis for comparison be established. A review of these factors is taken up in Part I so that the reader may have them in mind while examining individual cases later on.

*Because the saturation surface in a dam has come to be identified by its trace on a vertical cross section of the earth dam it is generally referred to as the saturation "line". It must however be thought of as a surface and, in nearly every case, a warped surface.

While it is sometimes difficult to differentiate between factors which influence position of the saturation line and those which complicate the engineers' job when he seeks to locate the saturation surface such an attempt has been made. Part II contains a review of these factors.

In Part III individual cases are taken up. The treatment includes a brief description and history of the dam, the method of observing the saturation surface with observations made, and finally some brief remarks by the writer.

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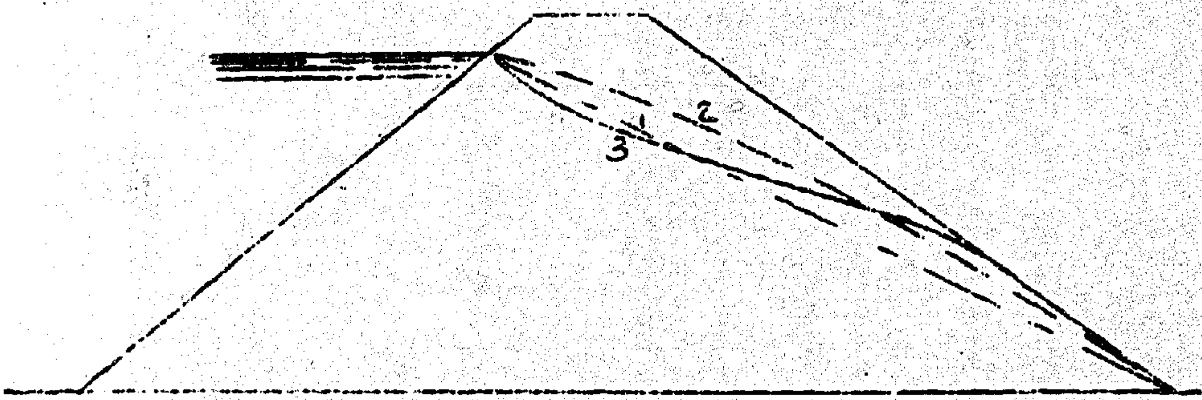
PART I
A REVIEW OF
FACTORS WHICH MAY INFLUENCE POSITION OF
THE SATURATION LINE

The following sketch indicates roughly the saturation line of a homogeneous earth dam on an impervious foundation as it might be estimated by several analytical methods. They will be seen to be at considerable variance.



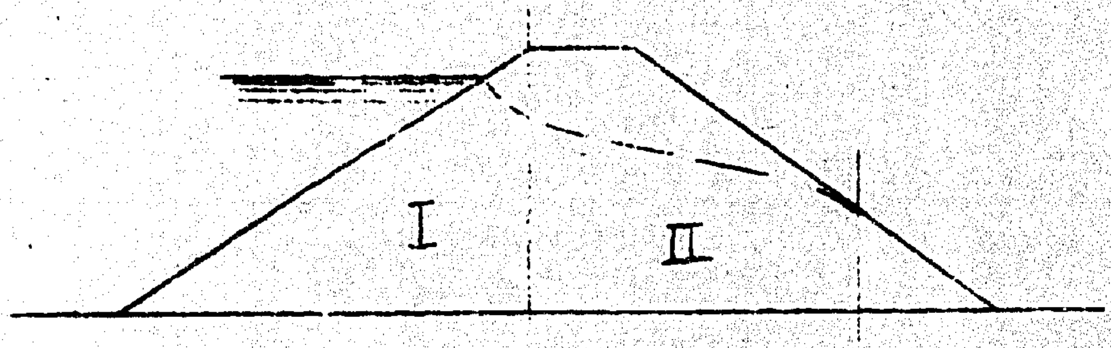
1. Straight line - First approximation generally employed.
2. Single curve concave upward - Turneaure & Russell "Public Water Supplies" (1913).
3. Triple curve - Prof. N. N. Pavlovsky[1] and Dr. Leo Casagrande[2].

It seems to be generally agreed that the position of the line of saturation is of great importance when considering stability of the dam. Merely gaging the quantity of seepage tells little of the conditions of flow within the body of the dam, for the location of the saturation line is believed by Prof. Pavlovsky to be independent of the percolation coefficient[3] of the material.

I. SHAPE OF THE CROSS SECTION.

The saturation line of a homogeneous dam on an impervious foundation is shown by Prof. N. N. Pavlovsky in his analytical treatment of the subject[1] and demonstrated by Engineer Davidenkov in the laboratory with sand and sand-clay models[1] to be of about this shape:

1 "Percolation of Water Through Earth Dams" by N. N. Pavlovsky, Tech. Memo. No. 383 (Translation from the Russian).
2 Report Int. Comm. on Large Dams, 1933. Vol. 4, p. 237.
3 See appendix C.



In section I water enters the dam perpendicular to the face; in section II the curve drops but gently and then drops sharply again when approaching the downstream slope. It has nothing in common with a straight line.

This curve will be seen to be roughly approximated in some of the cases which follow.

On the basis of his equations Pavlovsky concludes:

(1) For geometrically similar dams the saturation lines are similar.

(2) Increase in top width of the dam but slightly influences the downstream part of the saturation line (III) and has also but a slight effect on the discharge.

(3) The downstream part of the saturation line rises for flatter downstream slopes and drops for flatter upstream slopes.

(4) The discharge increases for steeper upstream and downstream slopes.

Flattening the downstream slope increases its resistance to sloughing, but also serves to bring the saturation line closer to the surface and so increases the danger of excessive wetting by the capillary water above the saturation line.

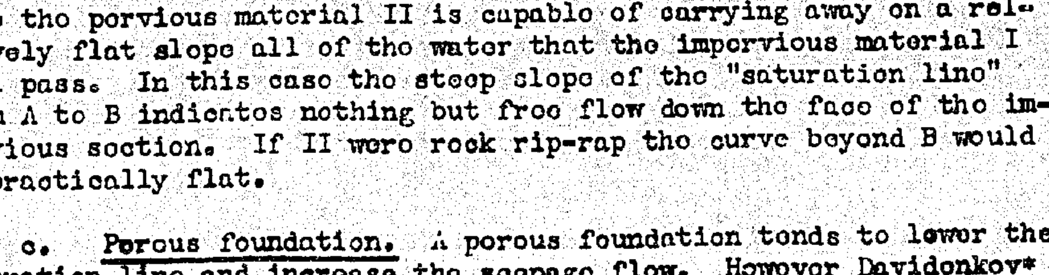
Rock rip-rap facing cannot be considered part of the dam in saturation studies because flow through coarse broken rock is not subject to the same laws as that through the relatively impervious soil of the dam body. The saturation line is usually horizontal through rip-rap facing. See Gatun Dam plates 25 and 26, and the south and north dikes of Wachusett Reservoir, plates 32 and 33.

II. DISTRIBUTION OF MATERIALS IN DAM AND FOUNDATION.

a. Core Walls and Facings. Water in percolating through soil encounters great resistance to flow and so suffers loss of head. The denser the soil the greater is this loss of head. Thus in a dam featuring a clay puddle or other form of relatively impervious core the saturation line is found to be steeper through the core wall than it is in the relatively pervious material on either side of it. See Gatun Type II (plate 26), Wachussett South Dike (plate 32), Mukti Reservoir Embankment (plate 15), and Unkal Reservoir Embankment (plate 19).

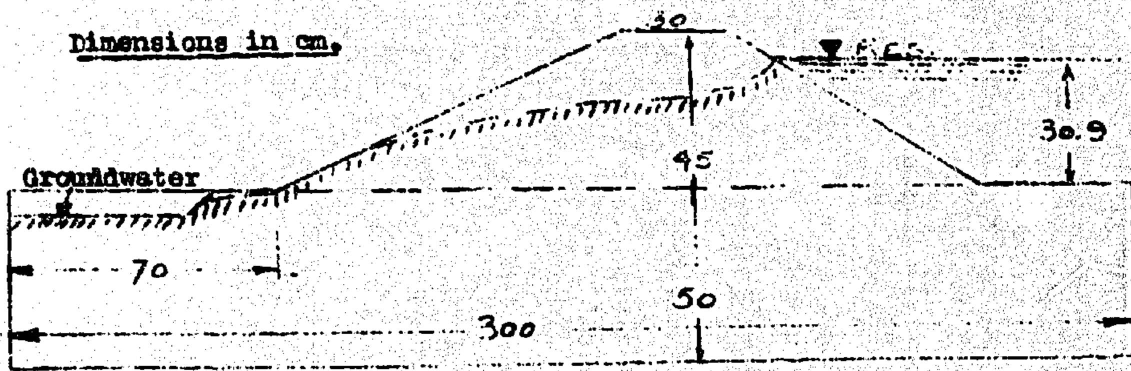
Concentration of impervious material at the upstream face will cause a great drop to occur there. Don Martin Dam (plates 2 & 3) is faced with a fairly tight concrete paving; the drop is experienced in passing through (or through the cracks of) this paving. The relatively pervious earth of the dam body causes proportionately small loss of head.

b. Drains. No matter where they are located drains appear to induce flow in their direction. Witness Coquille Dam (plate 41), Borov Elect. Co. Dam (plate 46), and Boz-Su Dam (plate 43). Where a drain is used it is seen that a drop in saturation line does not necessarily indicate presence of impervious material. As another example consider the following:



Here the pervious material II is capable of carrying away on a relatively flat slope all of the water that the impervious material I will pass. In this case the steep slope of the "saturation line" from A to B indicates nothing but free flow down the face of the impervious section. If II were rock rip-rap the curve beyond B would be practically flat.

c. Porous foundation. A porous foundation tends to lower the saturation line and increase the seepage flow. However Davidenkov* showed by experiment with models of sand that the saturation line "out the downstream slope even when the level of ground water was fixed at some distance from the dam."



*Report Int. Comm. on Large Dams, Vol. IV, p. 200.
This point appears to be contradicted by plates 9, 33 and 34. It would be interesting to know more regarding data gathered at these dams.

d. Pipe laid in the dam. Horse Creek Dam (plate 11) furnishes an example of failure allegedly caused by seepage along the outside of a concrete conduit laid perpendicular to the axis under the dam at its maximum section. An observation pipe, if driven through the impervious earth of the dam body and into a drain or underlying porous strata will act as a collecting chamber or funnel inducing flow down to the drain. The dip in saturation surface indicated at the Schwarze Dosse Dam (plate 6) illustrates this point.

III. SLIP PLANES AND CONSTRUCTION JOINTS.

While there is at hand no supporting data it seems that if a dam should settle locally after construction, or a portion should settle after reconstruction a path for percolating water in the form of a crack might be formed. Such a condition might result in localized saturation of the downstream face.

IV. CONSOLIDATION OF THE DAM BODY.

Progressive consolidation of the entire body of the dam has been deemed partially responsible for lowering of the saturation line in Boz-Su Dam (plate 43).

V. FLUCTUATIONS OF RESERVOIR LEVEL.

Both the amount and frequency of fluctuations in reservoir level affect position of the saturation line. Because velocities of percolation are very low (of the order of a few feet a year) considerable time is required for the saturation line to build up to its maximum position for a given reservoir elevation. This time may be of the order of weeks (if the material is pervious) or of years (if the material is impervious). Any great fluctuations of reservoir level in the interim may distort the saturation line considerably. There is much evidence in the sketches which follow to indicate that tightly packed earth parts with its water very slowly.

A rapid fall of reservoir leaves the upstream portion of the dam saturated and this water starts to flow both upstream and downstream to get out of the dam. A study of the Schwarze Desse and the Kreibitzbach Dams, plates 6 and 9 will bring out this effect. In passing it is pertinent to note the case of the Standley Lake and Belle Fourche Dams (plates 50 and 52). Portions of these dams sloughed at the upstream face because the clayey material of which they were composed did not drain rapidly enough.

VI SILTING OF THE UPSTREAM SLOPE WITH TIME.

Progressive silting-in of canals carrying suspended material has long been relied upon to reduce seepage losses. The same action in reservoirs affects a lowering of saturation line and a reduction in seepage flow.

VII GROUND WATER IN CONTIGUOUS HILLSIDES.

Flow of water around the ends of a dam is often greater than that through the body of the dam. The plan view of the Boz-Su Dam* (plate 44) and the water table contours shown there illustrate this point.

*"Some of the Results Gained During Investigation of the Loess Dam at Boz-Su" by Engr. A. A. Nichipurovich. Now available as Tech. Memo. #378, translation from the Russian by M. B. Karelitz.

Evidence of flow of a similar nature is found in other cases, namely Titicus Dam (plate 39) and Middle Branch Dam (plate 38).

VIII ALGAE GROWTH IN EMBANKMENT.

While there is no supporting evidence in the data presented here to show the sealing-up effect of algae growth in earth embankments, such growths have been noted in percolation experiments on earth materials of the Bureau of Reclamation soils laboratory. Investigation along these lines will no doubt be undertaken.

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IX. RAINWATER.

The effect of percolating rainwater is to raise the level of water in the observation wells. The rise in well levels seems sometimes to be out of all proportion to the amount of rainfall. In the case of Tji Panoenjang Dam*, a 44 mm. rainfall caused a 4.6

*p. 100, Vol. IV, Report of the International Commission on Large Dams, 1933.

meter rise in well level. Theoretical discussions of this phenomenon have been written by Prof. J. H. Thal Larssen* and by Dr. J. H. Engelhardt*.

*Loc. Cit.

X. RESERVOIR TEMPERATURE.

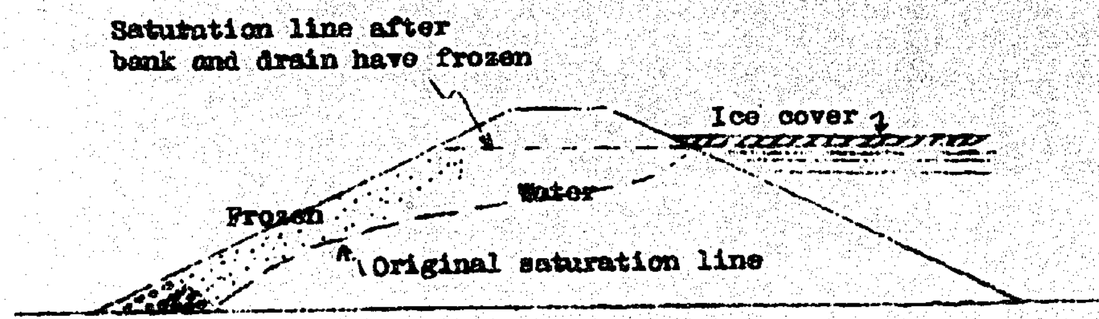
Water becomes more viscous as its temperature drops. In viscous flow such as is found in percolation through earth dams, the velocity of flow varies inversely as the viscosity of the water. In appendix G some observations on reservoir temperatures* are given. This reservoir is in a mild climate and never freezes over. Reservoirs in freezing climates would suffer even greater range of temperature than this one.

*W. E. Green, "Temperatures in Reservoirs" Tech. Memo. No. 379.

Also in appendix C is given a table showing how temperature affects the rate of percolation through a sand.

XI. FREEZING OF DRAINS.

When a drain at the downstream toe of a dam freezes the saturation line is raised. Engineer Davidonkov* in speaking of Russian Dams says that "the phenomenon has not been studied but it appears of great importance. In case the outcoming current of percolating water is frozen the saturation line will go up until the motion of the water through the dam stops and the latter appears saturated with water up to the level of the lower surface of the ice cover at the upper face.



In springtime when the downstream slope is thawing, the outcoming streams of water possess considerable gradients which can seriously threaten stability of the dam." Drains well buried are not apt to freeze.

*International Commission on Large Dams, Report, Vol. IV.

XII. BURROWING ANIMALS.

It is conceivable that burrowing animals might start "piping" in an embankment. Mr. Joel D. Justin* says that due to the fact that there is usually a guard at all large reservoirs the danger from gophers, etc. is not appreciable.

*Trans. A.S.C.E. (1924) p. 120.

PART II
A REVIEW OF FACTORS FOR CONSIDERATION BY THE ENGINEER WHEN MAKING FIELD DETERMINATIONS OF THE SATURATION LINE

Several methods for locating the saturation line in a dam have been employed. They include (1) placing of piezometers or open-ended pipe, (2) placing of perforated pipe, and (3) use of pressure cells such as the Meyer*. New methods are being devised.

*L. L. Meyer: Percolation Slope in dams measured by New Device. E.N.R., 1-26-33, p. 109.

In some ways the placing of wells is better adapted to investigations in existing dams than are other means. It is thought that a few remarks regarding experience of other investigators in this field might be helpful. Literature on the subject has provided the following list:

I. LOCATION OF SECTIONS.

Because seepage flow is not always perpendicular to the axis of the dam the saturation line obtained by observations at one section cannot in general be applied to a section some distance away. This can be seen by comparing plates 2 and 3 of Don Martin Dam and the three sections shown of the Kreibitzbach Dam (plate 9). Upon the choice of sections will largely depend the accuracy of the obtained saturation surface.

II. PLACING OF WELLS IN THE SECTION.

(a) Location. In general, wells give most satisfactory data when placed so that the effects on the saturation line of corewalls, drains, upstream blankets, berms, and major divisions of the different types soil making up the section can be studied.

The wells nearest the reservoir feel effects of fluctuation in level first. The wells near the downstream toe sometimes do not fluctuate at all, the effect of fluctuation in level of reservoir having been completely damped out by the time the farthest wells are reached. To give the complete picture of the saturation line wells must be driven in both upstream and downstream portions of the dam cross section.

When flow from or toward abutments is expected or lateral flow from other sources such as springs, or seepage from adjacent canals, wells should be placed accordingly.

(b) When to place wells. Wells placed as soon as the dam is built permit study of building up of the saturation line with time.

(c) Driving or boring. Messrs. Shin-Ichiro Kambara and Shizuwo Abe* gave their experience in placing open-end pipe at Ono and Murayama Dams (not included in this memorandum). "Sinking piezometers is not so simple. In Ono Dam they were driven like pile; in Murzama borings were used and were more satisfactory in some ways.

(1) Boring disturbs the dam body less but makes the hole too large for the pipe. It is necessary however where there is rubble stone in the embankment.

(2) Driving pipe compresses the earth around it. It is sometimes difficult to keep straight and perpendicular.

(3) Large size tube disturbs the earth more than small size tube.

(4) Joint sockets may be used but flush joints or nipples are preferable.

(5) One to two-inch pipe is just large enough to allow measurement of the water surface."

(d) Depth. If perforated pipe be driven just deep enough to permit measurement of saturation line for the lowest stage of reservoir a minimum of error is introduced in locating the saturation line for high stages.

(e) Kind of Well. Pipe wells seem very satisfactory. In passing, the size of holes in perforated pipe depend upon the material being penetrated. Pipe sometimes become clogged with earth.

*National Report of Japan to the Commission on Large Dams, Stockholm, 1933, Vol. IV.

Observations at a dam generally are discontinued because pipe have clogged. Straight and perpendicular pipe, checked occasionally for settlement will give best results.

III. SETTLEMENT OF DAM AND WELLS.

Generally the distance of water surface below top of pipe is recorded, the elevation of top of pipe being known. Plastic settlement of the earth fill or misuse of pipe may materially move it in the vertical. See appendix F.

IV. METHOD OF MEASURING TO FREE WATER SURFACE.

Several methods are used:

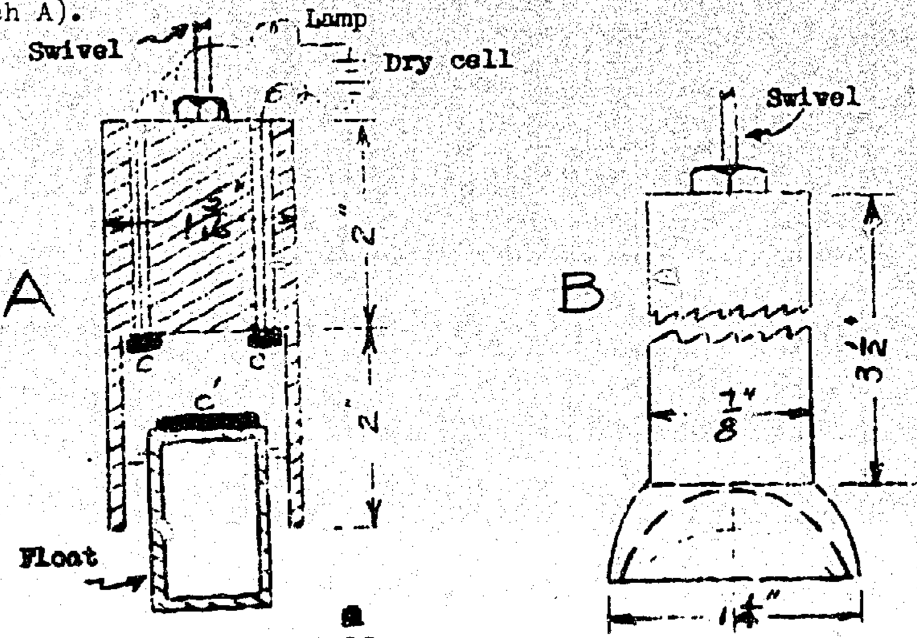
a. Julian Hinds: "The distance to the water surface can be measured by lowering a rubber tube and blowing or sucking on it as it does down. The point at which the tube strikes the water is easily detected." If the depth is too great and stretching of the tube becomes a factor the tube can be lashed to a wire at several points.

b. A steel tape weighted at the end may be lowered and the wetted portion noted. Allowance must be made for displacement of the volume of the weight in this case.

c. A. N. Khosla*: Electrical method as shown in the following

*Executive Engr. Panjnad Div. S.U.P. Punjab, India.

sketch "in which a float, suspended in a metal cylinder, is let down by a twin electric cable with its terminals connected one to the float and the other to the cylinder. As soon as the float touches the water the contact points of the float and the cylinder come together and an electric circuit is closed which rings a bell or lights a lamp." (See sketch A).



d. A bell sounder method (sketch B) also used by Mr. Khosla consists of a solid brass rod 7/8" diameter and 3-1/2" long ending in an inverted cup or hollow hemisphere and suspended from the steel tape by a swivel. "Directly the cup touches the water surface a definite sound is produced which cannot be mistaken or drowned, even in the roar of water shooting over the weir crest*. Readings can be accurate up to 1/16 of an inch but 1/8" may be taken as normal accuracy." Mr. Khosla deems this method simplest, most direct, and most accurate. These advantages foster collection of useful data.

*This cup was used in shallow wells in India when uplift pressures under barrages were being studied.

V. FREQUENCY OF OBSERVATIONS.

Observations of the building up of the saturation line as the reservoir is filling are very valuable. For accurate studies continuous or daily readings are shown to be definitely useful.

VI. TEMPERATURE OF PERCOLATING WATER.

Mention has been made of the effect of water temperature on percolation rate and position of the saturation line. In cases where temperature readings were taken the effect of temperature has been clearly discernable. Maximum and minimum thermometer or thermocouple might be used.

VII. QUALIFICATIONS OF THE OBSERVER.

Only one fairly well versed in the subject of saturation of earth dams should be entrusted with making observations. Too little is known of the subject at present for standardized observations to be all-inclusive in their scope. The situation must be viewed as a whole each time and new observations taken when and where they appear necessary. Records on many dams are practically meaningless because nothing is available but a few scattered well levels of questionable accuracy which are presented without supplementary data.

VIII. INTERPRETATION OF DATA.

Possibly the greatest single barrier to location of the saturation surface by the engineer is this factor.

In the plates which follow in Part III it is felt that the saturation lines shown very often represent a misinterpretation of the data gathered at the wells. Heterogeneous methods of classifying soils and diversified technique employed in obtaining saturation data complicate the problem of comparing any two cases. The desireability of uniformity here is evident. Adoption of standardized methods is, of course hindered by lack of adequate knowledge concerning the problem and all of its ramifications.

Probably because seepage through a dam is frequently looked upon as a weakness or the result of faulty design, data regarding it is not abundant. If proper checks on analytical methods and laboratory set ups are to be obtained, seepage data on existing dams must be provided. Considering the number of elements which influence the saturation line it is not possible to have too much data.

PART III
SATURATION LINES IN ACTUAL EARTH DAMS

The information in Part III was obtained chiefly from the files of the Bureau of Reclamation, the Technical Division of the Denver Public Library, and the personal libraries of several engineers who have long been interested in the subject. Some original data was obtained from projects at which active study of seepage is being conducted.* Original references were used when obtainable, but many of the sketches shown were taken from magazine cuts and probably a few inaccuracies in transferring data are present. Scales are often distorted vertically to bring out detail. It is recognized also that the data available on certain of the dams are sufficient to give only a hazy picture of the situation there, but they were included in the hope that more complete information might be offered. Further, while other saturation lines could be drawn in from the well levels indicated in the sketches, the line given in the reference is shown. Some may be definitely in error.

*A study on Belle Fourche Dam is not yet complete.

DON MARTIN DAM
MEXICO

COMISION NACIONAL DE IRRIGACION
ESTADOS UNIDOS MEXICANOS
(ANDREW WEISS)

I. DESCRIPTION AND HISTORY:

The Don Martin Dam was designed and constructed along lines similar to the McKay Dam of the Bureau of Reclamation. Earth fill was rolled in 6-inch layers. This dam cannot properly be said to have a drain - the rock at the downstream toe is ballast. The concrete paving on the upstream slope and the concrete cut-off wall were relied upon to give the necessary imperviousness. Mechanical analyses of six representative samples of the earth material in the dam show a porous fine gravel. (See chart.)

II. METHOD OF OBSERVING AND OBSERVATIONS:

Perforated pipe were placed at the two sections shown and records have been kept since August 20, 1930. No temperature records are at hand. It is believed that the two sections shown are out of the range of influence of ground water.

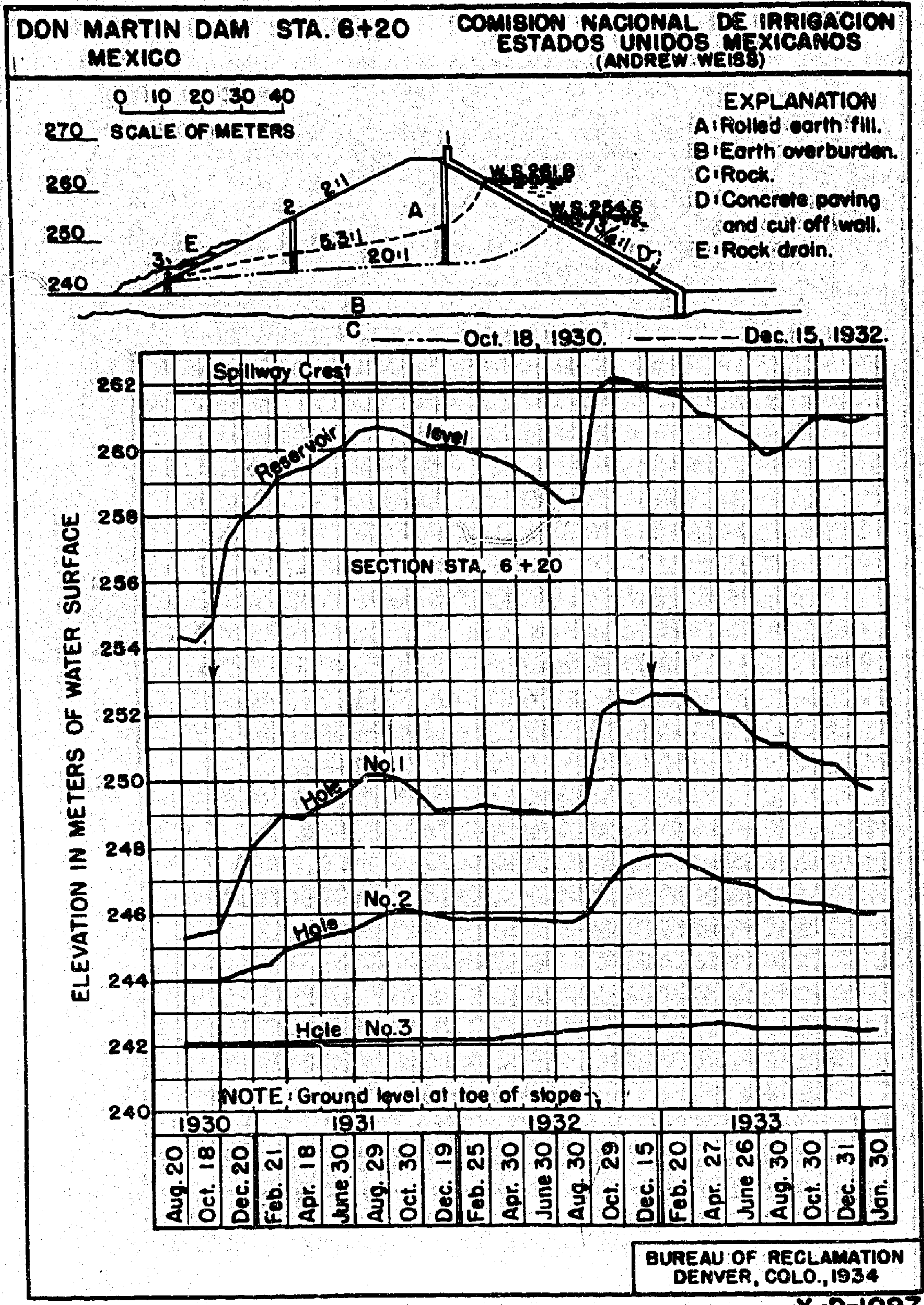
Headwater fluctuates considerably and at times rapidly, but the material in the dam is so porous that fluctuations in reservoir level quickly influence the position of the saturation line.

III. REMARKS:

For purposes of comparison saturation lines have been plotted at both sections for the dates Oct. 18, 1930 and Dec. 15, 1932. It will be seen that the lines for sta. 6+20 are in general higher than those for 8+50. Sta. 6+20 may be near a crack in the concrete facing.

The flat slope assumed by the percolating water is another indication of the porous nature of the embankment material and the sharp drop near the upstream face indicates the effect of the semi-watertight concrete facing. Water is measured by weirs at several points below the dam and the January 1934 records (the only ones available at this time) indicate a total seepage flow of about 1 c.f.s.

BUREAU OF RECLAMATION
DENVER, COLO., 1934


DON MARTIN DAM STA. 6+20
MEXICO
COMISION NACIONAL DE IRRIGACION
ESTADOS UNIDOS MEXICANOS
(ANDREW WEISS)
0 10 20 30 40
SCALE OF METERS
270
260
250
240
EXPLANATION
A: Rolled earth fill.
B: Earth overburden.
C: Rock.
D: Concrete paving and cut off wall.
E: Rock drain.
W.S. 261.8
W.S. 254.6
2:1
5.3:1
20:1
Oct. 18, 1930.
Dec. 15, 1932.
Spillway Crest
Reservoir level
SECTION STA. 6+20
Hole No. 1
Hole No. 2
Hole No. 3
NOTE: Ground level at toe of slope
ELEVATION IN METERS OF WATER SURFACE
262
260
258
256
254
252
250
248
246
244
242
240
1930
1931
1932
1933
Aug. 20
Oct. 18
Dec. 20
Feb. 21
Apr. 18
June 30
Aug. 29
Oct. 30
Dec. 19
Feb. 25
Apr. 30
June 30
Aug. 30
Oct. 29
Dec. 15
Feb. 20
Apr. 27
June 26
Aug. 30
Oct. 30
Dec. 31
Jan. 30
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DENVER, COLO., 1934

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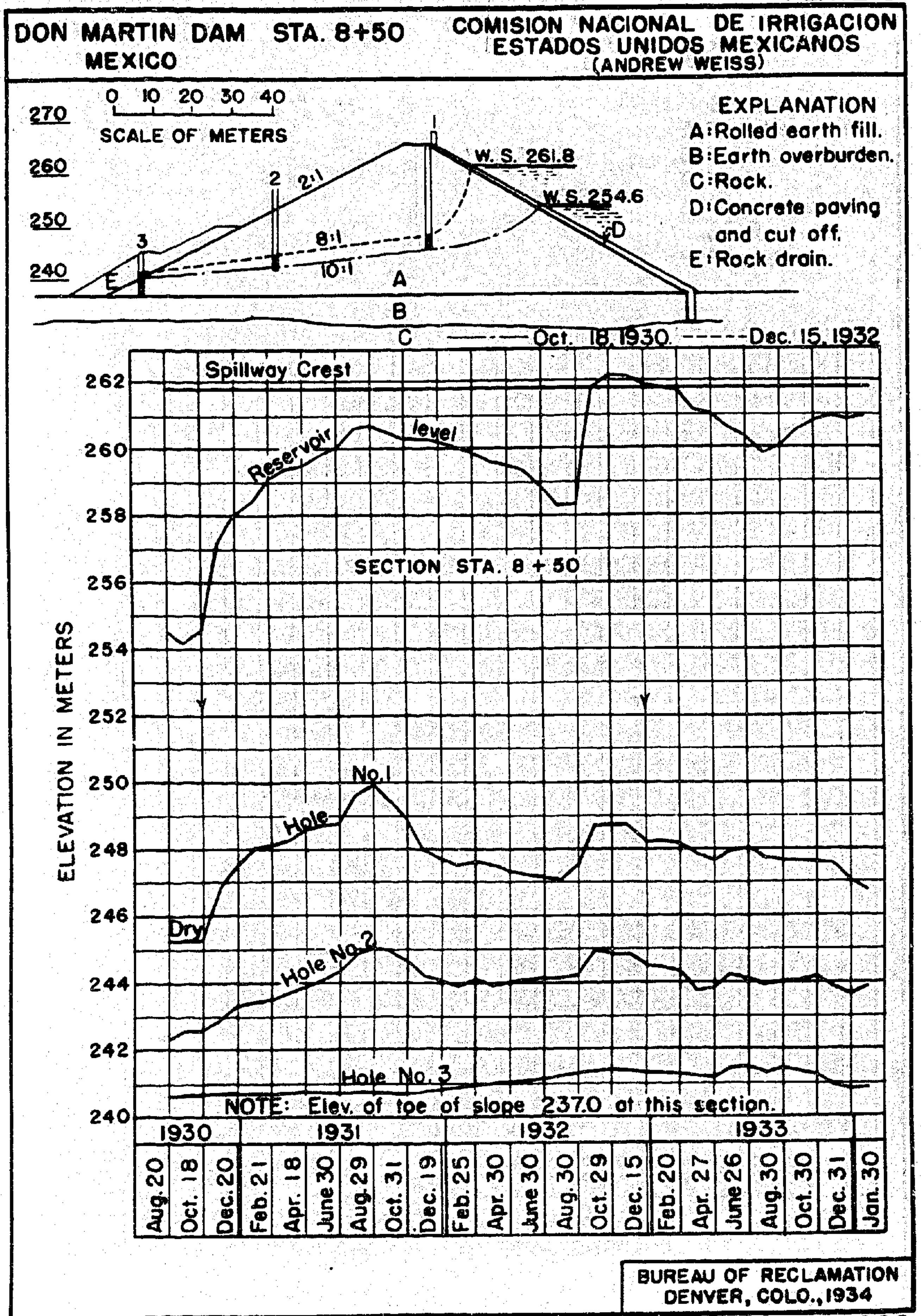
DON MARTIN DAM STA. 8+50
MEXICO
COMISION NACIONAL DE IRRIGACION
ESTADOS UNIDOS MEXICANOS
(ANDREW WEISS)
0 10 20 30 40
SCALE OF METERS
EXPLANATION
A: Rolled earth fill.
B: Earth overburden.
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D: Concrete paving and cut off.
E: Rock drain.
W.S. 261.8
W.S. 254.6
2:1
8:1
10:1
Oct. 18, 1930
Dec. 15, 1932
Spillway Crest
Reservoir level
SECTION STA. 8 + 50
ELEVATION IN METERS
Hole No. 1
Dry
Hole No. 2
Hole No. 3
NOTE: Elev. of toe of slope 237.0 at this section.
1930
1931
1932
1933
Aug. 20
Oct. 18
Dec. 20
Feb. 21
Apr. 18
June 30
Aug. 29
Oct. 31
Dec. 19
Feb. 25
Apr. 30
June 30
Aug. 30
Oct. 29
Dec. 15
Feb. 20
Apr. 27
June 26
Aug. 30
Oct. 30
Dec. 31
Jan. 30
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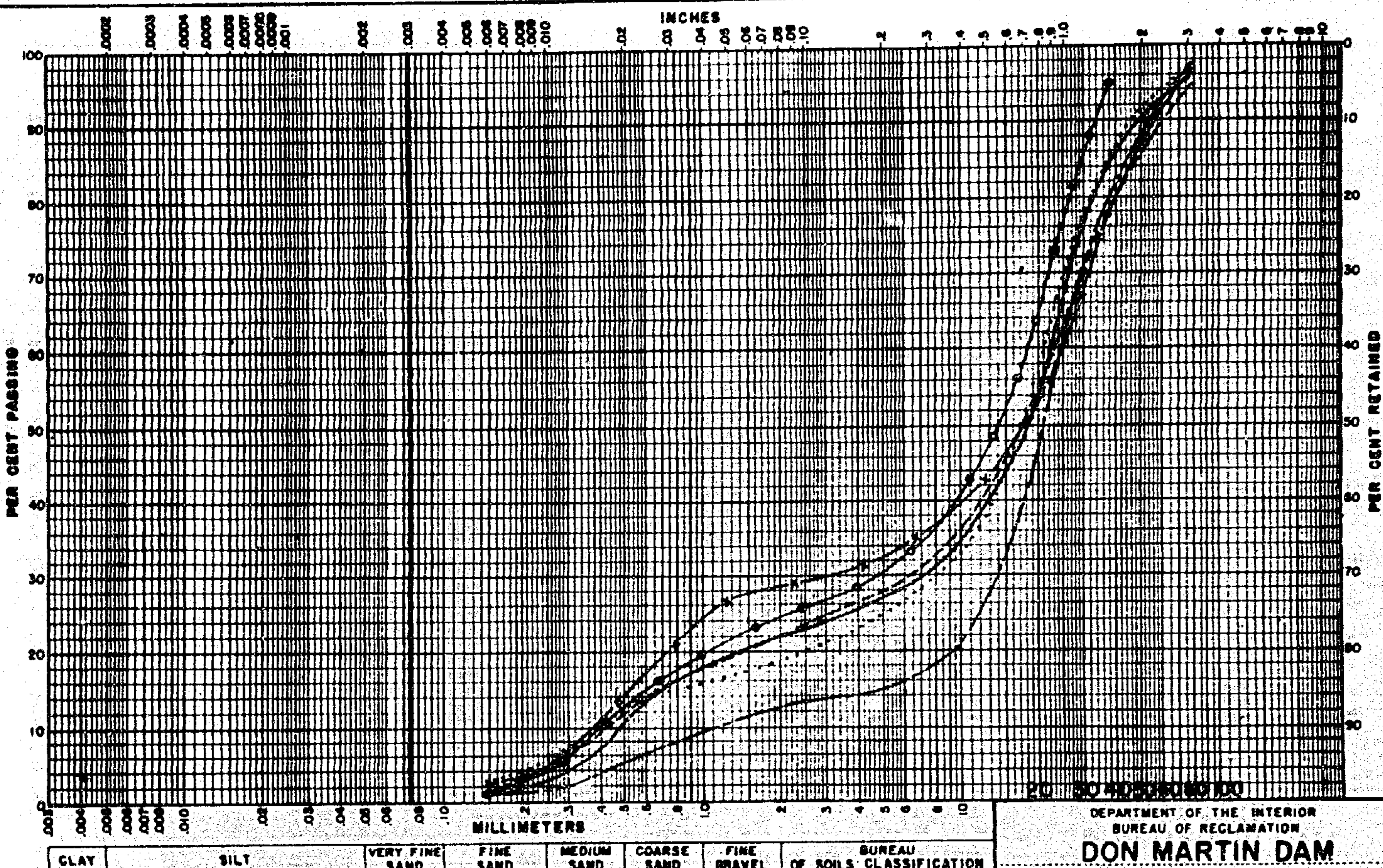
DENVER, COLO., 1934

X-D-1098



REMARKS

——— Sample No. 1	·········· Sample No. 4
– – – – Sample No. 2	—o—o— Sample No. 5
–·—·– Sample No. 3	—x—x— Sample No. 6

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

DON MARTIN DAM

MATERIALS

FROM FIVE BORROW PIT SAMPLES

DRAWN R. C. H. CHECKED DATE 4-11-34

X-D-1099

SCHWARZE DESSE DAM
CZECHOSLOVAKIA

FIRST CONGRESS ON LARGE DAMS
STOCKHOLM, SWEDEN 1933
REPORT VOL. 4, PAGE 139

Description and History

This dam, belonging to a private water company, was begun in June, 1912 and finished in 1924. No exact geological examination of the site was made before or during construction; similarly no soil investigations or suitability tests were made during construction. The material in the dam was supposed to have been placed in 40 cm. layers rolled to 30 cm. under a 3000 kg. roller drawn by horses. For the body of the dam the weathered and decomposed detritus of the valley floor and walls was utilized without test and without eliminating the larger blocks.

Upon completion of the dam the reservoir was gradually filled and served its purpose (storage for several small water works) until Sept. 29, 1926, when after failure of the dam in the neighboring valley of the Weisse Desse it was required to be emptied. Following this an official investigation of the dam and its operation was made.

Whereas a portion of the foundation was carried to bed rock about one-third the length of the dam rested on a kind of loam where the rock lay too far below. The overlying layers of weathered granite were pervious. The largest springs were plugged and sealed. A systematic drainage of the foundation was not undertaken. The examination revealed that the ground downstream from the dam was thoroughly saturated. It was opined that water had forced its way under the dam and saturated this ground.

Method and Observations.

For the purpose of examining the foundation, the dam, and movement of the water, the following were constructed after the failure of the dam on the Weisse Desse. Fig. 1:

(a) Test wells 1,2,3,4,5,6,7,8.
(b) Pits XI,XIV.
(c) Borings VIII, XVI.
(d) Observation Pipes VII,XV,IX,X,XXXI,XXX,XXXIX,XXXIII,XX, in the dam.
(e) Observation Pipes XXIII,XXV,XXVI,XXVII,XXVIII,XXIX,XXXI, downstream from the dam.
(g) Shaft (May 1921) 1--9.
(h) On the occasion of the strengthening of the dam in 1925-1927, the shafts VII,XIX,XV were sunk as pipes 23 cm in diameter at the bottom and 27 cm at the top.

From the comprehensive observations taken over a period of several years a few significant examples are offered:

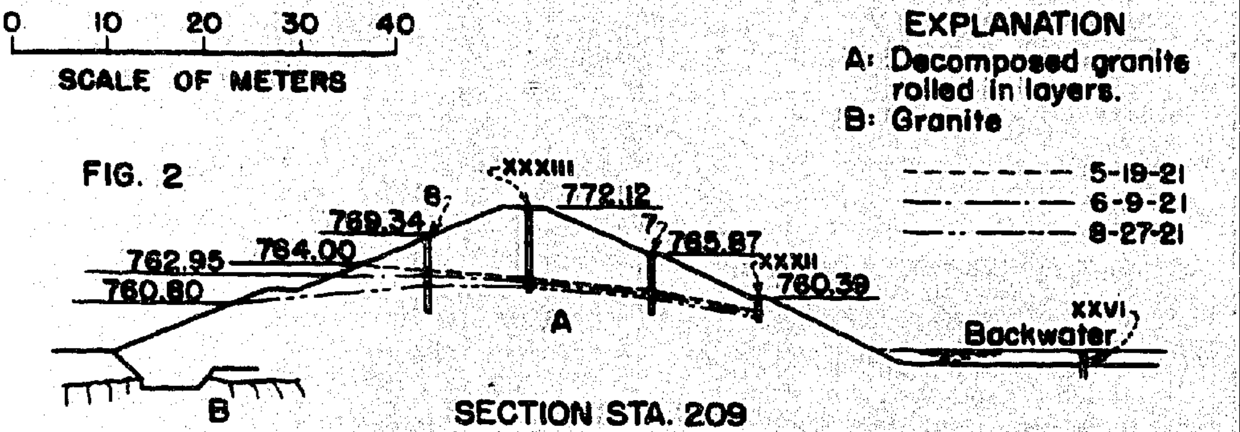
1. Fig. 2- Water forced into the dam during high reservoir level flows away toward both faces of the dam when the reservoir level drops.
2. Fig. 3- Low water stage in pipe VII is explained by the fact that this pipe extends down into the permeable material below the dam and acts as a collecting funnel draining toward the bottom. Seepage along the axis of dam from the adjacent hillsides may also influence the level of water in the wells to a limited extent.

BUREAU OF RECLAMATION
DENVER, COLO., 1934

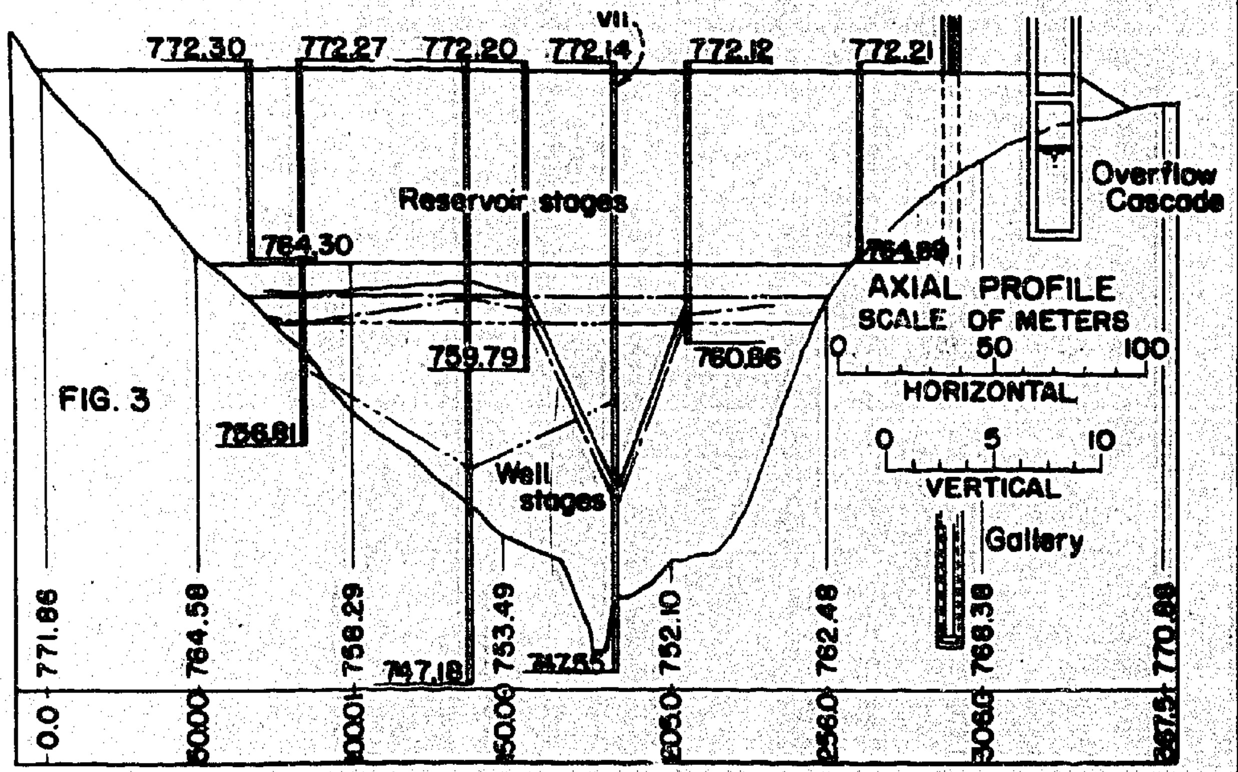
PLATE 6

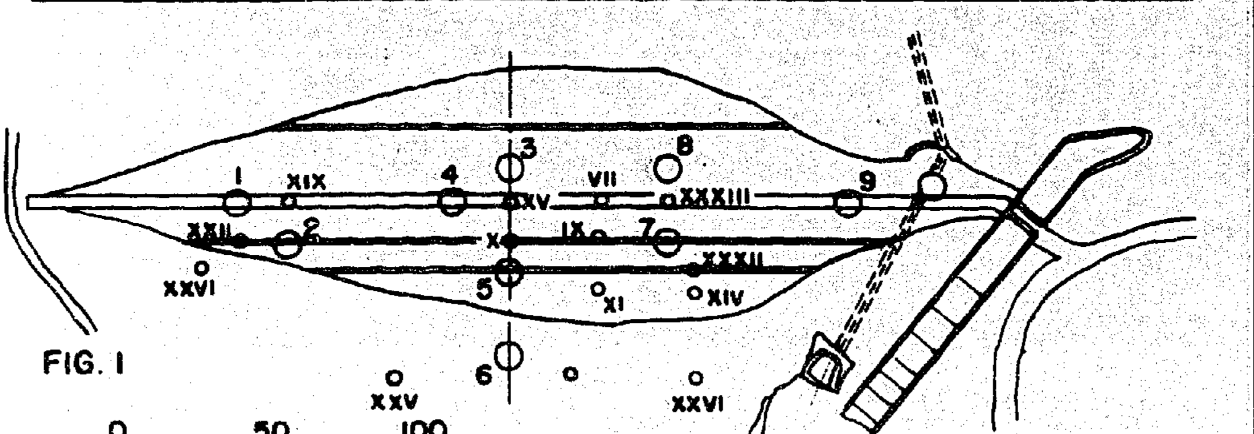
SCHWARZE DESSE DAM
CZECHOSLOVAKIA

FIRST CONGRESS ON LARGE DAMS
STOCKHOLM, SWEDEN 1933
REPORT VOL.4, PAGE 139



SECTION STA. 209

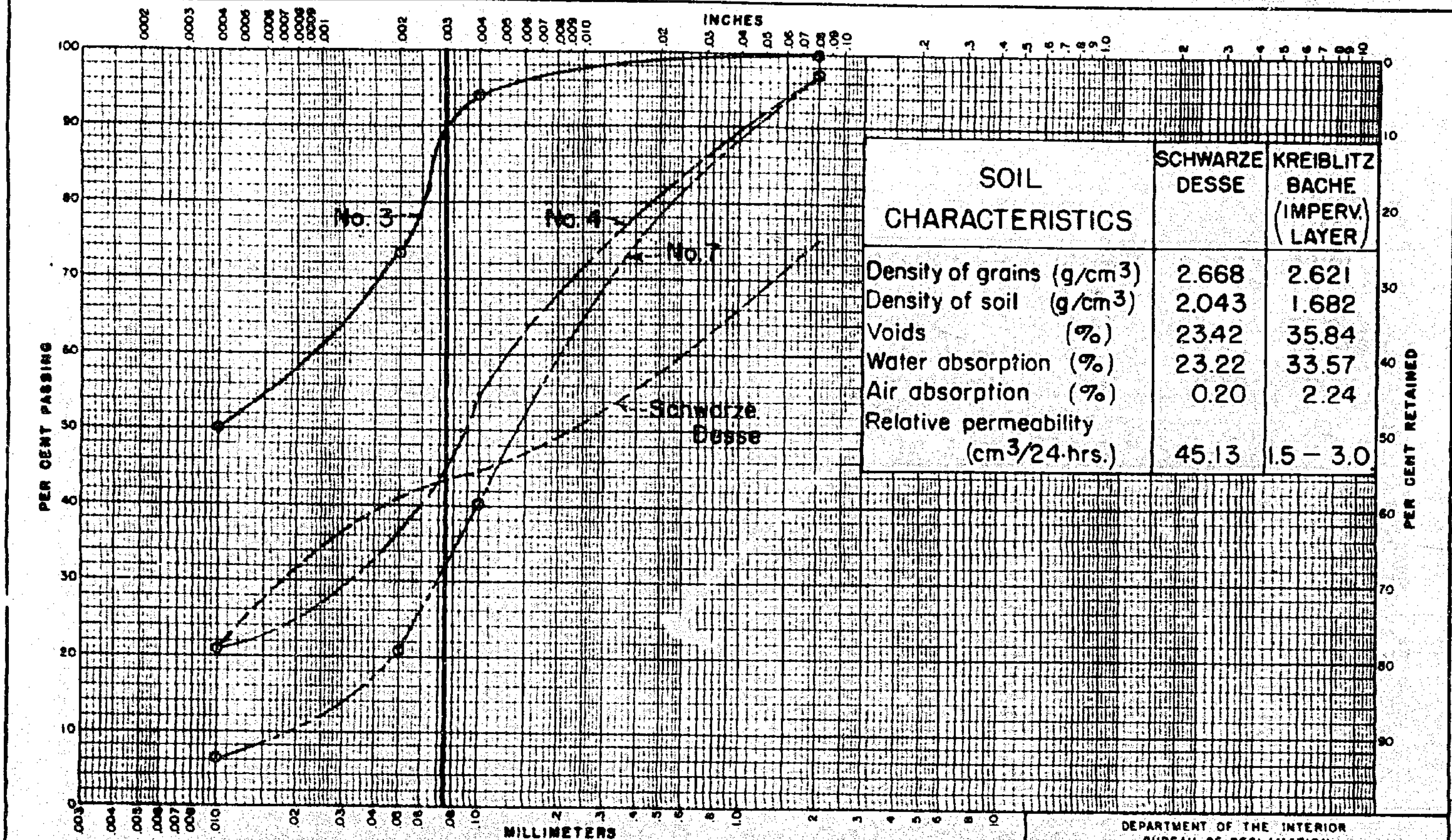




BUREAU OF RECLAMATION
DENVER, COLO., 1934

X-D-1101

PLATE 7



SOIL CHARACTERISTICS	SCHWARZE DESSE	KREIBLITZ BACHE (IMPERV. LAYER)
Density of grains (g/cm3)	2.668	2.621
Density of soil (g/cm3)	2.043	1.682
Voids (%)	23.42	35.84
Water absorption (%)	23.22	33.57
Air absorption (%)	0.20	2.24
Relative permeability (cm^3/24 hrs.)	45.13	1.5 – 3.0

REMARKS

KREIBITZBACHE
- ———— No. 3 - Impervious layer in undisturbed state.
- — — — No. 4 - From body of the dam.
- —-—-— No. 7 - From body of the dam.

SCHWARZE DESSE - - - - - - - Undisturbed portion of dam as left by the construction.

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

SCHWARZE DESSE DAM

KREIBITZBACHE DAM

MATERIALS

DRAWN R.C.H. CHECKED DATE 6-4-34

X-D-1102

KREIBITZ DAM
CZECHOSLOVAKIA

FIRST CONGRESS ON LARGE DAMS
STOCKHOLM, SWEDEN 1933
REPORT VOL. IV, PAGE 153

Description and History.

This dam was completed in 1924. It is carefully founded on sandstone and is lined on the upstream side with a cut-off of concrete with a filler of tamped loam. On the upstream face the dam carries an impervious layer of heavy binding soil. Mechanical analyses of the materials in the dam are indicated on the analysis sheet which follows. After failure of the Weisse Desse Dam this dam was also investigated and strengthened. The Relative Permeability Dw of this dam compares favorably with that of both the Weisse Desse and Schwarze Desse. The material comprising the main body of the dam is of course more permeable than that in the upstream face. (See chart).

Method and Observations:

Since 1926 simultaneous observations have been made of reservoir stage, rainfall, and well levels at three cross sections of the dam at a, b, and c. It is to be regretted that the pipes were placed too far from the reservoir. The reason can be seen from consideration of the following data:

1. Table A indicates that for a rise in reservoir level a corresponding rise in saturation line is not immediately felt. In some cases a drop is experienced. Note the 48-day period (2/284/17/1927). Reservoir stage rose 4.90 m; the level in "a" fell 0.10 m, and in "b" fell 0.05 m. Similar evidence may be found elsewhere in this table and in Table B.
2. Even with the great permeability of the body of the dam water takes time to get from the reservoir to the wells. Velocity of percolation depends upon this time and the average distance of the pipes from the reservoir. In the 48-day period referred to above the horizontal distances of pipes a, b, and c from the reservoir were 27 m at the beginning of the rise and 15.5 m at the peak. The average distance $= \frac{27.0 + 15.5}{2} = 21.25$ m.

   If, therefore, the reservoir may have had any influence on the level of water in the pipes the average velocity of the water through the dam must have been $\frac{21,250 \text{ mm}}{45 \text{ da.}} = 470$ mm/da.

   Prof. Kopecky had determined the relative permeability* of the impervious layer at 3 cm^3/da. "This corresponds to a velocity of 3mm/da." The seepage would, therefore have had to have moved with a velocity 160 times as great. This is improbable and also would have been a dangerous condition for the dam.
3. Since 1930 pipe "b" has shown changes which suggest that rain water may penetrate along the poorly sealed pipe walls at the crest.

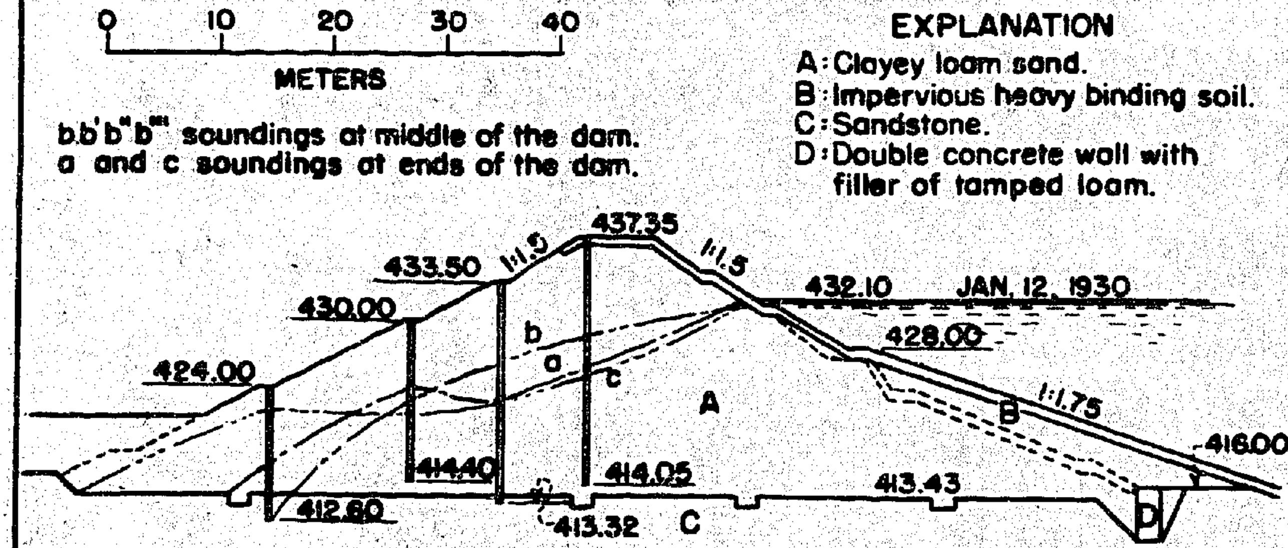
Thus the pipes show only the state of saturation of the dam and in no way indicate the causes or the coordination in time.

* It is not stated how this coefficient was obtained.

BUREAU OF RECLAMATION
Denver, COLO., 1934

KREIBITZ DAM
CZECHOSLOVAKIA

FIRST CONGRESS ON LARGE DAMS
STOCKHOLM, SWEDEN 1933
REPORT VOL. IV, PAGE 153



A

DATE	DAYS	RESER. STAGE	CHANGE IN RESER. STAGE	PIPE OBSERVATIONS					
				PIPE a		PIPE b		PIPE c	
				ELEV.	CHANGE	ELEV.	CHANGE	ELEV.	CHANGE
1-14 1927		432.45		423.90		423.45		424.50	
2-27 1927	45	427.25	-5.20	423.95	+0.05	423.45		424.50	
4-17 1927	48	432.15	+4.90	423.85	-0.10	423.40	-0.05	424.70	+0.20
1-6 1928	264	424.25	-7.90	424.30	+0.45	422.80	-0.50	425.20	+0.50

Reservoir stages shown in this period are maxima.
Duration: 257 days.

B

DATE	DAYS	RESER. STAGE	CHANGE IN RESER. STAGE	PIPE a ELEV.	PIPE a CHANGE	PIPE b ELEV.	PIPE b CHANGE	PIPE c ELEV.	PIPE c CHANGE
1-1 1929		425.90		423.75		423.75		425.00	
3-16 1929	75	420.60	-5.30	423.55	-0.20	421.95	-1.50	424.90	-0.10
4-23 1929	38	428.90	+8.30	423.80	+0.25	522.45	+0.50	424.95	+0.05
10-26 1929	186	420.10	-8.80	424.00	+0.20	424.00	+1.55	424.95	

Reservoir stages are maxima.
Duration: 299 days.

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BUREAU OF RECLAMATION
DENVER, COLO., 1934

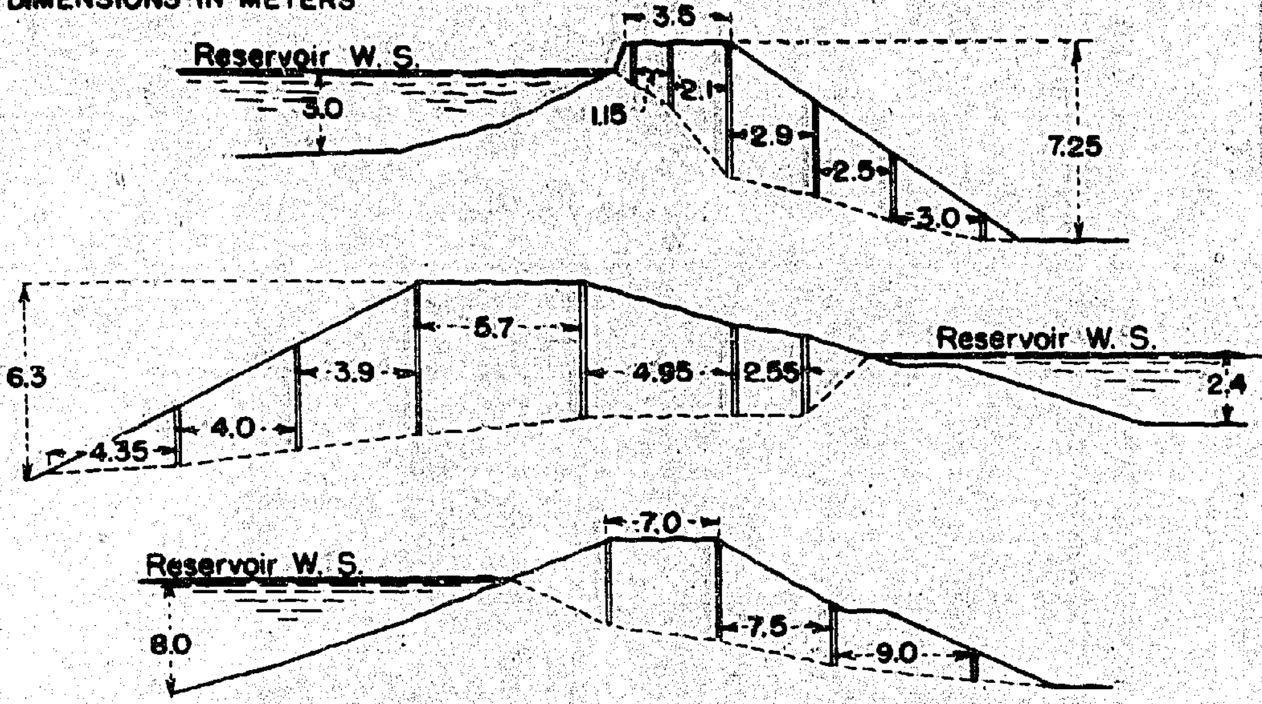
X-D-1104

PLATE 10

LOWER VOLGA DAMS
RUSSIA

FIRST CONGRESS ON LARGE DAMS
STOCKHOLM, SWEDEN 1933
REPORT VOL. IV, P. 202

DIMENSIONS IN METERS



Description and History.

Experimental works have been carried out on several dams of the Lower Volga Region (1929) and in Donbass (1932). The experiments on the Volga Region dams were to (1) Discover the saturation line in the dam body, and (2) to determine the coefficient of percolation of the dam material. The results of the recent investigations have not as yet been elaborated. The upper dam comprises a central puddle-core, the middle dam a "slimed upstream slope" (the pond is filled with "thawed water" comprising a large amount of sediments).

Method and Observations.

Water levels in perforated pipe were observed and the following results were obtained:

(1) The saturation surfaces observed in the body of the earthen dams show that the line of saturation has nothing in common with a straight line.

(2) In addition to percolation taking place in the planes normal to the dam, there is also percolation flow moving from the shores toward the axis of the valley.

The other data refer to individual cases and cannot as yet be generalized.

Remarks.

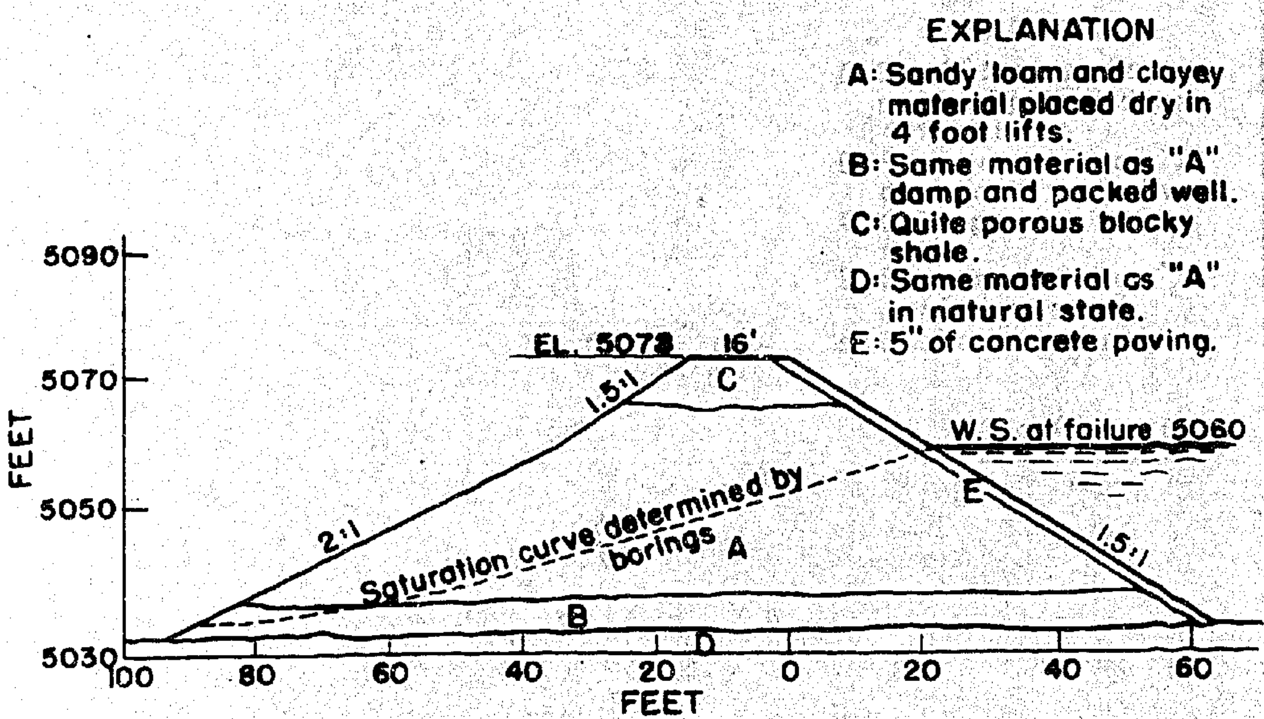
The experiments in Donbass referred to above also included measurement of the discharge of seepage water and determination of the modification of wettness of the dam body at various heights. "This allows one to judge the height of the capillary zone and to determine the pressure at various points of the dam profile."

BUREAU OF RECLAMATION
DENVER, COLO., 1934

X-D-1105

HORSE CREEK DAM

E. N. 1914, VOL. 71
PAGE 828



I DESCRIPTION AND HISTORY:

Three-foot lifts were specified in building the dam, but four-foot lifts were found after failure with water 13 feet below top of the dam. Failure is attributed to settlement caused by erosion around an 8-foot reinforced arch outlet which passed under the dam at its maximum section.

II METHOD OF OBSERVING AND OBSERVATIONS:

It is not stated just where the borings are located but this is the saturation line shown in the article.

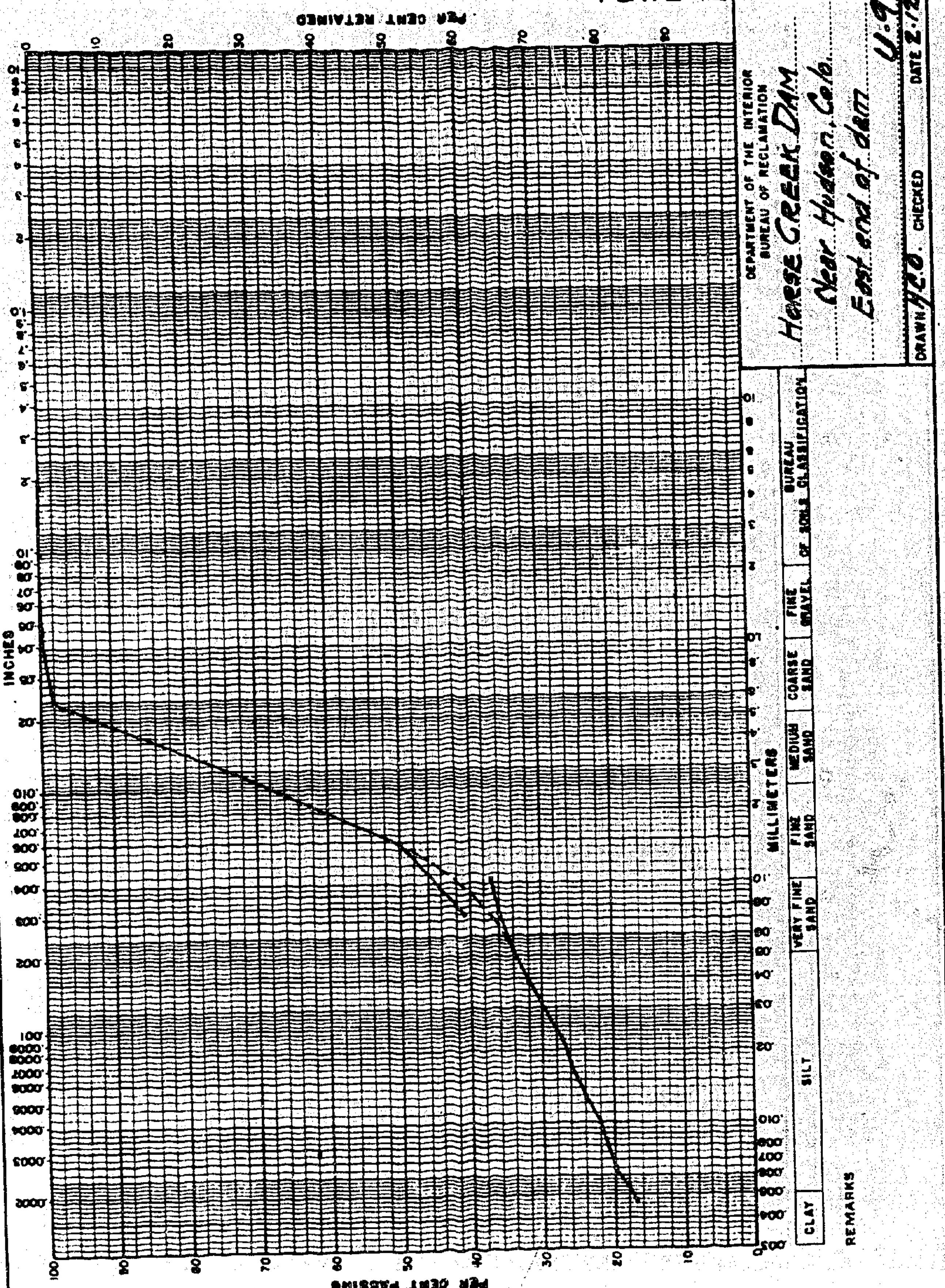
III REMARKS:

The U. S. Bureau of Reclamation Earth Testing Laboratory has made mechanical analysis of only one sample of the dam material. It is presented herewith.

BUREAU OF RECLAMATION
DENVER, COLO., 1934

X-D-1106

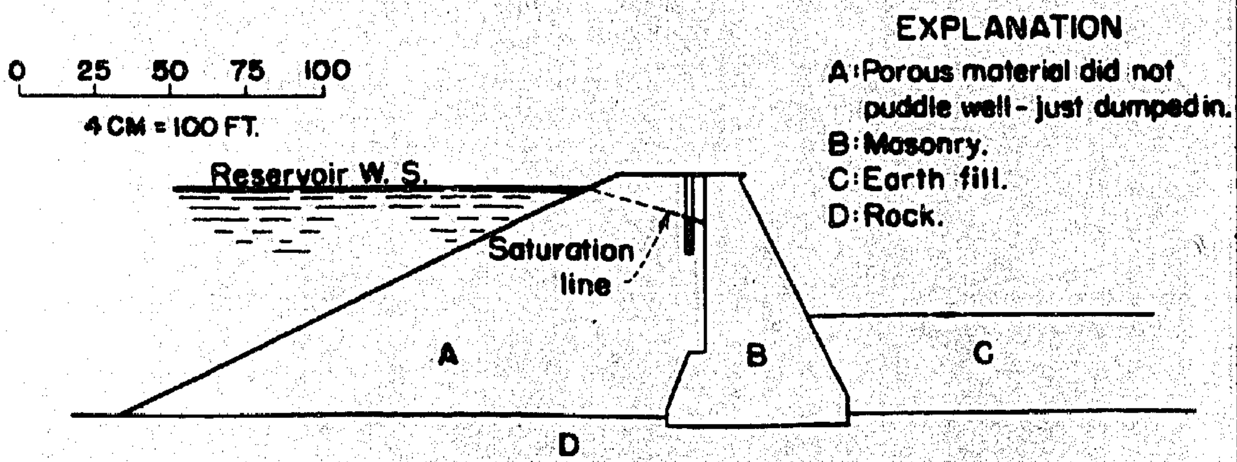
PLATE 12



X-D-1107

BOYD'S CORNERS DAM

ISTHMIAN CANAL COMM. REPORT 1908
PLATE 136



I DESCRIPTION AND HISTORY OF CONSTRUCTION:

This dam originally consisted of masonry section B with an earth backing C. For some reason earth was subsequently dumped in to create the section A. This material was rather porous.

II METHOD AND OBSERVATIONS:

Only one well was driven at this section and from the observation given, little can be deduced.

III REMARKS:

The peculiar saturation line shown here might indicate a number of conditions none of which can be definitely established with the data at hand:

(a.) The retaining wall B might be pervious.
(b.) The foundation might be pervious.
(c.) The reservoir level may have risen rapidly, and the earth fill has not as yet had time to respond.

BUREAU OF RECLAMATION
DENVER, COLO., 1934

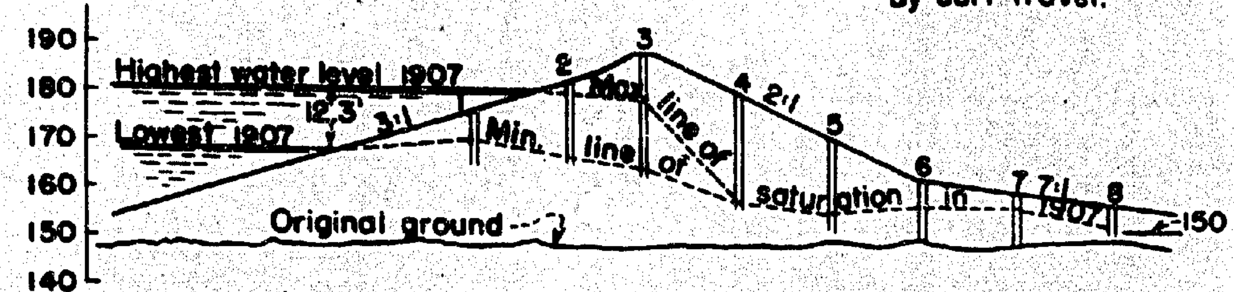
X-D-1108

MEDLERI RESERVOIR EMBANKMENT
INDIA

BUCKLEYS IRR. HB'K.
PAGE 383

0 10 20 30 40 50
1.25" = 50 FT.

EXPLANATION
Material very likely moorúm consolidated by cart travel.



I DESCRIPTION AND HISTORY:

The material of which the dam is built is described more fully on the next page.

II METHOD OF OBSERVING AND OBSERVATIONS:

Perforated pipe were placed in dug holes. Headwater fluctuated considerably during the year.

III REMARKS:

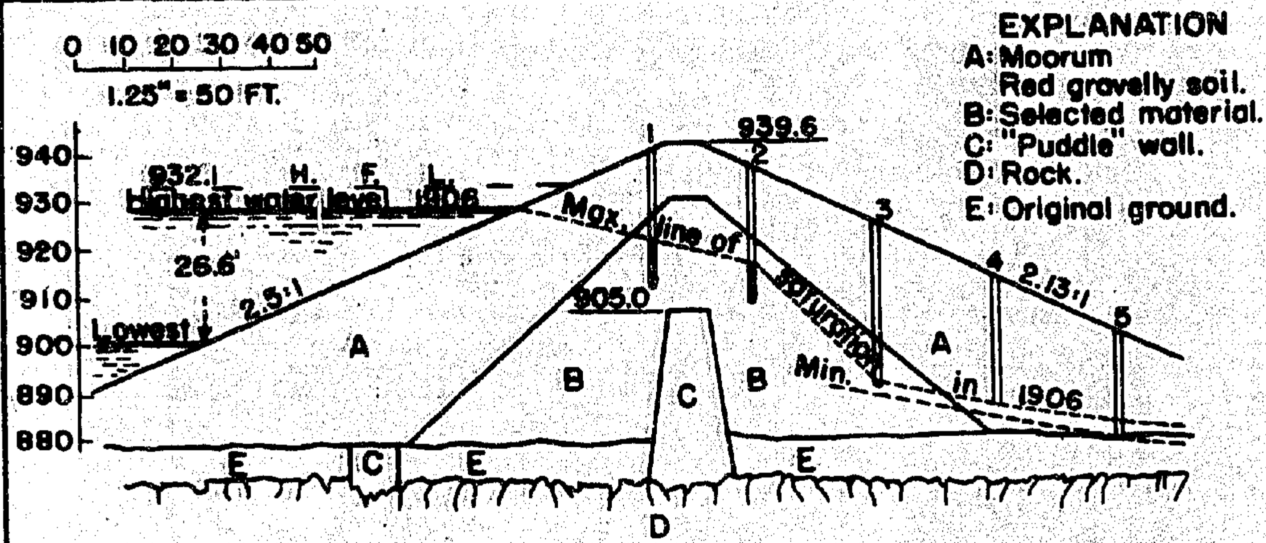
An examination of the upper end of the minimum saturation line will indicate that the soil is tight enough to hold water after the reservoir level has dropped. The increased slope in both saturation lines between holes No. 3 and No. 4 is an effect which could be given by a core wall but none is shown. The high spot between No. 6 and No. 7 might be due to rainwater, transverse flow in the dam, or ground water. These saturation lines were probably obtained by joining respectively the highest and the lowest elevations recorded in each pipe throughout the year.

Mr. Hill, in his paper #17 at the Irrigation Conference in Simla, India (1904) said that a study of some earth dams in India indicated that "in all cases where the bank slipped the hydraulic gradient through the dam (slope of the saturation line) is steeper than 4:1. The hydraulic gradient is called the slope from the point where the water touches the bank to the rear toe." He submits the following table:

NAME OF WORK		DEPTH OF WATER	HYDRAULIC GRADIENT
	(Waghad Dam	83 ft.	2.70 :1
Slipped Badly	(Mhsvad "	67 "	2.96 "
	(Nehr "	60 "	3.00 "
	(Ekruk "	58 "	3.48 "
	(Ashti "	50 "	3.09 "
Slipped at Toe	(Bhadalvadi Dam	44 "	3.50 "
	(Shirsuphal "	43 "	2.70 "
	(Pashan "	40 "	3.40 "
	(Matoba "	39 "	3.40 "

MUKTI RESERVOIR EMBANKMENT
INDIA

BUCKLEYS IRR. H'BK.
PAGE 383



I DESCRIPTION AND HISTORY:

Moorum is described on the next page. Indian "Puddle" is defined in Appendix E.

II METHOD OF OBSERVING AND OBSERVATIONS:

Perforated pipe were sunk in dug holes and the data given cover a year's observations of the free water surface in the pipes. Head-water fluctuated considerably.

To quote Mr. Hill in paper No. 17 of the Irrigation Conference, Simla, 1904:

"The year 1906 was one of good rainfall and the reservoir remained at full supply level for 3 months. The level in pipe No. 1 was about 8 feet below the level of water in the reservoir.

The levels in No. 2 and No. 3 indicate that the earth hearting was completely saturated but that the backing.... of moorum was free from water. The next year 1907 was one of poor supply and the reservoir did not fill. The maximum level reached in pipe No. 1 however was approximately the same as in 1906 though it was only 1½ feet below the highest level in the reservoir instead of 8 feet as it was in 1906."

III REMARKS:

Mr. Hill in his paper in 1904 said: As all banks get thoroughly saturated and as all earth swells when wetted, it seems that it is not desireable to water the bank during construction but that it is better to lay the material dry. If all the earth be carted onto the bank and distributed from the carts when in motion and if a heavy beam be drawn over the material an excellent bank is formed. A few lightly loaded carts give better consolidation than rollers.

BUREAU OF RECLAMATION
DENVER, COLO., 1934

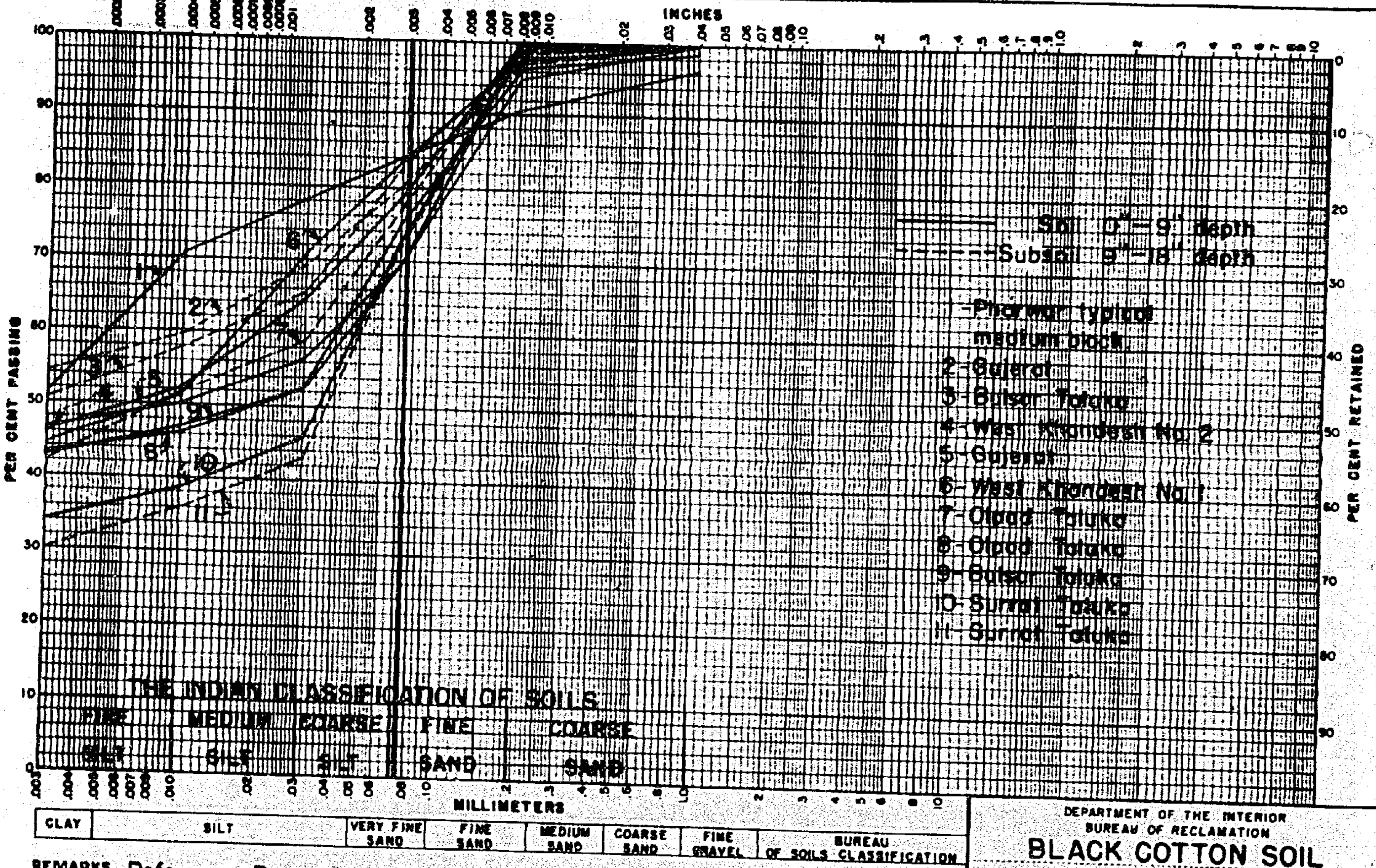
Dept. Agriculture Bombay
Bull. No. 160 of 1929 P.8.
"Soils of the Bombay Presidency"

BLACK COTTON SOIL is the term applied to deep black clayey soils found generally below the level of the foot-hills. It is found by the washing of the disintegrated material from a higher level. "Black Cotton soil" occurs within the area of the Deccan trap in undulating or sloping situations below the general level of the foot-hills. It varies in depth according to position and where very deep has been accumulated by alluvial deposit. In places in the valley of the Tapti, Narbuda, Godavari, and the Krishna, heavy black soil is often 20 feet in depth. Owing to its dense consistence it becomes unworkable during heavy rains. It often is mixed with Nodular pieces of limestone and small fragments of disintegrated trap. The subsoil contains a good deal of lime and, being shaly, allows free drainage to the trap rock below. Black soils vary in color, consistence, and fertility, but all are highly retentive of moisture. In hot weather shrinkage due to evaporation causes the formation of numerous cracks which are often several feet deep. Where the finest material and clay predominate, it forms a very clayey soil contracting enormously when dry and forming masses as hard as rock, and consisting of a slimy jelly-like mass when saturated with water. Where the clay is present in lesser quantity the special characters of the soil are exhibited to a smaller degree but they are not dissimilar in kind."

Moorum (murum)

The Deccan trap rock underlies the districts of the Deccan. This rock is found in various stages of disintegration. Moorum or "murum" is a material produced by decay of the trap rock "in situ". A moorum layer 4 to 6 inches deep is commonly, though not universally, found between the rock and the actual surface soil in the Deccan and is many times exposed at the surface. Alone it forms a poor dry soil made up of porous, half-decayed rock into which plant roots hardly penetrate. "Its color varies from whitish yellow to whitish black." Excessive dryness seems to prevent development of organic matter. It has a low moisture retentivity.

PLATE 17



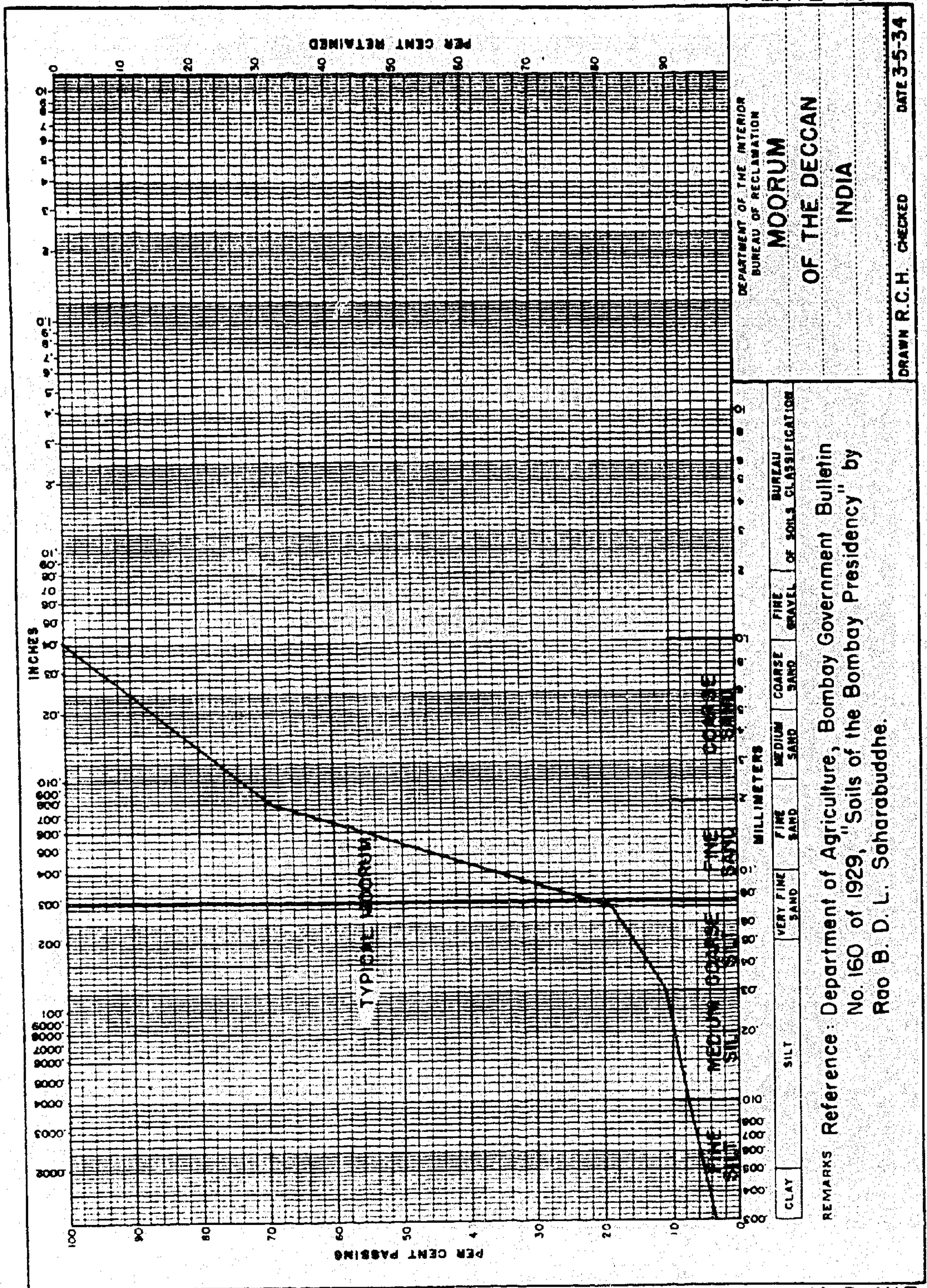
REMARKS Reference: Department of Agriculture, Bombay Government Bulletin No. 160 of 1929, "Soils of the Bombay Presidency" by Rao B. D. L. Saharabuddhe.

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

BLACK COTTON SOIL FROM VARIOUS INDIAN DISTRICTS

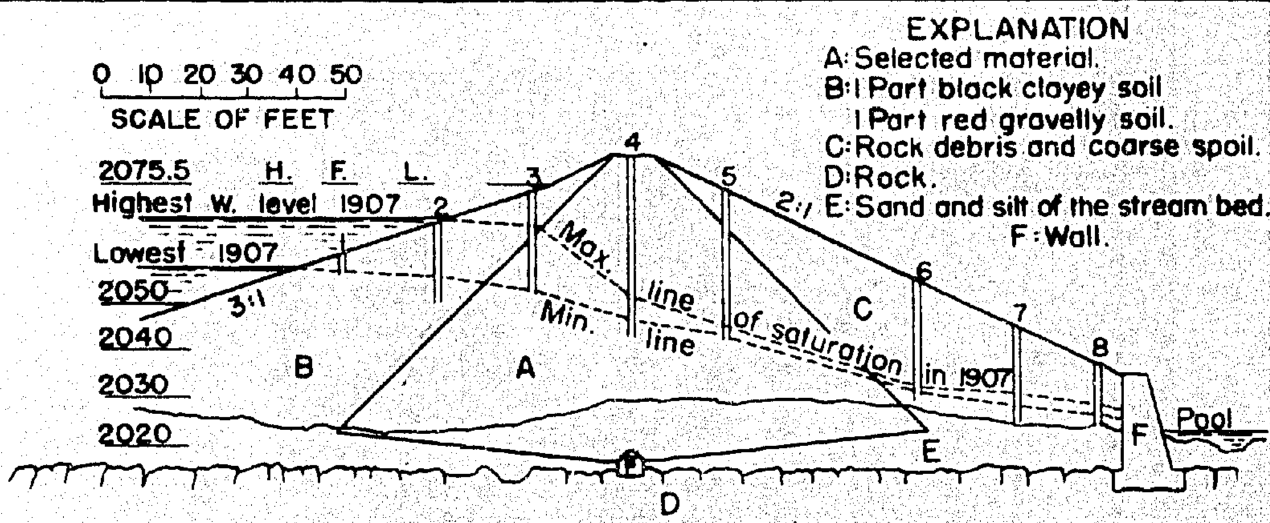
DRAWN R.C.H. CHECKED DATE 3-5-34

X-D-1112


DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MOORUM
OF THE DECCAN
INDIA
DRAWN R.C.H. CHECKED
DATE 3-5-34
PER CENT RETAINED
PER CENT PASSING
INCHES
MILLIMETERS
TYPICAL MOORUM
FINE SILT
MEDIUM COARSE SILT
FINE SAND
COARSE SAND
CLAY
SILT
VERY FINE SAND
FINE SAND
MEDIUM SAND
COARSE SAND
FINE GRAVEL
BUREAU OF SOILS CLASSIFICATION
REMARKS Reference: Department of Agriculture, Bombay Government Bulletin No. 160 of 1929, "Soils of the Bombay Presidency" by Rao B. D. L. Saharabuddhe.

UNKAL RESERVOIR EMBANKMENT
INDIA

BUCKLEYS IRRIGATION H'B'K.
PAGE 383



I DESCRIPTION AND HISTORY OF CONSTRUCTION:

This dam is part of the Hubli Water Works in India. Selected core material was consolidated by cart travel. A low cut-off wall (F) joins this material to the rock foundation.

II METHOD AND OBSERVATIONS:

Holes were dug and perforated pipes installed. The free water surface in the pipes was measured. Readings were kept for a series of years. The average gradient of the saturation line is 5 to 1. To quote Mr. Hill: "Thus in the case of the Unkal Embankment the level of water standing in pipe #4 changed but slightly; the maximum level in it was not reached until 2½ months after the reservoir was filled. On April 6 when the reservoir was at its lowest the difference between the water level in the reservoir and that in pipe No. 4 was 10 feet; on August 13 it was 18 feet. It will be seen from the diagram that the levels in pipes No. 5 and 6 varied very slightly throughout the whole year". The pool of water is due to leakage from dam and stream bank.

E.N.R. Aug. 21, 1909 "Observations between June and Dec. on which the highest water levels were reached showed it took very little time to saturate the bank to its maximum.

BUREAU OF RECLAMATION
DENVER, COLO., 1934

ROCKY RIVER MAIN DAM
NEW MILFORD, CONN.

EARTH DAM PROJECTS
J.B. JUSTIN, PAGE 272, 278

Rocky River Dam

DESCRIPTION AND HISTORY:

This dam was built in 1926-27 and is used for diversion. "Twenty-eight feet upstream from the centerline there is a thin diaphragm core-wall, only the bottom portion of which is reinforced concrete, the remainder being made up of Wakefield timber sheet piling of Oregon Fir. The ledge rock at the site is a hard granitic rock grading to mica schist in some places. The steep west or left side of the gorge consists entirely of this ledge rock with practically no soil cover as shown by the geological section. The right side of the gorge consists of glacial drift extending to a great but undetermined depth. The glacial drift is composed of a fairly tight mixture of stones, gravel, sand, and rock flour. (See mechanical analysis.)

The reinforced concrete base of the core-wall was founded on ledge rock to about sta. 600. At this point it was no longer practical to follow the ledge, as it dipped down below the glacial drift at a sharp angle. From this point east a core-wall trench 6 to 10 feet deep with vertical sides (braced when necessary) was dug about 3 feet wide in the glacial drift and filled with concrete to form the base of the core-wall. On the main dam the reinforced concrete core-wall was carried about 10 feet above the original surface.... The core-wall was continued to above high water line throughout the length of the dam by means of timber as described above." The dam was built by the hydraulic sluicing method and puddle-core samples taken from a "chimney" built into the core indicated effective sizes ranging from 0.005 to 0.015 mm.

METHOD AND OBSERVATIONS:

After the dam had been placed in service a number of well pipes were put down at various points. Records have been kept continuously since. L. A. Whitsit* has made some interesting studies based on these observations.

REMARKS:

Only the main dam is shown here. There is also a canal embankment about 2500 feet long on which saturation studies have been made. These studies along with those on the main dam section shown here should be referred to for the complete picture.

* LYLE A. WHITSIT Hydr. Engr., United Engrs. and Constructors, Inc., 112 No. Broad St., Philadelphia, Penn.

BUREAU OF RECLAMATION
DENVER, COLO., 1934

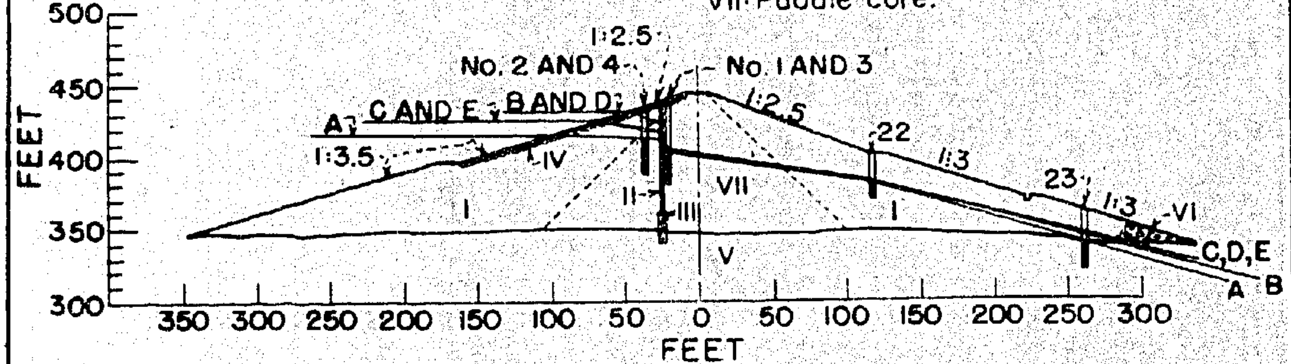
ROCKY RIVER MAIN DAM
NEW MILFORD, CONN.

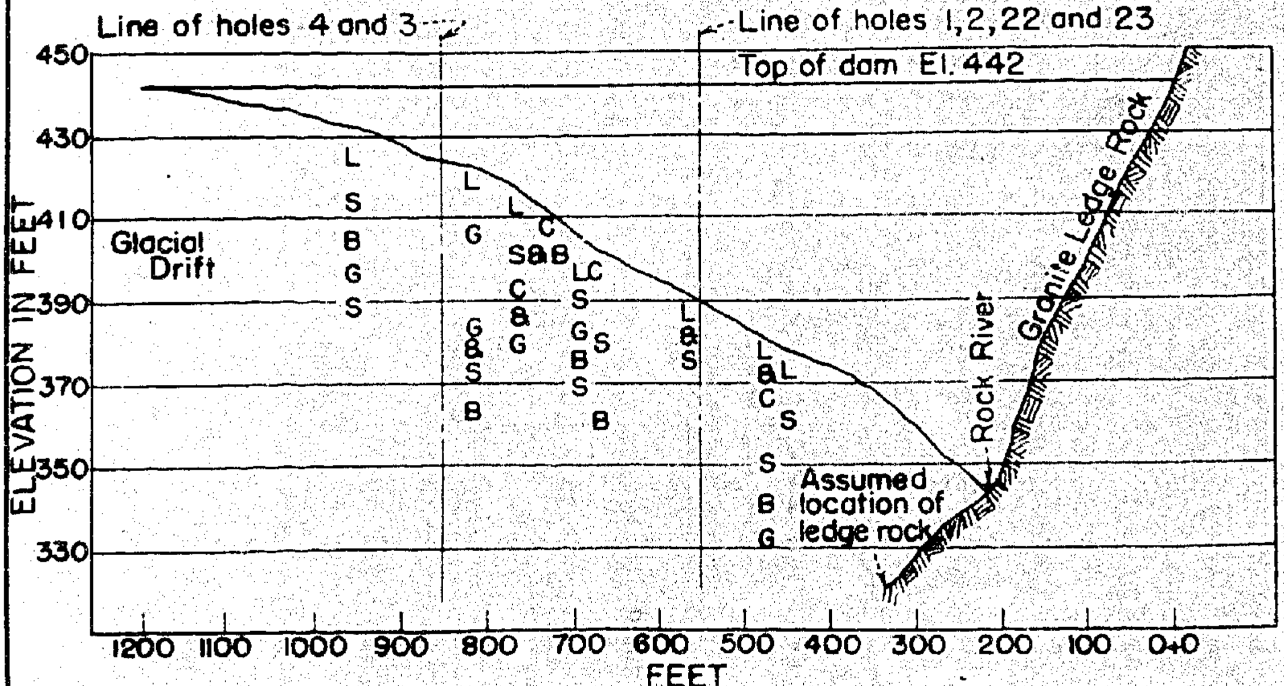
EARTH DAM PROJECTS
J. B. JUSTIN, PAGE 272, 278

Dimensions in feet.

EXPLANATION

I : Earth fill.
II : 6" Wakefield core-wall. timber
III : 24" Reinforced concrete core-wall.
IV : Rip rap.
V : Glacial drift.
VI : Rock drain.
VII : Puddle core.





ROCKY RIVER DAM GEOLOGIC SECTION AT SITE OF MAIN DAM
LOOKING UPSTREAM

LEGEND

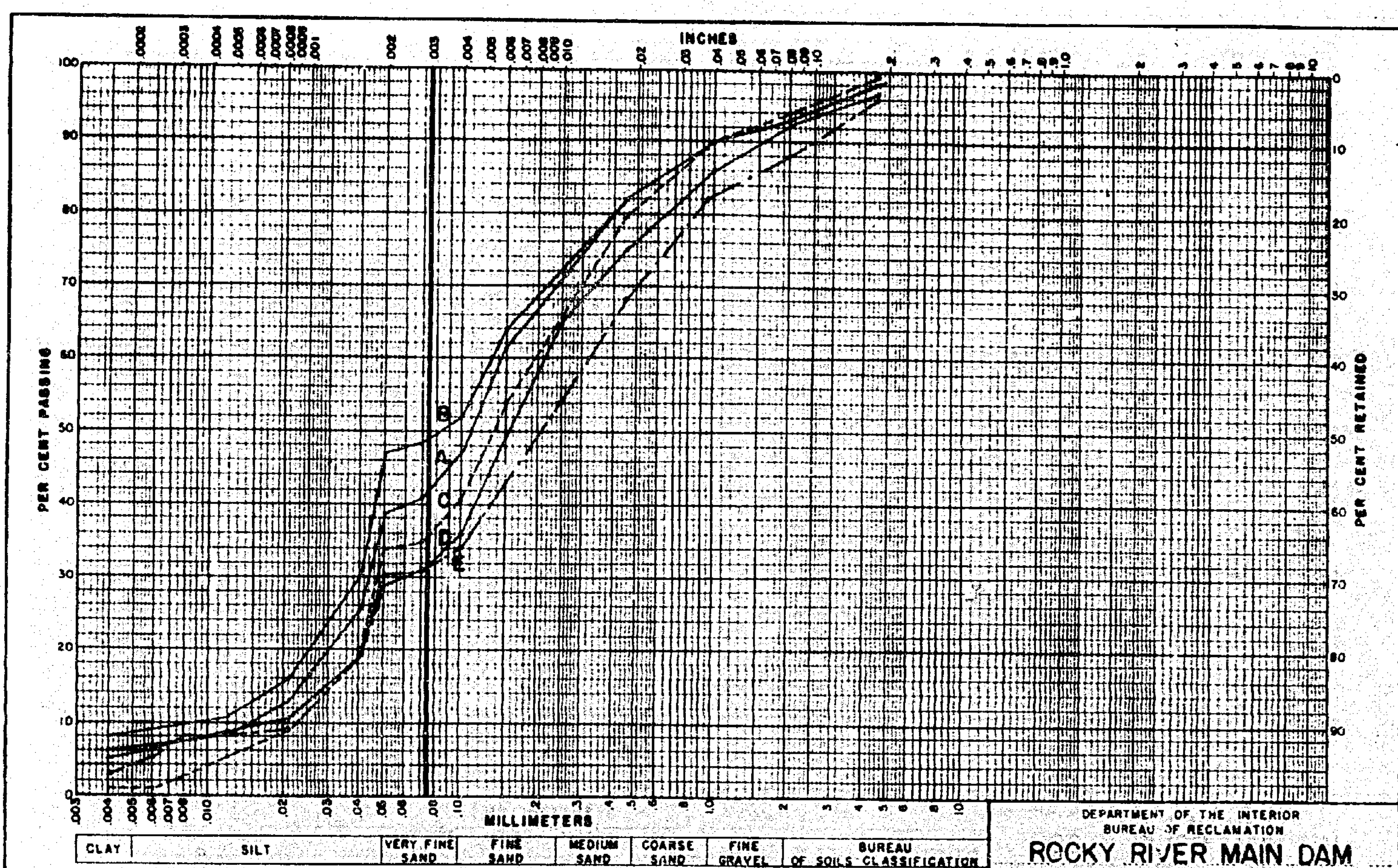
L-Loam.
S-Sand.
G-Gravel.
B-Boulders.
C-Clay.

NOTE

Material recorded as sand and gravel contained rock flour with the result that very little of the material had an effective grain size greater than 0.02 mm.

BUREAU OF RECLAMATION
DENVER, COLO., 1934

X-D-1116



REMARKS A - From Canal Sta. 12+75 Elev. 405.
B - " " " 9+25 " 400.
C - " " " 13+25 " 410.
D - " " " 13+75 " 435.
E - " " " 10+25 " 417.

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

ROCKY RIVER MAIN DAM

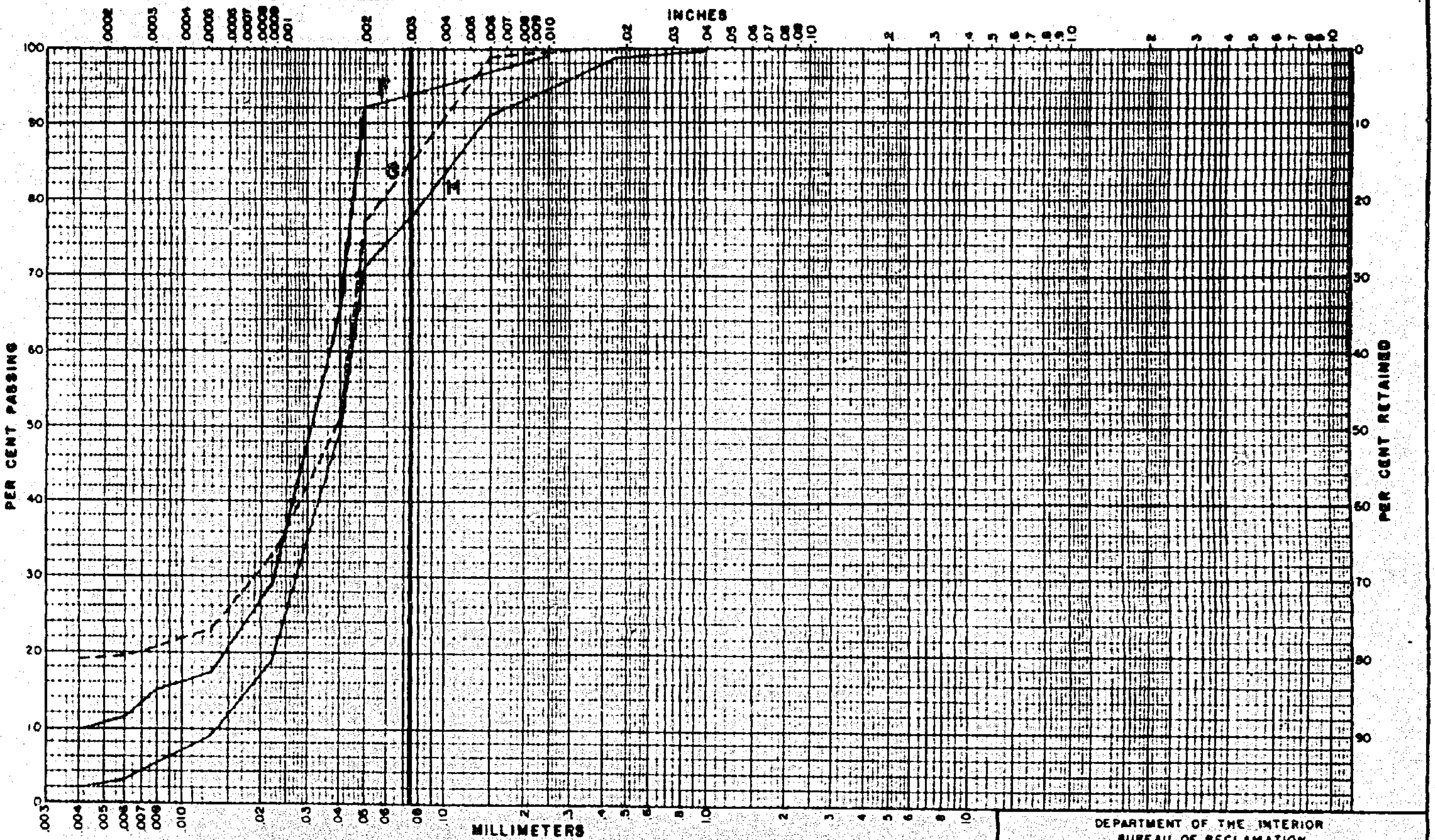
FOUNDATION

BORROW PIT ANALYSIS OF MATERIAL FOR MAIN DAM

DRAWN R.C.H. CHECKED DATE

PLATE 22

X-D-1117



CLAY	SILT	VERY FINE SAND	FINE SAND	MEDIUM SAND	COARSE SAND	FINE GRAVEL	BUREAU OF SOILS CLASSIFICATION

REMARKS F- Dam Core in front of equalizer. Sta. 5+43 Upstream Elev. 358.
G- " " " " " chimney " 6+15 " " 361.
H- " " " 5+82 Downstream " 361.

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

ROCKY RIVER MAIN DAM

CORE MATERIAL

TYPICAL CORE SAMPLES FROM MAIN DAM

DRAWN R.C.H. CHECKED DATE

GATUN, PANAMA
EXPERIMENTAL DAMS

REPORT ISTHMIAN CANAL COMMISSION
APPENDIX E, 1908

I. DESCRIPTION AND HISTORY:

In connection with these studies miniature dams were built on a scale 1:12 omitting the extreme tail end. These dams were about 75 feet long, 6 feet wide at the top, and 12 feet high. They were constructed with materials similar to those to be used in the prototype and placed by similar methods. These models are of such size that they are comparable to actual dams.

"Two of these dams were built; in one the material was deposited on the downstream face and allowed to flow to the upstream face where the finest material would be deposited with graduations back to the downstream slope..... In the other dam the materials were deposited on both slopes and allowed to flow toward the center where the finest materials were deposited, making this the most impermeable section. After construction the dam was allowed to drain 3 days. Then water was slowly let in on the upstream side so as not to endanger the structure.

It became evident that type I would be neither easy to construct on a large scale nor sufficiently stable after it was built, so type II was adopted. During construction of type I it was discovered that the concentration of fine material at the upstream face was giving an unstable slope, so the upstream half was pumped out and coarser material sluiced in to take its place. Construction of Type II appears to have been uninterrupted.

After the percolation tests had been run samples of the material in the dams were obtained and the contours of grain size distribution appear on the above distorted sketches. Type I shows a low dike which is inclined about 45° toward the upstream side. Type II presents a well defined core extending nearly to the top of the dam.

In both models "at the north or downstream end of the tank was a portion about a foot wide partitioned off forming an open space into which water could freely run from the sand in the dam. One-half-inch holes on 2-inch centers were cut in the partition and covered with netting to hold back any sand. Out of the open space a pipe was run to a measuring tank, and, after the experiments were begun constant readings were taken of the amount of water percolating through the dam."

II. METHOD OF OBSERVING AND OBSERVATIONS:

At intervals of 4 feet, 1-1/2-inch, galvanized pipe perforated with one-fourth-inch holes were placed across the tank near the bottom, the ends being threaded, and passed outside the tank. These pipes were covered with wire gauze and later with a little fine gravel. Each of the projecting ends of these pipes was held with locknuts outside the tank. On the east side these pipes were capped so that they could be used for drainage or for flushing out the pipes if they became clogged with sand. On the west side of a T-branch was screwed

GATUN, PANAMA
EXPERIMENTAL DAM TYPE I

TRANS. AM. SOC. C. E. 1924
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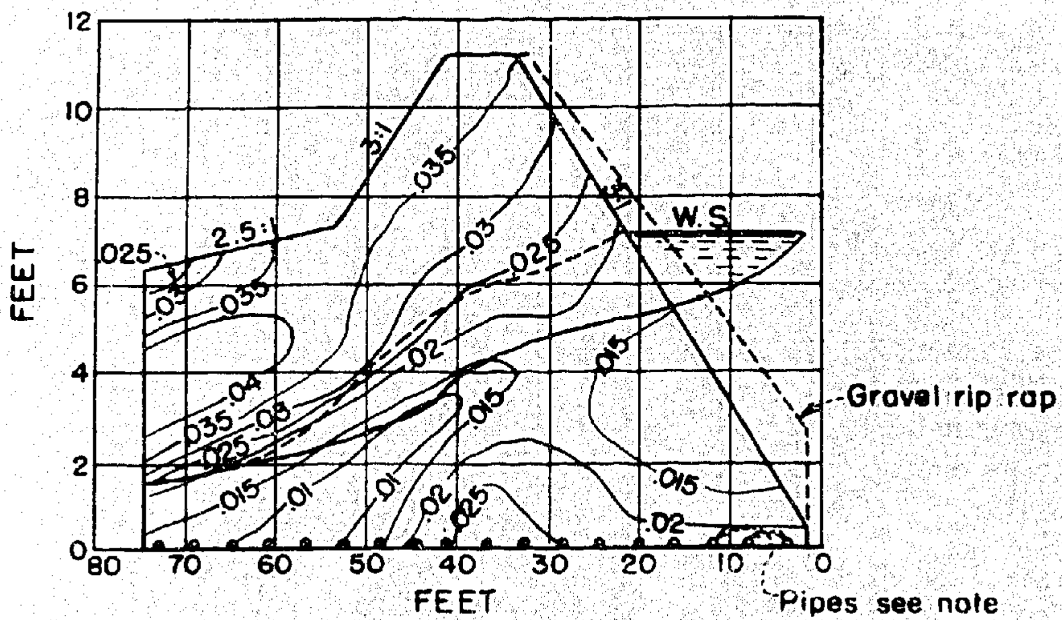

NOTE: 18 - 1½" perforated pipes spaced at approximately 4' centers laid across the bottom.

EXPLANATION

——————— Grade line of pressures along the bottom of the dam.
- - - - - - - - - Approximate saturation line derived from above pressure line.

II METHOD OF OBSERVING AND OBSERVATIONS: (continued)

in, the horizontal end capped, and into the vertical a wooden reducer fitted "a ½-inch glass gage reaching to the top of the tank". These tubes were for the purpose of observing the slope of saturation in the material. Observations were made continuously from the time water was let into the tank. It is not stated that temperatures of the water were recorded.

The runs lasted roughly two weeks. Headwater remained constant at 3.75 and then at 7.1 feet. (Tailwater was practically zero due to the way in which the models were built.)

Records for Type I are complete, but only the final curve for Type II is shown in the report. Speaking of tests on Type I it is stated: "All of the curves (showing the building up of pressures within the dam as time went on) show a marked change near the center of the dam. This distortion corresponds nearly with the slope on which the soft material was pumped out as mentioned above. The line for Type II shows just the kind of distortion that would be expected with a fairly tight core wall.

GATUN, PANAMA
EXPERIMENTAL DAM TYPE 2

TRANS. AM. SOC. C. E. 1924
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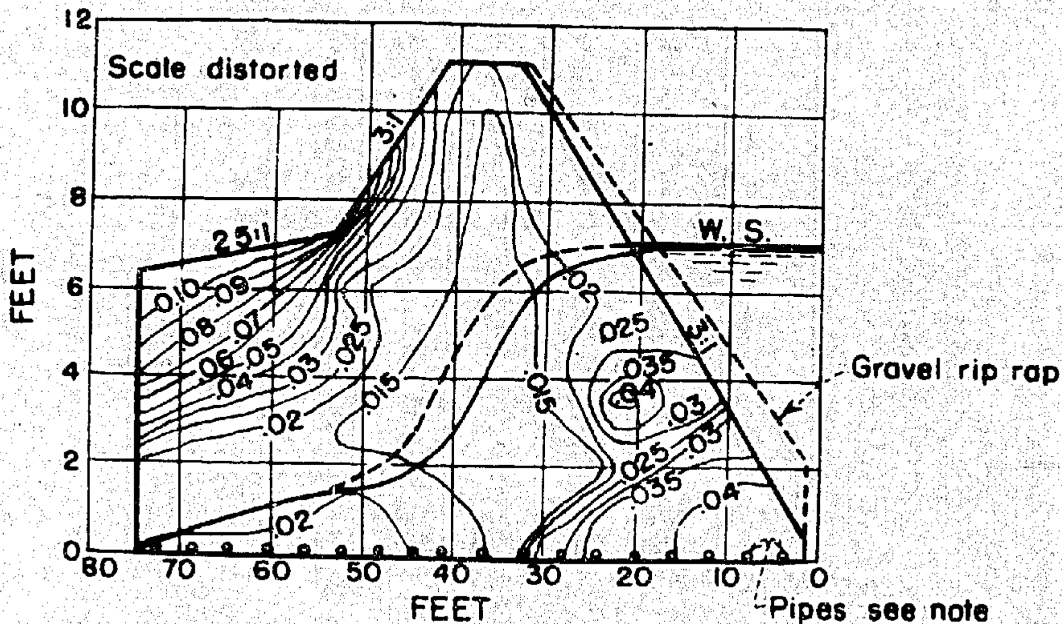
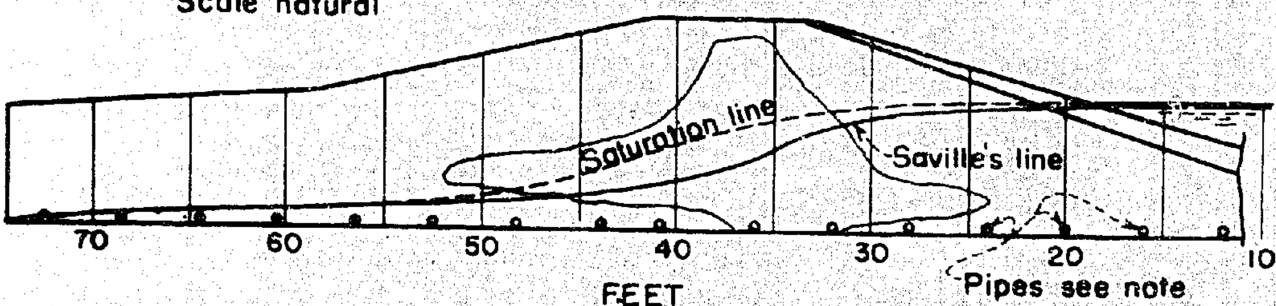




NOTE: 18-1½" perforated pipes spaced at approximately 4' centers laid across the bottom.

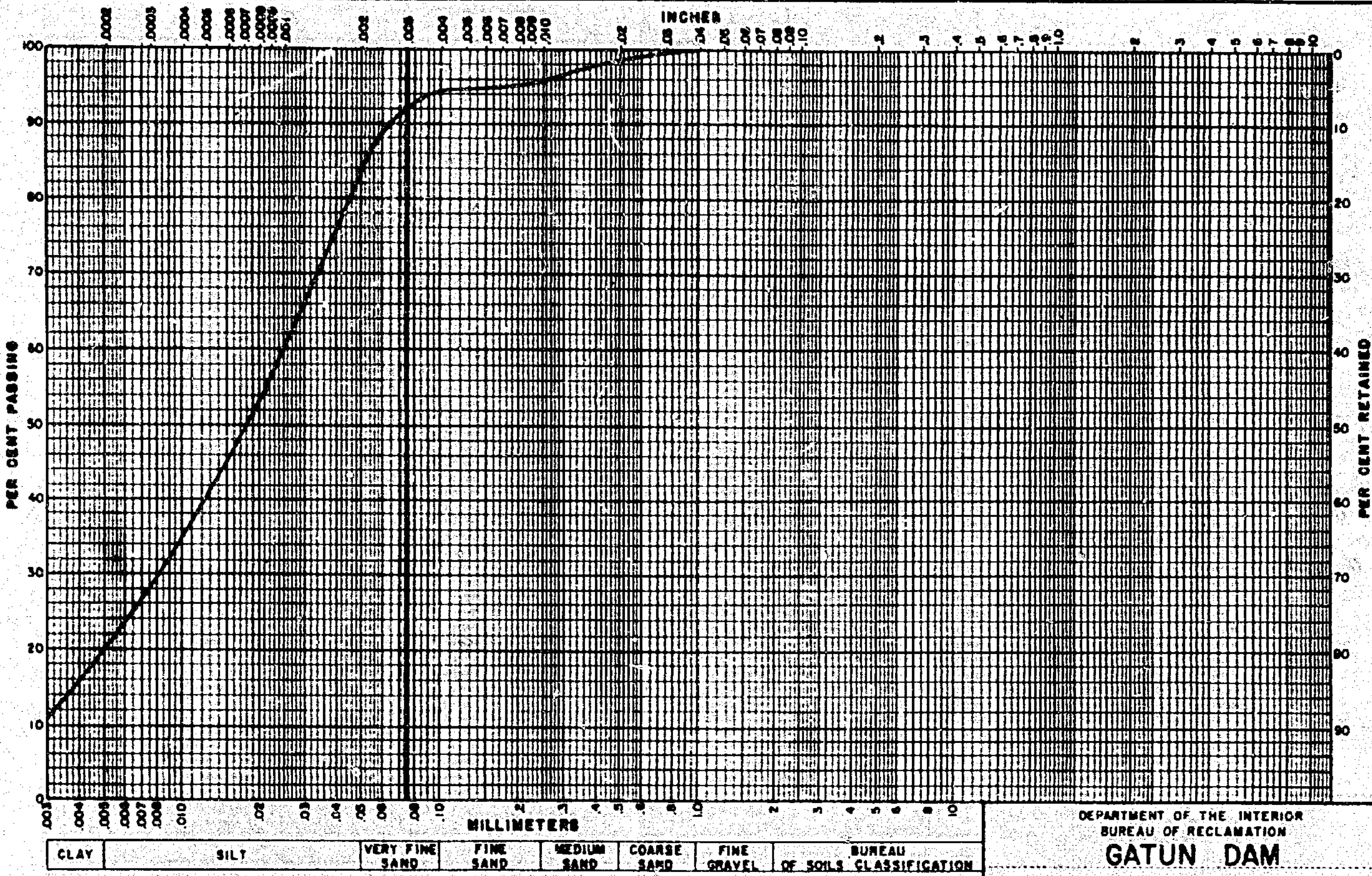
EXPLANATION

——————— Grade line of pressures along the bottom of the dam
- - - - - - - - Approximate saturation line derived from above pressure line.

III REMARKS:

It is felt that the solid black line indicated on the above sketches might not be correctly interpreted. It is the line of pressures along the bottom of the dam caused by the percolating water. Obviously it is not strictly the saturation line of the dam because of the way the pipes were laid. By a procedure outlined on a succeeding page the line of saturation may be approximately obtained from this line. The approximate saturation line is shown above as a dotted line. Type II, the one adopted, is drawn undistorted to show approximately the difference in position between these two lines.

BUREAU OF RECLAMATION
DENVER, COLO., 1934



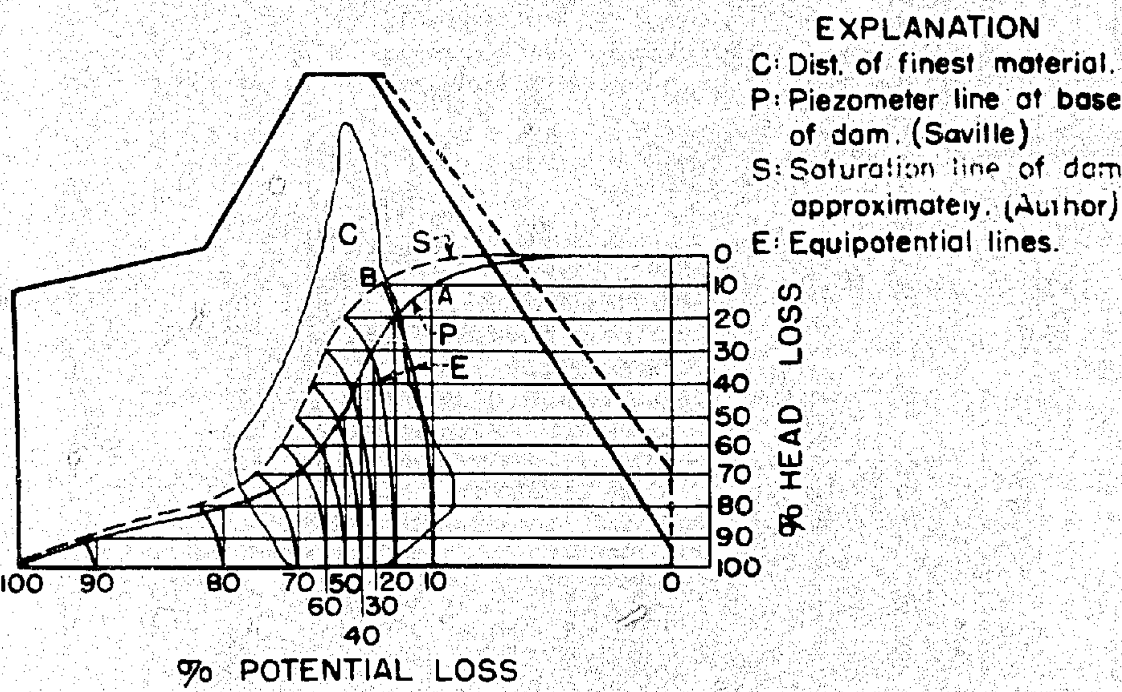
REMARKS Effective sizes range from 0.001 to 0.03.
Uniformity coefficients 7.25 to 2.6.

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
GATUN DAM
MATERIAL

DRAWN R.C.H. CHECKED DATE 4-24-34

GATUN DAM, TYPE 2

EXPLANATION OF METHOD OF OBTAINING SATURATION LINE FROM DATA GIVEN



In the Gatun experiments the perforated pipe were laid across the dam section at its base and so indicate the pressure grade line along the base of the dam. The saturation line is not obtainable directly. The following procedure was used to obtain it:

1. Points on Mr. Saville's pressure grade line which correspond to various percent-head-losses were projected to the base.
2. Taking into account the distribution of fine material in the dam, lines of equipotential* were drawn in at these points on the base. This, of course, is solely a matter of judgment.

   *The nature of equipotential lines is such that piezometers installed at any 2 points on the line will rise to the same level.

3. The point B on the 10% equipotential line is at the same level as A. Pressure is atmospheric in both cases.
4. Locating and joining a number of such points as A gives the saturation line.
   It can readily be seen that a saturation line so determined is only as accurate as the equipotential lines can be drawn in.

MINATARE DAM
NORTH PLATTE PROJECT
SEC. AT STA. 27+50

PATHFINDER IRRIGATION DISTRICT
MITCHELL, NEBR.
T.W.PARRY, MANAGER

I. DESCRIPTION AND HISTORY:

Drawing No. 20-C-166 shows the above cross-section with exception of the saturation line. This line was drawn in from observations made by Mr. Hinds on April 8, 1922. Pipes extending into the foundation were located at four other sections but are not shown in the above sketch. The chart shown below was plotted from original data furnished by Mr. T. W. Parry. Saturation wells were located at one section only.

While constructed on a foundation of Brule clay, the dam has no Brule clay in it.

II. METHOD AND OBSERVATIONS:

Four-inch pipe, perforated, with not less than twelve $\frac{1}{4}$-inch holes per foot were driven. Measurement was made of water level in the wells at intervals of about one week. Elevation of the bottoms of the holes was not recorded, and because the wells sanded in with time or were sometimes partly filled by childrens' dropping stones into them, the notation "Trace" is not particularly significant of any definite water level. Seepage flow was generally estimated at from 2 to 5 c.f.s. Many of the wells driven at the other sections became plugged after a short time.

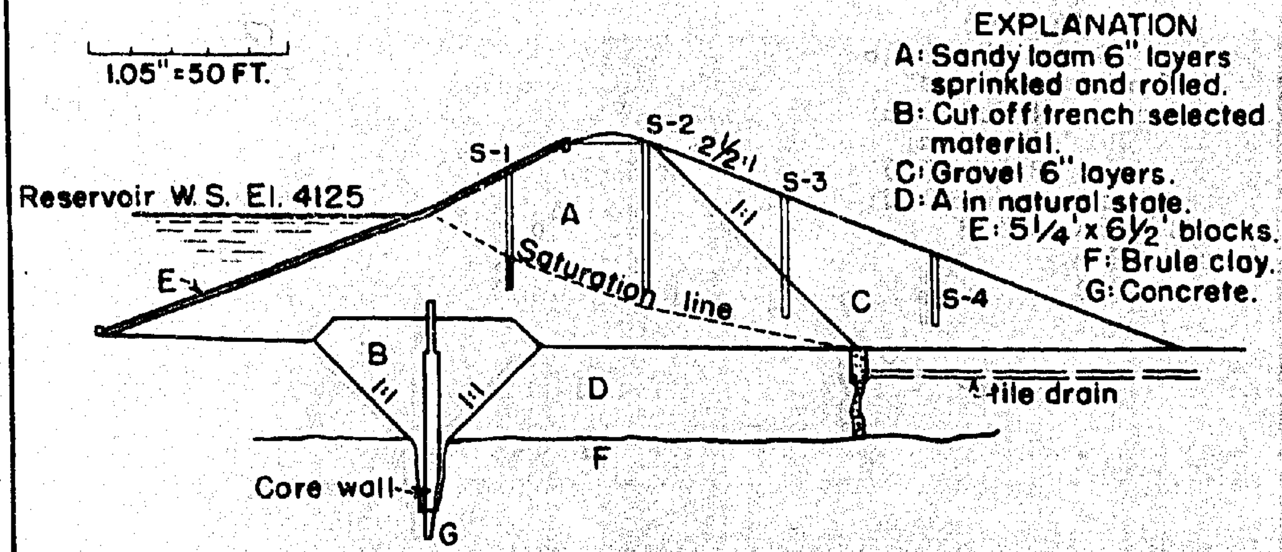
III. REMARKS:

The saturation line shown above is about what would be expected with a good drain, and indicates the efficiency of this structure in lowering the saturation line and increasing the stability of the section. The fact that fluctuations in reservoir level are felt quickly at well S-1 indicates a fairly permeable material for the body of the dam. On Sept. 30, 1930 the well S-1 was covered and plugged; so no records have been kept since. From Dec. 1928 to Sept. 1, 1930 the well was dry. It is hoped that more percolation studies can be carried on at this dam.

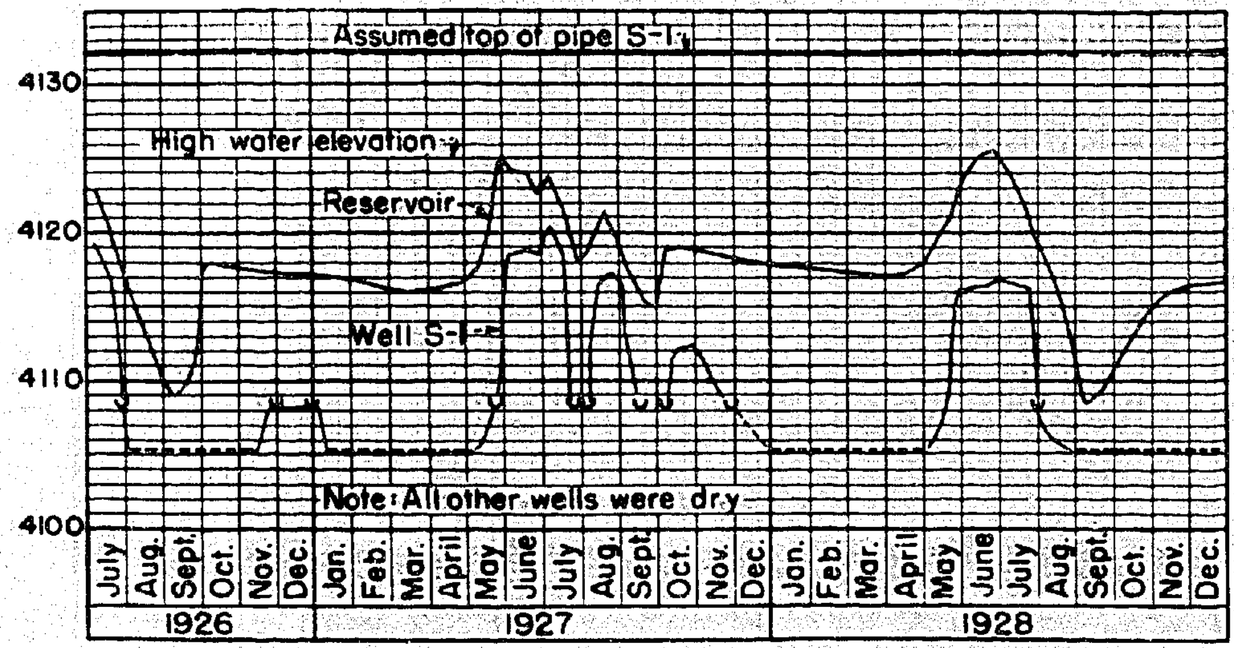
BUREAU OF RECLAMATION
DENVER, COLO., 1934

MINATARE DAM
NORTH PLATTE PROJECT SEC. AT STA. 27+50
DWG. No. 20-C-166

U. S. B. R. NORTH PLATTE FILE
HINDS MEMO TO DESIGNING ENGINEER
DATED DENVER, APRIL 8, 1922



ELEVATION OF WATER
IN RESERVOIR AND IN "SATURATION WELLS"*



EXPLANATION

ᴗ Indicates "trace of water in well".

---- Indicates "well is dry".

Note: Just how far well is sanded in on these dates is not known. Consequently the elevations of bottom of well is uncertain.

* These records are taken from originals supplied by Mr. T. W. Parry, Manager Pathfinder Irrigation District.

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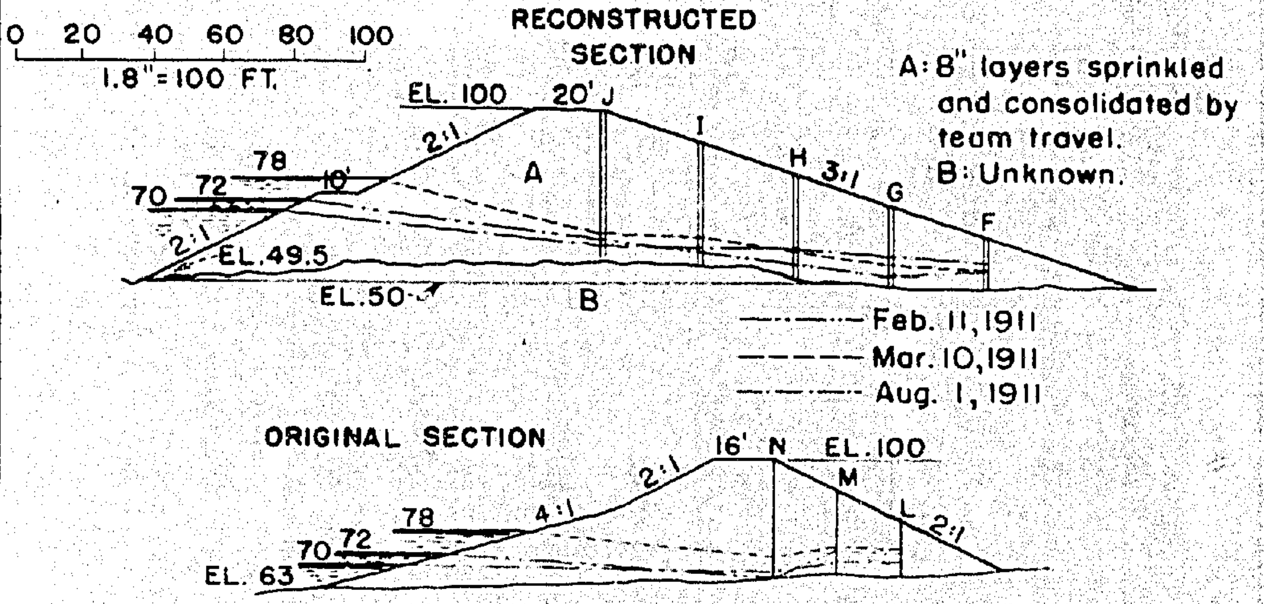
DENVER, COLO., 1934

X-D-1125

JUMBO DAM
COLORADO

E. N. OCT. 12, 1911
PAGE 447



I DESCRIPTION AND HISTORY:

This dam partially failed in 1910 and the damaged part was reconstructed. Both sections are shown above; they are 100 feet apart. In rebuilding the dam practically the same materials were used, but the downstream slope was flattened.

II METHOD OF OBSERVING AND OBSERVATIONS:

Pipe wells presumably perforated were sunk at both sections and observations at both sections were made on the dates indicated.

III REMARKS:

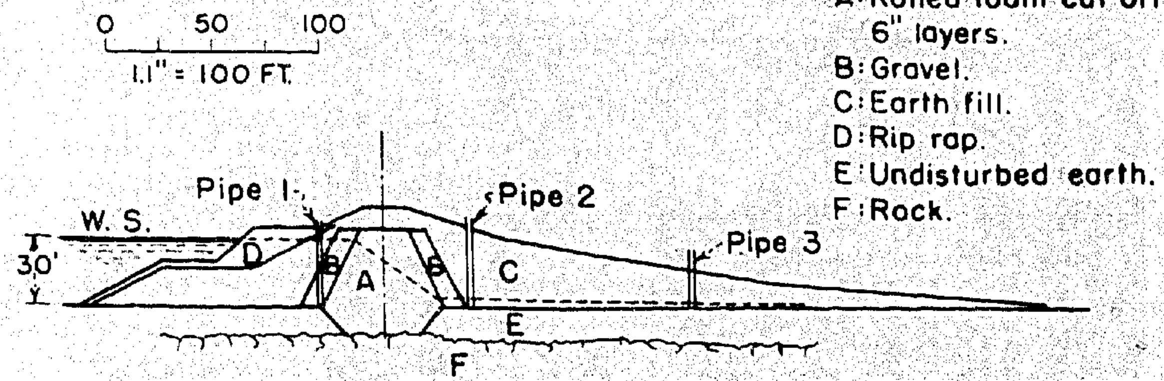
From the more complete records given in the article (and which were not included here) it is apparent that the reservoir level fluctuated considerably over a short time and remained at one elevation hardly long enough to allow a saturation line to become established. Ground water or seepage along the dam from some other section may have caused the rise indicated at M and L. What happens to the water after it passes points F and L is not known.

BUREAU OF RECLAMATION
DENVER, COLO., 1934

X-D-1126

WACHUSSETT RESERVOIR
SOUTH DYKE. MASS.

ENG. RECORD, JULY 18, 1908
PAGE 81



I DESCRIPTION AND HISTORY:

This is a well-constructed dike which incorporates many interesting features in its design.

II METHOD AND OBSERVATIONS:

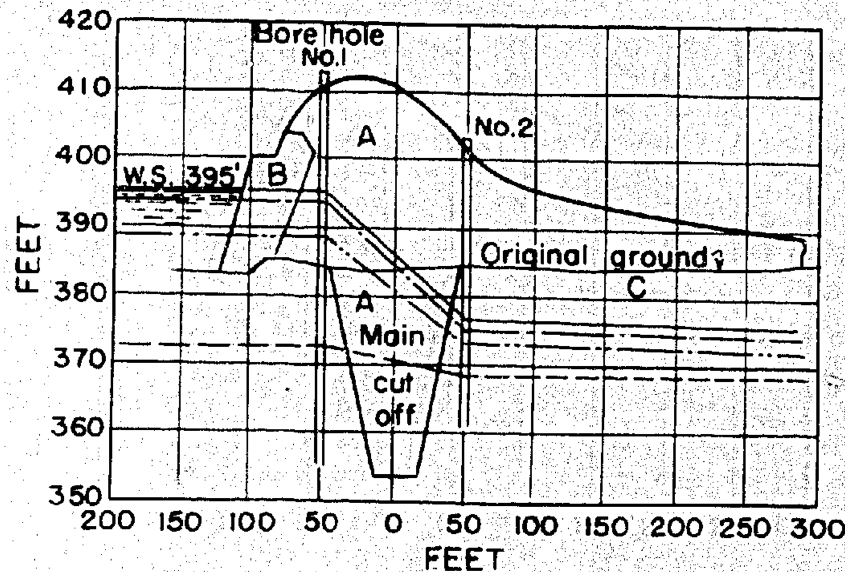
Three pipes were driven into and through the embankment. They end in somewhat porus undisturbed earth with their lower ends 30 to 36' below the reservoir level. Measurements made weekly while the reservoir was filling showed that water in pipe No. 1 rose to the same level as the reservoir and Nos. 2 and 3 rose but little. The latter pipes were more affected by rainwater than by seepage. "As an instance of this, the water in these pipes is about 0.6 ft. lower now, in the summer, with the reservoir practically full than it was at the beginning of the year when the reservoir was 10' lower. The greater height at the beginning of the year was due to the higher level of the ground water, caused by the excessive rainfall of the four preceding months. When the reservoir was full the height in pipe No. 2 was 27.9 feet below res. W.S. and pipe No. 3 was 29.4 feet below res. W.S.

Flow over a weir installed downstream to measure percolation was zero in the summer time. Winter flow over it was attributed to runoff and ground water from the rainsoaked downstream slope. The dike is practically watertight.

PLATE 33

WACHUSETT DAM NORTH DYKE
MET. W. W., MASS. STA. 22+50

TRANS. AM. SOC. C.E. 1924
VOL. LXXXVII, PAGE 98



EXPLANATION
A: Soil rolled in 6" layers.
B: Rip rap and gravel.
C: Unknown.

HYDRAULIC GRADIENT
——— June 5, 1908
—·— Apr. 3, 1908
—··— Jan. 31, 1908
– – – – July 5, 1907

I DESCRIPTION AND HISTORY:

The scale of the sketch has been distorted. The dam is 2 miles long and built of material stripped from the reservoir bottom. Slope upstream is 2:1 and downstream generally about 33:1 The upstream slope slipped on occasion but did not permanently damage the structure.

II METHOD AND OBSERVATIONS:

Two borings were made and position of the saturation line studied.

III REMARKS:

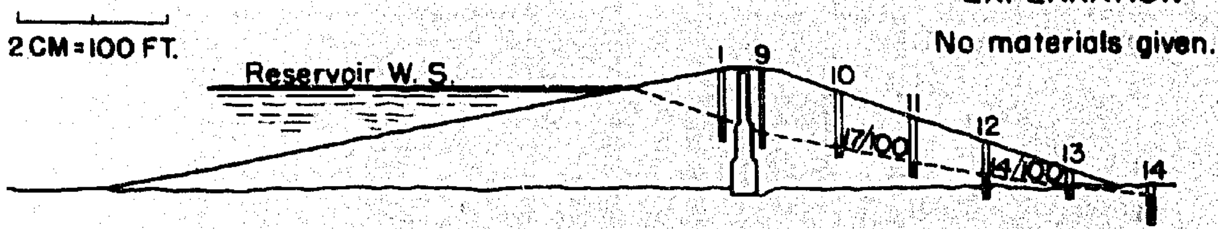
Distortion of the sketch indicates a steep slope of the saturation line between Hole 1 and Hole 2. Actually this slope is nearly 6:1. The foundation material appears pervious.

BUREAU OF RECLAMATION
DENVER, COLO., 1934

X-D-1128

AMAWALK DAM

ISTHMIAN CANAL COMM. REPORT 1908
PLATE 136



I DESCRIPTION AND HISTORY OF CONSTRUCTION:

This dam was completed in 1898 and "not very great care was taken in its construction". The core wall is probably masonry. Measurements to determine the location of the saturation line were made in connection with studies for the New Croton Reservoir.

II METHOD AND OBSERVATIONS: The wells are borings.

It is stated that "Saturation is not as complete as it will be in a few years". Reservoir level must fluctuate somewhat. The downstream slope was saturated to within 31 feet of the reservoir level and the saturation line was practically continuous through the core wall and on a fairly flat slope.

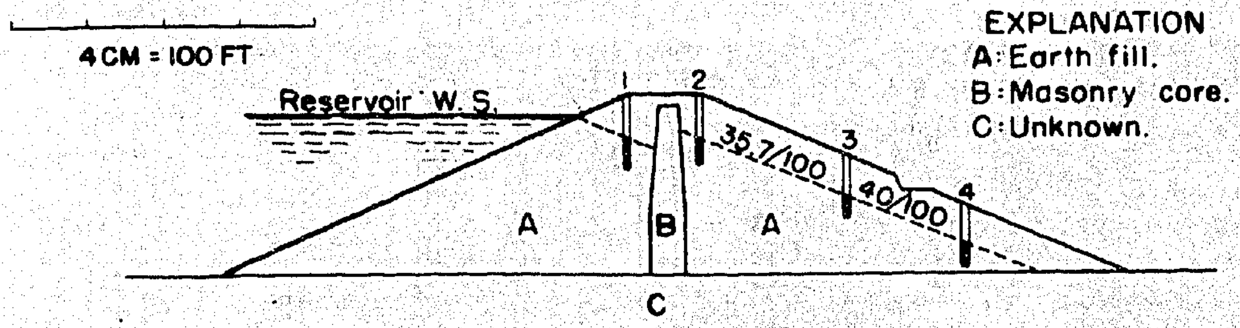
III REMARKS:

It is stated "There are places in the slopes of this dam where it is evident that the percolating water of saturation is mingled with ground water from a contiguous hillside and very nearly approaches the surface". This condition would modify the saturation line at sections within its range of influence.

BUREAU OF RECLAMATION
DENVER, COLO., 1934

BOG BROOK DAM No. I

ISTHMIAN CANAL COMM. REPORT 1908
PLATE 136



I DESCRIPTION AND HISTORY OF CONSTRUCTION:

Dam was completed in 1893 and not much information is available on methods of construction or materials used. The core wall is masonry. No slopes were indicated.

II METHOD AND OBSERVATIONS:

Four pipes were driven. (Perforated?) The downstream slope was saturated to within 7 feet of the reservoir level. Rainwater in the pipes or ground water flow in the downstream embankment may have influenced the levels in the pipes.

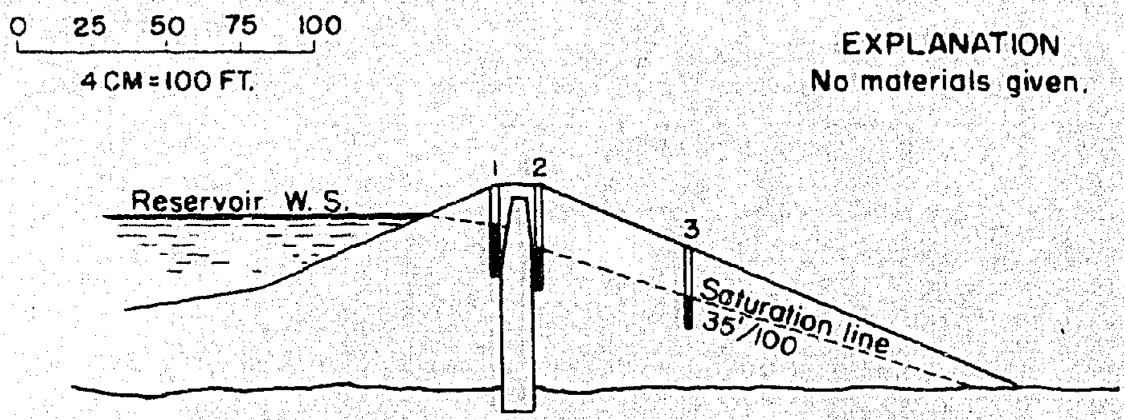
III REMARKS:

The peculiar position of the saturation line shown here may be the result of a misinterpretation of the data. The original sketch shows the level in pipe No. 2 slightly lower than that in No. 1 so that a line joining the two levels would have some slope downstream. This would mean a relatively pervious core wall. The disappearance of the saturation line into the foundation would indicate a pervious soil. No more accurate data is at hand.

BUREAU OF RECLAMATION
DENVER, COLO., 1934

CARMEL MAIN DAM

ISTHMIAN CANAL COMM. REPORT 1908
PLATE 136



I DESCRIPTION AND HISTORY:

This dam was completed in January 1896 and filled in April 1896. No data on kind or placing of materials is available although the core wall is very likely masonry.

II METHOD AND OBSERVATIONS:

Three pipes were sunk but whether or not they were perforated is unknown. The embankment was saturated to within 2 feet of the reservoir level.

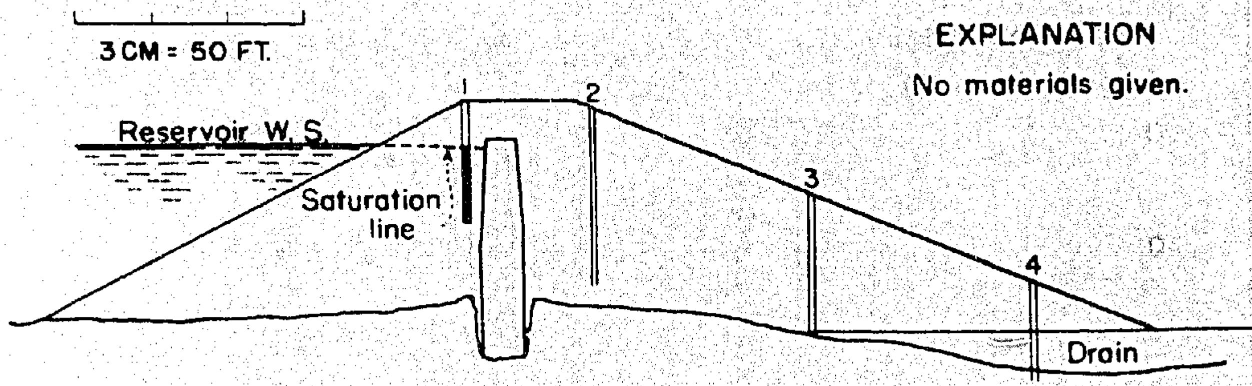
III REMARKS:

The saturation line is fairly steep and indicates a fairly impervious bank. The line indicated may not be the maximum possible with this reservoir level. Its disappearance into the foundation indicates a porus material there. Just what position the line occupies downstream from wall 3 is problematical.

BUREAU OF RECLAMATION
DENVER, COLO., 1934

CARMEL AUXILIARY DAM

ISTHMIAN CANAL COMM. REPORT 1908
PLATE 136



I DESCRIPTION AND HISTORY:

This dam was completed and filled in 1896. The core wall may be masonry. The drain is probably broken rock.

II METHOD AND OBSERVATIONS:

Four pipes (perforated?) were driven. "Water was encountered in the downstream embankment 28 feet below the reservoir level, but on driving the pipe 6 feet further the water disappeared in a few days showing existense of a water pocket which drained out at a lower level. This indicates that the core wall is not absolutely tight, and that with a lapse of time the bank will probably become saturated until the slope of saturation is determined".

III REMARKS:

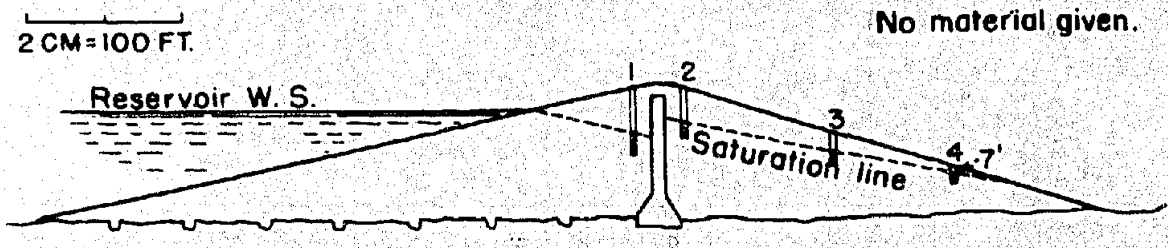
Indications point to an impervious core-wall and foundation and a well drained downstream embankment. Data gathered subsequently should be interesting.

BUREAU OF RECLAMATION
DENVER, COLO., 1934

MIDDLE BRANCH DAM

ISTHMIAN COMM. REPORT 1908
PLATE 136

EXPLANATION
No material given.



I DESCRIPTION AND HISTORY:

It is stated that not much care was taken in construction of this dam. It was completed in 1876 and no information is at hand regarding materials. The scale is approximate. The core wall shown may be timber or masonry.

II METHOD OF OBSERVATION:

Four pipes were placed as shown, and the slope of the saturation line downstream from the corewall was found to be about 5 to 1. At hole No. 4 water was found 7 feet below the surface. At hole No. 2 it was 15 feet below the reservoir level.

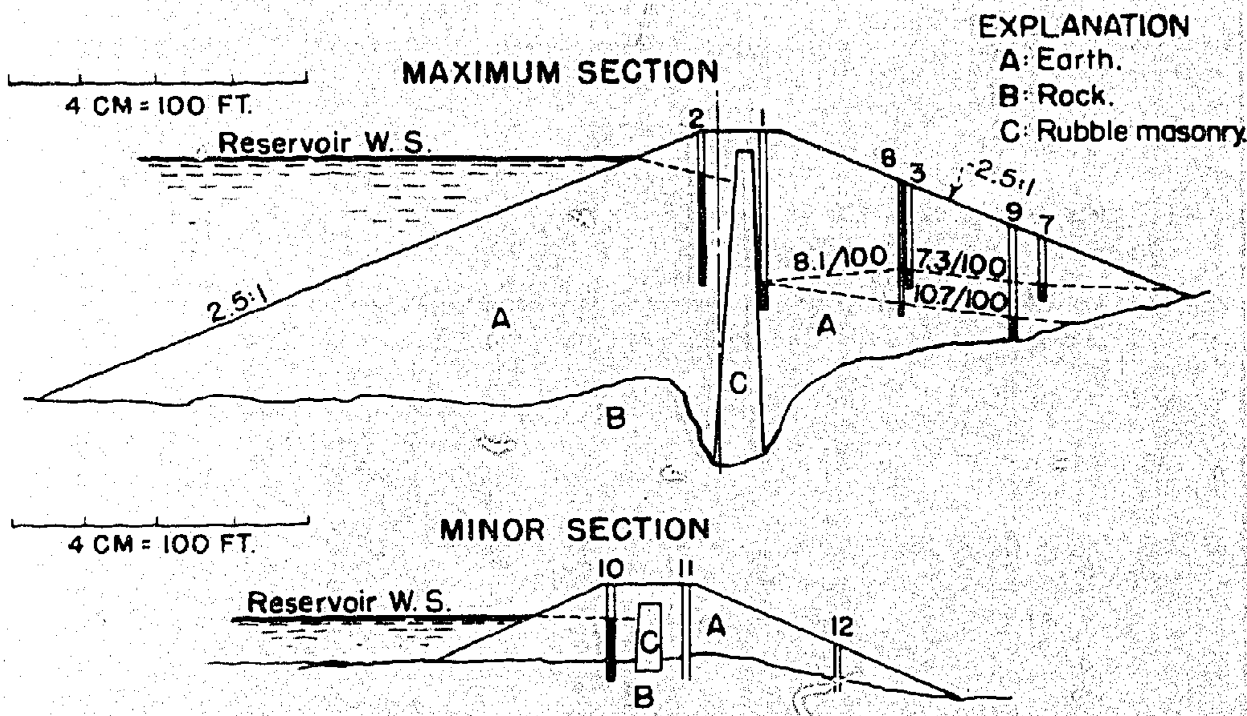
III REMARKS:

Unless rainwater has affected the levels in the pipes it is to be assumed that No. 2 is being affected by transverse flow downstream from the corewall which is not affecting No. 1. If Records of reservoir elevations were available the low level in No. 1 might be found to be due to a rapid fall or rise of reservoir level.

BUREAU OF RECLAMATION
DENVER, COLO., 1934

TITICUS DAM

ISTHMIAN CANAL COMM. REPORT 1908
PLATE 136



I DESCRIPTION AND HISTORY:

This dam was completed in 1895. Not much data is at hand regarding materials and construction. Data was gathered as a part of a study for the New Croton Reservoir.

II METHOD AND OBSERVATIONS:

It is not stated what kind of hole was bored to obtain the saturation line. The core wall seems to be impervious. "No percolating water was found in the downstream portion of the dam"; the water there is said to be ground water because when permitted to flow away by a drop in ground water table it flows away on a relatively flat gradient. The embankment appears very porous.

The minor section shows a tight core wall.

BUREAU OF RECLAMATION
DENVER, COLO., 1934

PLATE 40

MISSISSIPPI RIVER LEVEES
EXPERIMENTS OF 1898

U. S. WATERWAYS EXPERIMENT STA.
VICKSBURG, MISS.
MAY 1, 1932

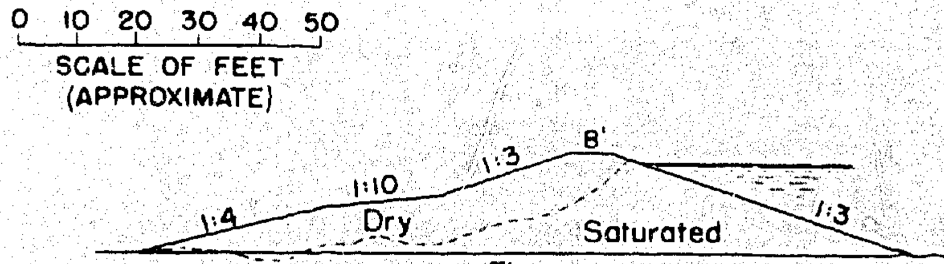


Fig. 1
BUCKSHOT
(CLAY)

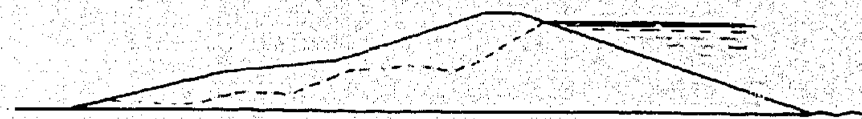


Fig. 2
BUCKSHOT AND LOAM

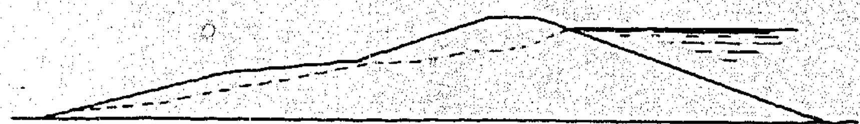


Fig. 3
LOAM

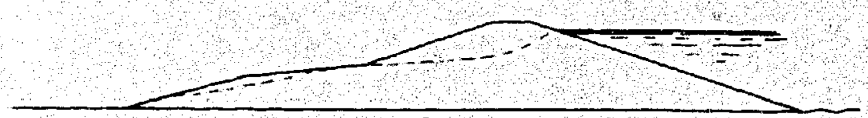


Fig. 4
SANDY LOAM

The above sketches were taken from a bulletin of the War Department entitled "IMPROVEMENT OF THE MISSISSIPPI RIVER FOR FLOOD CONTROL AND NAVIGATION" by D. O. Elliot, Major, Corps. of Engineers; vol. II, plate XL.

The data at hand are not sufficiently complete to justify any conclusions.

BUREAU OF RECLAMATION
DENVER, COLO., 1934

X-D-1135

COQUILLE DAM
OREGON

TRANS. AM. SOC. C. E. 1924
VOL. LXXXVII PAGE 124

I. DESCRIPTION AND HISTORY:

This dam was built on a clay foundation and provided with a puddle clay core wall laid in a crescent shape concave upstream. A system of tile drains was laid in the foundation material as shown on the plan view of the dam at the bottom of the page of sketches.

II. METHOD OF OBSERVING AND OBSERVATIONS:

Six wells were driven at the maximum section. Three were perforated pipe for observing the saturation line and three were not, the latter being used to measure hydrostatic pressure in the foundation material. "Measurements were taken every few days for three months and are plotted above. The 2-inch perforated pipes (shown in the sketch) were equipped with well points and perforated to within 10 feet of the surface of the dam."

Reservoir level was rising throughout the test. "No water has been observed to date (1924) in well No. 3. Seepage has never exceeded 40 gals. per minute and all of this seepage comes from the drainage system under the dam."

III. REMARKS:

The highest curve shown above is probably not quite the maximum that will develop if reservoir level remains at 385 for some time but is probably not materially below it. The method of plotting the well logs furnishes some idea of the length of time required for fluctuations of reservoir level to be felt at points within the dam. The effect of the drainage system is also apparent.

COQUILLE DAM
OREGON

TRANS. AM. SOC. C. E. 1924
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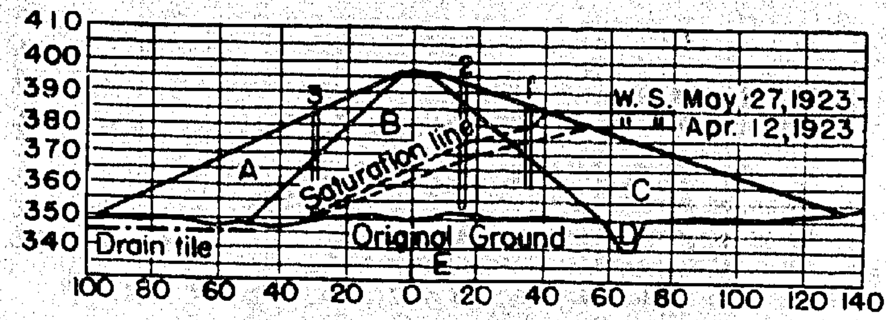
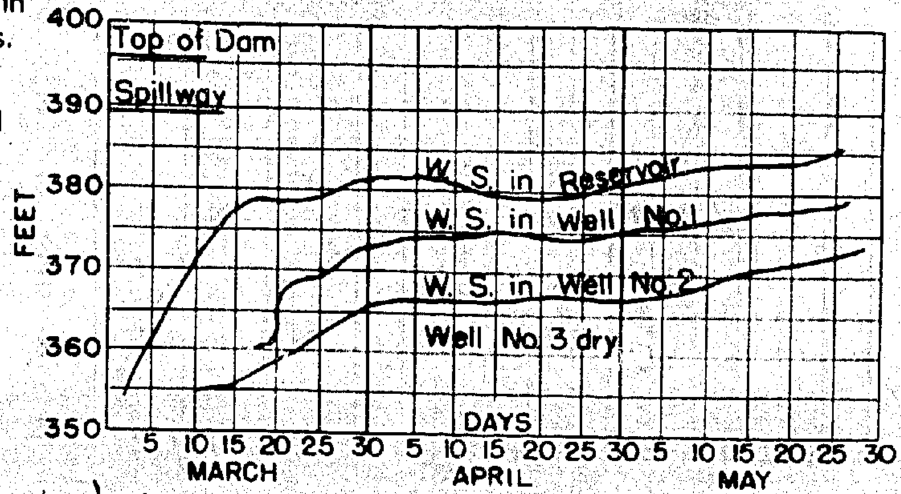
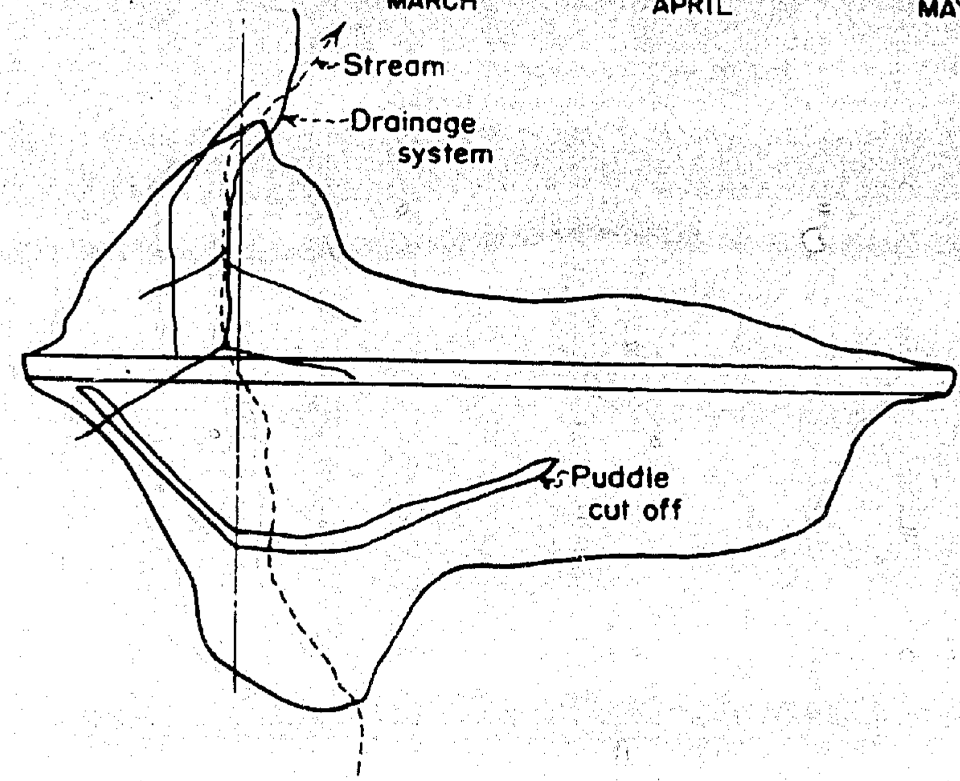
EXPLANATION

- A: Quarried sandstone spread in layers not over 3 feet thick.
- B: Borrow pit material sprinkled and rolled in not over 1 foot layers.
- C: Borrow pit clay sprinkled and rolled in not over 6 inch layers.
- D: Puddle of clay, sand and gravel deposited in water and mixed by poling.
- E: Alluvial material.





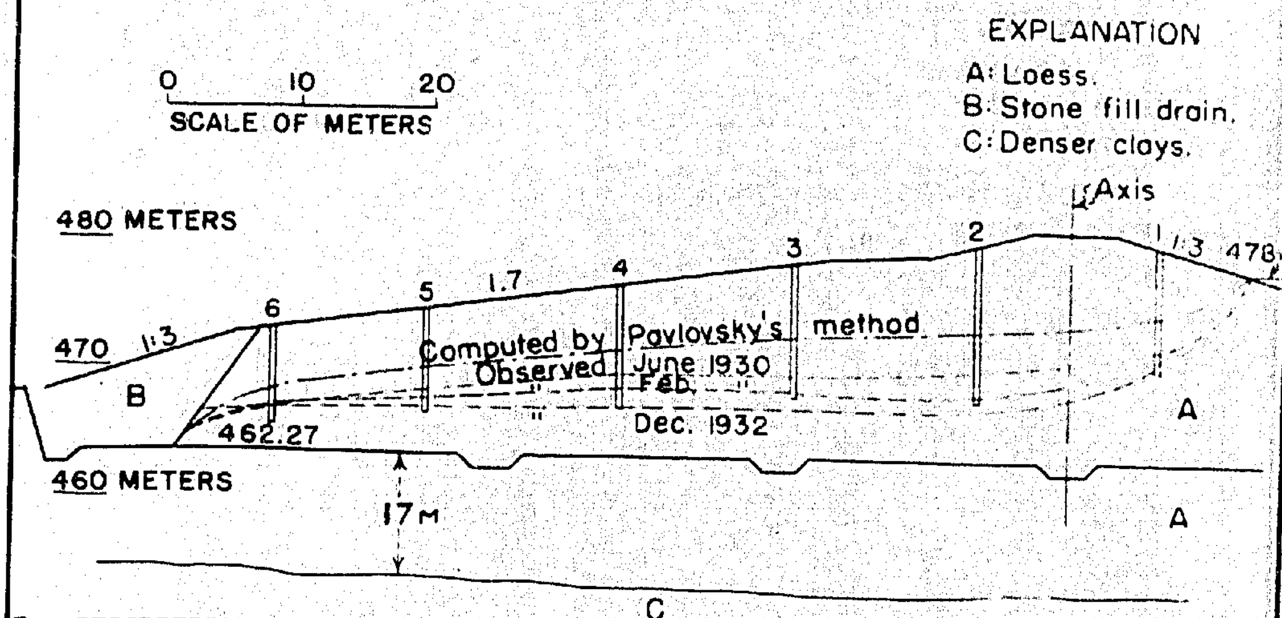


BUREAU OF RECLAMATION
DENVER, COLO., 1934

X-D-1137

BOZ-SU DAM
U. S. S. R.

"HYDRAULIC ENGINEERING" (RUSSIAN)
MOSCOW, JUNE 1933. PAGE 24



I DESCRIPTION AND HISTORY:

The dam and foundation are light yellow loess. (See description and analysis.) During construction the top 6 to 10 feet of soil was cut off and the tie-in of dam and foundation was accomplished by keys 6½ to 10 feet deep as shown. At the river banks the slopes were "stepped." The loess fill was first sprayed and then rolled in 6 to 10 inch layers with smooth 8-ton rollers 4 feet wide. Density of the fill was 7 to 8% greater than that of the foundation. Percolation coefficient obtained by an instrument similar to Forchheimer's was 0.000049 cm/sec. During design of the dam the coefficient was assumed .00005 cm/sec.

II METHOD AND OBSERVATIONS:

For details of percolation measurements this article* should be consulted. 14 Piezometers were placed in the dam proper and 19 Piezometers in the adjacent loess abutments. Three-dimensional studies of flow were made. See plate ___. Records were kept for 4 years. "In almost every piezometer since the filling of the reservoir the elevation of water was considerably increased and after that remained fairly constant. After 3 or 4 years the elevation in most piezometers somewhat decreased. At very low temperatures during the year a rise was noticed in some piezometers." This rise was attributed to freezing of the "drain" and consequent backing up of water in the dam. The quantity of seepage amounted to 0.12 c.f.s. in 1930 and 0.04 c.f.s. two years later. Indications are that the dam had become more impervious with time. It is shown that the greater part of the measured seepage flow took place beneath and around the body of the dam.

III REMARKS:

Compare the position of the saturation line as computed by the method of Pavlovsky with the lines subsequently located by the borings.

* Technical memo 378, U.S.B.R.

BUREAU OF RECLAMATION
DENVER, COLO., 1934

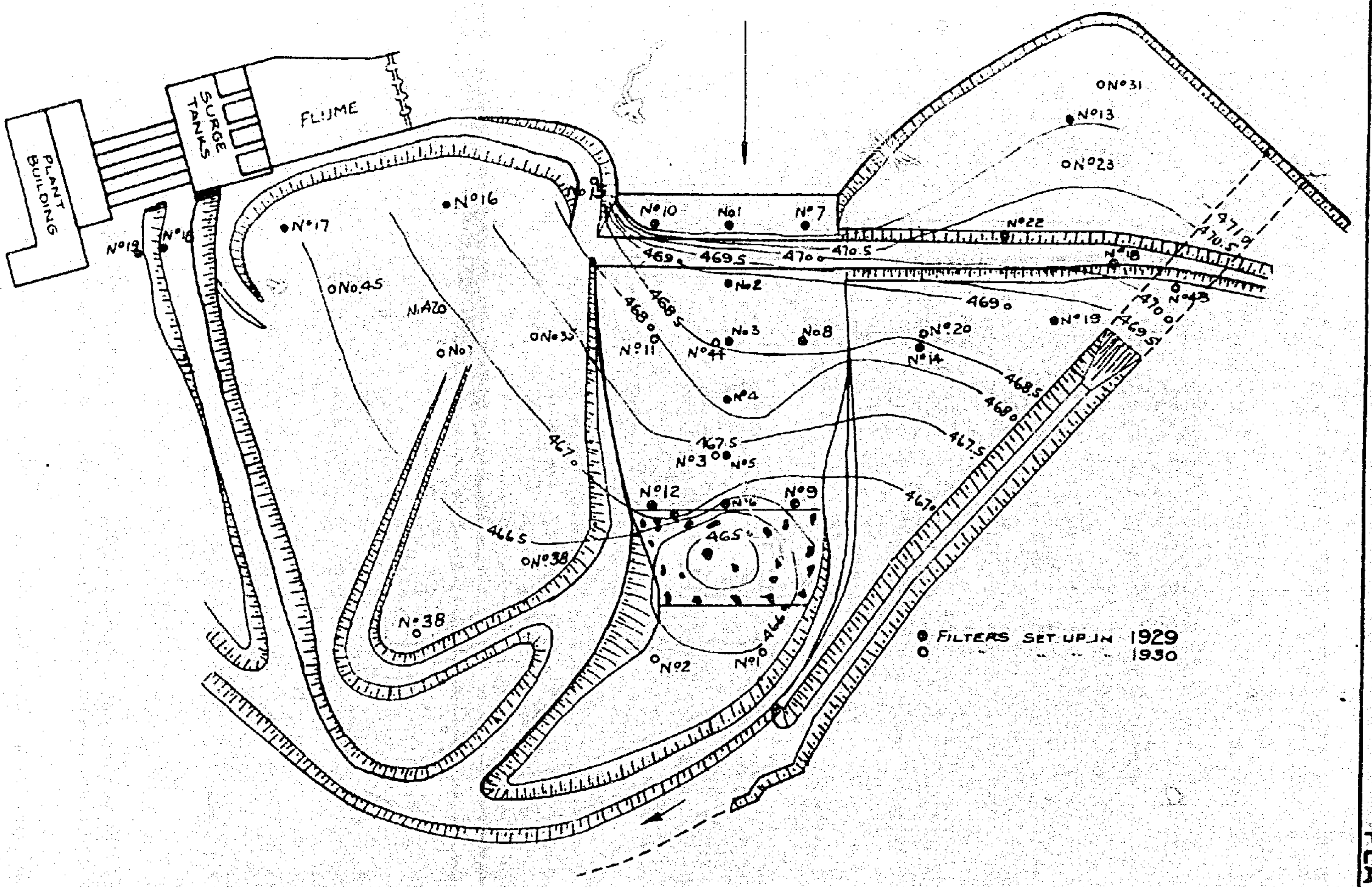
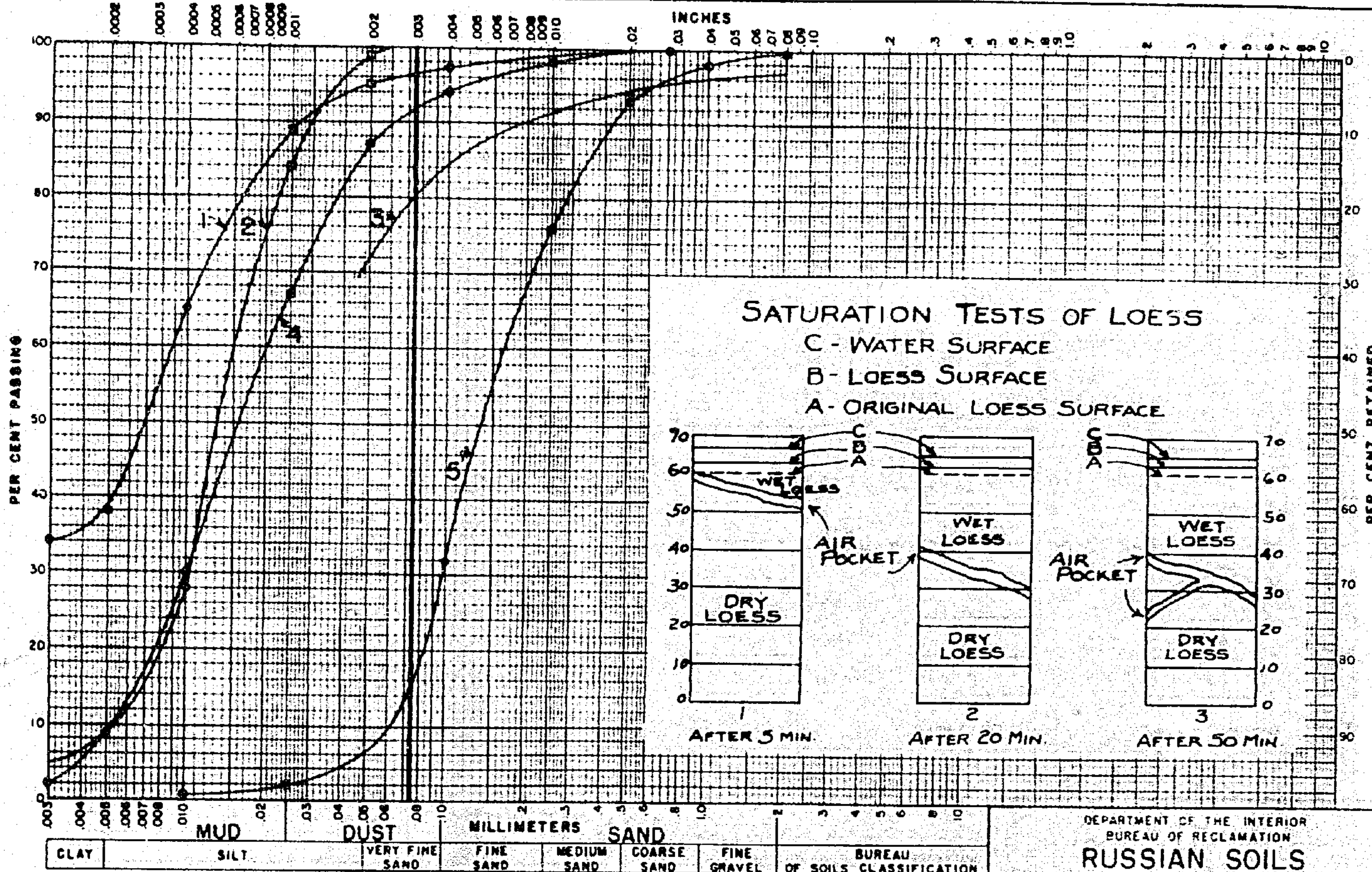


FIG. 4 PLAN OF DAM. LOCATION OF PIEZOMETERS; WATER CONTOURS AS MEASURED IN FEB. 1930

X-D-1139



REMARKS

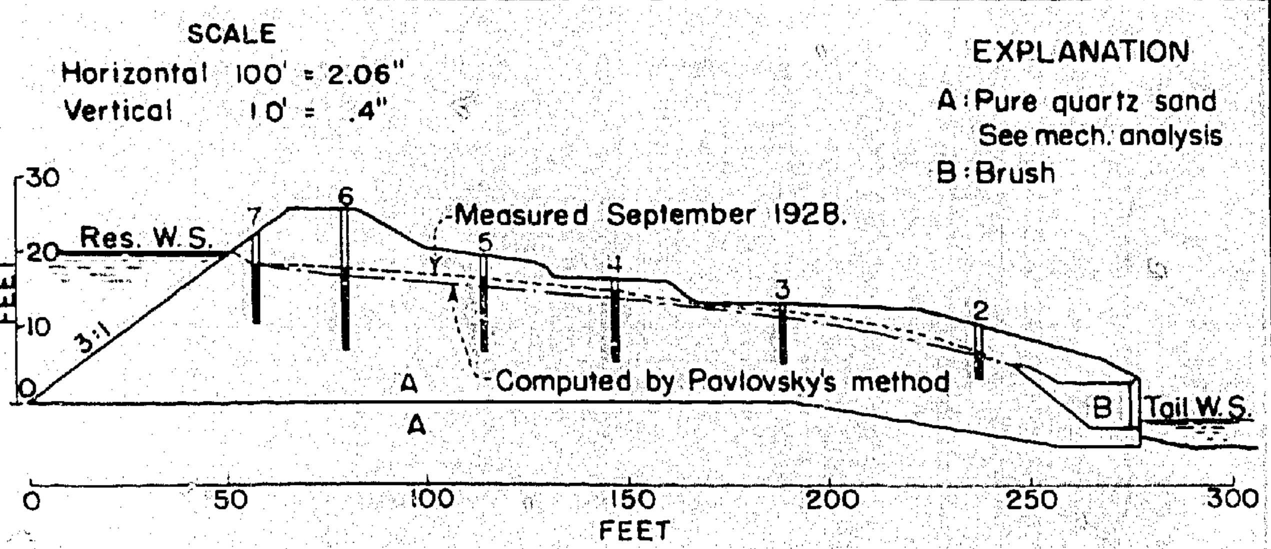
1 – Loess from the Boz-Su Hydroeletric Plant Dam.
2 – Loess from Virginia City, Ill.
3 – Loess from Rhine River at Neuwod.
4 – Loess clayey soil from Bobriky Dams.
5 – Pure quartz sand from the Borov Sand Dam.

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
RUSSIAN SOILS
DESCRIBED
IN THIS MEMORANDUM

DRAWN R.C.H. CHECKED DATE 3-5-34

BOROV ELECT. CO. DAM
U. S. S. R.

"HYDRAULIC ENGINEERING" (RUSSIAN)
MOSCOW, JUNE 1933, PAGE 24



I DESCRIPTION AND HISTORY:

Sand was used in this dam and a brush drain was relied upon to keep the saturation line within the structure of the dam. The foundation is also sand.

II METHOD AND OBSERVATIONS:

"Piezometers" were placed in this dam and much data was collected. It is not known that these pipes were perforated. Before the dam was built the saturation line was computed by the method of Pavlovsky. Subsequently the saturation line was located and the agreement is indicated by the sketch which has been distorted twice vertically.

III REMARKS:

More data on this dam should be available.

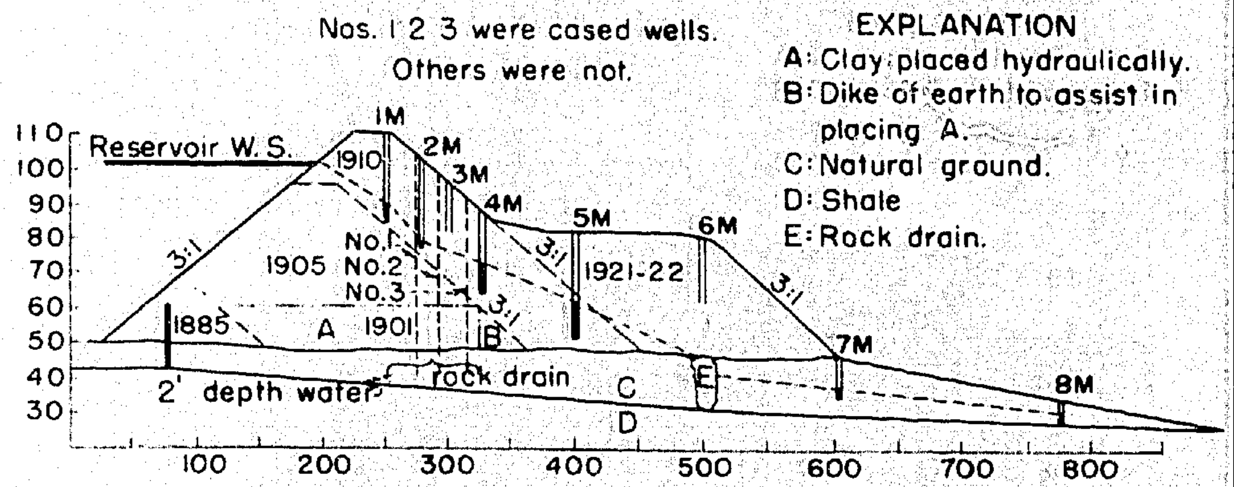
BUREAU OF RECLAMATION
DENVER, COLO., 1934

X-D-1141

PLATE 47

MARSHALL LAKE DAM
NEAR MARSHALL, COLO.

LAKESIDE CONST. CO. REPORT
JUNE 10, 1924. F-3-80



I DESCRIPTION AND HISTORY:

This dam was increased in size 5 times as shown by dates on the sketch. Not much data is available regarding materials or placing methods.

II METHOD AND OBSERVATIONS:

It is not known how long records were kept on this dam. Holes marked M-1,2,3,4,5,6,7,8 were probably of perforated pipe and the free water surface in each was read. Holes No. 1,2 & 3 shown by dotted lines were not of perforated pipe.

III REMARKS:

It can only be assumed that the curve shown is maximum for this reservoir level. The effect of the drain can be seen. The Bureau of Reclamation Soils Testing Laboratory has to date analized only one sample of the material. It is from the bulge on the dam near holes 5-M and 6-M and is obviously very fine.

The tabulated summary of soil analyses on the dam is by the Public Service Co. of Colorado.

BUREAU OF RECLAMATION
DENVER, COLO. 1934

X-D-1142

MARSHALL LAKE DAM
SUMMARY OF SOIL ANALYSIS

PUBLIC SERVICE CO.
OF COLORADO.

Percentage of materials relates to the percent of volume. One cubic foot equalling 100%. A.T.F.

DAM PRISM:

Specific Gravity	
Constituent	2.65
Mass	1.79
Weight lbs. per cu. ft.	
Nat. in place	112.0
Saturated	111.0
Percent Voids	
Compact	36.5
Uniformity Coefficient	5.1
Effective Size - mm	0.0082
Percent of Soluble Salts	0.1
Percent Organic	1.9
Angle of Repose	
In Place	29°00'
Saturated	20°50'
Percent Moisture	25.0
Percent Clay	34.6
Percent Sand	1.9

FOUNDATION:

Specific Gravity	
Constituent	2.62
Mass	1.83
Weight lbs. per cu. ft.	
Nat. in Place	114.4
Saturated	115.0
Percent Voids	
Compact	30.2
Uniformity Coefficient	5.7
Effective Size - mm	0.0094
Percent of Soluble Salts	0.1
Percent Organic	2.6
Angle of Repose	
in Place	42°53'
Saturated	30°00'
Percent Moisture	29.6
Percent Clay	25.6
Percent Sand	11.9

BUREAU OF RECLAMATION
DENVER, COLO., 1934

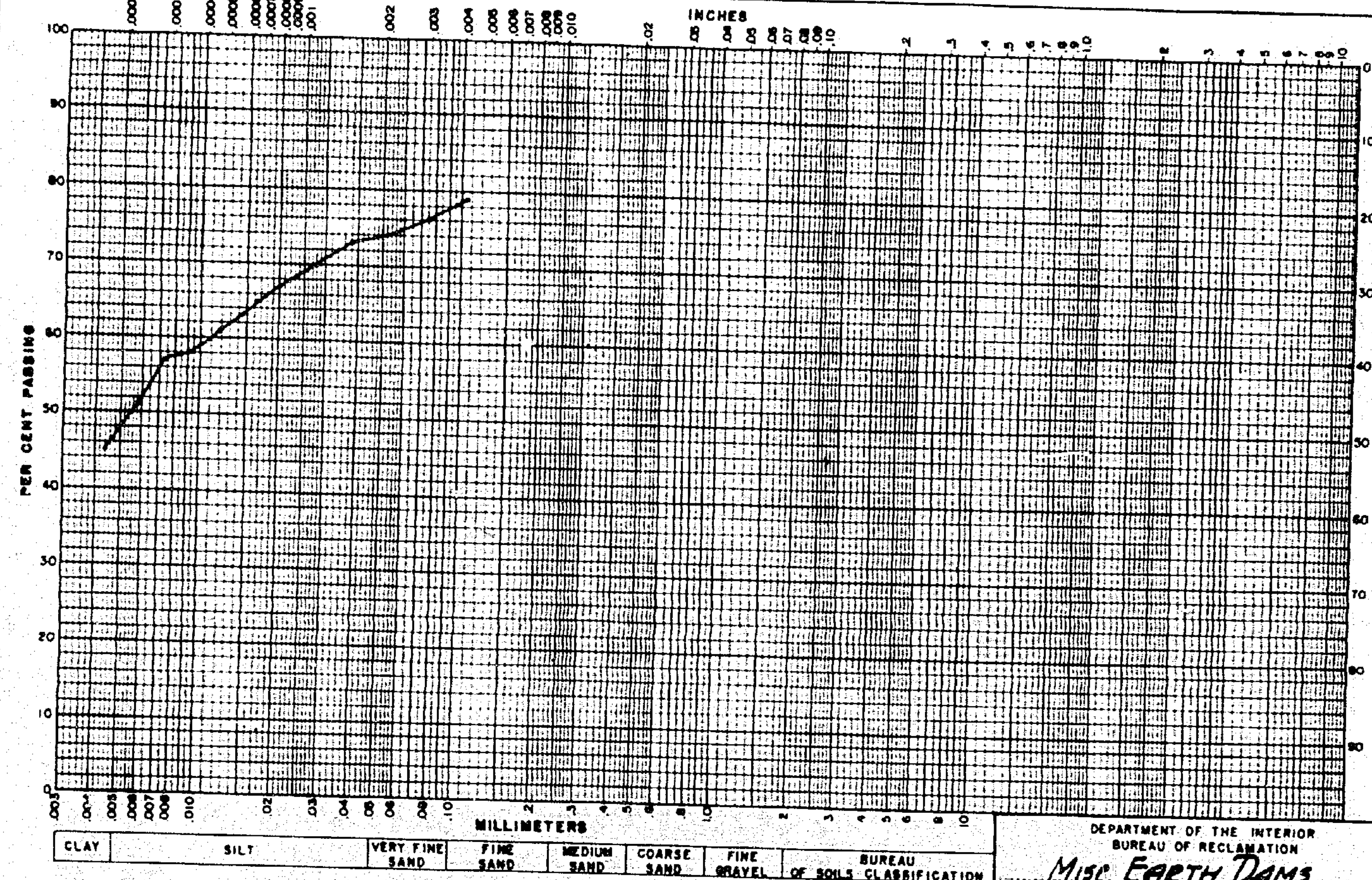


PLATE 49

REMARKS

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

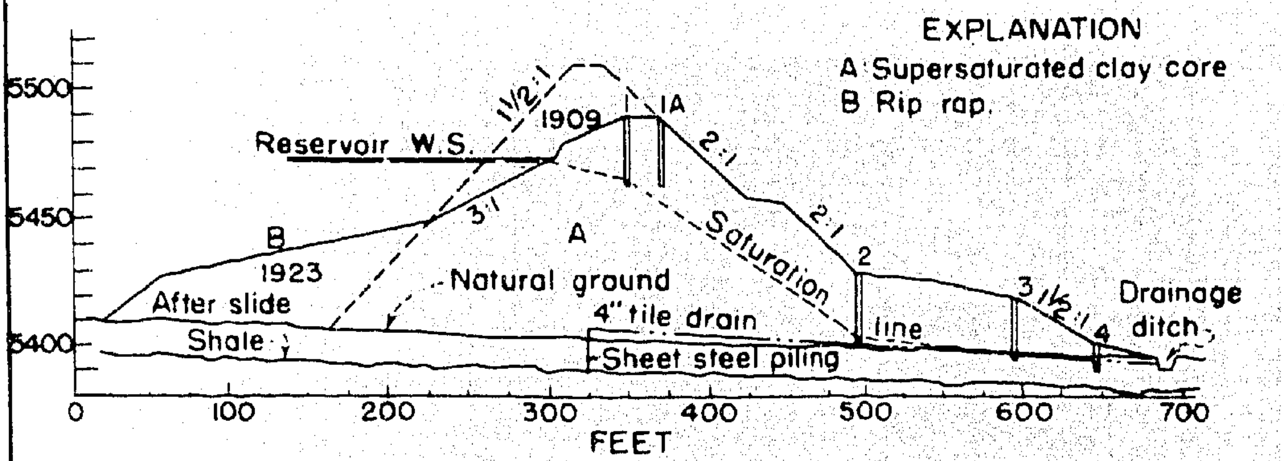
Misc. Earth Dams
Marshal Lake
Bulge on Dam
Sample #76

DRAWN H.C.O. CHECKED DATE 2-28-34

X-D-1144

STANDLEY LAKE DAM
COLORADO

LAKESIDE CONST. CO. REPORT, JULY 1, 1923
PLATE F-3-81



I DESCRIPTION AND HISTORY:

This dam has been redesigned and reconstructed after partial failure so often that even a fair idea of the distribution of material in it is difficult to obtain. The Engineering News Record* gives a fairly complete picture of the "Case of the Standley Lake Dam", but this article and the reference in the Lakeside Construction Co. report differ in the placing of the 4" tile drain at the base of the dam. A slight slip occurred in 1912 and a major slide in 1916. The dam was repaired after each slip. Failure was attributed to sudden lowering of the reservoir level and consequent flowing of the saturated clay core, "Later after further movement (of the upstream slope) which increased the height of the vertical face there appeared opposite sta. 32/35 a pronounced seepage at elevation 5450. Water ran from the vertical face in a small stream and at three other points (along the dam) similar conditions prevailed." (E.N.R. May 32, 1917. P.444) "Out of 21 tell-tale wells driven into the outer slope in August 1914 water showed in 9. Out of these water showed to any extent only in 2 when examined in Feb. 1917. Those showing water were scattered among the dry wells", (Editor E.N.R.)

III REMARKS:

A summary of soil analyses of dam and foundation material accompanies.

* E. N. R. May 31, 1917 - Page 444.

BUREAU OF RECLAMATION
DENVER, COLO., 1934

STANDLEY LAKE DAM
SUMMARY OF SOIL ANALYSIS

PUBLIC SERVICE CO.
OF COLORADO.

Percentage of materials relates to the percent of volume. One cubic foot equalling 100%. A.T.F.

DAM PRISM:

Specific Gravity	
Constituent	2.65
Mass	1.83
Weight lbs. per cu. ft.	
Nat. in Place	114.0
Saturated	114.7
Percent Voids	
Compact	40.9
Effective Size - mm	.0084
Percent of Soluble Salts	.02
Percent Organic	.01
Angle of Repose	
In Place	32°25'
Saturated	28°00'
Percent Moisture	25.7
Percent Clay	53.5
Percent Sand	5.9

FOUNDATION:

Specific Gravity	
Constituent	2.65
Mass	1.91
Weight lbs. per cu. ft.	
Nat. in Place	120.0
Saturated	138.0
Percent Voids	
Compact	3.82
Effective Size - mm	.013
Percent Organic	1.4
Angle of Repose	
In Place	39°00'
Saturated	33°40'
Percent Moisture	28.7
Percent Clay	18.7
Percent Sand	41.7

BUREAU OF RECLAMATION
DENVER, COLO., 1934

APPENDIX

A. SATURATION

Impregnation of one substance with another until the former can hold no more.

B. SATURATION LINE

This term is understood to apply to the upper boundary of flowing water in an earth dam. It is the trace of the "saturation surface" on a vertical cross-section through the dam. Above the saturation line the earth is wet but not saturated. "Saturation" implies "no flow" and velocities are so low that the connotation is a desirable one.

C. (TRANSMISSION CONSTANT* (PERCOLATION COEFFICIENT (COEFFICIENT OF PERMEABILITY

Generally designated K, the coefficient is usually given as the maximum discharge possible at a given temperature through a unit cube of earth material under a unit difference in elevation between headwater and tailwater.

*Schlichter in U.S.G.S.W.S. Paper No. 140, 1905.

This coefficient varies from about .00003 (cu.ft./minute) for very fine-grained material to 30. for gravel. The following table shows a "Variation, with temperature, of the flow of water of various temperatures through a sand, 60° F. being taken as the standard temperature".

"Relative flow means flow at given temperature compared with flow at 60° F. It is expressed as a percentage."

Temperature °F.	Relative Flow	Temperature °F.	Relative Flow
32	0.64	70	1.15
35	0.67	75	1.23
40	0.73	80	1.30
45	0.80	85	1.39
50	0.86	90	1.47
55	0.93	95	1.55
60	1.00	100	1.64
65	1.08		

APPENDIX (Cont'd.)

D. CAPILLARY WATER

Water held above the water table by capillary force. Upward moving or stationary water in the capillary fringe. Capillary water can move in any direction.

Most agriculturalists agree that the maximum height to which water can rise in a natural soil by capillary action is about 10 feet. Prof. F. H. King gives data which indicates that the rate of rise of capillary water in a circular cylinder 6" diam. x 12" high is proportional to the grain size as follows:

EFFECT OF SOIL CHARACTERISTICS (Distilled H_2O used)

Class of Material	Time to Climb 11 Inches	Mean Rate of Rise	
		First 24 Days	Saturated
Clay loam	6 days	Average of all samples .79 lbs/sq.ft. per day	2.05
Reddish clay	22 "		
Reddish clay	18 "		
Clay with sand	6 "		
Fine sand	2 "	.69	2.37

None of the soil columns was completely saturated at the end of 34 days. When the soil became saturated* the mean daily movement was greatly increased.

*Mr. King does not use the word saturation in the same sense that the writer uses it. Water may find a capillary path around an opening too large to permit capillary rise through it and the water may subsequently reach the surface of the soil column; but until water flows into the large opening by gravity the opening will not be filled with water. If there is a void in the column of soil which is not filled with water the column of soil is not strictly saturated.
In "Public Roads" Vol. 9, No. 1, p. 3, Dr. Terzaghi defines "capillary moisture": "A measure of the volume of voids of a soil sample prepared under certain arbitrary standard conditions, minus the void space which permanently remains filled with air."

In the case of fine sand the mean daily movement during the first 24 days was .69 lbs. daily per sq. ft. and when completely "saturated" was 2.37 lbs. daily per sq. ft., an increase of more than 300%.

Presence of various salts dissolved in the water influenced the rate of capillary rise. Addition of 0.08% of potassium nitrate to distilled water increased the rate in an 18" column of rather coarse

APPENDIX (Cont'd.)

D. CAPILLARY WATER (Cont'd.)

sand 22.84%. Similar test using 0.08% of common salt decreased the rate 12.82%. With a saturated solution of land plaster the decrease was 27.36%. These variations are compared to the rate of rise using pure distilled water. The temperature at which those tests were made is not stated.

E. PUDDLE

Because the American definition is not universal the following are given:

(1) Earthy material as a mixture of clay, sand and gravel, placed with water to form a compact mass to reduce percolation.[1]

(2) To place such material.[1]

[1]Standard symbols and glossary of terms used in hydraulics as applied to irrigation:" Special committee on Irrigation Hydraulics.

(3) Clayey and gravelly earth thoroughly mixed and wetted having a consistency of stiff mortar or mud. Clay puddle - predominating ingredient is pure clay.*

*Earth Dams" - Burr Bassell.

(4) Puddle in England* is an expensive material, very solid, the material is often carried very considerable distances, and it is invariably prepared in a pug mill."

(5) Puddle in India is "made of black cotton soil. Mud bricks laid carefully and rammed."*

*Proceed. of Irrig. Conf. Simla, India, 1904. Discussion by Mr. Preston.

F. SETTLEMENT OF WELLS

Using the wells for purposes other than as observation wells may also cause them to settle. The following changes in elevation occurred at Minatare Dam*, Nebraska:

Wells on the Upstream slope	Elevation July 10 1926	Elevation June 20 1928	Settlement (Ft.)
Sta. 21 ⨍ 50	4127.5	4124.5	3.0
23 ⨍ 25	26.7	25.1	1.6
24 ⨍ 90	28.7	25.0	3.7
26 ⨍ 50	26.2	25.0	1.2

F. SETTLEMENT OF WELLS (Cont'd.)

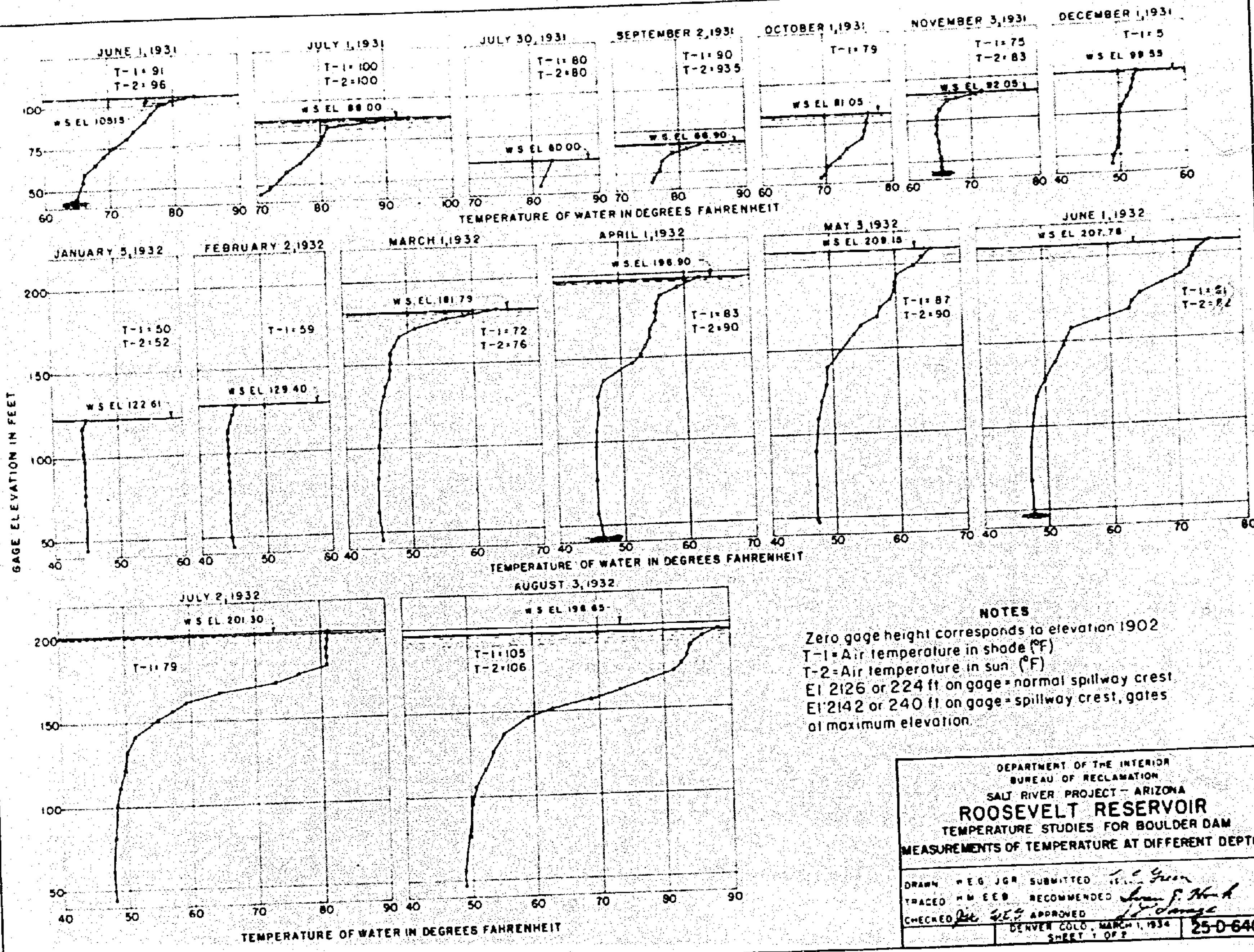
Those wells were not perforated. They were used to find pressures in the foundation under the dam. No change in elevation was noted for well S-1 referred to in this memo.

*Data furnished by Mr. T. W. Parry, Mgr. Pathfinder Irr. Dist., Mitchell, Nebraska.

G. WATER TEMPERATURES IN RESERVOIRS

The following plates* will indicate how the temperature of water will vary in reservoirs of size and location similar to that of the Roosevelt Reservoir. In reservoirs subject to greater seasonal variation of temperature than the Roosevelt the effect on percolation may be more marked. The general characteristics of all six large reservoirs studied were similar. The viscosity of water changes with temperature. Using this data in conjunction with that under "transmission constant" (App. C) some idea may be gained as to the way in which the transmission constant might vary with the depth of water in the reservoir. At present no known attempt has been made to take this effect into account.

*Taken from Mr. W. E. Green's Memo. No. 379, "Temperature of Water in Reservoirs".



NOTES

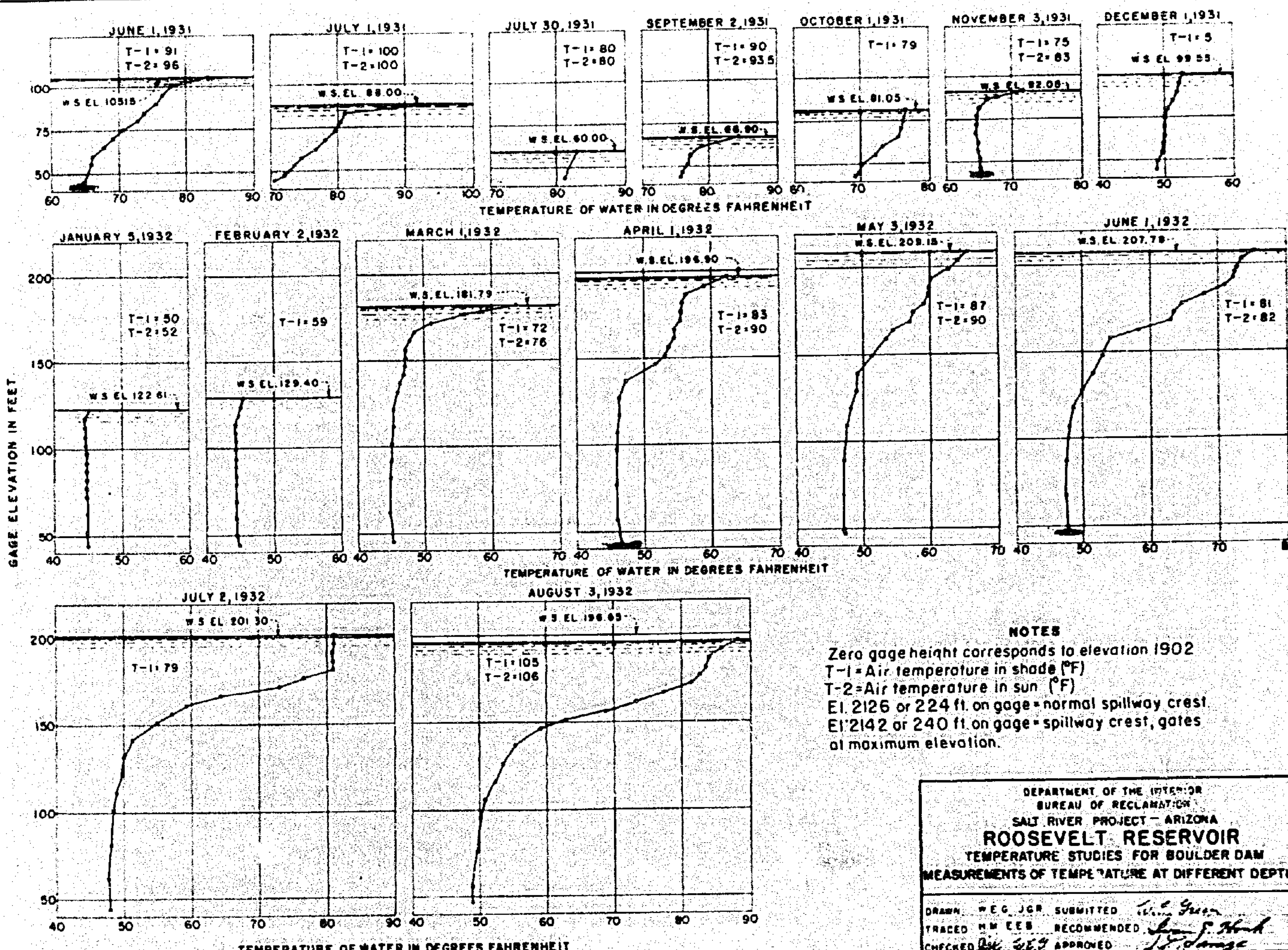
Zero gage height corresponds to elevation 1902
T-1 = Air temperature in shade (°F)
T-2 = Air temperature in sun (°F)
El 2126 or 224 ft on gage = normal spillway crest.
El 2142 or 240 ft on gage = spillway crest, gates at maximum elevation.

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SALT RIVER PROJECT – ARIZONA

ROOSEVELT RESERVOIR

TEMPERATURE STUDIES FOR BOULDER DAM
MEASUREMENTS OF TEMPERATURE AT DIFFERENT DEPTHS

DRAWN W.E.G. J.G.R. SUBMITTED
TRACED H.M. E.E.B. RECOMMENDED
CHECKED APPROVED
DENVER, COLO., MARCH 1, 1934 SHEET 1 OF 2
25-D-640

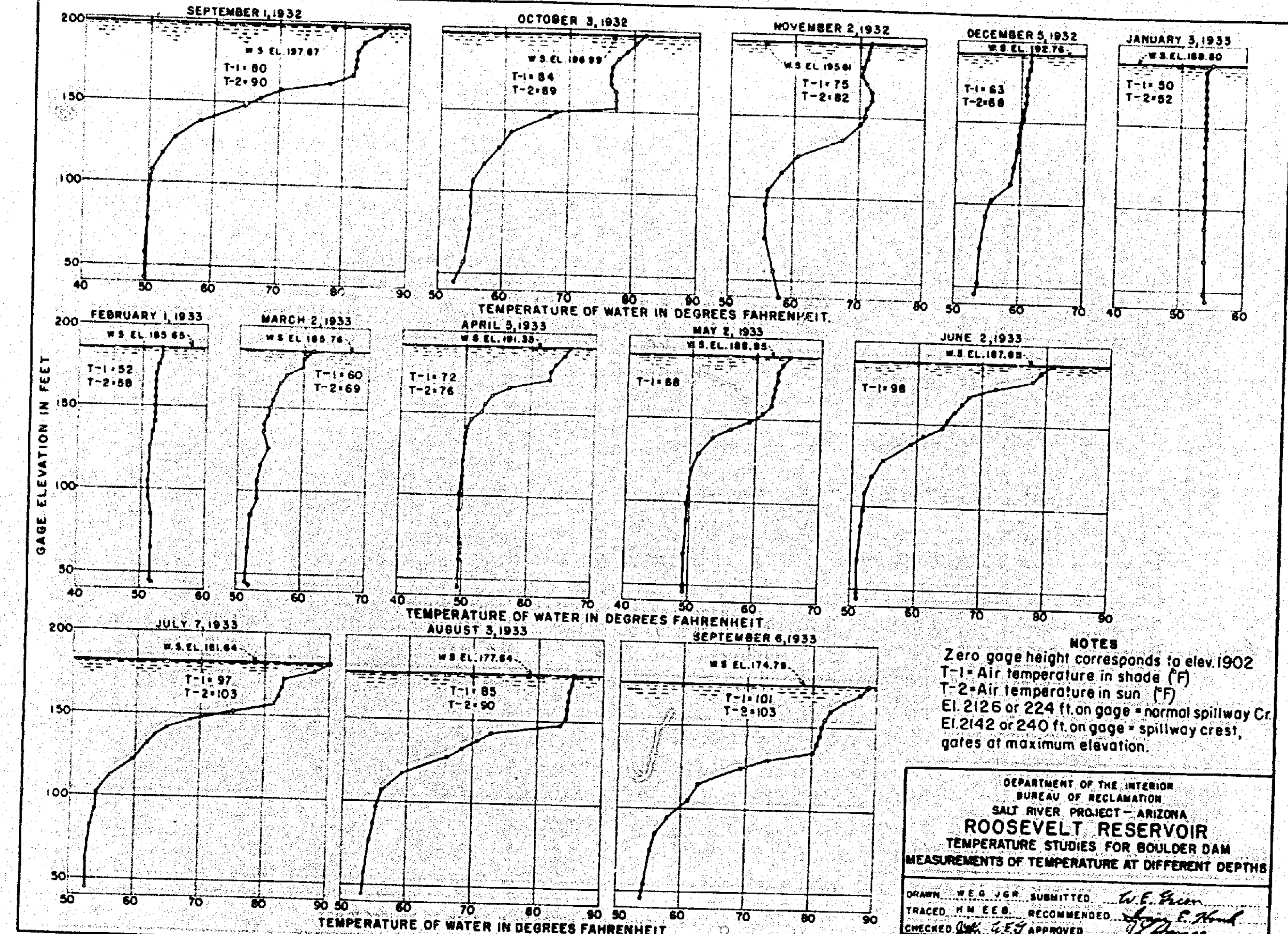


NOTES

Zero gage height corresponds to elevation 1902
T-1 = Air temperature in shade (°F)
T-2 = Air temperature in sun (°F)
El. 2126 or 224 ft. on gage = normal spillway crest.
El. 2142 or 240 ft. on gage = spillway crest, gates at maximum elevation.

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SALT RIVER PROJECT — ARIZONA
ROOSEVELT RESERVOIR
TEMPERATURE STUDIES FOR BOULDER DAM
MEASUREMENTS OF TEMPERATURE AT DIFFERENT DEPTHS

DRAWN: W.E.G. J.G.R. SUBMITTED [signature]
TRACED: H.M. E.E.B. RECOMMENDED [signature]
CHECKED [signature] APPROVED [signature]
DENVER COLO., MARCH 1, 1934 SHEET 1 OF 2
25-D-640



NOTES

Zero gage height corresponds to elev. 1902
T-1 = Air temperature in shade (°F)
T-2 = Air temperature in sun (°F)
El. 2126 or 224 ft. on gage = normal spillway Cr.
El. 2142 or 240 ft. on gage = spillway crest, gates at maximum elevation.

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SALT RIVER PROJECT — ARIZONA

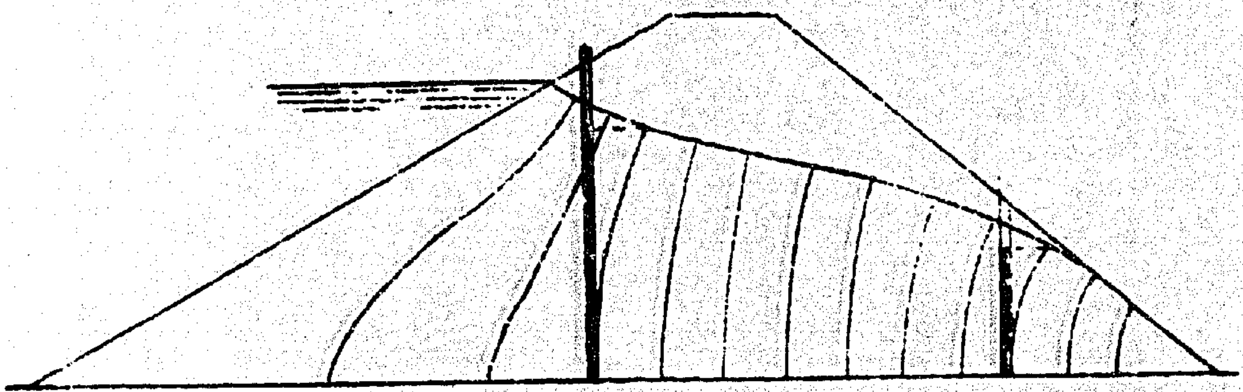
ROOSEVELT RESERVOIR

TEMPERATURE STUDIES FOR BOULDER DAM
MEASUREMENTS OF TEMPERATURE AT DIFFERENT DEPTHS

DRAWN W.E.G. J.G.R. SUBMITTED W. E. Green
TRACED H.M. E.E.B. RECOMMENDED
CHECKED APPROVED
DENVER, COLO., MARCH 1, 1934
SHEET 2 OF 2
25-D-641

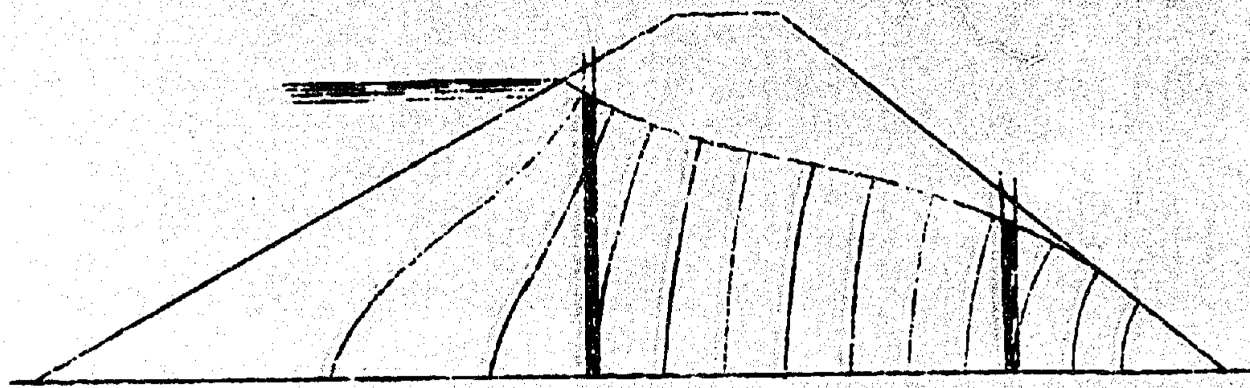
H. LEVEL INDICATED BY AN IMPERFORATE PIPE

A pipe open only at the ends will record the hydrostatic head on the water at the <u>end</u> of the pipe. This level will be lower than the saturation line as shown.



LEVEL INDICATED BY A PERFORATED PIPE

A perforated pipe integrates the pressures in the vertical and more nearly approximates the saturation line. There is an effect of inducing flow down the pipe due to the fact that the potential of water at the top is greater than at the bottom of the pipe, but just how important this effect is is not as yet known.



BIBLIOGRAPHY

PERCOLATION THROUGH AND UNDER EARTH DAMS

Amawalk Dam:
- Isthmian Canal Comm. Report, 1908, Plate 136
- Eng. News, Nov. 28, 1901, p. 413

Ashti Tank, Deccan, India:
- Irrigation Conference, Simla, 1904 Paper #17 (Hill)

Belle Fourche, Belle Fourche Project:
- Belle Fourche Project History, Vol. 2, Part 1 (Contract drawing #2)
- Earth Dams Data - Morgan Engin. Co., p. 152.

Bahadalwadi Tank, Deccan, India:
- Irrig. Conf., Simla, 1904, Paper #17, Hill

Bog Brook Dam:
- Isthmian Canal Comm. Report, 1908, Plate 136
- Eng. News, Nov. 28, 1901, p. 410-413
- Reservoirs for Irrigation, Water Power, and Domestic Supply, Schuyler, p. 238.

Bohio Dam:
- Trans. Am. Soc. Civ. Eng's. 1902, Vol. 48, p. 235.

Boyd's Corners Dam:
- Isthmian Canal Comm. Report, 1908, Plate 136

Boz-Su Dam, U. S. S. R.:
- Russian "Hydraulic Engineering" June, 1933, (Translation)

Borov Elect. Co. Dam:
- Hydraulic Engineering, June, 1933.

Bridgewater Dam:
- Trans. Am. Soc. C. E., Vol. 84, (1921) p. 331

Carmel Auxiliary Dam:
- Isthmian Canal Comm. Report, 1908, Plate 136
- Eng. News, Nov. 28, 1901, p. 413

Carmel Main Dam:
- Isthmian Canal Comm. Report, 1908, Plate 136.

Chicopoo Dam:
Journal New England W. W. Assn., Vol. 41, p. 252 (1927)

Cold Springs Dam, Umatilla Project, Oregon:
Eng. News, Vol. 57, No. 10, p. 250
54, 1911, p. 43.

Coquille Dam, Oregon:
Trans. Am. Soc. C. E. 1924, Vol. XXXVII, p. 122

Croton, New Dam & Jerome Park Reservoir: N. Y.:
Eng. News, Nov. 28, 1901; Dec. 12, 26, 1901
Jan. 16, 1902; Feb. 6, 1902.

Don Martin Dam:
E.N.R. Vol. 102, p. 452
104, p. 101
105, p. 223
5, p. 31
Dwg. P-3-42, File X-P-80(b)

Ekruk Tan, Deccan, India:
Irrig. Conf. Simla, 1904, Paper #17, Hill.

Gatineau Reservoir:
Quebec Streams Commission has made studies.

Gatun Dam (Experimental Models), Panama:
Trans. Am. Soc. C. E. 1924, Vol. LXXXVII, p. 97
Extract from Isthmian Canal Comm. Report 1908
(Appendix E. pp. 139 et. seq.)
Canal Record, 1907, 8(?) Gatun Experiments.
Trans. Am. Soc. C. E. Vol. 67, P. 61-90.

Horse Creek Dam:
Eng. News, Vo. 71, p. 828

"Hydraulic Engineering" in Russian, 1933, No. 6.

Jumbo Dam, Colorado:
Eng. News, Vol. 66, p. 447.

Kreibitsbach Dam, Czechoslovakia:
1er Congres des Grands Barrages, Vol. IV
(p. 153, Test pp. 150-156)

Lahontan Dam:
File 360-D Letter from Mr. Sturci.

Linville Dam:
Trans. Vol. 84 (1921) p. 331.

Lower Volga Dams:
1er Congrès des Grands Barrages, Vol. IV (p. 202)

Marshall Lake Dam, near Marshall, Colo.:
Lakeside Const. Co. Report, June 16, 1924

Matoba Tank, India:
Irrig. Conf. Simla, 1904, Paper #17, Hill
Eng. News, Aug. 21, 1909, p. 205

Mayni Tank, Deccan, India:
Irrig. Conf. Simla, 1904, Paper #17, Hill

McKay Dam:
E.N.R. Vol. 90, p. 934, 4-26, 5-24-33.
Trans. Am. Soc. C. E. Vol. 81 (1917) p. 1

Medleri Reservoir Embankment, India:
Buckley's Irrigation Handbook, p. 383

Mhaswad Tank, Deccan, India:
Irrig. Conf. Simla, 1904, Paper #17, Hill

Middle Branch Dam:
Isthmian Canal Comm. Report, 1908, Plate 136.

Minitare Dam, North Platte Project:
North Platte Project History, Vol. II, Part 3 (p. 229-233, Soil Tests Plate 40)

Mississippi River Levees:
War Dep't. Bulletin "Improvement of the Mississippi River for Flood Control and Navigation" by Maj. D. O. Elliot, C of E, Vol. II

Mukti Reservoir Embankment, India:
Buckley's Irrigation Handbook, p. 383

Nehr Tank, Deccan, India:
Irrig. Conf. Simla, 1904, Paper #17, Hill

Paddy Creek Dam:
Trans. Am. Soc. C. E., Vol. 84 (1921) p. 331.

Pashan Tank, India:
Irrig. Conf. Simla, 1904, Paper #17, Hill

Pingli Tank, Deccan, India:
Irrig. Conf. Simla, 1904, Paper #17, Hill

Rocky River Dam:
Earth Dam Projects, "Justin, 1932, p. 278

Saturation Slopes, Instruments for Observing:
E.N.R., 1933, Jan. 30.

Schwarze Desse Dam, Czechoslovakia:
1er Congrès des Grands Barrages, Vol. IV, p. 143
(Test pp. 140-146)

Shetphal Tank, Deccan, India:
Irrig. Conf. Simla, 1904, Paper #17, Hill

Shirsuphal Tank, India:
Irrig. Conf. Simla, 1904, Paper #17, Hill

"Soils of the Bombay Presidency":
Dept. of Agriculture, Bombay, Bull. No. 160 (1929)

Somerset Dam:
Trans. Am. Soc. C. E. (1921) p. 331, Vol. 84.

Standley Lake Dam, Colo.:
Lakeside Const. Co. Report, 1924.
E. N. R., May 31, 1917, Vol. 78, p. 445.
Eng. Rec. Nov. 13, 1903.

Titicus Dam (Max. and one other section):
Isthmian Canal Comm. Report, 1908, Plate 136
Eng. News. Nov. 28, 1901, p. 413.
Reservoirs for Irrig. Water Power, and Domestic Supply,
Schuyler, p. 237.

Unkal Reservoir Embankment, India:
Buckley's Irrigation Handbook, p. 383

Utica, N. Y. Earth Dam Failure:
Eng. News. Oct. 9, 1902, p. 290.

Wachusett Dam (North Dike), Mass.:
Seventh Annual Report, Met. Water & Sew. Bd. Mass. (1907)
Trans. Am. Soc. C. E. 1924, Vol. LXXXVII, p. 98.
Engin. Record Vol. 52, 1905, p. 64.

Waghad Tank, Deccan, India:
Irrig. Conf. Simla, 1904, Paper #17, Hill

AUTHOR INDEX

Bassoll, Burr:
"Earth Dams" Eng. News. Pub. Co. 1907

Bligh, W. G.:
"Dams and Woirs" (Book No. 170, Buroau Library)

Boston Socioty of Civil Enginoors: Journal:
"Modol Experiments on Hardford Diko", Nov. 1933, Vol. XX, No. 9, p. 223

Canal Record:
Gatun Dam Experimonts, 1907,8

Colman, J.B.T.:
"Tho Action of Water Undor Dams"
Trans. Am. Soc. Civ. Eng. 1916, Vol. LXXX, p. 421

Creager and Justin:
"Hydroelectric Handbook" p. 254 (1927 p. 223

Davidenkov, R. P. Moscow, U.S.S.R.:
"Experimental Studies of Percolation Through Earth Dams"
Proc. First Conf. on Water Works Const. of the Soviet Union, May, 19-25, 1929.

Engineering Societies Library, 29 W. 39th St., New York, N. Y.
Search No. S-3529. Mar. 14, 1922. (Denver Office Bib. No. 18)
"Percolation of Water Through and Under Earth Dams."

Fellows, A. L. Senior Irr. Eng., U. S. Dept. of Agriculture
Eng. News Rec. Mar. 1, 1923

Gilboy, G.
"Soil Mechanics Research"
Trans. Am. Soc. C. E., Vol. 98 (1933) p. 218

Green, W. E., Junior Engineer, U. S. Bureau of Reclamation:
"Measurement of Reservoir Water Temperatures in Southwestern United States"
Tech. Memo. No. 379, Apr. 24, 1934.

Hays, J. B.:
Designing an Earth Dam Having a Gravel Foundation---Model
Trans. Am. Soc. C. E., Vol. LXXIX, p. 1131 (1915)
Trans. Am. Soc. C. E., Vol. LXXXI, p. 1-24 (1917)

Hazen, Allen:
"Hydraulic Fill Dams"
Trans. Am. Soc. C. E., Vol. LXXXIII (1919-20) p. 1713

Henny, D. C.:
"Two Earth Dams of the Reclamation Service."
Trans. Am. Soc. C.E., Vol. LXXIV, Dec., 1911

Holmes, J. A.:
"Some Investigations and Studies in Hydraulic Fill Dam Construction"
Trans. Am. Soc. C. E., 1921, p. 331

Freeman, J. R.:
"Hydraulic Laboratory Practice" 1926-1929
pp. 116, 204, 411, 490.

International Commission on Large Dams of the World Power Conference, Stockholm, Sweden, June, July, 1933.
Reports in Vol. IV. (Question 2b)

Justin, J. B.:
"The Design of Earth Dams"
Trans. Am. Soc. C. E., Vol. LXXXVII (1924)

Justin, J. B.:
"Earth Dam Projects" 1932, p. 278

Meyer, L. L.:
"Percolation in Dams Measured by New Device"
Eng. News-Rec., Jan. 26, 1933, p.109.

Met. Water & Sewage Board (Mass.):
Seventh Annual Report (1907)

Noble, T. A.: No. Yakima, Wash. Mar. 13, 1907
Eng. News, Vol. 47, No. 18

Pavlovsky, N. N., Moscow, U.S.S.R.:
"On Percolation Through the Body of Earth Dams on Impervious Foundations."
Proc. First Water Works Conf., Soviet Union, May 19-25, 1929.
(Entire book by this author has been translated and is in the Bureau's Files as Tech. Memo. No. 383)

Parry, T. W., Mgr. Pathfinder Irr. Dist., Mitchell, Neb.
Minataro Dam Saturation Data. Original records

INDEX OF PLATES

Mr Hebert

UNITED STATES

DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

MEMORANDUM TO CHIEF DESIGNING ENGINEER

SUBJECT: SATURATION OF EXISTING EARTH DAMS

By R. C. HAVEN, JR., JUNIOR ENGINEER

Under direction of

MR. B. W. STEEL, CIVIL ENGINEER ON DAMS

TECHNICAL MEMORANDUM NO. 493
SUPPLEMENT TO T.M. NO. 389

Denver, Colorado.

September 15, 1935

(PRICE: $2.80)

FOREWORD

Since publication and subsequent wide distribution of T. M. no. 389, "Saturation of Existing Earth Dams", June, 1934, considerable data of a similar nature has been sent the Bureau. Some of it has been worked up and is herewith presented as a supplement to no. 389. More is at hand and with distribution of this supplement still more is expected to be sent in. In this way it will be possible to have at the designer's fingertips saturation data on earth dams which have stood the test of time.

PURPOSE

1. The designer lacks any cut and dried analytical method for locating the phreatic surface in a dam, so must base his design almost entirely upon judgment. His judgment is based largely on experience with actual dams.

2. Research is seeking an analytical solution through model studies. Until this type solution can be found, model studies are the most dependable scientific approach. Any model study technique is on probation with the designer until it can be shown that such a study checks observations on existing dams. The more data on existing dams available, the more readily can similarities between model and actual dam be recognized.

3. One of the important factors in stability of earth dams is saturation. Professor K. Terzaghi[1] has stated in effect that the factor of safety in many existing earth dams is closer to 1.00 than most engineers realize. Much study on percolation phenomena is needed. Much is being carried on, and it is the function of the research division to keep abreast of developments and to acquaint the designing section with them as fast as they make their appearance. The most neglected phase of the subject is that which deals with data on existing structures. Studies of saturation made on Bureau dams already built would aid materially in design of future structures. As canal embankments are in the same category as earth dams as regards seepage, a double purpose will be fulfilled by getting the seepage problem well in hand. Technical Memo. 389 presented data on 30 dams. Included in this supplement are 15 more, among them Belle Fourche which because it is of particular interest, has been presented in rather more complete form.

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1 Die Prüfung von Baumaterialien für Gewaltze Erddämme "in" 1 er Congres des Grands Barrages " Stockholm, 1933, pp. 89-101. -08.

CAUTION

This supplement is essentially a collection of basic data. While its scope cannot include a discussion of theory, it is necessary to emphasize the point that the picture of percolation is not complete with the drawing in of the line joining water surface in wells placed in the dam. Such a line is neither the true phreatic line nor the saturation line. Flow in the capillary zone generally could not be studied for want of the necessary data. For the present this line is a close enough approximation for most purposes, but analogies must be drawn with care.

Appended to this supplement are two memoranda by D. P. Barnes, Assistant Engineer, which should render intelligible some terms frequently used in connection with percolation phenomena. The first, "Ground Water Classifications", states what is meant by the terms "phreatic" and "saturation"; the second, "A Universal Permeability Classification", defines and illustrates the "coefficient of permeability, K."

BELLE FOURCHE DAM
SOUTH DAKOTA

U. S. BUREAU OF RECLAMATION
TECHNICAL DATA FILE

DESCRIPTION OF DAM AND HISTORY

A. GENERAL:

Belle Fourche Dam was begun in 1906 and completed in 1911. At the time it was built it was one of the largest dams in the world. The nature of the borrow pit material and adverse weather conditions were troublesome factors during its construction. Since 1906 it has become apparent that the adobe mud of which the dam is constructed is less stable than it is watertight. Some minor slips of the upstream face have occurred and waves have damaged the paving. In 1931 the extreme drouth necessitated large and rapid drawdown of the reservoir. The waterlogged upstream face proved unstable under these severe conditions and a section of the face sloughed in. The disturbed material was removed, a sand-adobe mix was rolled into place, the pavement was replaced, and no slides have occurred since. Quotations which follow are from Belle Fourche Project History on file in the Denver office.

B. MATERIAL UNDERLYING DAM:

"The materials on the damsite were thoroughly prospected and were found to consist of a very heavy adobe clay overlying a slatey shale. The transition from clay to shale is gradual, and, as revealed by an artesian well boring just below damsite, the shale does not become a hard rock until a depth of several hundred feet is reached. The overlying shale follows closely the surface contours at a depth of from 20 to 40 feet as shown on the profile; and aside from occasional gravel pockets beneath the creek bed the earth is a hard, compact, impervious clay, weighing from 105 to 110 lbs. per cubic foot in place when sufficiently dry to be friable. Next to solid rock a material better adapted to resist the passage of water could hardly be imagined; it is expected that seepage will be inappreciable."

C. MATERIAL FOR DAM EMBANKMENTS:

"The character of the soil upon all of the area of the damsite is similar to that just described, with the exception that on the ridges at each end of the dam it is somewhat denser than on the flats, while on the high ground to the south there are found in the soil soluble salts of lime and magnesia to an extent making this material undesirable for use in the embankment. . . . When the embankment material is exposed to standing water it swells slightly and becomes very slippery.". . . . It is indicated by small scale experiments that about 7% of the water by weight is ordinarily required in compacting; and that very thorough ramming or rolling is necessary to break up the small, hard lumps in the soil as excavated. In order to insure a homogeneous mass the specifications require that the embankment shall be thoroughly rolled in 6-inch layers with steam rollers weighing not less than 200 lbs. per linear inch of roller rim."

Tests on this adobe material made by the Bureau of Reclamation soils laboratory indicate an impervious clay of dry density in place (from a large hard chunk sent in from the interior of the dam) approximately 118 lbs. per cubic foot. Dry density when broken up and repacked in the standard compaction cylinder, becomes lbs. per cubic foot at % moisture. Because the material has the property of shrinking as it dries, it is impossible to place it in embankment at maximum dry density. When an air dry chunk of this material was tested for approximate percolation rate over a period of nine months under no vertical load it was found that K is of the order of 0.2 ft. per year; this was accompanied by a swelling of about 40%.

D. CONSTRUCTION:

The entire area underlying the dam embankment was stripped and plowed and all pockets of mud or silt as well as the material in the present creek channel were removed. The center cut-off trench was then dug to a depth of 5 feet. Embankment was rolled in 6-inch layers having a transverse slope of 3% draining toward the reservoir and being subjected to watering and rolling to secure maximum density. Work was discontinued when either embankment or borrow pit materials were frozen or were too wet to permit of satisfactory consolidation. Photograph shows the material in its natural state and enroute to the embankment. Sprinkling was done with a 2" hose and rolling with a 2?-ton traction engine and a 13-ton smooth roller.

The Owl Creek Gap was filled and rolled after the rest of the dam was completed. Some floods passed through this gap during construction. "The first 100 feet at the upper end was filled and rolled as rapidly as possible. Three cut-off trenches excavated across the Owl Creek Channel were filled with selected material to act as cut-off collars. The center cut-off was moved downstream enough to protect the piers of the bridge" (across the gap). "On the 3th of the month (August) dumping dirt from the bridge began" and this was continued through September "as fast as same could be cared for. At the close of the month the entire gap was brought up to elevation 2020 and was now considered out of danger from a small flood. Water was encountered in the old channel of Owl Creek, so it was decided by the consulting board to place drains in the downstream portion of the dam in the gap. In October, the embankment in the gap was brought to elevation 2051, the bridge removed, and the railroad track was laid on earth across the gap."

The upstream slope was trimmed of loose material and concrete paving blocks were laid with open joints and embedded on a filter of 12 inches of screened gravel laid on 12 inches of natural gravel. Drains are provided on the downstream berms with connecting gutters to lead rainfall to the toe of the slope.

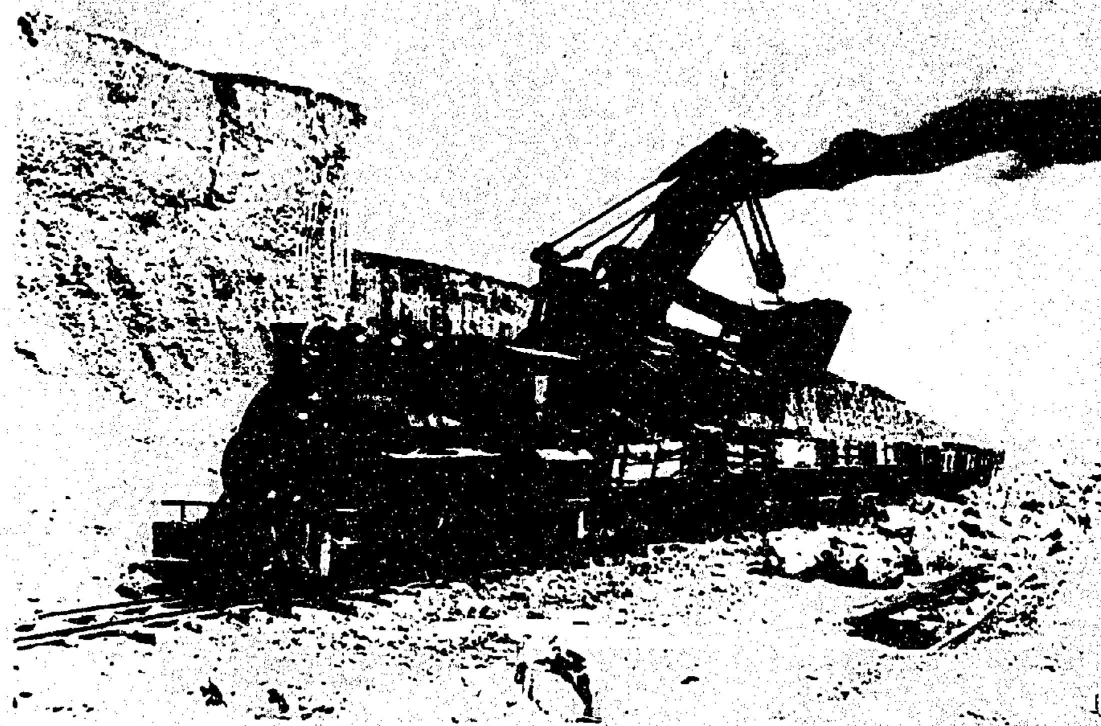
The two irrigation canals are served through concrete conduits built beneath the dam embankment in trenches cut in the natural ground, the flow being regulated by sluice gates operating through gate chamber wells constructed near the center of the cross section.

E. SEEPAGE:

"During the summer of 1910 seepage water began to show on the surface of the ground below the dam, water having been in the reservoir to elevation 2930, and during the latter part of the summer stood at 2920, the ground surface below being about 2910. Borings were made which showed that a stratum of disintegrated shale and gravel about 10 feet from the surface was water bearing and the water was percolating through from the reservoir side. They also showed that while the long records on the center line of the dam from station 26 to 41 would indicate that the shale overlaid with about 3 feet of sand and gravel was from 30 to 40 feet below the surface, the facts of the case were that from station 26 to 36 this was true, but that from station 36 to 40 the shale was in reality 6 to 8 feet from the surface and a layer of sand and gravel 2 or 3 feet thick lay on top of the shale. The drainage trench indicated on plate 53 was constructed during November and December, 1910.

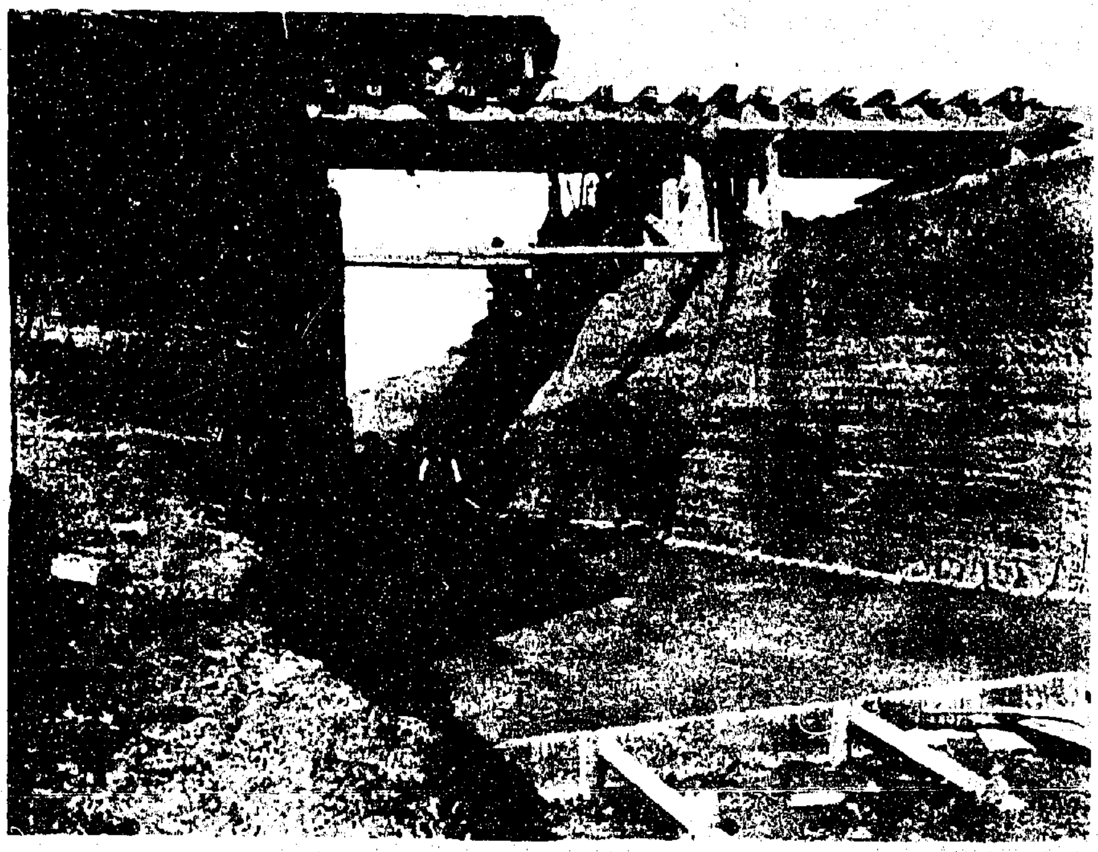
"In the latter part of the year 1911 a series of wells was drilled in the embankment between stations 36 and 39 for the purpose of determining the plane of saturation and obtaining data on its movements. A wash-boring apparatus was used in sinking the wells through the completed embankment, after which they were cased with 2" w.i. pipe, open at the bottom but not perforated. A plug in the upper end excludes surface water, rain, etc. In all, 34 wells were sunk in this section, ranging in depth from 10 to 90 feet. Their location and depths are shown on the drawing." The water surface readings were accurate to about 0.1 ft.

Records on these original wells are continuous from 1912 to 1923. From 1924 to 1928 records were kept on "Saturation wells" and "Uplift wells"; the former were wells driven into the embankment only and the latter extended clear through the embankment and into the foundation material. From 1931 to 1933 the "saturation" wells were read again. All data from these wells have been tabulated and in the case of certain significant wells the logs are plotted here. A table on plate 54 shows the correlation in plan between the two sets of wells referred to above.



BELLE FOURCHE DAM; NORTH SIDE STEAM SHOVEL PIT. DETAILED VIEW OF STEAM SHOVEL LOADING CARS. W.J.L. MAY 15, 1909

OWL CREEK GAP, SHOWING GRAVEL TRAIN CROSSING HIGH BRIDGE.
VIEW ALSO SHOWING HIGHEST POINT OF DAM WHEN FINISHED. W.J.L. MAY 15, 1909



LAYING THE FLOOR FOR THE NORTH CONDUIT. W.W.P. 1907

OWL CREEK COMING THROUGH GAP IN BELLE FOURCHE DAM

S.C.B. MAY 26, 1907

REMARKS BY THE WRITER

GENERAL:

The data on Belle Fourche Dam have been collected over a period of 24 years. That which is presented here is an abridgment of what was available in Project History and the files of the research division. Tabulations from which the logs were plotted and much other detailed information regarding settlement, cracks, slides, windstorms, climate, etc., are on file; only general statements regarding those items will be made here.

The principal feature of the data is the long record on the observation wells which were installed just after the dam was completed. Such wells placed in an embankment do not disclose the extent of capillary saturation; they merely aid in locating the phreatic surface. Where capillary action is of slight importance, the phreatic surface is in general accurate enough for most purposes; but in the case of the Belle Fourche clay it seems likely that the ultimate height of capillary rise is very great even though the velocity of flow might be very low. For this reason, the accuracy of graphical representation of the well logs was deemed sufficient. Further, no attempt has been made in any case to correct the indicated phreatic line for capillary saturation. A study by core sampling for moisture content is proposed for this dam and the information thus obtained will clear up the problem.

That the observations on the wells are inadequate to fully describe the conditions of saturation is further evidenced by the following:

1. Model studies on sand dams have indicated that a considerable proportion of the total seepage flow is traceable to the capillary fringe above the phreatic line.
2. Axial flow is no doubt present, due to the irregular shape of the original ground surface, as seen in the longitudinal profile.
3. From the fact that levels in wells immediately adjacent are not consistent with theory of uniform laminar flow, it is suspected that flow is occurring through fissures and permeable layers within the dam.
4. Underseepage through gravel deposits not blocked off by the core trench has been noted in the region of Owl Creek channel. Water levels in the toe wells between stations [illegible] and 21 are also high. All the zones of underseepage have probably not been located. The tile drainage system serves only one-third the length of the dam.
5. Volumetric adjustment in the piezometer is present in all problems in which the phreatic line in a dam is located from observation of the free water surface in a piezometer. The lag

correction for its presence is a function of the diameter of the well, the permeability K of the material into which the well is driven, the amount and frequency of the reservoir fluctuations, the boundary conditions within the dam which dictate the pattern of flow in the dam outside the pipe, temperature, barometric pressure, and possibly a few other items. In general, very few of these are known quantities - certainly too few to accurately evaluate the correction. In a very pervious dam with relatively small diameter pipe, the lag correction is for all practical purposes negligible. In the case of Belle Fourche dam where the pipes are large, the material tight, the reservoir fluctuations great and frequent, the boundary conditions extremely hazy, and temperature, barometric pressure, etc., known only approximately, the piezometer becomes practically useless as a perpetual accurate indicator of the phreatic surface. It might take weeks, or even months, for enough water to flow into or out of a pipe to accurately portray conditions after the reservoir had risen or fallen ten feet. Meantime, the reservoir may have raised or fallen 20 feet.

In certain instances behavior of well levels bears no relationship to reservoir stage. The case of wells S-5 and P-6 during 1924-26 is illustrative. Here the wells both start from elevation 62 on September 10, 1924, and descend to equilibrium in 1.75 years unaffected meanwhile by the rise and fall of the reservoir. The equilibrium elevation for each is different because the potentials tapped by the two pipes are not the same.

In passing it is evident that V = KS is applicable but that lack of knowledge of just how to obtain S is a barrier to solution for K. The principal use of these curves is to give some idea of how long it may take a well in a tight bank to regain equilibrium after it has been badly knocked out of balance by being filled from the top.

PHREATIC LINES AND UNDERFLOW GRADIENTS:

While the presence and importance of the above mentioned capillary flow, axial flow, fissure flow, underflow, and volumetric adjustment are recognized, it does not follow that the 24 years of well records are worthless. A rough idea of conditions can be obtained at least at one cross-section. Plotted on Plate 54 are phreatic lines showing progress with time of the water percolating through the dam body and artesian gradients indicating flow under the dam. Only the great length of time covered by the records makes such an approximation valuable. Because the well levels change so slowly, it obviously is not possible to refer any well level to its corresponding reservoir level. Conditions on a given date are pictured. Because it cannot be known accurately from the well levels available just where the phreatic line lies at any time, that portion of the line upstream from the

F row of wells especially is almost entirely conjecture.

The effect of the paved and drained upstream facing on position of the phreatic surface is probably insignificant; the earth material is too watertight by comparison. By the same criterion, flow out of the bank when the reservoir is lowered is probably not appreciably accelerated by the presence of the drainage material.

SEEPAGE QUANTITY:

Fluctuations in seepage discharge (Plate 55) tend in general to follow reservoir fluctuations during the youth of the dam, but later on the fluctuations are ironed out and seepage approaches a constant lower value. That the synchronism at times is not marked may be due in some instances to local and temporal conditions, for instance temperature changes or hard continued rain. 22 g.p.m. at the drain is a minimum, and even the maximum of 28 g.p.m. is a negligible quantity. Seepage through the other two-thirds of the dam not served by the 12-inch tile drain is not known. It seems likely that a large portion of the measured discharge is underflow and not flow through the dam body.

SETTLEMENT:

Measurements on benchmarks kept over a period of 14 years indicate that settlement has been roughly proportional to the height of the fill, the maximum being about 2 feet at station 38.

CRACKS:

In 1928 several hundred feet of cracks running parallel to the axis appeared just back of the crest of the dam (Plate 53). Exploration shafts were sunk and it was found that the cracks were a maximum of 3 inches wide at the top and extended into the dam to a maximum depth of 12 feet. Because of prolonged low water in the reservoir the top portion of the dam had become very dry, and indeed the shaft was dry to the depth noted. The cracks were believed due to shrinkage of the drying clay. That cracks occurred where the height of fill is greatest lends credence to the view that they were caused by the mass acting as a whole and not by some surface phenomenon. Because the material swells when it becomes wet, the belief that cracking may be due to this cause instead of shrinkage is not without foundation.

WAVES:

Because the long axis of the reservoir is parallel to the direction of prevailing winds, high waves frequently batter the dam and damage the paving; occasionally the wind approaches 60 m.p.h. Spray helps to keep the dam moist but the waves occasionally fill the F row of pipes.

RAIN:

The maximum 24-hour rain for each month forms part of the record on plate 55. On several occasions it is possible to ascribe extraordinary behavior of well levels to hard rains. The well rises suddenly and then drains slowly. Rain water may affect a well in more than one way. Direct precipitation into the well probably would not raise it more than an inch or so, but surface water flowing into the well, or formation of a so-called "capillary ring" [1] within the dam may raise the well level several feet.

SLIDE OF 1931:

The slide of 1931 was studied in some detail. From consideration of the impermeability of the material and the reservoir hydrograph it was determined that the total height of drawdown is of more significance from the standpoint of stability than the rate of drawmdown. The upstream slope (2:1) is evidently a little too steep to be stable under severe conditions of drawdown. The profile of the slide surface at station 43 is indicated on plate 54.

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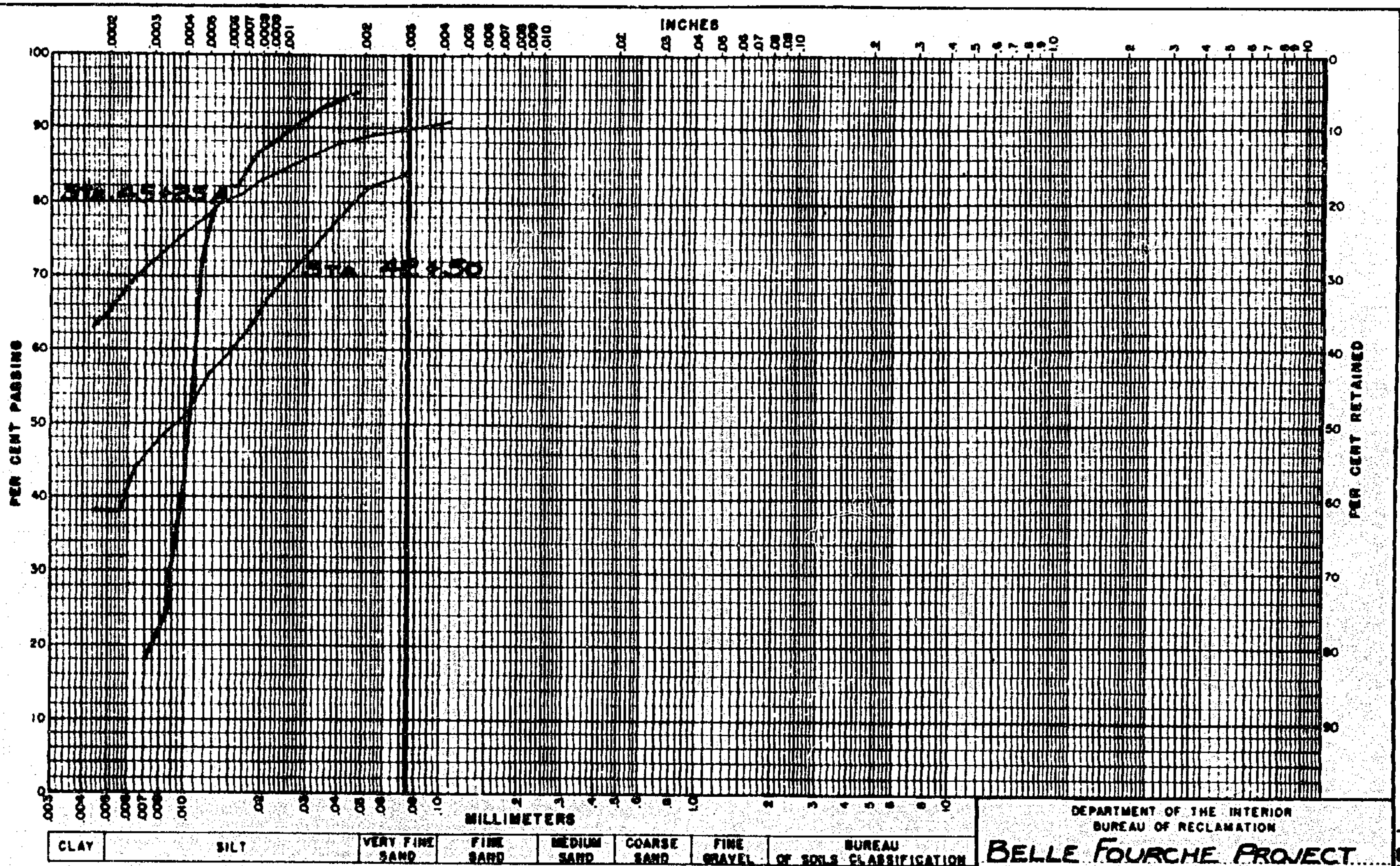
1 International Commission on Large Dams, Stockholm, Sweden, 1933. Report Vol. IV p. 100 Discussion by Professor J. H. Thal Larssen and Dr. J. H. Engelhardt.

PLATE 52



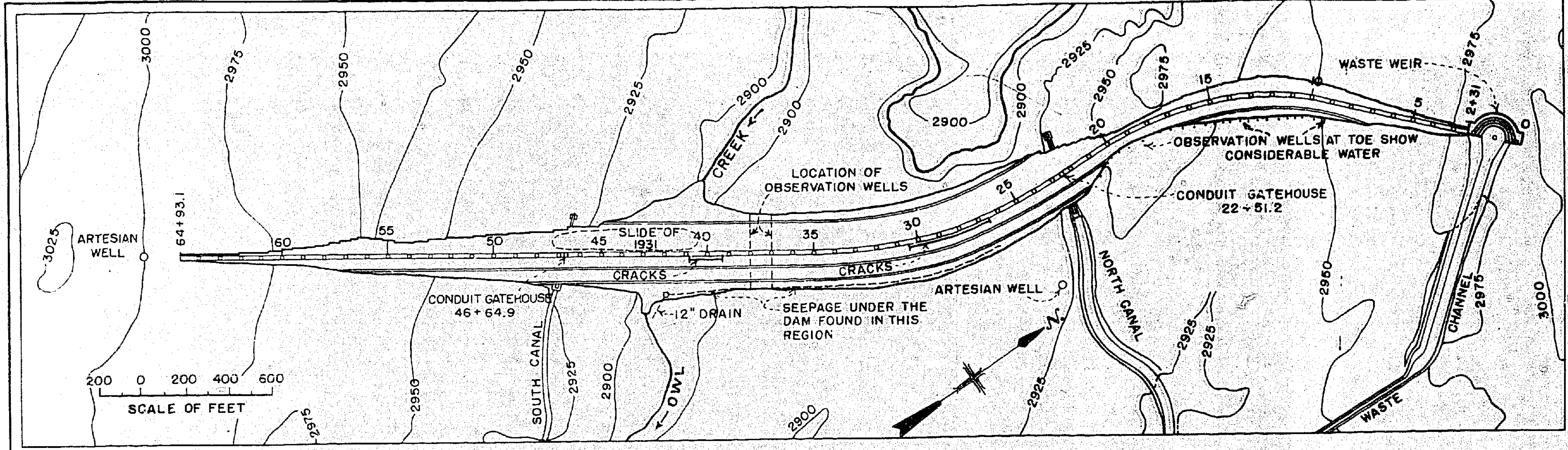
REMARKS This material is classified as adobe clay or gumbo soil, and while very watertight is unstable when saturated with water. Because the material flocculated in the hydrometer cylinder these curves are only approximate.

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

BELLE FOURCHE PROJECT
BELLE FOURCHE DAM
HYDROMETER ANALYSIS OF MATERIAL IN THE DAM

DRAWN R.C.H. CHECKED DATE 1935

X-D-1616



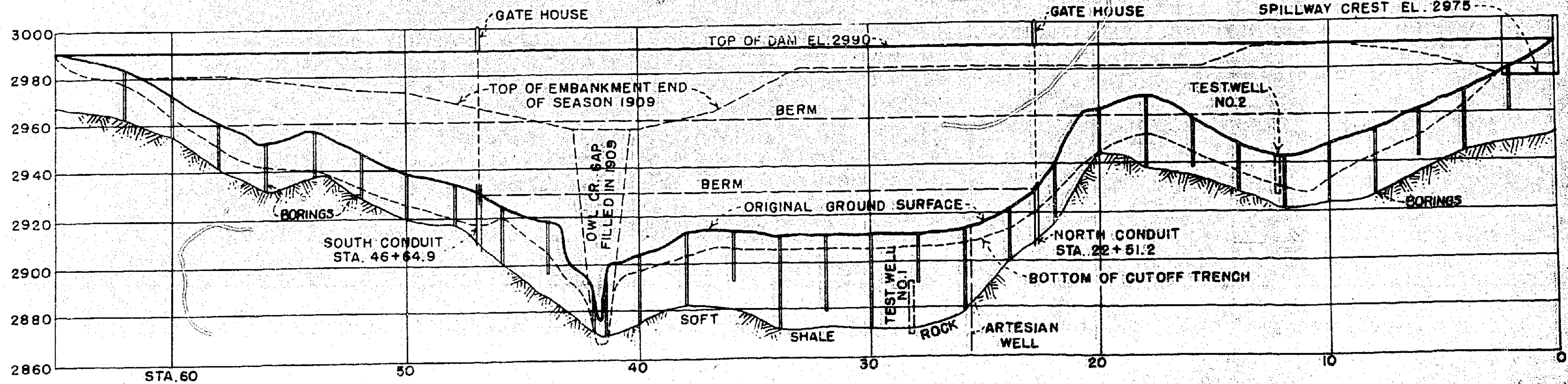
BELLE FOURCHE DAM

GENERAL PLAN

REFERENCES

(1) GENERAL LAYOUT (1926 PROJECT HISTORY)
(2) SHRINKAGE CRACKS (LETTER 11-6-28 YOUNGBLUTT TO CHIEF)
(3) OBSERVATION WELLS (PROJECT HISTORY)
(4) SLIDE AREA (DWG. 1-P-32 (b) JAN. 1932)
(5) UNDERSEEPAGE AREA (PROJECT HISTORY)

LONGITUDINAL PROFILE LOOKING UPSTREAM



LONGITUDINAL PROFILE

REFERENCES

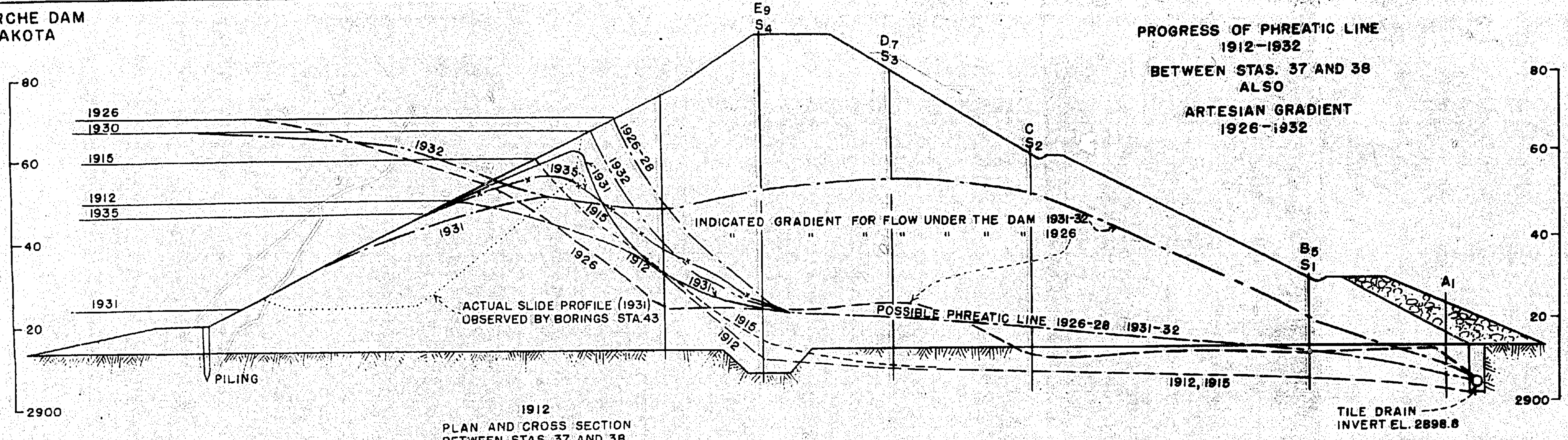
(1) GEOLOGICAL BORINGS (CONTRACT DWG. NO. 2)
(2) CUTOFF TRENCH (DWG. 1-P-27) MAY 1916
(3) PROGRESS OF FILL PROJECT HISTORY GENL. MAP DEC. 1909

BUREAU OF RECLAMATION
DENVER, COLO. 1935.

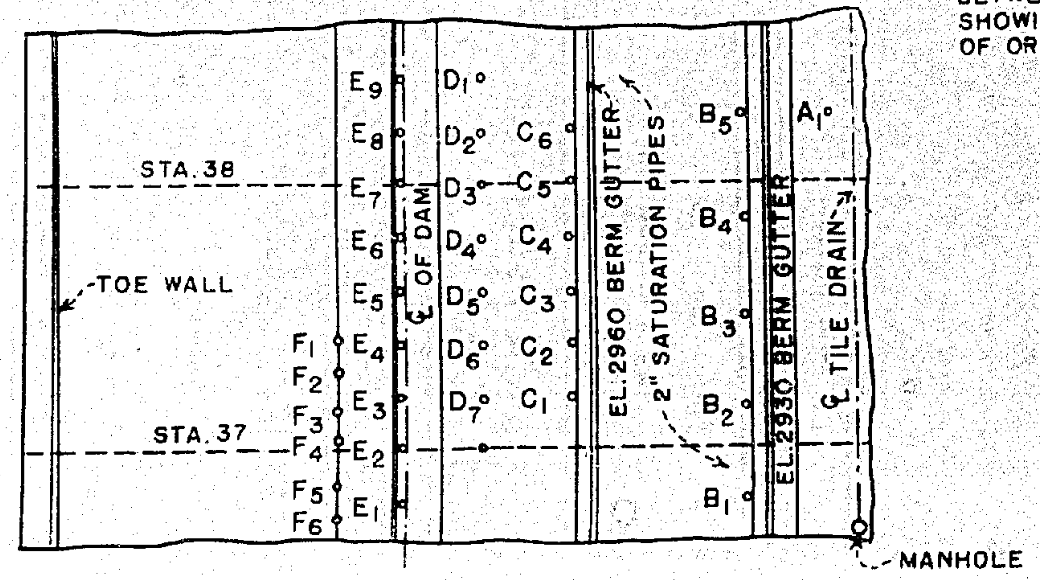
X-D-1617

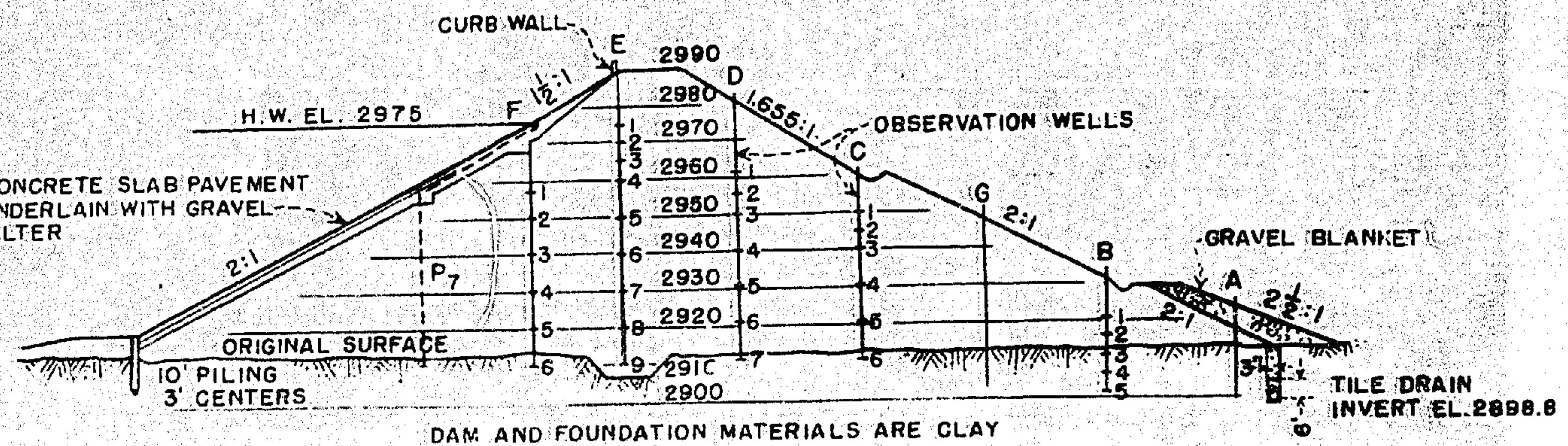
BELLE FOURCHE DAM
SOUTH DAKOTA

PROGRESS OF PHREATIC LINE 1912–1932 BETWEEN STAS. 37 AND 38 ALSO ARTESIAN GRADIENT 1926–1932



1912
PLAN AND CROSS SECTION
BETWEEN STAS. 37 AND 38
SHOWING LOCATION AND DEPTH
OF ORIGINAL OBSERVATION WELLS.





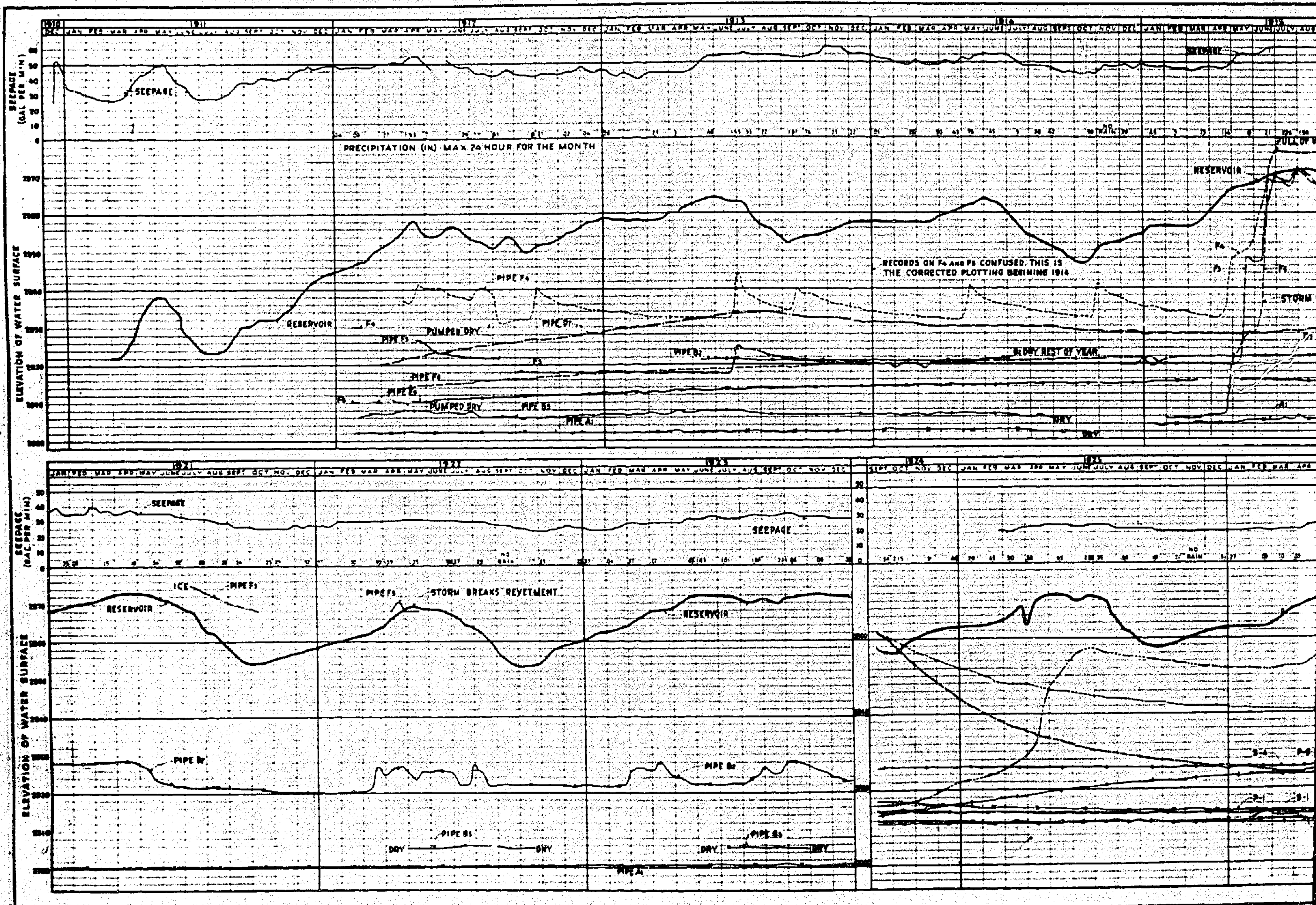
DAM AND FOUNDATION MATERIALS ARE CLAY

CORRELATION IN PLAN OF OBSERVATION PIPES

1911	1922	1924
		P7
F6	F6	P6
F4		S5
E7 OR 8		S4
D7 OR 8	D6 OR 7	P5
D5		S3
C5		S2
C6		P4
B2		S1
	G1	P3
B5	B5	P2
A1	A1	P1

BUREAU OF RECLAMAT
DENVER, COLO. 193

X-D-16



SEEPAGE (GAL PER MIN)
SEEPAGE
PRECIPITATION (IN) MAX 24 HOUR FOR THE MONTH
ELEVATION OF WATER SURFACE
RESERVOIR
PIPE F4
PIPE F5
PIPE B2
PIPE B3
PIPE A1
PUMPED DRY
DRY
B2 DRY REST OF YEAR
RECORDS ON F4 AND F5 CONFUSED. THIS IS THE CORRECTED PLOTTING BEGINNING 1914
ICE
STORM BREAKS REVETMENT
NO RAIN

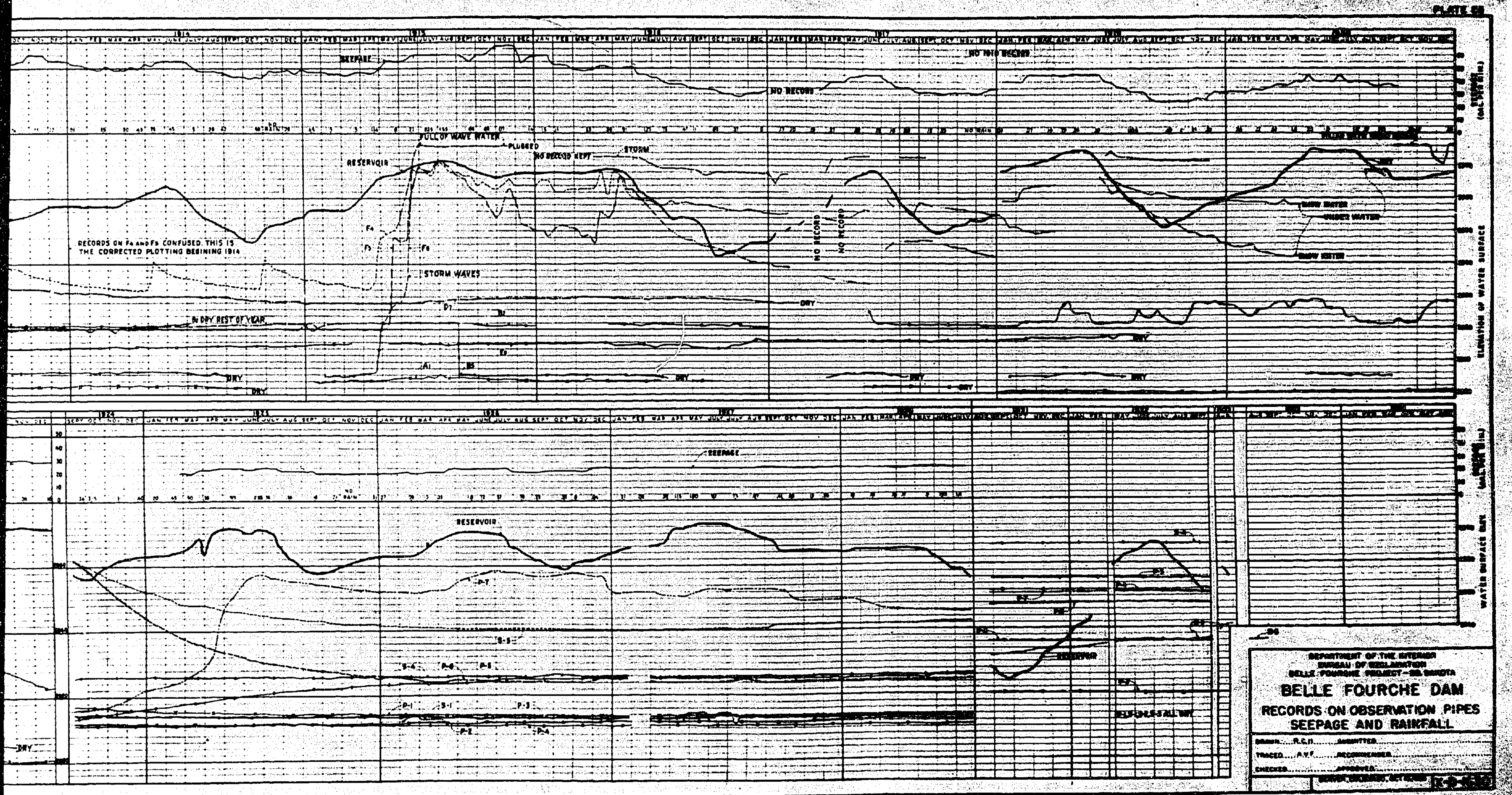


PLATE 68
1914
1915
1916
1917
SEEPAGE
NO RECORD
RESERVOIR
FULL OF WAVE WATER
PLUGGED
NO RECORD KEPT
STORM
RECORDS ON F4 AND F5 CONFUSED. THIS IS THE CORRECTED PLOTTING BEGINING 1914
STORM WAVES
DRY REST OF YEAR
DRY
NO RECORD
SNOW WATER
1924
1925
1926
1927
RESERVOIR
SEEPAGE
DRY
ELEVATION OF WATER SURFACE
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BELLE FOURCHE PROJECT—SO. DAKOTA
BELLE FOURCHE DAM
RECORDS ON OBSERVATION PIPES
SEEPAGE AND RAINFALL
DRAWN R.C.H. SUBMITTED
TRACED A.V.F. RECOMMENDED
CHECKED APPROVED

GENERAL REMARKS BY MR. HILL:

"These experiments on the saturation of tank embankments were originally ordered by Mr. Tate, Chief Engineer, Public Works Department, Bombay, when a project for a very high earthen embankment was under consideration. A series of years of drought occurred after the commencement of the experiments and the Deccan tanks did not fill and no good observations could be made. No year of really good rain, when all the tanks would fill, has occurred in the Deccan since the commencement of the experiments, but there have been years when some tanks have obtained good supplies and have filled. The data now printed are thus the results of a great deal of time and of many more of observations than indicated by the tables. The best series of observations are now printed, a selection being made of the tanks which had the best supply. No attempt has been made to select the observations; and returns, which are classed as "errors" by the Executive Engineers, have not been struck out from the lists. I have left them in, for two reasons, first because if they are really errors they indicate that the rest of the observations are reliable, and secondly, because none of the results are impossible and they may be due to some cause not understood. The general results, however, are uniform and afford good evidence of the conditions of saturation of the embankment.

2. The first important point to notice is that free water was observed in all the embankments. The levels given are those of actual water in the interior of the bank and are not merely the levels of wet earth.

At first holes were drilled into the embankments and the level to which the water rose in the holes observed. The natural side, however, fell in after a time. To meet this difficulty iron pipes were placed in holes drilled vertically into the embankments and the pipes were perforated at intervals along their length, so that water had means of access at about every foot length of the pipe as well as at the bottom.

There are one or two cases reported of pipes clogging and having to be cleared, but considering the results generally, it is remarkable how consistent they are and how closely the returns from banks of similar character agree.

3. The banks may be broadly divided into two classes:- I those made of clayey material throughout, and II those made with clayey material in the heart only, or in the heart and upstream portion and with good drainage material at the back or downstream portion. Comments are made on each tank separately, but Natoba, Pashan, Parsul, Mhaswad, Wadshivne, Ekruk, Nehr and Waghad are examples of class I and Mukli, Unkal of class II. The construction of the interior of Wadleri and Mayni is not exactly known but they are on well drained foundations and are more closely in

agreement with class II than class 1. The results show that a very much larger proportion of the banks in class 1 is saturated than in class II.

Matoba, Pashan, Parsul and Wadshivne are typical of the almost complete saturation of class 1 and Mukti and Unkal of class II show how free the rear portion of the dam is of water when constructed of drainage material.

4. The observations also show that the clayey material, whether in bank of class 1 or in the hearting of bank of class II, takes time to saturate and after saturation parts with the water slowly, the level of water in the saturated clay falling much more slowly than in the tank when water was drawn off for Irrigation.

5. On the diagrams the line of saturation for 1906 only has been plotted but a study of the other results in the tables and comparison with the diagrams giving the position of the pipes in the embankments will be repaid.

6. In my opinion, the results show very clearly that it is not safe to construct a high embankment entirely of clayey material and illustrate clearly how necessary it is to use good drainage material in the downstream part of the bank."

DESCRIPTION, HISTORY AND OBSERVATIONS BY MR. HILL:

"The dam is constructed of uniform clayey material with a thin moorum skin only. It is filled annually from the Mutha Canal and is annually emptied for irrigation. In 1906, the highest level was reached on 29th September. The water level in pipe No. 5 on the upstream side rose gradually as the tank was filled and reached its maximum for the season on the same date approximately as the highest level in the tank. In pipe No. 4, on the downstream slope, however, the maximum level did not occur until October 27th or about 35 days after date of the F.S.L. in tank. Similarly, in 1907, the F. S. level in the tank was first reached on 17th August, the highest level in the pipe on the water slope, on 31st August or 14 days later, and in pipe 4 on the downstream slope on 19th October or 62 days later. The highest levels in the remaining pipes on the downstream side were also reached on 19th October. Hence it appears to have taken 62 days to reach the slope of maximum saturation in this bank. The full supply level remained nearly steady during the period. Pipe No. 1 is at the toe of the downstream slope, the top level is 60·13 and in 1906 the water level in this pipe for August to March was over 58 so that there was less than 2 feet of dry material. A slight slip at the toe occurred once at Matoba Tank. The tank is a good instance of a bank made mostly of clayey material on a good foundation impervious to water."

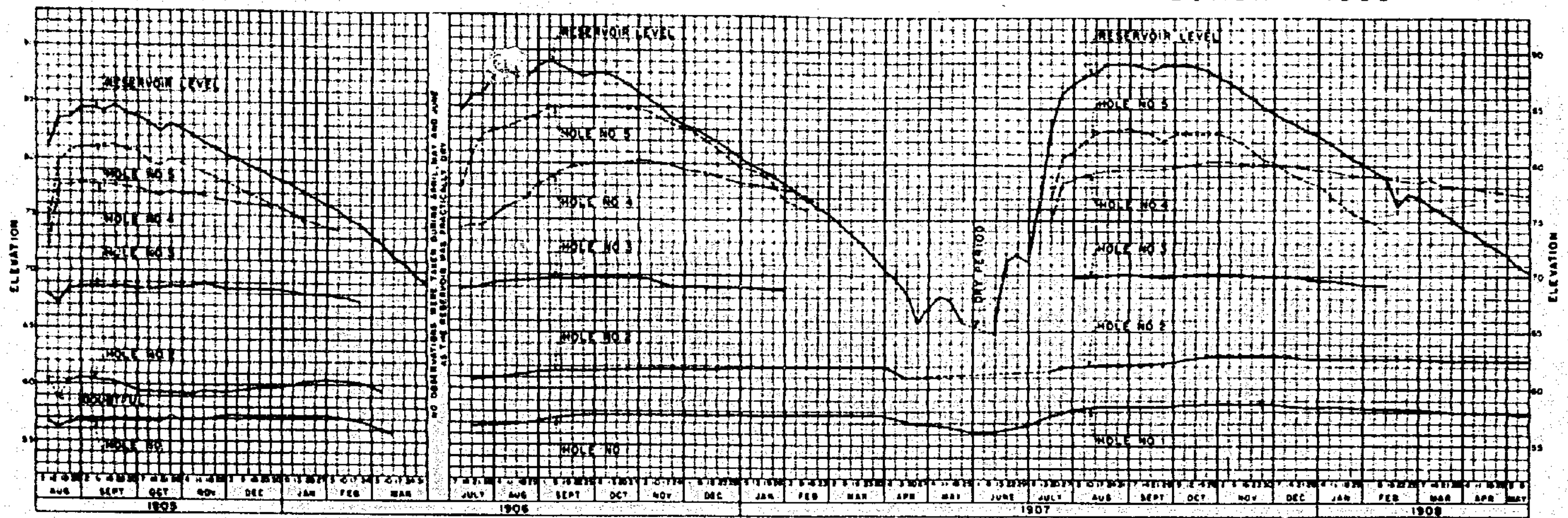
REMARKS:

The almost cyclic replenishment and drawdown of the reservoir here indicated present an excellent opportunity to study rise and fall of the phreatic line. That the effect of the first cycle on pipes 1, 2, 3, and 4 is carried over into the second and third cycles is evident from the graph. In September 1906 and October 1907 equilibrium conditions for full reservoir are probably very closely approached.

It is significant that elevation 58.8 for the water surface in pipe No. 1 is above the surface of the dam at that point. This piezometric height gives an idea of the pressure required there to force water up through the fill.

MATOBA TANK DAM
INDIA

PUBLIC WORKS DEPARTMENT
BOMBAY 1909

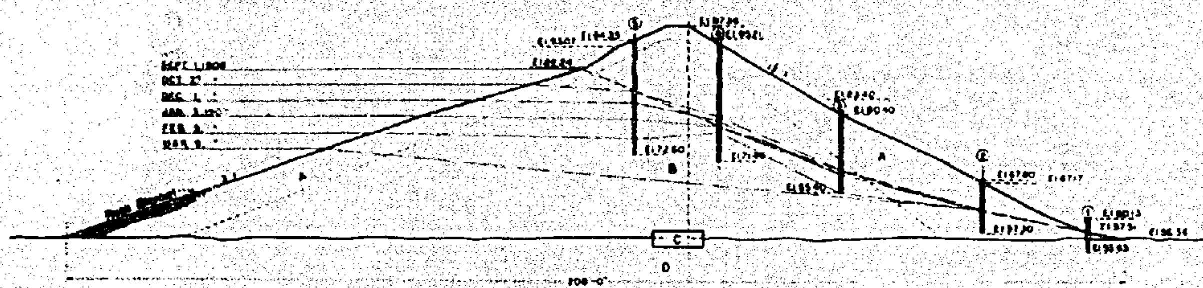


RECORD OF WATER LEVELS IN RESERVOIR AND PIPES

SUPPLEMENTARY DATA

HIGHEST AND LOWEST WATER LEVELS IN PIPES
FOR YEAR 1913

	HIGHEST LEVEL	DATE	LOWEST LEVEL	DATE	REMAINED DRY FROM	REMAINED DRY TO
RESERVOIR	[illegible]	JULY 31	[illegible]	MAR 27	MAR 27	JUNE 24
PIPE NO 1	57.88	OCT 30	55.23	JUNE 26	"	"
" " 2	65.26	JULY 17	62.10	MAR 27	"	JULY 17
" " 3	70.05	OCT 23	67.93	MAR 27	"	SEPT 4
" " 5	86.85	OCT 30	83.35	JULY 10	JAN 1	JULY 8
					DEC 11	DEC 31



EXPLANATION
A Earth and Murum
B Selected Earth
C Puddle
D Good impervious Foundation

CROSS SECTION OF MATOBA TANK DAM
(SHOWING POSITION OF PIPES AND DECLINE OF PHREATIC LINE WITH FALLING RESERVOIR)

BUREAU OF RECLAMATION
DENVER, COLO., 1935

PLATE 89

X-D-1619

PASHAN TANK

COMMENTS BY MR. HILL (1908):

"This is a tank with an uncertain supply but which always gets some replenishment. The embankment has a puddle wall in the centre and is made mostly of clayey material. A very noticeable feature in the results for this tank is that in the pipe, on the water slope, the level did not fall so rapidly as the water in the tank. At maximum level, on 29th September 1906, the levels in the tank and in the pipe were almost the same, but on 20th July 1907 or ten months later, whilst the water in the tank had fallen 12 feet, the water in the pipe had fallen 4-1/4 feet only and was actually 8 feet higher than the water in the tank. In pipe No. 4 on the downstream slope but well in the body of the dam, the variation of water level was small, 2 feet only against the 12 feet in the tank. In both 1906 and 1907, the maximum saturation seems to have been very quickly reached: in 1906, the full supply was first reached on September 15th and maximum saturation attained on September 22; in 1907, full supply occurred on August 17th and the bank seems to have been at once saturated.

I suggest that the quick saturation is due to the retentive nature of the material of the greater portion of the bank.

A slip occurred in the downstream toe of the bank and it was strengthened."

REMARKS BY THE WRITER:

Pipes No. 1 and 2 are sensitive to reservoir fluctuations. There is very likely some under-seepage.

Pipes No. 3 and 4 fluctuate very slowly. The retentive nature of the clay spoken of by Mr. Hill is thus made evident.

PARSUL TANK

COMMENTS BY MR. HILL:

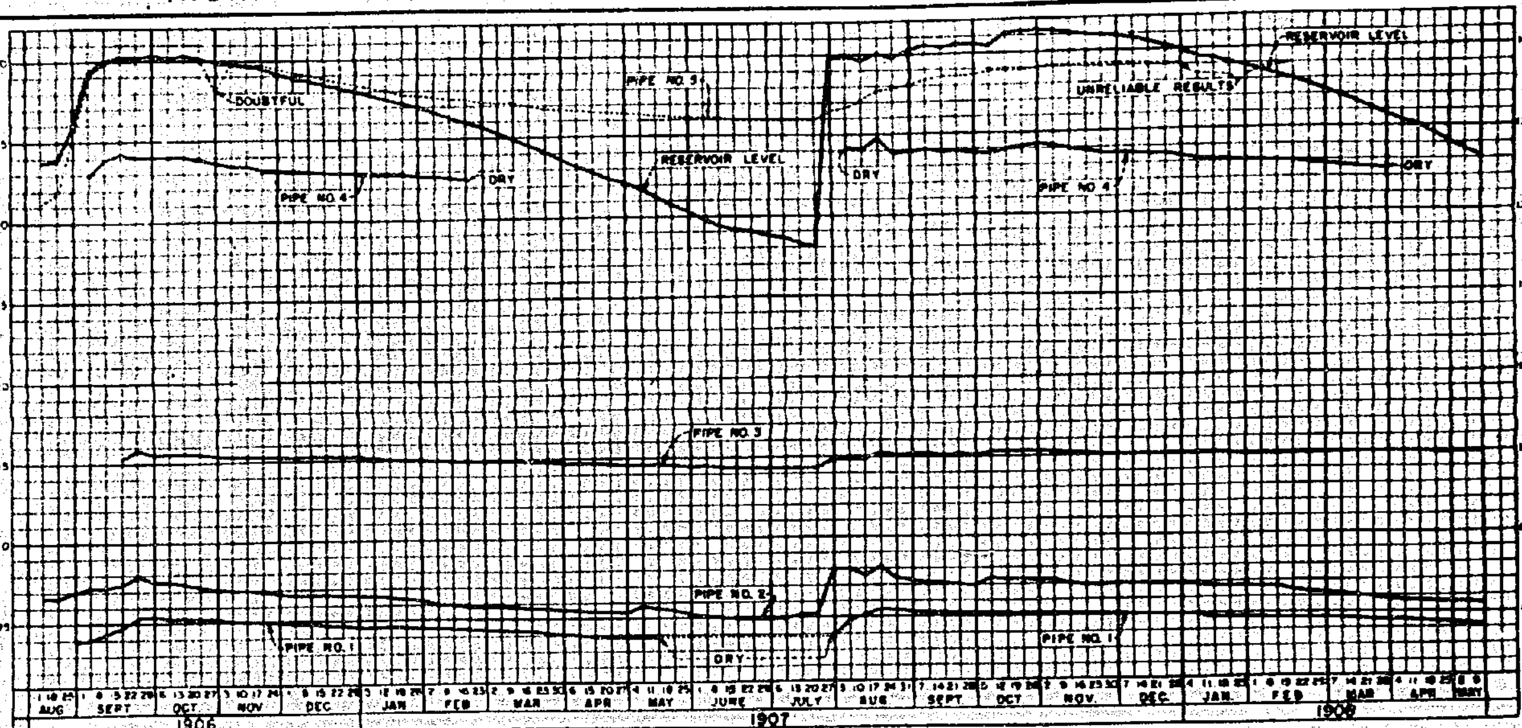
"This embankment is made of a khaki coloured clay locally called "man", a good retentive clay; on the downstream slope, the clay is 1½ to 1 and then moorum is used to make up the slope to 2 to 1. Dry stone drainage is provided at the base of the bank downstream. The downstream pipes seem to have reached the dry stone drains and do not show any water levels and apparently the drainage is complete.

The levels of water pipes Nos. 1, 2, and 3 in the clayey mass of the dam indicate that almost the whole of the clay is saturated. Some difficulty appears to have been experienced in keeping pipe No. 3 clear, but the observations in September and October 1906 are a good series and water was found in pipe No. 3 at a level which indicated that the whole of the earth was saturated.

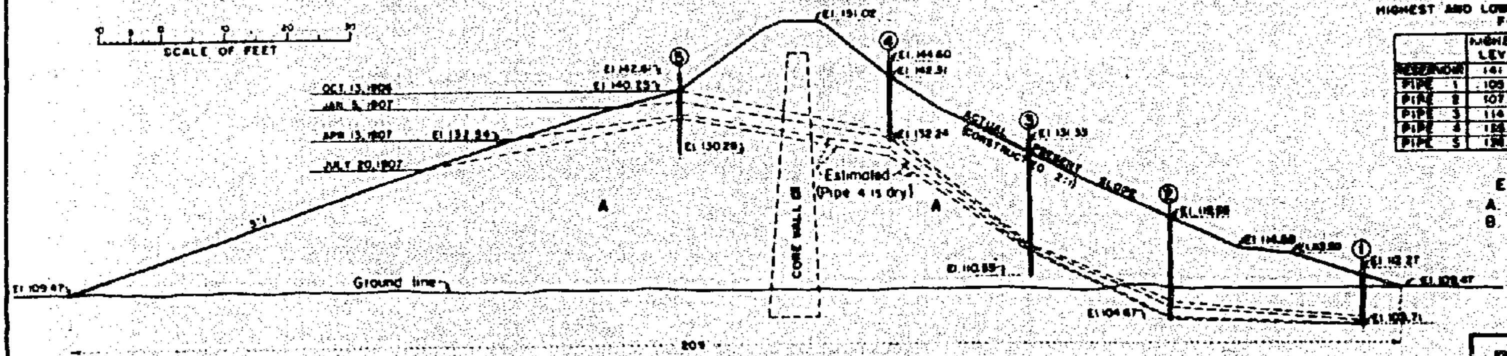
1907 was a year of weak rainfall and the level in the tank did not remain high so long as in 1906 and the bank was not so completely saturated."

PASHAN TANK DAM
INDIA

PUBLIC WORKS DEPARTMENT
BOMBAY 1909



RECORD OF WATER LEVELS IN RESERVOIR AND PIPES



CROSS SECTION OF PASHAN TANK DAM
(SHOWING POSITION OF PIPES AND DECLINE OF PHREATIC LINE WITH LOWERING RESERVOIR

SUPPLEMENTARY DATA
HIGHEST AND LOWEST WATER LEVELS IN PIPES FOR YEAR 1916

	HIGHEST LEVEL	DATE	LOWEST LEVEL	DATE
RESERVOIR	141.77	OCT [illegible]	[illegible]	[illegible]
PIPE 1	105.71	NOV [illegible]	[illegible]	[illegible]
PIPE 2	107.81	AUG. 21	104.76	[illegible]
PIPE 3	114.34	JAN [illegible]	[illegible]	[illegible]
PIPE 4	[illegible]	NOV [illegible]	[illegible]	[illegible]
PIPE 5	[illegible]	OCT 30	[illegible]	[illegible]

EXPLANATION
A. Clayey Material
B. Core Wall

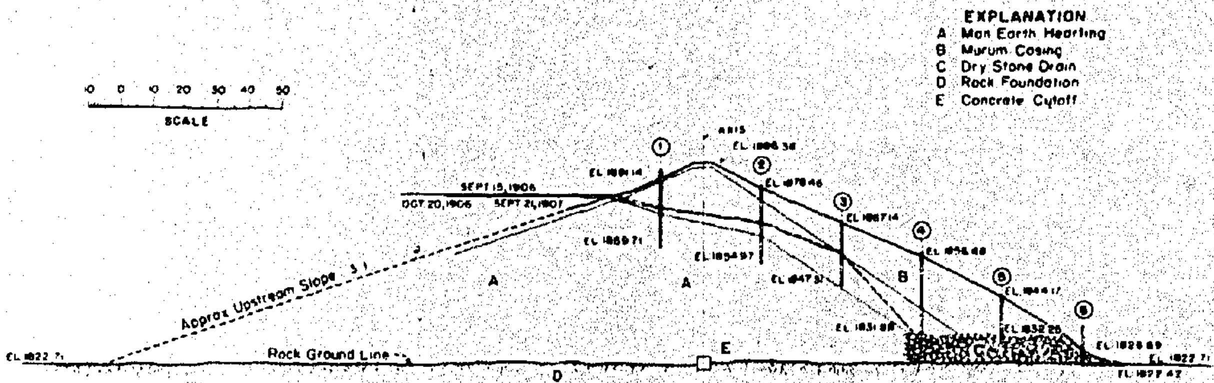
BUREAU OF RECLAMATION
DENVER, COLO., 1935

PLATE 67

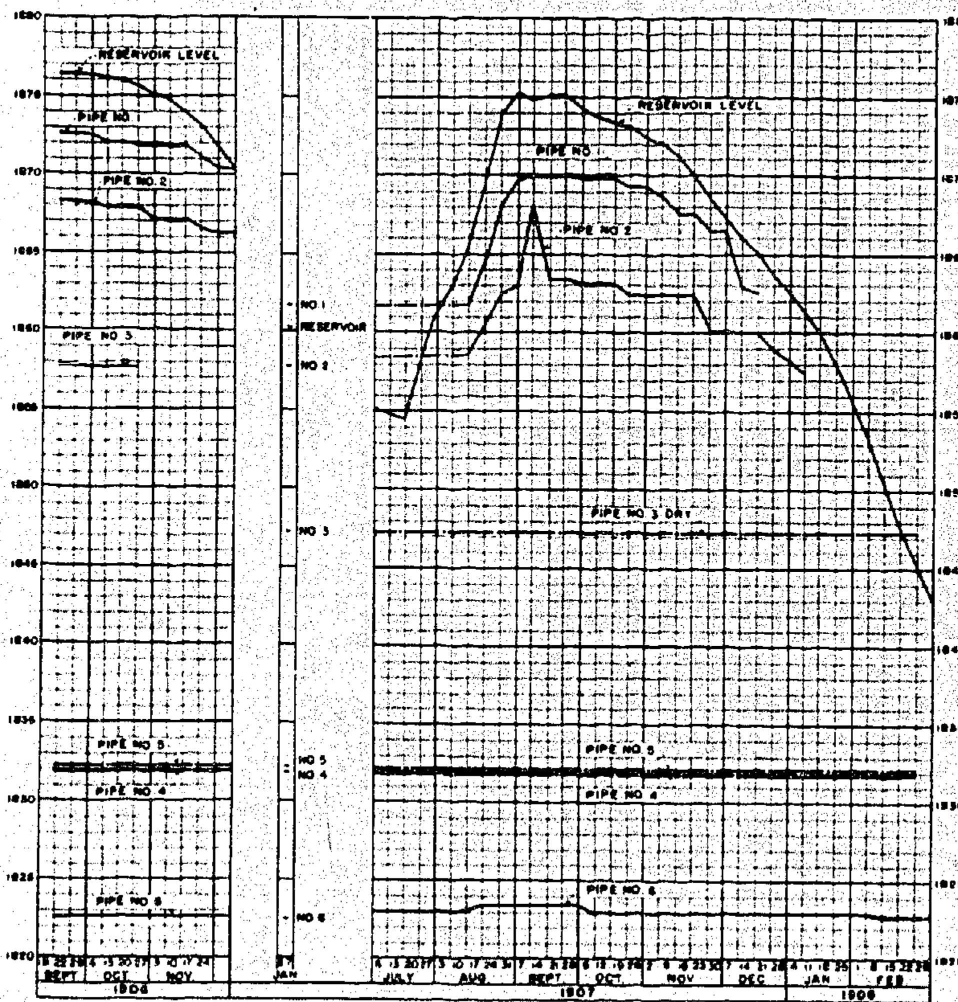
X-D-1850

PARSUL TANK DAM
INDIA

PUBLIC WORKS DEPARTMENT
BOMBAY 1909



CROSS SECTION OF PARSUL TANK DAM
(SHOWING POSITION OF PIPES FOR OBSERVING LINE OF SATURATION)



RECORD OF WATER LEVELS IN RESERVOIR AND PIPES

BUREAU OF RECLAMATION
DENVER, COLO., 1935.

X-D-1621

WADSHIVNE TANK

COMMENTS BY MR. HILL:

"This is a new tank completed in 1903-1904 and constructed entirely of clayey materials being 1 of black soil to 2 of moorum in the centre and 1 to 1 of the same materials; on the outer portion a berm is also provided.

The records of water levels in the pipes seem to indicate that the embankment has not yet been thoroughly saturated, as the levels in all the pipes slowly increased throughout the year. Very little water was drawn off during the 8 months of observations, the level in the tank falling 3 feet only, as the distributing channel was not completed and there was no issue of water from the tank.

The diagram indicates that the greater part of the material is saturated."

REMARKS BY THE WRITER:

From the standpoint of lowering the phreatic line it appears that draining the toe within the "C" portion would have accomplished the purpose more easily than adding the berm.

EKRUK TANK

COMMENTS BY MR. HILL:

"This is a large tank and high embankment but unfortunately the tank did not fill during the period of observation.

The embankment is believed to be of uniform construction of clayey material.

The pipes are all on the outer slope of the bank.

The levels in pipe No. 1 show that the water in the bank falls more slowly than the water in the tank."

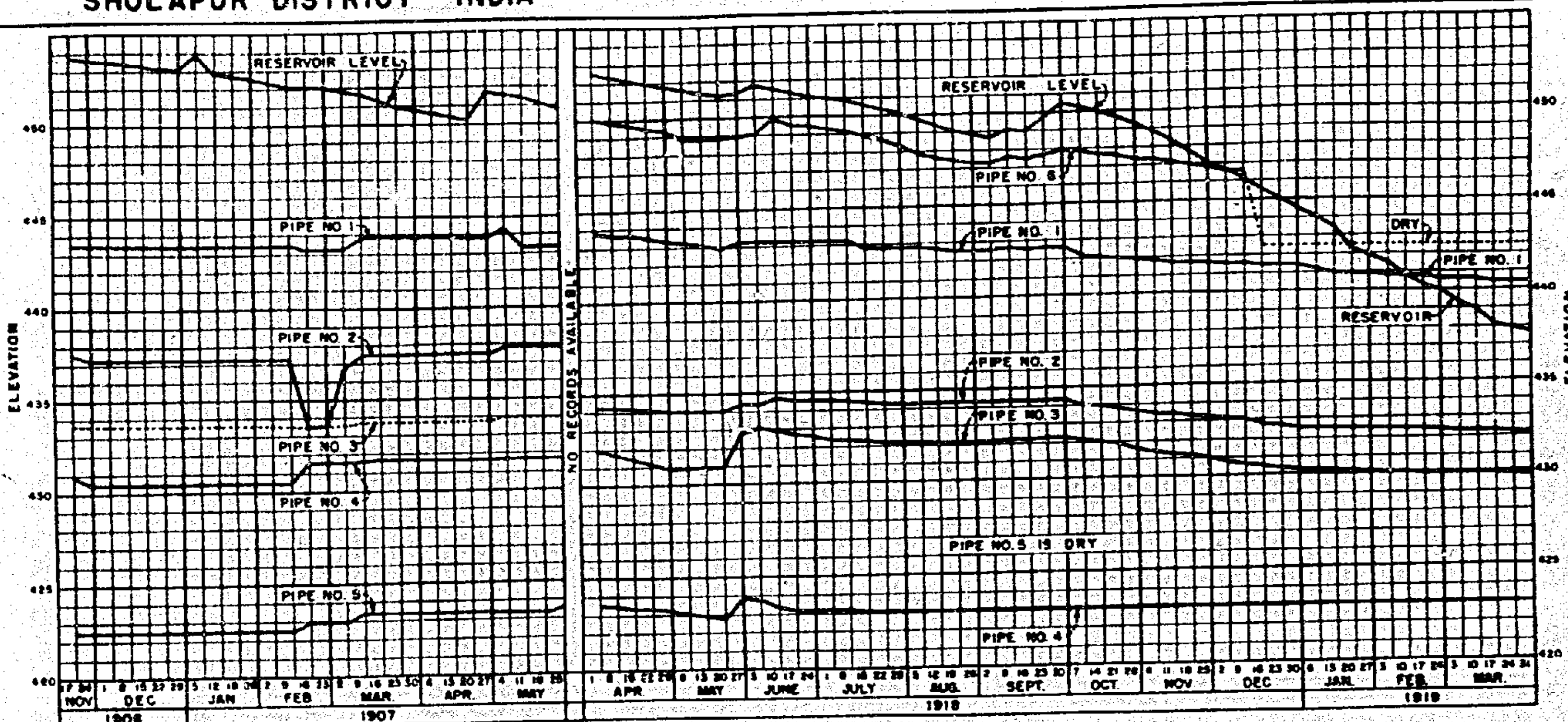
REMARKS:

Apparently the puddle trench "B" is an effective barrier to underflow through the moorum layer "C" which appears quite pervious. It is not inconceivable that a large portion of the flow is through the pervious moorum underlying the upstream portion, over the puddle trench, and back down into the moorum again.

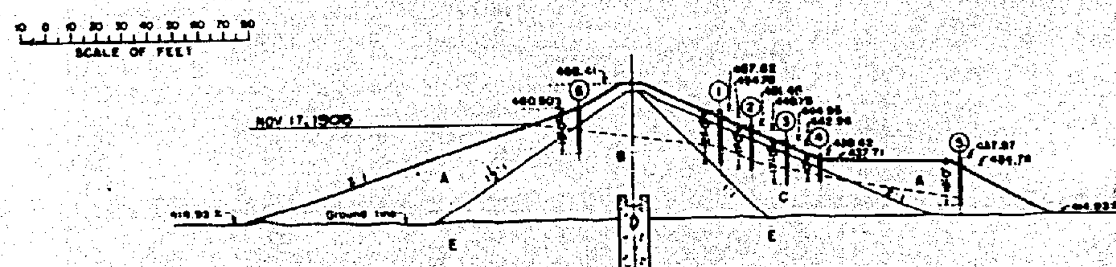
PLATE 69

WADSHIVNE TANK DAM
SHOLAPUR DISTRICT — INDIA

PUBLIC WORKS DEPARTMENT
BOMBAY 1909



RECORD OF WATER LEVELS IN RESERVOIR AND PIPES



CROSS SECTION OF WADASHIVNE TANK DAM (1919)
(SHOWING POSITION OF PIPES FOR OBSERVING LINE OF SATURATION)

EXPLANATION

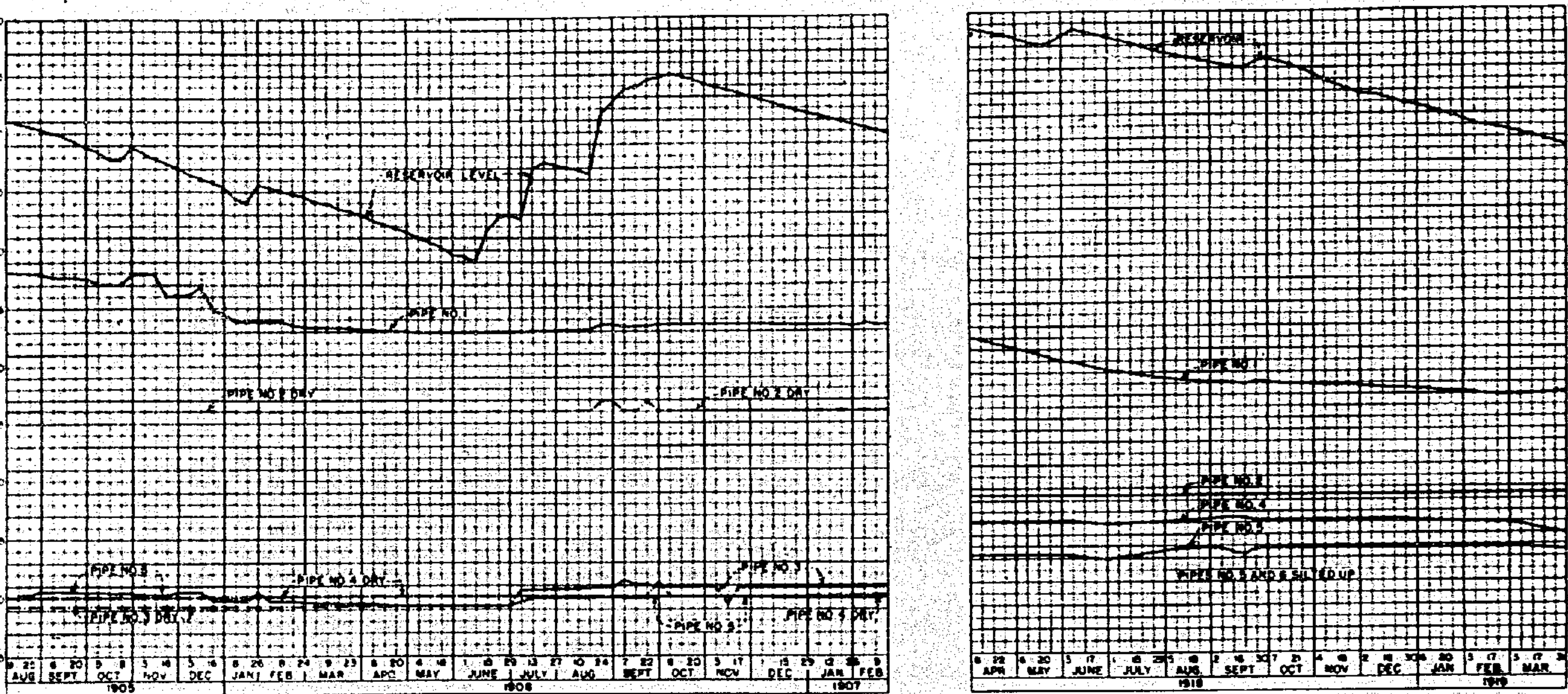
- A SELECTED MATERIAL 1ST CLASS 1½ BLACK SOIL TO 1 MURUM
- B HEARTING 2 BLACK SOIL TO 1 MURUM
- C SELECTED MATERIAL 2ND CLASS 1 BLACK SOIL TO 1½ MURUM
- D CONCRETE WALL
- E MURUM

BUREAU OF RECLAMATION
DENVER, COLO. 1935

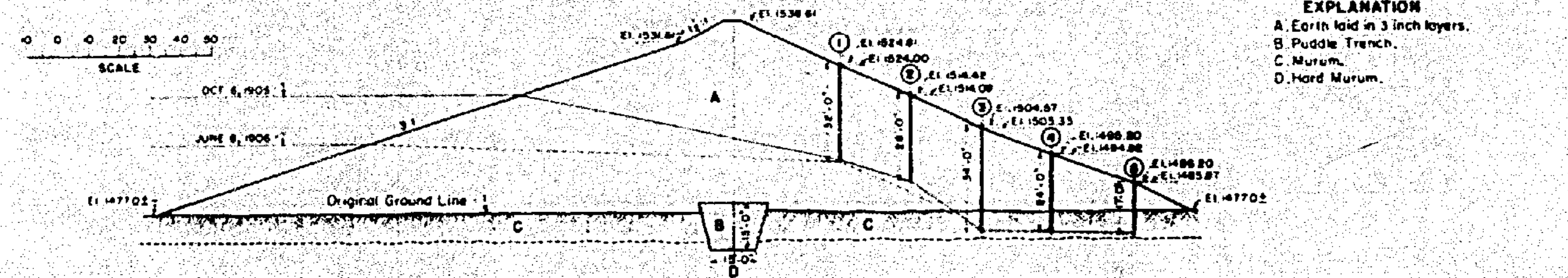
X-D-1822

EKRUK TANK DAM
SHOLAPUR DISTRICT INDIA

PUBLIC WORKS DEPARTMENT
BOMBAY 1909



RECORD OF WATER LEVELS IN RESERVOIR AND PIPES



CROSS SECTION OF EKRUK TANK DAM
SHOWING POSITION OF PIPES FOR OBSERVING LINE OF SATURATION

EXPLANATION
A. Earth laid in 3 inch layers.
B. Puddle Trench.
C. Murum.
D. Hard Murum.

BUREAU OF RECLAMATION
DENVER, COLO., 1935

PLATE 60

X-D-1623

COMMENTS BY MR. HILL:

"This is a bank of uniform construction of a clayey material- earth and moorum mixed. It slipped seriously on one occasion and a berm has been a dded to the weakest part.

The pipe No. 2 was inserted on the upstream slope about 7 feet from the top edge of the bank.

The levels recorded in this pipe No. 2 show regular and gradual rise ard fall following, but not coinciding with rise and fall in the tank. Thus, in 1906, the maximum level in the tank was reached on September 26th and was 2661'10.

The level recorded in pipe No. 2 was then 2653'61 or about 7-1/2 feet lower. The level in the tank remained nearly the same until 27th October, but the levels in pipe No. 2 continued to rise until 22nd October when they were only 4 feet lower than in the tank.

The water in the tank then fell more rapidly than in this pipe until 27th April, 1907, when the difference of level was 1-3/4 feet only.

Similarly, when the tank was replenished, the water in the tank rose more quickly than in the pipe No. 2.

On July 10th, 1907, the difference was 3-1/4 feet, on July 27th, it was 8-1/2 feet; at the end of August, it was 6 feet and for the two months - September and October - when the level in the tank was nearly steady, the difference also was steady and between 6 feet and 5-1/2 feet. The distance from the water edge on the bank to the pipe horizontally was about 25 feet, so that the gradient seems to have been about 1 in 4 or less for this portion of the bank."

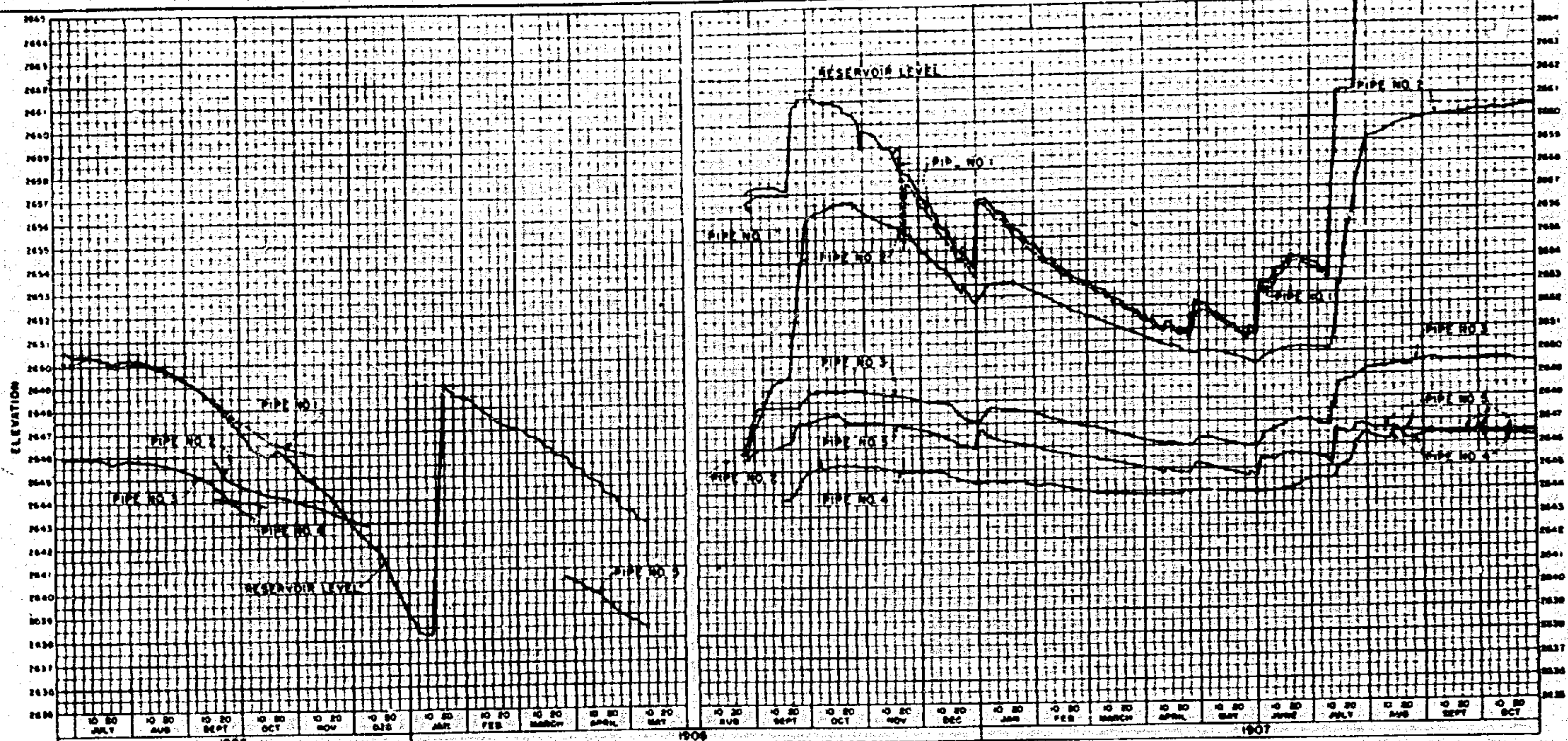
REMARKS BY THE WRITER:

Here is a good example of the building up of the phreatic line with time. Starting with July 11, 1907 and ending with October 15, the progress of the line is graphically portrayed on plate 61. The reservoir rose rapidly 8 feet July 11-14 and then stayed at the same elevation for 10 days. Pipe No. 2 scarcely rose at all July 11-14; but in the 10 day interval July 14-24 it rose 5 feet. This may be accounted for by a combination of two factors; lag in the rise of the actual phreatic line, and volumetric adjustment in the well No. 2 which is used to locate the phreatic line. After July 24 the reservoir rises another 5--foot step and again it takes time for well No. 2 to reach equilibrium. Probably because the length of travel from face of the dam to the well is shorter for the higher reservoir level, the time lag is shorter for the second step.

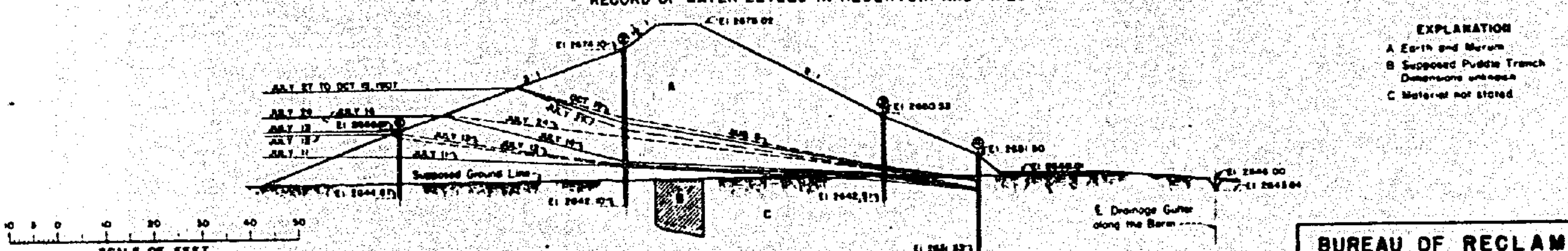
PLATE 61

NEHR TANK DAM
INDIA

PUBLIC WORKS DEPARTMENT
BOMBAY 1909



RECORD OF WATER LEVELS IN RESERVOIR AND PIPES



CROSS SECTION OF NEHR TANK DAM
(SHOWING POSITION OF PIPES AND RISING OF PHREATIC LINE)

BUREAU OF RECLAMATION
DENVER, COLO., 1935

X-D-1624

MUKTI TANK

COMMENTS BY MR. HILL:

"This is one of the best embankments in the Deccan and has never given trouble. The interior is reported to be of selected earth and the outer portion both upstream and downstream of moorum, whilst the foundations are rock.

1906 was a year of good rainfall and the tank overflowed and remained at full supply level for 3 months.

The level in pipe No. 1, which was sunk well into the hearting in the upstream side, was about 8 feet below the level of the water in the tank at maximum supply.

The levels in pipes 2 and 3 on the downstream slope indicated that the earth hearting was completely saturated but that the moorum backing was free of water.

Pipes 4, 5 and 6 give the levels of the water in the toe of the moorum backing and indicate the gradient necessary to carry off the water.

The next year, 1907, was one of poor supply and the tank did not fill, but the maximum level reached in pipe No. 1 was very approximately the same as for 1906, though it was 1-1/2 feet below highest level in the tank instead of 8 feet as in 1906.

In pipes 3 and 4 the levels recorded in 1907 were higher than in 1906, and the reason is not clear.

The general results for this tank, even allowing for the discrepancy in the pipes 3 and 4 in the two years, show that the form of construction adopted is good."

REMARKS BY THE WRITER.

As regards lowering of the phreatic line and providing a stable upstream slope under severe drawdown of reservoir, this design of rolled fill appears to combine all of the advantages of the hydraulic fill with none of its uncertainties. Carrying the heart closer to the top of the dam might assist in preventing formation of the capillary siphon [2] over the heart. See Matoba, Pathri, Wadshivne, Unkal, Parsul, Mhaswad.

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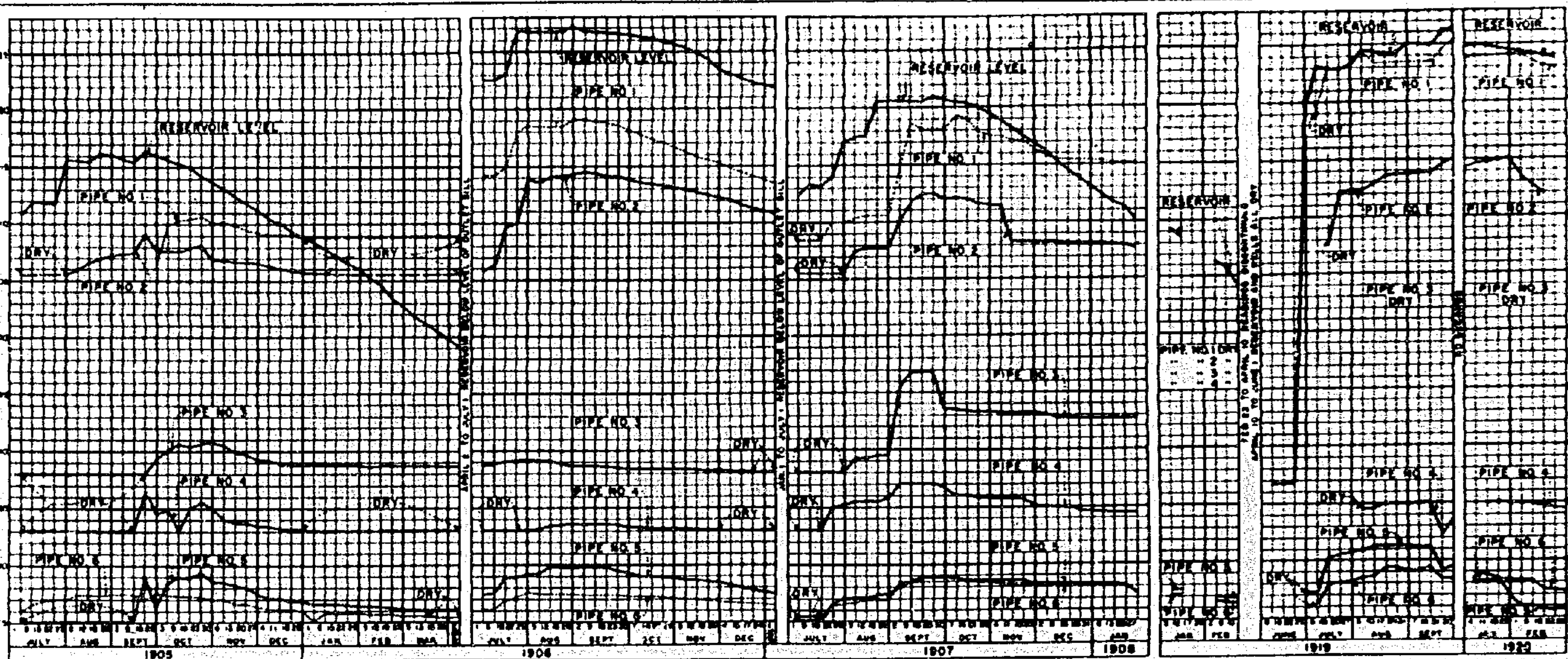
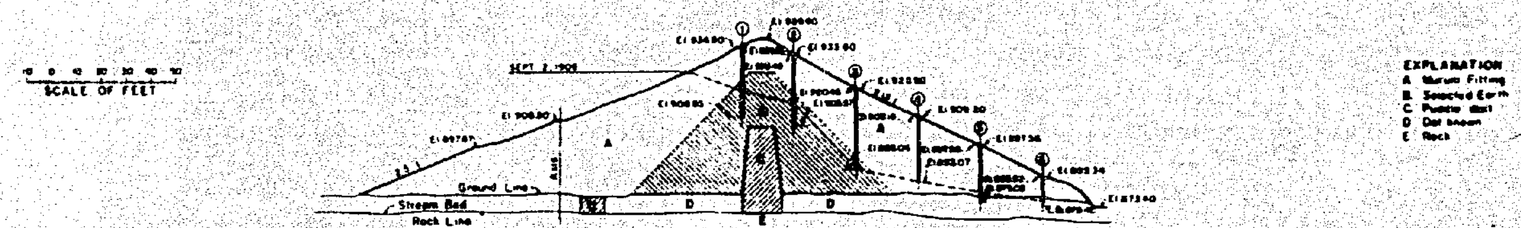
[2] "Capillary Movement of Soil Moisture"
W. M. McLaughlin, Senior Irrigation Engineer.
U.S.D.A. Bull. No. 835, Aug. 6, 1920.

MUKTI TANK DAM
KHANDESH DISTRICT - INDIA

PUBLIC WORKS DEPARTMENT
BOMBAY 1909





CROSS SECTION OF MUKTI TANK DAM
(SHOWING POSITION OF PIPES FOR OBSERVING LINE OF SATURATION)

BUREAU OF RECLAMATION
DENVER, COLO. 1935

PLATE 92

X-D-1625

COMMENTS BY MR. HILL:

"This embankment is of recent construction and was constructed in 1893. The materials of which it is made are known and are indicated on the diagram: the upper side and hearting are of clayey material, and the downstream portion, of good drainage material.

The tank was filled to overflowing on August 4th, 1907, and continued full until October 12th, 1907.

Pipes have been inserted in both upstream and downstream slopes of this embankment and pipe No. 3 is the one on the upstream side just above H. F. L.

The water level in the pipe No. 3 fluctuated quickly with the rise and fall of the water in the tank when nearly full, but at lower levels, changed slowly. Thus, from July 20th to August 4th, the level rose 2-1/2 feet and there is a reading on August 3rd which shows a rise of 6 feet. Again, from September 21st to September 28th, the rise was 7-1/2 feet in pipe No. 3. After October 5th, when the tank level began to fall, the level in No. 3 pipe fell more rapidly than the level in the tank until December 28th, the fall in the tank being almost 2 feet and in pipe No. 3 the fall was 8 feet.

On the other hand, the level in pipe No. 4, which is in the very centre of the dam, changed but slightly, the maximum level was not reached until November 16th or 2-1/2 months after the tank's first filling in August, and whilst on April 6th the difference between level of water in pipe 4 and in the tank was 10 feet only, on August 13th, it was 18 feet.

The levels in pipe No. 5, which was sunk into the clay hearting on the downstream side, also varied but slightly.

The levels in pipes Nos. 6 and 7, in the drainage material in the rear slope varied very slightly during June to December 1907. The variation between the readings for pipe 6 before and after June 15th appears to be due to the refixing of pipe 6 on 15th June and the later readings are the safer to take."

REMARKS (ABRIDGED) BY W. H. BEALE, SUPERINTENDING ENGINEER, S.D.

Sept. 22 - Oct. 6, 1906. Pipe No. 8 - Saturated earth at given level. Pipe No. 1 - Mouth of pipe is close to the ground. Rainwater must have entered through pinholes in the pipe to cause abnormal rise.

June 15, 1907 - Pipe No. 6 is now refised.

June 22, 1907 - Pipe No. 3 is now refixed.

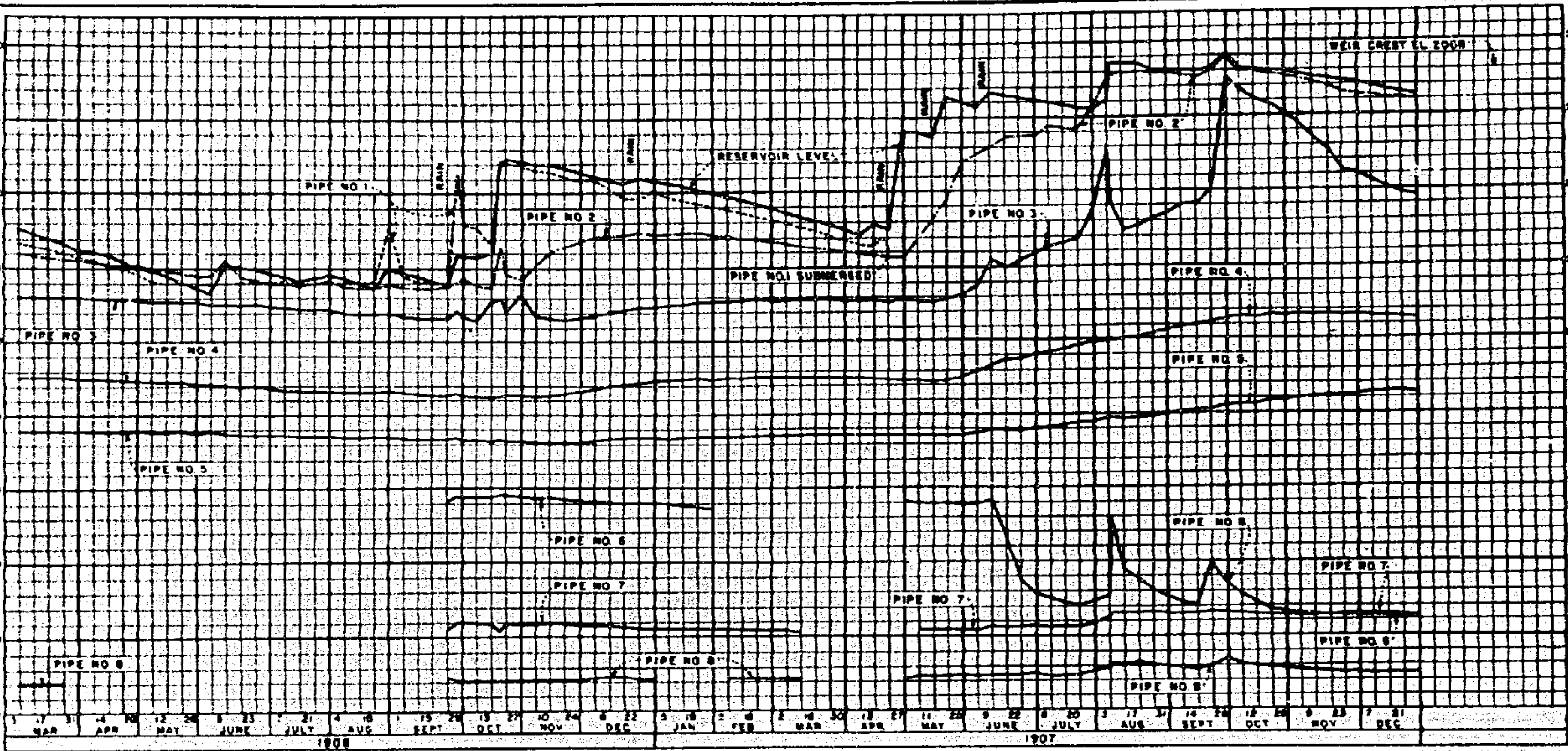
June 23, 1907 - Pipe No. 2 is now refixed.

July 20, 1907 - The rise in pipes 3, 4, 5, and 8 is due to the dam getting saturated by a former rise in level of tank.

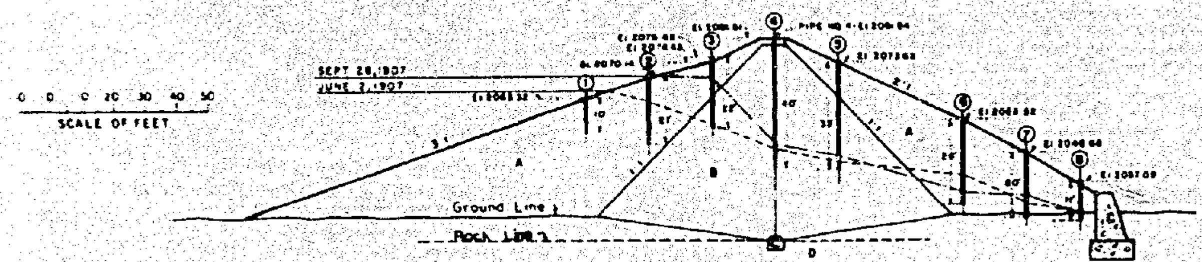
Sept. 27, 1907 - Rainwater must have entered into Pipe No. 6.

UNKAL TANK DAM
INDIA

PUBLIC WORKS DEPARTMENT
BOMBAY 1909



RECORD OF WATER LEVELS IN RESERVOIR AND PIPES



CROSS SECTION OF UNKAL TANK DAM

(SHOWING POSITION OF PIPES FOR OBSERVING LINE OF SATURATION)

LEVELS AS PER SANCTIONED DESIGN

TOP OF DAM	EL. 2081.80
TOP OF TOE WALL	EL. 2035.14
UPSTREAM SLOPE	3 TO 1
DOWNSTREAM SLOPE	2 TO 1
THICKNESS AT BASE (APPROX.)	280 FT.

EXPLANATION

- A 1 PART BLACK SOIL AND 1 PART MURUM
- B 2 PARTS BLACK SOIL AND 1 PART MURUM
- C CONCRETE
- D ROCK

BUREAU OF RECLAMATION
DENVER, COLO., 1935

PLATE 93

X-D-1628

COMMENTS BY MR. HILL:

"This is an old tank and the character of the construction of the embankment is not known but it is a good sound bank. Pipe No. 1 is on the water slope of the bank and pipe No. 2 also, and at a little above H. F. L. Pipe No. 3 is on the centre line of the bank. The results recorded show that the bank was almost completely saturated as far as pipe No. 3 on the centre line of the bank. The pipes are of iron with holes punched in them at intervals, and pipe No. 3 had several times to be cleared of silt.

2-1/4 years of complete seasons records are available and one or two observations in 1904.

In August 1906, the tank filled rather suddenly, the levels in pipe No. 2 rose rapidly but in pipe No. 3, in the centre of the bank, the maximum level was not reached until 13th October or 1-3/4 months after first filling of the tank; after that, the levels fell gradually until June 1st, 1907. The tank level fell 12 feet, the level in pipe No. 2 about the same, and in pipe No. 3, the fall was 13 feet. The levels of water in the pipes on the downstream slope Nos. 4, 5, 6, 7 and 8 indicate that the back portion of the dam was very well drained and the line of saturation low.

In 1906, the maximum level in these pipes was reached on the same date as in pipe No. 3, namely, October 13th, 1906, and in 1907, the results were very similar, the tank being filled on September 28th and maximum level in the downstream pipes reached in the week - October 19th to 26th.

REMARKS BY T. W. DeWINTON, SUPERINTENDING ENGINEER, S.D.:

Nov. 8, 1904 - Water level at rear toe of the dam is 148.47.

June 16, 1906 - Pipes 1 to 4 are filled with dry clay. Have been ordered pulled up and cleaned.

Jan. 5, 1907 - Extra height in pipes 6 and 7 probably due to late rains.

It is curious why pipe 5 consistently reads lower. Probably due to unequal consolidation.

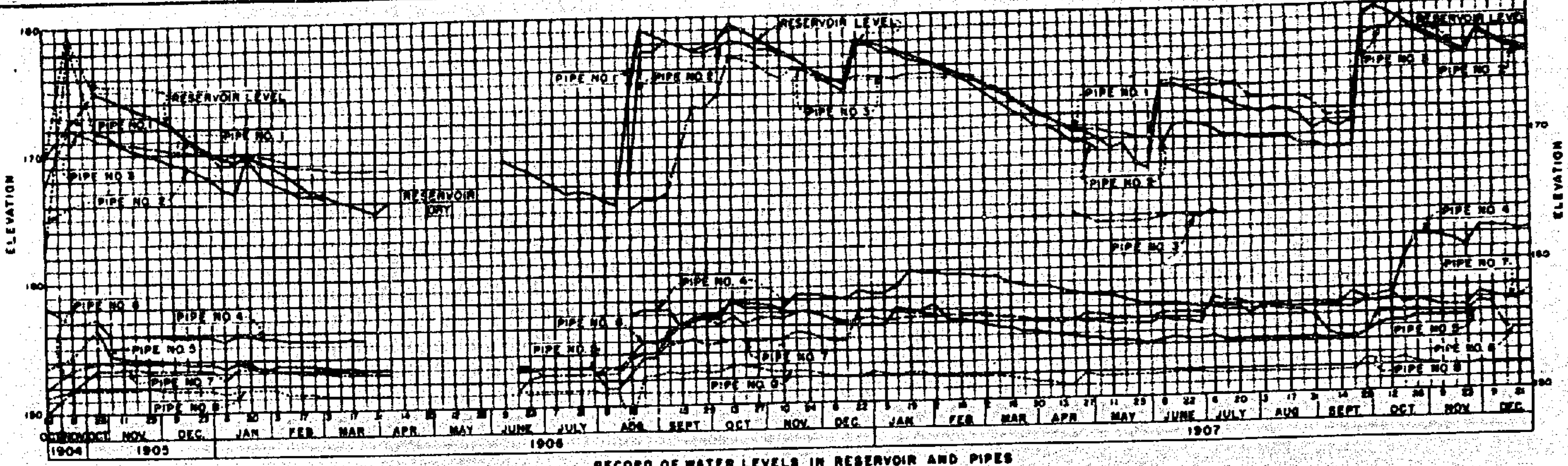
Mar. 2, 1907 - While lifting pipe No. 3 to ascertain whether there was any obstruction in it, the upper pipe came out and the lower one remained inside so no reading.

Apr. 13, 1907 - Pipe No. 3 has been newly fixed and levels will be reported soon.

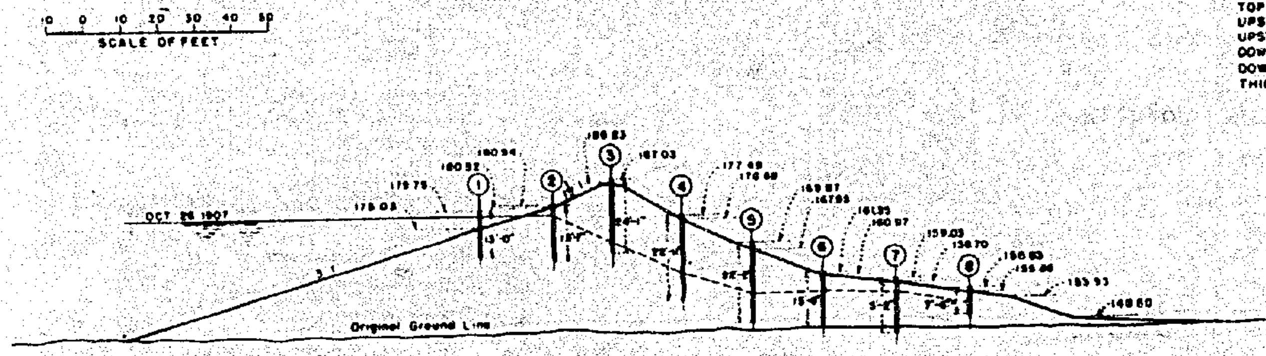
July 20, 1907 - Pipe No. 3 is silted and is being removed and cleared.

MEDLERI TANK DAM
INDIA

PUBLIC WORKS DEPARTMENT
BOMBAY 1909



RECORD OF WATER LEVELS IN RESERVOIR AND PIPES



CROSS SECTION OF MEDLERI TANK DAM
(SHOWING POSITIONS OF PIPE FOR OBSERVING LINE OF SATURATION)

LEVELS AS PER SANCTIONED DESIGN

TOP OF DAM	EL 187.00
UPSTREAM SLOPE 3 TO 1 UP TO	EL 182.00
UPSTREAM SLOPE 1½ TO 1 ABOVE	EL 182.00
DOWNSTREAM SLOPE 2 TO 1 UP TO	EL 182.00
DOWNSTREAM SLOPE 1½ TO 1 ABOVE	EL 182.00
THICKNESS AT BASE (APPROX.)	300 FT

EXPLANATION

MATERIAL VERY LIKELY MURUM CONSOLIDATED BY CART TRAVEL

BUREAU OF RECLAMATION
DENVER, COLO., 1935

PLATE 64

X-D-1627

MAYNI TANK

COMMENTS BY MR. HILL:

"This is a tank which has an excellent supply and fills regularly, but the bed is heavily silted and the depth between silted bed and full supply is about 8 feet only; the weir crest has since been raised.

The variation of level is thus not large. The tank, however, remained at or near full supply level from 24th August 1906 to 9th December 1906 and from 24th April 1907 to end of October 1907. Pipe No. 2 was sunk near the upstream edge of the top of the bank and pipe No. 3 about 13 feet from the top edge of the downstream slope.

The results recorded in these pipes and also in pipes 4, 5 and 6 indicated that the water level changed very little in the interior of this bank.

The bank is founded on moorum, so that the foundations are well drained, and the bank is a very satisfactory one. This substantial berm was added during famine as a famine work.

A curious fact in these Mayni Tank figures is the sudden change in the levels recorded for pipe No. 2 in October of 1907. This rise in water level is due to the bank being disturbed by digging a pit 10 feet diameter to put in a new pipe. Mud was found at 2,300 level.

The other pipes are not said to have been choked and considerable care was taken with the observations on this tank.

The Superintending Engineer, at one inspection, verified the levels in this particular pipe No. 2 and found them as reported and the pipe not choked.

REMARKS BY THE WRITER:

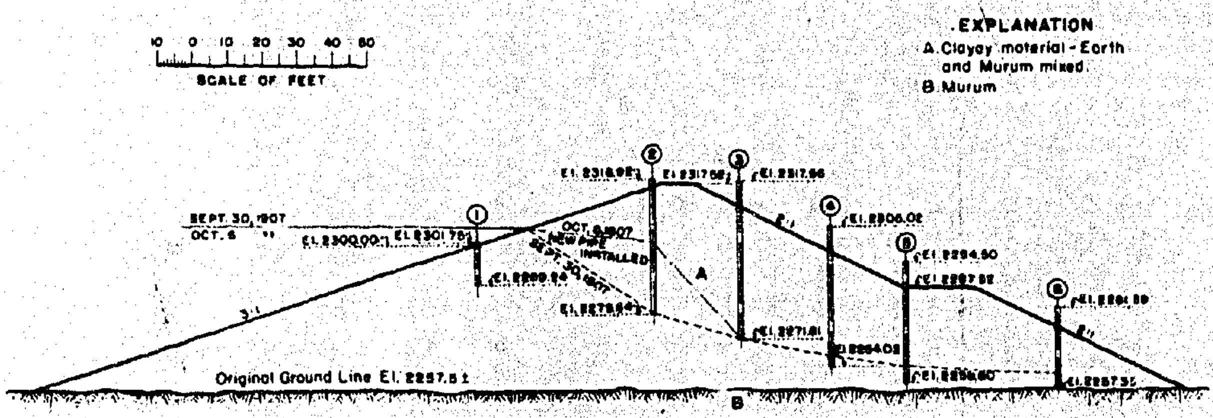
It is not quite clear from the above comments whether "mud" was found at elevation 2300 before or after October 6, 1907. If before, some clue is given as to relative height of saturation line above phreatic line.

NOTE BY F. WRIGHT, EXEC. ENGINEER, SATARA DISTRICT:

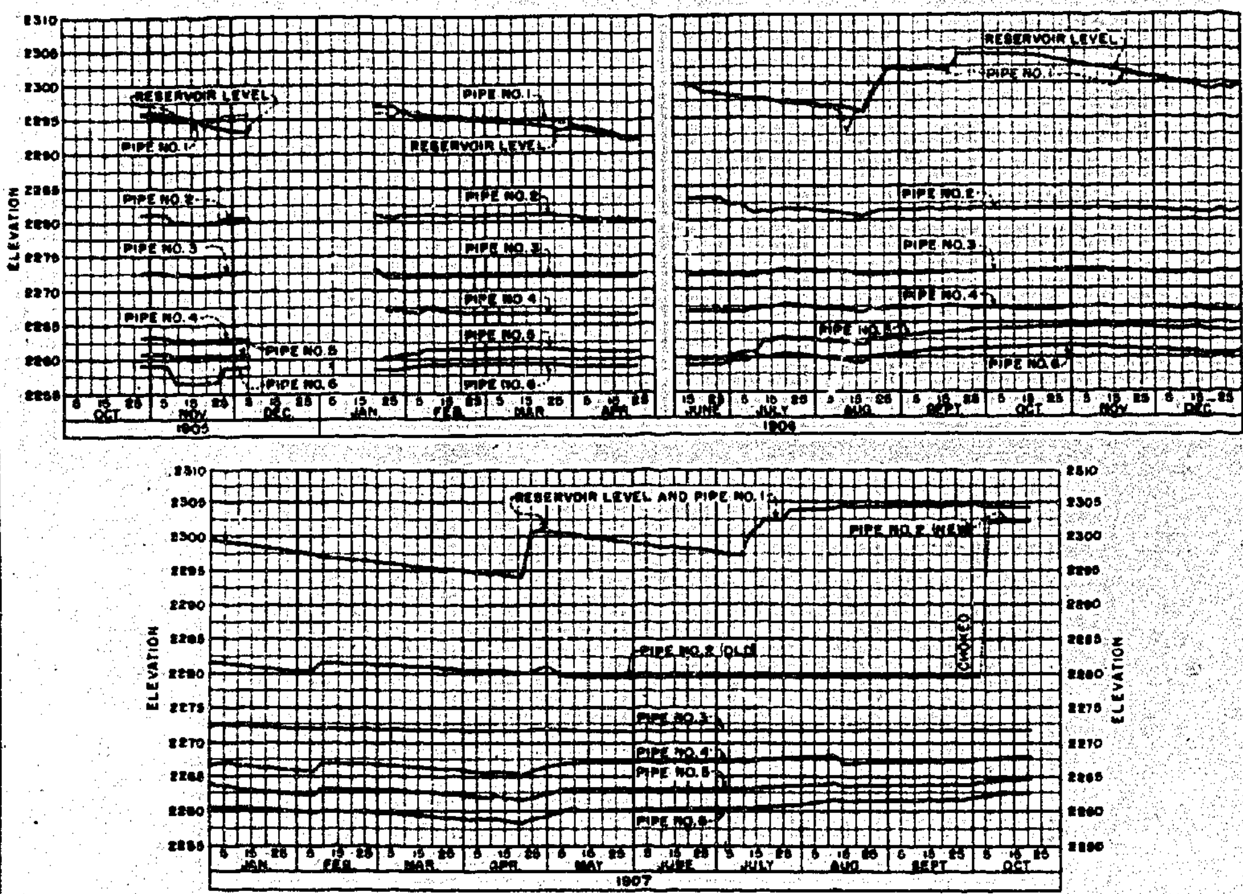
Oct. 3, 1907. Pipe No. 2 having got choked, an auxiliary pipe was inserted on 6th October 1907 and the bottom level of this is 2300.28.

MAYNI TANK DAM
INDIA

PUBLIC WORKS DEPARTMENT
BOMBAY 1909



CROSS SECTION OF MAYNI TANK DAM
SHOWING POSITION OF PIPES FOR OBSERVING LINES OF SATURATION



RECORD OF WATER LEVELS IN RESERVOIR AND PIPES

BUREAU OF RECLAMATION
DENVER, COLO., 1936

X-D-1628

MHASWAD TANK

COMMENTS BY MR. HILL:

This is a high embankment constructed entirely of earth. The levels recorded in pipe 1 on the upstream side of the bank show in 1905 that the level of saturation did not fall so rapidly as the water in the tank, for, on January the first, the difference of level was 7 feet and on June 10, was 1½ foot only.

In 1906-1907, the level in pipe 1 shows that it takes a long time to saturate this bank, the maximum water level in the tank was reached on October 13th, 1906, and after that date, the water in the tank gradually fell, but in pipe No. 1 the level rose until 29th December 1906 or 2-1/2 months after full supply.

The bank is a high one and the remaining pipes seem to have been too short.

PATHRI TANK

DESCRIPTION AND HISTORY:

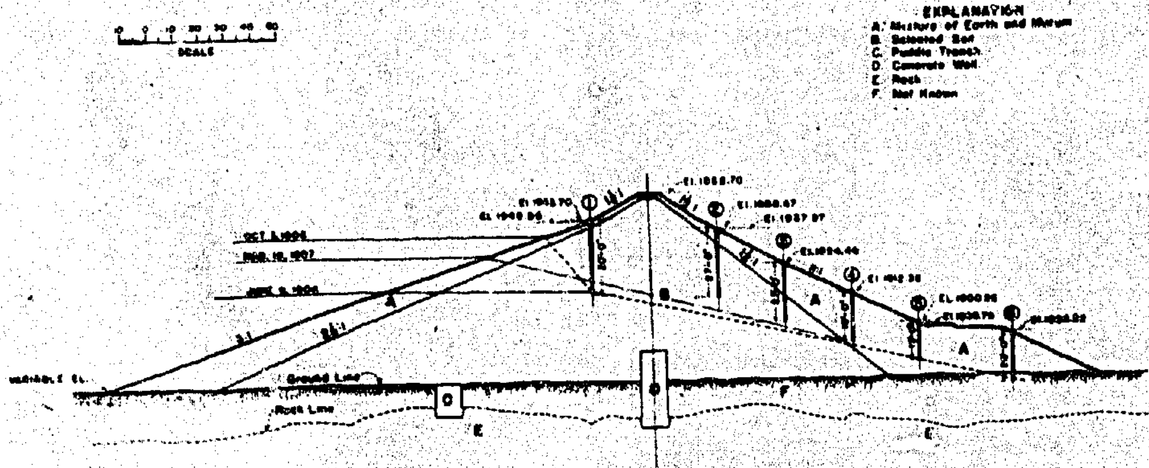
Commenced in 1826 and completed in 1905, this 63-foot dam is now used for domestic water and irrigation. The bank is of black soil and moorum, provided with a concrete core wall faced front and rear with a puddle trench. The foundation is sand, gravel, and boulders overlying moorum and the Deccan trap rock. The average annual rainfall is 27 inches, with a maximum 24-hour rain of 5.40 inches on 9-23-24.

REMARKS BY THE WRITER:

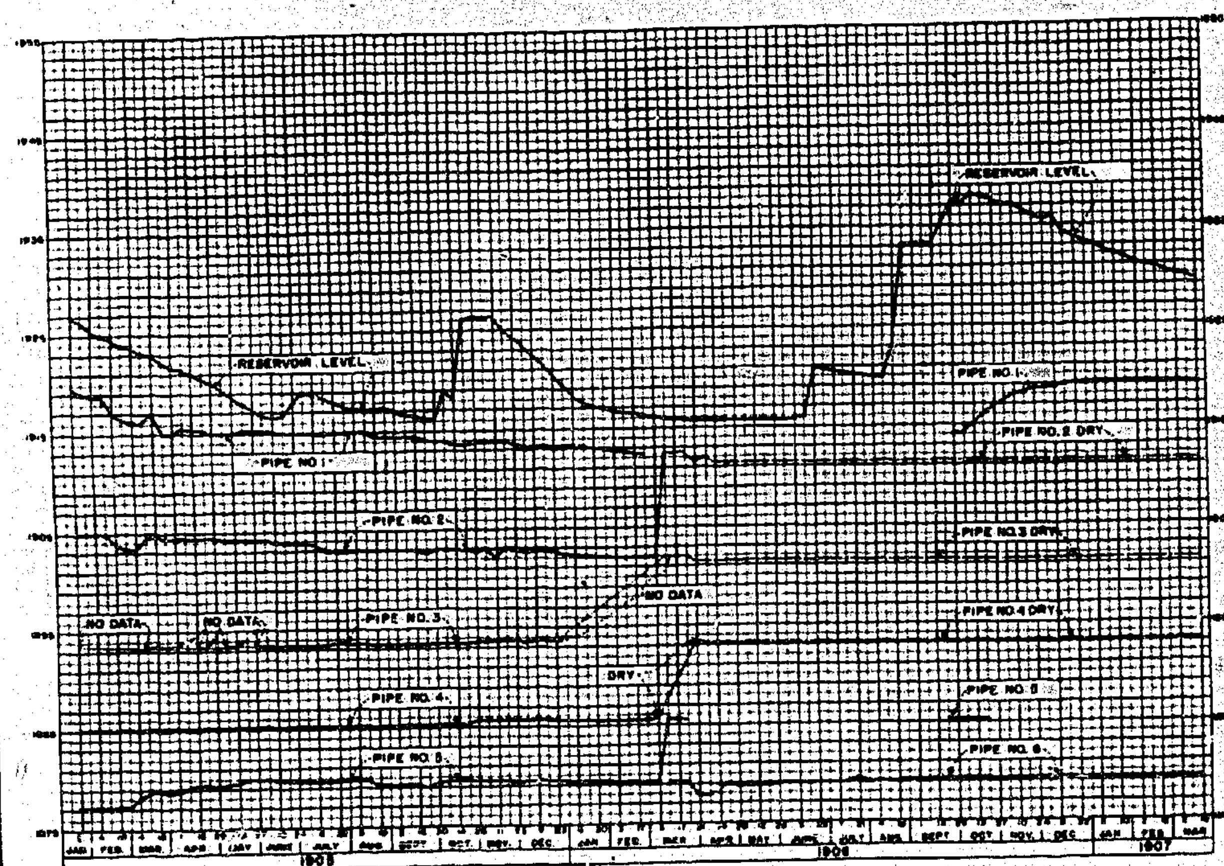
The top phreatic line in the sketch is based on the assumption that the heart material is the most impervious. The high level indicated at well 2 may be due to some special cause other than normal seepage.

MHASWAD TANK DAM
INDIA

PUBLIC WORKS DEPARTMENT
BOMBAY 1909



CROSS SECTION OF MHASWAD TANK DAM
(SHOWING POSITION OF PIPES FOR OBSERVING LINE OF SATURATION)



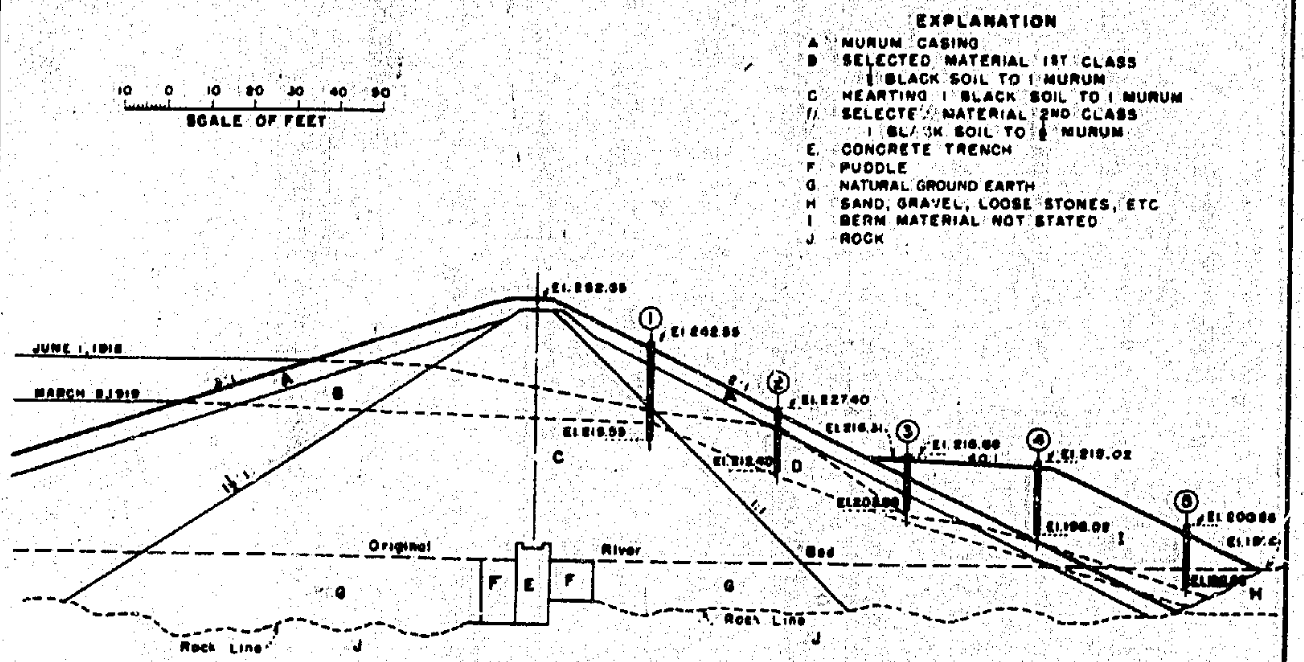
RECORD OF WATER LEVELS IN RESERVOIR AND PIPES

BUREAU OF RECLAMATION
DENVER, COLO., 1936.

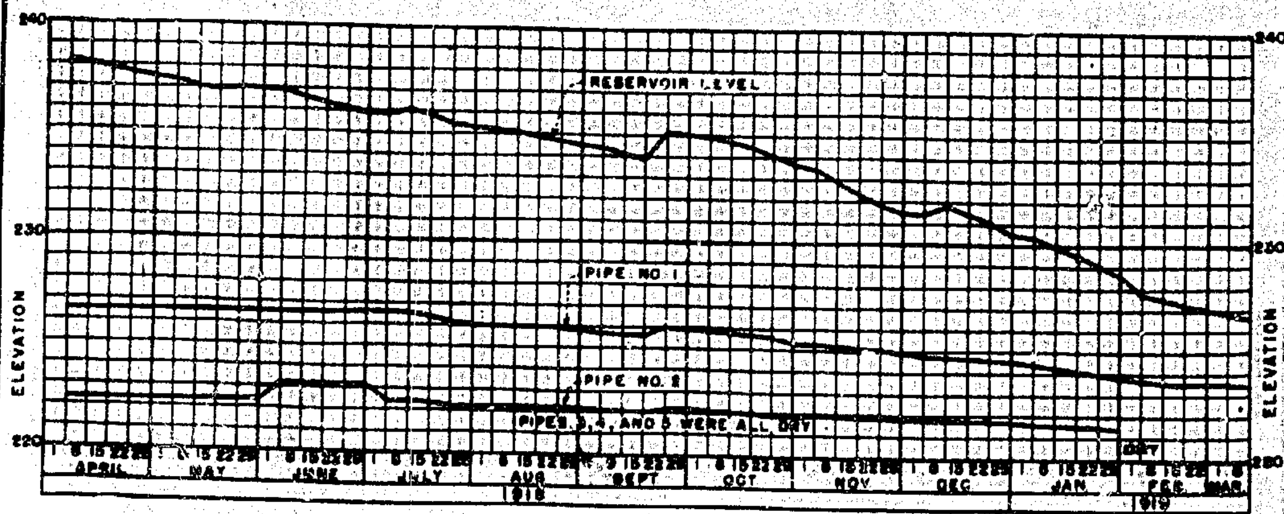
X-D-1629

PATHRI TANK DAM
SHOLAPUR DISTRICT-INDIA

PUBLIC WORKS DEPARTMENT
BOMBAY 1909



CROSS SECTION OF PATHRI TANK DAM
SHOWING POSITION OF PIPES



RECORD OF WATER LEVELS IN RESERVOIR AND PIPES

BUREAU OF RECLAMATION
DENVER, COLO., 1935

X-D-1608

ASHTI TANK

DESCRIPTION AND HISTORY:

This 58-foot embankment was begun in 1876 and was completed in 1883. It is used for irrigation. Built of earth and moorum, on a foundation of sand and trap rock, it is provided with a concrete core with puddle trench below ground level. The location of the concrete core wall is not indicated. Annual rainfall is 23 inches; the maximum 24-hour rain recorded 5.50 inches on 8-27-32.

REMARKS:

The rise of silt into pipes 4 and 5 indicates that high velocities near the toe should be dissipated in a filter drain and not permitted to move the earth material in the dam.

PINGLI TANK

COMMENTS BY MR. HILL:

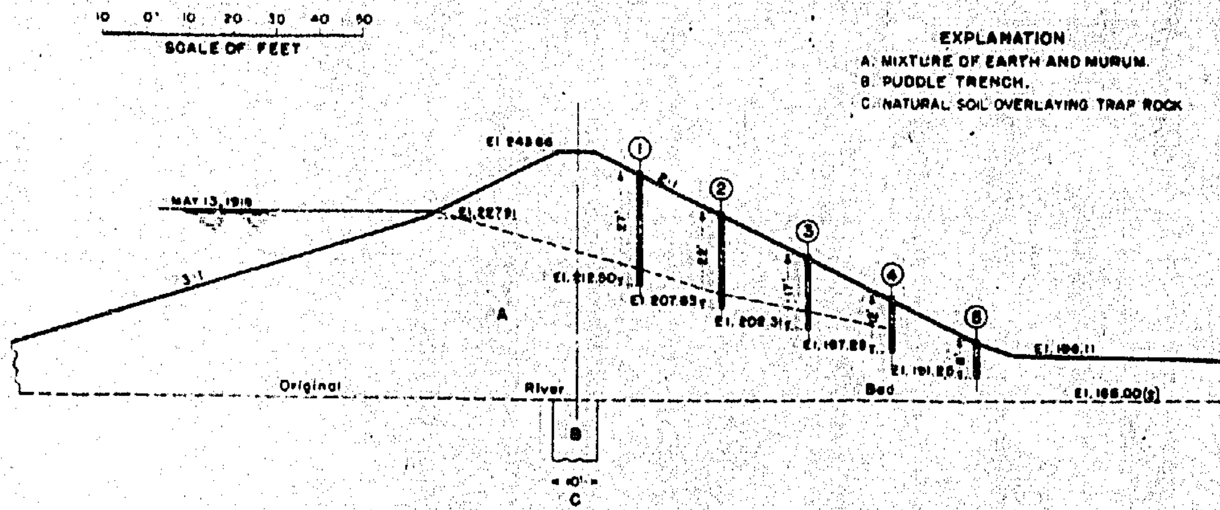
"This tank did not fill during the period of observations. The pipes at first were in the downstream berm and showed that this portion was well drained and there was but little variation in the water-level. Subsequently, a pipe was inserted on the upstream slope, the maximum level in the tank was reached on 10th October, but the water in the pipe continued to rise until 12th November and subsequently fell in the pipe much more slowly than in the tank and during half of January and February was higher in the pipe than in the tank.

REMARKS:

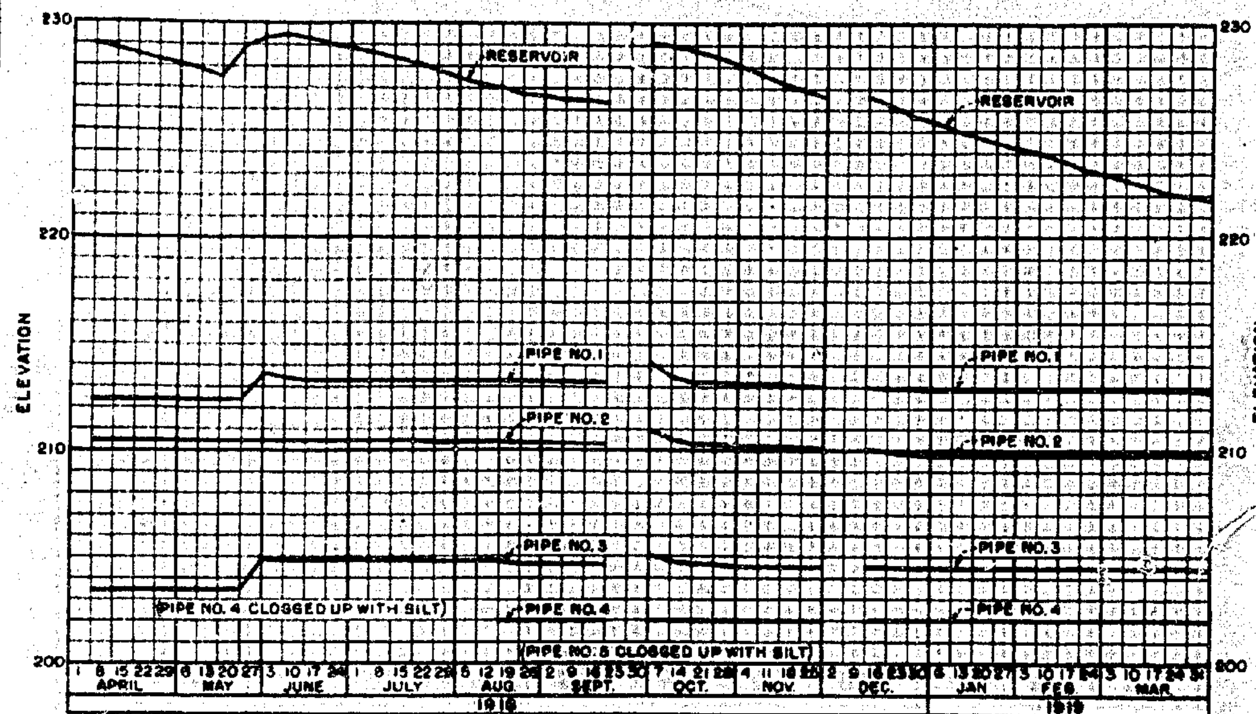
Location of pipe No. 1 is not known.

ASHTI TANK DAM
SHOLAPUR DISTRICT-INDIA

PUBLIC WORKS DEPARTMENT
BOMBAY 1909



CROSS SECTION OF ASHTI TANK DAM



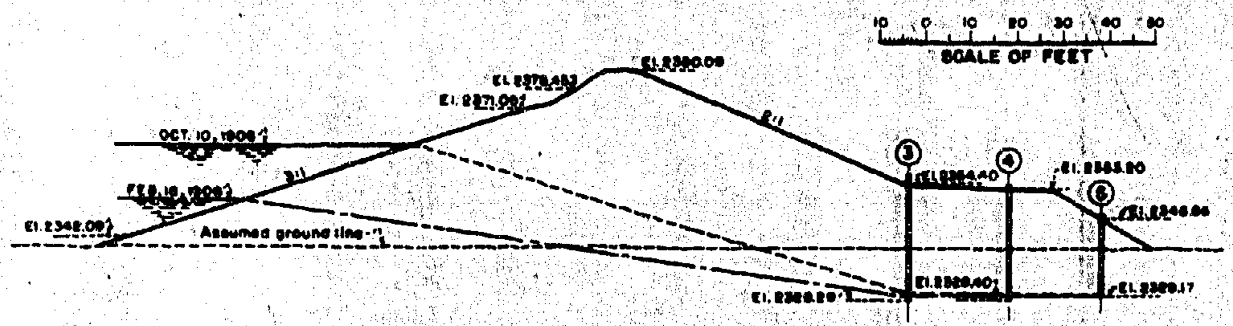
RECORD OF WATER LEVELS IN RESERVOIR AND PIPES

BUREAU OF RECLAMATION
DENVER, COLO., 1935

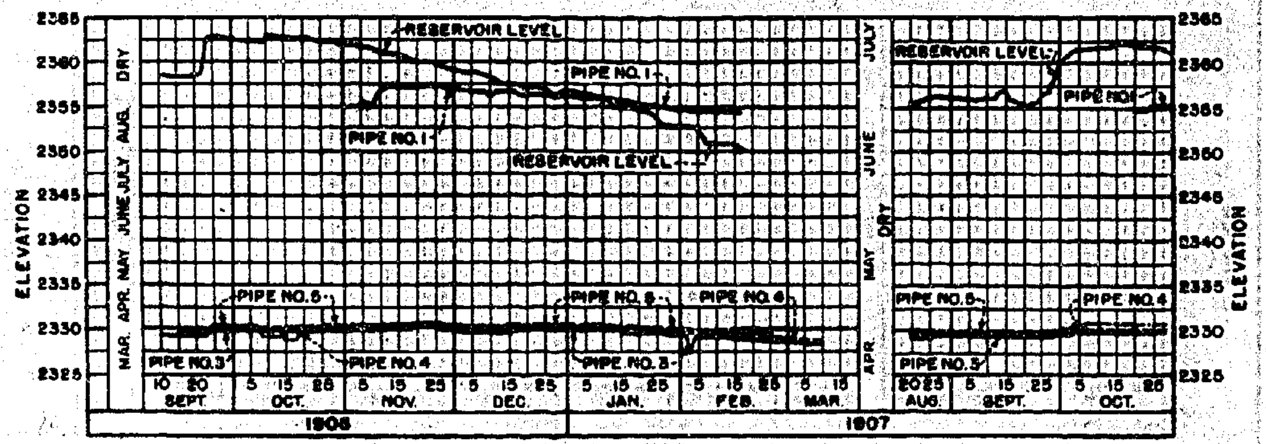
X-D-1609

PINGLI TANK DAM
INDIA

PUBLIC WORKS DEPARTMENT
BOMBAY 1909



CROSS SECTION OF PINGLI TANK DAM
SHOWING POSITION OF PIPES FOR OBSERVING LINE OF SATURATION
NO INFORMATION AS TO POSITION OF PIPES 1 AND 2



RECORD OF WATER LEVELS IN RESERVOIR AND PIPES

BUREAU OF RECLAMATION
DENVER, COLO., 1935

X-D-1610

SOFT MAPLE DAM | W. P. CREAGER HYDRAULIC ENGINEER

DESCRIPTION OF DAM:

"The Soft Maple Dam was a hydraulic fill but there were very few fines for the core. Borrow-pit material had an effective size of about 0.19 mm. and the core was not much finer. When the Soft Maple Dam was completed, the failure of a cofferdam allowed the pond to fill very rapidly. The line of saturation intersected the surface on the downstream face at about sta. 100 + 60 and a slide occurred near sta. 200 as shown" on plate 70. "However, very shortly the line of saturation receded and no further trouble was experienced.

METHOD OF OBSERVING AND OBSERVATIONS:

"The Soft Maple piezometers were pipes with perforated points driven into the dam a short distance below the plane of saturation. Salt was dropped into the bottom of the pipe and the level of water surface was determined when the bare end of an insulated wire made contact with the salt water, closing the circuit with the steel pipe. This worked very satisfactorily. Just how much error was caused by the surface of salt water being lower than the surface of fresh water in the pipe is not known, but it is believed to be very small since the depth of water in the pipe was not great and the reading was taken before the salt had a chance to affect the water surrounding the pipe.

The discharge is steady and perfectly clear and the plane of saturation is steady.

The discharge through the dam all passed over weir A; the other weirs measure the discharge through the adjacent hill. Note that the flow is toward the center of the dam. . . . . . "

On plate 72 "the variation of discharge with temperature is clearly indicated, and, during recent years, is unusually uniform. A comparison of maximum and minimum discharges in these years, with corresponding maximum and minimum temperatures gives a remarkable check of Slichter's temperature correction." The piezometer readings show a tendency to vary with the temperature but the variation is not as uniform as that for discharge.

MOSHIER DAM | W. P. CREAGER HYDRAULIC ENGINEER

DESCRIPTION:

Data on composition of this dam is very meagre. Mr. Creager states that seepage through the dam was and is very small. The complete record of well levels indicates a steady descent in all wells of about two feet from January 15 to August 30, 1930.

REMARKS:

This dam is includedbecause it affords a case in which sloughing of the downstream slope is experienced even in the presence of a large rock-fill drainage section. Had the drain become temporarily clogged for any reason, say by freezing, the downstream slope might readily have become sufficiently saturated to cause sloughing.

SOFT MAPLE DAM

PLATE 70

W. P. CREAGER
HYDRAULIC ENGINEER

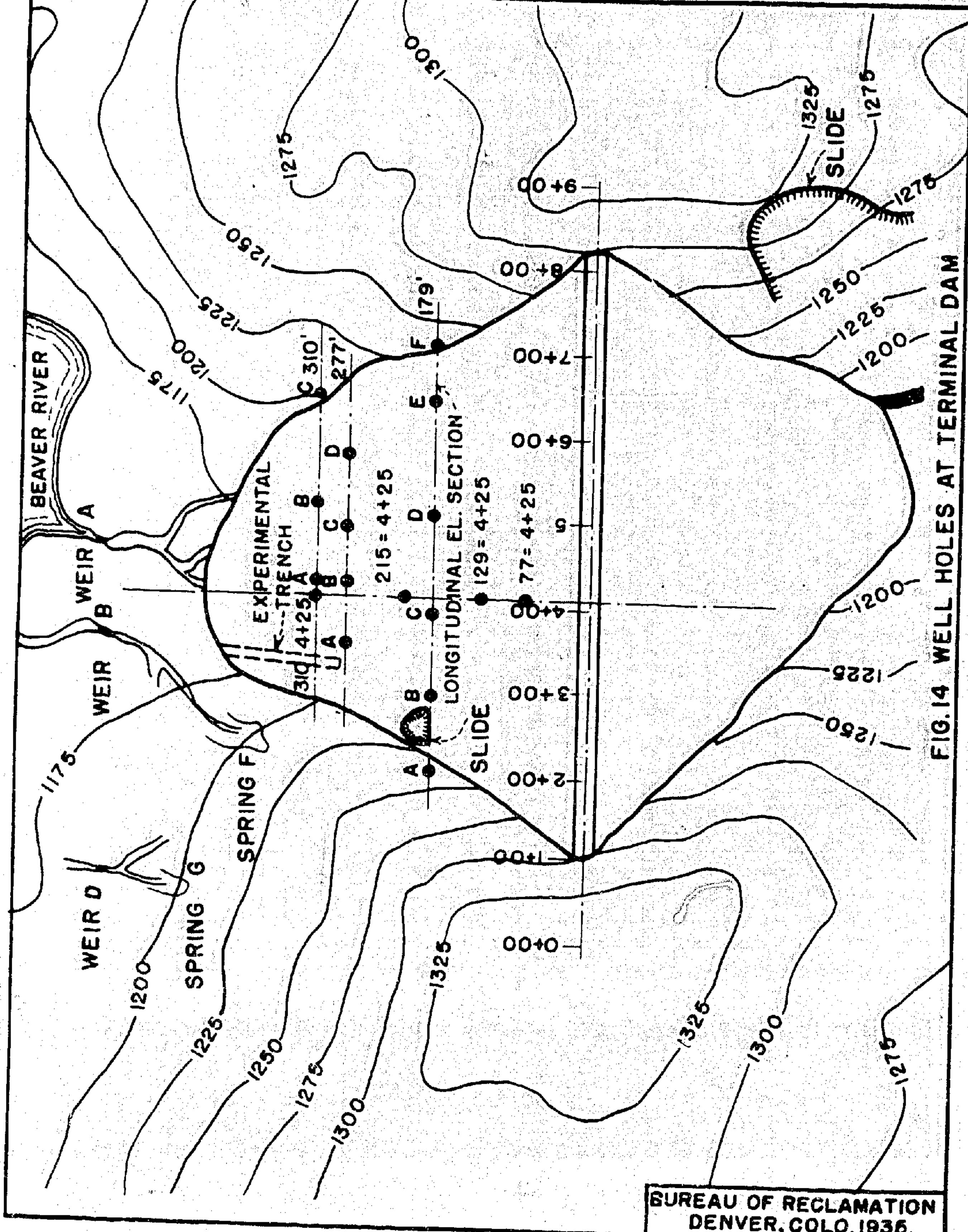
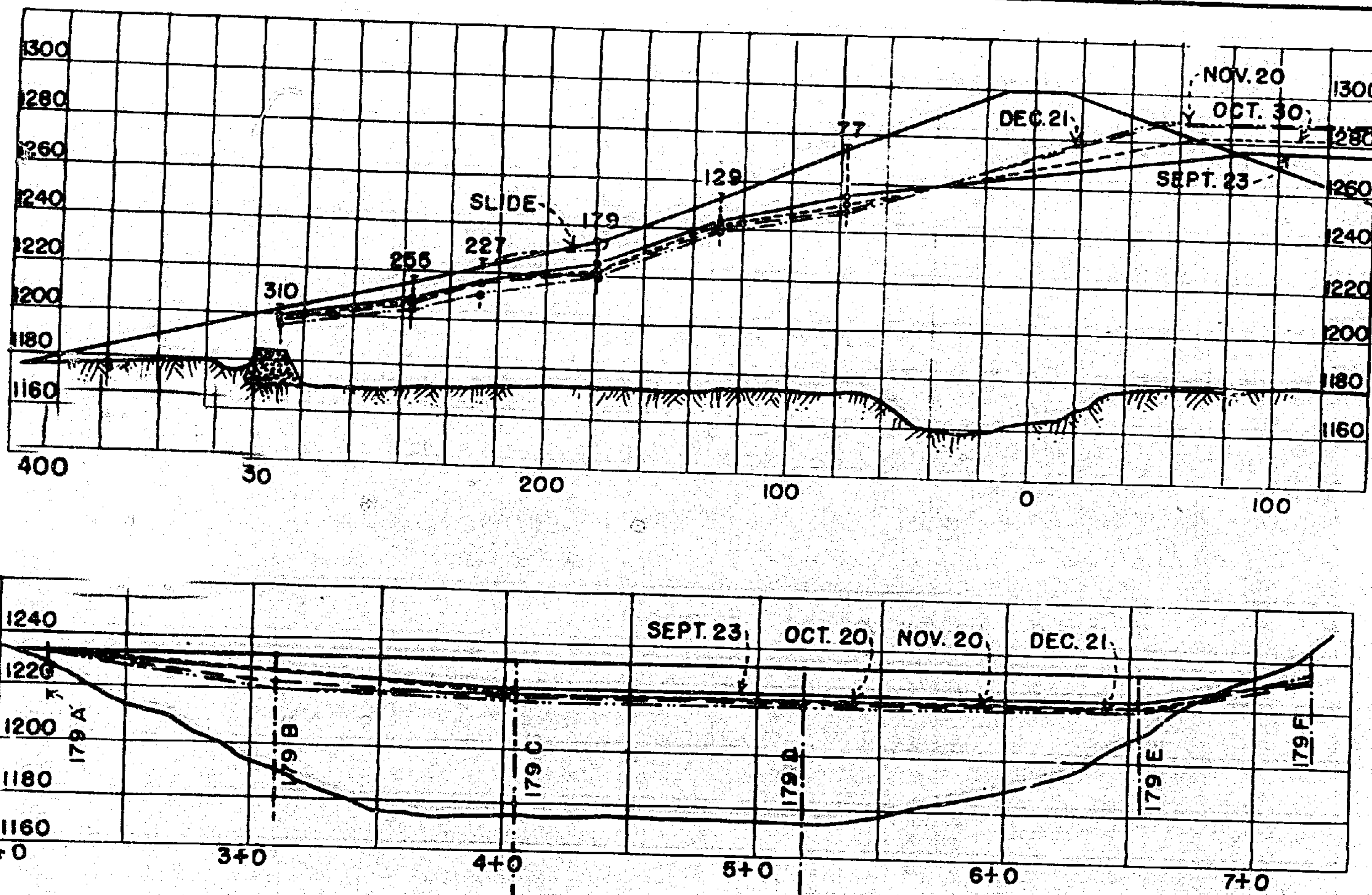


FIG. 14 WELL HOLES AT TERMINAL DAM

BUREAU OF RECLAMATION
DENVER, COLO. 1936.

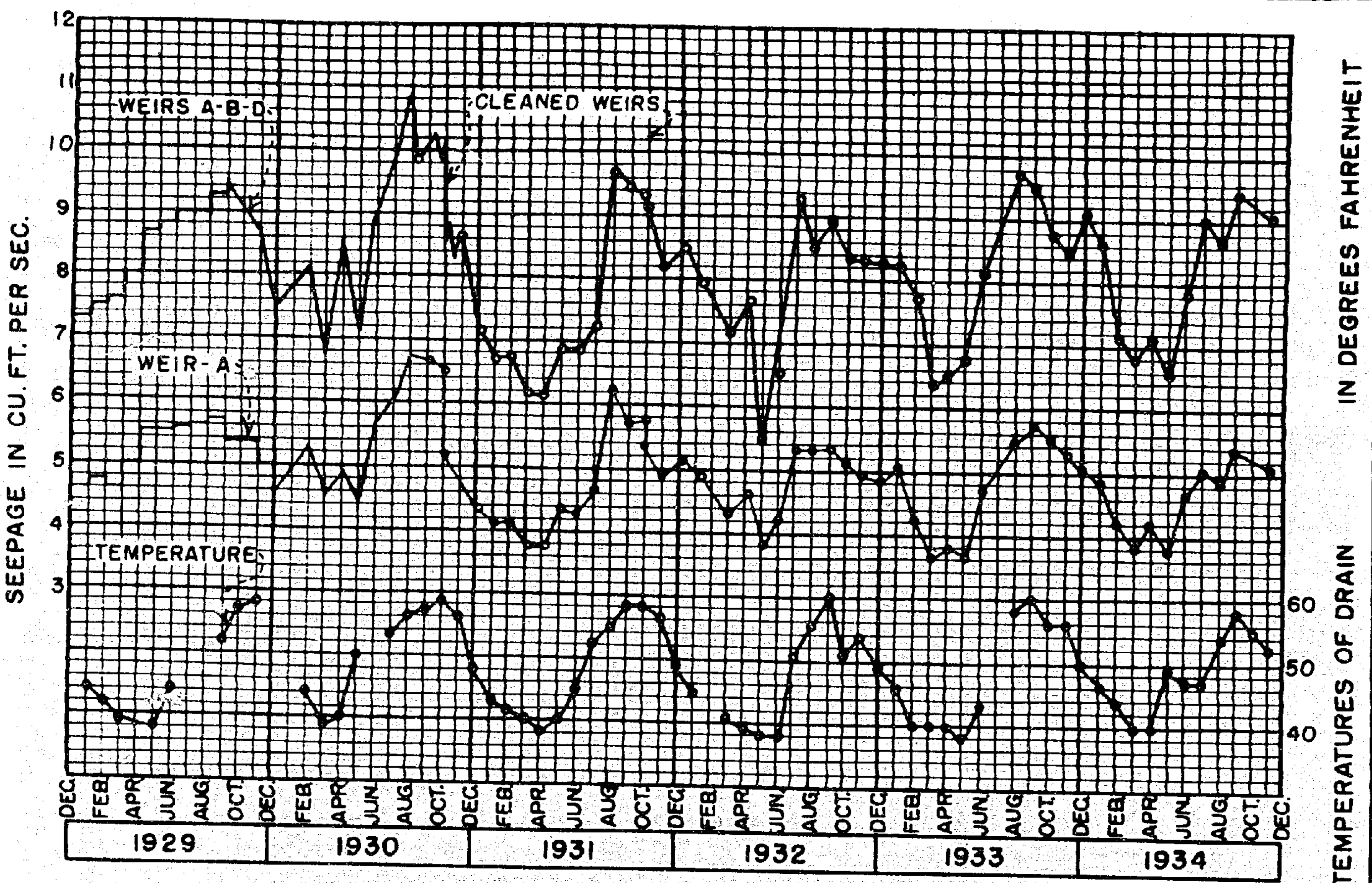
X-D-1613



SOFT MAPLE TERMINAL DAM

LINES OF SATURATION WHEN THE DAM WAS ABOUT THREE YEARS OLD

X-D-1614



SEEPAGE AT SOFT MAPLE DAM

PLATE 72

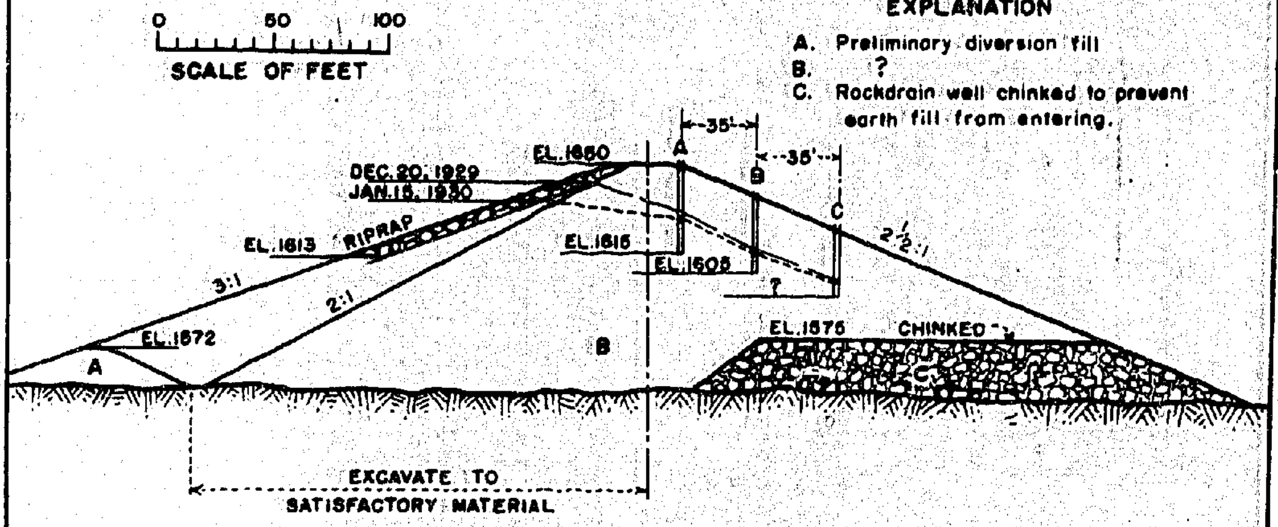
BUREAU OF RECLAMATION
DENVER, COLO. 1935

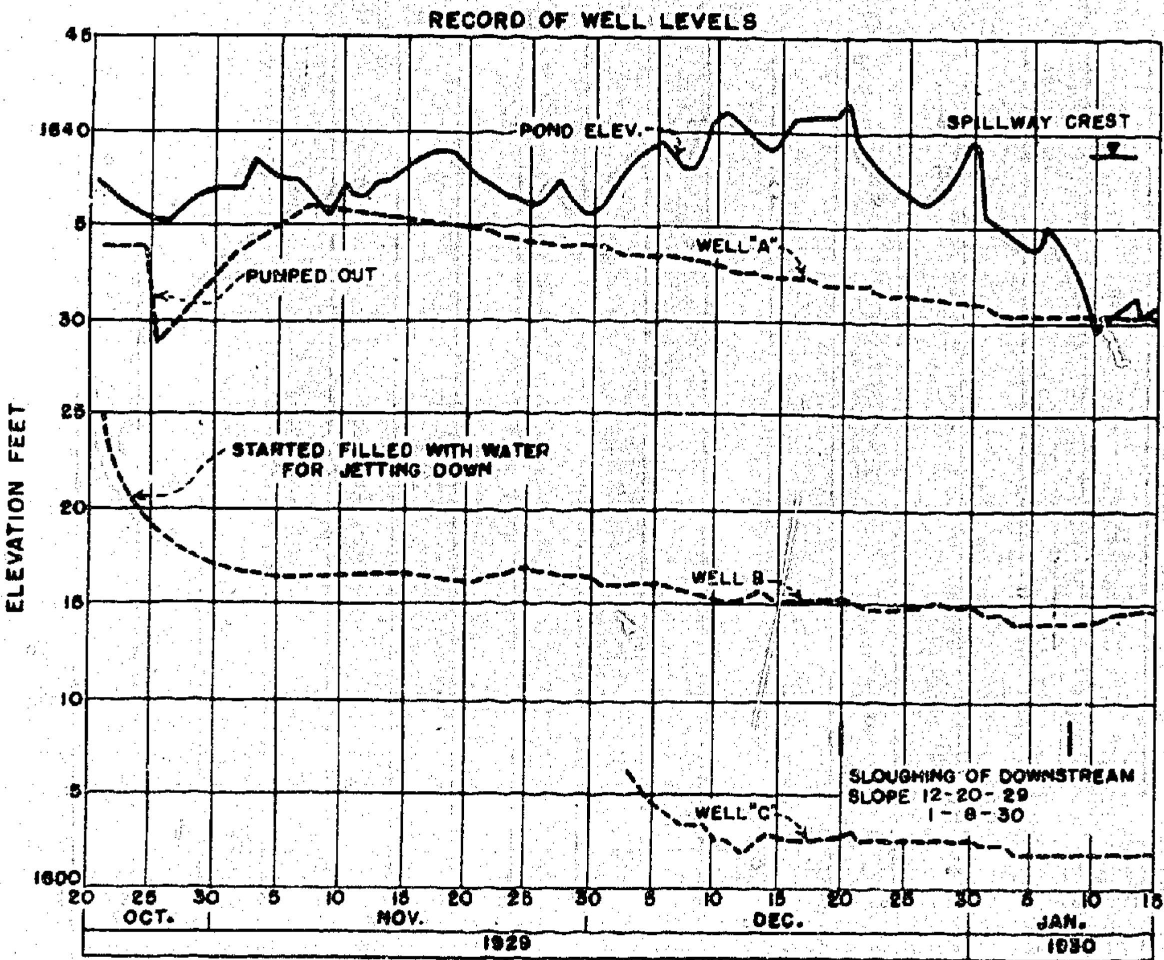
X-D-1615

PLATE 73

MOSHIER DAM

W. P. CREAGER
HYDRAULIC ENGINEER





BUREAU OF RECLAMATION
DENVER, COLO. 1938

X-D-1611

DISCUSSION BY MR. MERRIMAN:

"In 1918, two borings were made for the purpose of determining the condition of the materials in the embankments of the Ashokan Reservoir of the Catskill Water Supply System. These borings were located as shown in Figs. 50 and 51.

The boring shown in Fig. 50 was made in order to disclose the condition of the materials both in the embankment proper and in the original material beneath it. Dry samples were taken at 10-ft. intervals and their moisture content was determined. The results indicated an average moisture content of 12 to 18%, based on the dry weight. After drying, the evaporated water was replaced, and it was found that, in order to produce saturation, the addition of approximately 7% more moisture than that originally contained was required. Here is a case in which material lying up-stream from a core-wall and from 0 to 70 feet below water level was not saturated.

The material incorporated in this dam is the local glacial drift, composed largely of rock flour and clay with some fine sand. It is highly impervious to water and was placed in layers 4 inches thick after compacting with a 15-ton roller.

The boring shown in Fig. 51 was made in order to determine the condition of the embankment near the bottom, where the material had been placed by dumping into a pool of water, to Elevation 522, above which the embankment was rolled in 4-inch layers, as already described.

Between Elevations 597 and 522, the material which had been rolled showed the same moisture content as that described for Boring No. 1. Below Elevation 522, the material became softer, until at Elevation 511 it was saturated. Therefore, this material, which was placed in 1909, had not, in 9 years, given up its original moisture, whereas, during the same length of time, the material above it had received but little, if any, moisture, in addition to that which it had when placed.

In other words, this structure has no "line of saturation." It is a difficult and tedious operation to determine the line of saturation in a completed embankment. The pipes driven are usually jetted or washed down, and the process results in injecting unknown quantities of water into the structure. Before the line of saturation can be determined, the effects resulting from this added water must be allowed to pass. Weeks, and possibly months, are required before trustworthy results can be obtained in a structure built of impervious material. No water-level results of value were obtained from the borings described."

ASHOKAN DAM
NEW YORK

THADDEUS MERRIMAN
TRANS. A.M. SOC. C.E. 1924 P. 110

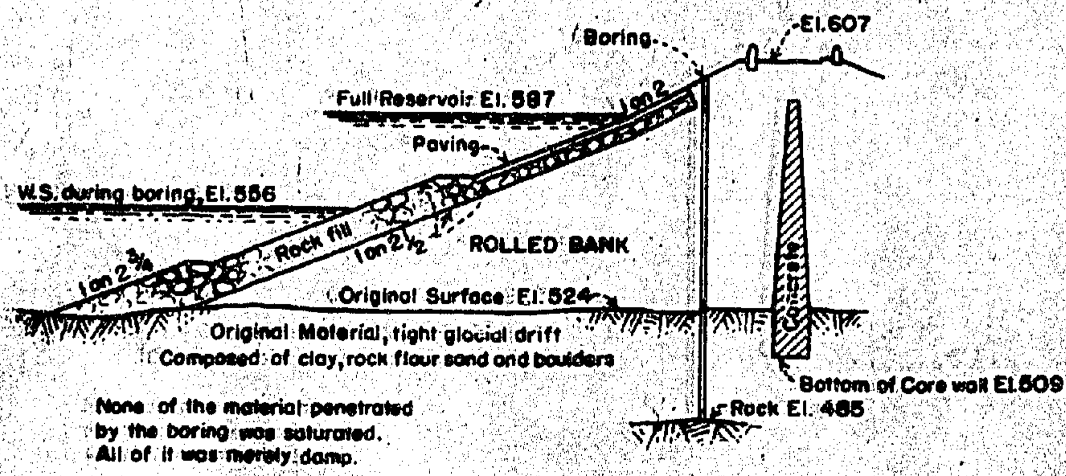


FIG. 50

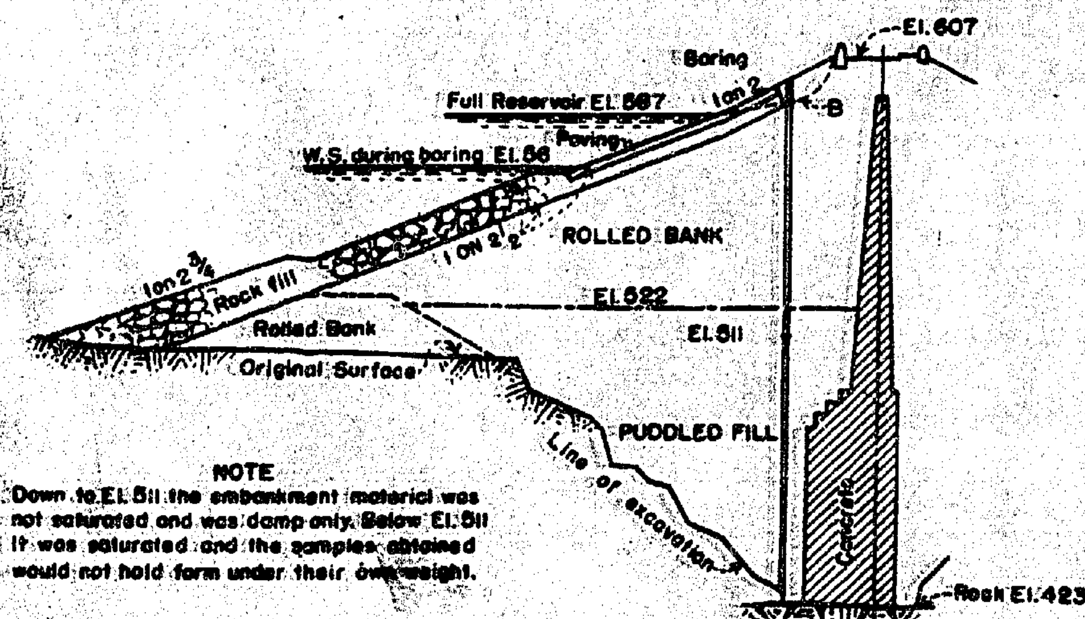


FIG. 51

BUREAU OF RECLAMATION
DENVER, COLO., 1938.

X-D-1612

Denver, Colorado,
May 16, 1935.

MEMORANDUM TO E. W. LANE, RESEARCH ENGINEER
(D. P. Barnes, Assistant Engineer)

Subject: Ground water classifications (Phreatic and Capillary Zones).

1. Recent experiments on the flow of ground water both in the Earth Laboratory of the Bureau of Reclamation and elsewhere have demonstrated that where a zone of complete capillary saturation exists in conjunction with a flowing ground water table, flow will take place between the zones; the line of zero pressure thus ceases to represent either a stream line or a saturation line, both of which identities are generally conceded when capillary effects are ignored. In order to prevent increasing confusion of terms, the following definitions and distinctions are proposed.

2. Capillary zone vs. Gravity zone. No significant difference appears to exist between the character of the flow in a completely saturated capillary zone and that of the flow in the zone of positive pressure. The direction of flow is determined in either zone by the boundaries of the permeable material and by the available capillary rise. The only distinction remaining between the zones is that of their hydrostatic pressures which pass from positive in the gravity zone to negative in the capillary zone; in other words, the line of zero pressure thus becomes the boundary which marks the transition from capillary water to gravity water or the reverse.

3. Terminology. In 1923 O. E. Meinzer[1] presented a brief etymological sketch of the term "phreatic", stating that it was first "introduced by Daubree[2] (1887) to designate the water in the zone of saturation except the deeper water below impermeable beds." He mentions also that a few American geologists[3] have used the term, and concludes by recommending that the expression "'phreatic water' be regarded as a synonym of ground water--including all water in the zone of saturation." However, Meinzer makes no distinction which recognizes a zone of complete capillary saturation, for on a succeeding page he describes ground

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1 U.S.G.S. Water Supply Paper No. 489, pp. 38 et. seq.
2 Les Eaux Souterraines a l'Epoque Actuelle, Vol. 1, p. 19, Paris.
3 Hay, R.; Artesian and Underflow Investigations; 52nd. Cong., 1st session, S. Ex. Doc. 41, pt. 3, p. 8, 1893.
McGee, W.J.; Potable Waters of the Eastern United States; U.S.G.S., 14th Am. Rept., pt. 2, pp. 15-16, 1893.
Daly, R.A.; Genetic Classification of Underground Volatile Agents; Econ. Geol., Vol. 12, pp. 495-499, 1917.

water as that which supplies springs and wells. Furthermore he provides a term, "vadose" or "suspended subsurface water" for water in the zone of aeration, a term which might well be extended to include water in the zone of complete capillary saturation.

Other writers, including Zunker[4], Körner[5], Kozeny[6], and Nemenyi[7], describe the zero pressure line as the "ground water" line, the "free water line", or the "apparent ground water level". In a paper by Wyckoff, Botset, and Muskat[8], the upper boundary of the zone of complete capillary saturation is called the "capillary free surface."

Although it is not entirely clear whether Meinzer intended to comprehend the zone of capillary saturation within the term ground water (since he states both that ground water supplies springs and wells, and that ground water should include all the water in the zone of saturation), it is fair to conclude that the term is most generally used in the sense of free water under zero or positive pressures. To describe all water below the zero pressure line as "phreatic" water appears even more justifiable, for the word being less known will not be subject to ambiguous interpretation resulting from conflicting usage. Its general definition (Webster), of or pertaining to wells, may be thought of as suggesting that the phreatic surface is the surface indicated by the water level in a well when the well is not driven so deeply as to intersect regions at different potentials.

This precise usage of the term appears in an article by G. H. Van Mourik Broksman and A.S. Buisman[9], in which the line of zero pressure in a model earth dam is clearly illustrated as the "phreatic" line.

4. <u>Conclusion</u>. In view of the foregoing, it is proposed that subsoil waters be distinguished as to whether they line within (1) the zone of aeration, (2) the zone of complete

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4 F. Zunker; Handbuch der Bodenlehre, Vol. VI, 1930.
5 B. Korner; Erforschung der physikalischen Gesetze nach velchen die Durcheickerung durch eine Talsperre oder durch den Untergrund stattfindet, ler Congres des Grands Barrages, Stockholm, 1933.
6 Kozeny; Uber Grundwasserbewegung (Concerning Ground water flow), Wasserkraft u Wasserwirtschaft, no. 5 et. seq., 1927.
7 P. Nemenyi; Die Grundwasserbewegung (groundwater flow), Handbuch der techn. u. phys. Mechanik, Vol. V, 1930, p. 1116.
8 Flow of Liquids through Porous Media, Physics, V. 3, Aug., 1932.
9 Waterspanningen in Dijken en Dammen, De Ingenieur, V.49, n.32, Aug. 10, 1934.

capillary saturation, or (3) the zone of positive hydrostatic pressure. It is further proposed that the line of zero pressure representing the boundary between zones (2) and (3) be known as the phreatic line, and that the boundary between zones (1) and (2) be known as the saturation line. Alternate expressions describing the three zones might be equally acceptable as follows:

(1) Zone of Aeration = Zone of Partial Capillary Saturation.

(2) Zone of Complete Capillary Saturation.

(1) and (2) Combined. Capillary zone - Zone of Suspended sub-surface Water = Zone of Vadose Water = Zone of Negative Hydrostatic pressure.

(3) Zone of Positive Hydrostatic Pressures = Zone of Phreatic Water = Free Ground Water Zone = Gravity Zone.

It is thought that the term ground water should only be used when properly qualified or when further distinction is of no significance.

Denver, Colorado, May 6, 1935.

MEMORANDUM OF MR. E. W. LANE, RESEARCH ENGINEER
(D. P. Barnes, Assistant Engineer)

Subject: A universal permeability classification.

1. Although "permeability" is a term upon whose general meaning there is almost universal agreement, the units in which it is at present measured differ widely. A method is herewith suggested by means of which dimensions peculiarly suitable to particular fields of investigation would be retained, but an additional classification scale covering the entire range of porous materials would be introduced.

2. Present practice in the earth laboratory defines permeability, k, as cu. ft. per year per sq. ft. for a head loss of one foot in a foot of length; or simply, ft. per year through unit area under unit gradient, the units being homogeneous. In the concrete laboratory, permeability is given in ft. per second. European soil mechanics laboratories and the laboratories of the U. S. Bureau of Public Roads and the Massachusetts Institute of Technology refer to k in cm. per sec.

3. Tests made in the laboratories of the Bureau of Reclamation and elsewhere indicate that the extreme range of k likely to be encountered in studies with granular materials lies between about 2.3×10^{-11} cm. per sec. for dense concrete and 3.1×10^{-1} cm. per sec. for fine sand and gravel (see table I). For this reason it has been thought logical that the basis for classification should be the power of ten which expresses the magnitude of k when the units employed are cm. and seconds. Thus a permeability of 2.5×10^{-5} cm. per sec. would indicate a class 5 material.

4. As examples of typical materials arranged in accordance with the classification proposed, table I is presented. Table II is a table of equivalents defining the ranges of k within each class in terms of different systems of units.

TABLE 1

Representative Values of the Permeability Coefficient, k

Material	k (ft./yr.)	k (cm./sec.)	Class
Concrete (water-cement ratio .5 to .6)	.000 024 to .000 36	.000 000 000 023 to .000 000 000 35	11-10
Granite	.000 046 to .000 24	.000 000 000 046 to .000 000 000 23	11-10
Concrete (W/C .6 to .7)	.000 072 to .002 4	.000 000 000 07 to .000 000 002 3	11-9
Slate	.000 072 to .000 17	.000 000 000 07 to .000 000 000 16	11-10
Concrete (W/C .7 to .8)	.000 19 to .014 2	.000 000 000 18 to .000 000 013 7	10-8
Breccia	.000 48 on up	.000 000 000 46 to	10-
Calcite	.000 72 to .096	.000 000 000 7 to .000 000 093	10-8
Limestone	.000 72 to .12	.000 000 000 7 to .000 000 12	10-7
1. Concrete (W/C .8 to 1.0	.000 96 to .096	.000 000 000 93 to .000 000 093	10-8
Limestone as at Madden Dam	.001 2 to .096	.000 000 001 2 to .000 000 093	9-8
Dolomite	.004 8 to .012	.000 000 004 6 to .000 000 012	9-8
Clay cores for earth dams	.024 to 24.	.000 000 023 to .000 023	8-5
Biotite gneiss, undisturbed	.024 to 2.4	.000 000 023 to .000 002 3	8-6
Sandstone	.17 to 12.	.000 000 16 to .000 012	7-5
Slate, undisturbed	.024 to 24.	.000 000 023 to .000 023	8-5
Concrete canal lining	2.4 to 48.	.000 002 3 to .000 048	6-5
Colo. River silt	1 500.		3
Beach sand	9 200. to 22 300	.008 9 to .021 6	3-2
Dune sand	19 100.	.018 5	2
2. River sand	42 000. to 276 000	.041 to .266	2-1
Loam and river sand	2 300.	.002 2	3
Undisturbed soils, fine sand to gravel	16 900. to 327 000	.016 3 to .316	2-1
Casper Alcova	.46	.000 000 44	7
Rye Patch	.50	.000 000 48	7
Hyrum	.41	.000 000 40	7
3. Agency Valley	.02	.000 000 019	8
All American Canal	.20	.000 000 19	7
Belle Fourche Dam	.20	.000 000 19	7

1. Compiled by S. P. Wing and A. F. Johnson - See technical memo. no. 377.
2. K. Terzaghi, in "Erdbaumechanik."
3. Average values obtained in earth laboratory.

TABLE II

Equivalent Permeability Ranges

Class	k cm./sec.	ft./yr.	ft./da.	ft./hr	ft./min.	ft./sec.	in./hr.	gal./ft.²/da.
11	1×10^{-11} to 1×10^{-10}	1.03×10^{-5} to 1.03×10^{-4}	2.84×10^{-8} to 2.84×10^{-7}	1.18×10^{-9} to 1.18×10^{-8}	1.97×10^{-11} to 1.97×10^{-10}	3.28×10^{-12} to 3.28×10^{-11}	1.42×10^{-8} to 1.42×10^{-7}	2.13×10^{-7} to 2.13×10^{-6}
10	to 1×10^{-9}	to 1.03×10^{-3}	to 2.84×10^{-6}	to 1.18×10^{-7}	to 1.97×10^{-9}	to 3.28×10^{-10}	to 1.42×10^{-6}	to 2.13×10^{-5}
9	to 1×10^{-8}	to 1.03×10^{-2}	to 2.84×10^{-5}	to 1.18×10^{-6}	to 1.97×10^{-8}	to 3.28×10^{-9}	to 1.42×10^{-5}	to 2.13×10^{-4}
8	to 1×10^{-7}	to 1.03×10^{-1}	to 2.84×10^{-4}	to 1.18×10^{-5}	to 1.97×10^{-7}	to 3.28×10^{-8}	to 1.42×10^{-4}	to 2.13×10^{-3}
7	to 1×10^{-6}	to 1.03×10^{0}	to 2.84×10^{-3}	to 1.18×10^{-4}	to 1.97×10^{-6}	to 3.28×10^{-7}	to 1.42×10^{-3}	to 2.13×10^{-2}
6	to 1×10^{-5}	to 1.03×10^{1}	to 2.84×10^{-2}	to 1.18×10^{-3}	to 1.97×10^{-5}	to 3.28×10^{-6}	to 1.42×10^{-2}	to 2.13×10^{-1}
5	to 1×10^{-4}	to 1.03×10^{2}	to 2.84×10^{-1}	to 1.18×10^{-2}	to 1.97×10^{-4}	to 3.28×10^{-5}	to 1.42×10^{-1}	to 2.13×10^{0}
4	to 1×10^{-3}	to 1.03×10^{3}	to 2.84×10^{0}	to 1.18×10^{-1}	to 1.97×10^{-3}	to 3.28×10^{-4}	to 1.42×10^{0}	to 2.13 to 10^{1}
3	to 1×10^{-2}	to 1.03×10^{4}	to 2.84×10^{1}	to 1.18×10^{0}	to 1.97×10^{-2}	to 3.28×10^{-3}	to 1.42×10^{1}	to 2.13×10^{2}
2	to 1×10^{-1}	to 1.03×10^{5}	to 2.84×10^{2}	to 1.18×10^{1}	to 1.97×10^{-1}	to 3.28×10^{-2}	to 1.42×10^{2}	to 2.13×10^{3}
1	to 1×10^{0}	to 1.03×10^{6}	to 2.84×10^{3}	to 1.18×10^{2}	to 1.97×10^{0}	to 3.28×10^{-1}	to 1.42×10^{3}	to 2.13×10^{4}