THE USE OF NON-UNIFORM SAND
IN MOVABLE-BED HYDRAULIC MODELS

A Thesis
Presented to
The Faculty of Engineering
The University of Manitoba

In Partial Fulfillment
of the Requirements for the Degree
Master of Science in Civil Engineering

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December 1965

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ABSTRACT

The purpose of this study is to investigate the behaviour of non-uniform sand when used as bed material in movable-bed hydraulic models.

A review of the literature was made and an introductory chapter is included outling the history and utilization of hydraulic models, their laws of similitude, and the various types of hydraulic models. Special reference is made to movable-bed hydraulic models and the selection of bed material.

A channel was constructed in sand with a bottom width of four feet and side slopes of two horizontal to one vertical. A rectangular cofferdam extended from one bank to the centre line of the channel. Several preliminary tests were run to establish a typical scour pattern under a fixed set of flow conditions. Scale models of this arrangement were built and tested. The object of the tests was to attempt to reproduce the established scour pattern adjacent to the cofferdam and on the established set of flow conditions.

The study concludes that, in flow situations resulting in both bed and side slope scour, representative scour patterns cannot be reproduced in a scale model using non-uniform sand without some form of distortion being employed.

With respect to depth of scour in a non-uniform sand bed, it is indicated that the depth of scour depends primarily on the size of the largest particles in the bed material and to a secondary degree on the shape of the grain-size distribution curve.

Acknowledgement

I wish to thank Professor E. Kuiper for his inspiration during my post graduate studies; and also Professors W.F. Riddell and A.J. Carlson for their continued encouragement and support during the writing of this thesis.

To my wife, Margaret

TABLE OF CONTENTS

CHAPTER PAGE

I HYDRAULIC MODELS. 1

A. Utilization 1
B. Laws of Similitude. 2
C. Distortion in Models. 5
D. Fixed-Bed and Movable-Bed Models. 9
E. Materials for Movable-Bed Models. 11
F. Relationship of Grain Size & Distribution to Scour Depth. 14

II OUTLINE OF PRESENT STUDY. 18

A. Object. 18
B. The Structure 18
C. The Materials 19
D. The Program of Investigation. 20

III DISCUSSION OF CONSTRUCTION AND TESTING PROCEDURE. . 22

A. The 1:50 Scale Model. 22
B. The 1:100 and 1:200 Scale Models. 26

IV OUTLINE OF TESTS AND OBSERVATIONS 30

A. Preliminary Tests - Scale 1:50. 30
B. Model Scale 1:100 33
C. Model Scale 1:200 38
D. General Observations. 39

V CONCLUSIONS AND RECOMMENDATIONS 43

APPENDIX A: TABLES AND FIGURES. 46

APPENDIX B: SIEVE ANALYSIS FORMS. 57

APPENDIX C: SPECIFIC GRAVITY TESTS. 66

APPENDIX D: TEST RESULTS. 72

SOURCES CONSULTED. 226

List of Figures

FIGURE PAGE

1(a) Grain Size vs. Critical Tractive Force. 16

1(b) Grain Size Distribution. 16

1(c) Discharge Distortion Necessary to Reproduce Side Slope Erosion vs. Model Scale. 49

2 Depth of Scour at Proper Side Slope Erosion vs. Model Scale. 50

3 Depth of Scour vs. Selected Material Properties . 51

4 Depth of Scour vs. D_{90} Size 52

5 Depth of Scour vs. Uniformity Coefficient 52

6 Depth of Scour vs. Mean Deviation 53

7 Grain Size Distribution Curves. 54

8 Flow Pattern 1:50 Model. 55

9 Photograph of Apparatus for 1:100 and 1:200 Models 56

List of Tables

TABLE I - MATERIAL PROPERTIES. 47

TABLE II - TEST DATA. 48

NOTATION

A - Area (ft.^{2})

a - Acceleration (ft/sec.^{2})

C_u - Coefficient of uniformity

D - Grain size

D_{10},D_{50}, etc. - subscript denotes the percentage of material that is finer than the given size

d_s - Depth of scour

e - Subscript denoting elasticity

F - Force (lb.)

g - Acceleration of gravity

i - Subscript denoting inertia

L - Length (ft.)

m - Mass - also subscript denoting model.

p - Pressure - also subscript denoting prototype

Q - Discharge (ft^3/sec)

q - Discharge per unit width (ft^3/sec)

r - Subscript denoting ratio of model to prototype

R - Hydraulic radius (ft)

S - Friction slope

T - Time (sec)

t - Subscript denoting surface tension

v - Subscript denoting viscosity

V - Velocity (ft/sec)

$\overline{V}$ - Volume (ft^3)

ρ - Density (lbs/ft^2/sec^2)

τ_c - Critical tractive force

CHAPTER I

HYDRAULIC MODELS

A. UTILIZATION(6,8)

The idea of using models as a means of determining full scale performance was conceived by Sir Isaac Newton almost 300 years ago when he stated the "Principle of Similitude" in his treatise, the "Principia". It was not until about 1860 however, that the principle was first put to use. Froude, an English Naval engineer used it to study the best design of a ship's hull by the use of several models, and a towing tank. The first true river models made their appearance in 1875 in France and ten years later in England, when Professor Reynolds used scale models to study tidal flows in the Mersey estuary.

The beginning of the twentieth century saw activity in the science of river research under Professor Engel of Dresden and Dr. deThierry of Berlin. Following the World War I, the use of scale models was extended to include studies of bed movement in rivers. Since that time, the utilization of hydraulic models has expanded until at present in most of the major countries of the world, there are an increasing number of laboratories engaged in the study of a wide range of problems, from the design of hydraulic machinery to the best means of dissipating energy below hydraulic structures in order to reduce river bed scour. The design of hydraulic structures and machinery today is commonly either accomplished or checked by model measurements.

B. LAWS OF SIMILITUDE(5,6)

In showing the development of the principles of similitude, it is necessary first, to mention the various forms of similarity involved. These are defined as follows:

1. Geometric similarity exists when the ratios of all homologous dimensions on the model and prototype are equal.
2. Kinematic similarity exists when the ratios of all homologous velocities and accelerations are equal in the model and prototype.
3. Dynamic similarity requires that the ratios of all homologous forces be the same in model and prototype.

Thus geometric similarity is similarity of form, kinematic similarity is similarity of motion, and dynamic similarity is similarity of force system.

If the model and prototype are geometrically similar, then the scale ratio (or length ratio) is denoted by:

$$L_r = \frac{L_m}{L_p}$$

where L_m and L_p are corresponding linear dimensions in model and prototype respectively.

Then:

$$\text{Area Ratio } A_r = \frac{L_m^2}{L_p^2} = L_r^2$$

and

$$\text{Volume Ratio } \bar{V}_r = \frac{L_m^3}{L_p^3} = L_r^3$$

Kinematic similarity is expressed in terms of the time ratio, T_r, and the length ratio, L_r . Thus

$$\text{Velocity ratio } V_r = \frac{V_m}{V_p} = \frac{L_m T_p}{T_m L_p} = \frac{L_r}{T_r}$$

Then,

$$\text{Acceleration ratio} = \frac{a_m}{a_p} = \frac{V_r}{T_r} = \frac{L_r}{T_r^2}$$

and

$$\text{Discharge ratio } Q_r = A_r V_r = \frac{L_r^3}{T_r} .$$

Dynamic similarity implies that the ratio of the inertial forces must equal the ratio of the vector sums of the active forces. This follows from Newton's second law of motion and can be written:

$$(F_i)_r = m_r a_r = (F_p +\!\!\!\rightarrow F_g +\!\!\!\rightarrow F_v +\!\!\!\rightarrow F_t +\!\!\!\rightarrow F_e)_r$$

where F_i = inertial force or mass reaction to the forces acting.

and F_p, F_g; F_v, F_t are F_e are, respectively, the forces due to pressure, gravity, viscosity, surface tension and elasticity.

Perfect similitude requires in addition that:

$$(F_i)_r = (F_p)_r = (F_g)_r = (F_v)_r = (F_t)_r = (F_e)_r \quad .$$

The pressure ratio is usually regarded as the dependent quantity and does not enter into further development of similitude equations.

No model fluid has the required viscosity, surface tension and elasticity to assure conditions of perfect dynamic similitude. However, for practical purposes, a particular fluid motion can be simulated in the model by considering only one of the forces on the right of the equation as the dominant force and neglecting the others. It has been stated(5) that, in at least 90% of all hydraulic model studies, the forces connected with surface tension and elastic compression are relatively small and can be neglected safely.

In most hydraulic models, as far as the civil engineer is concerned, either gravity forces or viscous forces predominate. In open channel models the similitude relationships are based on the assumption that gravity is the dominant force. Since viscous forces must also exist, they must either be shown to be negligible or measures taken to minimize their effect.

Considering that gravity forces predominate, and ignoring the other forces, the equation for dynamic similarity becomes:

$$\frac{(F_i)_m}{(F_i)_p} = \frac{(F_g)_m}{(F_g)_p}$$

or

$$(F_i)_r = (F_g)_r$$

since

$$F_i = ma = \rho L^3 \frac{L}{T^2} = \frac{\rho L^4}{T^2}$$

and

$$F_g = \gamma L^3 = \rho g L^3$$

then

$$\frac{\rho_r L_r^4}{T_r^2} = \rho_r g_r L_r^3$$

and

$$L_r^2 V_r^2 = g_r L_r^3$$

or

$$\frac{V_r}{\sqrt{g_r L_r}} = 1 \quad .$$

The expression $\frac{V}{\sqrt{gL}}$ is recognized as the Froude number. The equality of the number in model and prototype is the well known Froude Law.

For an open channel model when the Froude law applies, the model prototype relationships are obtained from:

$$V_r = \sqrt{g_r L_r}.$$

Since g_r is unity:

$$V_r = L_r^{1/2}$$

from which $$T_r = \frac{L_r}{V_r} = L_r^{1/2}$$

$$a_r = \frac{L_r}{T_r^2} = 1$$

$$Q_r = \frac{L_r^3}{T_r} = L_r^{5/2}$$

The above ratios apply to undistorted models, that is, models in which the horizontal and vertical scale ratios are the same or in other words, where there is geometric similarity between model and prototype.

C. DISTORTION IN MODELS

Models are not always made geometrically similar to their prototype. It is common practice in models of river channels, canals, floodways, etc. to use different vertical and horizontal scale ratios when the channel width is great in comparison to the depth. This is usually made necessary by space limitations. An undistorted model may have to be quite large so that the depth will be sufficient to insure representative flow conditions. For example, the United States Water Ways Experimental Station Criteria for turbulent flow is that the product of velocity and depth in the model should not be less than a value of 0.02 ft^2/sec.

The U.S. Bureau of Reclamation lists some of the advantages and disadvantages of distorted models.

The advantages of distorted models are:

(1) Sufficient tractive force can be developed to produce bed load movement with a reasonably small model and available model sediment;

(2) Water surface slopes are exaggerated, and therefore easier to determine;

(3) The width and length of the model can be held within economical limits for the required depth; and

(4) Operation is simplified by use of a smaller model.

Several disadvantages are:

(1) Velocities are not necessarily correctly reproduced in magnitude and direction;

(2) Some of the flow details are not correctly reproduced;

(3) Slopes of cuts and fills are often too steep to be molded in sand or erodible material; and

(4) There is an unfavourable psychological effect on the observer who views distorted models.

An additional feature of distorted models is mentioned which may be regarded as a disadvantage. That is, when a model is distorted, the distortion is planned to accomplish a definite objective and the results from such a model are definitely limited to this objective.

Marshall Gysi in his thesis "An Investigation of Distortion in Hydraulic Models",(3) made the following general conclusions with reference to distorted models:

"Distortion should not be used in a movable bed model unless an economic study has shown that an undistorted model cannot be constructed at reasonable cost. If distortion is required, every effort should be made to minimize its effect, and special care should be taken in the verification and analysis of the model. Prototype performances to date, have proven the value of the results obtained from distorted models.

"1. Vertical Distortion

"More care and experience is required in the construction and operation of distorted models. Since the distortion magnifies secondary currents, the analysis of velocity and erosion patterns becomes more difficult, especially if the model contains complicated flow conditions, and channel junctions. Greater bed load movement and more disturbance of flow pattern is likely to occur in vertically distorted model than is a slope distorted model, if they contain the same tractive force.

"Structures in vertically distorted models should be constructed with their longitudinal horizontal scale identical to the vertical scale. If the method used to maintain the proper width of flow over the structure dictates distorted bays between piers, exaggerated side-wall effects will result. Accurate measurements of discharge coefficients and flow profiles would then have to be taken on a larger, undistorted model of the structure. Also if the flow from the structure remains confined, the high velocity jet will appear to travel further downstream in a distorted model than in an undistorted model with the same vertical scale.

"2. Discharge Distortion

"If a laboratory has sufficient pump capacity discharge distortion can be the most economical and versatile method of distortion available. Tests can be run at the normal discharge to obtain flow patterns and water surface profiles and for demonstrative processes. The discharge can then be increased until sufficient tractive force is available for erosion studies. Tests have shown that the discharge ratio can be increased in models with complicated flow patterns without measurably affecting the velocity distribution."

A slight change in discharge distortion can also be used to obtain the proper water surface slopes in verification tests if the exact model roughness is not available.

With regard to Mr. Gysi's statement, "Distortion should not be used in movable bed model unless an economic study has shown that an undistorted model cannot be constructed at reasonable cost", and "every effort should be made to minimize its effect"; it is the author's view that distortion of some kind (scale, discharge or material) is practically always necessary if an analysis of side slope erosion in the model is to have any meaning. Thus, distortion should not be reduced beyond the point where it produces the desired result.

The similitude ratios for distorted models based on the Froude Law are:

Horizontal length ratio = L_r
Depth ratio = D_r
Horizontal area ratio = L_r^2
Vertical area ratio = $L_r \, D_r$
Slope ratio = D_r/L_r
Velocity ratio = $D_r^{1/2}$

D. FIXED-BED AND MOVABLE-BED MODELS

Open channel models usually involve studies of flow patterns or movements of sediment and may be classified into two types: fixed-bed and movable-bed models.

1. Fixed-Bed Models

Problems involving relatively long stretches of a canal or river, wherein actual changes in bed configuration are not critical, are usually studied with the aid of fixed-bed models. Such problems include study of backwater effects in a channel due to obstructions or changes in backwater conditions due to channel improvements, flood routing studies, determination of flow distribution in estuary channels and diversions. Special attention must be given to the similarity of boundary resistance. For a large model the velocity may be high enough to insure turbulent flow and if the minimum model roughness gives smooth enough boundaries to properly represent the prototype, a geometrically similar model may be used.

In smaller models distortion of slope is required; (1) to offset the disproportionately high resistance of the model boundaries and, (2) to obtain a sufficiently high value of Reynolds number to insure turbulent flow.

Distortion in slope required to satisfy condition (1) can be computed by the Manning formula:

$$V_r = D_r^{1/2} \frac{R_r^{2/3} S_r^{1/2}}{n_r}$$

Substituting D_r/L_r for S_r and rearranging:

$$\frac{D_r}{L_r} = \frac{n_r^2 D_r}{R_r^{4/3}}$$

Thus, if n_r is known, the distortion can be computed for the hydraulic radius ratio of the mean section.

When the slope distortion required to satisfy condition (2) is greater than that required for condition (1), the model must be made rougher by artificial means to compensate for the exaggerated slope.

Usually the model distortion is determined first on the basis of space limitations and Reynolds number requirements and then verified by adjusting the roughness at several mean sections to reproduce a series of known or computed backwater curves for the prototype. This is a cut and try method involving the placing of screens or metal rods at the various sections.

2. Movable-Bed Models

To study an open channel problem involving scouring, deposition and transportation of channel-bed material, movable-bed models are used. Despite the limitations of the similitude obtainable with movable-bed models, they have proved to be a valuable aid in the solving of complex problems involving the shifting of stream bed materials.

The essential difference in the design of movable-bed models and fixed bed models is that in the former the criteria for successful operation depends largely on similitude of bed movement rather than on strict mathematical laws of similitude. The general design approach is to select scales and bed material which will result in bed movement similar to that in the prototype. When the model study is done to determine probable trends in bed movement prior to the construction of the prototype, the usual procedure is to select model scales as dictated by space requirements using as little distortion as possible and selecting a bed material which will show general movement under simulated conditions to that of the prototype bed material. The difficulty here sometimes lies in finding a material which will give the required movement and yet be coarse enough not to result in excessive rippling. It is often necessary to resort to a greater degree of distortion (scale, discharge or slope), or a lightweight bed material or both. As a rule, distortion should be kept as low as possible. The undesirable effects of vertical distortion have already been mentioned. In models built to study the performance of structures in open channels, it is feasible to construct the model with a fixed-bed upstream of the model structure and a movable bed downstream. In this way, upstream backwater and structure inlet performance can be studied as well as downstream erosion. In the case of the Portage Diversion model study, carried out by the University of Manitoba in 1964, the problem was to study the performance of various drop-structure designs in a straight transition channel. Since prototype design velocities upstream were below critical eroding velocity, a material (medium mortar sand-material #3) was chosen which would give the correct model roughness and this was used both upstream and downstream of the structure. By the nature of the model, any available sand would erode below the structure and therefore, by choosing the correct roughness, the above mentioned model was considered to be a fixed-bed having Froude law similitude upstream and a movable-bed downstream.

E. MATERIALS FOR MOVABLE-BEDS

Much could be written here and has been written elsewhere on the subject of movable-bed material. There does not appear, as yet, to be any acceptable criteria for the selection of material for movable-bed models. Most laboratories have their own set of rules based on their own experience. By the very reason for model testing, no two models are identical and each, therefore, must be dealt with on its own merits. The selection of material is generally made by trial and error during the verification process of the model.

Engineering Monograph No. 18 of the United States Bureau of Reclamation contains the following comments on bed material:

> When the dimensions of a water course, including the particle size of the bed material, are scaled down to model size, a discontinuity is encountered. The usual model scales result in sediment particles which are so small that they no longer act like bed material, but tend to become either suspended or compacted into an unyielding bed. The necessity for using bed material of particle size greater than required on a dynamic basis necessitates the use of geometrical distortion in order to obtain the essential movement of bed material.
>
> In problems involving the study of sediment action relating to a structure such as the canal intake and sluiceway of a diversion dam, distortion which would include the structure, is not advisable. In such cases, the model must be large enough to insure movement of available model sediment.
>
> The difficulties of compromising resistance and bed movement have been minimized by using various model materials of lower specified gravity, so that less scale distortion is required to produce proper movement. Among such materials are coal, pumice, sawdust, ground plastics, etc.

A.S.C.E. Manual of Engineering Practice, No. 25(4), contains the following comments:

> The bed material most suitable in movable-bed river models is a processed coal, carefully prepared as to grain size and specific gravity. A commercial lightweight concrete aggregate "haydite" is sometimes used, and is often mixed with coal to simulate the areas composed of relatively resistant materials. In several tidal models, gilsonite has been used for simulating silt carried in suspension. This is an asphaltic material, almost pure bitumen , and is difficult to handle in water. Other gilsonites of specific gravity 1.05 and 1.20 and a number of resins of specific gravity 1.09 and 1.13 which, together with crushed coal (1.30) haydite (1.85) and sands of various sizes (2.65) consistitute the principal stack of movable-bed material used at present.

Marshall Gysi in his thesis included a discussion of movable-bed material based on a tour of several large laboratories in the United States, and a review of the literature. He made the following general conclusions:

(1) Such lightweight materials as pumice and sawdust should usually be avoided, since their specific gravities tend to change under prolonged exposure to water.

(2) Coal is a very dirty material when used in a circulating laboratory system. In a system where the water is only used once and then discharged, this problem is overcome. There is a tendency for the particles to float in clusters, as the model is being filled.

(3) Crushed plastics are a very clean material with which to work. They have a variety of specific gravities, from bakelite at 1.40 to styro-plastics at close to 1.00. Their specific gravities do not change under exposure to water. However, the cost of plastics for bed materials is relatively high. They should be considered only for very small models or as a necessary measure to avoid extreme distortion. They have been used successfully for suspended sediment studies.

(4) Sand or srushed stone appear to be the widely accepted bed material used in hydraulic model studies in North America. No standard practice is followed in choosing the proper grain size, and experience is a valuable asset when performing this task.

(5) If an attempt is to be made to actually predict the quantity of scour in the prototype from the results of the model study, it has been suggested that fall velocity of the bed material should be chosen according to the velocity scale of the model. Great care should be taken

in the verification of this type of model.

(6) The majority of movable bed model studies are carried out for the purpose of comparing the reaction of alternative man-made hydraulic structure, on the regime of a channel. For these studies, verification of the model is not as important. In the interests of keeping the required testing time to a minimum, as fine a material as possible should be chosen, the limit being set by the occurence of rippling. The material should be reasonably "one-sized", (a uniformity modulus less than two), to avoid the premature movement of the finer particles, which would result in sorting.

(7) Preliminary flume tests can aid in the choice of the bed material, but may give a misleading picture of its rippling qualities."

The author concurs with Gysi's conclusions in particular with reference to the widely accepted use of sand as a bed-material and as to its choice being dependent largely on individual experience. This of course, is with reference to bed-material only and not suspended load.

F. RELATIONSHIP OF GRAIN SIZE AND DISTRIBUTION TO SCOUR DEPTH

There is no general agreement among researchers as to the effect of grain size and grain size distribution on the maximum depth of scour.

Ahmad(1) has suggested the following formula for flow depth plus depth of scour around spur dikes:

$$(D + d_s) = K\, q^{2/3}$$

where q is the discharge intensity at the contraction and K is a constant depending on flow concentration and angle of spur dike. This shows that depth of scour is a function of q but does not indicate what role sediment size and void ratio may have on scour depth.

In a discussion on the model study of the Brown Canyon debris barrier(2), E. Scimemi showed that maximum possible scour depends on the balance between the energy in the plunging nappe and the energy loss in the whirlpool below a structure and that the actual depth is also a function of the material size in the hole with the scour approaching a finite maximum as the material size approaches zero.

It is obvious that in a given flow situation, scour will occur if there is more energy available in the moving fluid mass than is required to cause the bed material to move. To what extent scour takes place in a given situation has been the subject of many such experiments as those mentioned above. Most of the experimental work has been done with more or less uniform material. An approach to the analysis of scour in scaled models with bed materials containing an assortment of sizes has been offered by R.W. Newbury.(7)

Mr. Newbury says, in effect, that given a certain flow condition over a movable sand bed, sand grains under a given size in the bed can be expected to move by virtue of the available tractive force. Due to velocity variation as with turbulent flow, the given size will actually be within a certain range of critical tractive force values, (Fig. 1A). (See following page 16).

Given the grain size distribution of the bed material, the weight of material that can potentially be moved (disregarding paving) can be calculated. (Fig. 1B).

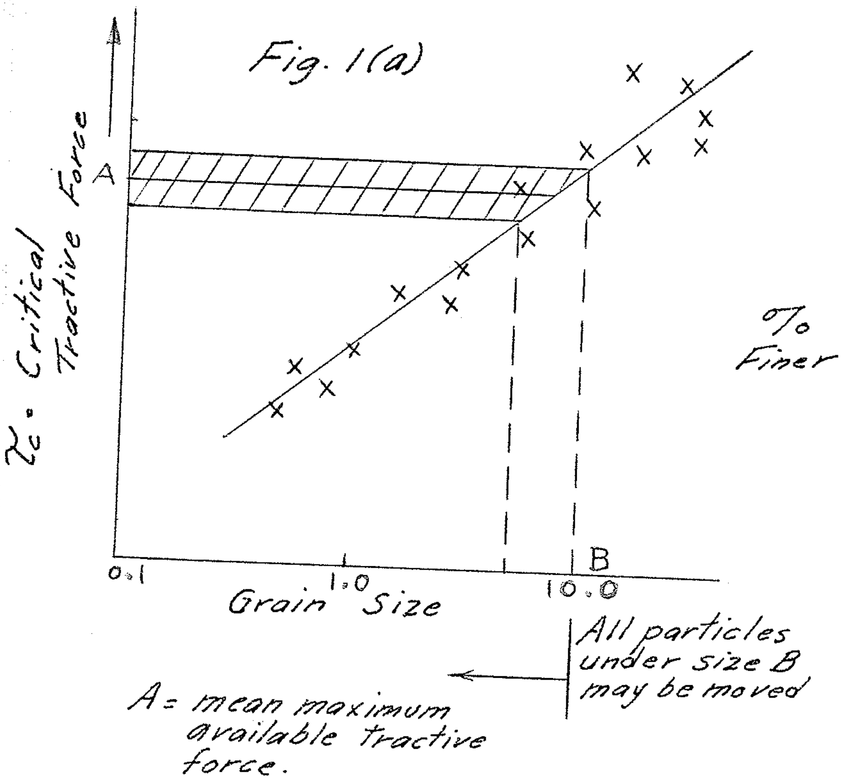
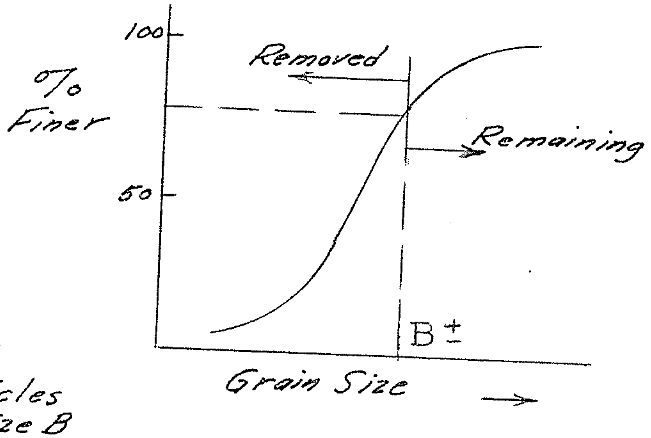


Fig. 1(a)

Fig. 1(b)



The change in volume associated with the weight removed will be a function of the grain size distribution of the material.

Mr. Newbury says, further, that if the removal of particles did not affect the tractive force, fine material would be removed until the bed was paved with particles requiring more tractive force than that available. Thus, the depth of scour is a function of:

1. available tractive force;
2. the fraction of particles (volume change) that can be moved by the available tractive force;
3. the availability of movable particles at the surface of the bed.

Actually as scour progresses local tractive force is reduced proportionally by virtue of lower velocities so that the equilibrium between available tractive force and the critical tractive force of the larger particles will occur at a lesser depth than if the original tractive force could be maintained.

When the scour process is scaled down in models, we have reduced the tractive force. The scaling down of scour depends as much on the grain size distribution as on the new available tractive force. Thus, a new relationship between available tractive force and the portion of bed material that can be moved by this force, must be derived.

The problem, says Newbury, is to make the volume that can be moved vary directly as the tractive force varies with the different scales. This, he points out, is unlikely if the same material is used in model and prototype.

With regard to the latter statement, it should be mentioned that slope and discharge distortion can be used to regain tractive force lost by scaling when using the same material. This is the method that was used in this study as the author has restricted himself to the use of materials having the same specific gravity.

CHAPTER II

OUTLINE OF PRESENT STUDY

A. OBJECT:

From the foregoing chapter it can be surmised that, allowing for exceptions arising due to space limitations, movable bed models should be as nearly undistorted as possible and therefore necessarily quite large. Among the problems encountered in selecting suitable bed material for such models is the matter of economy. Large models require large quantities of bed material. The ideal material is one which possesses as near as possible, all of the theoretical characteristics required of it for exact similitude and which is readily available at low cost. Such a material is not likely to be found.

Furthermore, it has been stated that a movable bed model study is rarely, if ever, a quantitative analysis. Usually it is used in determining the trend of scour patterns developing near hydraulic structures and minimizing the extent of scour by suitable modifications in structure design or channel alignment. Frequently all that is required of the material is that it should develop scour trends without excessive rippling. It is desirable, of course, that the material should move at critical eroding velocities representing prototype behaviour.

It is the purpose of this investigation to study the behaviour of various readily available materials when used in several models of the same prototype. The primary objective is to reproduce the scour pattern in each model by the use of one or more of three types of distortion:

(1) material,

(2) vertical scale,

(3) discharge.

It is hoped that, in this study a useful relationship may be suggested between model-prototype ratio and model distortion which will provide further assistance to model builders in selecting suitable bed material. The scope of this investigation does not include those studies involving the introduction of sediment into the model during testing.

B. THE STRUCTURE

The type of structure chosen for this investigation was a rectangular cofferdam extending half-way across a trapezoidal channel having side slopes of two horizontal to one vertical. It was felt that this arrangement would be more realistic than merely employing vertical non-erodable side walls, which would limit the investigation to a study of depth of scour on the channel bed. Actually a combination of bed scour and bank scour is the usual case.

It should be pointed out that the use of a rectangular cofferdam in this investigation was not for the express purpose of studying the particular scour pattern by flow around a rectangular cofferdam. The purpose of the cofferdam was principally to ensure that scour would occur. The essential feature of the study was the attempt to reproduce the initial pattern in subsequent models. The construction of the models will be discussed in Chapter III.

C. THE MATERIALS

The materials used in the study were chosen for their availability and range in fineness. A brief description of the materials is given :

Material No. 1: Coarse mortar sand.

Material No. 2: Same material as (1) except screened to a more uniform size.

Material No. 3: Medium mortar sand.

Material No. 4: Fine mortar sand.

Material No. 5: Coarse white silica sand.

Material No. 6: Fine white silica sand.

Table I, Appendix A, gives the characteristics of the materials listed above.

The standard sieve analysis forms for the materials are included in Appendix B.

D. THE PROGRAM OF INVESTIGATION

The initial phase of the program involved the establishing of a set of basic conditions to be used as criteria for subsequent experiments. This required as large a model as space would permit with a maximum depth permitted by the height of existing model walls and with a maximum discharge consistent with channel stability (prior to introducing the cofferdam).

The next phase was to establish an erosion pattern by introducing the rectangular cofferdam into the model and running tests using the previously established conditions of depth and discharge.

The final phase of the program involved the construction and testing of successively smaller models and attempting to reproduce the initial scour patterns. In these tests various materials were used as well as distortions of discharge and vertical scale.

Chapter IV contains an outline of the testing program as actually carried out. All models referred to are shown for convenience, as scale models of a hypothetical prototype channel having a bottom width of 200 feet, side slopes of 2 horizontal to 1 vertical and having a rectangular cofferdam extending half-way across the channel and for a distance of 150 feet longitudinally. Actually, the first and largest of the test channels is the prototype for the remaining ones and is frequently referred to as such.

CHAPTER III

DISCUSSION OF CONSTRUCTION AND TESTING PROCEDURE

A. THE 1:50 SCALE MODEL

1. Facilities

It was necessary to start with as large a model as space would permit so that it could be scaled down several times during the various phases of the investigation. The area used for the study of the Red River Floodway outlet model was chosen for the initial model. Although not as large as the inlet model, it is much easier to operate. It also has the advantage of having a head tank to ensure a steady flow through the measuring weirs. Water is supplied to the headtank from a sump by a centrifugal pump with a capacity of approximately 5 cfs. The discharge is controlled by a valve located in the 10 inch supply line near the head tank. Two undershot slide gates control the flow into the model. The water flows through the gates into two head boxes containing gravel boxes for stilling and hence through two 90° V-notch brass weirs each with a capacity of 2.5 cfs. The head over the weirs is measured by hook gauges. To maintain a constant head the flow not entering the model passes over a 20 ft. long sill at the rear of the head tank into a return channel to the sump. After passing through the weirs the water is again stilled by gravel boxes before entering the model area. A flap gate at the outlet to the sump controls the tailwater elevation, which is measured by a hook gauge located near the gate.

After examining the above described facilities, it was decided that a channel with a four foot bottom width and sides slope of 2 horizontal to 1 vertical would be most easily accommodated in the available space, bearing in mind that the next model, which was to be just half as large, was to be accommodated in the four foot wide concrete flume in the hydraulics laboratory.

A wall consisting of three courses of building block was built part way across the model area to divide it into two sections; a reservoir area and a channel area. The walls adjacent to the channel area were then fitted with rails to support a male template for forming the channel. Female templates were placed at the upstream and downstream ends of the channel section to contain the sand. At the upper end, drain tiles and chicken wire were used to still and distribute the flow. The channel was then molded by a male template using the material previously described as No. 1 Material. A simple plywood cofferdam was built and made ready to be placed in the channel after initial tests.

2. Testing Procedure

Several trial tests were run to establish the best combination of depth and discharge consistent with the adopted requirements of no sand movement and maximum discharge. After several trials the established conditions were set as follows:

Depth of flow - 0.8 ft.(model) - 40 ft.(prototype)
Discharge - 2.86 cfs.(model)- 50,500 cfs.(prototype)

Several more trials were required to adjust the entrance conditions for good flow distribution. A gravel box was built, but this proved to have too high a head loss and did not contribute to good flow distribution. The gravel was removed and two rows of drain tile placed at the entrance. After placing some rubble in the reservoir to reduce eddies, the arrangement was found to give satisfactory flow distribution.

The cofferdam was placed in the channel and several preliminary tests run to observe the distribution of flow and the occurence of scour in the movable bed. The model channel was filled slowly from both ends so that the flow would meet at the cofferdam thus preventing scour during filling. When the water reached the correct depth, the head valve and tail gate were opened slowly to build up to the required discharge, while keeping the depth of flow constant.

The observations from these preliminary tests will be dealt with here as they have a bearing on the procedure established for the remaining tests. The main observations were:

(1) A scour hole developed at the upstream corner of the cofferdam.

(2) Erosion of the channel bank opposite the cofferdam occured, causing a gradual flattening of the slope, beginning at a station approximately opposite the upstream side of the structure and continuing most of the way along the bank in a downstream direction.

(3) No erosion occured on the bank adjacent to the structure or at the downstream side of the structure.

(4) As soon as the scour hole appeared, a roller occured in the hole, which caused sand to drift up the downstream sloping side of the hole with much the same appearance as sand blown by wind. This caused a dune to form which moved steadily downstream.

From these observations, the following testing procedure was adopted for all tests run in the large models:

(a) The model was first filled slowly from both ends to avoid premature scour.

(b) When the correct depth was reached, the tail gate and supply valve were both opened to thus increase the discharge while keeping the depth constant.

(c) During the test run, the dimensions of the hole and the progression of the sand bar were measured at definite intervals of time.

(d) At the end of the test period, the pump was shut off and the tail gate closed. Contours were laid at intervals of 0.1 feet (5 foot contours) by successively lowering the water level and placing white wool yarn along the water line.

(e) Cross strings were laid at one foot stations from one foot upstream of the structure to two feet downstream and then at two foot intervals for an additional six feet. These were to aid in comparing erosion patterns.

(f) A row of white stones were placed along the toe of slope on both sides of the channel.

(g) A dashed line (using short pieces of yarn) was laid to indicate the original toe of slope before testing. This was done by measuring from the centre line and dropping a plumb bob.

(h) All contours were identified by an appropriate number and four photographs taken. (See Appendix D).

(i) The slope was measured at each station on the bank opposite the cofferdam.

(j) The maximum depth of the scour hole was measured.

In the large model, only Materials No. 1 and No. 2 were used and tests were run for time periods of 1, 2, 4 and 8 hours for each material.

B. THE 1:100 MODEL AND 1:200 MODEL

The concrete flume in the Hydraulics Laboratory was used for the remainder of the testing program.

It is 4 feet wide, 2 feet deep and 36 feet long. Prior to making modifications, it contained two pieces of apparatus; a rectangular suppressed weir and a hook gauge. The flume is supply by a centrifugal pump through a six inch line discharging into the tank which houses a model turbine. The turbine discharges through a cylindrical draft tube into the flume and hence over the weir to the sump.

So that graduate experiments could be carried out in the flume during the regular term without interrupting the undergraduate program, certain modifications were necessary. A twenty foot long sub-floor consisting of 2½ inch by 2 foot by 4 foot tongue and groove concrete planks supported on steel angles was placed one foot above the existing floor. A steel slide gate was then installed at the upstream edge of the sub-floor so that water could be allowed to pass either over or under the sub-floor. The top sides of the flume were fitted with 4 inch channels on which were mounted 1 inch diameter steel tube rails for carrying a travelling point gauge. A flap gate was installed at the lower end of the sub-floor; and between the flap gate and the weir, a concrete sill 8 inches high and a foot wide was built to form a sand trap. The existing hook gauge was maintained, but as it was necessary to lower the weir, the latter was replaced by a 90° V-notch weir. Flow straighteners were made by cutting 2 inch diameter aluminum pipe into 1 foot sections and stacking them where required.

A plywood and plexiglass cofferdam was built to one half the scale of the previous model. The sides were made of plexiglass for viewing sand movement. The flume was then lined with a sheet of polyethelene to prevent leakage while laying contours and the model cofferdam set in place. Drain tiles were laid on both sides of the flume along the walls to provide drainage for lowering the water level in the scour hole. Female templates were placed at the upstream and downstream ends of the channel and one male template was fixed to a sliding frame supported on the travelling gauge tracks.

To complete the apparatus, a 2½ inch water line, with valve, was brought into each end of the channel for filling from the domestic supply. One of these was located upstream of the head gate and the other just upstream of the flap gate. The test channel was then formed with Material No. 2 for preliminary testing.

2. Testing Procedure (1:100 Model)

Several trial runs were necessary to establish a starting procedure. It was not difficult to establish the correct discharge with the head gate in the 'up' position, ie., with the flow passing under the subfloor. However, when the gate was lowered, it was found to leak excessively. There was not way of measuring the leakage and therefore the flow through the test channel was unknown. It was obvious that the gate must be sealed off in the 'down' position and a new starting procedure found. Several methods were tried, but the one used involved the use of the 30 foot high orifice tank, which is supplied by the same pump and connected through a valve in the side of the tank to the supply line for the flume. Water was pumped into the tank until there was a head over this valve. Some of the flow was also by-passed back into the sump through the outlet valve of the tank so that the pump would not stall at low flows. The valve to the supply line was then opened and the correct discharge was found by manipulation of the three valves. After the correct discharge was established, the pump was shut-off and the three valves left at their respective settings. The channel could then be modelled and filled and the pump simple started with the valves already set for the correct discharge.

The testing procedure for the 1:200 model was similar to the previous tests. Notable differences are:

(a) No contours were laid on the channel slope adjacent to the cofferdam.

(b) The volume of the scour hole was measured after each test by filling it with water over a layer of "Saran Wrap", then lifting the water out and weighing it.

(c) The tests were not repeated for increasing time periods, but were for the most part, run for the equivalent of one hour (large model time) during which the scour hole reached its maximum depth.

(d) Photographs were taken vertically only.

(e) For the 1:200 model, the domestic supply line was sufficient to provide the required discharge.

In this chapter, a description of the apparatus and testing has been given. The observations and results of the tests will be dealt with in the subsequent chapters.

It should be mentioned that the 40 foot contour seen in the photographs was deliberately set below the elevation of the channel bottom. This was done so as to avoid having a contour wandering about the bottom of the channel in patterns influenced largely by tolerances in channel modelling.

CHAPTER IV

OUTLINE OF TESTS AND OBSERVATIONS

A. PRELIMINARY TESTS (MODELSCALE 1 to 50)

Several preliminary tests were run and the observations made from these tests have been dealt with in the previous chapter. As already mentioned, these tests were run to establish flow criteria without the cofferdam in place and to observe the trends in erosion with the cofferdam in place. These tests numbered about twelve and required about one month of testing time. Details of these tests need not be dealt with as their purpose was to establish criteria for the testing program which will be discussed in this chapter.

Test No. 1

Test No. 1 is insignificant as it was run with discharge of 2.05 cfs. instead of the discharge established by the preliminary test of 2.86 cfs. The only interesting feature of this test is that even though it was run for a full nine hours which was longer than any of the subsequent tests and at a lower discharge than used subsequently, the erosion on the opposite bank was still continuing very slowly at the end of the nine hour period.

Test No. 2 to Test No. 5

As in Test No. 1, these tests were run using unsieved mortar sand from the Red River Floodway Model outlet, referred to here as Material No. 1. The time duration of these tests were four, one, two and eight hours respectively. The hole at the upstream corner of the cofferdam reached full depth very early in Test No. 1 probably in about fifteen minutes, and it was found that the depth of the hole was the same for all of these tests. Although the volume of the hole increased with time up to the four hour test and was actually less at the end of the eight hour test, than at the end of the four hour test. Erosion at the upstream corner of the dam was violent at first and sand boiled to the surface for about the first fifteen minutes of the test. Several observations were made from this first series of tests. The sand from the scour hole formed a dune at the downstream side of the hole. This dune progressed in a downstream direction throughout the test reaching the downstream side of the cofferdam in about forty-five minutes to an hour's time. Erosion continued at a reducing rate on the bank opposite the cofferdam throughout the test. The slope of this bank became flatter with time.

The depth of the scour hole was practically the same for all tests, having reached its maximum depth in less than one hour. In all cases the bottom of the hole was fairly well paved with the larger material. In Test No. 2 after one and half hours, a flat stone was removed from the bottom of the hole, but erosion did not continue. At the end of test no. 5, the eight hour test, the sand dune which had shown as an isolated 40 foot contour at the end of the four hour test had completely disappeared. Although the rate of erosion was progressing very slowly at the end of the eight hour test, it is not known whether or not equilibrium could be established without introducing sediment into the bottom, nor how long a time would be required to establish equilibrium.

Test No. 6 to Test No. 9

Material No. 1 was removed from the model and replaced by Material No. 2. These tests were a repitition of the previous set of tests and were carried out at time periods of one, two, four and eight hours respectively. Some general observations from these tests:

(1) The depth of the hole was the same for all four tests and, on the average, slightly lower than the previous set of tests. This is contrary to Jarocki's[9] findings which showed that the depth of scour depends on the coefficient of uniformity of sand granular metric composition. In other words, since this material has a smaller uniformity coefficient, that is, it is more uniform than the previous material, it might have been expected that the depth of erosion would have been greater. Also since the mean grain size is less, that is 0.70 as compared to 0.75 millimeters for the previous material, and therefore a smaller fall velocity, a greater degree of erosion might have been expected. More accurate measurements were made in Tests 6 to 9 and this may account for the apparent discrepancy.

(2) In general, for the same time period as in the previous series of tests, the scour holes were not only shallower and smaller in volume, but were less spread out.

(3) For the same time period, the slope on the eroded bank did not become quite so fat, for instance in Test No. 5, the eight hour test on Material No. 1, the flattest slope was 3.75 to 1 at station 2; whereas in Test No. 9 which was the eight hour test for Material No. 2, the flattest slope was 1.79 to 1 at station 2. In general, the flattest slope occured further upstream in Tests 5 and 9 than in the previous test.

(4) It will be noted in the photographs of Test No. 7 that the sand has been removed from the downstream side of the cofferdam. This was not due to erosion but occurred during the filling process

of the model. This also happened in Test No. 6 but was replaced during the test. It was not replaced in Test No. 7 as it was felt that it would not affect the other erosion patterns.

From these series of tests, it was decided that, since the maximum depth of the hole was obtained within one hour, the erosion in Test No. 6 should be selected as a standard erosion pattern and an attempt to reproduce this erosion pattern would be made in subsequent tests. No further tests were carried out in the large model.

B. MODEL SCALE 1 to 100

Test No. 10 to Test No. 12

These tests were run using Material No. 2. The tests were .7, 1.4 and 2.8 hours duration. For successive tests, no remodelling was done. The model was carefully refilled and the next test was carried on from where the last test was left off. These tests were similarity tests of Test Nos. 6, 7 and 8; that is of one, two and four hours duration at a model scale of 1 to 50 of the same material.

In none of these tests did any erosion occur at the right bank. That is, the side upon which the cofferdam was placed, or of the left bank. The depth of scour was stable after twenty-five minutes and did not change up to the end of the 2.8 hours tests. The horizontal dimensions of the hole were considerably smaller than those of the hole obtained on the large model. Although the horizontal scale was 1 to 2, the dimensions of the hole were about a quarter of the corresponding tests of 1 to 50. The rest of the erosion pattern to forty and forty-five foot contours had not progressed as far downstream (to scale) as in the original model.

After .7 hours, the hole began to flatten out although it got no deeper and the volume continued to increase.

As can be seen in the photograph, a considerable amount of paving occured in all tests.

It was apparent from these tests that without distortion of some kind, erosion patterns could not be reproduced, although the depth of scour was approximately to scale.

Test No. 13

This test was run using fine silica sand for duration of .7 hours. There was no erosion at the left bank but violent erosion at the right bank and the bank fell in halfway through the test. The depth of hole was considerably deeper than for the mortar sand and minimum paving occured. Maximum depth took considerably longer, (42 minutes) to be reached. The erosion pattern consisted of excessive ripples and the pattern could not be compared with that of the mortar sand. The hole itself extended considerably further across the stream and downstream diagonally. The sand dune downstream of the hole had been raised considerably higher than that in the coarse mortar sand. It was thought at that time that through negative distortion, a comparable pattern could be obtained.

Test No. 14 and Test No. 15

These were .7 and 1.4 hours similarity tests on coarse silica sand, that is Material No. 5. The pattern was similar to that of Test No. 14 though not quite as exaggerated. Again the erosion pattern was quite unsuitable.

Test No. 16 to Test No. 18

These were .7 and 1.4 and 2.8 hours similarity tests on medium mortar sand. Considerable paving caused the hole to be almost stable in twenty-five minutes, although the volume increased steadily throughout the 2.8 hours. The hole was found to be not as deep as that in coarse mortar sand probably because the coarse mortar sand was sieved and the medium sand contained larger $D_{84.1}$ and D_{90} sizes, (Table I) and therefore greater paving occurred. The size of the hole compared with that of Test No. 10 and 12. While the rest of the erosion pattern was further downstream, it was not as far as in Test No. 6. There was no erosion of the banks in any of these tests.

Test No. 19

This test was run for .7 hours using fine mortar sand, that is, Material No. 4. The amount of paving was very noticeable as the material consisted of some large particles, few medium sized particles and mostly fine particles. Erosion was violent but stabilized rapidly due to paving as the hole was stable in twenty minutes. The opposite bank washed away in seventeen minutes after the beginning of the test. The rest of the erosion pattern was unsuitable due to excessive ripples.

Test No. 20

This test was run using the same material as the previous test, with the larger particles sieved out. This was done by washing the material through a number 10 sieve. This time the scour hole became much deeper and wider. Paving still occurred but with smaller material on a smaller scale. Again erosion was very violent and the erosion pattern was unsuitable, due to rippling.

Test No. 21 and Test No. 22

These tests were run using Material No. 3S which was placed in the vicinity of the hole. Material No. 3S is a medium mortar sand washed through a number 10 sieve. As can be seen in Table I, this resulted in a considerable reduction in the uniformity coefficient, although the mean grain size is slightly smaller. The significant observations on these tests is that the scour hole was approximately twice as deep as that in Test Nos. 17 and 18 with Material No. 3. In Test No. 17 and 18 however, the depth was almost to scale. The general flow pattern approached that of the other more uniform materials although it took longer (about 50 minutes) to stabilize the hole. There was no side slope erosion.

Test No. 23 to Test No. 27

These tests consist of various discharge distortions on sieved coarse mortar sand (Material No. 2), to attempt to reproduce the erosion pattern of the side slope obtained in Test No. 6. The closest approach was a plus 35% distortion, but the hole was considerably deeper, although the lateral dimensions of the hole appeared to scale. The rest of the erosion pattern was swept considerably downstream. The most notable observations is that no side slope erosion at all occured until distoriton was beyond 30%. The closest erosion pattern of the forty-five and forty foot contours was achieved at the plus 30% distortion although negligible erosion of the side slopes occured. Some curves were drawn to show the relationship between depth of scour and discharge distortion, where the discharge distortion is used on different materials to produce the approximately correct side slope erosion. These curves will be discussed later.

Test No. 28(a)

This test was run using Blench's Scale. This was a vertical distortion of 1.26 to 1. Although the length of the structure in the downstream direction should have been distorted according to the vertical scale, this was neglected. Although the hole was shallow and narrow, the rest of the erosion pattern looked fairly good. There was less erosion of the bank opposite the cofferdam.

Test No. 28(b)

Using the same material, this test was run with a vertical distortion of 2 to 1. The test failed when the material would not remain at these slopes. It seems likely that the correct side slope erosion could be obtained with a vertical distortion somewhere between 1.26 to 1 and 2 to 1, although the scour hole would likely be too shallow owing to the greater depth of flow. This was not attempted because several tests would be required to determine the critical slope at which the banks would remain standing.

Test No. 29 and Test No. 30

These tests were discharge distortions on Material No. 3 to reproduce side slope erosion of Test No. 6. It will be noted that, due to considerably more paving at the high distortion, although the side slope erosion was greater and all patterns further downstream, the hole was smaller and shallower. The most nearly correct pattern occured at twenty percent distortion. The size of hole was almost to scale and the depth was to scale. Other erosion features were flattened out. A study of the photograph indicates that the front of the mound had travelled almost the correct distance. Distortion of a few more percent or a little longer time might reproduce a pattern more satisfactorily, as the slopes were also a little too steep.

Test No. 31

This was a short time test on fine mortar sand, run for thirteen minutes. As previously, the erosion pattern was not suitable as ripples formed immediately. Erosion took place completely differently than coarse or medium mortar sand.

Discharge distortion on fine mortar sand in the range tested was not suitable. Instead of becoming stable, the hole would continue moving until it reached the bank opposite the cofferdam and undermined. This was the discharge distortion necessary to give the required erosion on the slope at the start of the test. At distortions great enough so that the hole moved slowly, the sides would not erode similarly to coarse or medium mortar sand.

C. MODEL SCALE 1 to 200

Test No. 32

Using Material No. 2, the required side slope erosion was obtained at a discharge distortion of 75% but the hole while being good in width was considerably deeper and the rest of the erosion pattern was swept further downstream. Although the maximum slope was the same, it occured considerably further downstream. It is obvious that a discharge distortion as great as 75% upsets the flow regime to the extent that occurences happen farther downstream and are not representative.

Test No. 33(a)

Using medium mortar sand (Material No. 3), a discharge distortion of 45% gave proper depth of hole, although the hole was not quite as wide and the erosion pattern was further downstream.

Test No. 33(b)

This test was similar to Test No. 33(a) except that fine mortar sand was used. As previously experienced, the pattern of erosion obtained with fine mortar sand was unsuitable due to formation of large ripples and paving. Thus, further testing on fine mortar sand was discontinued. As can be seen from the photograph, erosion of the hole progressed diagonally across the channel and undermined the opposite bank.

D. GENERAL OBSERVATIONS

Using the same material in the model as in the prototype, it is possible to reproduce the scour hole to scale, but no side slope erosion occurs without using distortion of some kind.

Side slope erosion can be reproduced using discharge distortion, but the depth of scour is then not to scale. A relationship can be found between the discharge distortion and the scour depth at a given model scale. The relationship appears to be exponential as shown in Fig. 1, (c) but no attempt is made here to express anything conclusive with such limited data.

On materials other than the prototype material, discharge distortion semmed to work quite well on medium mortar sand as previously discussed under Test 29. It is to be noted that this is the only one of the materials having a uniformity coefficient approaching that of the prototype material. Discharge distortion did not produce a similar erosion pattern on any of the other materials.

Similarity of side slopes erosion appears to be possible by finding the correct vertical distortion. In this case the scour hole tends to be too shallow because of the increased depth instead of too deep as is the case with positive discharge distortion. It is suggested that a relationship could be found between the vertical distortion necessary for correct side slope erosion and the depth of scour. (Fig. 2)

In using Blench's regime scales, the 40 and 45 foot contours on the channel bottom resembled those of Test 6, and the scour hole was almost to scale, being too shallow. Side slope erosion occured but was less pronounced and the flattest slope occured further downstream. The Blench regime scales,

$$(D_r^3 = L_r^2) \quad \text{or} \quad (D_r = L_r^{2/3})$$

seem to give a fair representation of both scour and side slope erosion, but to a lesser extent than in the prototype.

MATERIALS

See Fig. 3 "Depth of Scour vs. Selected Material Properties". Considering Material Nos. 5, 3, 3S and 6, it is seen that depth of scour seems to be a function of uniformity coefficient and weighted mean grain size. The depth of scour falls off rapidly beyond a size of 0.68 mm. An important variable, and one that cannot be listed, is the amount and size of the material which, in each case, paved the hole. In this respect, it would appear that the position of the distribution curve above 90% is very important. It is seen (Fig. 4) when plotting D_{90} size vs. depth of scour for all tests on the 1:100 model (undistorted) for the same time period, that the materials fall into two definite groups and in each group the depth of scour is more or less inversely proportional to the D_{90} size. The significant thing is the fact of the two groups. The same occurs if C_u is plotted against depth of scour (Fig. 5). It would seem that the scour depth is a function of the grain size characteristics shown but that some other variable is involved, otherwise the points would all fall on a single line. A study of the material data does not reveal any such group characteristics.

It is found, however, that the grain size distribution curves (Fig. 7) show definite group characteristics. The materials of the lower group (4, 2 and 3), which resulted in a shallower hole all have material retained on the number 8 sieve, whereas all of the materials of the upper group (4S, 6, 5, 3S) all have 100% passing the number 8 sieve. This indicates that the depth of scour is primarily dependent upon the few largest particles in a given material. It can be seen that when Material Nos. 3 and 4 were passed through a number 10 sieve, they fall in the upper group (3S and 4S). It is probable that Material No. 2 would likewise fall on the upper line if similarly sieved. Since all of the points would then fall on the same line, it would indicate a definite relationship between depth of scour and some characteristic of material size.

If, however, we ignore point 3S in the upper group, we see that the depth of scour is almost constant regardless of the variation in size characteristics. As material 3S exhibits a different shaped curve than the other materials of the upper group, which are fairly similar, then it is indicated that similarity in shape of distribution curve is

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as important a factor in reproducing scour depth as grain size. In this respect, the mean deviation ($D_{84.1}$ - D_{50}), when plotted against depth (for materials 6, 5, 4S and 3S) yields a straight line showing a slight decrease in scour depth with variation in mean deviation from 0.15 to 0.44. (Fig. 6).

From the above, it is suggested that the depth of scour is dependent primarily on the size of the largest particles in the material; and when this size is kept within definite limits for several materials, then the depth of scour depends, to a secondary degree on the shape of the grain size distribution curve.

Qualitatively, the latter statement suggests the validity of Newbury's theory mentioned in Chapter I. As the prime objective during the testing program was to attempt to reproduce a scour pattern, only measurements pertaining to the scour pattern were made and velocity and slope measurements were not taken. The above mentioned theory was presented to the author several months after the apparatus was dismantled and the materials discarded and, therefore, no attempt is made to undertake a quantitative analysis with respect to tractive force and depth of scour.

It is recommended that a comprehensive analysis of this interesting a-nd direct approach to the phenomena of scour be undertaken as another research project with the use of a less complicated flow situation.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

From the foregoing chapters, the following conclusions are made:

The Use of Sand as a Bed Material

The use of sand as a bed material in movable bed models is a widely accepted practice; the choice of material being made largely on individual laboratory experience. In cases where sand is used, the model study is primarily a qualitative analysis of scour and erosion tends. It is desirable that the bed material in the model should move at the critical eroding velocity (to scale) as determined in the prototype. If the material has the correct scale roughness factor, model channels can be made hydraulically similar to the prototype without the use of screens or other roughness aids. In addition, the sand must be coarse enough to avoid rippling which alters the hydraulic characteristics of the channel.

Limitations of the Use of Sand

In flow situations that produce both bed scour and side slope erosion, the use of sand as a bed material can give misleading results. Within the limits of these tests, and considering the largest structure to be the prototype, no representative side slope erosion occured with the coarser materials without the use of distortion. When using the finer materials , which exhibited excessive rippling, side slope erosion was produced without distortion, but the degree of erosion was not representative. It can be concluded that representative patterns of both bed and side slope erosion cannot be obtained using sand in an undistorted model.

In this respect it can be further concluded that, as a bed material, sand is limited by its almost constant specific gravity regardless of size.

Discharge Distortion

Discharge distortion can be used to obtain more representative scour patterns. As localized scour holes, such as at the corner of a cofferdam or spur dike, will occur at almost any discharge, the procedure is to vary the discharge until the required side slope erosion is attained. This is a trial and error procedure and once the correct amount of distortion is found, the test can be run at that discharge. In these experiments, the best results were obtained in the 1:100 model when using a discharge distortion of +35% and the same material as the prototype. (Test No. 26). In using positive discharge distortion, localized scour holes will be deeper than normal and other erosion patterns, although similar to the prototype, will occur further downstream. It was also found that the degree of discharge distortion required increases exponentially with the model-prototype scale ratio and that less distortion is required for fine sands than for course sands.

Vertical Distortion

It is suggested that the maximum possible depth of local bed scour, produced by an unique flow condition,depends on the energy or tractive force available. It is indicated from these experiments, that the actual depth of scour attained in a given situation depends primarily on the largest particles in the bed material and to a secondary degree on the shape of the material distribution curve.

Recommendations

The author recommends that the following projects be undertaken when interested post-graduate students become available:

1. A continuation of this study using materials of various specific gravities such as coal, plastic, pumice and lightweight aggregates. Measurements necessary for the determination of tractive force and bed velocities should be taken so that a quantitative analysis can be made.
2. A separate project utilizing a more simplified apparatus, for the purpose of analysing Newbury's theory on scour depth as a function of grain size distribution of bed materials.

APPENDIX A

TABLE I - MATERIAL PROPERTIES

No.	MATERIAL: (SAND)	GRAIN SIZES (mm.)					Uniformity Coefficient Cu.	Mean Deviation mm.	Fineness Modulus	Specific Gravity
		D_{10}	D_{50}	D_{60}	$D_{84.1}$	D_{90}	D_{60}/D_{10}	$D_{84.1}-D_{50}$		
1	Coarse Mortar	0.22	0.75	0.94	1.73	2.08	4.28	0.98	2.83	2.74
2	Sieved Coarse Mortar	0.19	0.70	0.76	0.94	0.98	4.01	0.24	2.54	2.74
3	Medium Mortar	0.20	0.58	0.73	1.26	1.57	3.61	0.68	2.55	2.74
3S	Sieved Medium Mortar*	0.25	0.57	0.67	1.01	1.18	2.66	0.44	2.48	2.74
4	Fine Mortar	0.15	0.25	0.28	0.43	0.56	1.91	0.18	1.41	2.72
4S	Sieved Fine Mortar*	0.16	0.32	0.37	0.50	0.54	2.36	0.18	1.57	2.72
5	Coarse Silica	0.39	0.62	0.68	0.85	0.90	1.76	0.23	2.55	2.66
6	Fine Silica	0.32	0.44	0.49	0.59	0.65	1.52	0.15	2.11	2.66

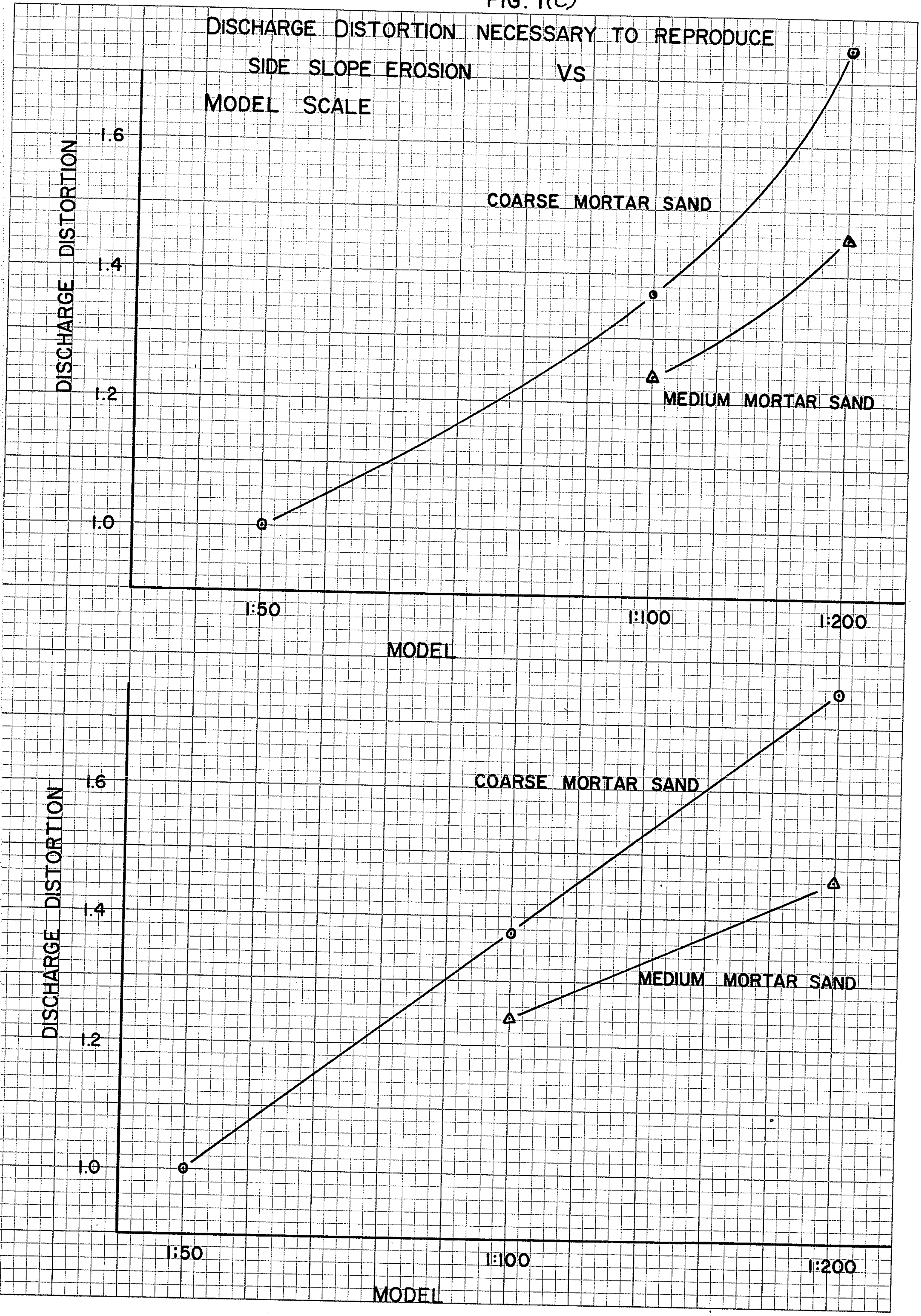
* No. 10 Sieve

Note: Material 4S was washed through the sieve.

TABULATION OF TEST DATA TABLE II

Test	Model Scale 1 :	Material	Discharge cfs.	Depth of Flow ft.	Velocity fps.	Time hr.	Depth of Scour ft.	Volume cu. ft.
1	50	1	2.05	0.765	0.485	9	0.31	0.145
2	50	1	2.86	0.800	0.639	4	0.39	0.557
3	50	1	2.86	0.800	0.639	1	0.35	0.329
4	50	1	2.86	0.800	0.639	2	0.37	0.425
5	50	1	2.86	0.800	0.639	8	0.33	0.535
6	50	2	2.86	0.800	0.639	1	0.34	0.374
7	50	2	2.86	0.800	0.639	2	0.32	0.364
8	50	2	2.86	0.800	0.639	4	0.32	0.377
9	50	2	2.86	0.800	0.639	8	0.34	0.358
10	100	2	0.505	0.400	0.451	0.7	0.158	0.0125
11	100	2	0.505	0.400	0.451	1.4	0.158	0.0130
12	100	2	0.505	0.400	0.451	2.8	0.158	0.0145
13	100	6	0.505	0.400	0.451	0.7	0.272	0.1150
14	100	5	0.505	0.400	0.451	0.7	0.264	0.0709
15	100	5	0.505	0.400	0.451	1.4	0.270	0.0945
16	100	3	0.505	0.400	0.451	0.7	0.138	0.0173
17	100	3	0.505	0.400	0.451	1.4	0.140	0.0180
18	100	3	0.505	0.400	0.451	2.8	0.146	0.0208
19	100	4	0.505	0.400	0.451	0.7	0.199	0.0829
20	100	4s	0.505	0.400	0.451	0.7	0.273	0.1150
21	100	3s	0.505	0.400	0.451	0.7	0.252	0.0520
22	100	3s	0.505	0.400	0.451	1.4	0.255	0.0895
23	100	2	0.606	0.400	0.542	0.7	0.192	0.0336
24	100	2	0.707	0.400	0.631	0.7	0.246	0.0905
25	100	2	0.657	0.400	0.587	0.7	0.238	0.0452
26	100	2	0.682	0.400	0.609	0.7	0.233	0.0477
27	100	2	0.682	0.400	0.609	1.4	0.234	0.0596
28	100	2	0.715	0.505	0.475	0.8	0.148	0.0151
29	100	3	0.586	0.400	0.524	0.7	0.178	0.0282
30	100	3	0.606	0.400	0.542	0.7	0.168	0.0197
31	100	4	0.505	0.400	0.451	0.2	0.143	0.0200
32	200	2	0.156	0.200	0.558	0.5	0.113	0.0170
33	200	3	0.130	0.200	0.465	0.5	0.089	0.0053

FIG. 1(C)

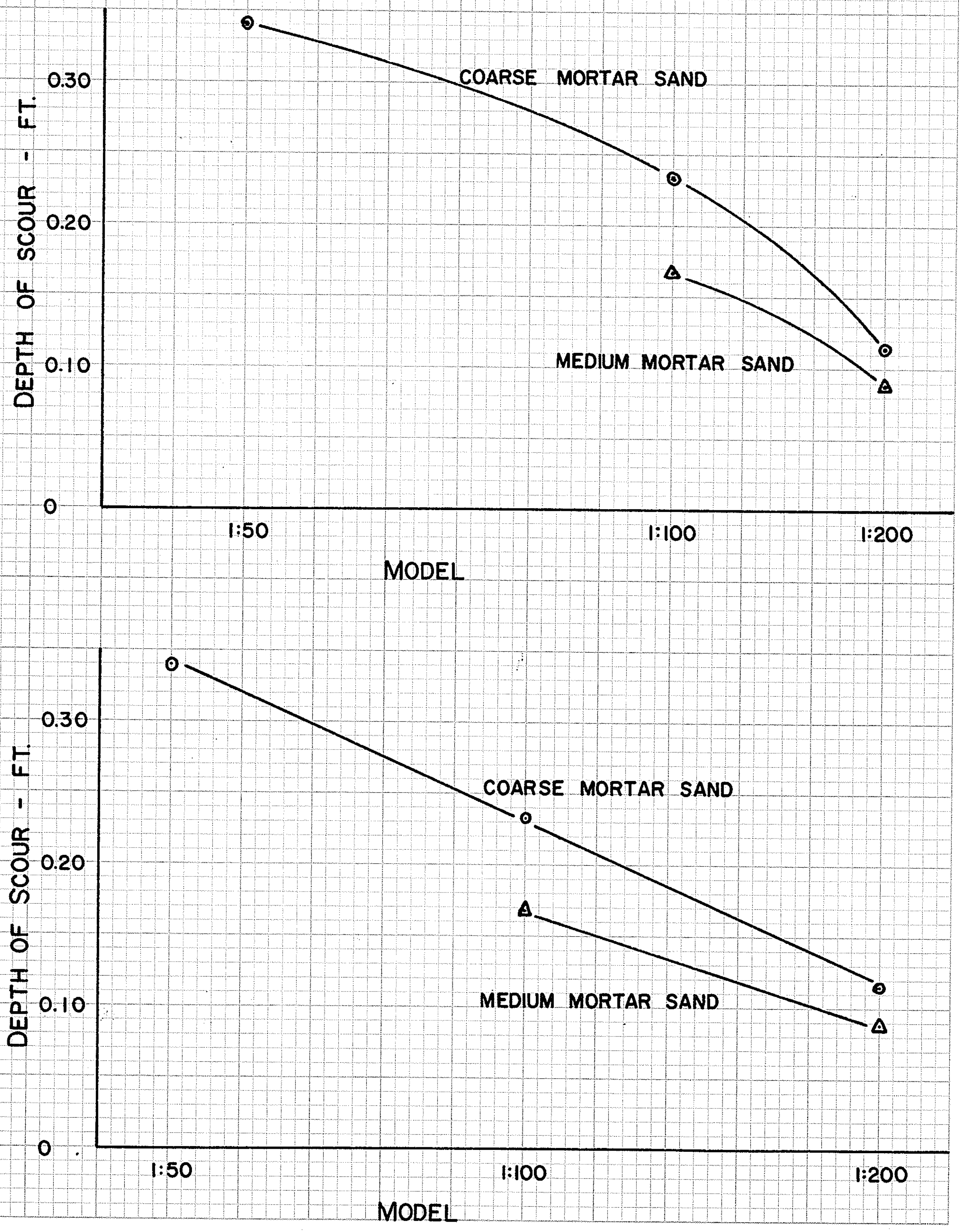


DISCHARGE DISTORTION NECESSARY TO REPRODUCE SIDE SLOPE EROSION VS MODEL SCALE

Inch

FIG. 2

DEPTH OF SCOUR AT PROPER SIDE SLOPE EROSION
Vs
MODEL SCALE

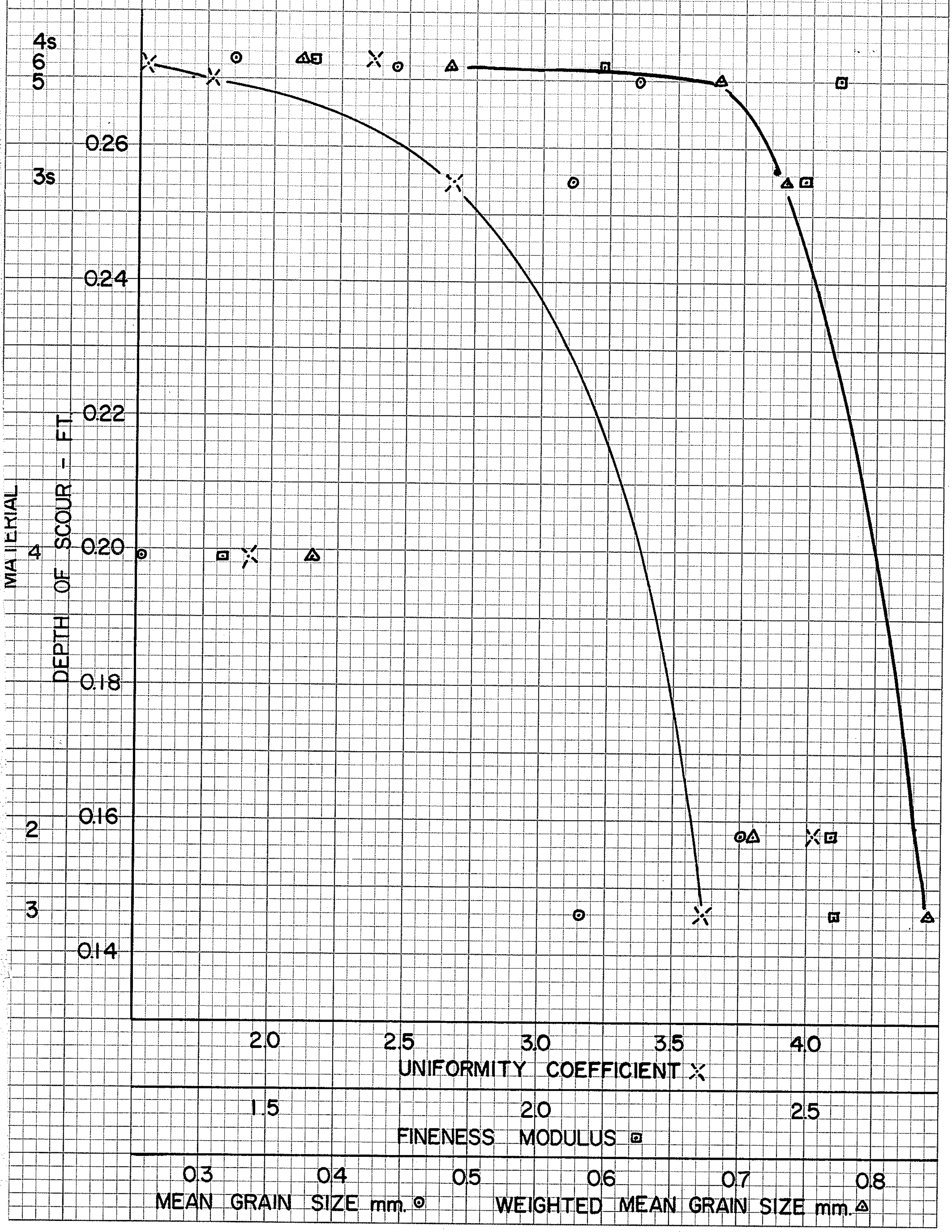


ie Inch

FIG. 3

DEPTH OF SCOUR Vs SELECTED MATERIAL PROPERTIES

MODEL 1:100 UNDISTORTED



Inch

FIG. 4

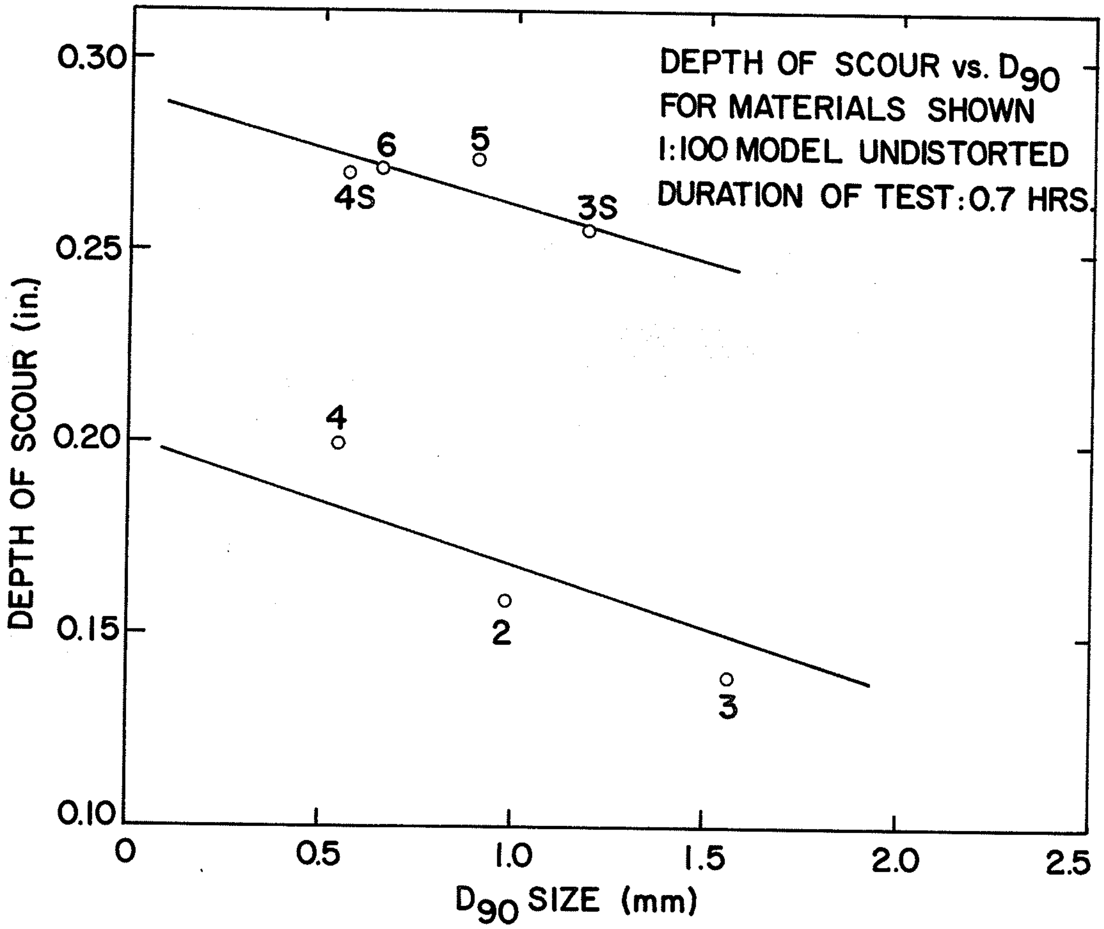

DEPTH OF SCOUR vs. D90
FOR MATERIALS SHOWN
1:100 MODEL UNDISTORTED
DURATION OF TEST: 0.7 HRS.
DEPTH OF SCOUR (in.)
0.30
0.25
0.20
0.15
0.10
0
0.5
1.0
1.5
2.0
2.5
D90 SIZE (mm)
6
5
4S
3S
4
2
3

FIG. 5

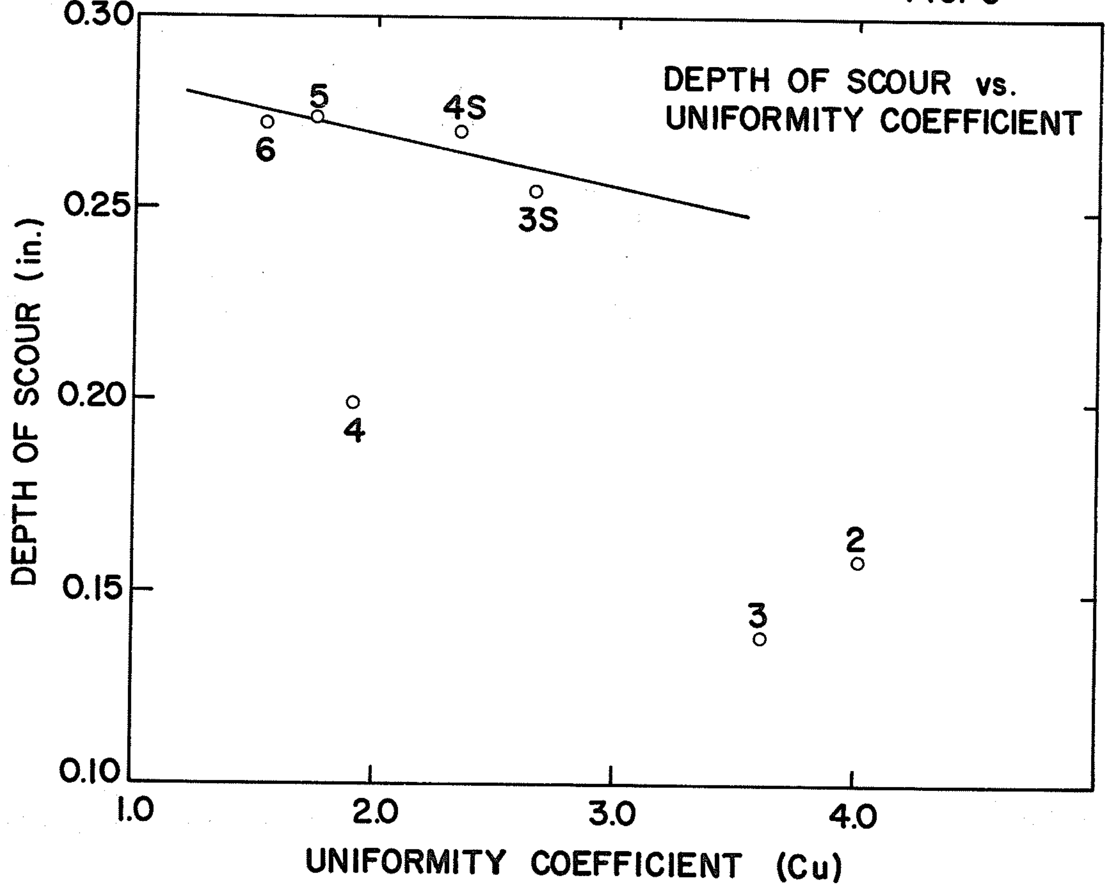
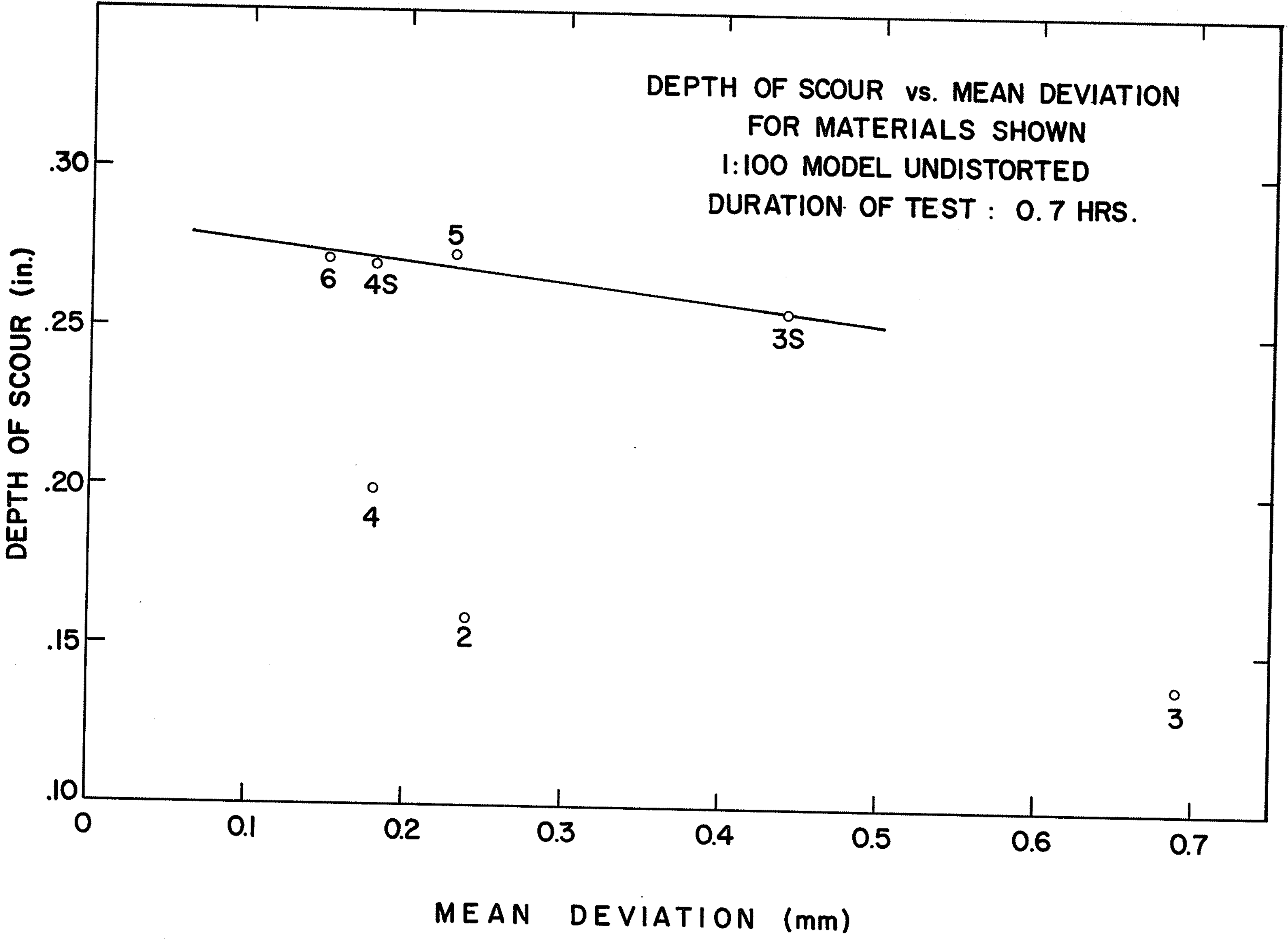

DEPTH OF SCOUR vs.
UNIFORMITY COEFFICIENT
DEPTH OF SCOUR (in.)
0.30
0.25
0.20
0.15
0.10
1.0
2.0
3.0
4.0
UNIFORMITY COEFFICIENT (Cu)
5
4S
6
3S
4
2
3

FIG. 6



DEPTH OF SCOUR vs. MEAN DEVIATION
FOR MATERIALS SHOWN
1:100 MODEL UNDISTORTED
DURATION OF TEST : 0.7 HRS.

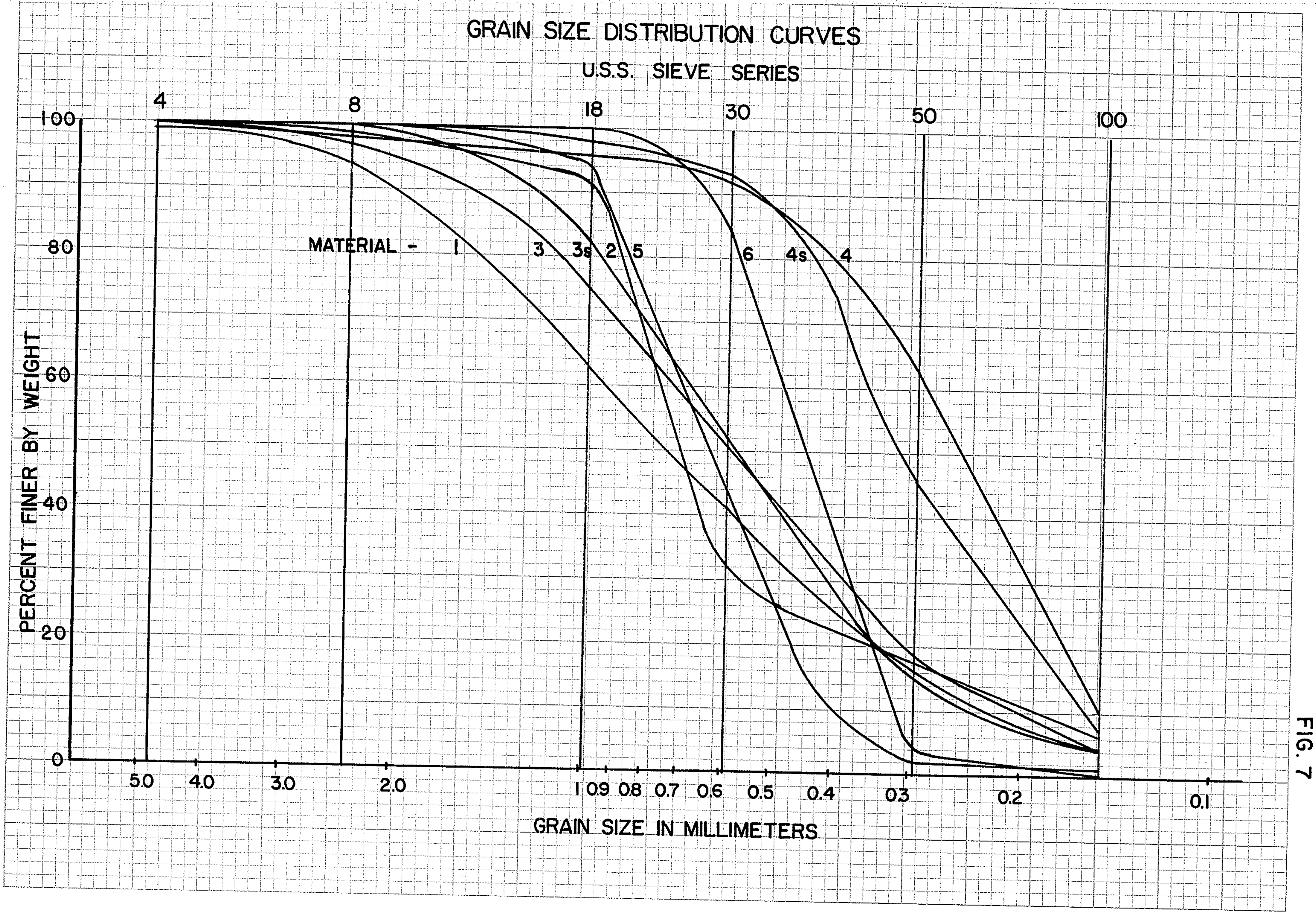
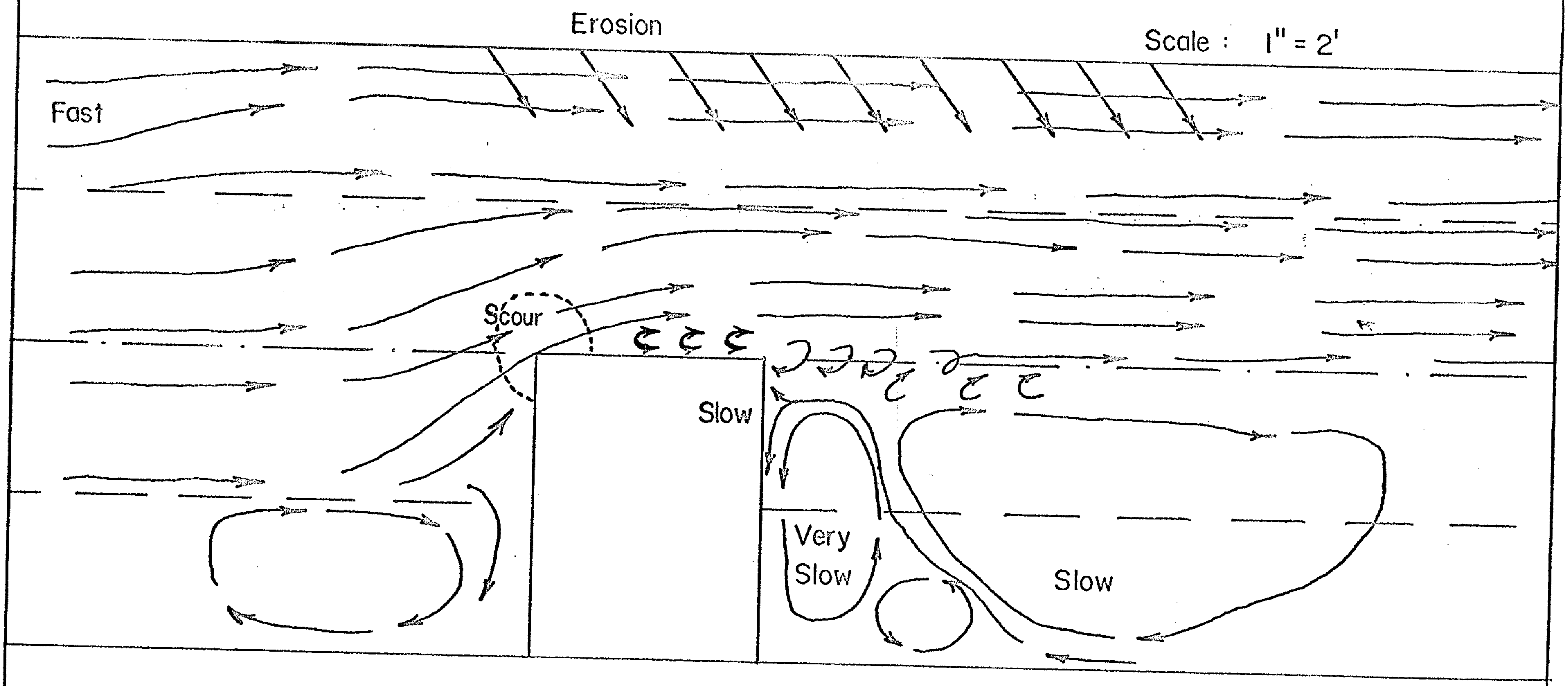

GRAIN SIZE DISTRIBUTION CURVES
U.S.S. SIEVE SERIES
4
8
18
30
50
100
100
80
60
40
20
0
PERCENT FINER BY WEIGHT
MATERIAL - 1
3
3s
2
5
6
4s
4
5.0
4.0
3.0
2.0
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
GRAIN SIZE IN MILLIMETERS

FIG. 7



FLOW PATTERN - 1:50 MODEL

FIG. 8

AUG • 64 •

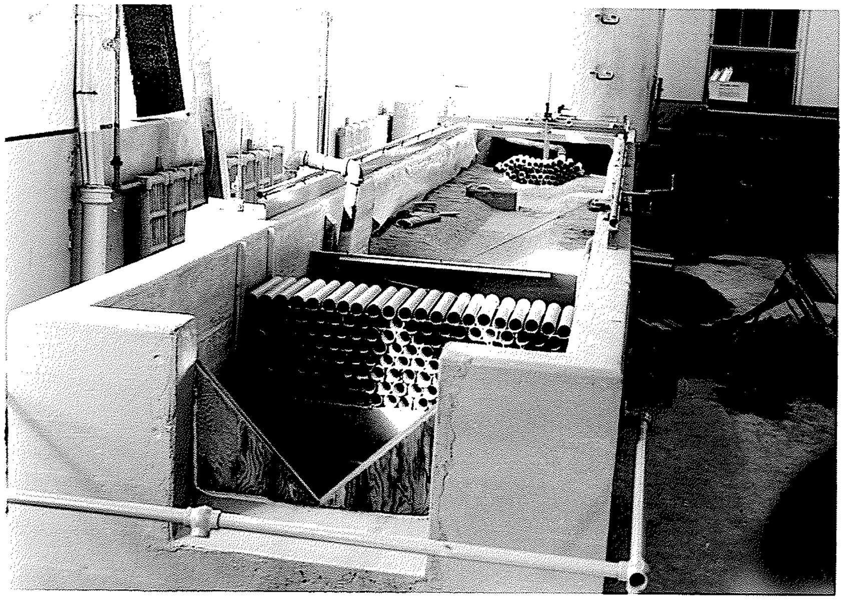


FIG. 9

APPARATUS FOR 1:100 AND 1:200 MODELS

1:200 MODEL SHOWN.

APPENDIX B

SIEVE ANALYSIS

SM ________

PROJECT: PROF. CLAYTON, MASTER'S THESIS

TEST HOLE NO. ________ SAMPLE NO. 20 A DEPTH ________

DESCRIPTION OF SAMPLE AND GRAINS: UNSIEVED MORTAR SAND FROM RED RIVER FLOODWAY MODEL

REMARKS: ________

WT. OF SAMPLE + TARE = ________ GM.

WT. OF TARE = ________ GM.

INITIAL WT. OF SAMPLE = ________ GM.

FINAL WT. OF SAMPLE = 1000 GM.

EVAPORATING DISH NO. ________

SIZE OF LARGEST STONE = ________ MM.

DRYING OVEN: IN ______ OUT ______

ROTAP: IN ______ OUT ______

SIEVE NO (U.S.S.)	TOTAL WT. RETAINED + TARE (GM.)	TARE (GM.)	TOTAL WT. RETAINED (GM.)	TOTAL WT. PASSING (GM.)	PERCENT PASSING	SIEVE OPENING (MM.)	PERCENT RETAINED
1						26.67	
½						12.7	
4	7.9		7.9	992.1	99	4.76	1
~~10~~ 8	56.6		56.6	935.5	94	2.00	6
~~20~~ 18	304.2		304.2	631.3	63	0.84	37
~~40~~ 30	219.2		219.2	412.1	41	0.42	59
~~80~~ 50	251.1		251.1	161.0	16	0.25	84
100	118.6		118.6	42.4	4	0.149	96
200						0.074	
PAN	42.4		42.4				

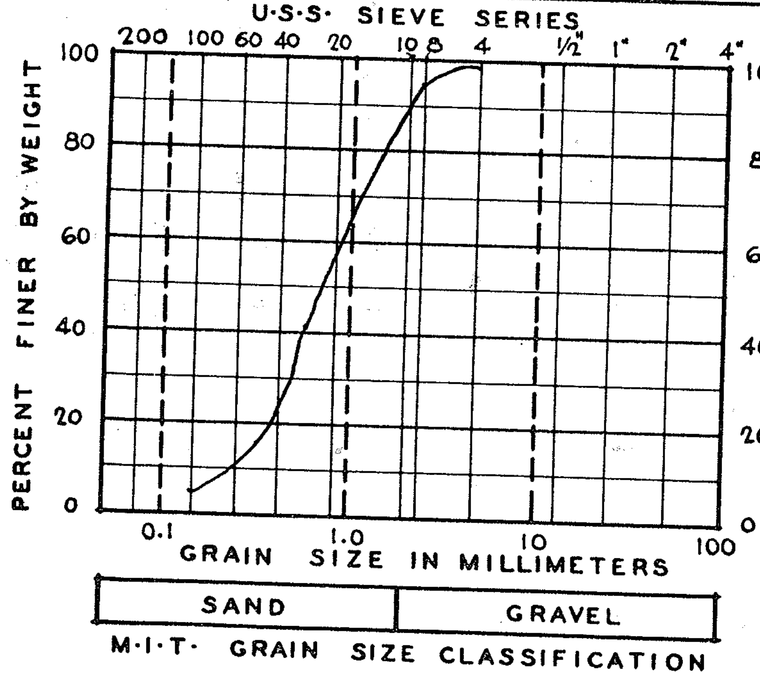
283/100 = 2.83

Fineness Modulus = 2.83

Grain Size = 0.7$\overset{8}{5}$ mm.

Specific Gravity = 2.74

GRAIN SIZE DISTRIBUTION CURVE



TESTED: W.D.G. DATE: 8/6/64

PLOTTED: ________ DATE: ________

COMPUTED: ________ DATE: ________

CHECKED: ________ DATE: ________

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UNIVERSITY OF MANITOBA
FORT GARRY MANITOBA

SIEVE ANALYSIS

SM ________

PROJECT PROF. CLAYTON, MASTER'S THESIS

TEST HOLE NO. ________ SAMPLE NO. 21 A DEPTH ________

DESCRIPTION OF SAMPLE AND GRAINS: SIEVED MORTAR SAND FROM RED RIVER FLOODWAY MODEL

REMARKS: ________

WT. OF SAMPLE + TARE = ________ GM.
WT. OF TARE = ________ GM.
INITIAL WT. OF SAMPLE = ________ GM.
FINAL WT. OF SAMPLE = 1000 GM.

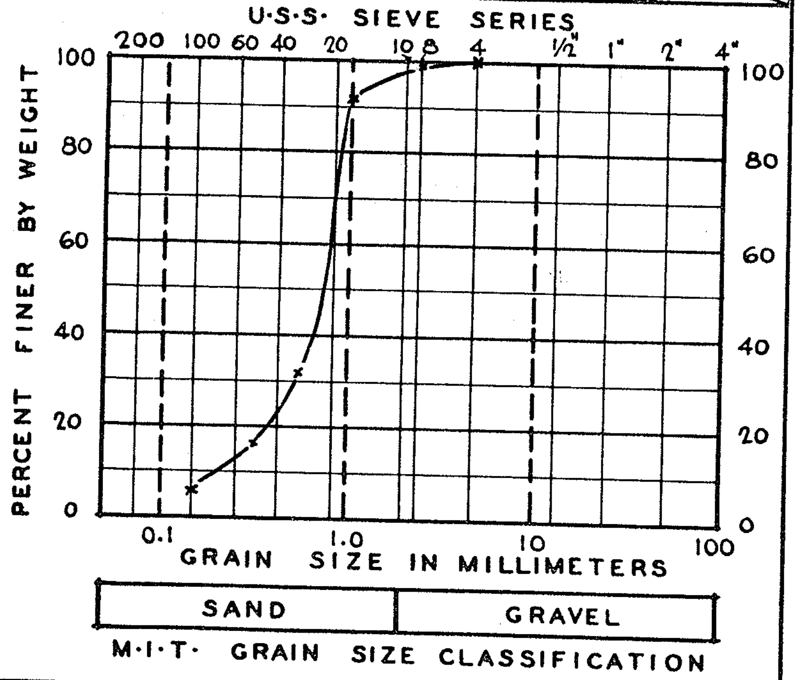
EVAPORATING DISH NO. ________
SIZE OF LARGEST STONE = ________ MM.
DRYING OVEN: IN ______ OUT ______
ROTAP: IN ______ OUT ______

SIEVE NO (U.S.S.)	TOTAL WT. RETAINED + TARE (GM.)	TARE (GM.)	TOTAL WT. RETAINED (GM.)	TOTAL WT. PASSING (GM.)	PERCENT PASSING	SIEVE OPENING (MM.)	PERCENT RETAINED
1						26.67	
½						12.7	
4			0.0	1000.0	100	4.76	0
~~10~~ 8			6.9	993.1	99	2.00	1
~~20~~ 18			74.0	919.1	92	0.84	8
~~40~~ 30			600.0	319.1	32	0.42	68
~~60~~ 50			151.3	167.8	17	0.25	83
100			105.1	62.7	6	0.149	94
200						0.074	254/100
PAN			62.7				

= 2.54

Fineness Modulus = 2.54
Grain Size = 0.70 mm.

GRAIN SIZE DISTRIBUTION CURVE



TESTED : W.D.G. DATE: 8/6/64
PLOTTED : ________ DATE: ________
COMPUTED: ________ DATE: ________
CHECKED : ________ DATE: ________

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FORT GARRY MANITOBA

SIEVE ANALYSIS

SM ________

PROJECT PROF. CLAYTON, MASTER'S THESIS

TEST HOLE NO. ________ SAMPLE NO. ________ DEPTH ________

DESCRIPTION OF SAMPLE AND GRAINS: MEDIUM

REMARKS: ________

WT. OF SAMPLE + TARE = ________ GM.

WT. OF TARE = ________ GM.

INITIAL WT. OF SAMPLE = ________ GM.

FINAL WT. OF SAMPLE = 1000 GM.

EVAPORATING DISH NO. ________

SIZE OF LARGEST STONE = ________ MM.

DRYING OVEN: IN ________ OUT ________

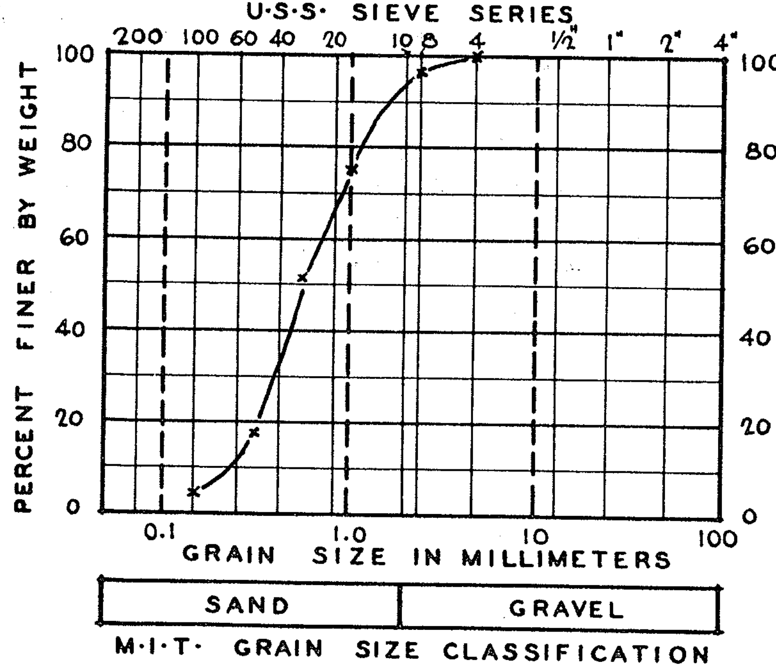
ROTAP: IN ________ OUT ________

SIEVE NO (U.S.S.)	TOTAL WT. RETAINED + TARE (GM.)	TARE (GM.)	TOTAL WT. RETAINED (GM.)	TOTAL WT. PASSING (GM.)	PERCENT PASSING	SIEVE OPENING (MM.)	PERCENT RETAINED
1						26.67	
½						12.7	
4			0.0	1000.0	100	4.76	0
~~10~~ 8			29.0	971.0	97	2.00	3
~~20~~ 18			217.4	753.6	75	0.84	25
~~40~~ 30			246.0	507.6	51	0.42	49
~~60~~ 50			331.0	176.6	18	0.25	82
100			135.0	41.6	4	0.149	96
200						0.074	255/100
PAN			41.6				

= 2.55

Fineness Modulus = 2.55
Grain Size = 0.58mm.

GRAIN SIZE DISTRIBUTION CURVE



TESTED : W.D.G. DATE: 8/6/64
PLOTTED : ________ DATE: ________
COMPUTED: ________ DATE: ________
CHECKED : ________ DATE: ________

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FORT GARRY MANITOBA

3s

SIEVE ANALYSIS

SM ______

PROJECT: PROF. CLAYTON, MASTER'S THESIS

TEST HOLE NO. ______ SAMPLE NO. 4 A DEPTH ______

DESCRIPTION OF SAMPLE AND GRAINS: SIEVED MEDIUM MORTAR SAND

REMARKS: ______

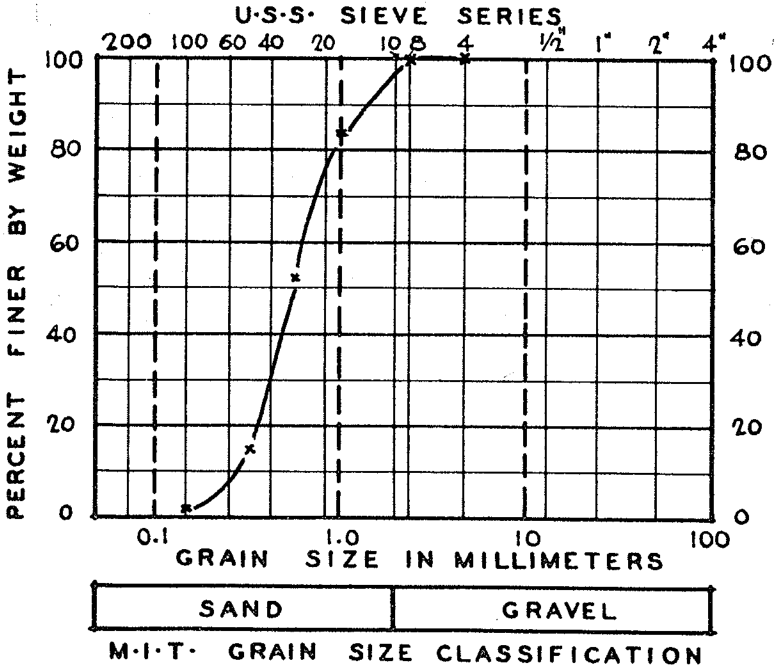
WT. OF SAMPLE + TARE = ______ GM.	EVAPORATING DISH NO. ______
WT. OF TARE = ______ GM.	SIZE OF LARGEST STONE = ______ MM.
INITIAL WT. OF SAMPLE = ______ GM.	DRYING OVEN: IN ______ OUT ______
FINAL WT. OF SAMPLE = 1000 GM.	ROTAP: IN ______ OUT ______

SIEVE NO (U.S.S.)	TOTAL WT. RETAINED + TARE (GM.)	TARE (GM.)	TOTAL WT. RETAINED (GM.)	TOTAL WT. PASSING (GM.)	PERCENT PASSING	SIEVE OPENING (MM.)	PERCENT RETAINED
1						26.67	
½						12.7	
4			0.0	1000.0	100	4.76	0
~~10~~ 8			1.1	998.9	100	2.00	0
~~20~~ 18			166.0	832.9	83	0.84	17
~~40~~ 30			317.1	515.8	52	0.42	48
~~60~~ 50			366.2	149.6	15	0.25	85
100			128.2	21.4	2	0.149	98
200						0.074	248/100
PAN			21.4				= 2.48

Fineness Modulus = 2.48

Grain Size = 0.57 mm.

GRAIN SIZE DISTRIBUTION CURVE



TESTED : L.J.K.	DATE: 26/6/64
PLOTTED : ______	DATE: ______
COMPUTED: ______	DATE: ______
CHECKED : ______	DATE: ______

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FORT GARRY MANITOBA

SIEVE ANALYSIS

SM ______

PROJECT PROF. CLAYTON, MASTER'S THESIS

TEST HOLE NO. ______ SAMPLE NO. 23 A DEPTH ______

DESCRIPTION OF SAMPLE AND GRAINS: FINE

REMARKS: ______

WT. OF SAMPLE + TARE = ______ GM.

WT. OF TARE = ______ GM.

INITIAL WT. OF SAMPLE = ______ GM.

FINAL WT. OF SAMPLE = 1000 GM.

EVAPORATING DISH NO. ______

SIZE OF LARGEST STONE = ______ MM.

DRYING OVEN: IN ______ OUT ______

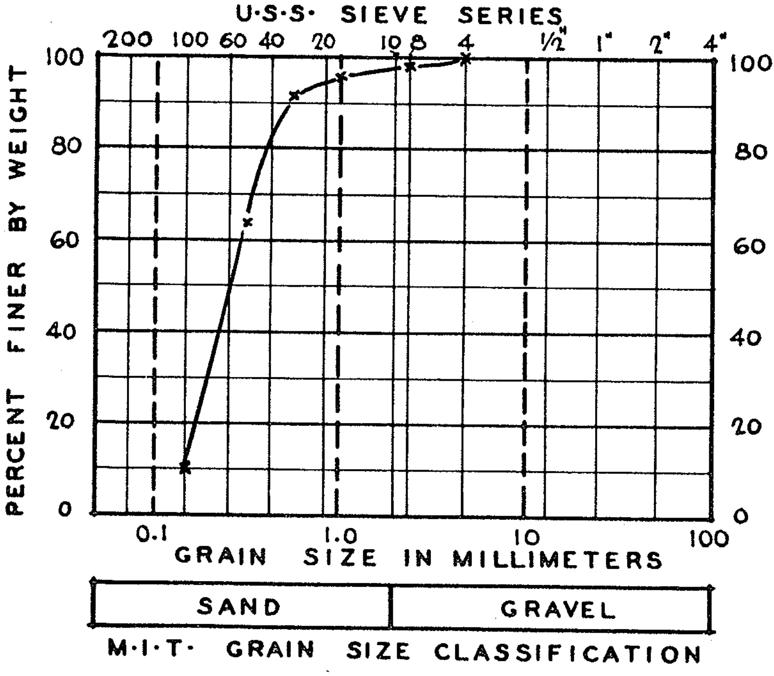
ROTAP: IN ______ OUT ______

SIEVE NO (U.S.S.)	TOTAL WT. RETAINED + TARE (GM.)	TARE (GM.)	TOTAL WT. RETAINED (GM.)	TOTAL WT. PASSING (GM.)	PERCENT PASSING	SIEVE OPENING (MM.)	PERCENT RETAINED
1						26.67	
½						12.7	
4			0.0	1 000.0	100	4.76	0
~~10~~ 8			16.9	983.1	98	2.00	2
~~20~~ 18			22.2	960.9	96	0.84	4
~~40~~ 30			36.8	924.1	92	0.42	8
~~60~~ 50			293.7	630.4	63	0.25	37
100			533.1	97.3	10	0.149	90
200						0.074	141/100
PAN			97.3				

= 1.41

Fineness Modulus = 1.41
Grain Size = 0.25 mm.

GRAIN SIZE DISTRIBUTION CURVE



TESTED : W.D.G. DATE: 8 / 6 / 64
PLOTTED : ______ DATE: ______
COMPUTED: ______ DATE: ______
CHECKED : ______ DATE: ______

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FORT GARRY MANITOBA

SIEVE ANALYSIS

SM ________

PROJECT: PROF. CLAYTON, MASTER'S THESIS

TEST HOLE NO. ________ SAMPLE NO. 3 A DEPTH ________

DESCRIPTION OF SAMPLE AND GRAINS: SIEVED FINE MORTAR SAND (no.10)

REMARKS: ________

WT. OF SAMPLE + TARE = ________ GM.

WT. OF TARE = ________ GM.

INITIAL WT. OF SAMPLE = ________ GM.

FINAL WT. OF SAMPLE = 1000 GM.

EVAPORATING DISH NO. ________

SIZE OF LARGEST STONE = ________ MM.

DRYING OVEN: IN ________ OUT ________

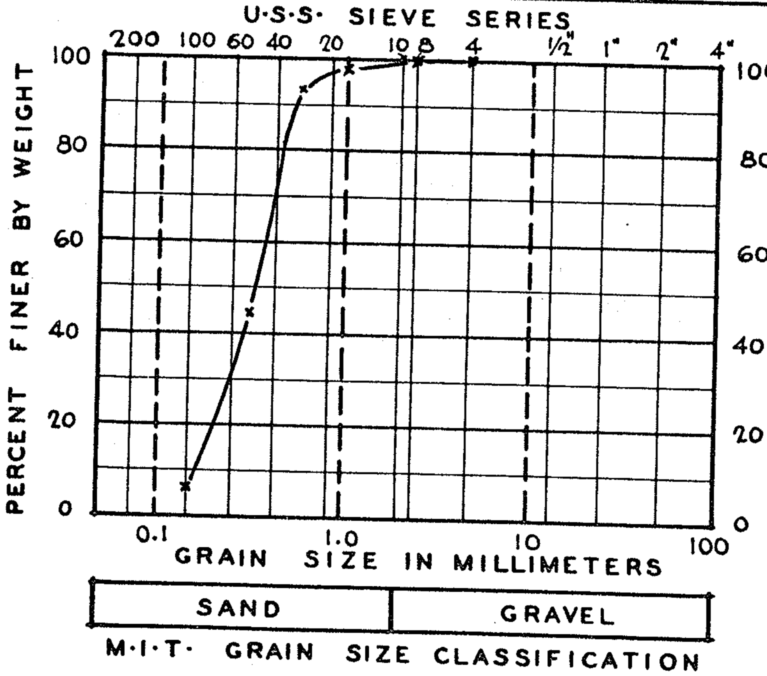
ROTAP: IN ________ OUT ________

SIEVE NO (U.S.S.)	TOTAL WT. RETAINED + TARE (GM.)	TARE (GM.)	TOTAL WT. RETAINED (GM.)	TOTAL WT. PASSING (GM.)	PERCENT PASSING	SIEVE OPENING (MM.)	PERCENT RETAINED
1						26.67	
½						12.7	
4			0.0	1000.0	100	4.76	0
~~10~~ 8			0.0	1000.0	100	2.00	0
~~20~~ 18			18.0	982.0	98	0.84	2
~~40~~ 30			48.6	933.4	93	0.42	7
~~60~~ 50			482.0	451.4	45	0.25	55
100			384.3	67.1	7	0.149	93
200						0.074	
PAN			67.1				157/100

= 1.57

Fineness Modulus = 1.57
Grain Size = 0.32 mm

GRAIN SIZE DISTRIBUTION CURVE



TESTED: L.J.K. DATE: 26/6/64

PLOTTED: ________ DATE: ________

COMPUTED: ________ DATE: ________

CHECKED: ________ DATE: ________

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FORT GARRY MANITOBA

SIEVE ANALYSIS

SM ______

PROJECT PROF. CLAYTON, MASTER'S THESIS

TEST HOLE NO. ______ SAMPLE NO. 2A DEPTH ______

DESCRIPTION OF SAMPLE AND GRAINS: COARSE SILICA SAND

REMARKS: ______

WT. OF SAMPLE + TARE = ______ GM.

WT. OF TARE = ______ GM.

INITIAL WT. OF SAMPLE = ______ GM.

FINAL WT. OF SAMPLE = 1000 GM.

EVAPORATING DISH NO. ______

SIZE OF LARGEST STONE = ______ MM.

DRYING OVEN: IN ______ OUT ______

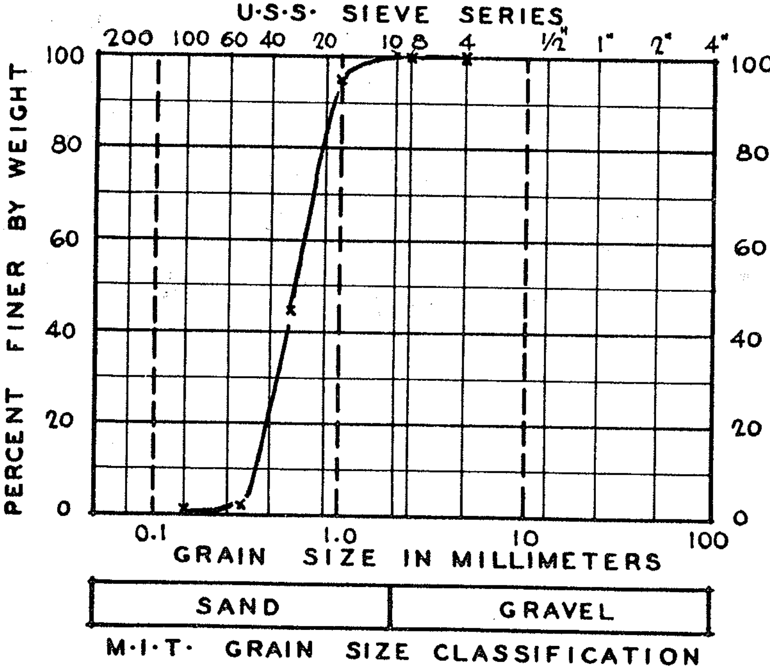
ROTAP: IN ______ OUT ______

SIEVE NO (U.S.S.)	TOTAL WT. RETAINED + TARE (GM.)	TARE (GM.)	TOTAL WT. RETAINED (GM.)	TOTAL WT. PASSING (GM.)	PERCENT PASSING	SIEVE OPENING (MM.)	PERCENT RETAINED
1						26.67	
½						12.7	
4			0.0	1000.0	100	4.76	0
~~10~~ 8			0.0	1000.0	100	2.00	0
~~20~~ 18			56.9	943.1	94	0.84	6
~~40~~ 30			504.2	438.9	44	0.42	56
~~60~~ 50			419.5	19.4	2	0.25	98
100			11.0	8.4	1	0.149	95
200						0.074	255/100
PAN			8.4				= 2.55

Fineness Modulus = 2.55

Grain Size = 0.62 mm.

GRAIN SIZE DISTRIBUTION CURVE



TESTED : L.J.K. DATE: 26/6/64

PLOTTED : ______ DATE: ______

COMPUTED: ______ DATE: ______

CHECKED : ______ DATE: ______

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SIEVE ANALYSIS

SM ______

PROJECT: PROF. CLAYTON, MASTER'S THESIS

TEST HOLE NO. ______ SAMPLE NO. 1 A DEPTH ______

DESCRIPTION OF SAMPLE AND GRAINS: FINE SILICA SAND

REMARKS: ______

WT. OF SAMPLE + TARE = ______ GM.

WT. OF TARE = ______ GM.

INITIAL WT. OF SAMPLE = ______ GM.

FINAL WT. OF SAMPLE = 1000 GM.

EVAPORATING DISH NO. ______

SIZE OF LARGEST STONE = ______ MM.

DRYING OVEN: IN ______ OUT ______

ROTAP: IN ______ OUT ______

SIEVE NO (U.S.S.)	TOTAL WT. RETAINED + TARE (GM.)	TARE (GM.)	TOTAL WT. RETAINED (GM.)	TOTAL WT. PASSING (GM.)	PERCENT PASSING	SIEVE OPENING (MM.)	PERCENT RETAINED
1						26.67	
½						12.7	
4			0.0	1000.0	100	4.76	0
~~10~~ 8			0.0	1000.0	100	2.00	0
~~20~~ 18			0.4	999.6	100	0.84	0
~~40~~ 30			146.4	853.2	85	0.42	15
~~60~~ 50			809.1	44.1	4	0.25	96
100			42.0	2.1	0	0.149	100
200						0.074	
PAN			2.1				

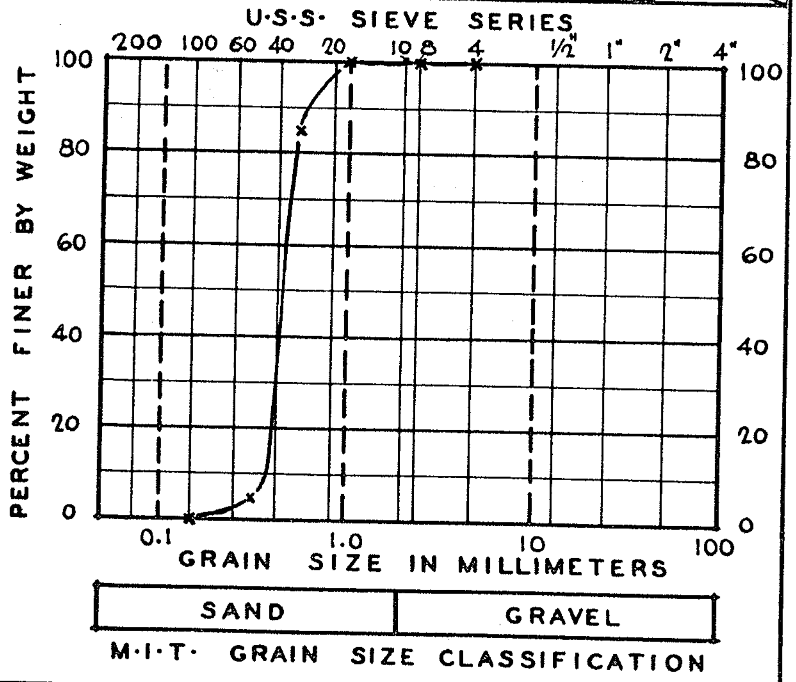
211/100

= 2.11

Fineness Modulus = 2.11

Grain Size = 0.44 mm.

GRAIN SIZE DISTRIBUTION CURVE



TESTED: L.J.K. DATE: 26 / 6 / 64

PLOTTED: ______ DATE: ______

COMPUTED: ______ DATE: ______

CHECKED: ______ DATE: ______

SOIL MECHANICS LABORATORY
DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF MANITOBA
FORT GARRY MANITOBA

APPENDIX C

SPECIFIC GRAVITY TESTS

SM ______

PROJECT PROF. CLAYTON, MASTER'S THESIS

TEST HOLE NO. ______ SAMPLE NO. 2B DEPTH ______

DESCRIPTION OF SAMPLE: SIEVED COARSE MORTAR SAND FROM RED R. FLOODWAY MODEL.

REMARKS: ______

FLASK NO.		E		
THERMOMETER NO.		79-717		
COHESIONLESS SOILS ONLY	WT. FLASK + DRY SOIL	248.32 gm.		
	WT. FLASK	167.28		
	WT. DRY SOIL, W_s	81.04		
TIME UNDER VACUUM		1 hr.		
WT. FLASK + WATER + SOIL, W_{bws}		716.60 gm.		
TEMP. OF SUSPENSION, T° C.		25.30		
WT. FLASK + WATER, W_{bw}		665.10		
COHESIVE SOILS ONLY	EVAP. DISH NO.			
	WT. DRY SOIL + TARE			
	WT. TARE			
	WT. DRY SOIL, W_s			
SPECIFIC GRAVITY, G_s		2.74		
AVERAGE SPECIFIC GRAVITY		2.74		

FORMULA:

$$G_s = \frac{W_s}{W_s + W_{bw} - W_{bws}.}$$

WHERE

G_s = SPECIFIC GRAVITY OF SOLIDS

W_s = WT. OF DRY SOIL

W_{bw} = WT. OF FLASK + WATER AT T° C. (FROM CALIBRATION CURVE FOR FLASK)

W_{bws} = WT. OF FLASK + WATER + SOIL AT T° C.

TESTED: L.J.K. DATE: 27/7/64

COMPUTED: L.J.K. DATE: 28/7/64

CHECKED: ______ DATE: ______

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FORT GARRY MANITOBA

SPECIFIC GRAVITY TESTS

SM ________

PROJECT PROF. CLAYTON, MASTER'S THESIS

TEST HOLE NO. ________ SAMPLE NO. 3A DEPTH ________

DESCRIPTION OF SAMPLE: MEDIUM MORTAR SAND

REMARKS:

FLASK NO.		F		
THERMOMETER NO.		79-717		
COHESIONLESS SOILS ONLY	WT. FLASK + DRY SOIL	231.55 gm.		
	WT. FLASK	151.20		
	WT. DRY SOIL, W_s	80.35		
TIME UNDER VACUUM		1 hr.		
WT. FLASK + WATER + SOIL, W_{bws}		700.13 gm.		
TEMP. OF SUSPENSION, T° C.		25.30		
WT. FLASK + WATER, W_{bw}		649.09		
COHESIVE SOILS ONLY	EVAP. DISH NO.			
	WT. DRY SOIL + TARE			
	WT. TARE			
	WT. DRY SOIL, W_s			
SPECIFIC GRAVITY, G_s		2.74		
AVERAGE SPECIFIC GRAVITY		2.74		

FORMULA: $$G_s = \frac{W_s}{W_s + W_{bw} - W_{bws}}$$

WHERE

G_s = SPECIFIC GRAVITY OF SOLIDS

W_s = WT. OF DRY SOIL

W_{bw} = WT. OF FLASK + WATER AT T° C. (FROM CALIBRATION CURVE FOR FLASK)

W_{bvs} = WT. OF FLASK + WATER + SOIL AT T° C.

TESTED: L.J.K. DATE: 27/7/64

COMPUTED: L.J.K. DATE: 28/7/64

CHECKED: ________ DATE: ________

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SPECIFIC GRAVITY TESTS

SM ________

PROJECT: PROF. CLAYTON, MASTER'S THESIS

TEST HOLE NO. ________ SAMPLE NO. 4A. DEPTH ________

DESCRIPTION OF SAMPLE: FINE MORTAR SAND

REMARKS:

FLASK NO.		M		
THERMOMETER NO.		79-717		
COHESIONLESS SOILS ONLY	WT. FLASK + DRY SOIL	260.30 gm.		
	WT. FLASK	181.53		
	WT. DRY SOIL, W_s	78.77		
TIME UNDER VACUUM		1 hr		
WT. FLASK + WATER + SOIL, W_{bws}		729.39 gm.		
TEMP. OF SUSPENSION, T° C.		25.30		
WT. FLASK + WATER, W_{bw}		679.58		
COHESIVE SOILS ONLY	EVAP. DISH NO.			
	WT. DRY SOIL + TARE			
	WT. TARE			
	WT. DRY SOIL, W_s			
SPECIFIC GRAVITY, G_s		2.72		
AVERAGE SPECIFIC GRAVITY		2.72		

FORMULA: $$G_s = \frac{W_s}{W_s + W_{bw} - W_{bws}}.$$

WHERE
G_s = SPECIFIC GRAVITY OF SOLIDS
W_s = WT. OF DRY SOIL
W_{bw} = WT. OF FLASK + WATER AT T° C.
(FROM CALIBRATION CURVE FOR FLASK)
W_{bws} = WT. OF FLASK + WATER + SOIL AT T° C.

TESTED: L.J.K. DATE: 27/7/64
COMPUTED: L.J.K. DATE: 28/7/64
CHECKED: ________ DATE: ________

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FORT GARRY MANITOBA

SPECIFIC GRAVITY TESTS

SM ________

PROJECT PROF. CLAYTON, MASTER'S THESIS

TEST HOLE NO. ________ SAMPLE NO. 5B DEPTH ________

DESCRIPTION OF SAMPLE: COARSE SILICA SAND

REMARKS: ________

FLASK NO.		B		
THERMOMETER NO.		79-717		
COHESIONLESS SOILS ONLY	WT. FLASK + DRY SOIL	241.53 gm.		
	WT. FLASK	159.46		
	WT. DRY SOIL, W_s	82.07		
TIME UNDER VACUUM		1 hr.		
WT. FLASK + WATER + SOIL, W_{bws}		708.76 gm.		
TEMP. OF SUSPENSION, T° C.		25.30		
WT. FLASK + WATER, W_{bw}		657.57		
COHESIVE SOILS ONLY	EVAP. DISH NO.			
	WT. DRY SOIL + TARE			
	WT. TARE			
	WT. DRY SOIL, W_s			
SPECIFIC GRAVITY, G_s		2.66		
AVERAGE SPECIFIC GRAVITY		2.66		

FORMULA:

$$G_s = \frac{W_s}{W_s + W_{bw} - W_{bws}}.$$

WHERE

G_s = SPECIFIC GRAVITY OF SOLIDS

W_s = WT. OF DRY SOIL

W_{bw} = WT. OF FLASK + WATER AT T° C.
(FROM CALIBRATION CURVE FOR FLASK)

W_{bws} = WT. OF FLASK + WATER + SOIL AT T° C.

TESTED: L.J.K. DATE: 27/7/64

COMPUTED: L.J.K. DATE: 28/7/64

CHECKED: ________ DATE: ________

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FORT GARRY MANITOBA

SPECIFIC GRAVITY TESTS

SM ________

PROJECT PROF. CLAYTON, MASTER'S THESIS

TEST HOLE NO. ________ SAMPLE NO. 6B DEPTH ________

DESCRIPTION OF SAMPLE: FINE SILICA SAND

REMARKS:

FLASK NO.		L		
THERMOMETER NO.		79-717		
COHESIONLESS SOILS ONLY	WT. FLASK + DRY SOIL	245.60 gm.		
	WT. FLASK	166.34		
	WT. DRY SOIL, W_s	79.26		
TIME UNDER VACUUM		1 hr.		
WT. FLASK + WATER + SOIL, W_{bws}		713.72 gm.		
TEMP. OF SUSPENSION, T° C.		25.30		
WT. FLASK + WATER, W_{bw}		664.21		
COHESIVE SOILS ONLY	EVAP. DISH NO.			
	WT. DRY SOIL + TARE			
	WT. TARE			
	WT. DRY SOIL, W_s			
SPECIFIC GRAVITY, G_s		2.66		
AVERAGE SPECIFIC GRAVITY		2.66		

FORMULA: $$G_s = \frac{W_s}{W_s + W_{bw} - W_{bws}}$$

WHERE
G_s = SPECIFIC GRAVITY OF SOLIDS
W_s = WT. OF DRY SOIL
W_{bw} = WT. OF FLASK + WATER AT T° C. (FROM CALIBRATION CURVE FOR FLASK)
W_{bws} = WT. OF FLASK + WATER + SOIL AT T° C.

TESTED: L.J.K. DATE: 27/7/64
COMPUTED: L.J.K. DATE: 28/7/64
CHECKED: ________ DATE: ________

SOIL MECHANICS LABORATORY
DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF MANITOBA
FORT GARRY MANITOBA

TEST DATA SHEET

[illegible] DATE Jan. 8/64

[illegible] SCALE HORIZ. 1:50

VERT. 1:50

MATERIAL: [illegible] MORTAR SAND FROM RED RIVER FLOODWAY MODEL

	MODEL	PROTOTYPE
[illegible] Height (ft.)	0.700	
Discharge (CFS)	2.050	36,200.
Depth of Flow (ft.)	0.765	38.35
Area (sq.ft.)	4.230	10,600.
Mean Velocity in Channel (ft/sec)	.485	3.42
Time of Run	9 hours	63.63
Number of Photos Taken	6	

APPENDIX D

REMARKS:

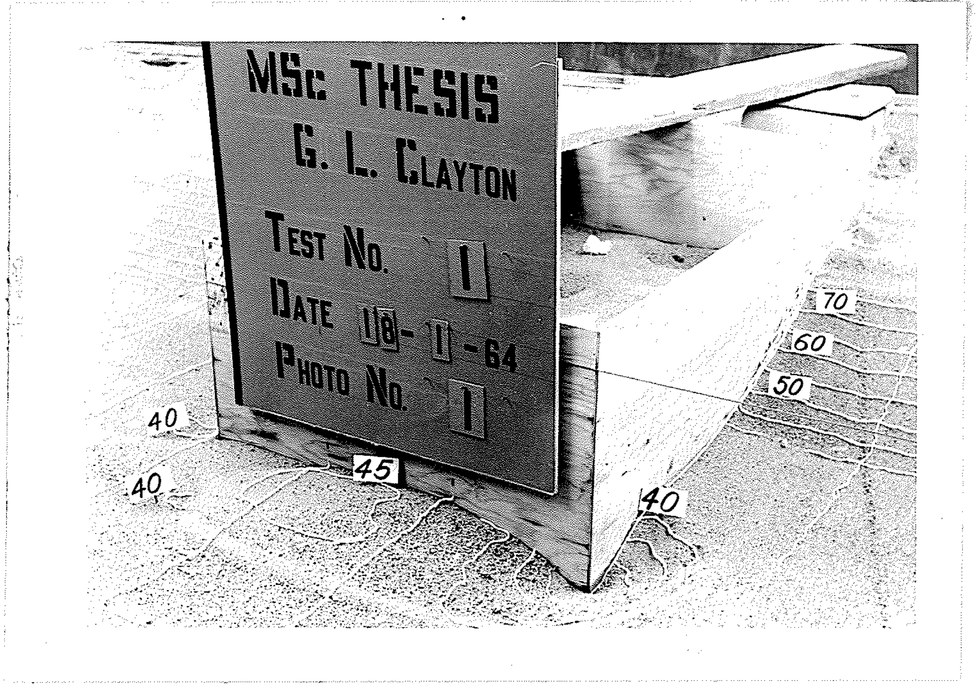
Started at 9:45 A.M. Some erosion during filling. Sand boils to surface just below upstream corner. Stopped after 15 min.

2:00 P.M. - Erosion on opposite bank still progressing, but at a slower rate. Difficult to see if hole still eroding because of cloudy water.

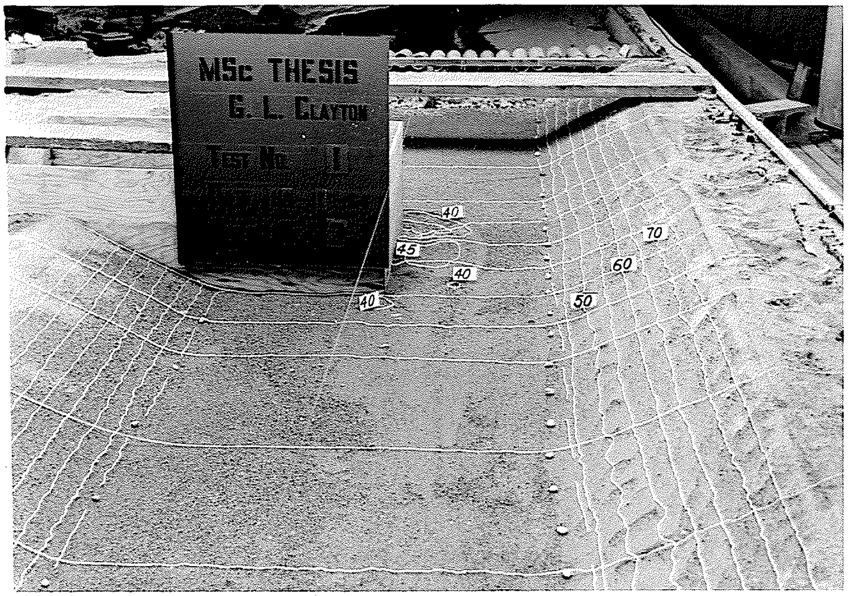
4:00 P.M. - Erosion on bank still progressing slowly. Hole no larger.

6:45 P.M. - Shut down. Erosion on bank continues very slowly. Depth of flow 0.7' not 0.8'.

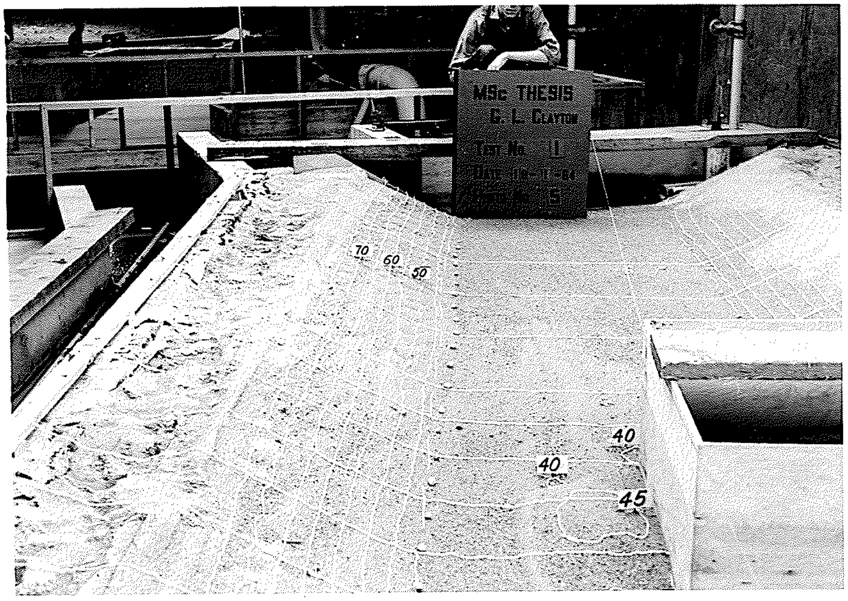
Test Performed by: glc

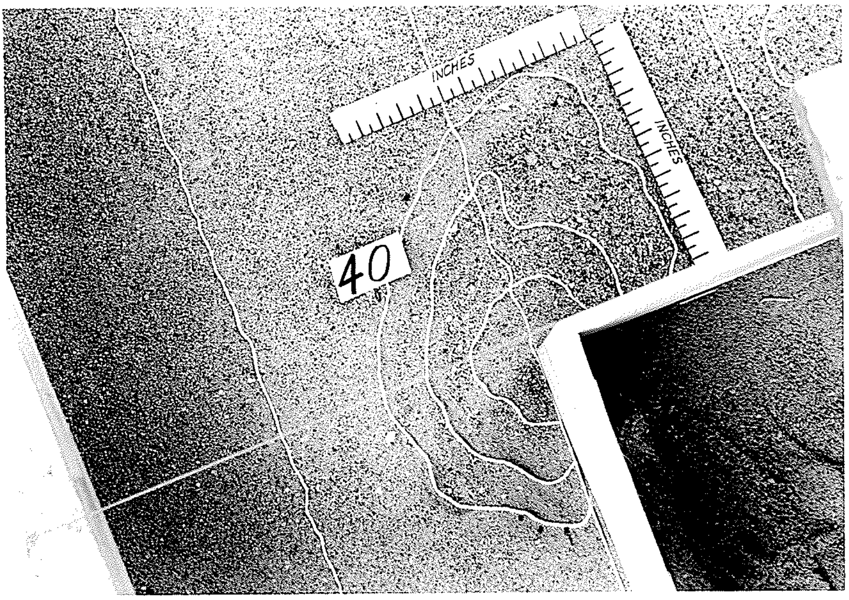

MSc THESIS
G. L. CLAYTON
TEST No. 1
DATE 18-1-64
PHOTO No. 1
70
60
50
40
40
45
40


MSc THESIS
G. L. CLAYTON
TEST No. 1
DATE 18-1-64
PHOTO No. 2
70
60
50
45
40
40
40

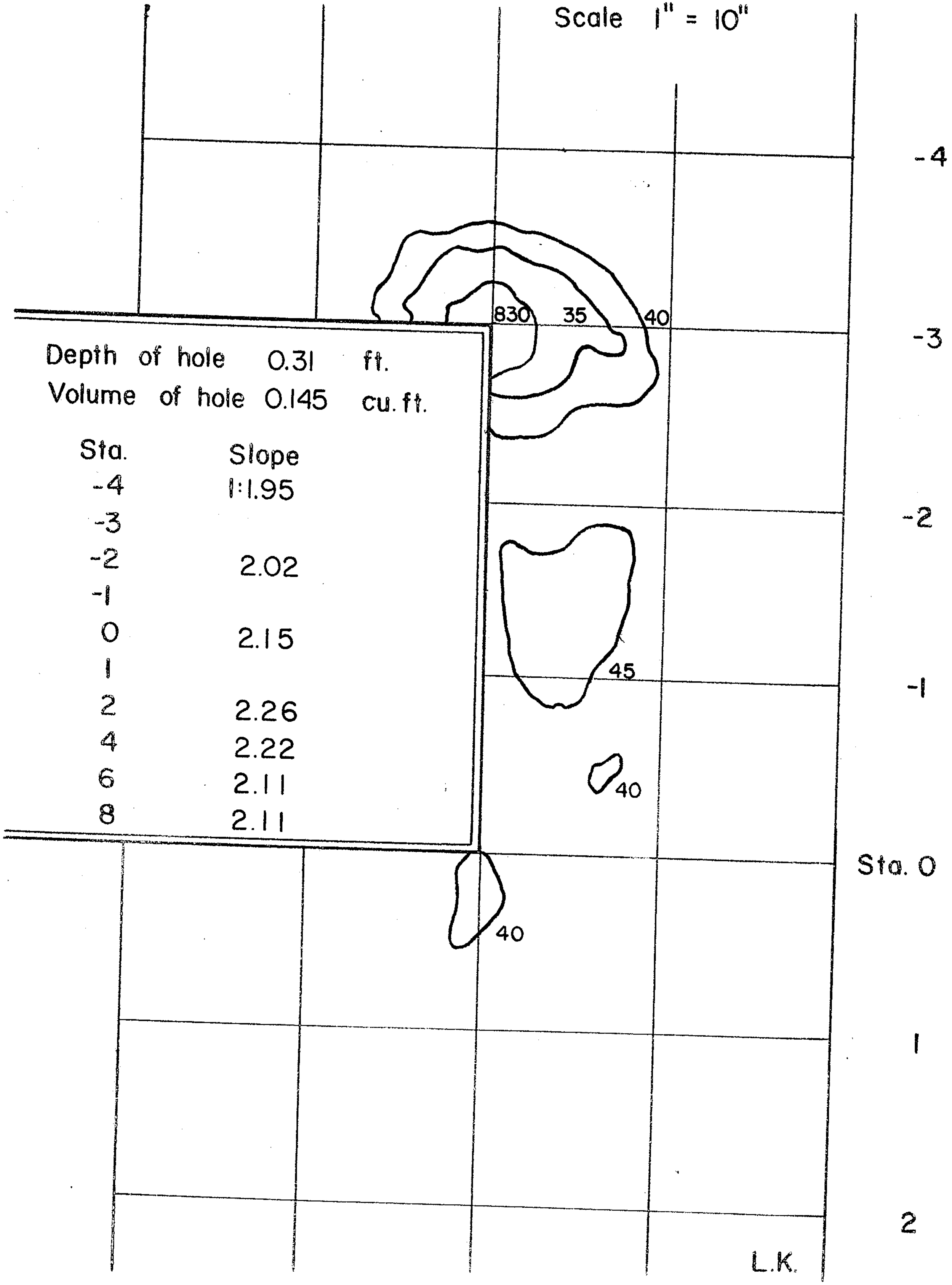

MSc THESIS
G. L. CLAYTON
TEST No. 1
40
45
40
40
70
60
50


G. L. CLAYTON
TEST No 1
DATE
4
70
60
50


MSc THESIS
G. L. CLAYTON
TEST No. 11
DATE 10-11-'84
5
70
60
50
40
40
45


INCHES
INCHES
40

TEST 1



Depth of hole 0.31 ft.
Volume of hole 0.145 cu. ft.

Sta.	Slope
-4	1:1.95
-3	
-2	2.02
-1	
0	2.15
1	
2	2.26
4	2.22
6	2.11
8	2.11

TEST DATA SHEET

TEST NO. 2

DATE Jan. 25/64

MODEL SCALES:

HORIZ. 1:50

VERT. 1:50

MATERIAL: UNSIEVED MORTAR SAND FROM RED RIVER FLOODWAY MODEL

	MODEL	PROTOTYPE
Gauge Height (ft.)	0.800	
Discharge (CFS)	2.860	50,500.
Depth of Flow (ft.)	0.800	40.
Area (sq.ft.)	4.480	11,200.
Mean Velocity in Channel (ft/sec)	0.639	4.51
Time of Run	4 hours	28.28
Number of Photos Taken	5	

REMARKS:

Some erosion during filling. Probably has no affect on test results. Erosion violent at first and sand boiled to surface at side of dam. This stopped after about 15 minutes.

Water was clear at first, so erosion could be observed. Hole eroded rapidly and was almost as large in 15 minutes as at end of Test 1.

Left bank erosion rapid. Still rapid after 1½ hours.

After 1½ hours, removed flat stone from bottom of hole. Depth of hole did not increase.

At 2½ hours, erosion on left bank still rapid. Shut down at 4 hours.

Test Performed by: glc


TEST NO. 2
DATE 11-2-64
PHOTO NO. 1
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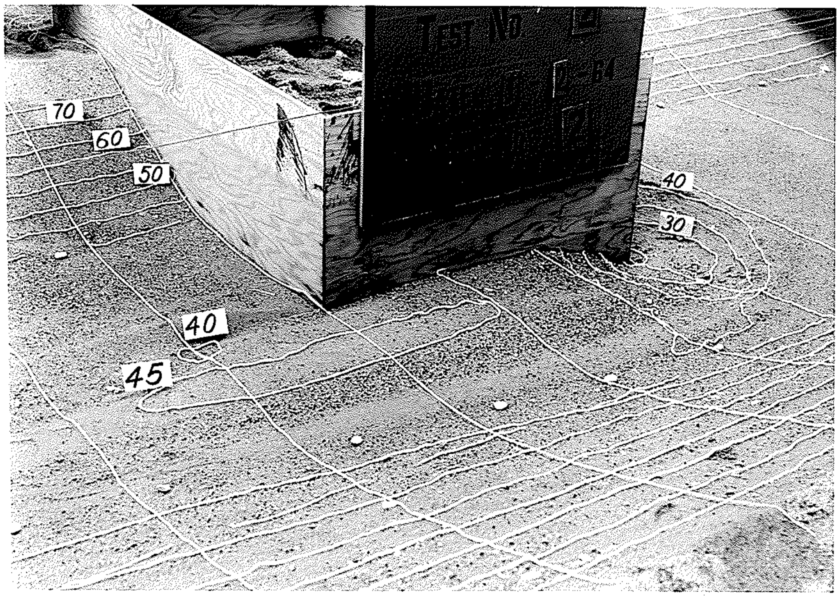
60
50
40
30


TEST NO. 2
11-2-64
2
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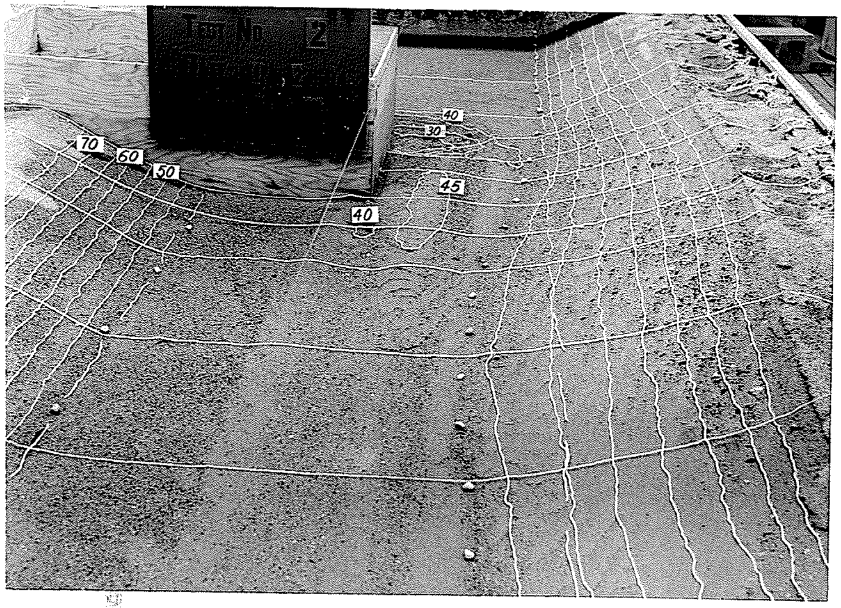
40
45


TEST NO. 2
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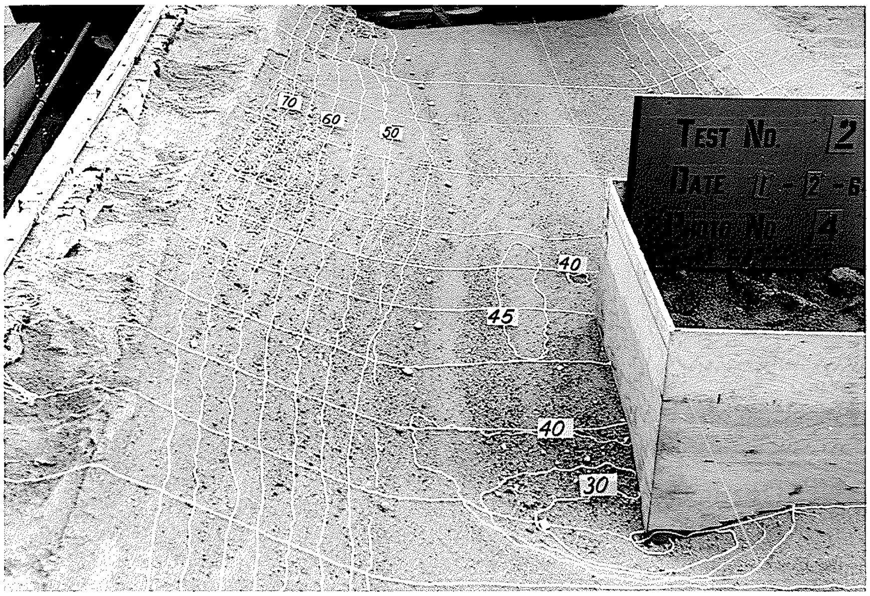
70
60
50
TEST NO. 2
DATE 11 - 2 - 6
PHOTO NO. 4
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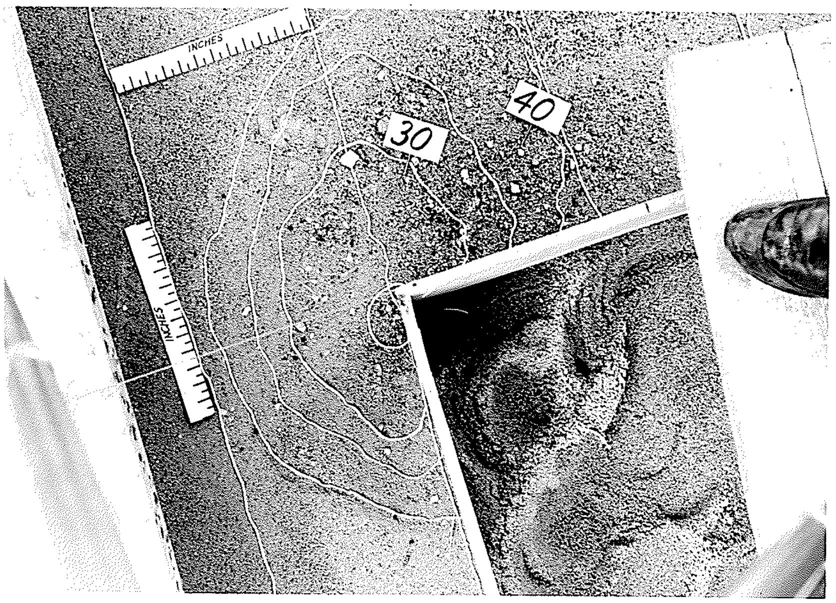
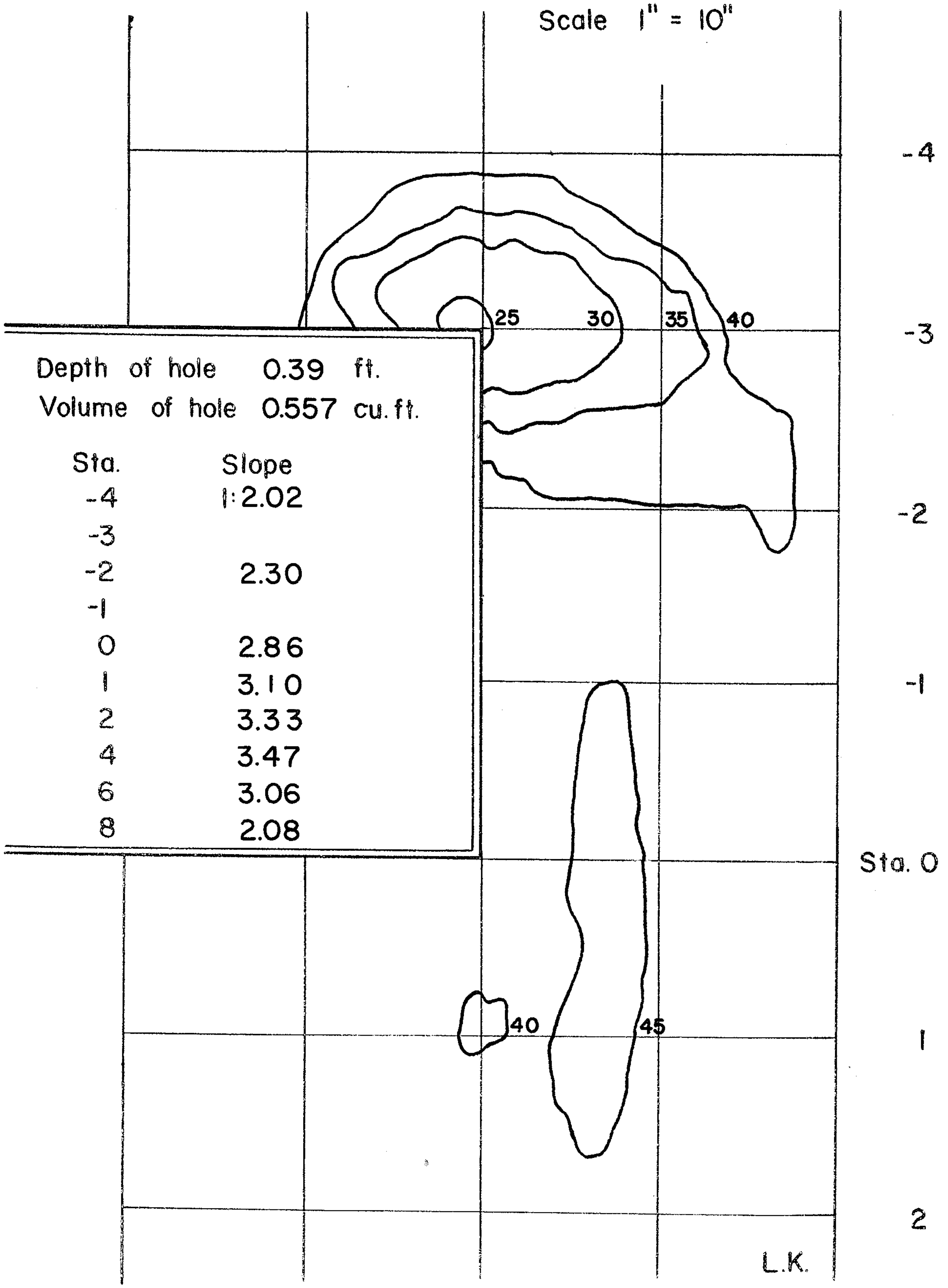
45
40
30

FEB



TEST 2



Depth of hole 0.39 ft.
Volume of hole 0.557 cu. ft.

Sta.	Slope
-4	1:2.02
-3	
-2	2.30
-1	
0	2.86
1	3.10
2	3.33
4	3.47
6	3.06
8	2.08

TEST DATA SHEET

TEST NO. 3

DATE Feb. 1/64

MODEL SCALES: HORIZ. 1:50

VERT. 1:50

MATERIAL: UNSIEVED MORTAR SAND FROM RED RIVER FLOODWAY MODEL

	MODEL	PROTOTYPE
Gauge Height (ft.)	0.800	
Discharge (CFS)	2.860	50,500.
Depth of Flow (ft.)	0.800	40.
Area (sq.ft.)	4.480	11,200.
Mean Velocity in Channel (ft/sec)	0.639	4.51
Time of Run	1 hour	7.07

Number of Photos Taken 5

REMARKS:

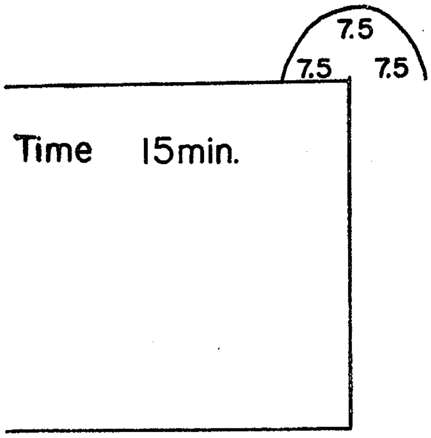
After 15 minutes, hole had radius of about 7½ inchs.

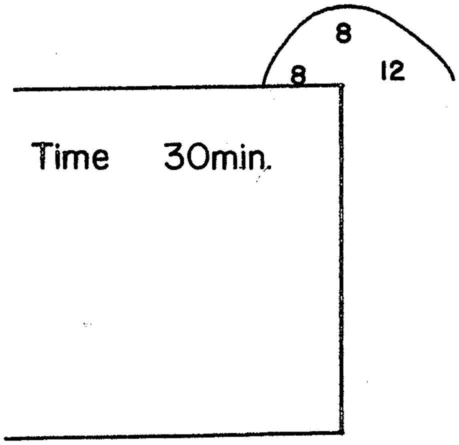
Have new device for viewing bottom of channel. It is made from a one foot length of airplane strut with a piece of plexiglass shaped to fit on end and glued on. Since it is streamlined, it does not disturb the flow pattern and can be lowered to bottom of channel without causing undue sand movement. Can now take more data on hole formation.

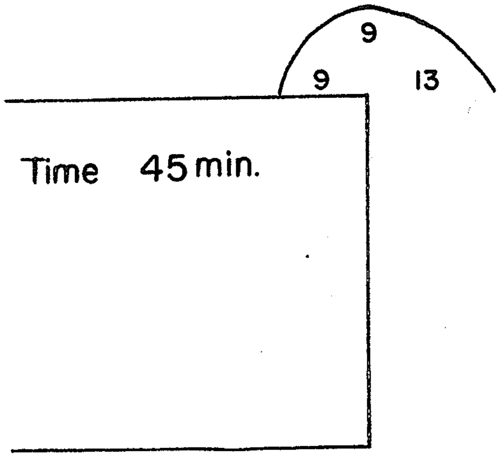
Test Performed by: glc

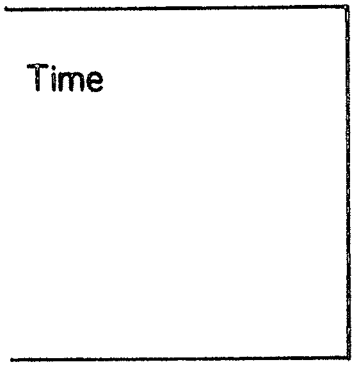
TEST 3

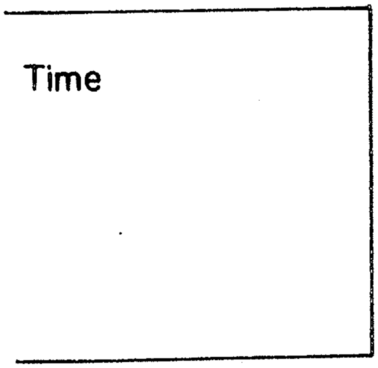
Scale: 1" = 20"

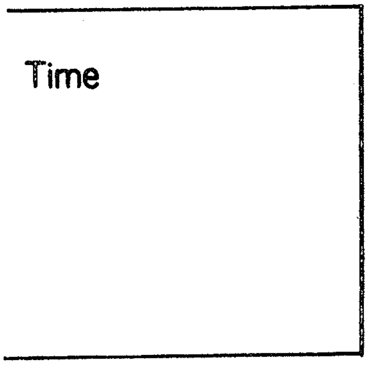












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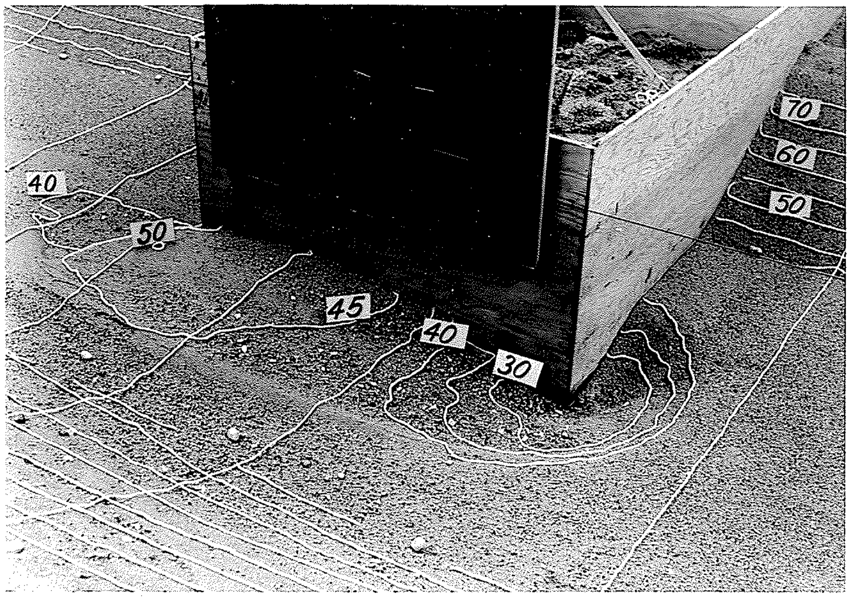

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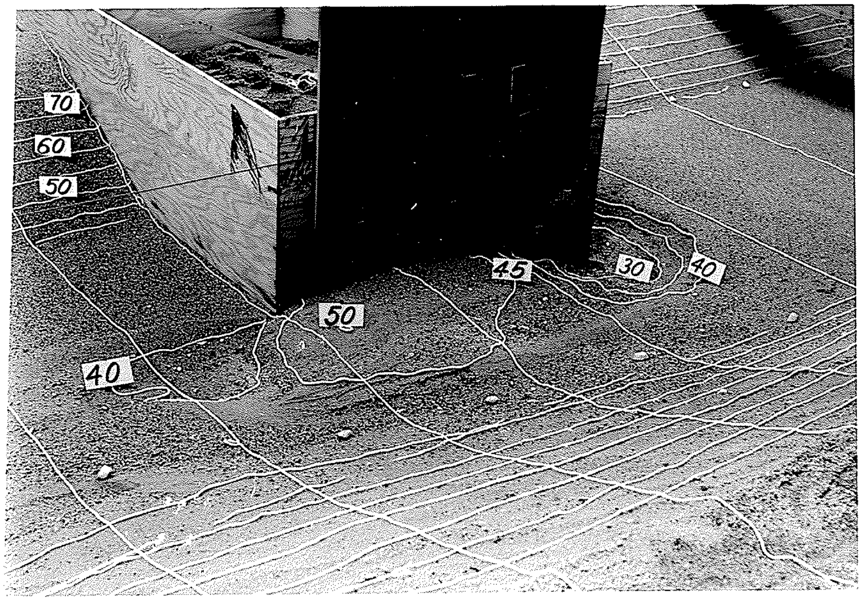

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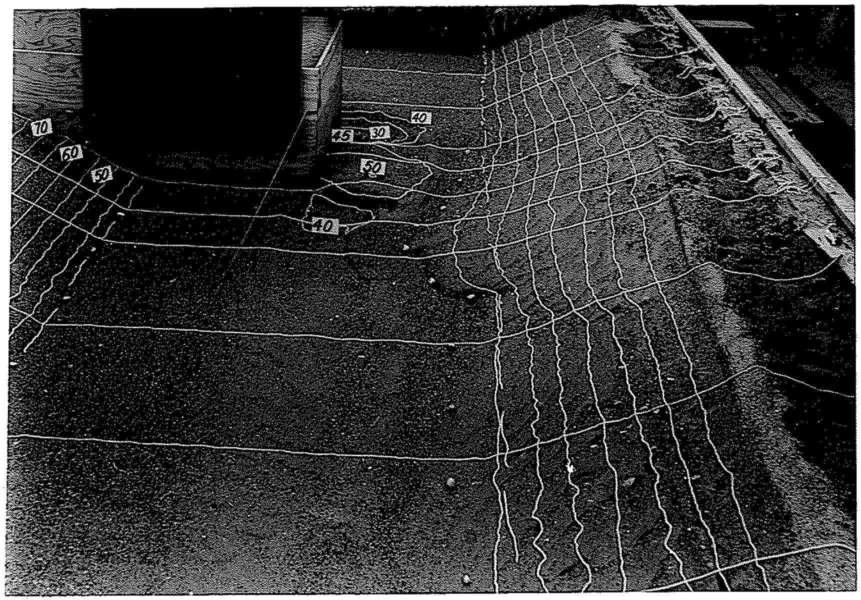

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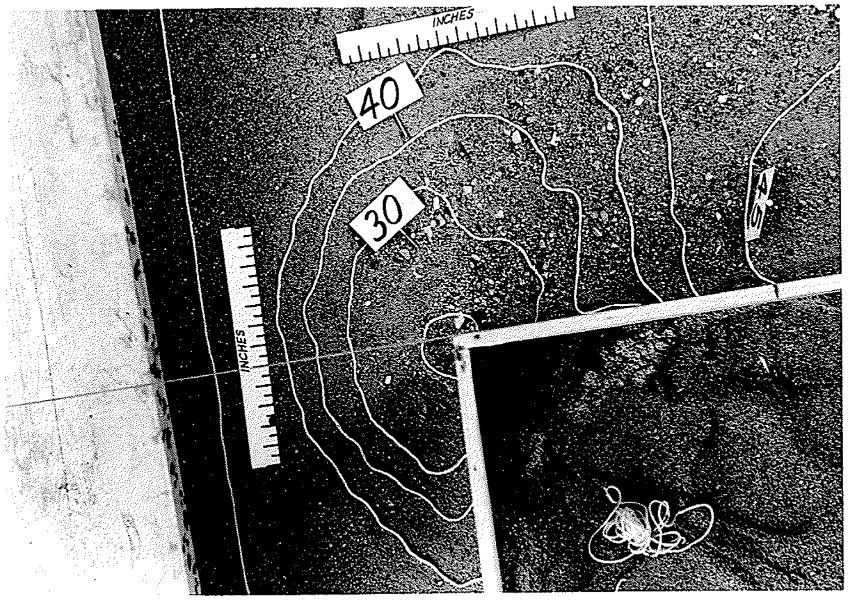
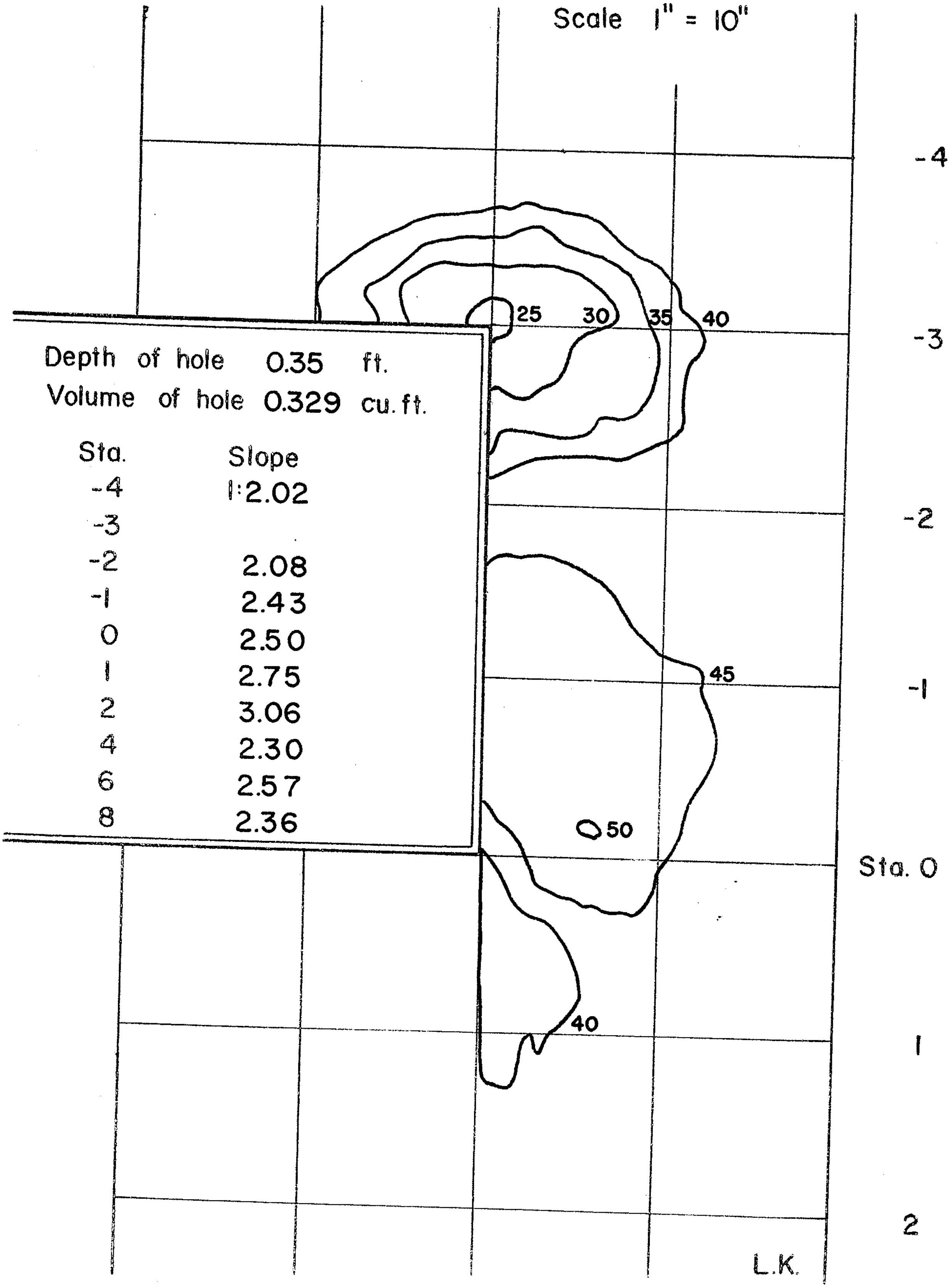
FEB



TEST 3

Scale 1" = 10"



Depth of hole 0.35 ft.
Volume of hole 0.329 cu. ft.

Sta.	Slope
-4	1:2.02
-3	
-2	2.08
-1	2.43
0	2.50
1	2.75
2	3.06
4	2.30
6	2.57
8	2.36

TEST DATA SHEET

TEST NO. 4

DATE Feb. 15/64

MODEL SCALES: HORIZ. 1:50

VERT. 1:50

MATERIAL: UNSIEVED MORTAR SAND FROM RED RIVER FLOODWAY MODEL

	MODEL	PROTOTYPE
Gauge Height (ft.)	0.800	
Discharge (CFS)	2.860	50,500.
Depth of Flow (ft.)	0.800	40.
Area (sq.ft.)	4.480	11,200.
Mean Velocity in Channel (ft/sec)	0.639	4.51
Time of Run	2 hours	14.14
Number of Photos Taken	4	

REMARKS:

No erosion during filling.

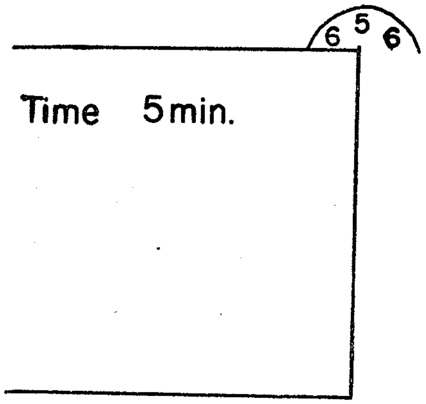
Small 50 contour appearing in previous test is not present here. Hole is wider, but not as deep.

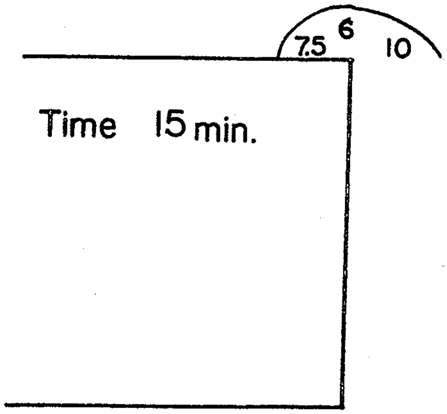
45 contour extends further downstream.

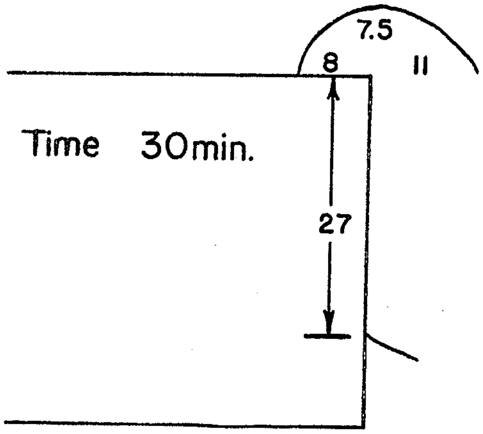
Test Performed by: glv

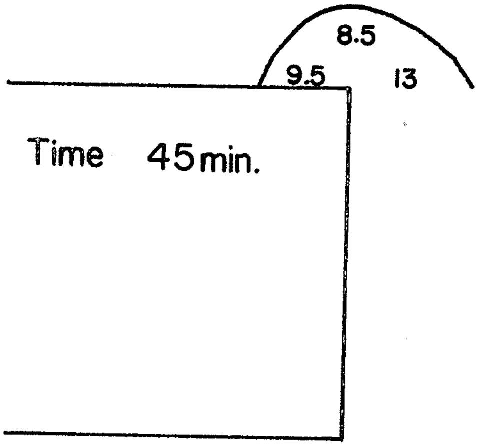
TEST 4

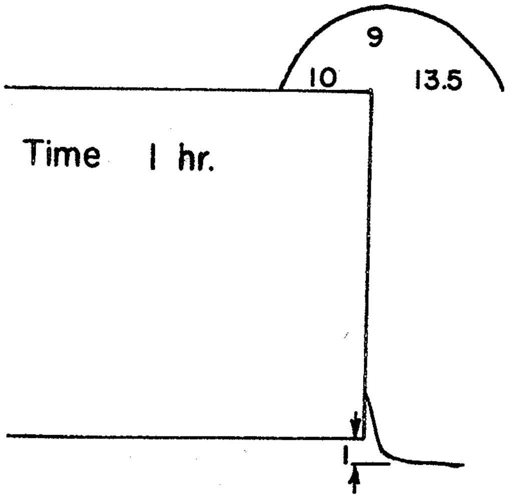
Scale: 1" = 20"

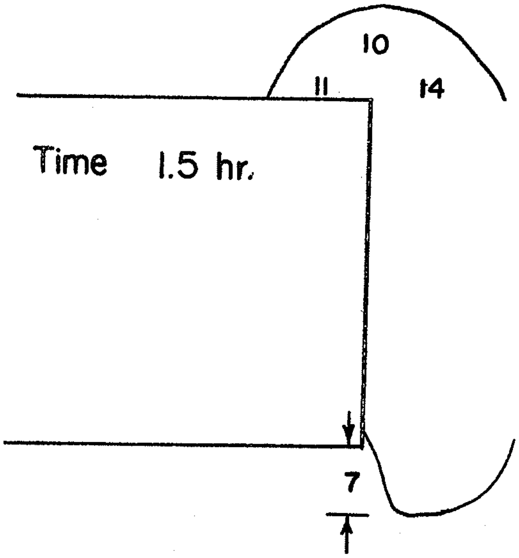












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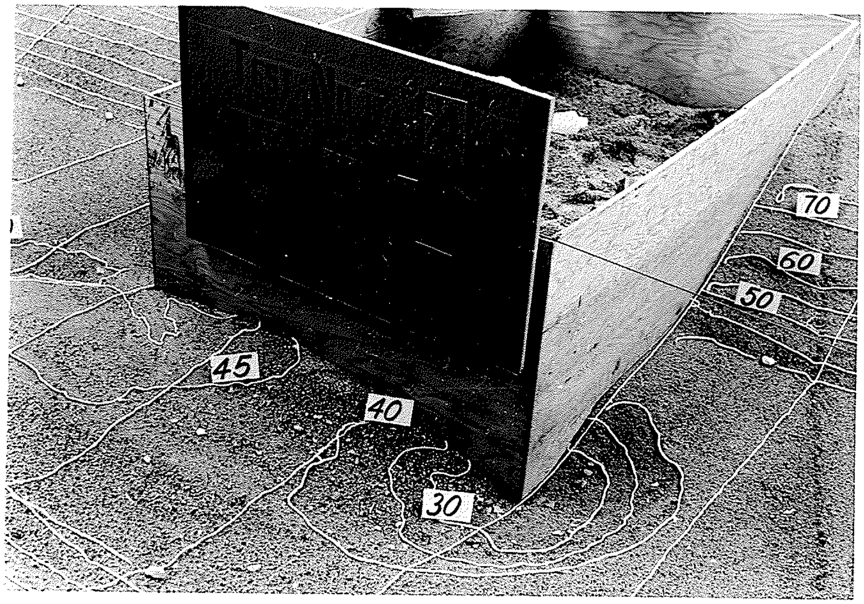

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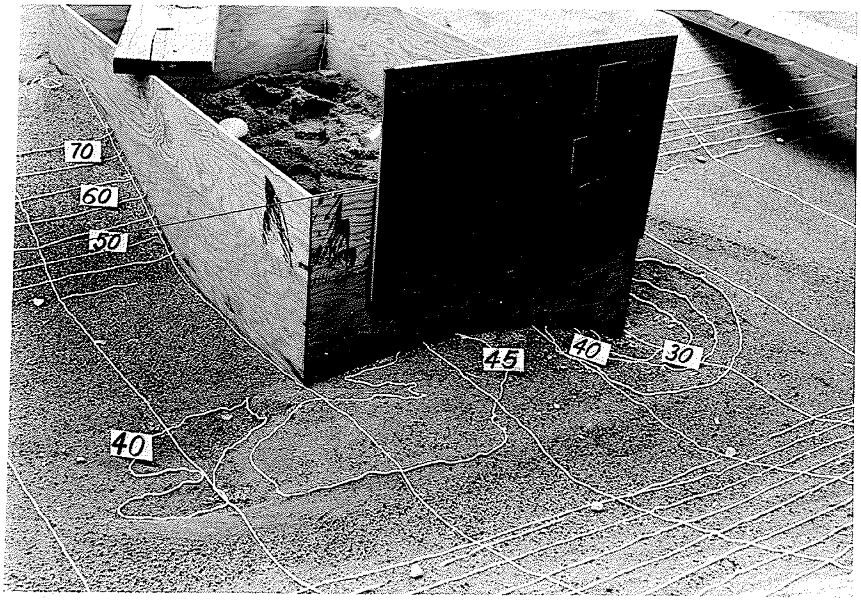
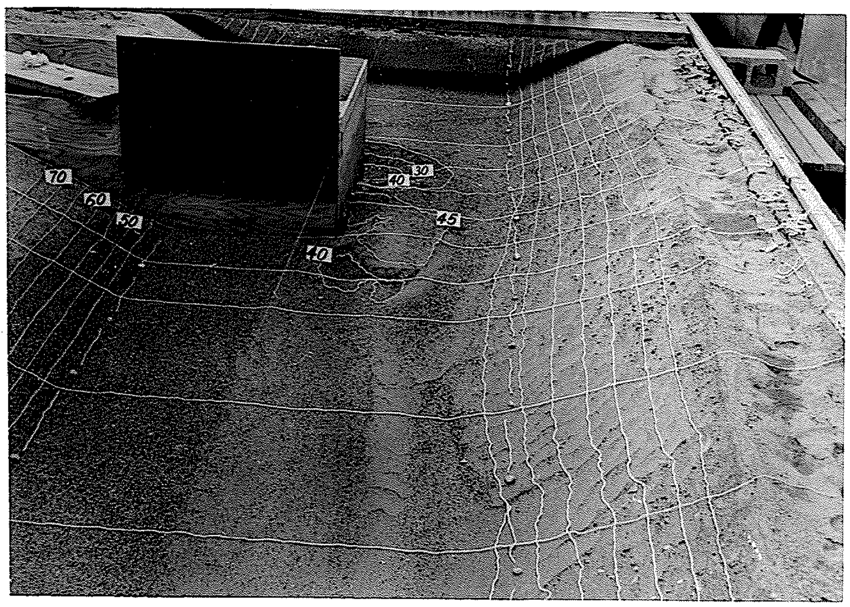
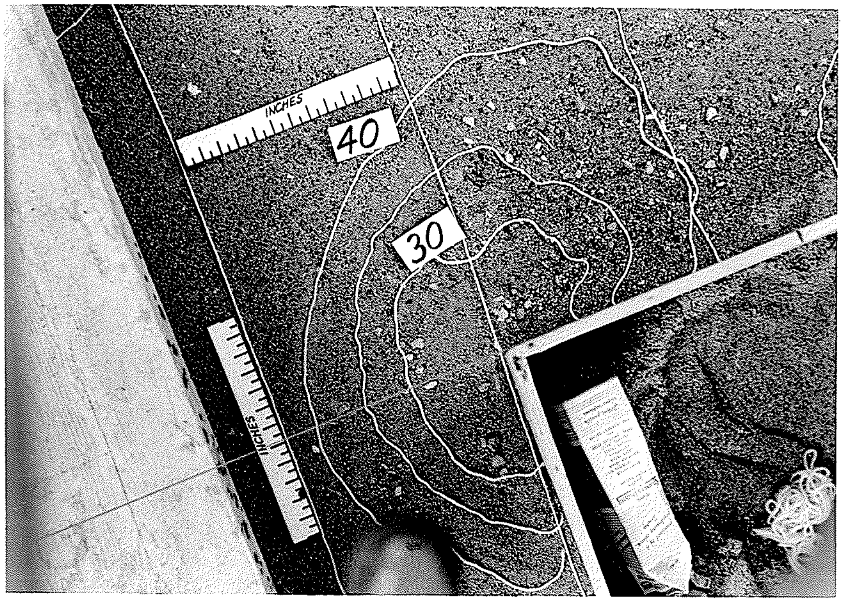


FEB •

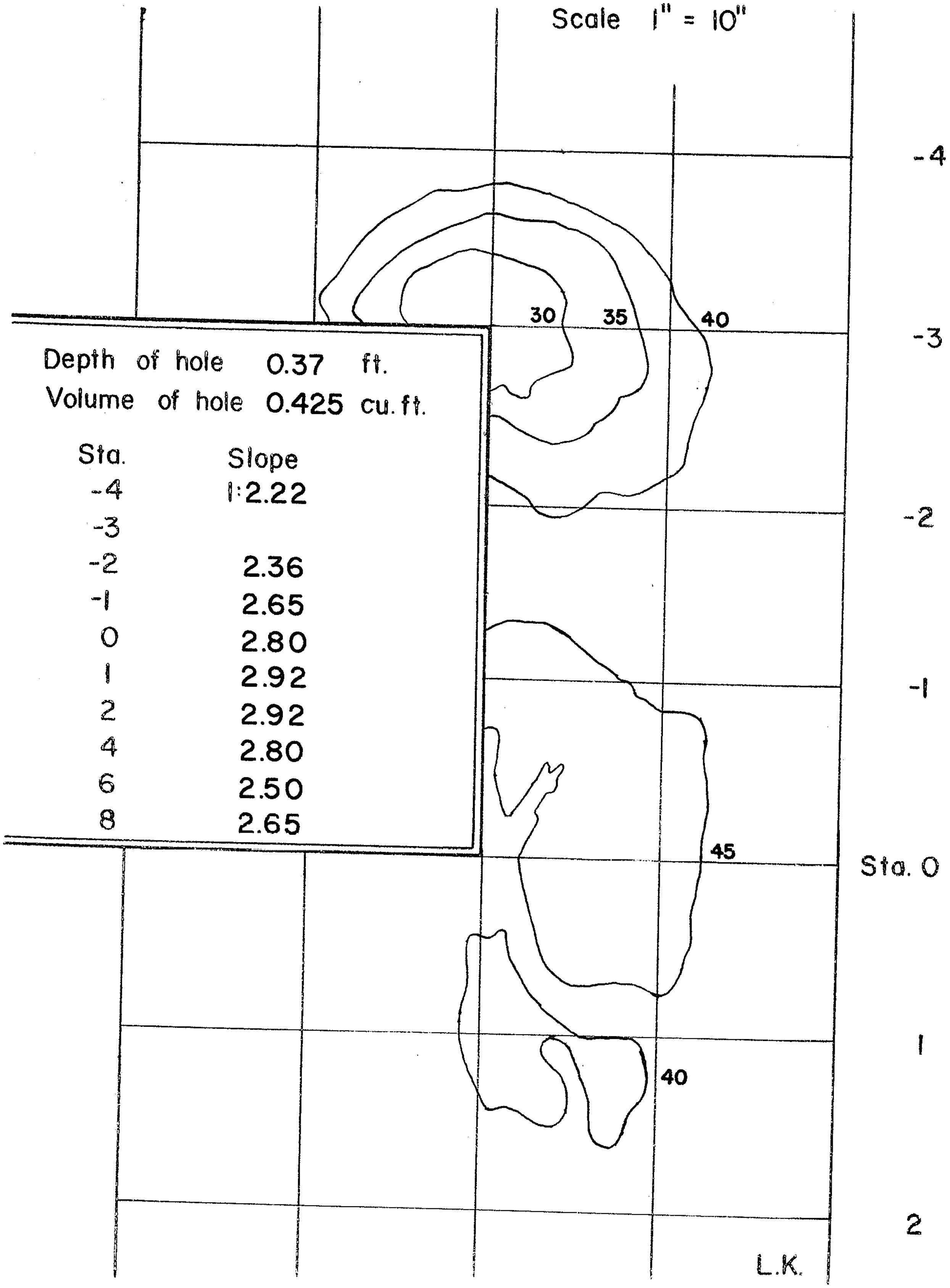


FEB •



TEST 4

Scale 1" = 10"



Depth of hole 0.37 ft.
Volume of hole 0.425 cu. ft.

Sta.	Slope
-4	1:2.22
-3	
-2	2.36
-1	2.65
0	2.80
1	2.92
2	2.92
4	2.80
6	2.50
8	2.65

TEST DATA SHEET

TEST NO. 5

DATE Feb. 21/64

MODEL SCALES:

HORIZ. 1:50

VERT. 1:50

MATERIAL: UNSIEVED MORTAR SAND FROM RED RIVER FLOODWAY MODEL

	MODEL	PROTOTYPE
Gauge Height (ft.)	0.800	
Discharge (CFS)	2.860	50,500.
Depth of Flow (ft.)	0.800	40.
Area (sq.ft.)	4.480	11,200.
Mean Velocity in Channel (ft/sec)	0.639	4.51
Time of Run	8 hours	56.56
Number of Photos Taken	4	

REMARKS:

No erosion during filling.

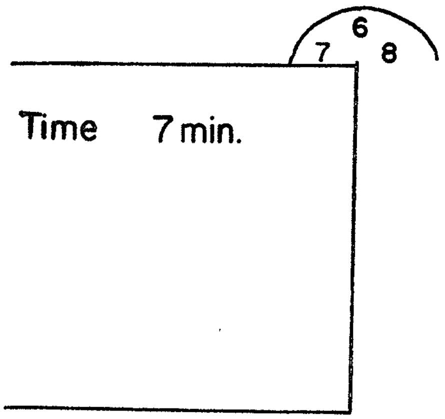
Hole wider and shallower than before.

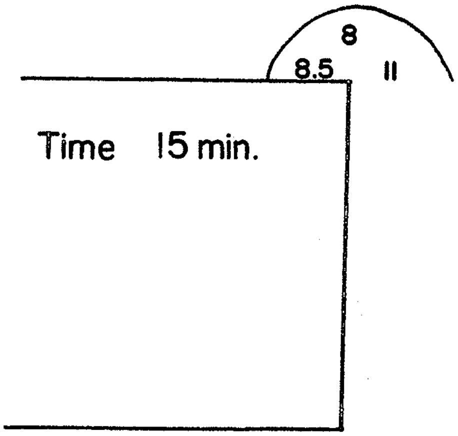
Erosion of bank still progressing slowly at 8 hours.

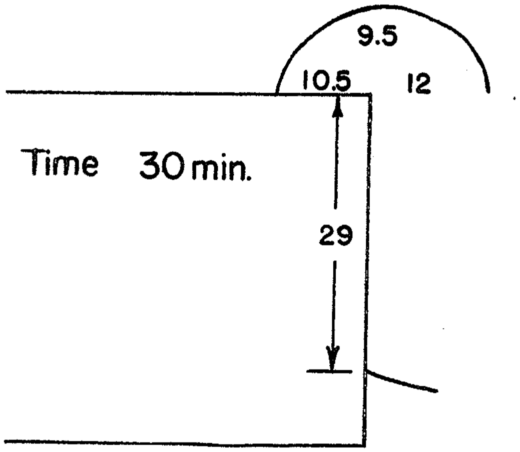
Test Performed by: glc

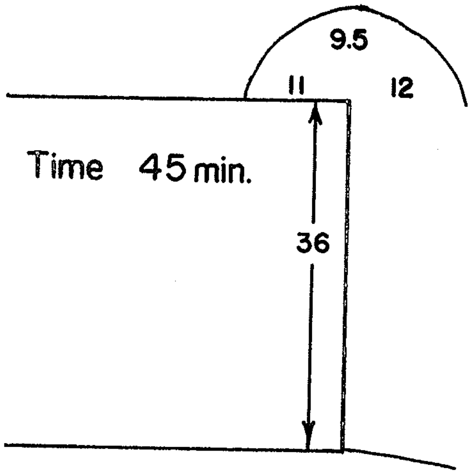
TEST 5

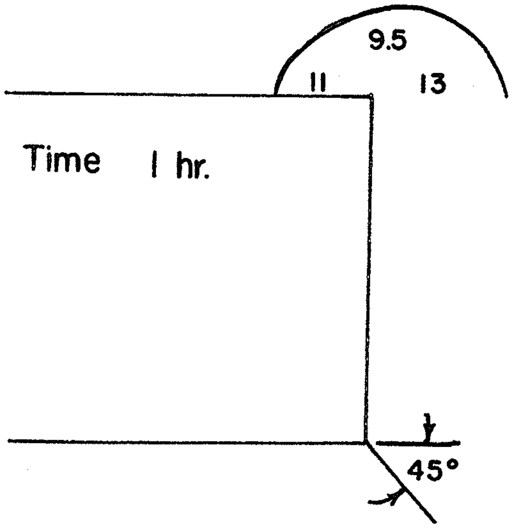
Scale: 1" = 20"

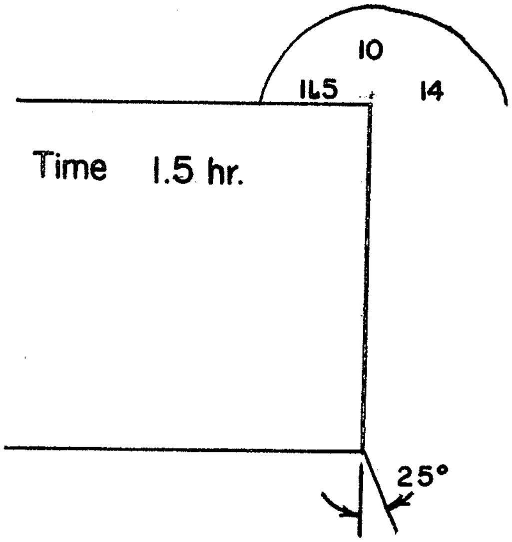






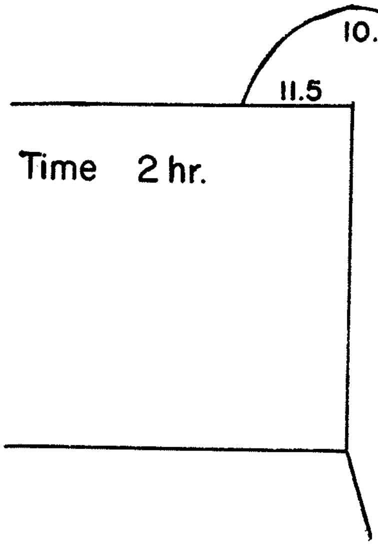


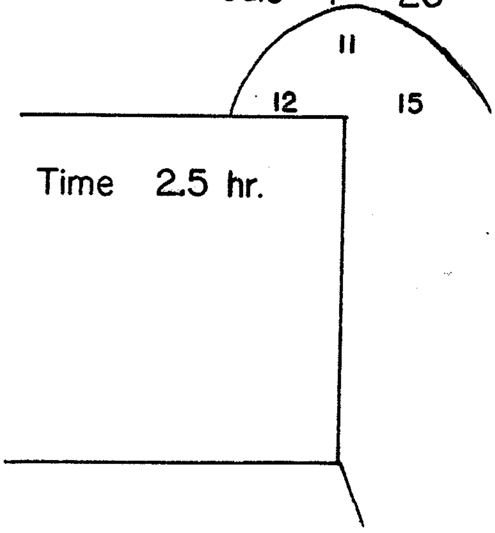


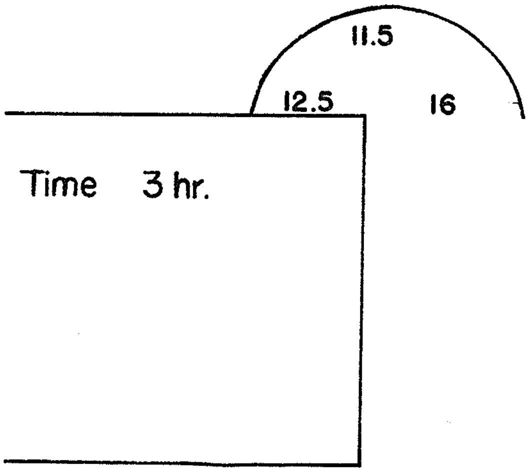


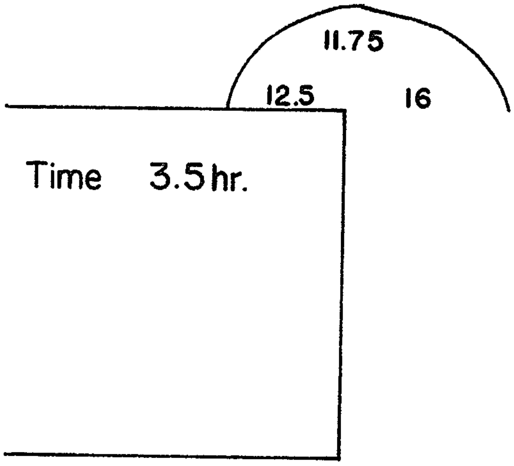
TEST 5

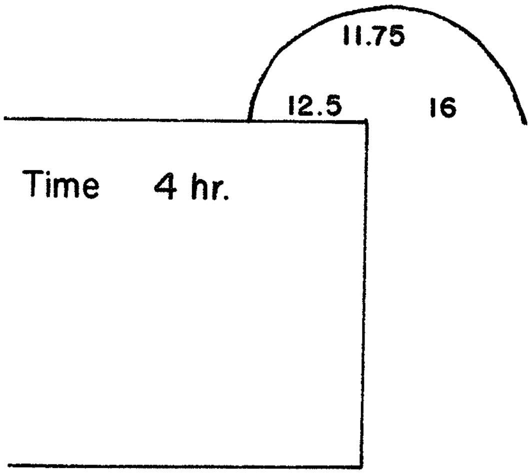
Scale: 1" = 20"

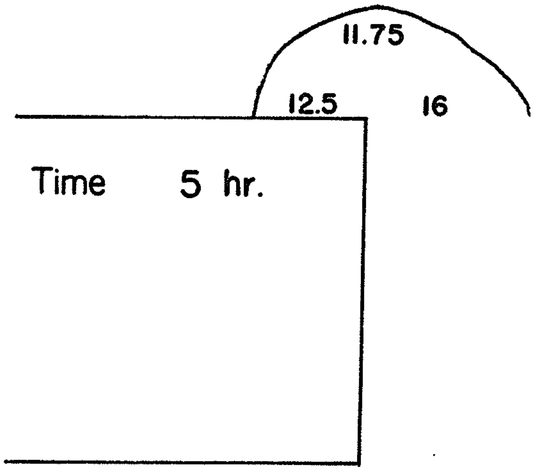






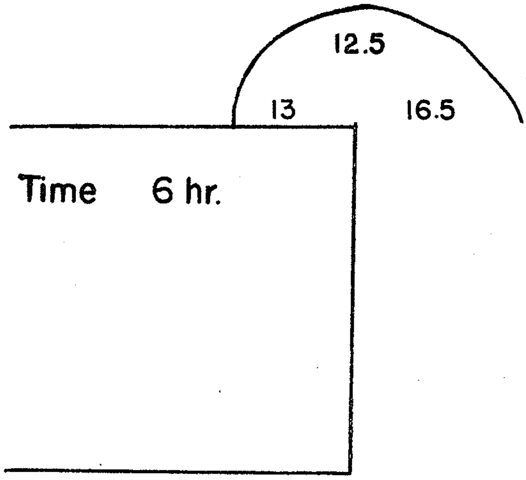


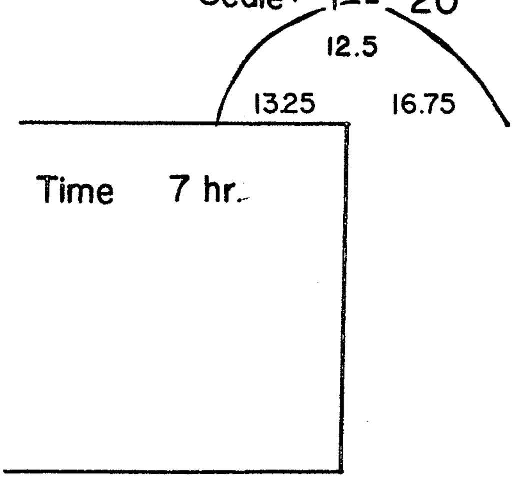




TEST 5

Scale: 1" = 20"





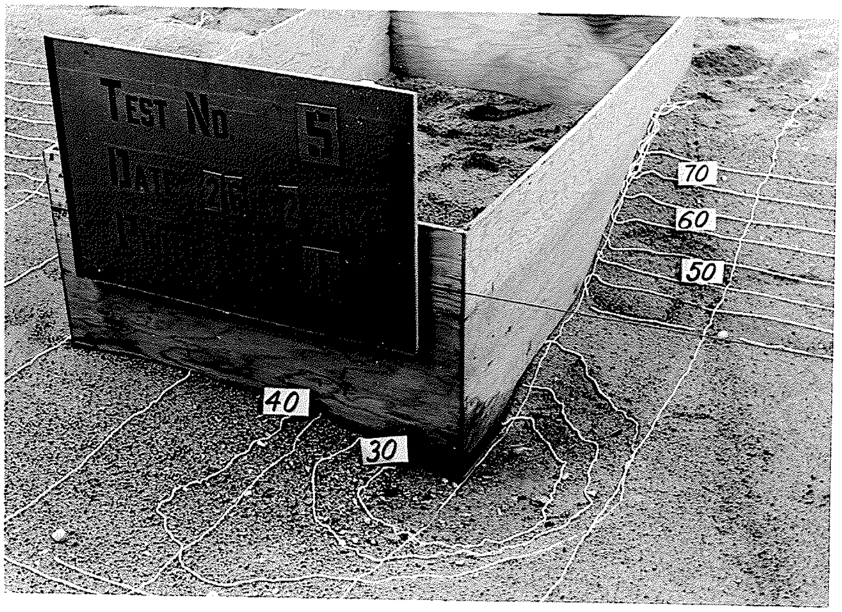
Time

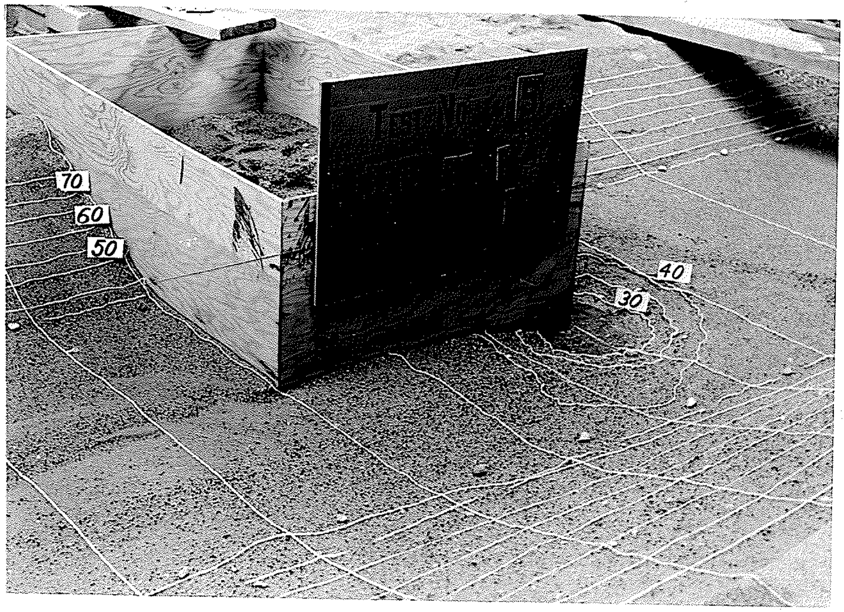
Time

Time

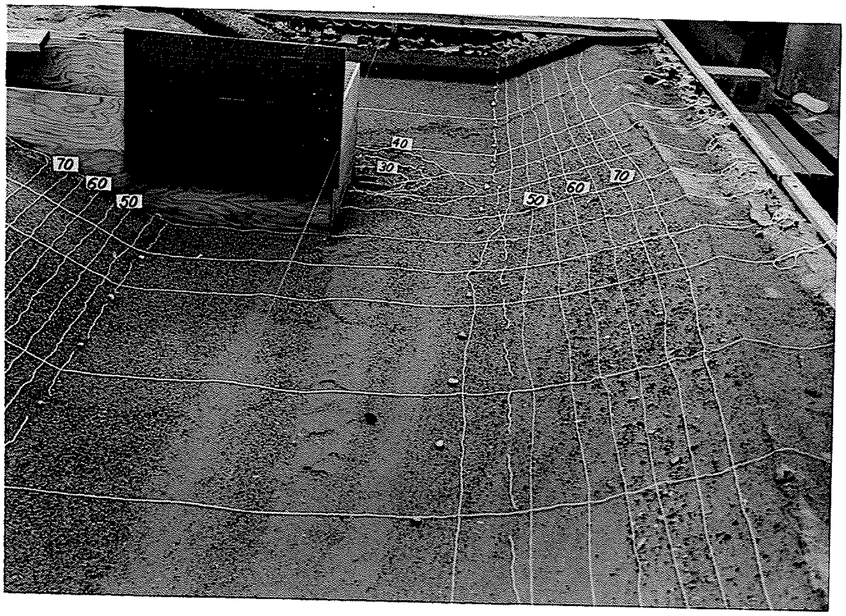
Time

FEB

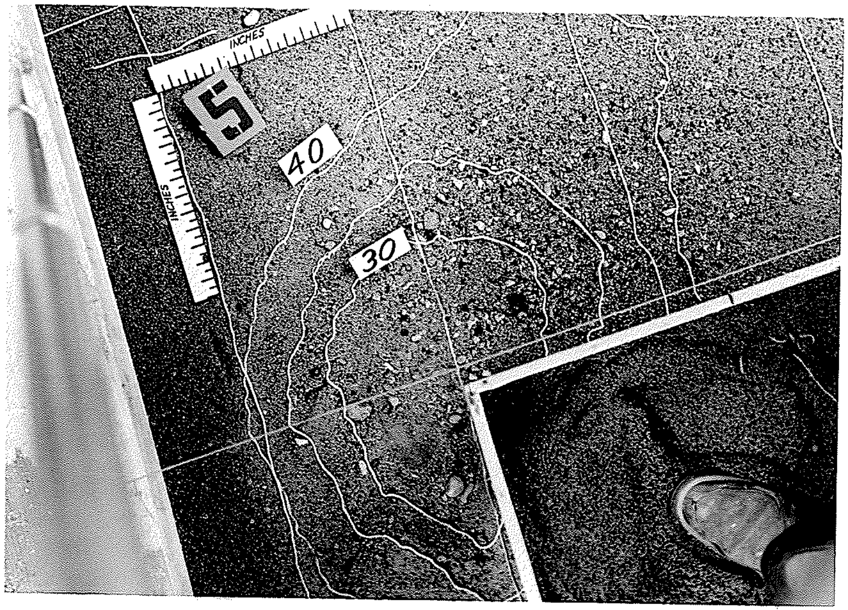




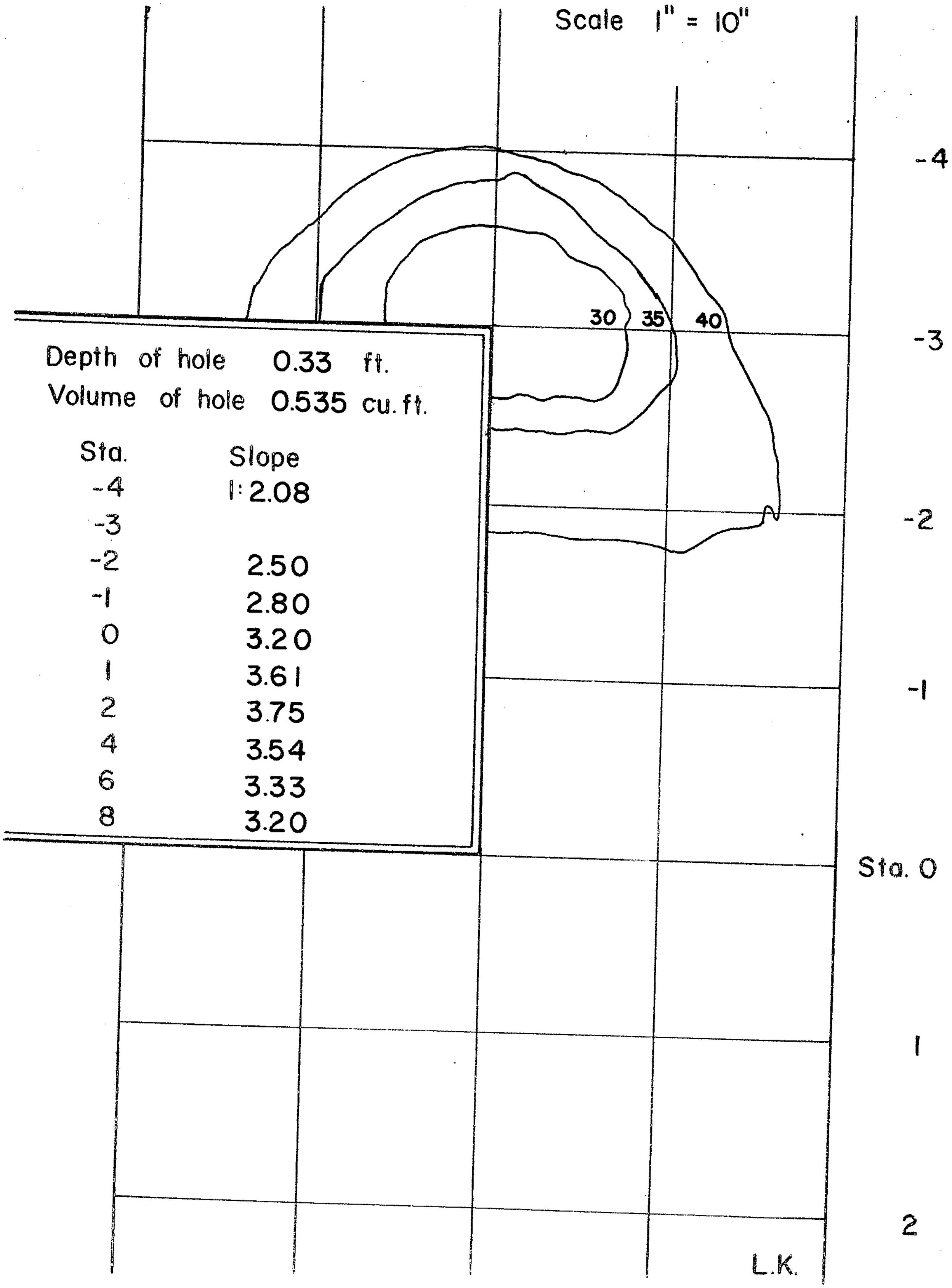
FEB •



FEB •



TEST 5



Depth of hole 0.33 ft.

Volume of hole 0.535 cu. ft.

Sta.	Slope
-4	1:2.08
-3	
-2	2.50
-1	2.80
0	3.20
1	3.61
2	3.75
4	3.54
6	3.33
8	3.20

TEST DATA SHEET

TEST NO. 6

DATE Mar. 7/64

MODEL SCALES:

HORIZ. 1:50

VERT. 1:50

MATERIAL: SIEVED MORTAR SAND FROM RED RIVER FLOODWAY MODEL

	MODEL	PROTOTYPE
Gauge Height (ft.)	0.800	
Discharge (CFS)	2.860	50,500.
Depth of Flow (ft.)	0.800	40.
Area (sq.ft.)	4.480	11,200.
Mean Velocity in Channel (ft/sec)	0.639	4.51
Time of Run	1 hour	7.07
Number of Photos Taken	4	

REMARKS:

No erosion during filling.

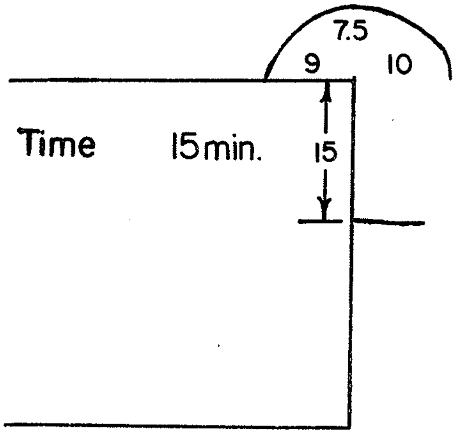
Air under cofferdam forced all sand away from downstream side of cofferdam during filling. Now know this is not caused by erosion which was thought to be the case in one preliminary test. It only happens when new sand is put in. (The first time it is wetted).

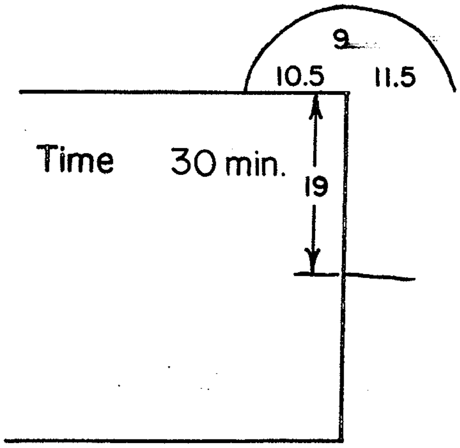
Sieved sand does not pave as readily.

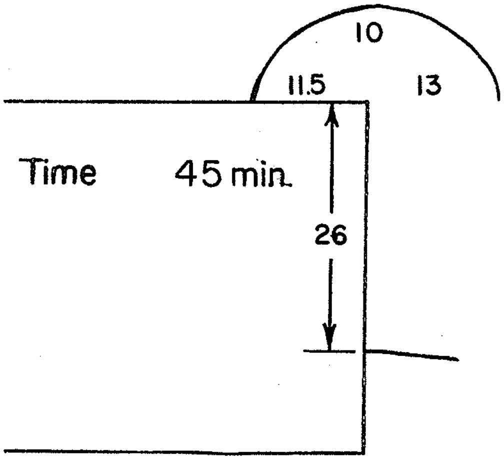
Test Performed by: glc

TEST 6

Scale: 1" = 20"





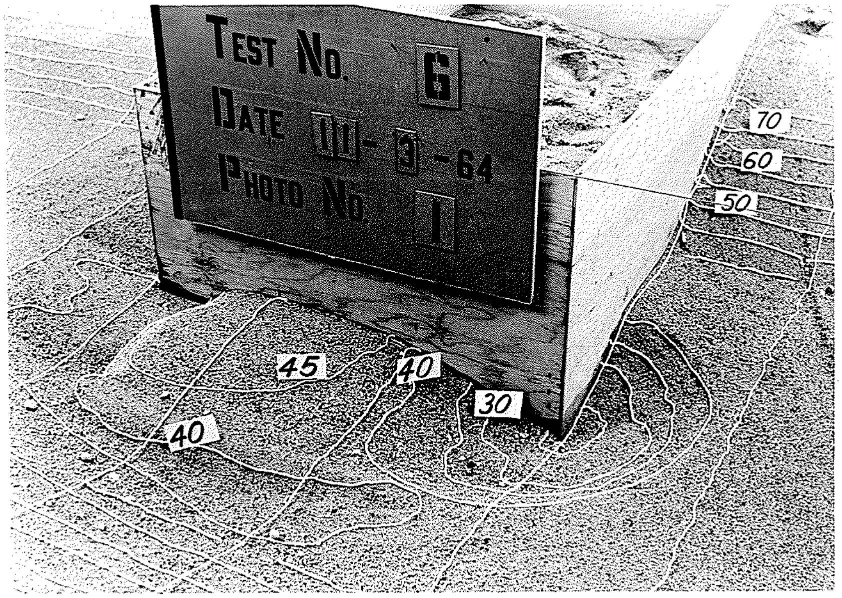


Time

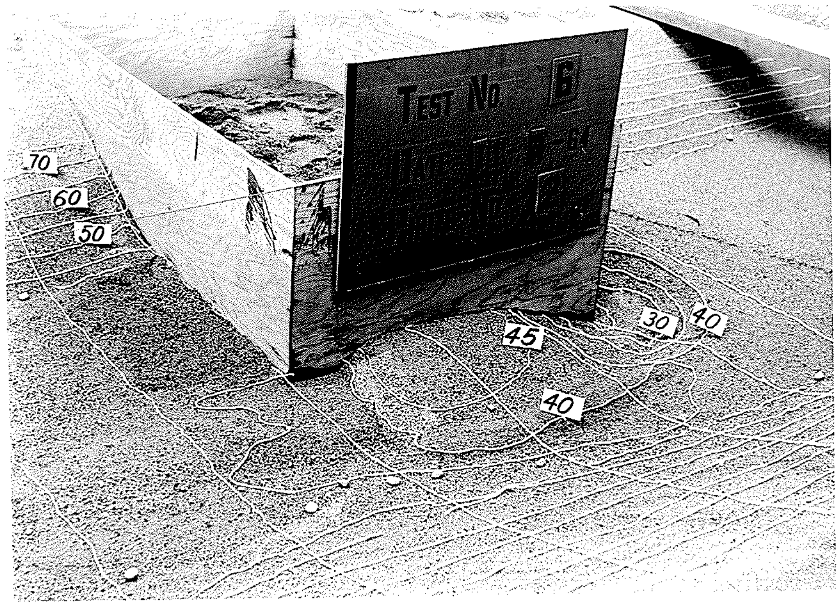
Time

Time

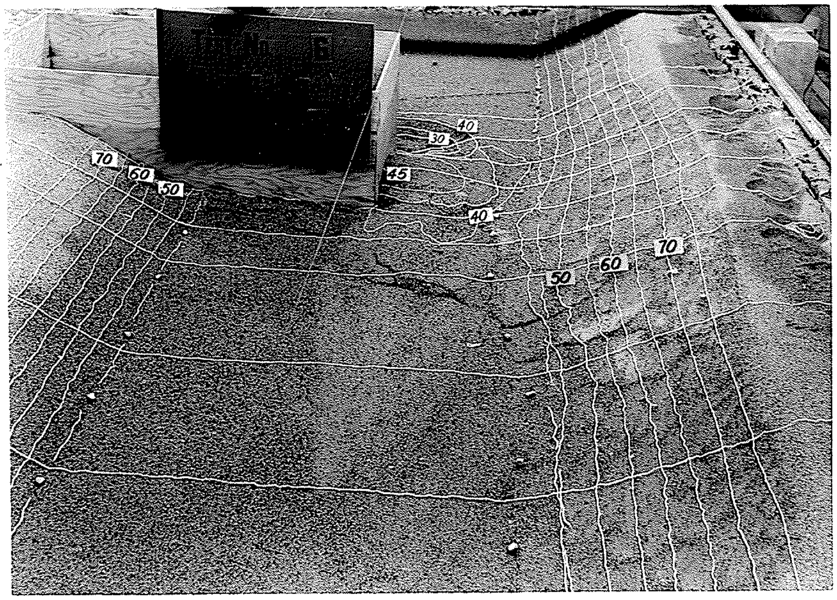
MAR


TEST No. 6
DATE 11-3-64
PHOTO No. 1
70
60
50
45
40
30
40

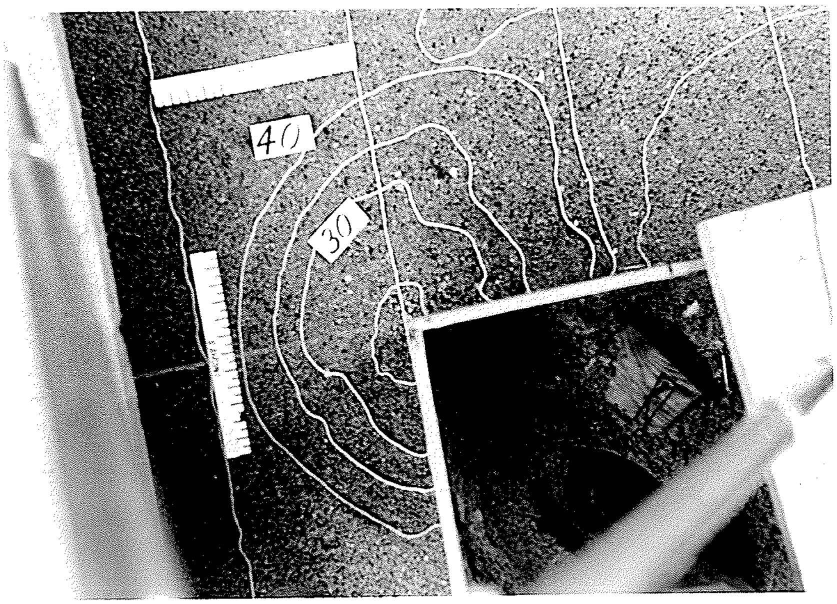
MAR


TEST No. 6
DATE 11- -64
PHOTO No. 2
70
60
50
45
30
40
40

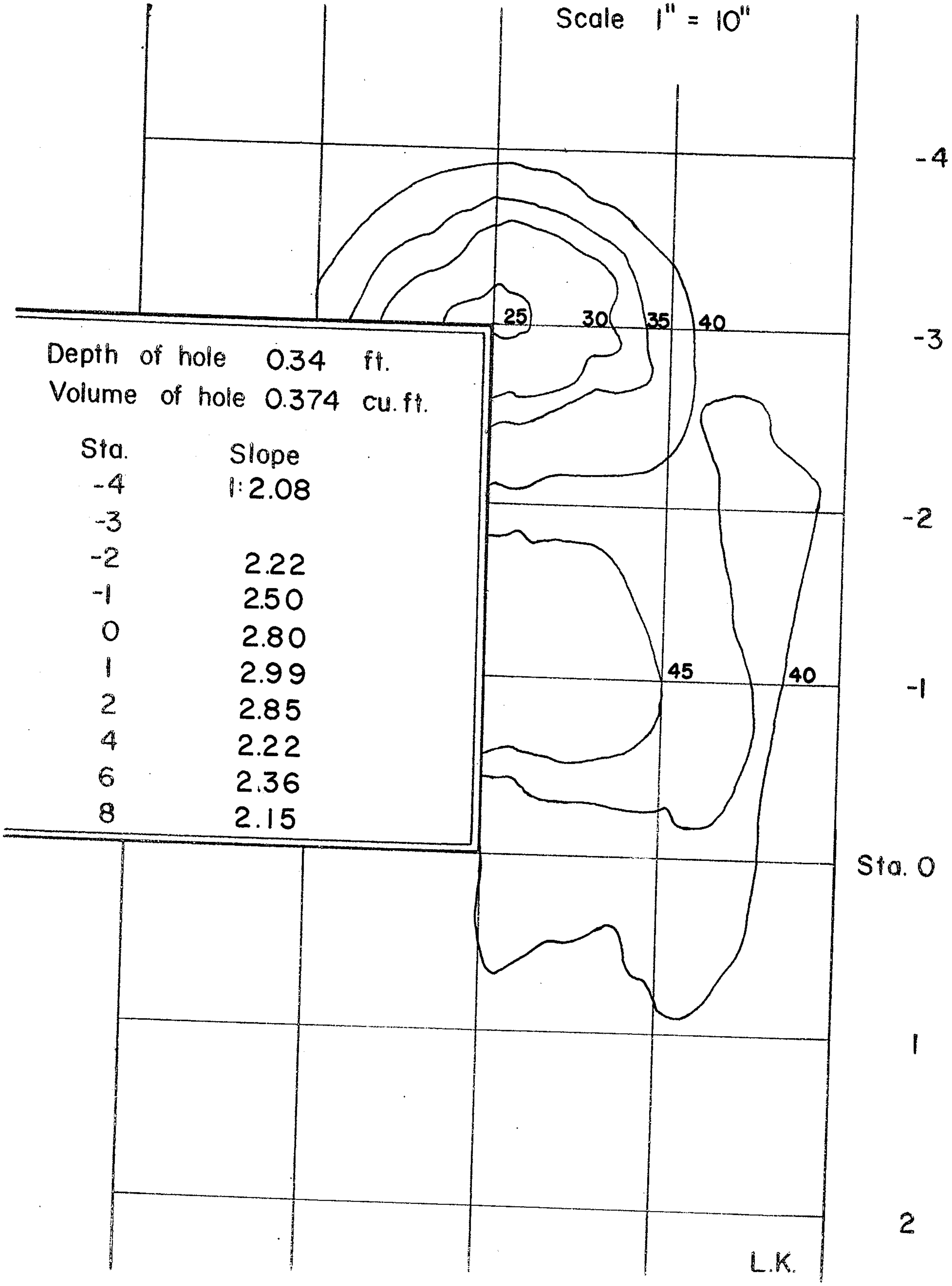
MAR •



MAR •



TEST 6



Scale 1" = 10"

Depth of hole 0.34 ft.
Volume of hole 0.374 cu. ft.

Sta.	Slope
-4	1:2.08
-3	
-2	2.22
-1	2.50
0	2.80
1	2.99
2	2.85
4	2.22
6	2.36
8	2.15

TEST DATA SHEET

TEST NO. 7

DATE Mar. 18/64

MODEL SCALES: HORIZ. 1:50

VERT. 1:50

MATERIAL: SIEVED MORTAR SAND FROM RED RIVER FLOODWAY MODEL

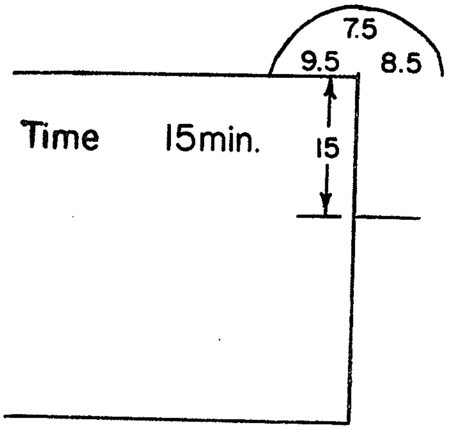
	MODEL	PROTOTYPE
Gauge Height (ft.)	0.800	
Discharge (CFS)	2.860	50,500.
Depth of Flow (ft.)	0.800	40.
Area (sq.ft.)	4.480	11,200.
Mean Velocity in Channel (ft/sec)	0.639	4.51
Time of Run	2 hours	14.14
Number of Photos Taken	4	

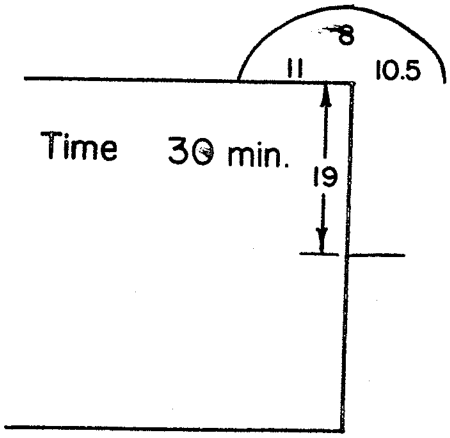
REMARKS:

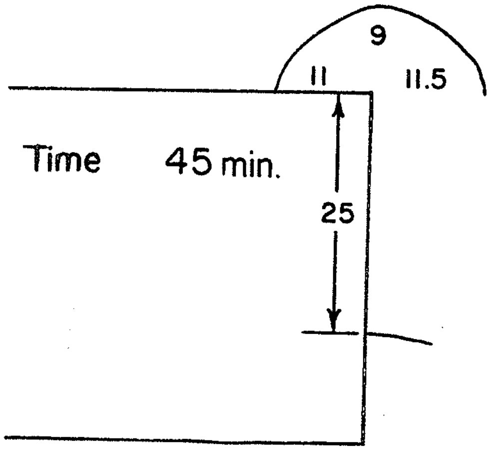
Sand removed from downstream again during filling. Was not replaced during test as in Test 6 as it does not effect other erosion.patterns. May have filled too rapidly. Will fill more slowly in future.

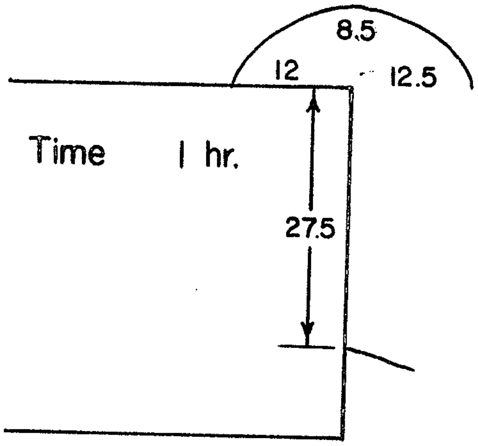
Test Performed by: gcl

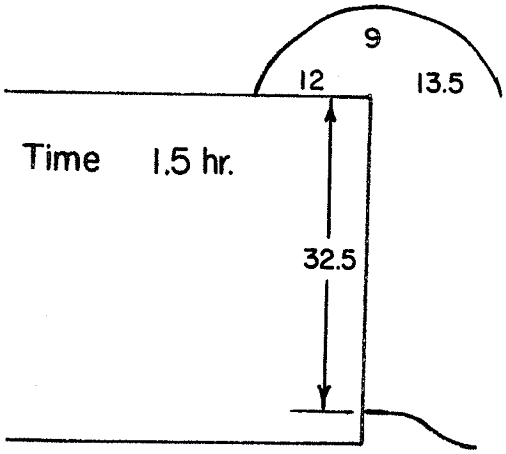
Scale: 1" = 20"

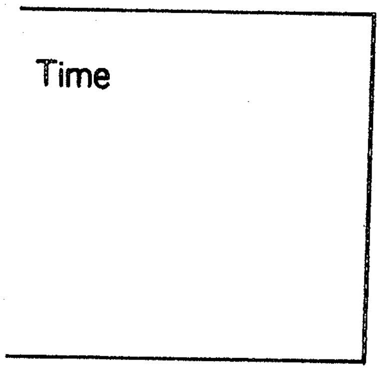

7.5
9.5
8.5
Time 15min.
15


8
11
10.5
Time 30 min.
19

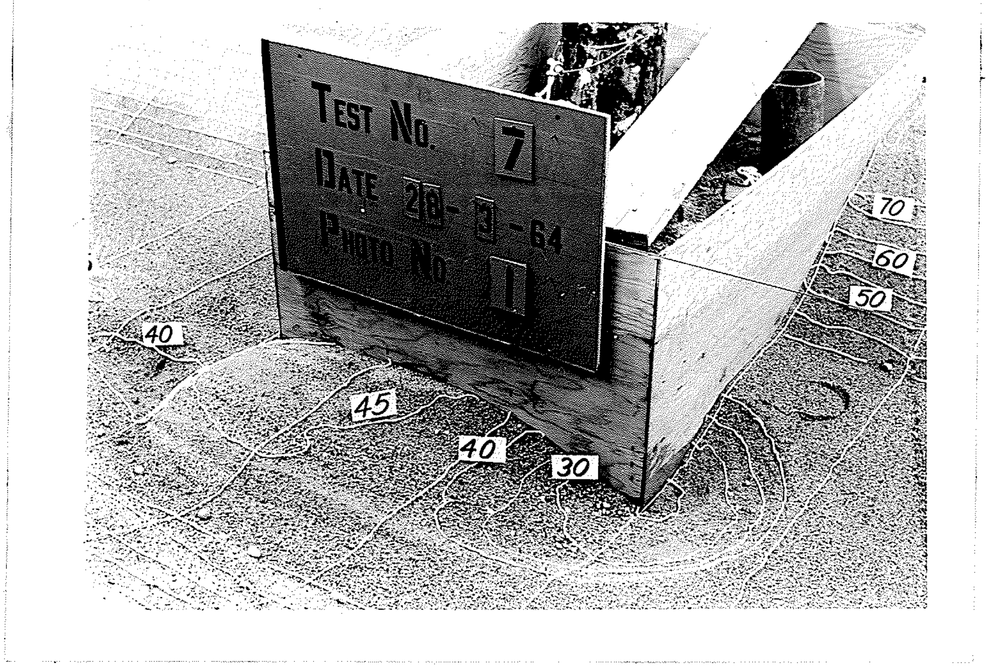

9
11
11.5
Time 45 min.
25


8.5
12
12.5
Time 1 hr.
27.5

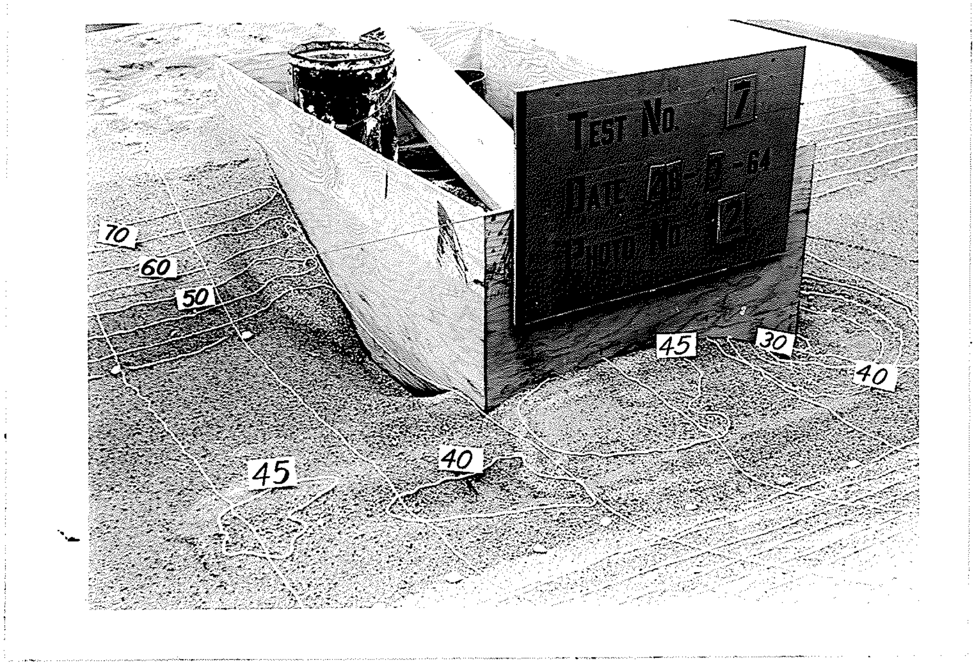

9
12
13.5
Time 1.5 hr.
32.5


Time

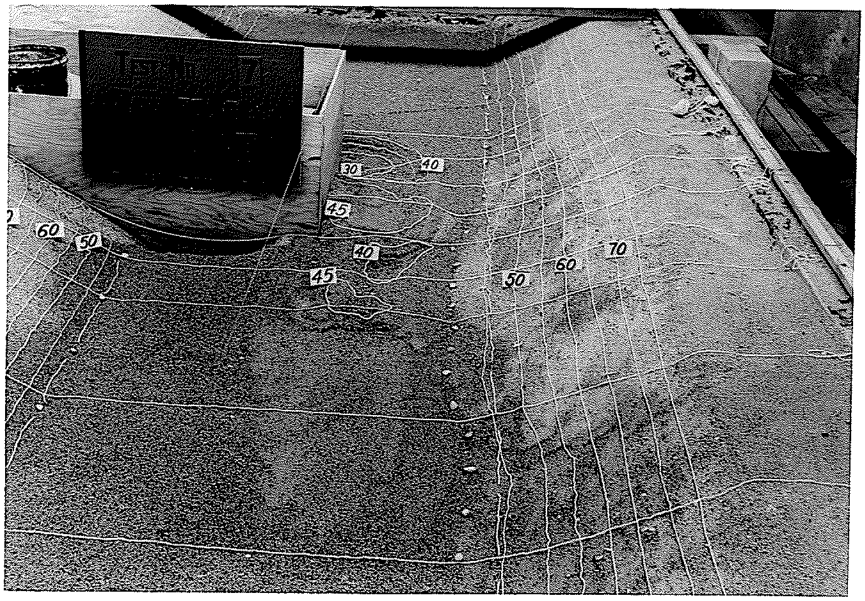
MAR


TEST NO. 7
DATE 28-3-64
PHOTO NO. 1
70
60
50
40
45
40
30

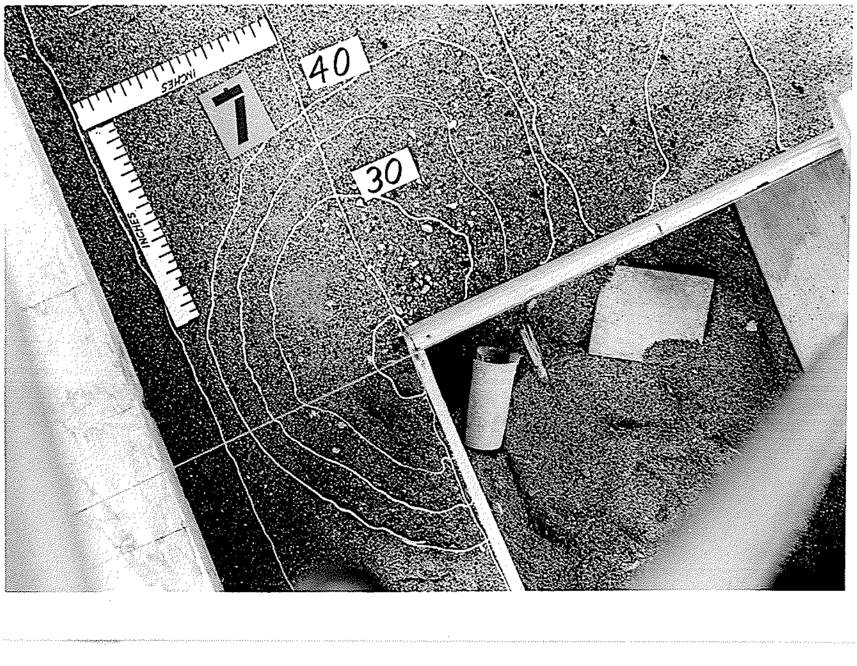
MAR


TEST NO. 7
DATE -64
PHOTO NO. 2
70
60
50
45
30
40
45
40

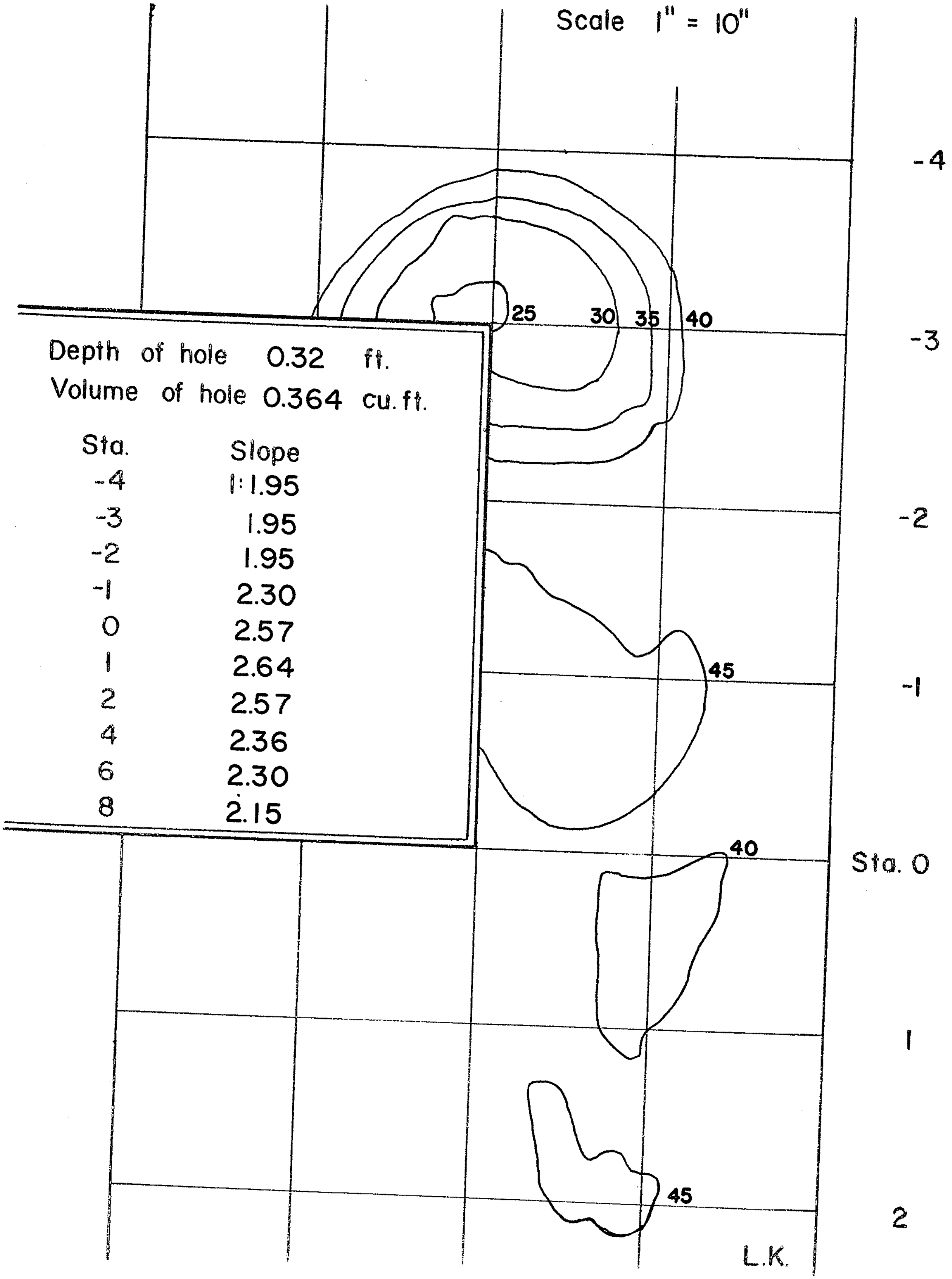
64



64



TEST 7



Depth of hole 0.32 ft.
Volume of hole 0.364 cu. ft.

Sta.	Slope
-4	1:1.95
-3	1.95
-2	1.95
-1	2.30
0	2.57
1	2.64
2	2.57
4	2.36
6	2.30
8	2.15

TEST DATA SHEET

TEST NO. 8

DATE May 14/64

MODEL SCALES: HORIZ. 1:50

VERT. 1:50

MATERIAL: SIEVED MORTAR SAND FROM RED RIVER FLOODWAY MODEL

	MODEL	PROTOTYPE
Gauge Height (ft.)	0.800	
Discharge (CFS)	2.860	50,500.
Depth of Flow (ft.)	0.800	40.
Area (sq.ft.)	4.480	11,200.
Mean Velocity in Channel (ft/sec)	0.639	4.51
Time of Run	4 hours	28.28
Number of Photos Taken	4	

REMARKS:

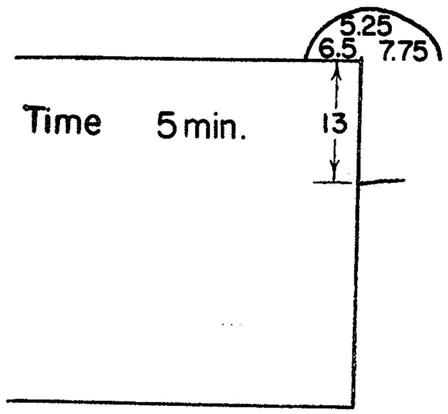
Left bank erosion continues to end of test.

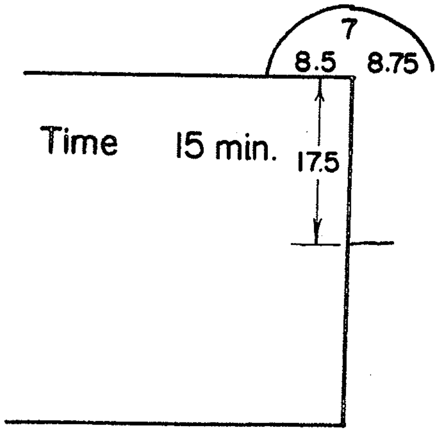
Hole shallower and wider than before.

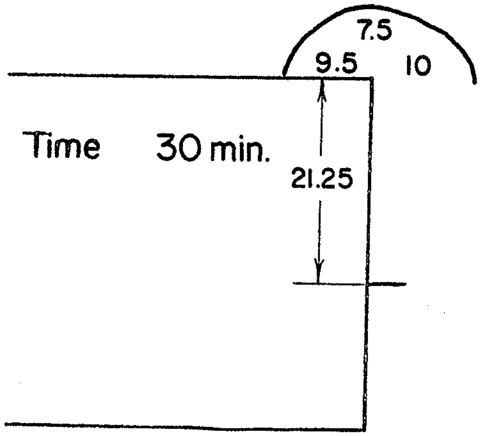
Test Performed by: lk

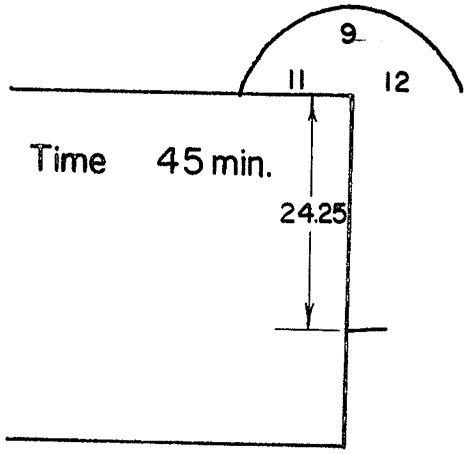
TEST 8

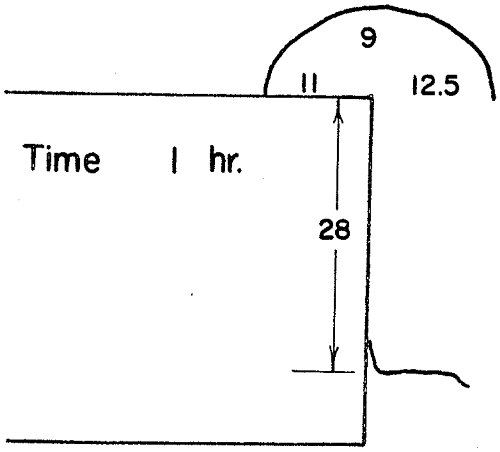
Scale: 1" = 20"

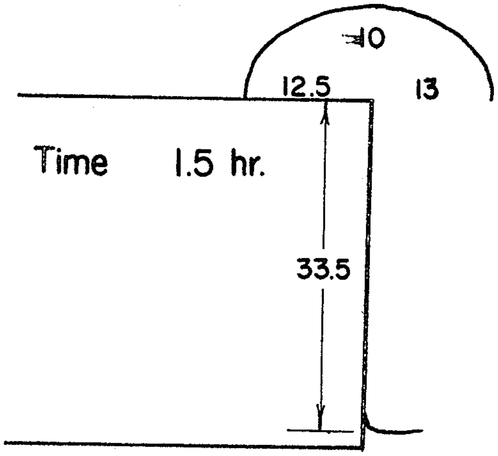






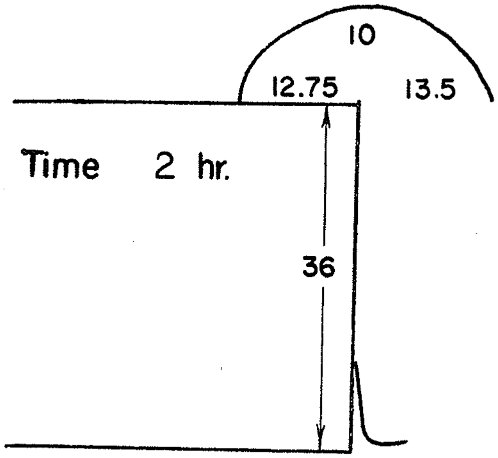


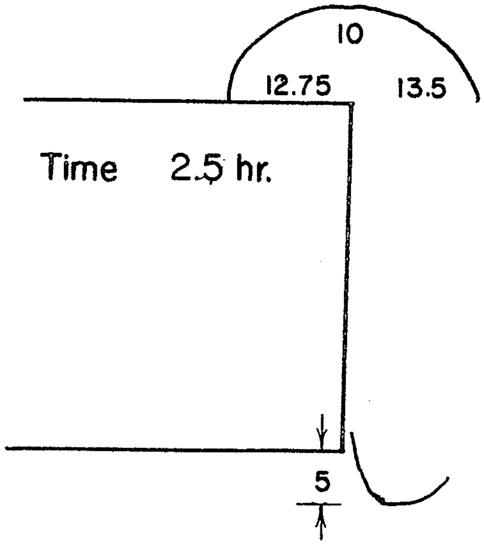


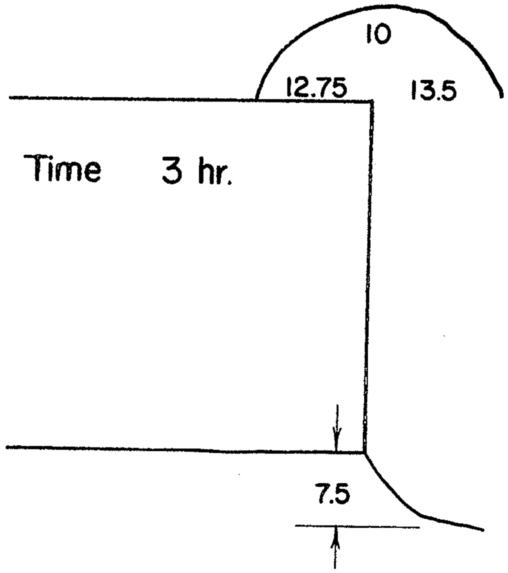


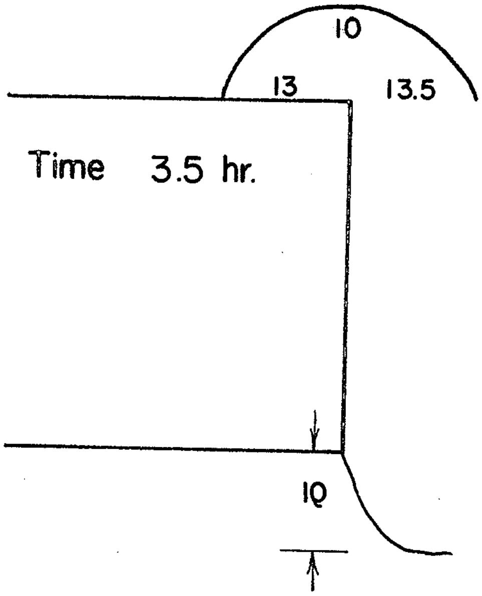
TEST 8

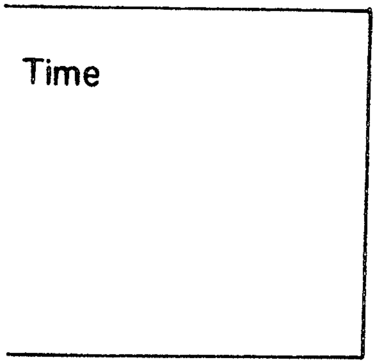
Scale: 1" = 20"

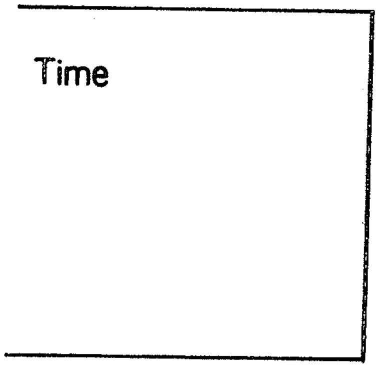




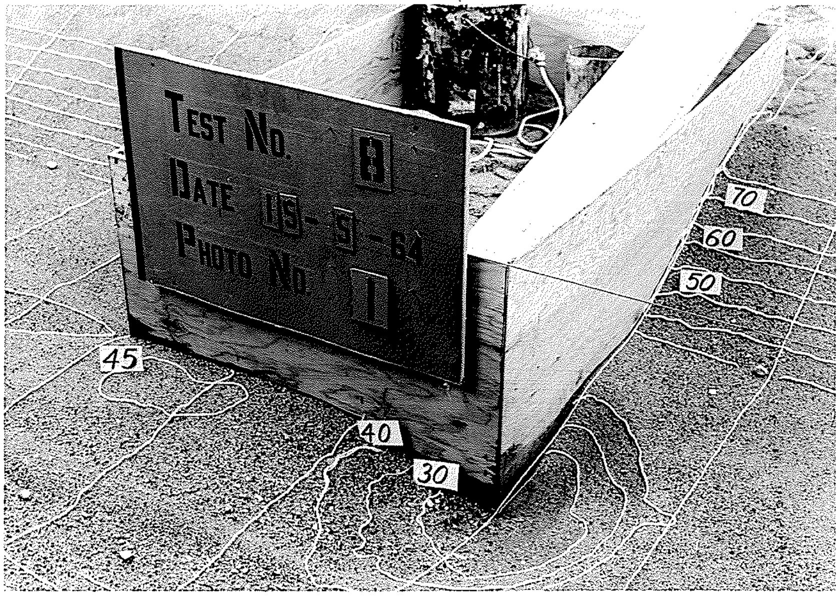




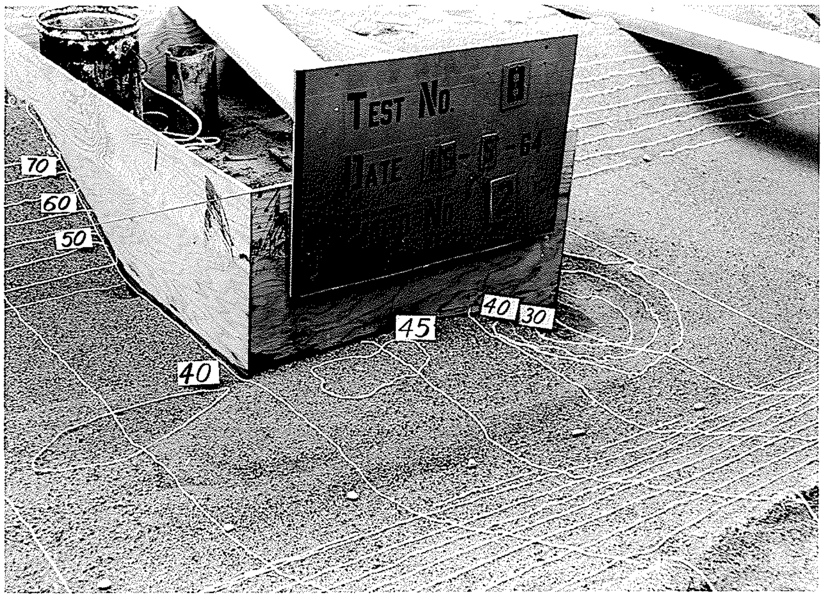




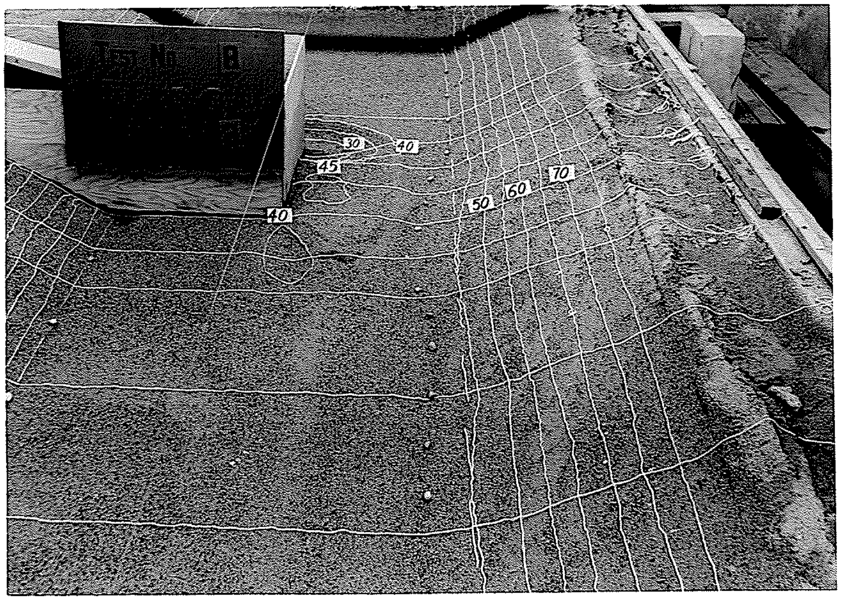
64


TEST NO. 8
DATE 15-5-64
PHOTO NO. 1
70
60
50
45
40
30

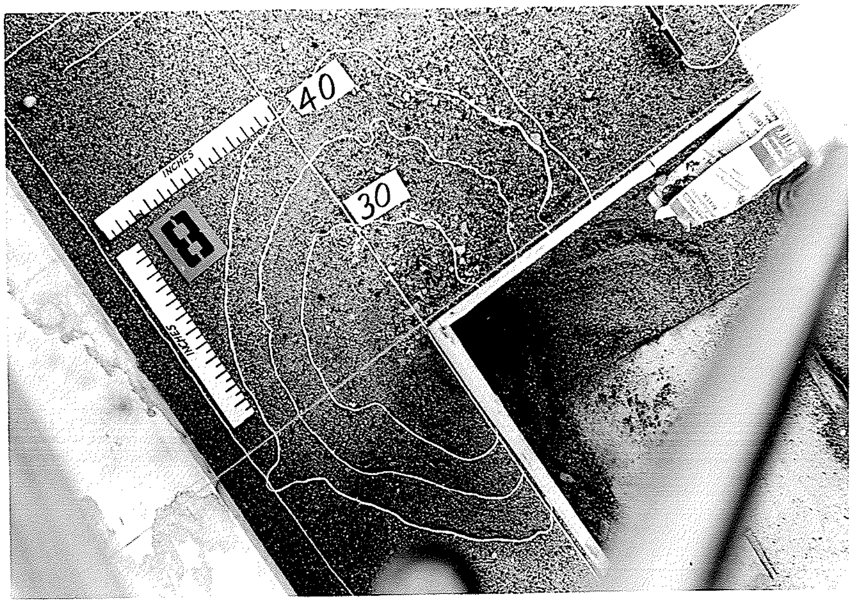
64


TEST NO. 8
DATE 15-5-64
PHOTO NO. 2
70
60
50
40
45
40
30

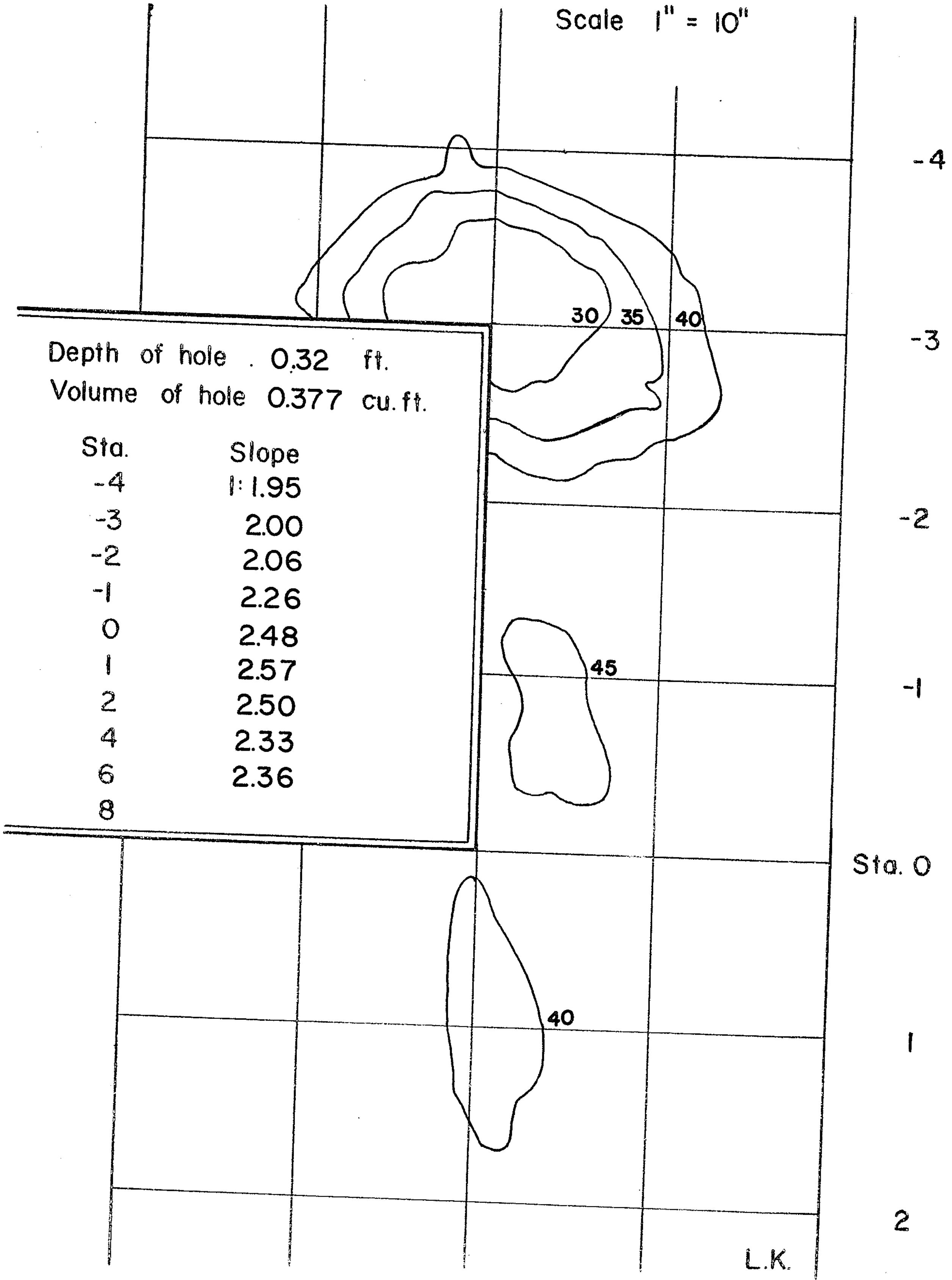
64



64



TEST 8



Depth of hole . 0.32 ft.
Volume of hole 0.377 cu.ft.

Sta.	Slope
-4	1: 1.95
-3	2.00
-2	2.06
-1	2.26
0	2.48
1	2.57
2	2.50
4	2.33
6	2.36
8	

TEST DATA SHEET

TEST NO. 9

DATE May 19/64

MODEL SCALES: HORIZ. 1:50

VERT. 1:50

MATERIAL: SIEVED MORTAR SAND FROM RED RIVER FLOODWAY MODEL

	MODEL	PROTOTYPE
Gauge Height (ft.)	0.800	
Discharge (CFS)	2.860	50,500.
Depth of Flow (ft.)	0.800	40.
Area (sq.ft.)	4.480	11,200.
Mean Velocity in Channel (ft/sec)	0.639	4.51
Time of Run	8 hours	56.56
Number of Photos Taken	4	

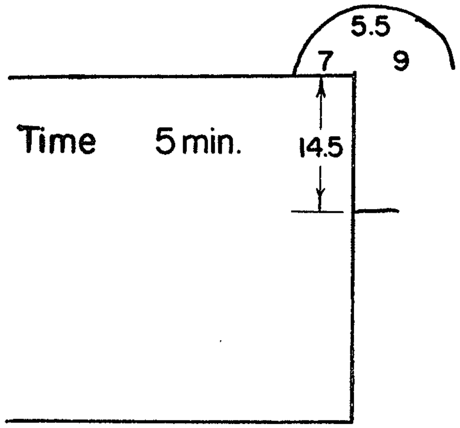
REMARKS:

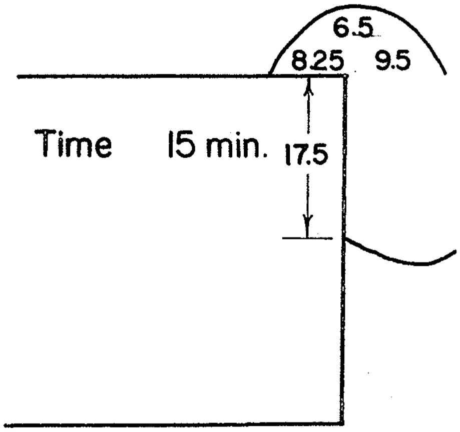
Left bank erosion continues to end of test.

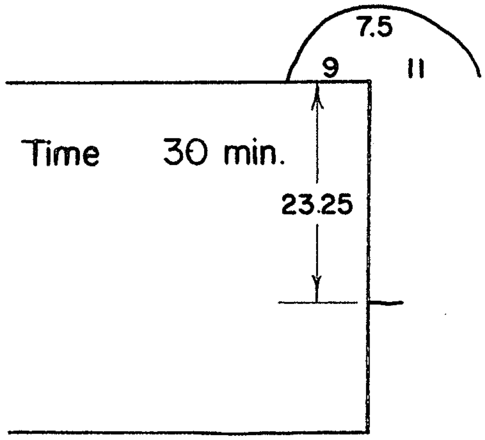
Test Performed by: lk

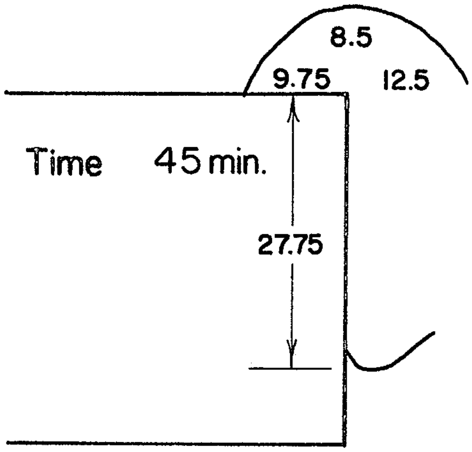
TEST 9

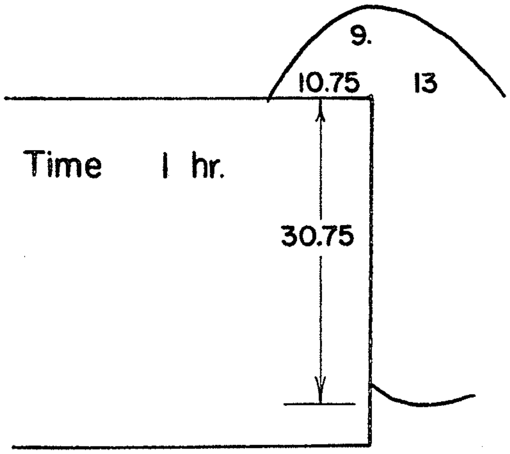
Scale: 1" = 20"

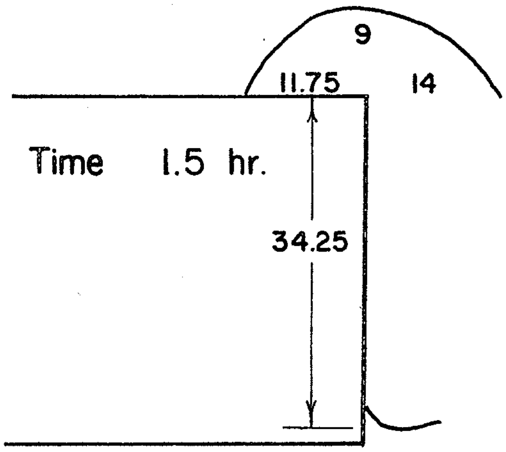






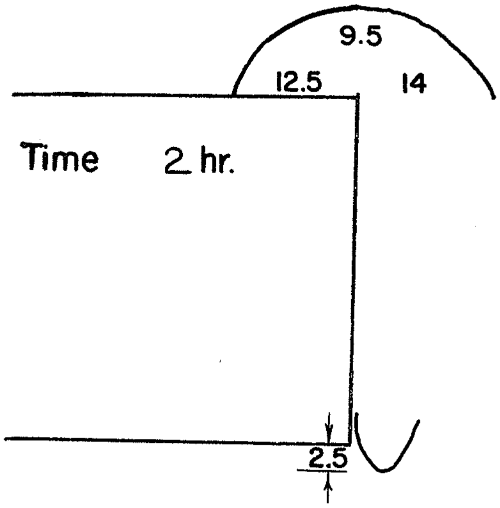


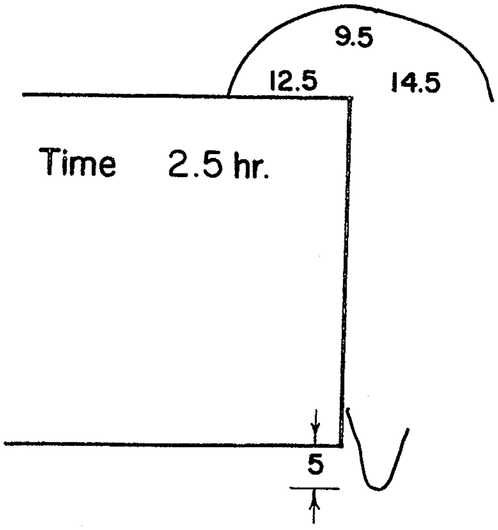


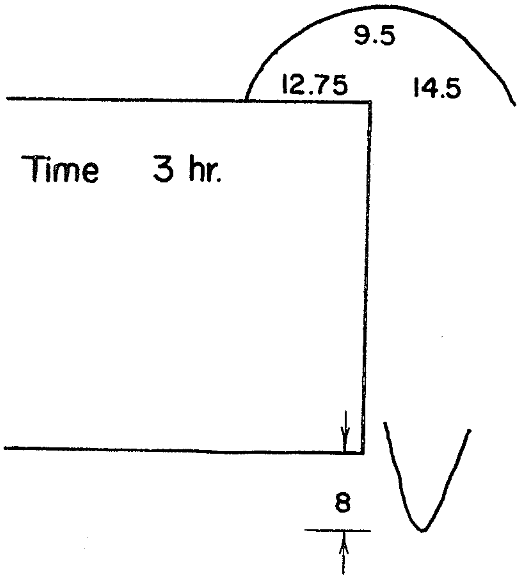


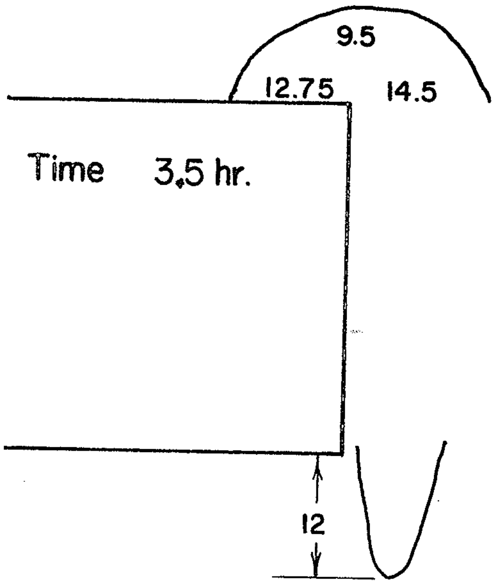
TEST 9

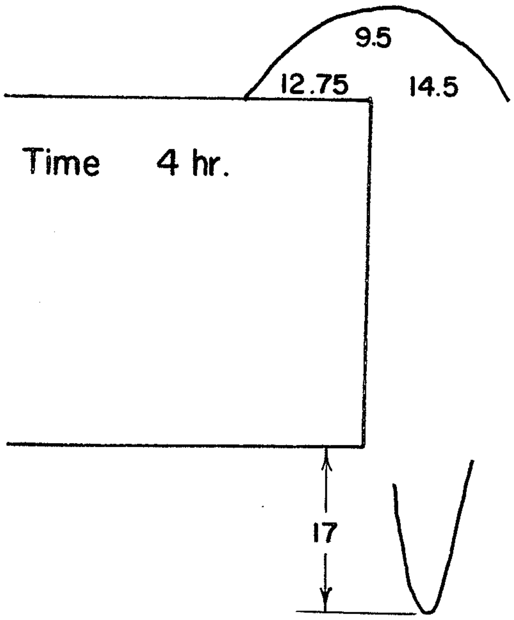
Scale: 1" = 20"

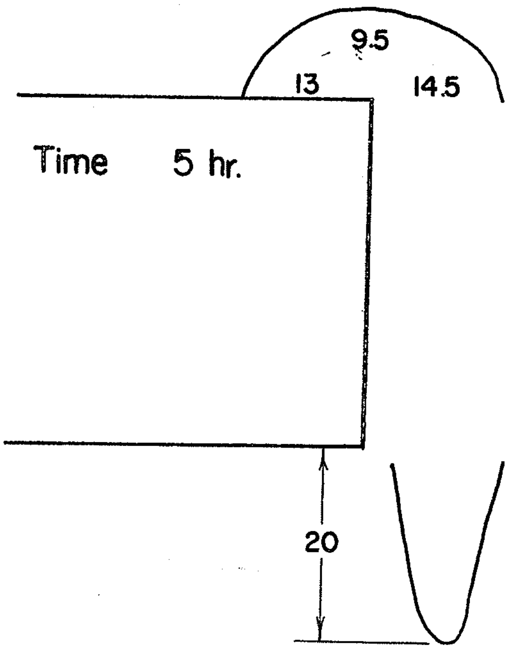




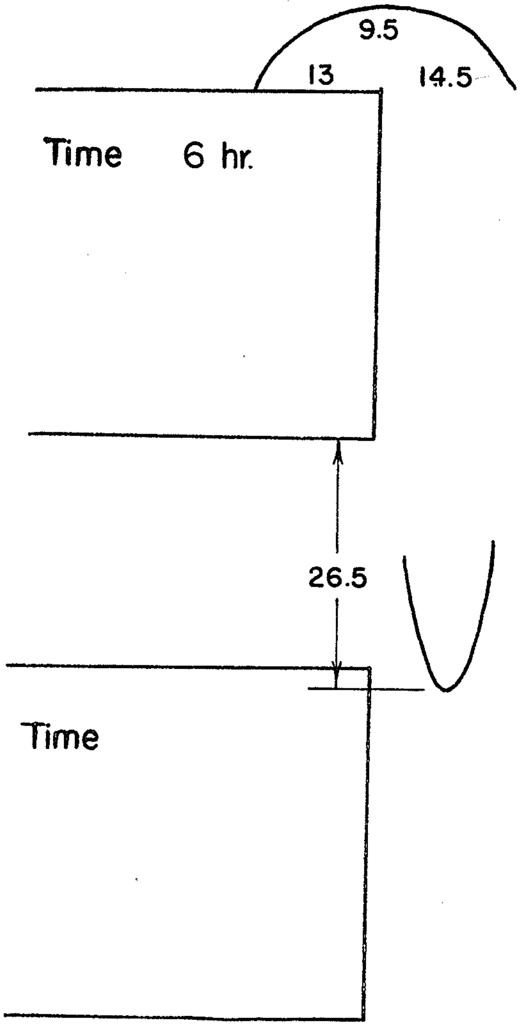


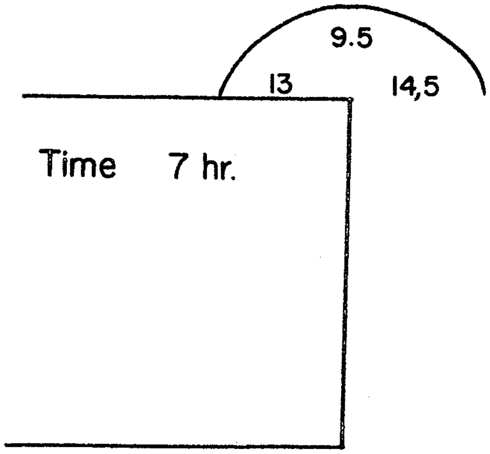


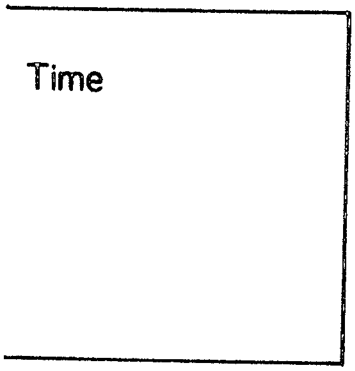


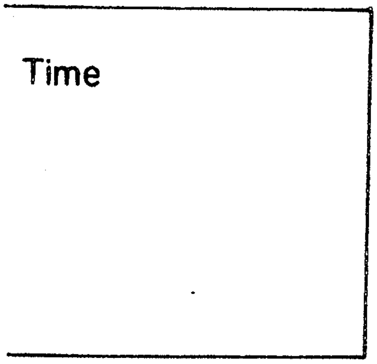


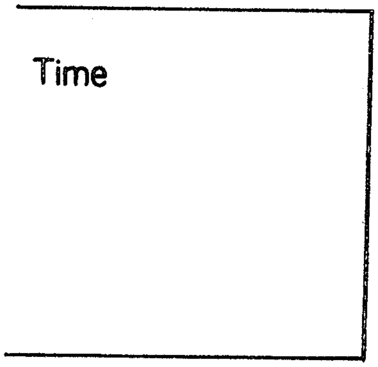
Scale: 1" = 20"

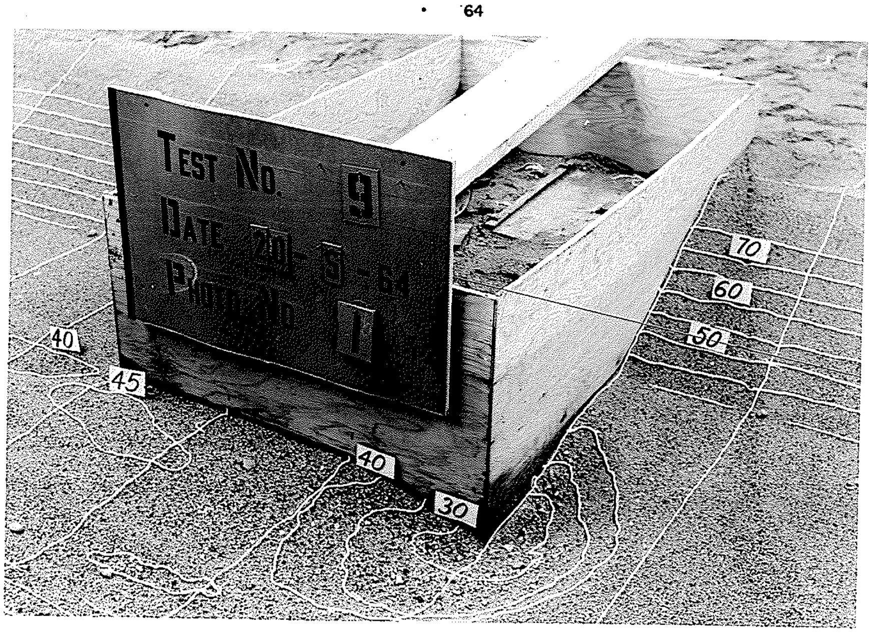


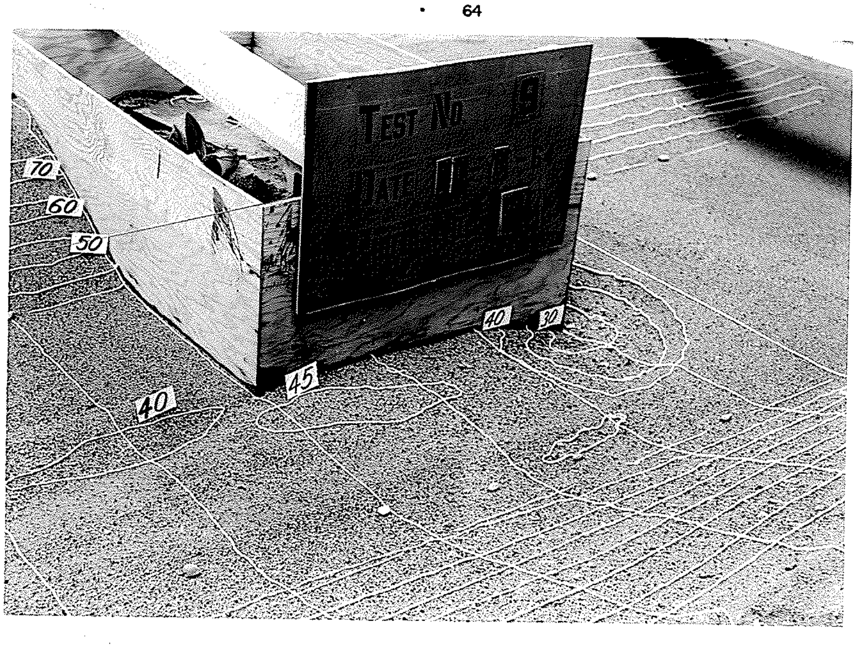


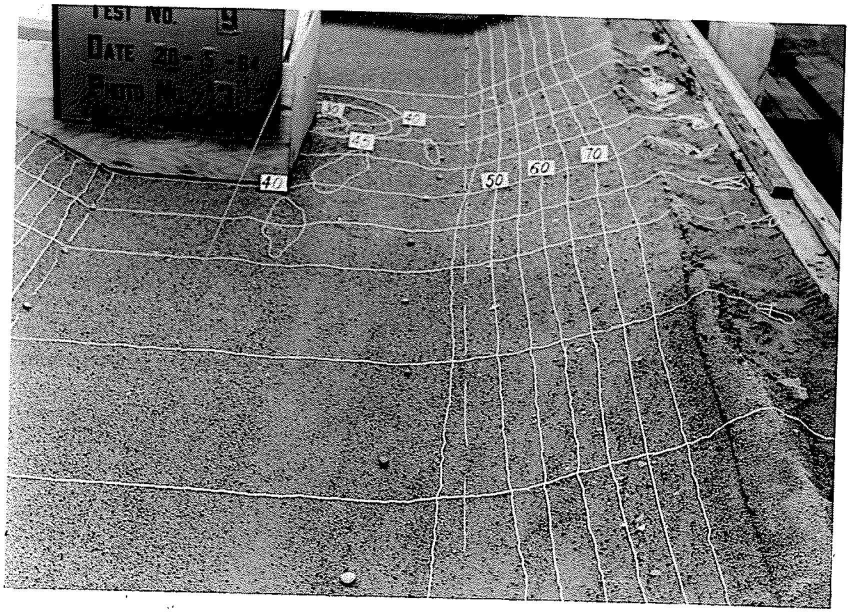




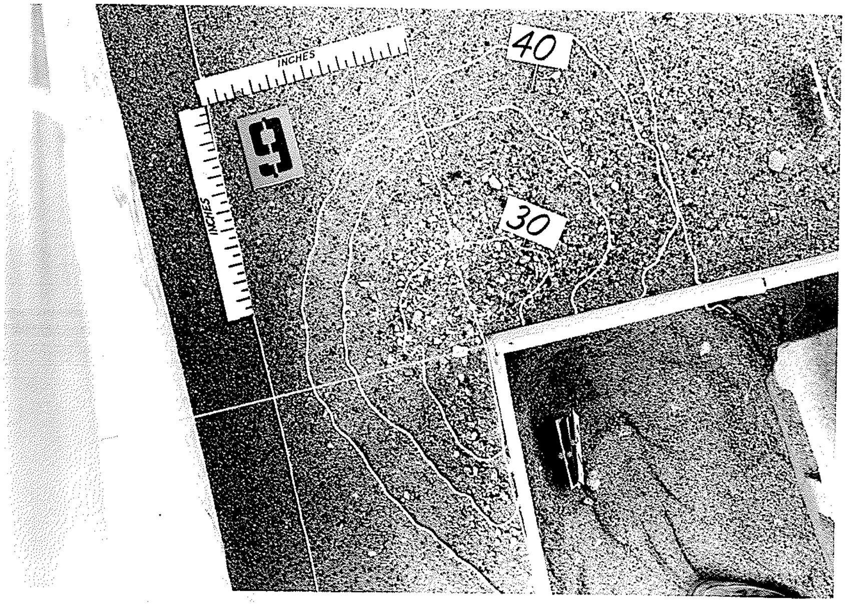



64
TEST No. 9
DATE 20-5-64
PHOTO No. 1
70
60
50
40
45
40
30


64
TEST No. 9
DATE
70
60
50
40
45
40
30

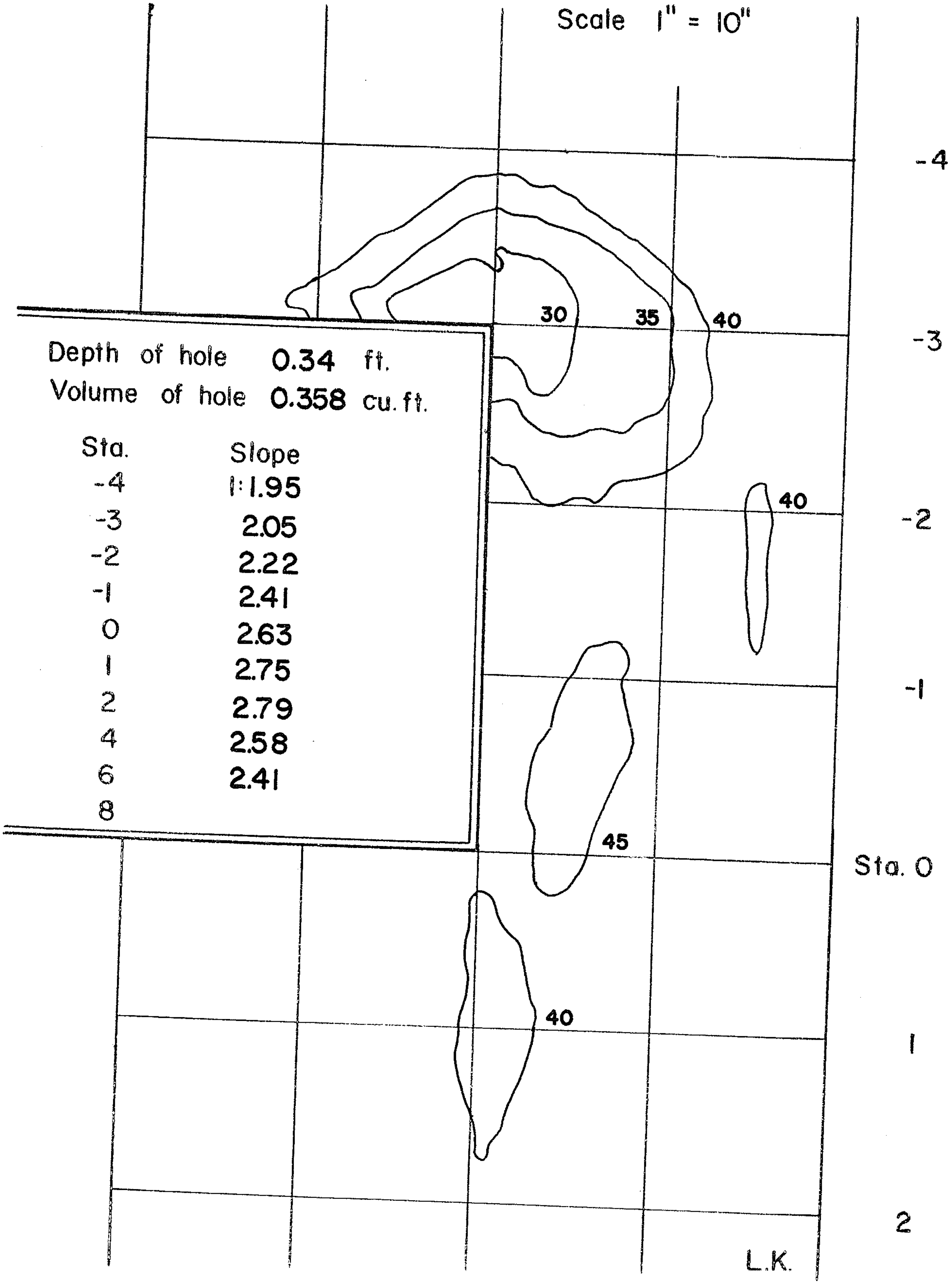

MAY • 64

TEST No. 9
DATE 20-5-64
PHOTO No.
40
40
50
60
70


MAY • 64

INCHES
INCHES
9
40
30

TEST 9



Depth of hole 0.34 ft.
Volume of hole 0.358 cu. ft.

Sta.	Slope
-4	1:1.95
-3	2.05
-2	2.22
-1	2.41
0	2.63
1	2.75
2	2.79
4	2.58
6	2.41
8	

TEST DATA SHEET

TEST NO. 10

DATE June 10/64

MODEL SCALES:

HORIZ. 1:100

VERT. 1:100

MATERIAL: SIEVED MORTAR SAND FROM RED RIVER FLOODWAY MODEL

	MODEL	PROTOTYPE
Gauge Height (ft.)	0.528	
Discharge (CFS)	0.505	50,500.
Depth of Flow (ft.)	0.400	40.
Area (sq.ft.)	1.120	11,200.
Mean Velocity in Channel (ft/sec)	0.451	4.51
Time of Run	42.4 minutes	7.07 hours
Number of Photos Taken	1	

REMARKS:

No erosion of left bank.

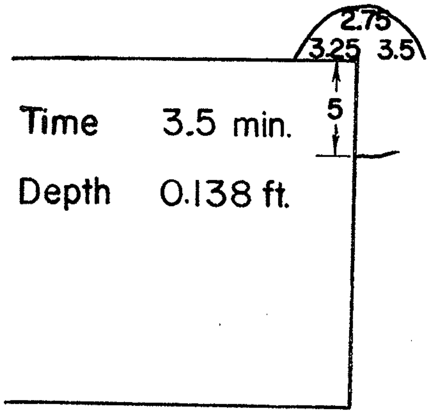
No erosion of right bank.

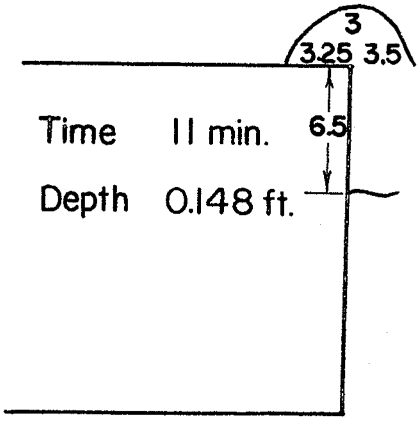
Hole reaches full depth in 25 minutes.

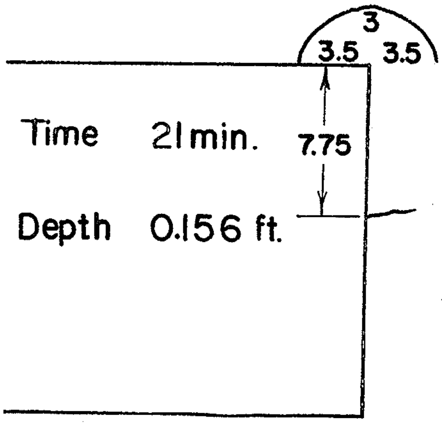
Test Performed by: lk

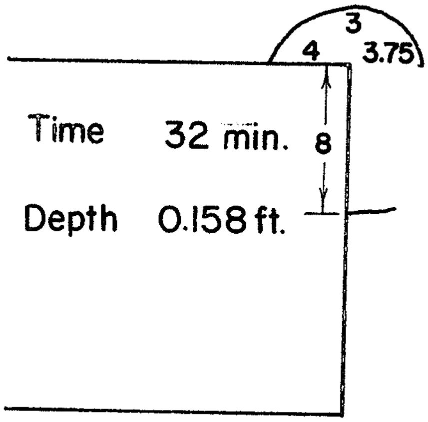
TEST 10

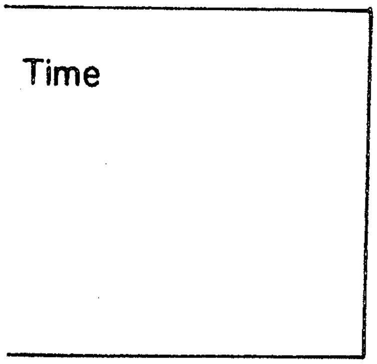
Scale: 1" = 10"

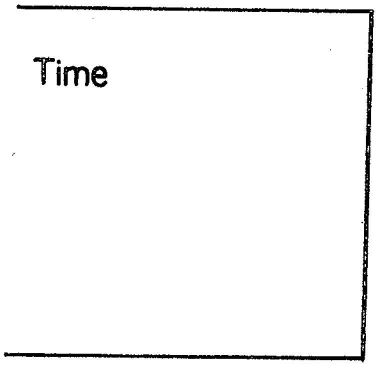




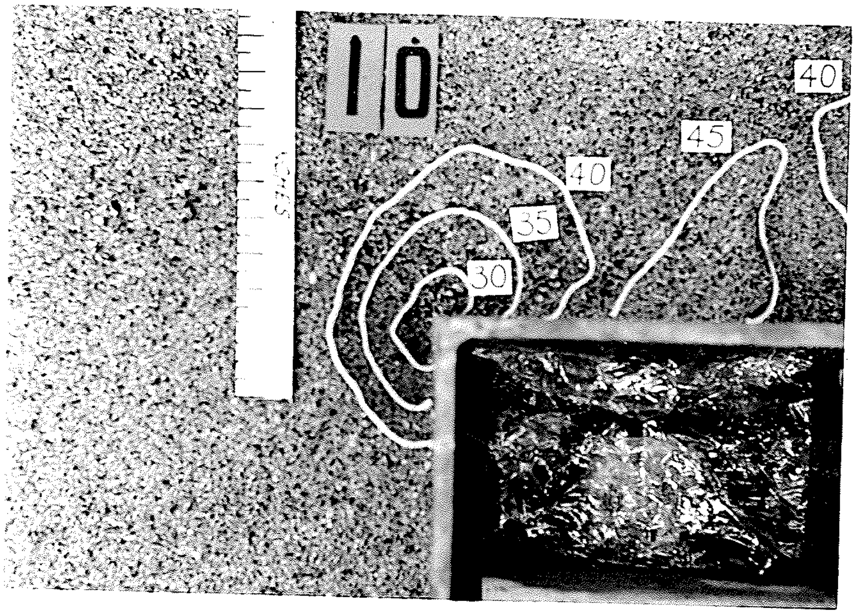




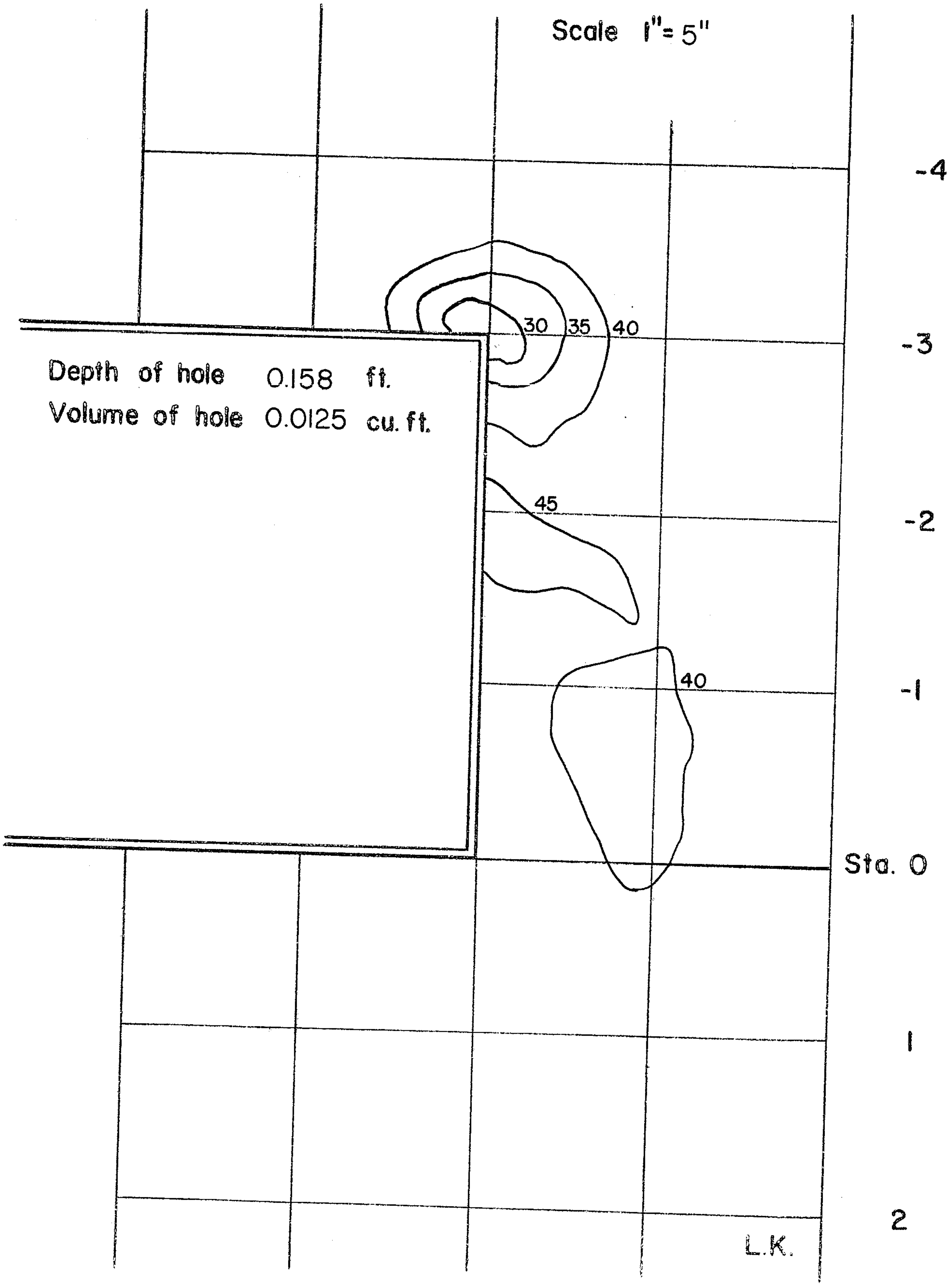




JUN • 64



TEST 10



Depth of hole 0.158 ft.
Volume of hole 0.0125 cu. ft.

TEST DATA SHEET

TEST NO. 11

DATE June 10/64

MODEL SCALES: HORIZ. 1:100

VERT. 1:100

MATERIAL: SIEVED MORTAR SAND FROM RED RIVER FLOODWAY MODEL

	MODEL	PROTOTYPE
Gauge Height (ft.)	0.528	
Discharge (CFS)	0.505	50,500.
Depth of Flow (ft.)	0.400	40.
Area (sq.ft.)	1.120	11,200.
Mean Velocity in Channel (ft/sec)	0.451	4.51
Time of Run	1.414 hour	14.14 hours

Number of Photos Taken 1

REMARKS:

No erosion of left bank.

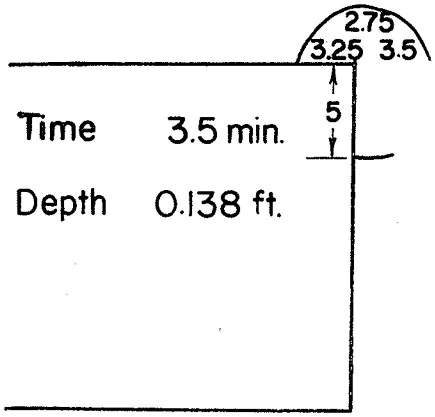
No erosion of right bank.

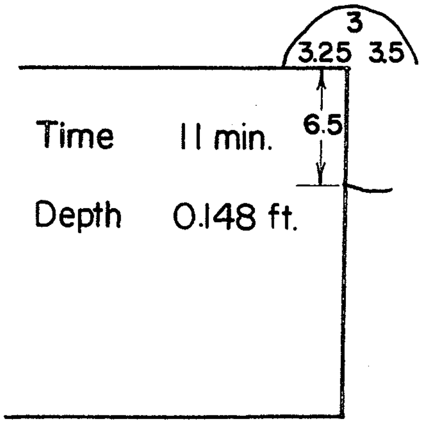
Hole reaches full depth in 25 minutes.

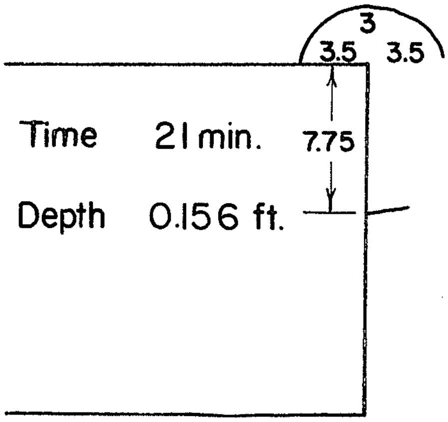
Test Performed by: lk

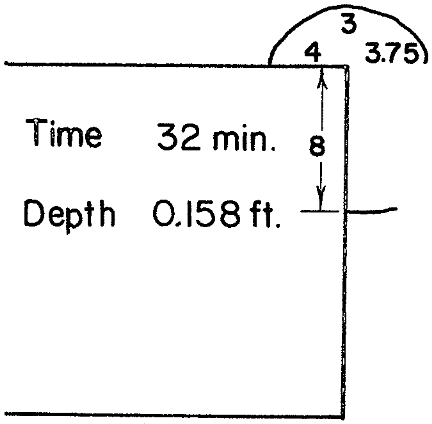
TEST II

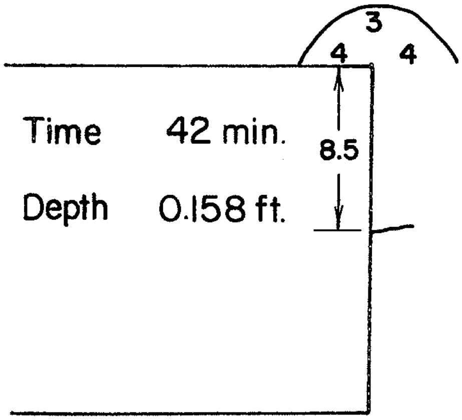
Scale: 1" = 10"

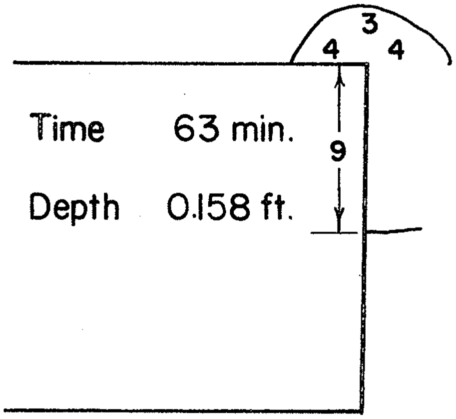




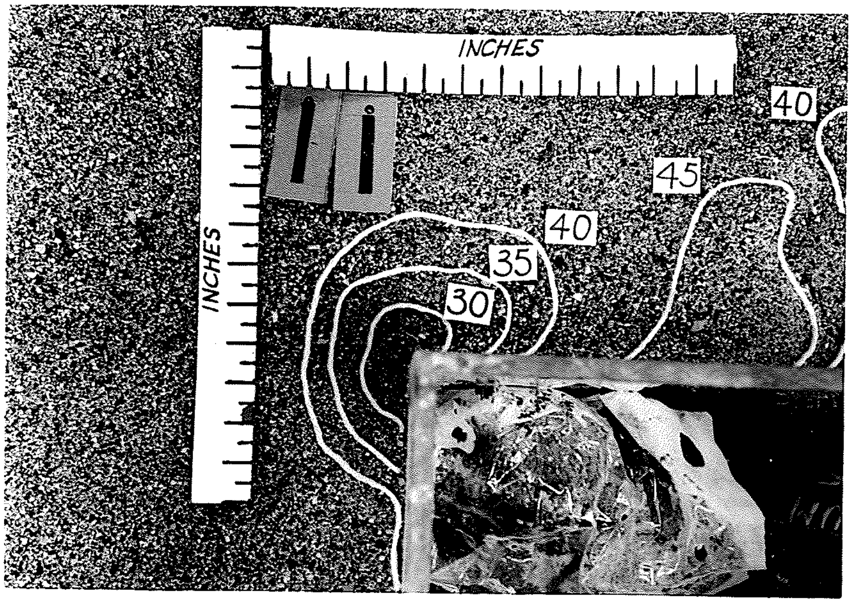




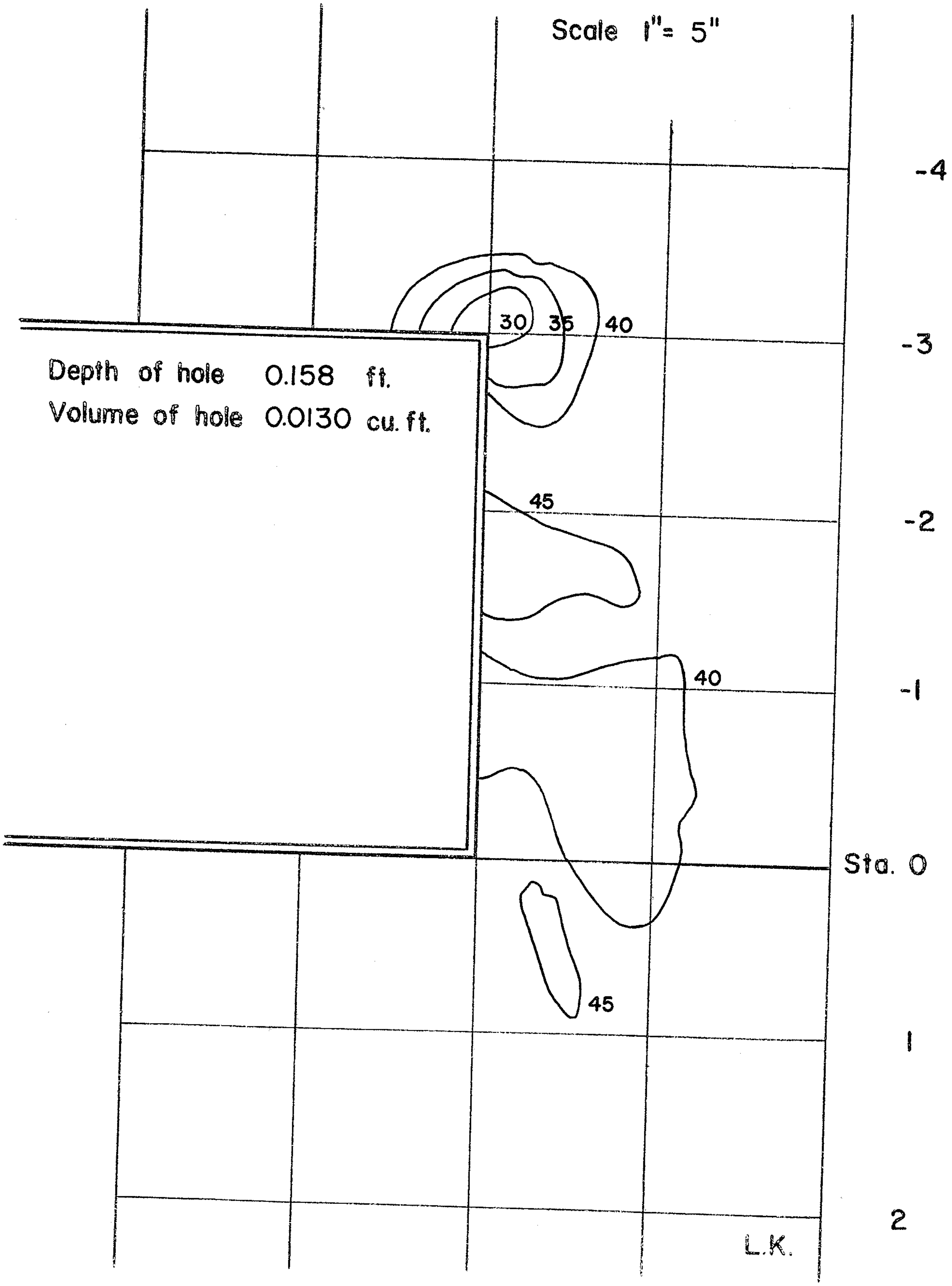




JUN • 64 •



TEST II



Scale 1" = 5"

Depth of hole 0.158 ft.
Volume of hole 0.0130 cu. ft.

TEST DATA SHEET

TEST NO. 12

DATE June 11/64

MODEL SCALES: HORIZ. 1:100

VERT. 1:100

MATERIAL: SIEVED MORTAR SAND FROM RED RIVER FLOODWAY MODEL

	MODEL	PROTOTYPE
Gauge Height (ft.)	0.528	
Discharge (CFS)	0.505	50,500.
Depth of Flow (ft.)	0.400	40.
Area (sq.ft.)	1.120	11,200.
Mean Velocity in Channel (ft/sec)	0.451	4.51
Time of Run	2.828 hours	28.28 hour

Number of Photos Taken 1

REMARKS:

No erosion of left bank.

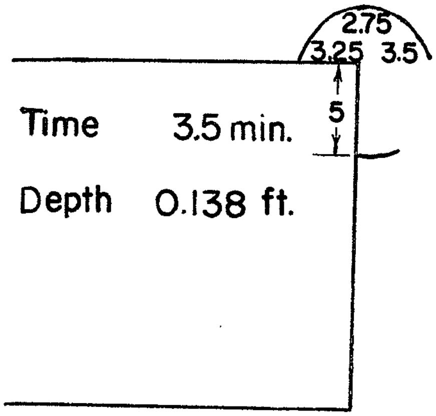
No erosion of right bank.

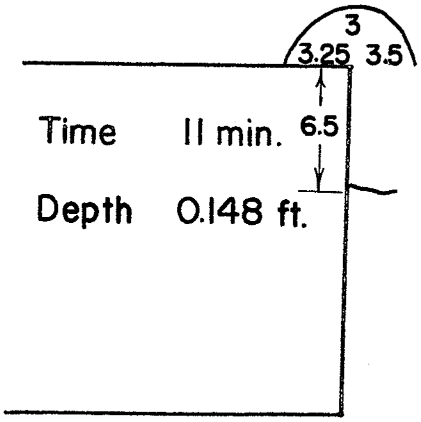
Hole reaches full depth in 25 minutes.

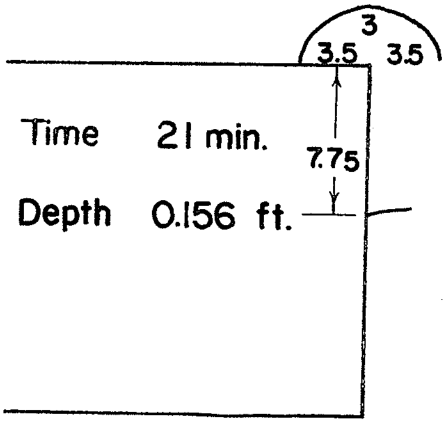
Test Performed by: lk

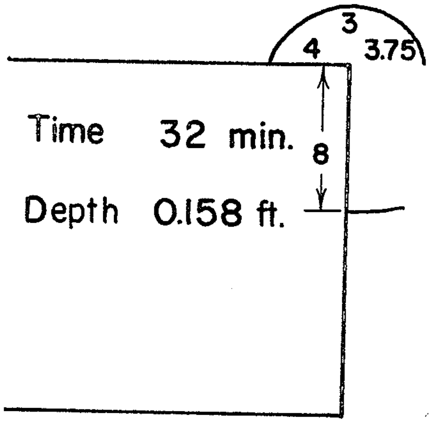
TEST 12

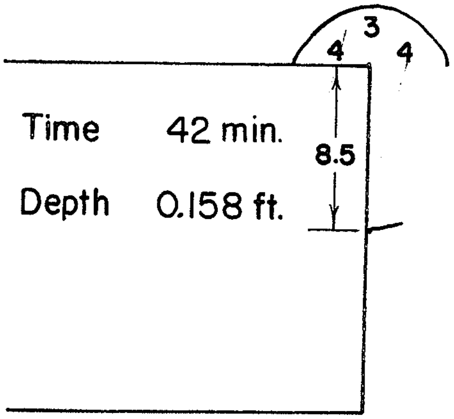
Scale: 1" = 10"

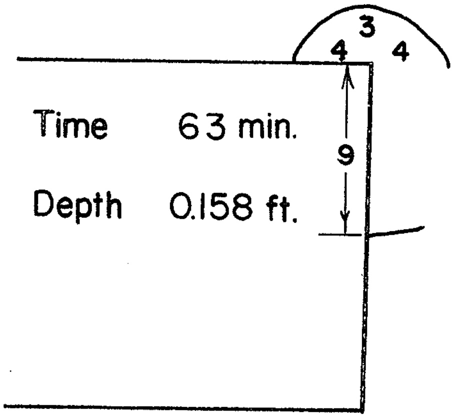






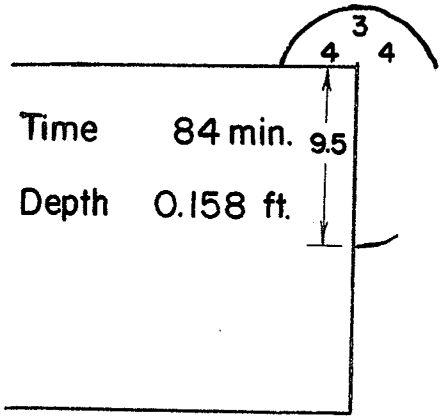


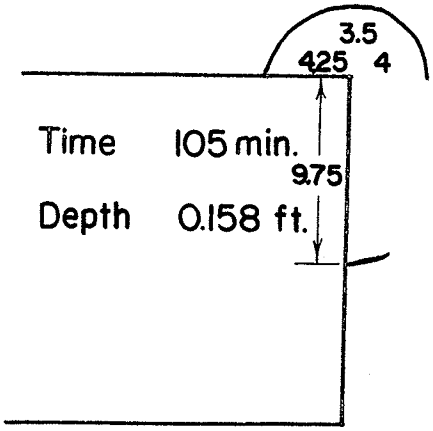


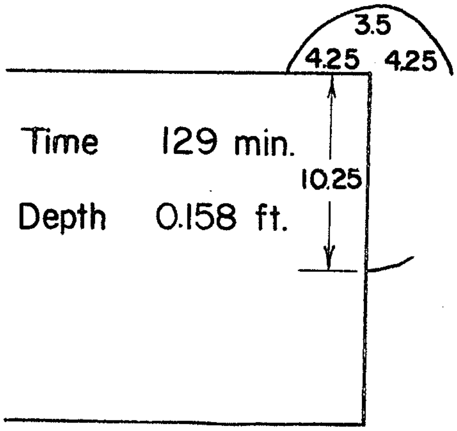


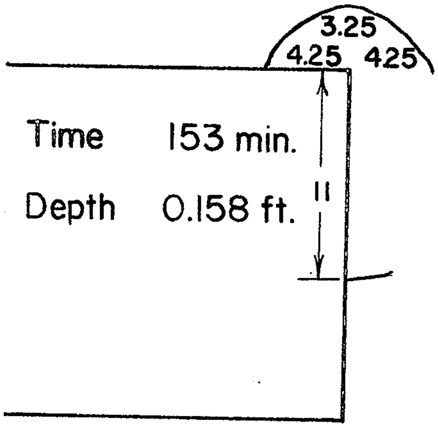
TEST 12

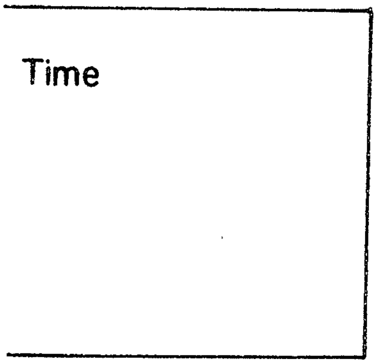
Scale: 1" = 10"

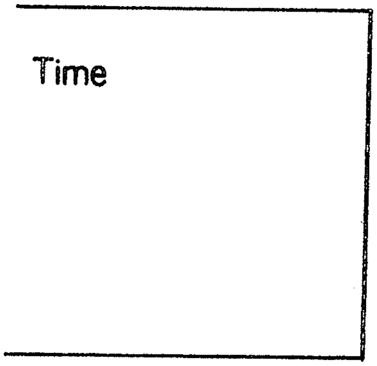




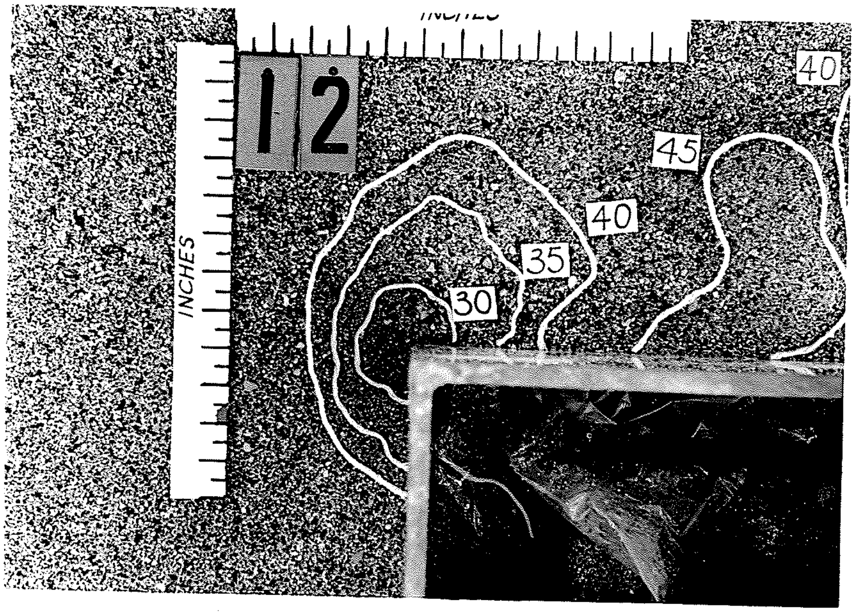




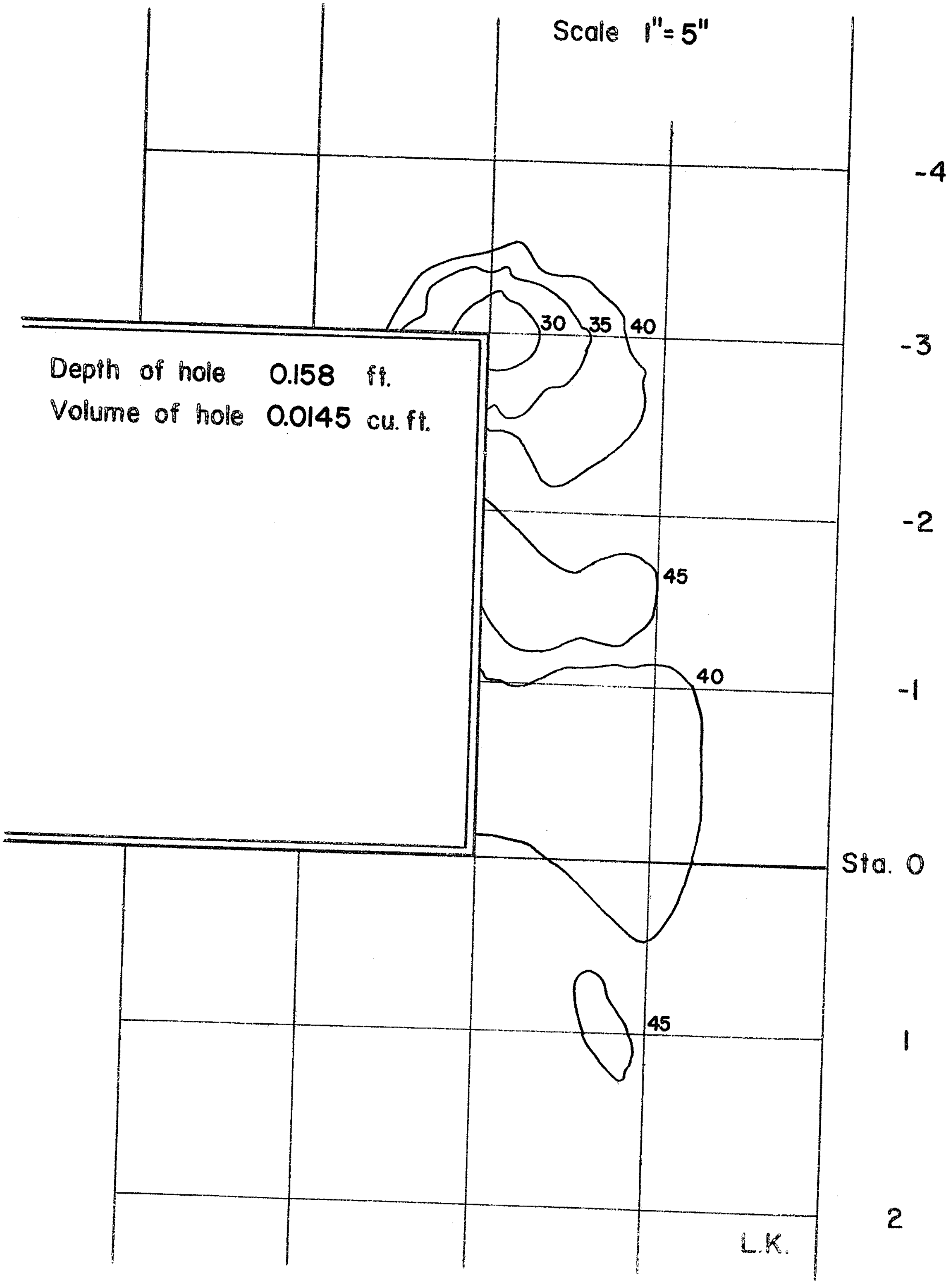




JUN • 64 •



TEST 12



Depth of hole 0.158 ft.
Volume of hole 0.0145 cu. ft.

TEST DATA SHEET

TEST NO. 13

DATE June 15/64

MODEL SCALES: HORIZ. 1:100

VERT. 1:100

MATERIAL: SILICA SAND (FINE)

	MODEL	PROTOTYPE
Gauge Height (ft.)	.528	
Discharge (CFS)	.505	50,500.
Depth of Flow (ft.)	.400	40.
Area (sq.ft.)	1.120	11,200.
Mean Velocity in Channel (ft/sec)	.451	4.51
Time of Run	42.5 minutes	7.07 hours
Number of Photos Taken	1	

REMARKS:

No erosion of left bank.

Violent erosion of right bank throughout test beginning at Sta.-1.5 and progressing downstream.

Right bank fell in at 25 minutes at Sta.+2.

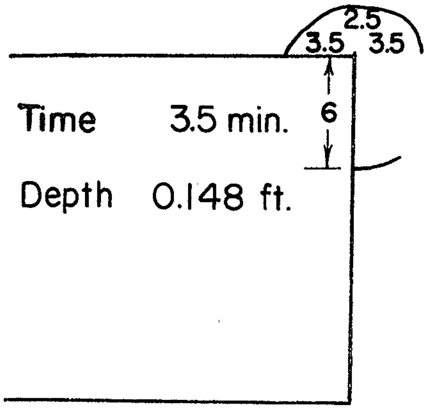
Full depth of hole had almost been reached at 42 minutes.

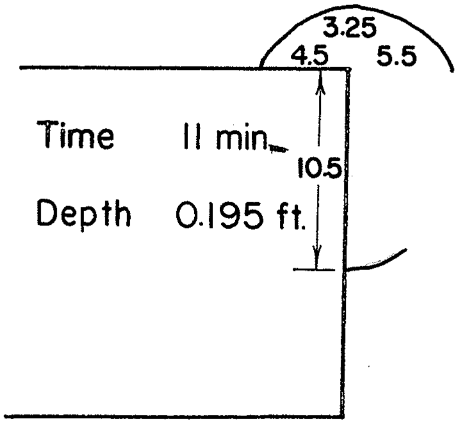
Excessive riffles formed.

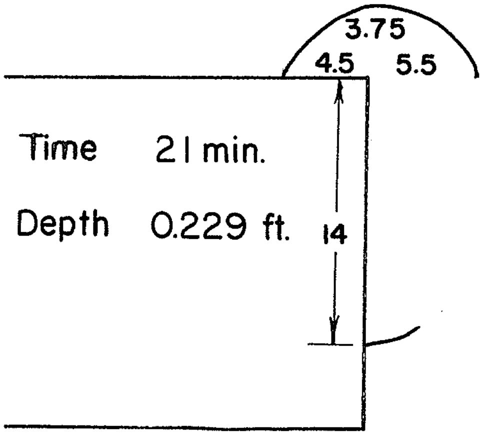
Test Performed by: lk

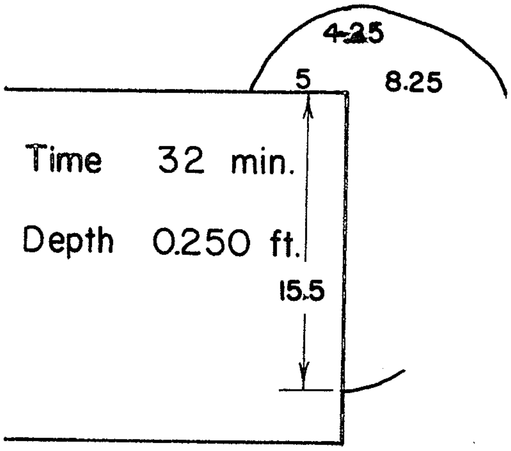
TEST 13

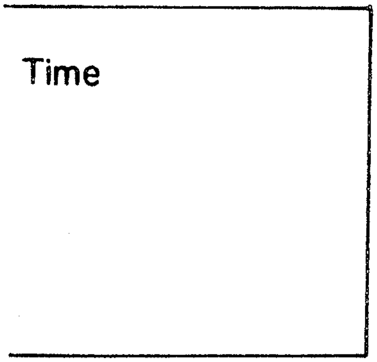
Scale: 1" = 10"

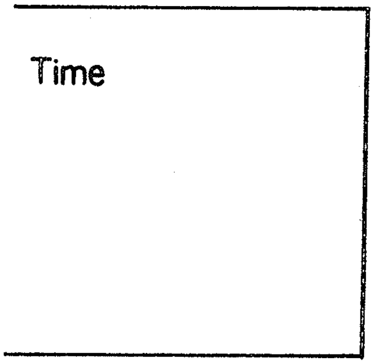




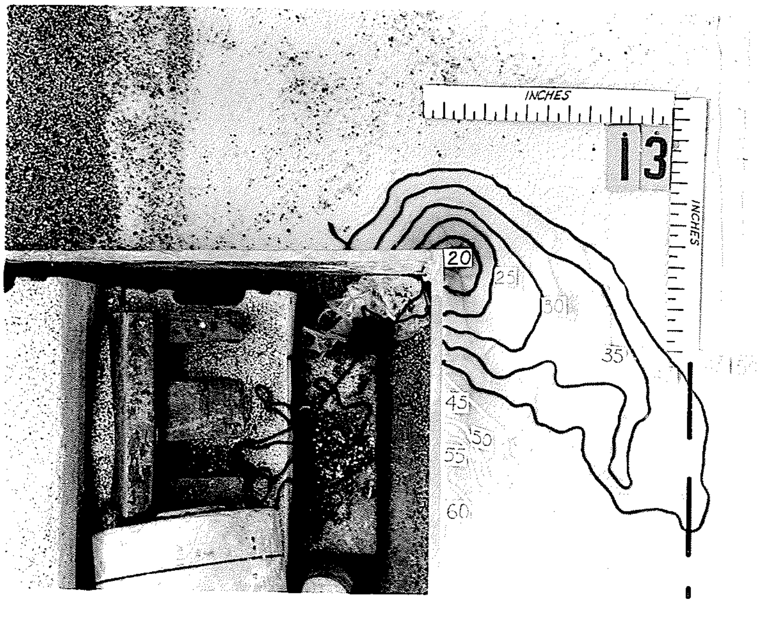




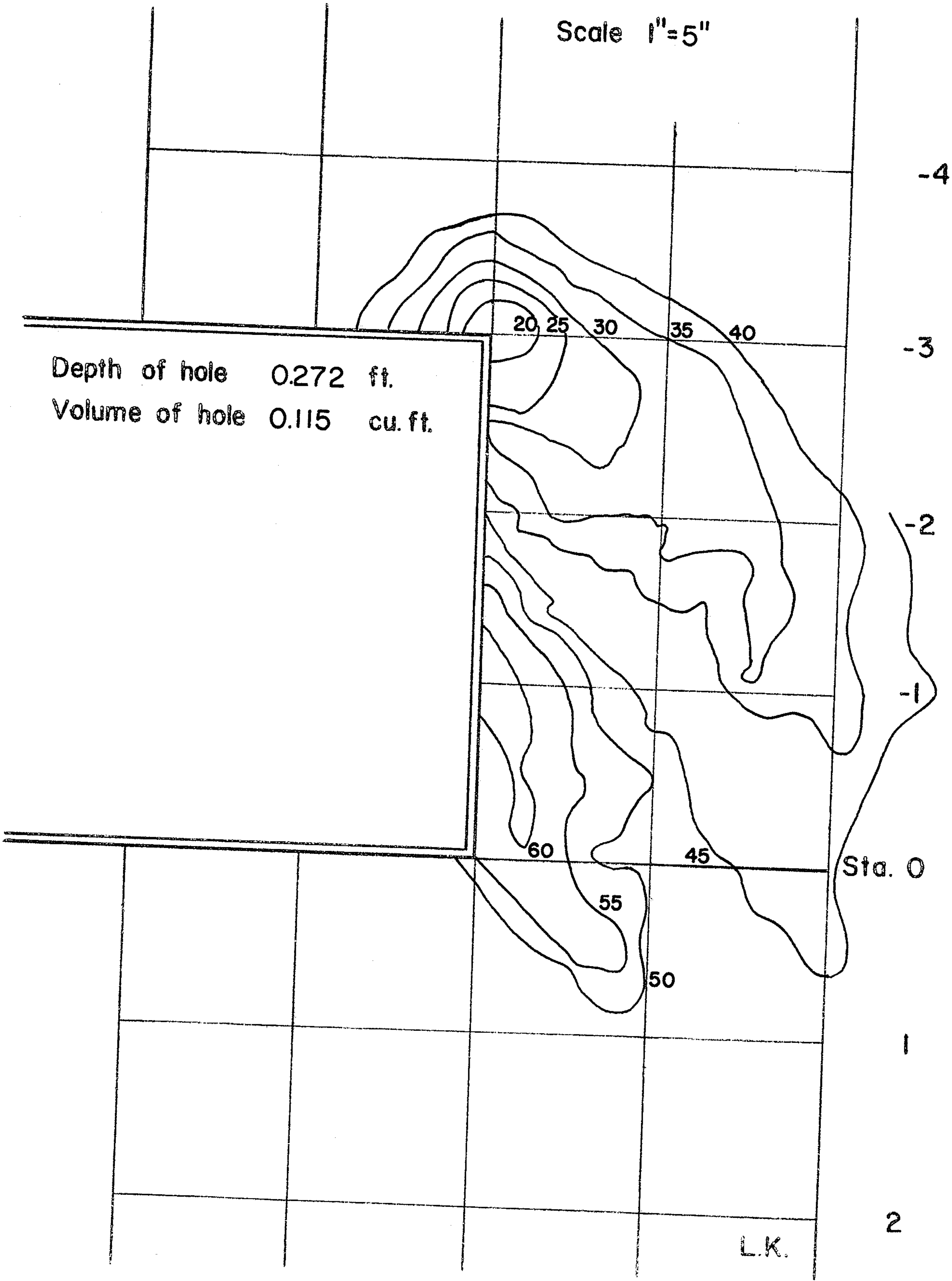




JUN • 64



TEST 13



Depth of hole 0.272 ft.
Volume of hole 0.115 cu. ft.

TEST DATA SHEET

TEST NO. 14

DATE June 16/64

MODEL SCALES: HORIZ. 1:100

VERT. 1:100

MATERIAL: SILICA SAND (COARSE)

	MODEL	PROTOTYPE
Gauge Height (ft.)	.528	
Discharge (CFS)	.505	50,500.
Depth of Flow (ft.)	.400	40.
Area (sq.ft.)	1.120	11,200.
Mean Velocity in Channel (ft/sec)	.451	4.51
Time of Run	42.5 minutes	7.07 hours

Number of Photos Taken -

REMARKS:

No erosion of left bank.

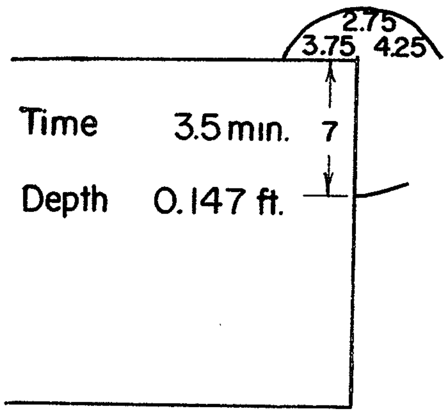
Right bank still erodes rapidly at 42 minutes.

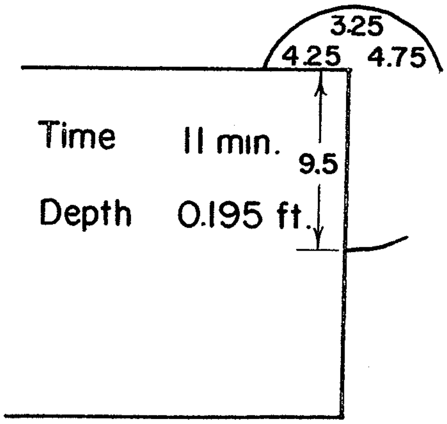
Full depth of hole reached in 40 minutes.

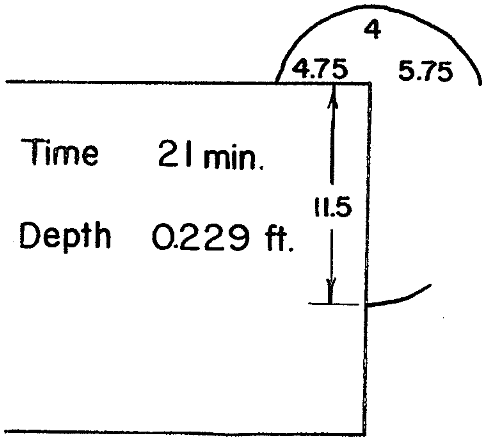
Test Performed by: lk

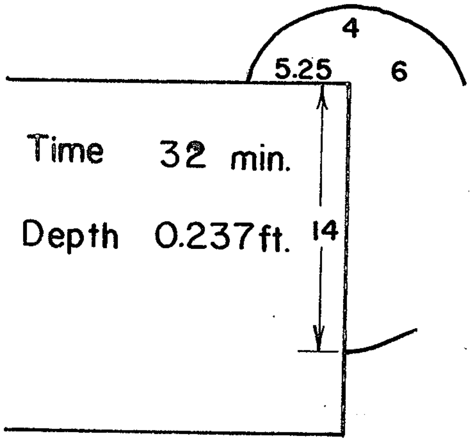
TEST 14

Scale: 1" = 10"





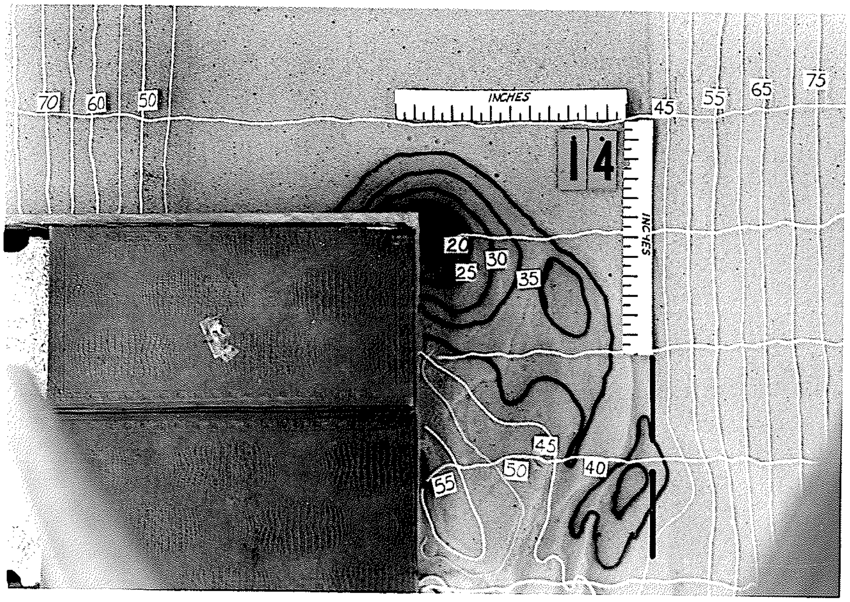




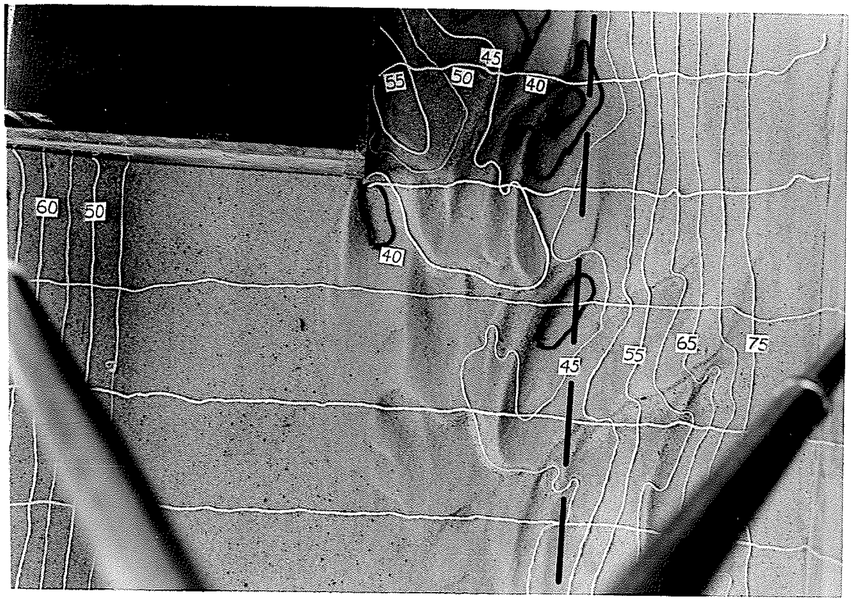
Time

Time

JUN • 64

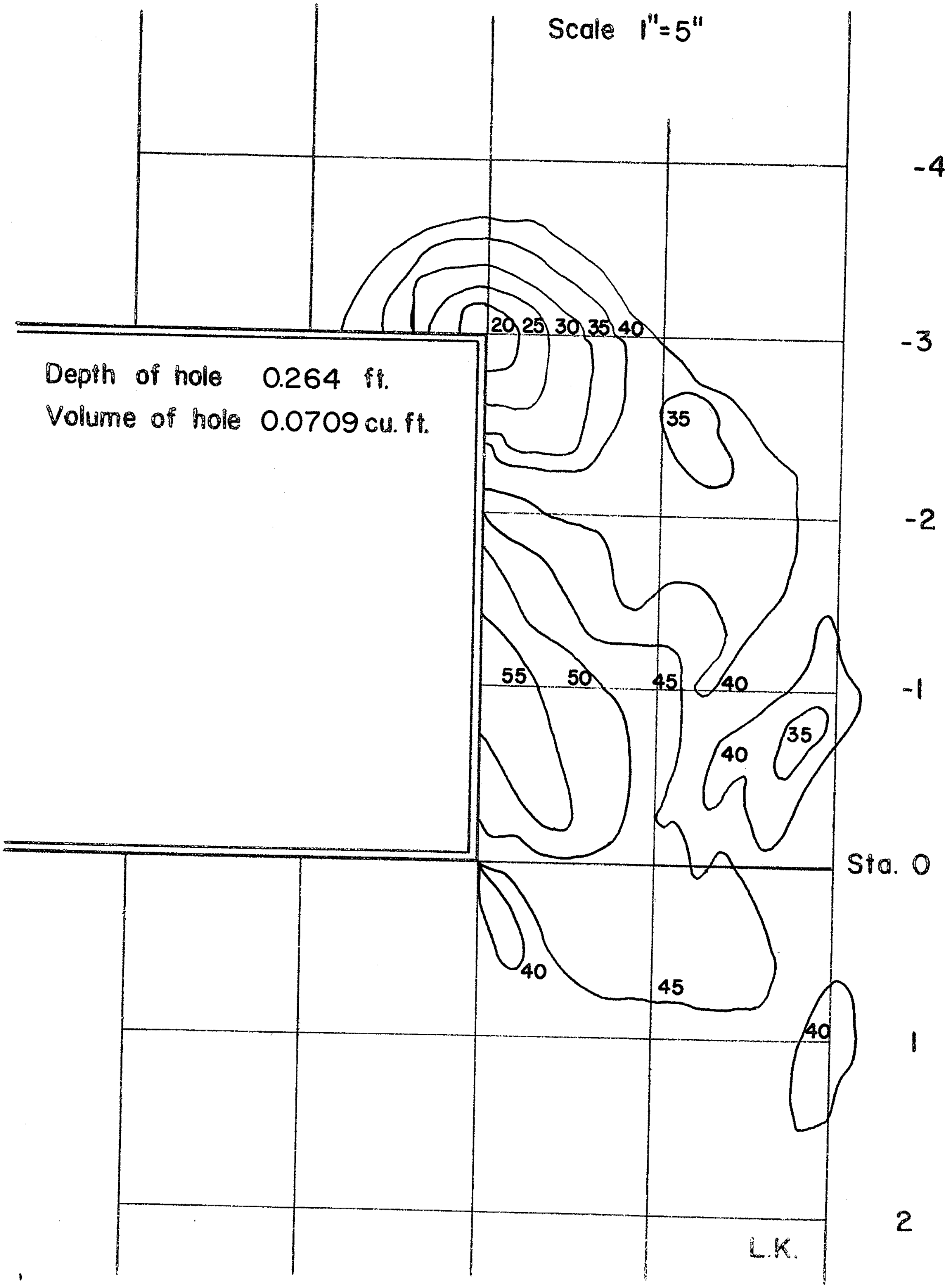


JUN • 64



JUN • 64

TEST 14



Scale 1"=5"

Depth of hole 0.264 ft.
Volume of hole 0.0709 cu. ft.

TEST DATA SHEET

TEST NO. 15

DATE June 17/64

MODEL SCALES: HORIZ. 1:100

VERT. 1:100

MATERIAL: COARSE SILICA SAND

	MODEL	PROTOTYPE
Gauge Height (ft.)	.528	
Discharge (CFS)	.505	50,500.
Depth of Flow (ft.)	.400	40.
Area (sq.ft.)	1.120	11,200.
Mean Velocity in Channel (ft/sec)	.451	4.51
Time of Run	1 hour 25 minutes	14.14 hours
Number of Photos Taken	3	

REMARKS:

No erosion of left bank.

Erosion of right bank is rapid especially 6"-3' downstream of the cofferdam.

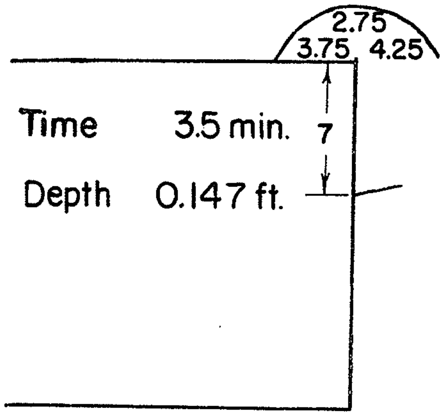
At 55 minutes the right bank disappears 5" downstream of Sta. 0.
Full dpeth of hole is reached at 50 minutes.
A roller about ½" deep whirls up the downstream slope of the hole and dies out at the top.

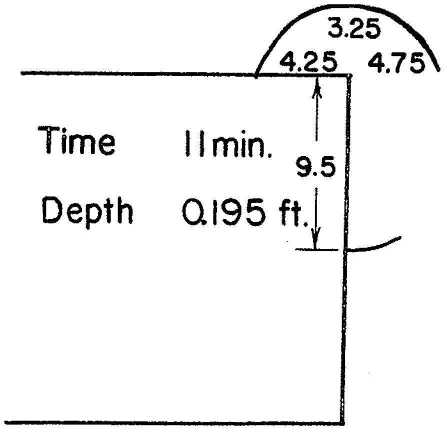
After 70 minutes the bottom of the hole becomes much flatter. The roller moves up only about 1" above the bottom of the hole. Sand falls back into it and is swept up and over.

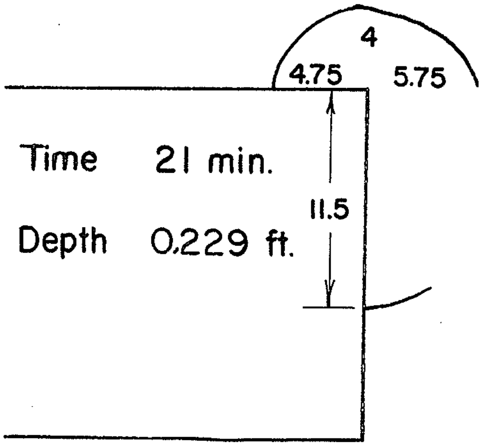
Test Performed by: lk

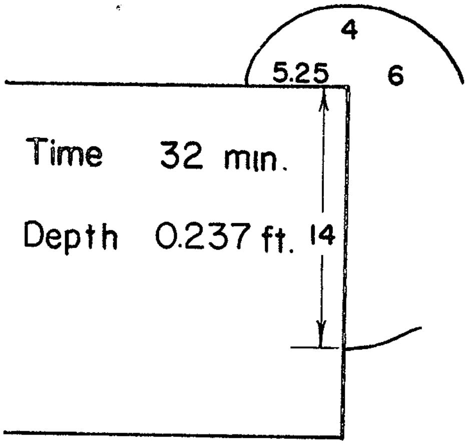
TEST 15

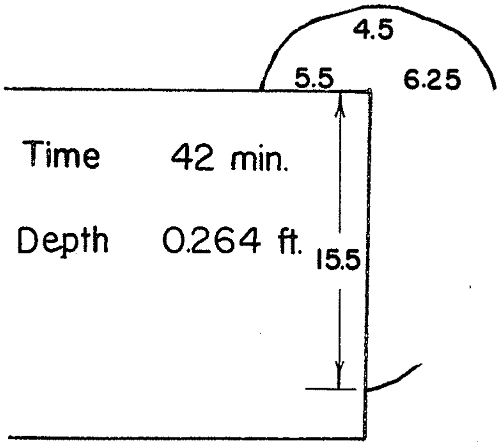
Scale: 1" = 10"

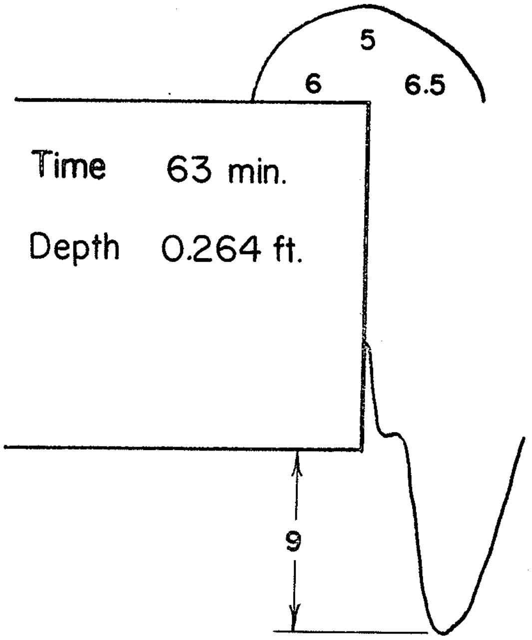


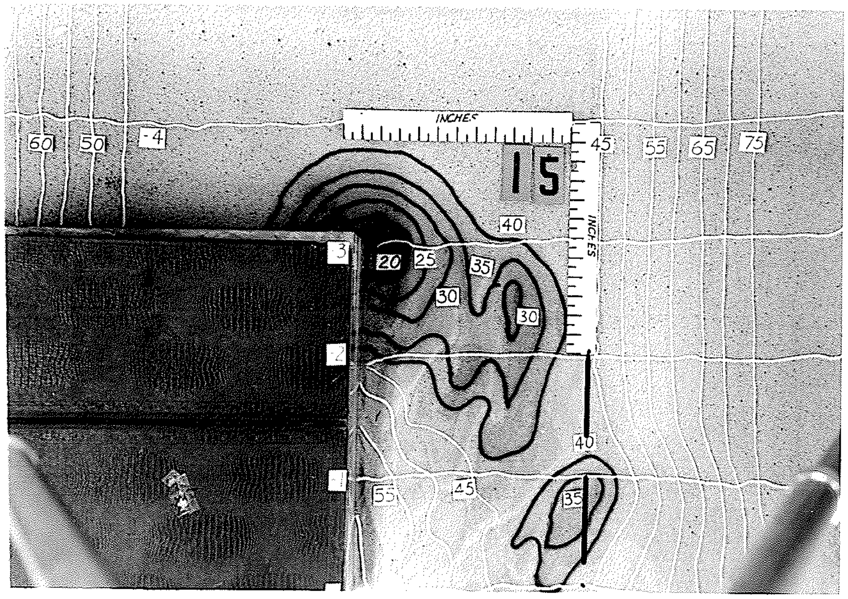


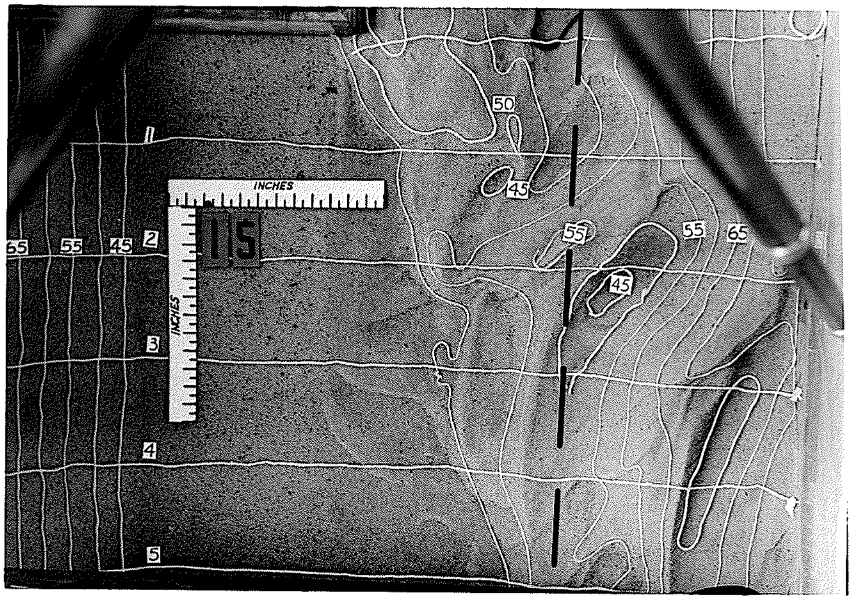




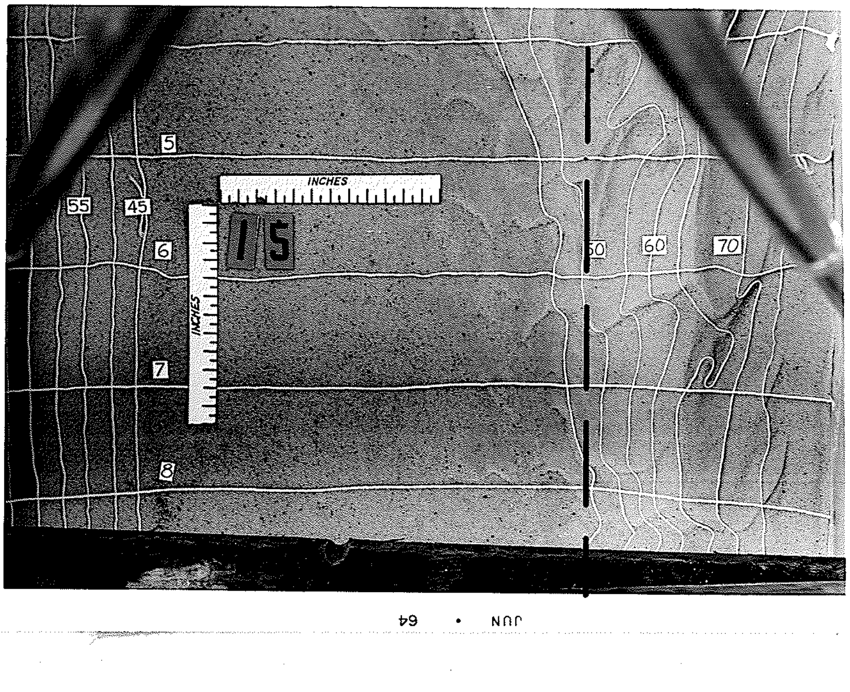





INCHES
60
50
4
45
55
65
75
15
INCHES
40
3
20
25
35
30
30
2
40
1
55
45
35

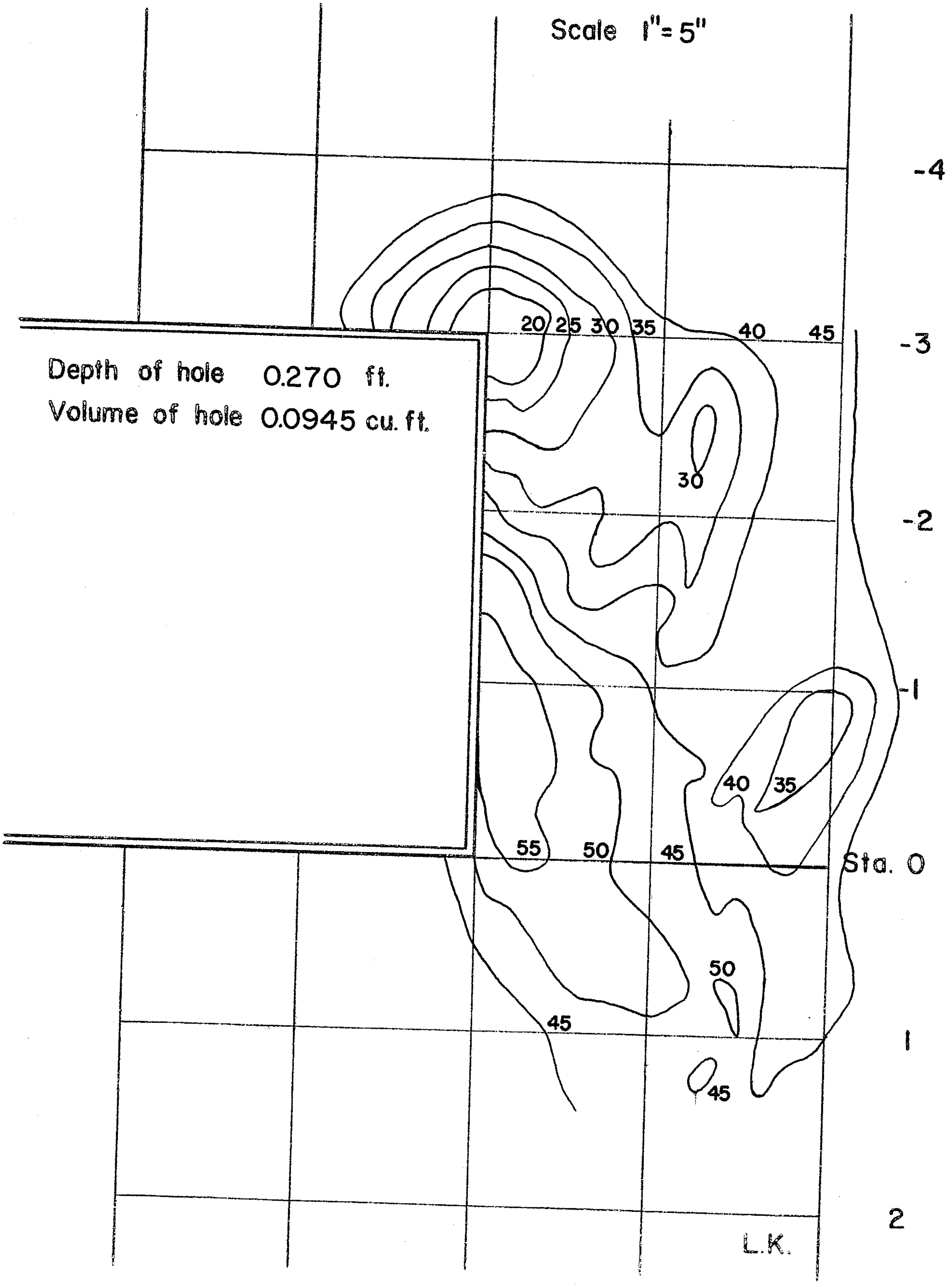

50
1
INCHES
45
15
65
55
45
2
55
55
65
45
INCHES
3
4
5

JUN • 64


5
INCHES
55
45
6
15
50
60
70
INCHES
7
8

JUN • 64

TEST 15



Scale 1" = 5"

Depth of hole 0.270 ft.

Volume of hole 0.0945 cu. ft.

TEST DATA SHEET

TEST NO. 16

DATE June 19/64

MODEL SCALES: HORIZ. 1:100

VERT. 1:100

MATERIAL: MEDIUM MORTAR SAND

	MODEL	PROTOTYPE
Gauge Height (ft.)	.528	
Discharge (CFS)	.505	50,500.
Depth of Flow (ft.)	.400	40.
Area (sq.ft.)	1.120	11,200.
Mean Velocity in Channel (ft/sec)	.451	4.51
Time of Run	42 minutes	7.07 hours

Number of Photos Taken 1

REMARKS:

No erosion of left bank.

Erosion of the right bank progresses very slowly directly opposite cofferdam. All fine particles are swept away, exposing coarse material.

At 15 minutes, many large particles begin to pave the downstream slope of the hole.

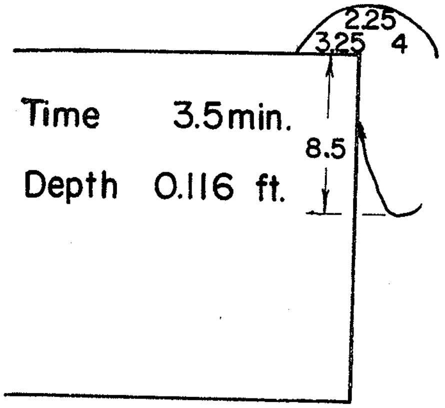
At 20 minutes, erosion of the hole is very slow due to the presence of these large particles.

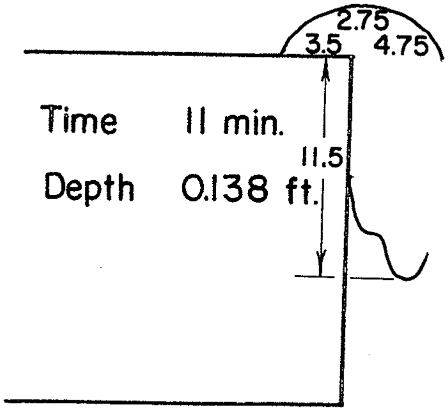
Full depth of the hole is reached at 25 minutes.

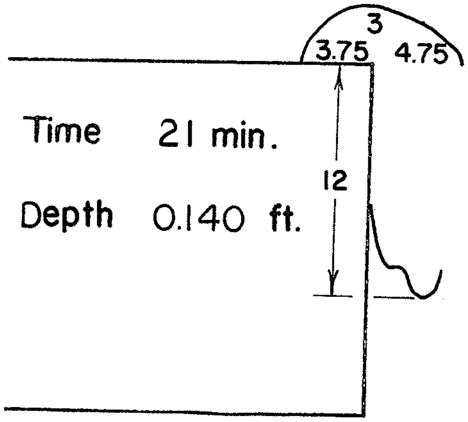
Test Performed by: lk

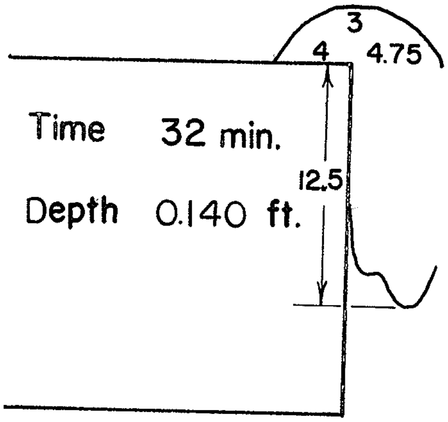
TEST 16

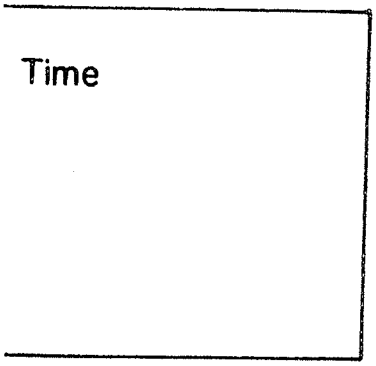
Scale: 1" = 10"

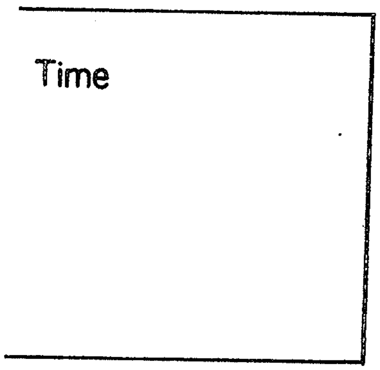




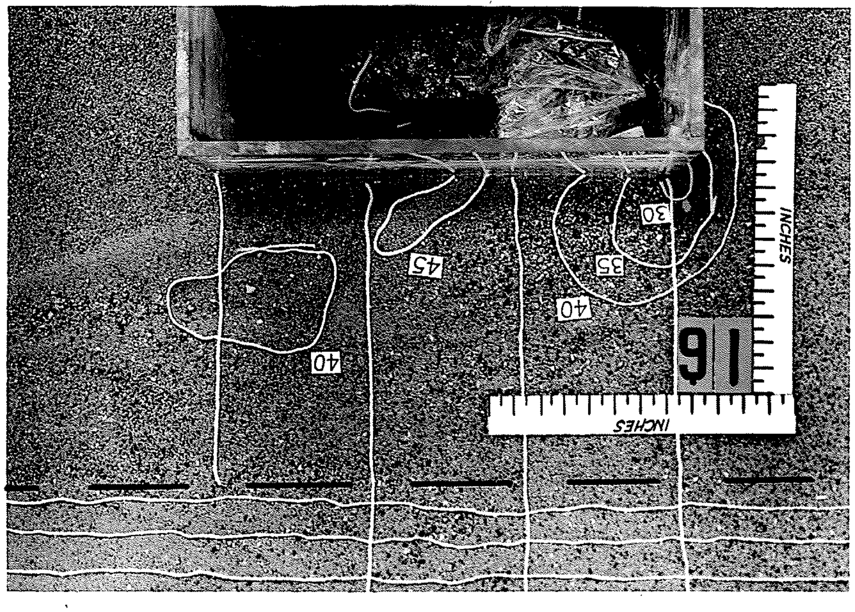




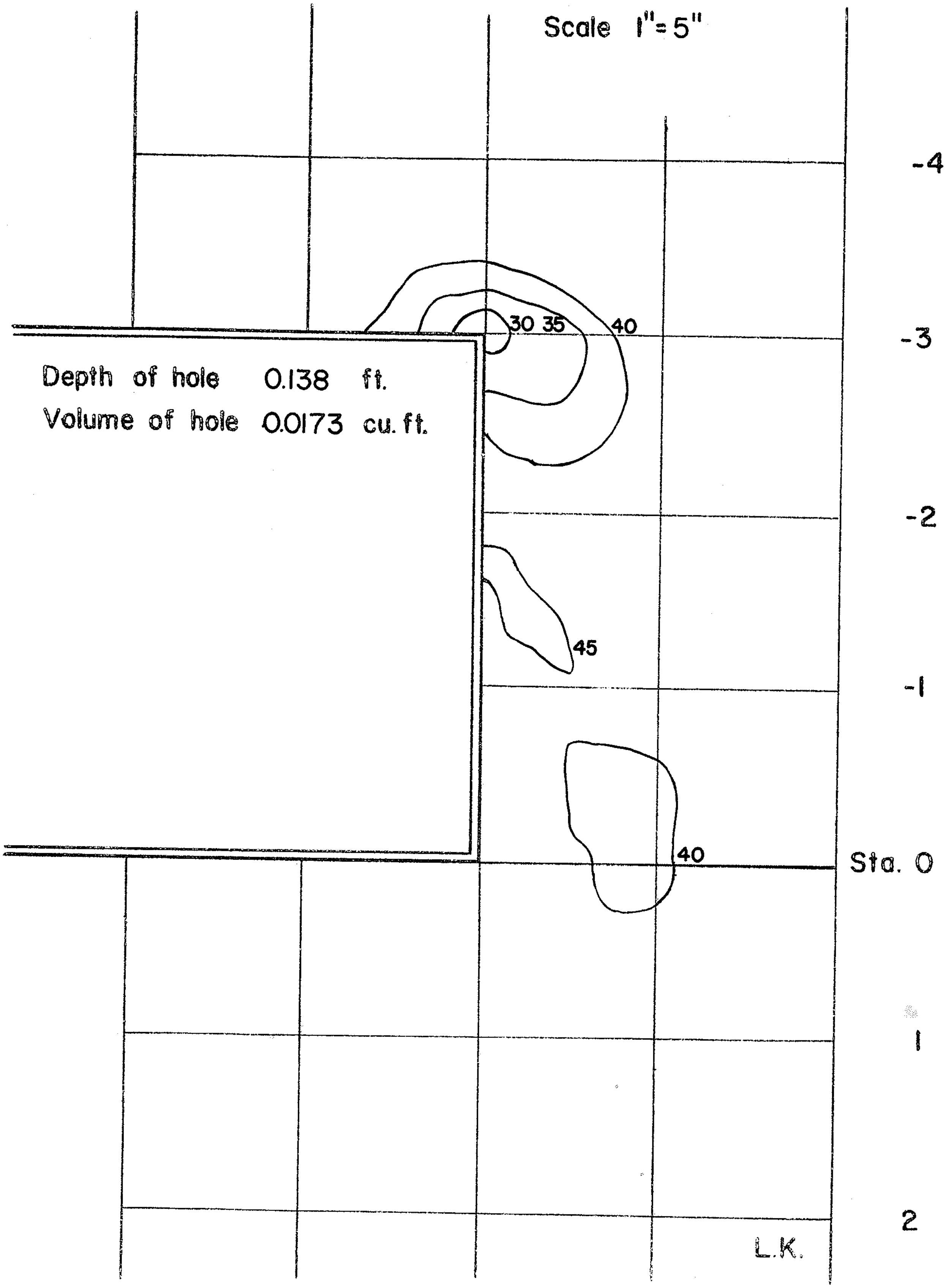




JUL · 64



TEST 16



Depth of hole 0.138 ft.
Volume of hole 0.0173 cu. ft.

TEST DATA SHEET

TEST NO. 17

DATE June 19/64

MODEL SCALES: HORIZ. 1:100

VERT. 1:100

MATERIAL: MEDIUM MORTAR SAND

	MODEL	PROTOTYPE
Gauge Height (ft.)	.528	
Discharge (CFS)	.505	50,500.
Depth of Flow (ft.)	.400	40.
Area (sq.ft.)	1.120	11,200.
Mean Velocity in Channel (ft/sec)	.451	4.51
Time of Run	85 minutes	14.14 hours
Number of Photos Taken	1	

REMARKS:

No erosion of left bank.

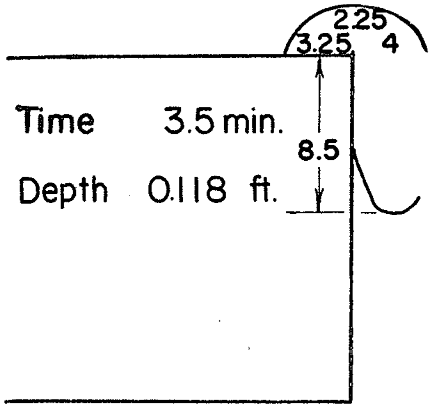
Erosion of right bank progresses slowly throughout.

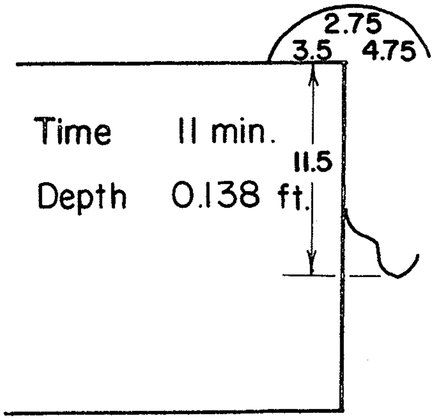
Full depth of hole is reached in 25 minutes.

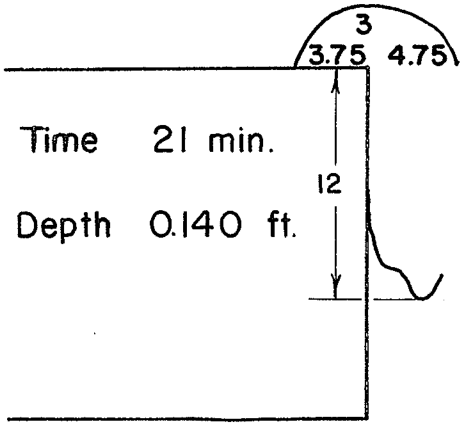
Test Performed by: 1k

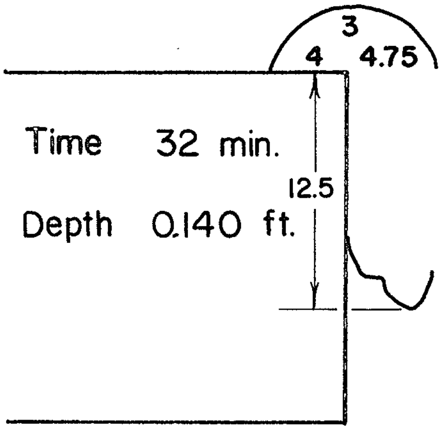
TEST 17

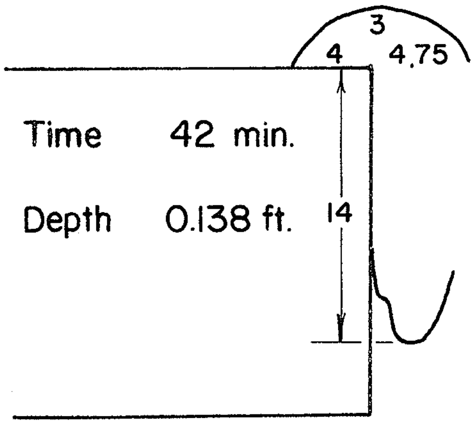
Scale: 1" = 10"

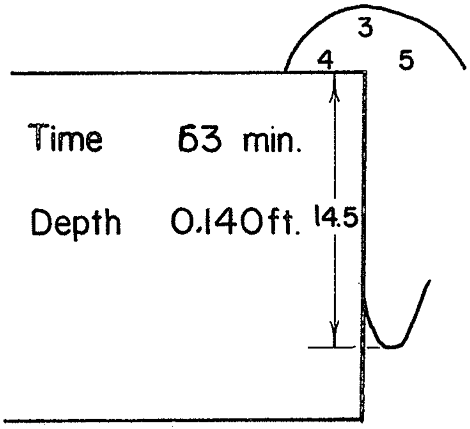


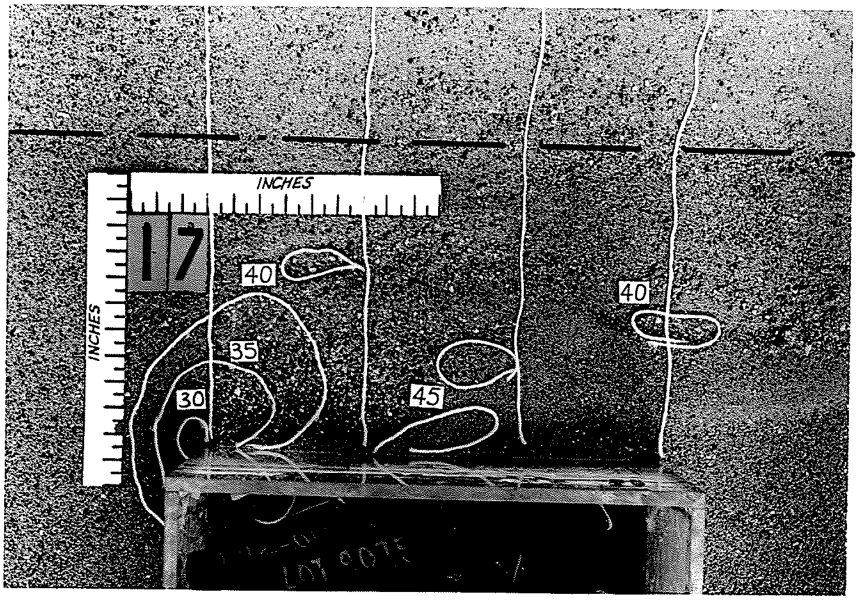






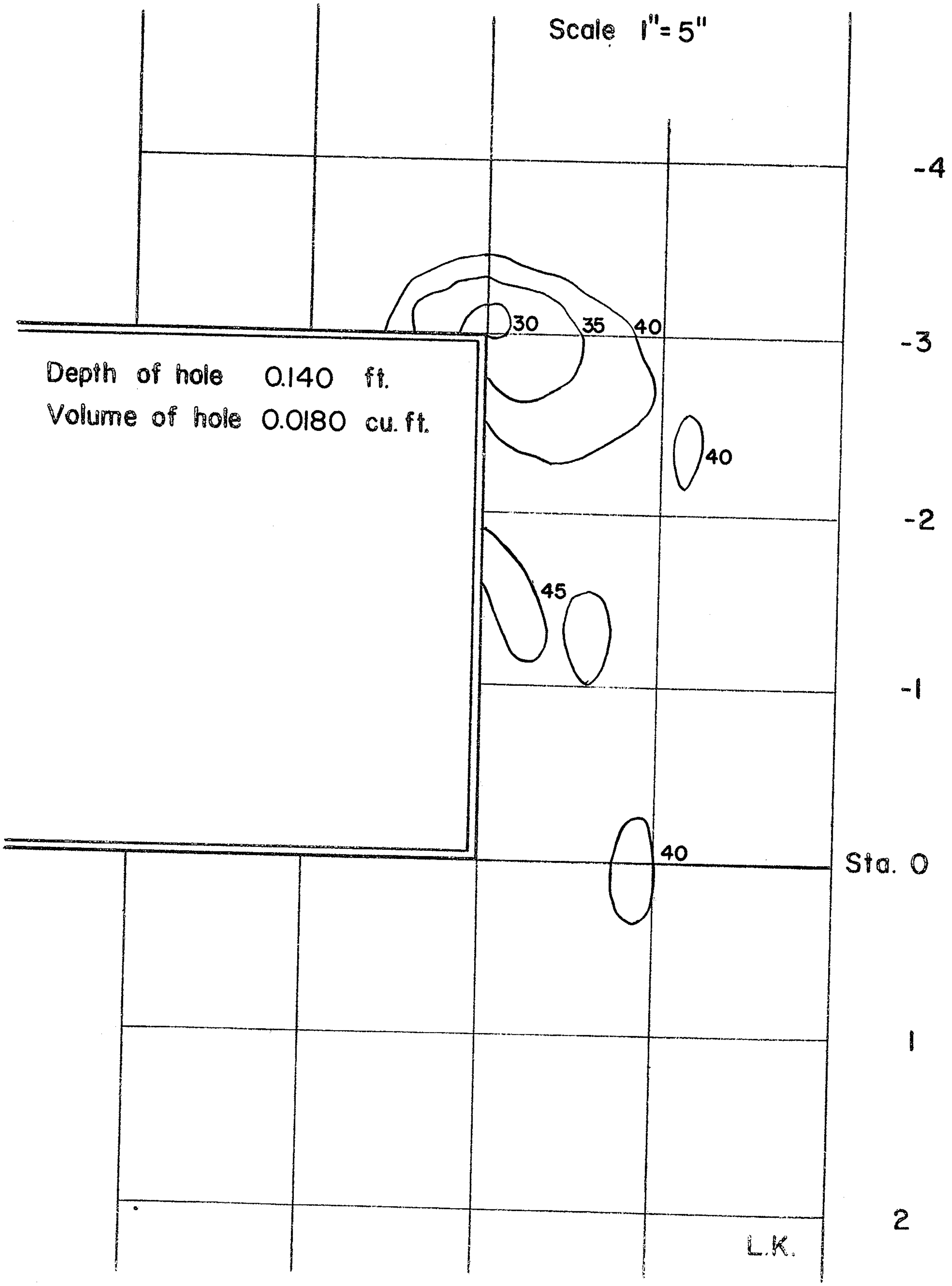






JUL · 64 ·

TEST 17



Depth of hole 0.140 ft.
Volume of hole 0.0180 cu. ft.

TEST DATA SHEET

TEST NO. 18

DATE June 22/64

MODEL SCALES: HORIZ. 1:100

VERT. 1:100

MATERIAL: MEDIUM MORTAR SAND

	MODEL	PROTOTYPE
Gauge Height (ft.)	.528	
Discharge (CFS)	.505	50,500.
Depth of Flow (ft.)	.400	40.
Area (sq.ft.)	1.120	11,200.
Mean Velocity in Channel (ft/sec)	.451	4.51
Time of Run	127 minutes	28.28 hours

Number of Photos Taken 1

REMARKS:

No erosion of left bank.

Erosion of right bank proceeds at a constant slow rate throughout the test.

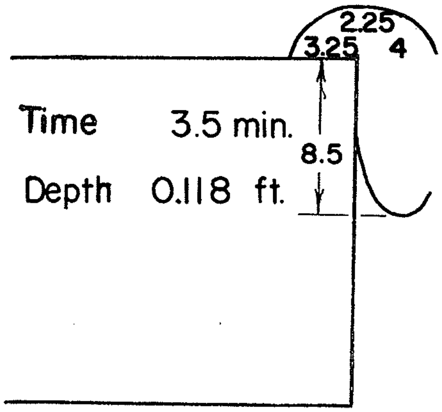
Periodic bursts occur at the moving front end of the built up mound.

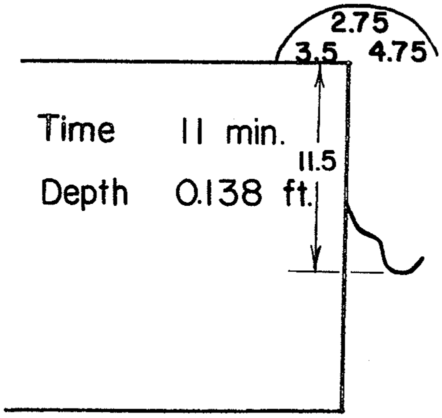
Fine particles of sand are continually being removed from the hole uncovering coarser material which paves the bottom and downstream slope of the hole.

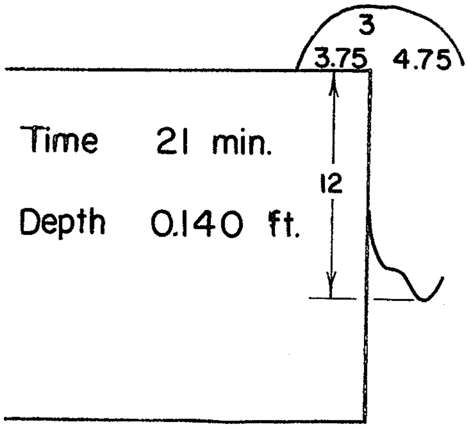
Test Performed by: lk

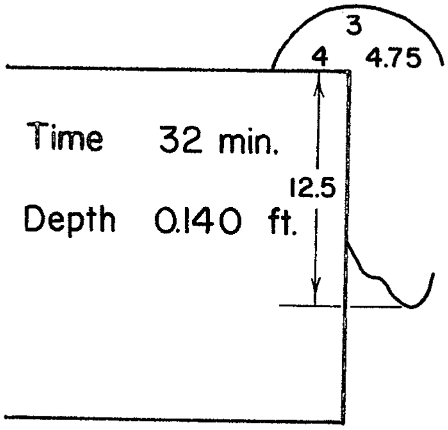
TEST 18

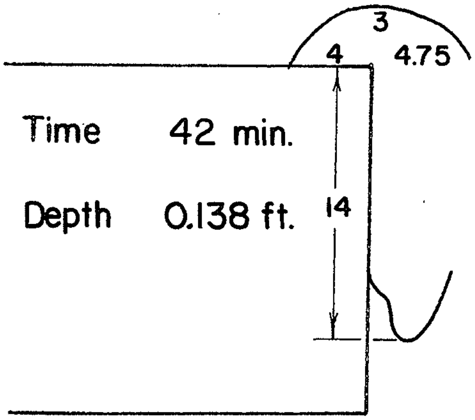
Scale: 1" = 10"

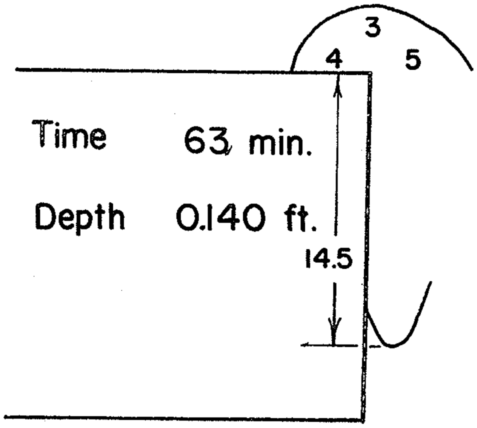




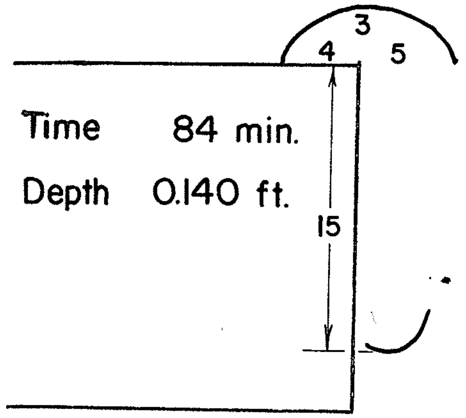






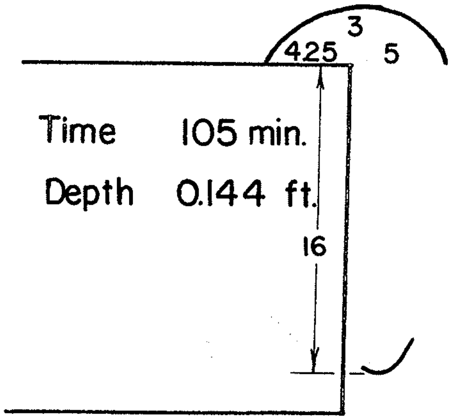


Scale: 1" = 10"



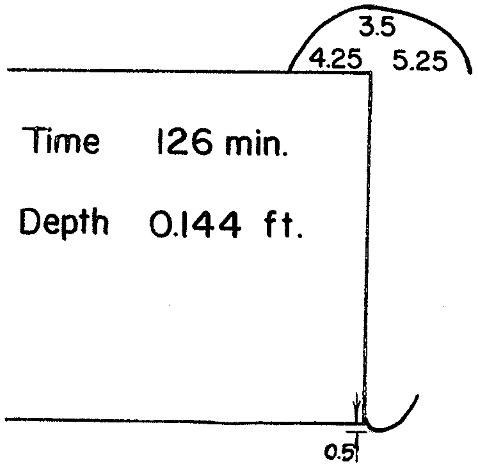
Time 84 min.

Depth 0.140 ft.



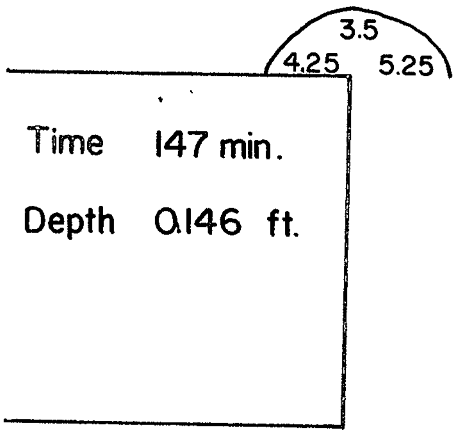
Time 105 min.

Depth 0.144 ft.



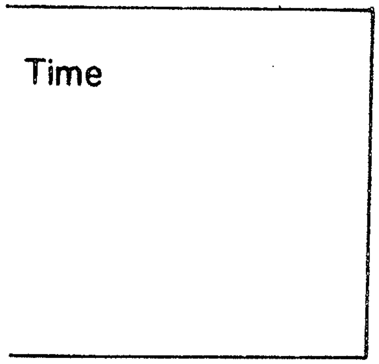
Time 126 min.

Depth 0.144 ft.

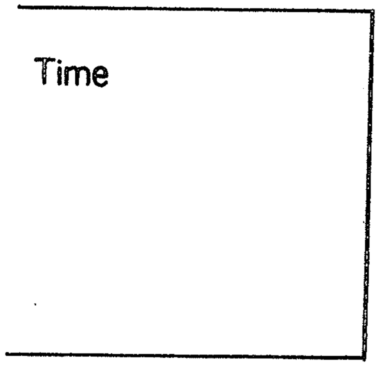


Time 147 min.

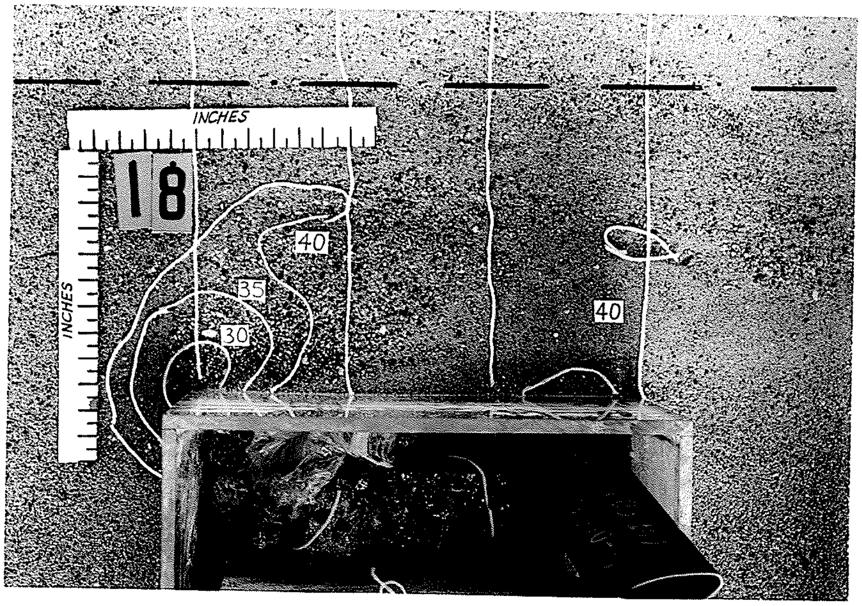
Depth 0.146 ft.



Time

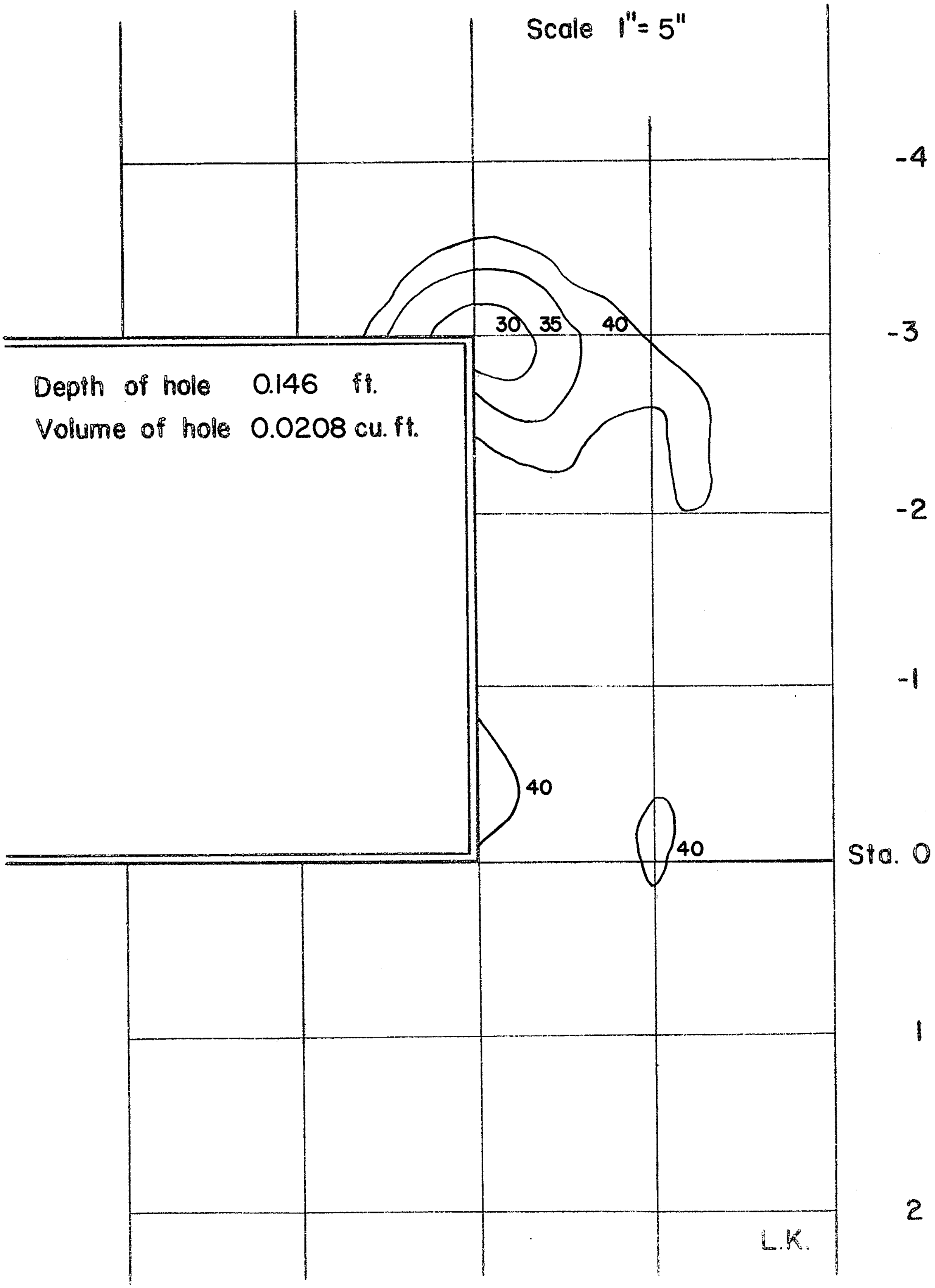


Time



JUL - 64

TEST 18



Depth of hole 0.146 ft.
Volume of hole 0.0208 cu. ft.

TEST DATA SHEET

TEST NO. 19

DATE June 23/64

MODEL SCALES: HORIZ. 1:100

VERT. 1:100

MATERIAL: FINE MORTAR SAND

	MODEL	PROTOTYPE
Gauge Height (ft.)	.528	
Discharge (CFS)	.505	50,500.
Depth of Flow (ft.)	.400	40.
Area (sq.ft.)	1.120	11,200.
Mean Velocity in Channel (ft/sec)	.451	4.51
Time of Run	42.4 minutes	7.07 hours

Number of Photos Taken 2

REMARKS:

No erosion of left bank.

Erosion of the right bank is violent opposite and downstream of the cofferdam.

In 17 minutes the bank disappears 4" downstream of Sta. 0.

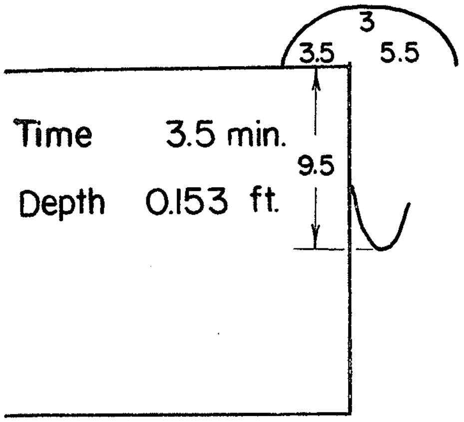
The depth of hole is reached in 20 minutes, quite rapidly due to larger particles settling on the downstream slope of the hole.

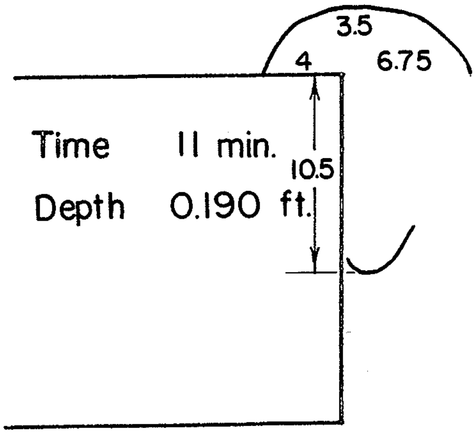
Paving of the hole and between riffles is excessive.

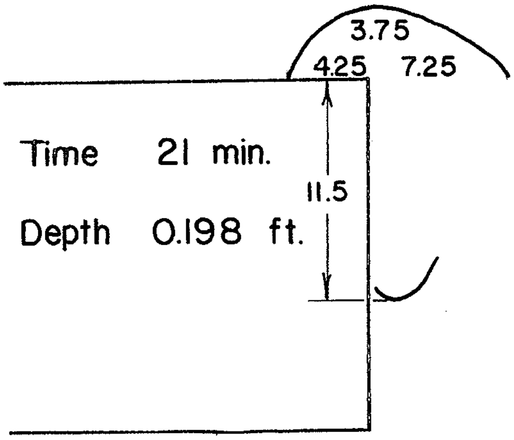
Test Performed by: lk

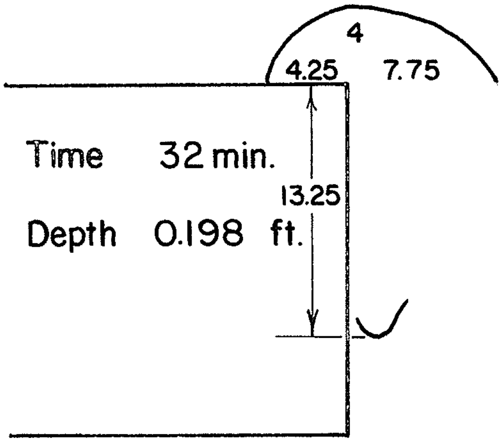
TEST 19

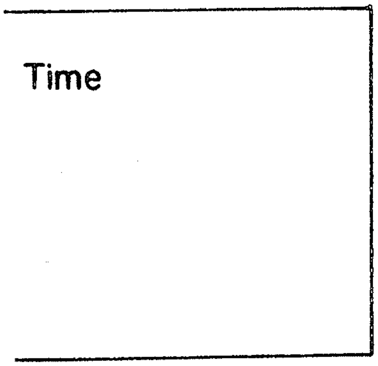
Scale: 1" = 10"

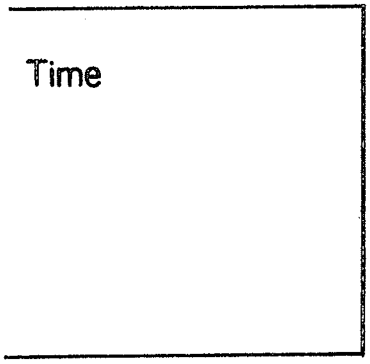


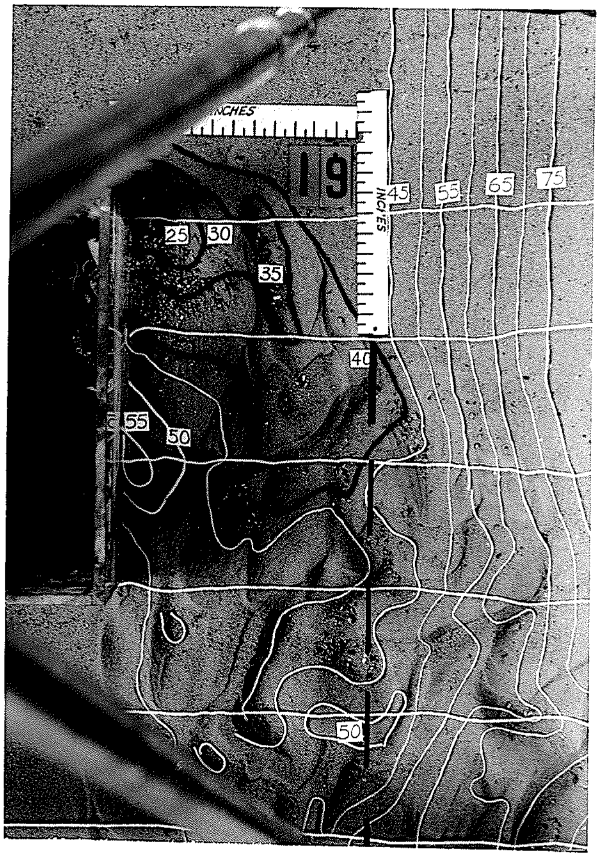




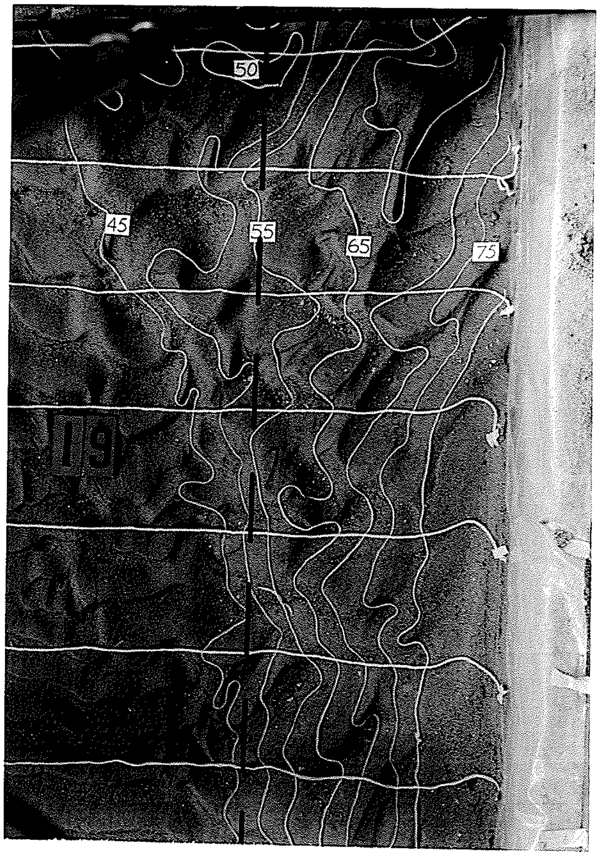






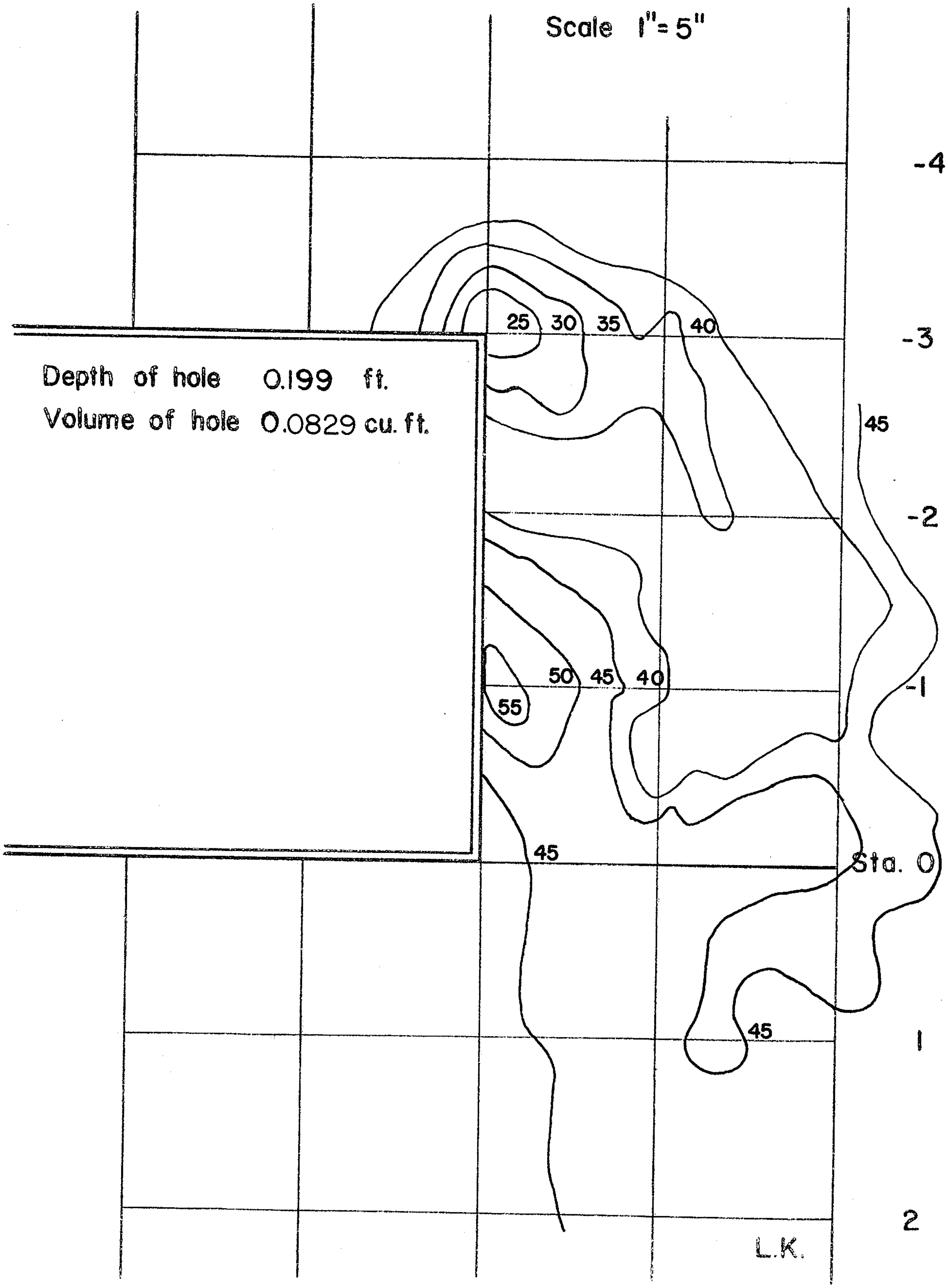


JUL • 64



JUL • 64

TEST 19



Depth of hole 0.199 ft.

Volume of hole 0.0829 cu. ft.

TEST DATA SHEET

TEST NO. 20

DATE June 23/64

MODEL SCALES: HORIZ. 1:100

VERT. 1:100

MATERIAL: FINE MORTAR SAND SIEVED THROUGH #10 SIEVE

	MODEL	PROTOTYPE
Gauge Height (ft.)	.528	
Discharge (CFS)	.505	50,500.
Depth of Flow (ft.)	.400	40.
Area (sq.ft.)	1.120	11,200.
Mean Velocity in Channel (ft/sec)	.451	4.51
Time of Run	85 minutes	14.14 hours

Number of Photos Taken 2

REMARKS:

No erosion of left bank.

Rapid erosion of right bank.

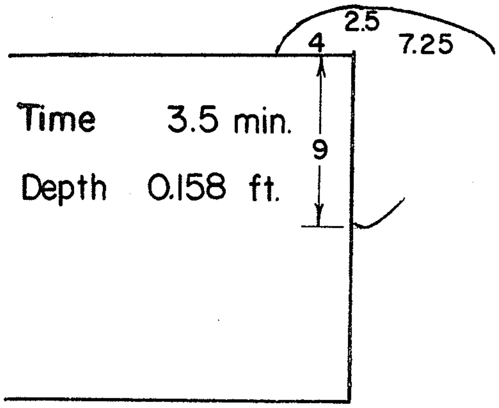
The sand is not yet quite uniform and the largest particles, considerably smaller than those in the previous test, pave the downstream slope of the hole.

The erosion pattern is similar to that of the previous test but is greatly accelerated and has progressed further downstream.

Test Performed by: lk

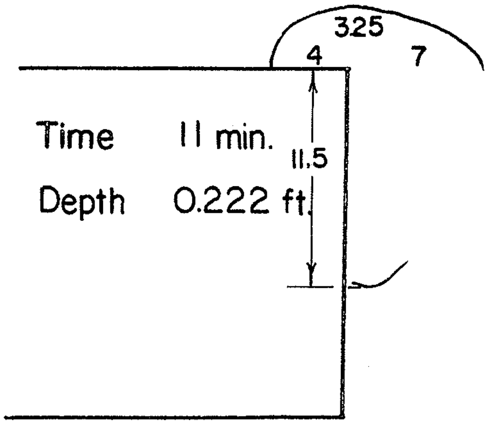
TEST 20

Scale: 1" = 10"



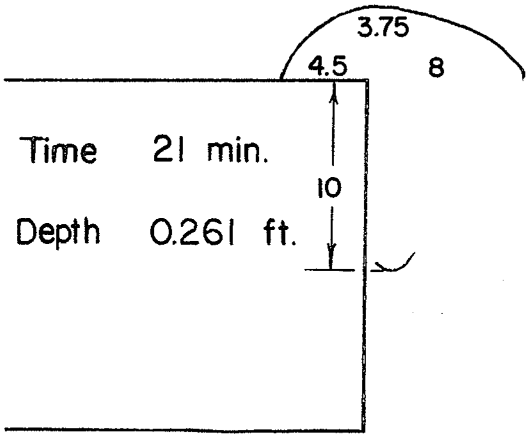
Time 3.5 min.

Depth 0.158 ft.



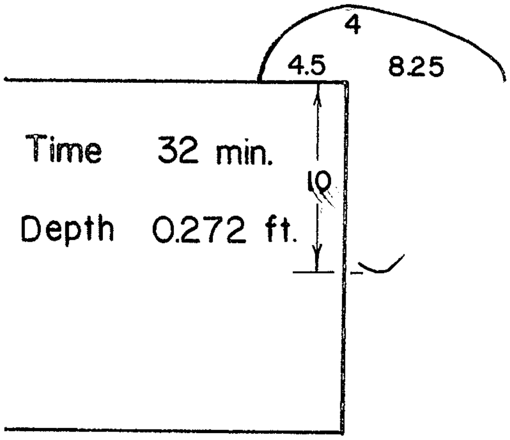
Time 11 min.

Depth 0.222 ft.



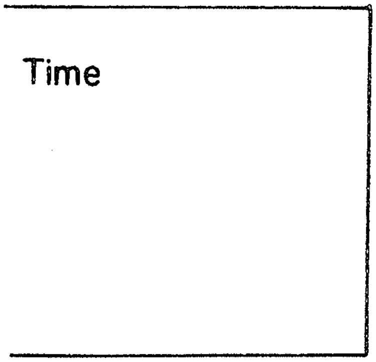
Time 21 min.

Depth 0.261 ft.

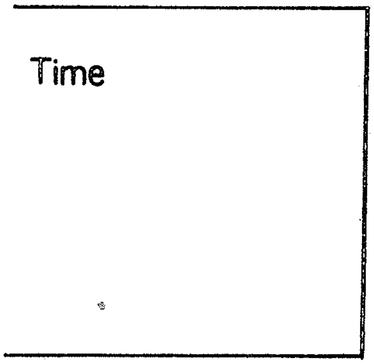


Time 32 min.

Depth 0.272 ft.

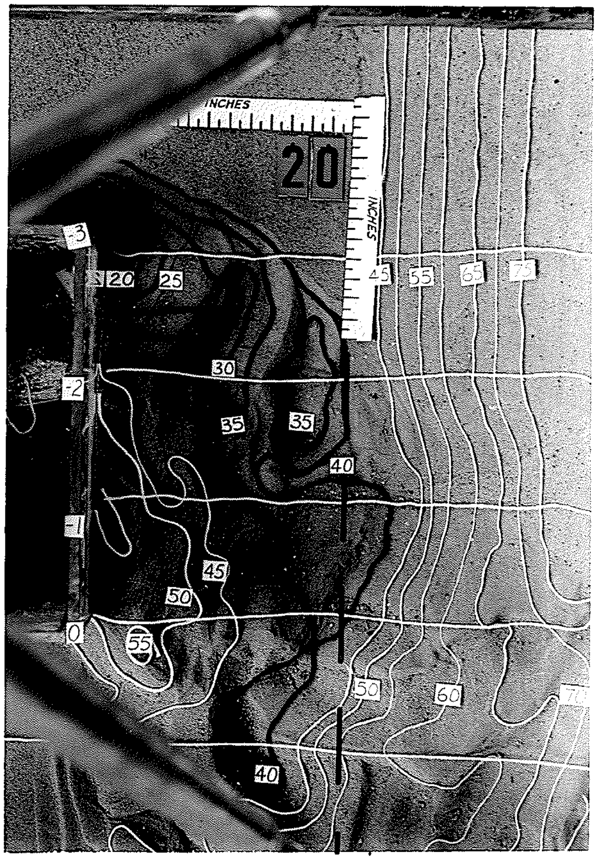


Time

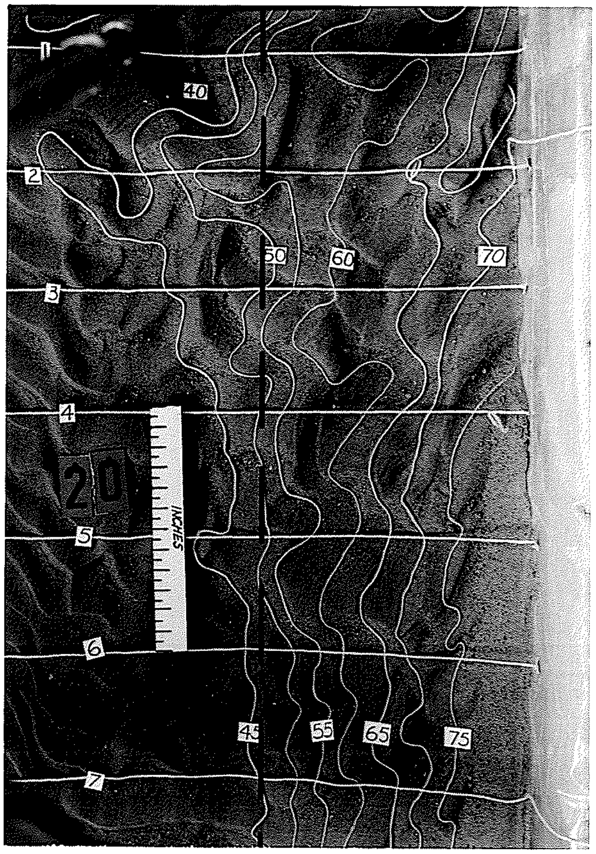


Time

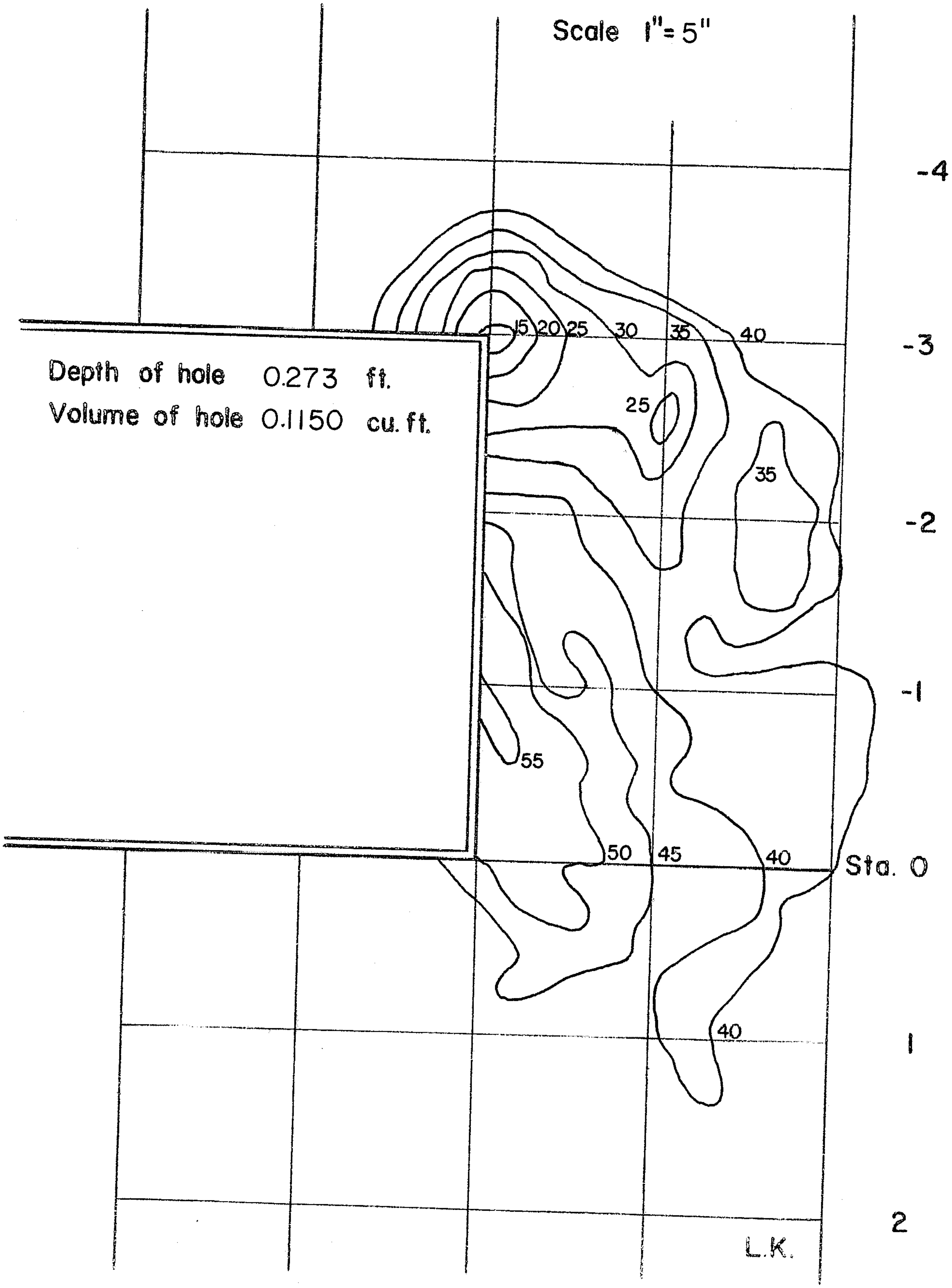
JUL · 64


INCHES
20
INCHES
-3
20
25
45
55
65
75
30
-2
35
35
40
-1
45
50
0
55
50
60
70
40

JUL · 64


1
40
2
50
60
70
3
4
20
INCHES
5
6
45
55
65
75
7

TEST 20


Scale 1" = 5"
Depth of hole 0.273 ft.
Volume of hole 0.1150 cu. ft.
15
20
25
30
35
40
25
35
55
50
45
40
40
-4
-3
-2
-1
Sta. 0
1
2
L.K.

TEST DATA SHEET

TEST NO. 21

DATE June 24/64

MODEL SCALES: HORIZ. 1:100

VERT. 1:100

MATERIAL: MEDIUM MORTAR SAND THROUGH #10 SIEVE

	MODEL	PROTOTYPE
Gauge Height (ft.)	.528	
Discharge (CFS)	.505	50,500.
Depth of Flow (ft.)	.400	40.
Area (sq.ft.)	1.120	11,200.
Mean Velocity in Channel (ft/sec)	.451	4.51
Time of Run	42.5 minutes	7.07 hours
Number of Photos Taken	2	

REMARKS:

No erosion of left bank.

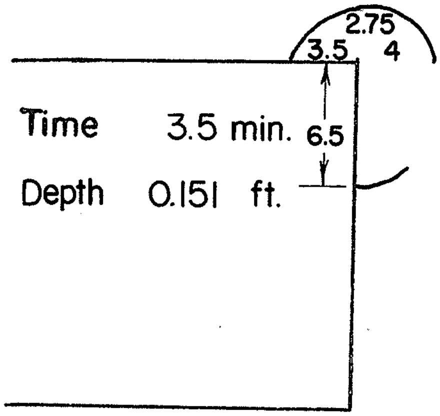
Erosion of right bank progresses at a fast rate.

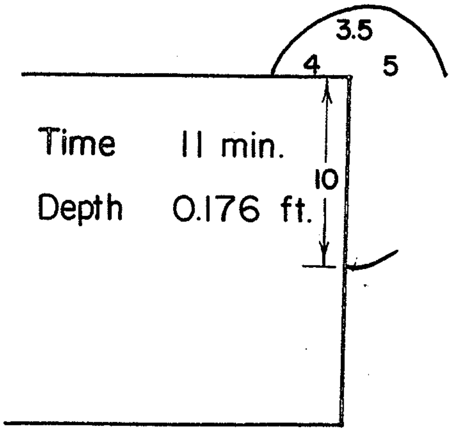
The depth of hole is not stationary at the end of the test.

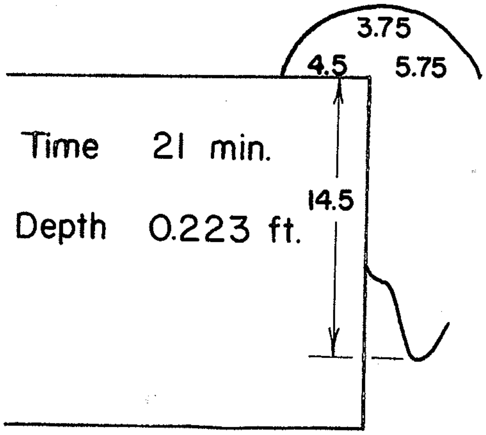
Test Performed by: lk

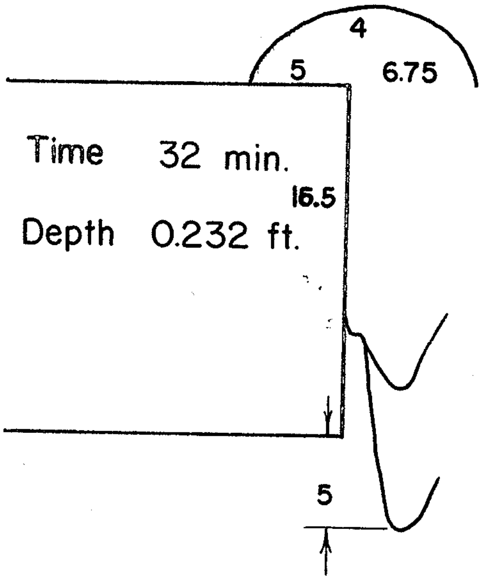
TEST 21

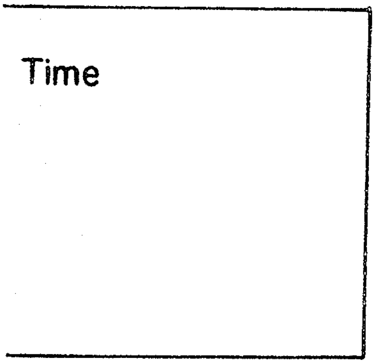
Scale: 1" = 10"

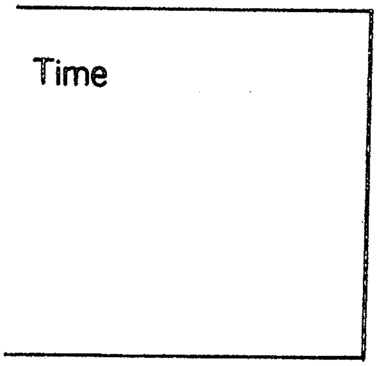






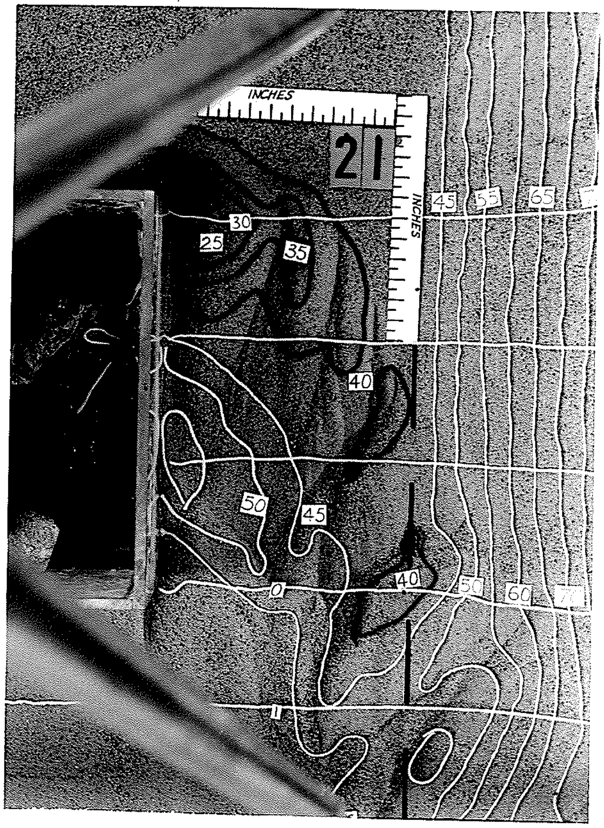




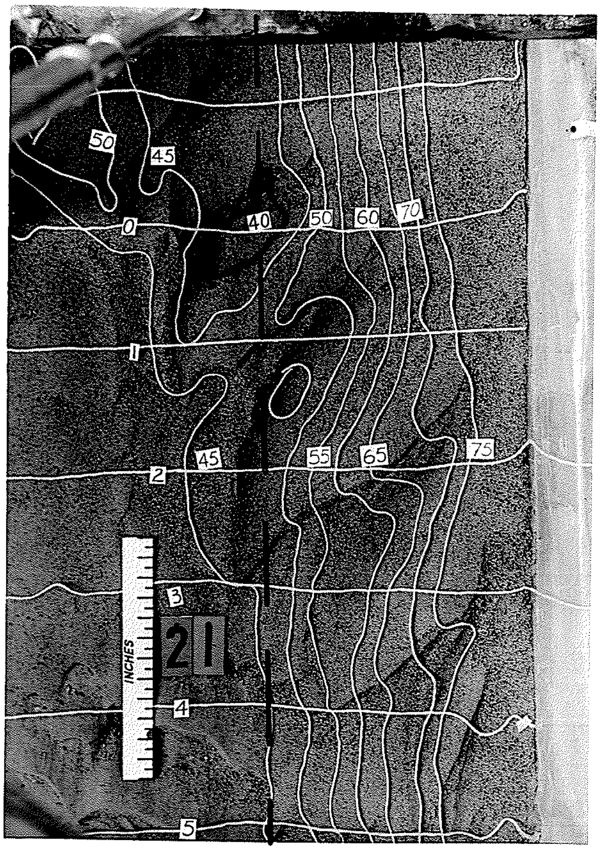


172.

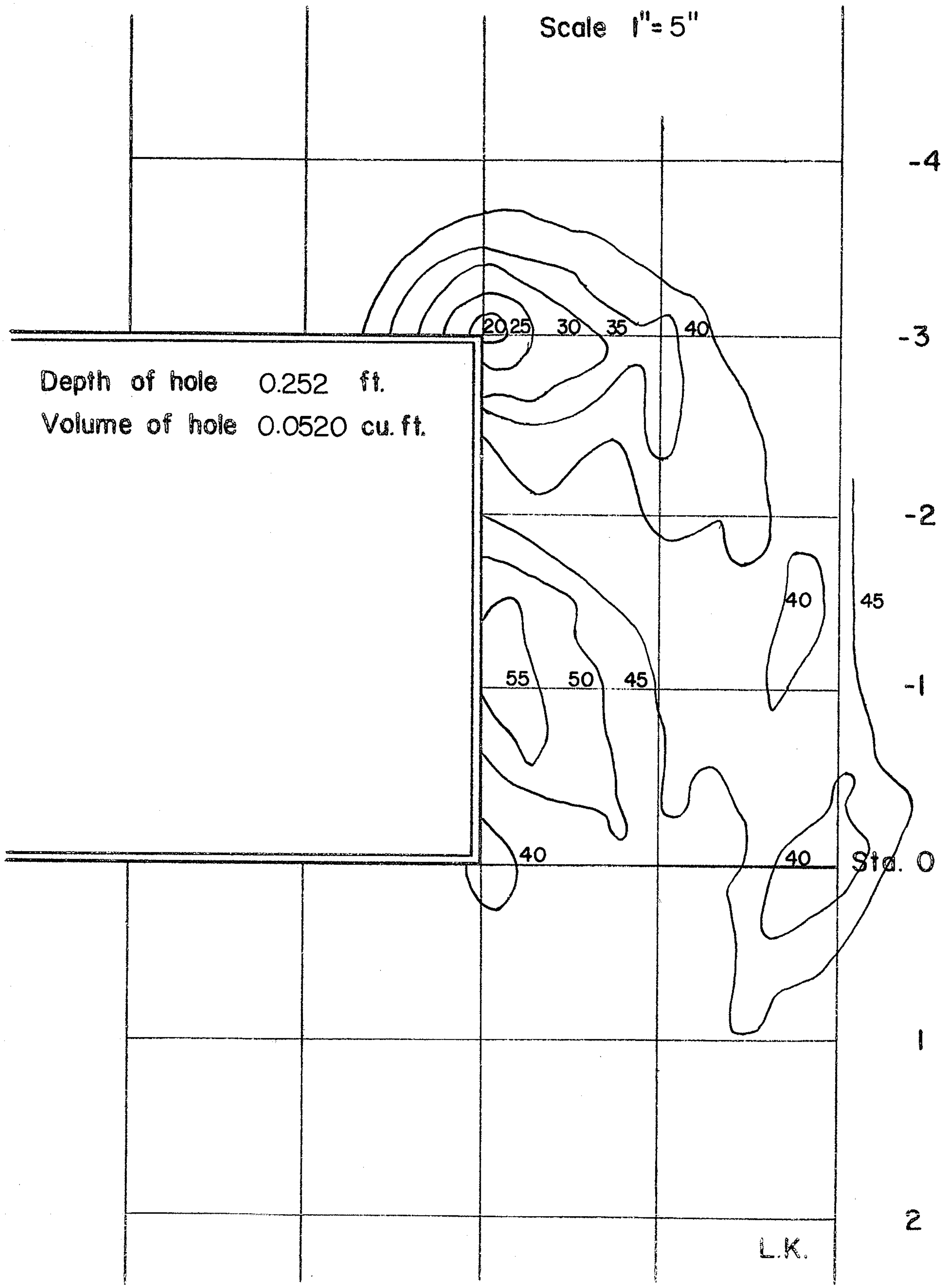
JUL · 64



JUL · 64



TEST 21


Scale 1" = 5"
-4
-3
-2
-1
Sta. 0
1
2
20
25
30
35
40
40
45
55
50
45
40
40
Depth of hole 0.252 ft.
Volume of hole 0.0520 cu. ft.
L.K.

174

TEST DATA SHEET

TEST NO. 22

DATE June 26/64

MODEL SCALES: HORIZ. 1:100

VERT. 1:100

MATERIAL: MEDIUM MORTAR SAND THROUGH #10 SIEVE

	MODEL	PROTOTYPE
Gauge Height (ft.)	.528	
Discharge (CFS)	.505	50,500.
Depth of Flow (ft.)	.400	40.
Area (sq.ft.)	1.120	11,200.
Mean Velocity in Channel (ft/sec)	.451	4.51
Time of Run	85 minutes	14.14 hours

Number of Photos Taken 2

REMARKS:

No erosion of left bank.

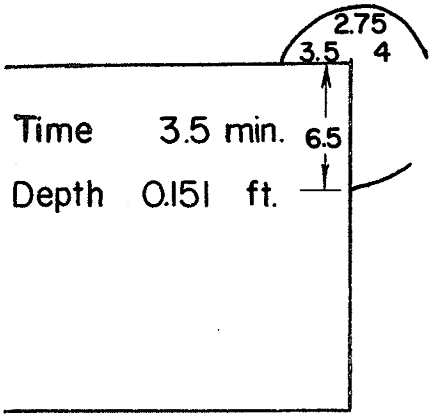
Right bank disappears after 55 minutes - Sta. 2.5.

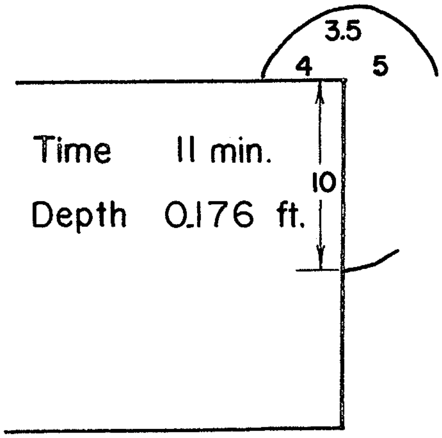
Depth of hole is stable at 55 minutes.

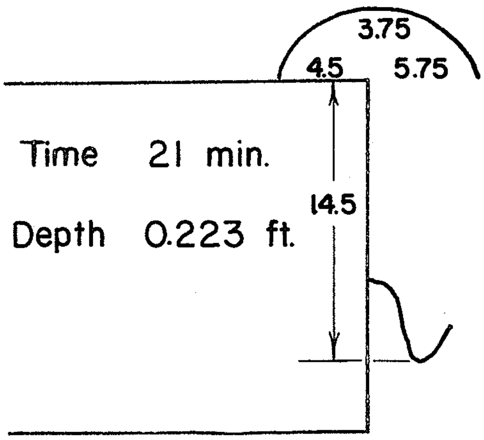
Test Performed by: lk

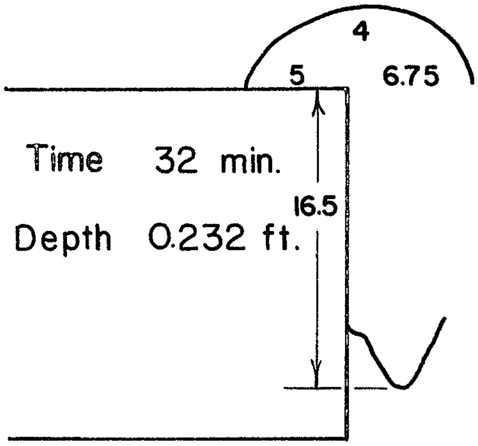
TEST 22

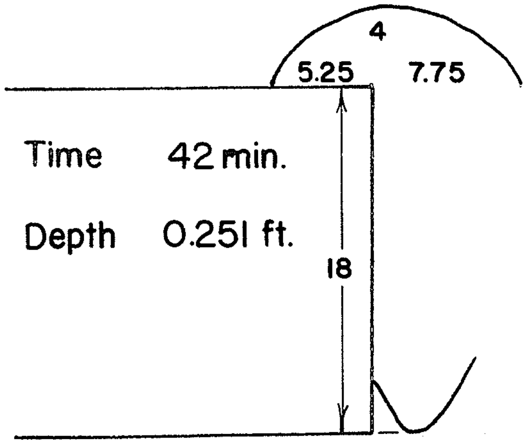
Scale: 1" = 10"

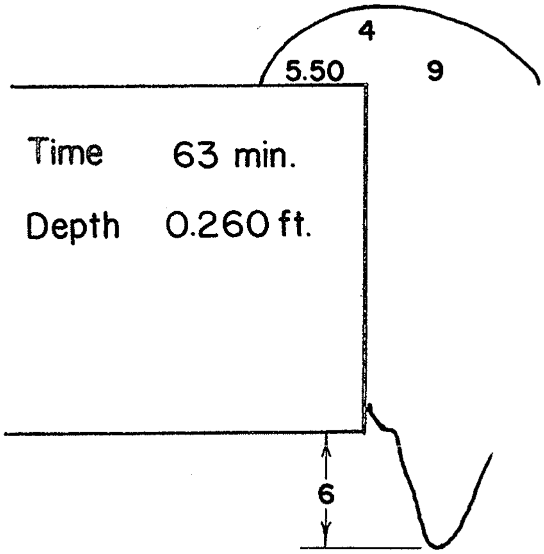




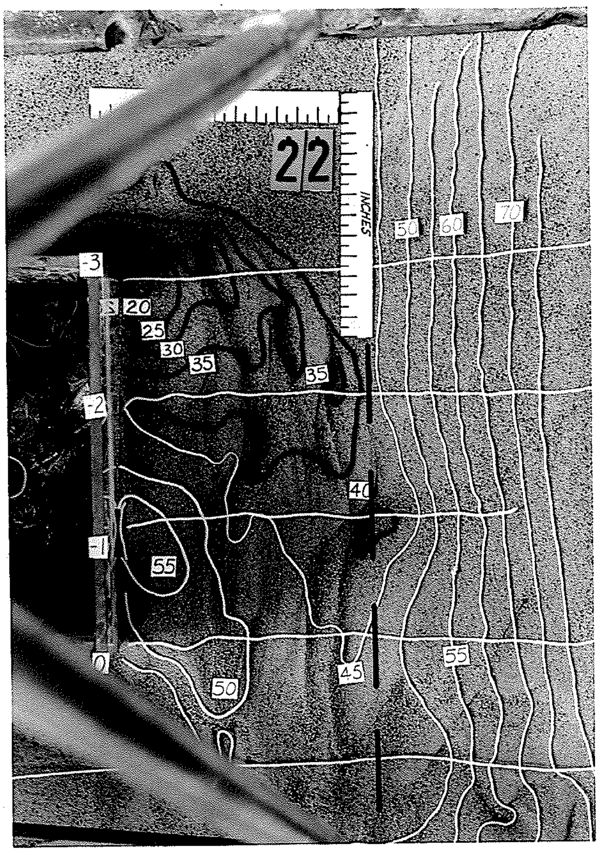




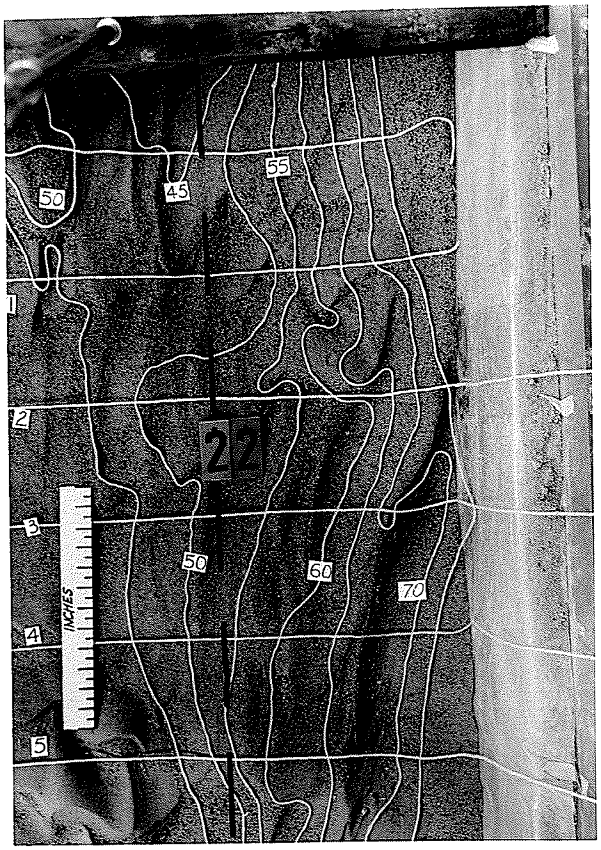




176.



JUL • 64



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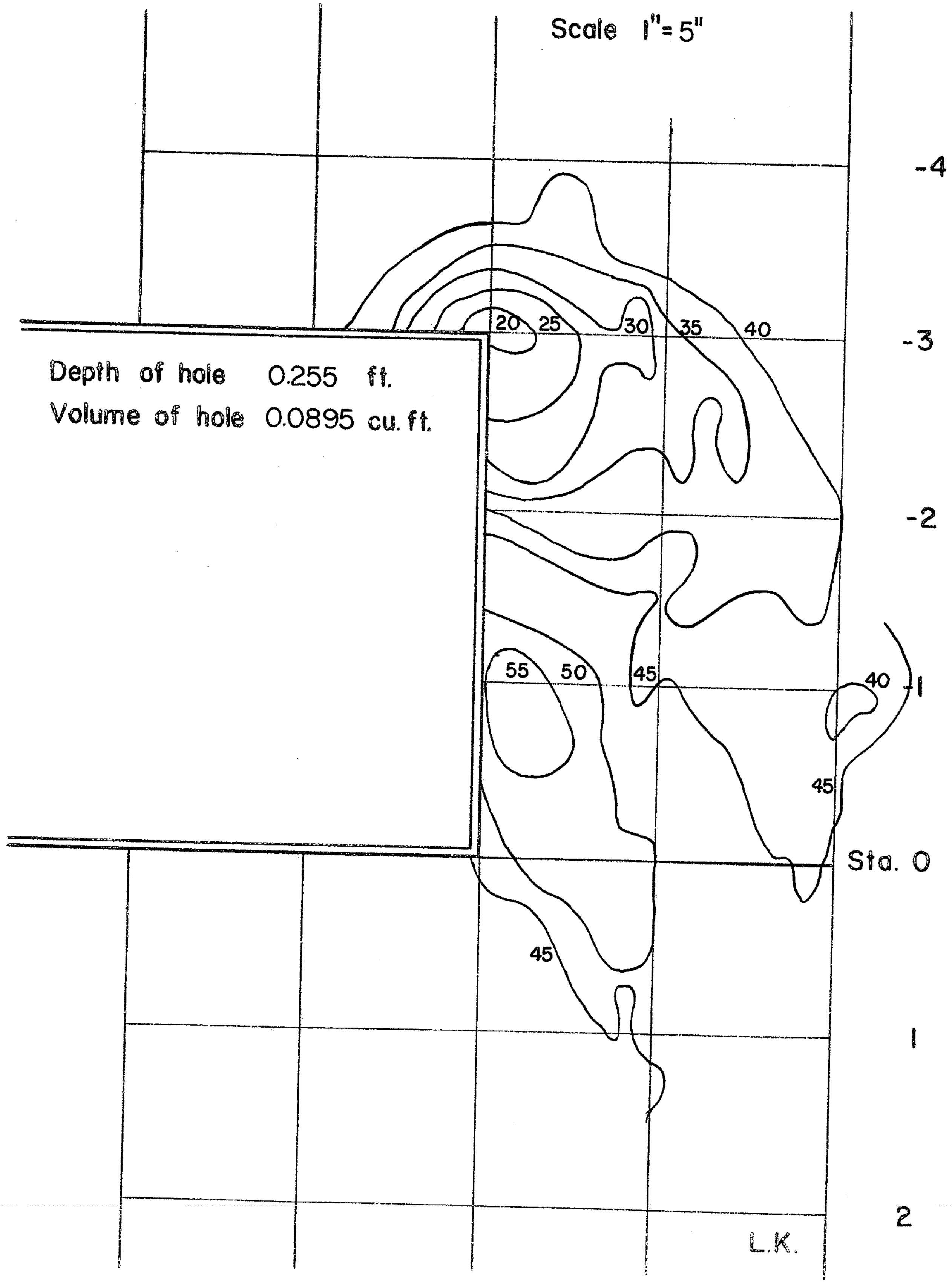
TEST 22



Depth of hole 0.255 ft.
Volume of hole 0.0895 cu. ft.

TEST DATA SHEET

TEST NO. 23

DATE July 6/64

MODEL SCALES: HORIZ. 1:100

VERT. 1:100

MATERIAL: SIEVED COARSE MORTAR SAND FROM RED RIVER FLOODWAY MODEL

	MODEL	PROTOTYPE
Gauge Height (ft.)	.568	
Discharge (CFS)	.606	50,500.
Depth of Flow (ft.)	.400	40.
Area (sq.ft.)	1.120	11,200.
Mean Velocity in Channel (ft/sec)	.542	4.51
Time of Run	42.5 minutes	7.07 hours
Number of Photos Taken	1	

REMARKS:

No erosion of left bank.

Moderate erosion of right bank from Sta. 0 to Sta.-2. Slow erosion from Sta. 0 on.

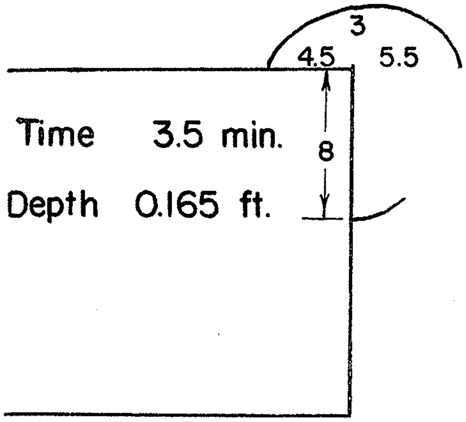
Final depth of hole reached in 30 minutes.

There is no significant change in side slopes to warrant laying contours on the sides.

Test Performed by: 1k

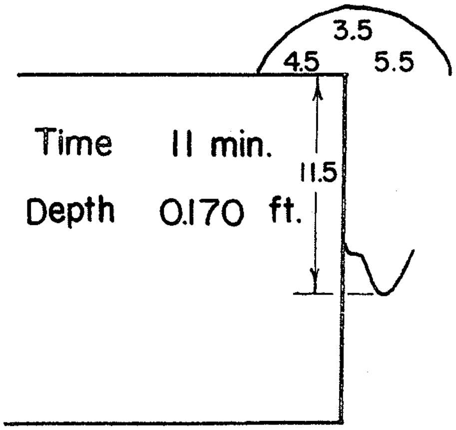
TEST 23

Scale: 1" = 10"



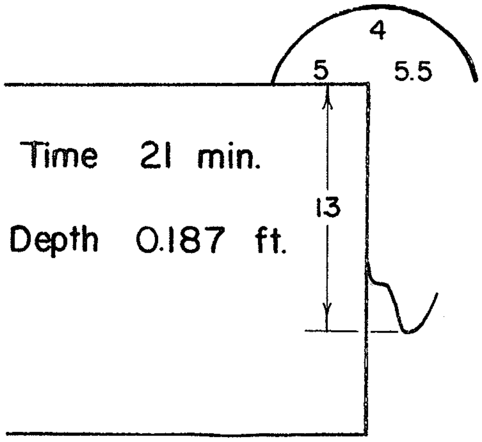
Time 3.5 min.

Depth 0.165 ft.



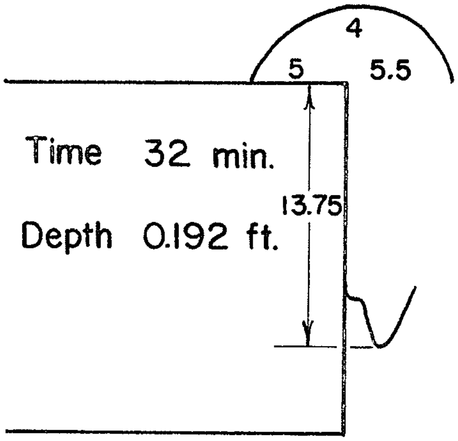
Time 11 min.

Depth 0.170 ft.



Time 21 min.

Depth 0.187 ft.



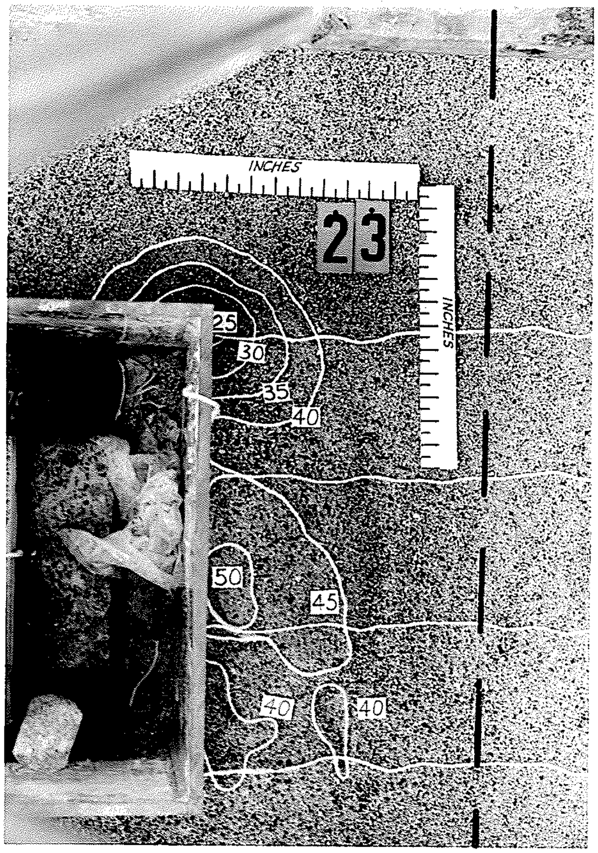
Time 32 min.

Depth 0.192 ft.

Time

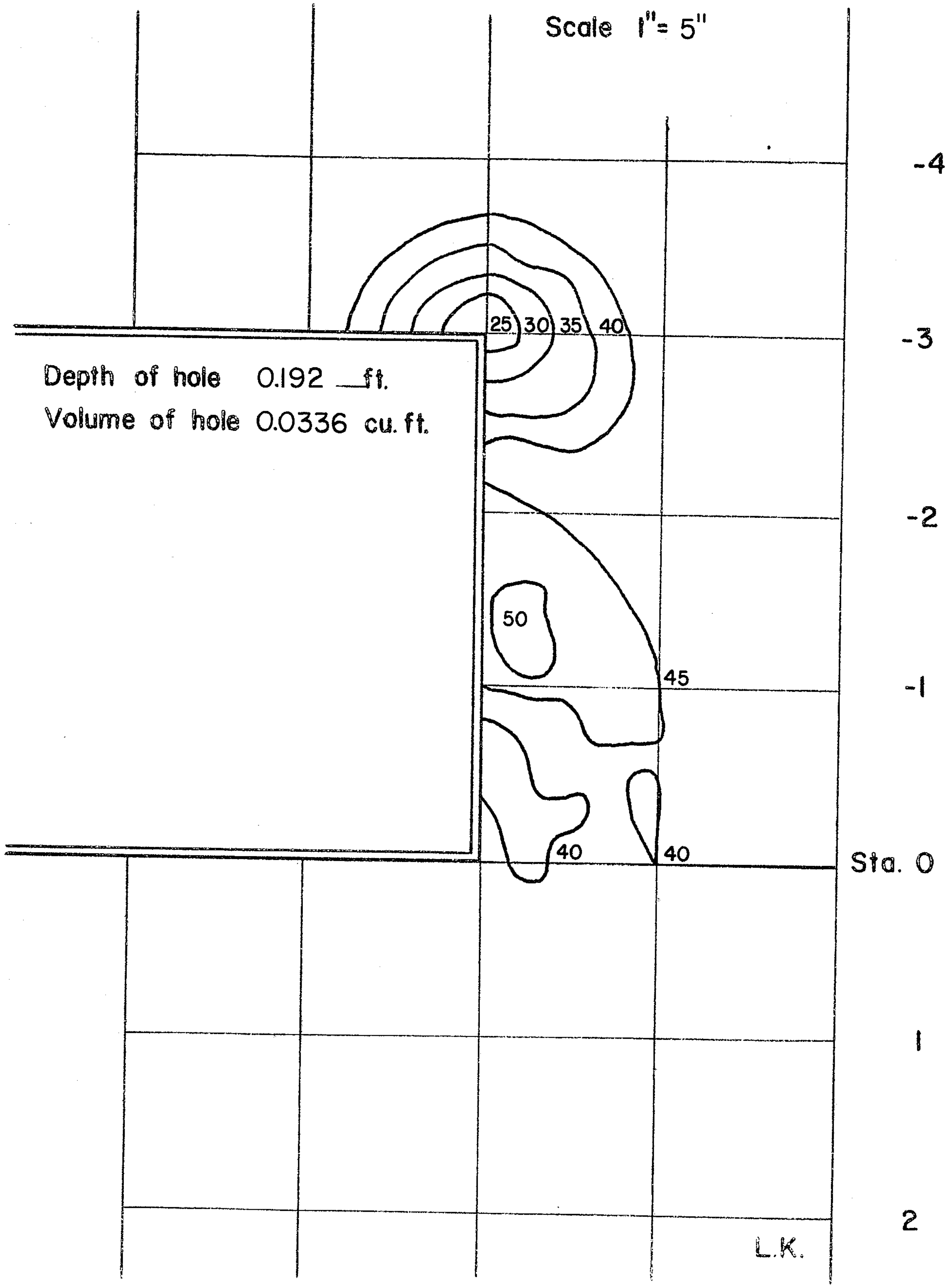
Time

180.



JUL • 64

TEST 23



Depth of hole 0.192 ft.

Volume of hole 0.0336 cu. ft.

TEST DATA SHEET

TEST NO. 24

DATE July 7/64

MODEL SCALES: HORIZ. 1:100

VERT. 1:100

MATERIAL: SIEVED CORASE MORTAR SAND FROM RED RIVER FLOODWAY MODEL

	MODEL	PROTOTYPE
Gauge Height (ft.)	0.604	
Discharge (CFS)	0.707	50,500.
Depth of Flow (ft.)	0.400	40.
Area (sq.ft.)	1.120	11,200.
Mean Velocity in Channel (ft/sec)	0.631	4.51
Time of Run	42.5 minutes	7.07 hours

Number of Photos Taken 2

REMARKS:

No erosion of left bank.

Rapid erosion of right bank between Sta.(-3) to (+4).

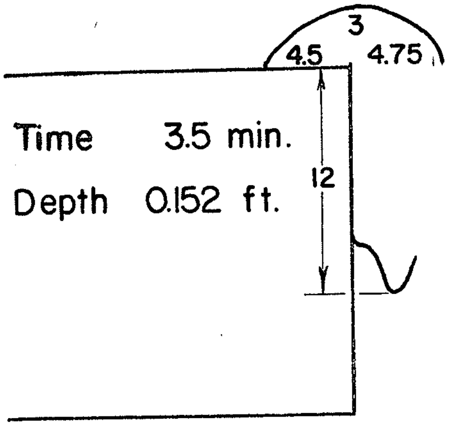
Right bank disappears at Sta.(+2) at 40 minutes.

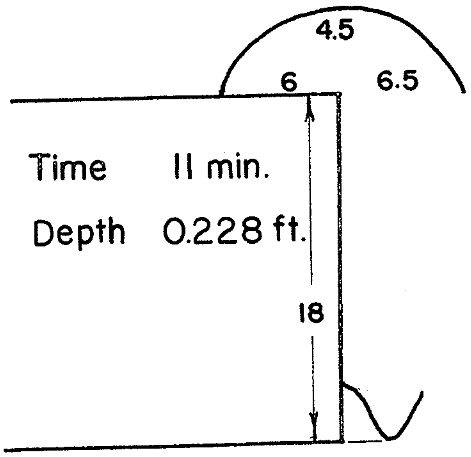
The hole reaches full depth in 30 minutes.

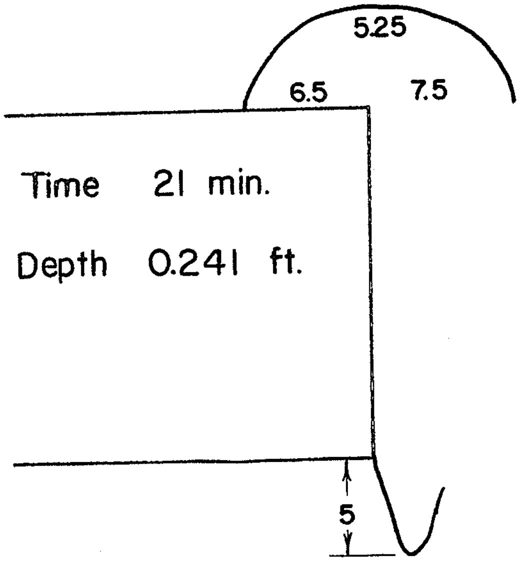
Test Performed by: lk

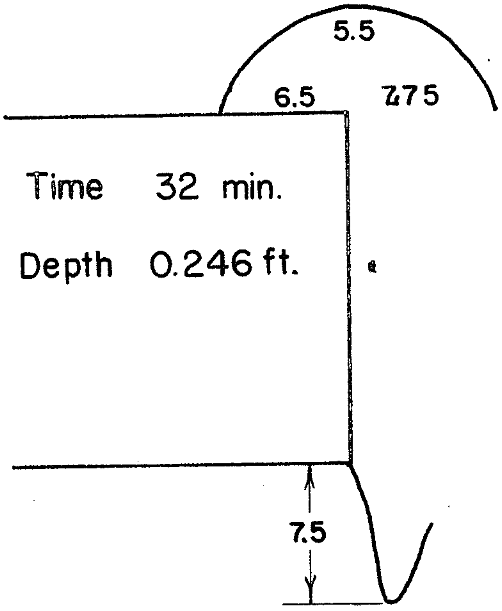
TEST 24

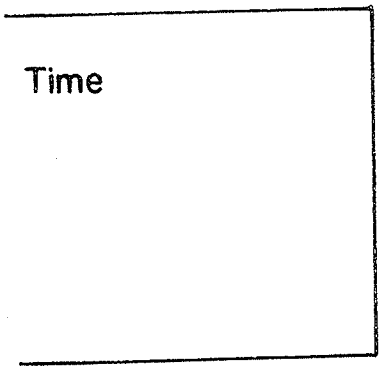
Scale: 1" = 10"

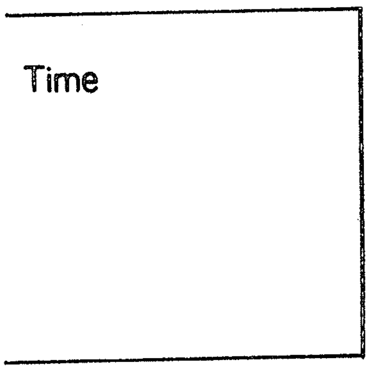


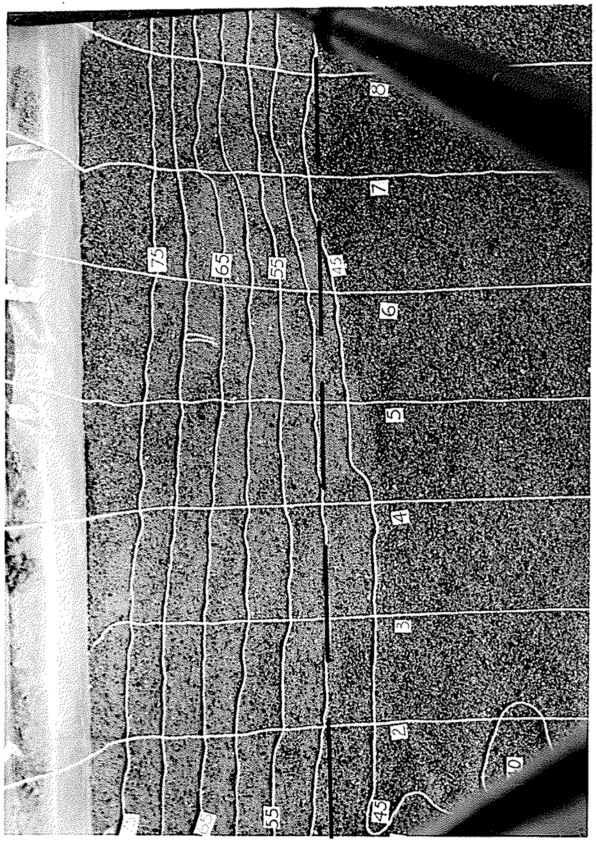




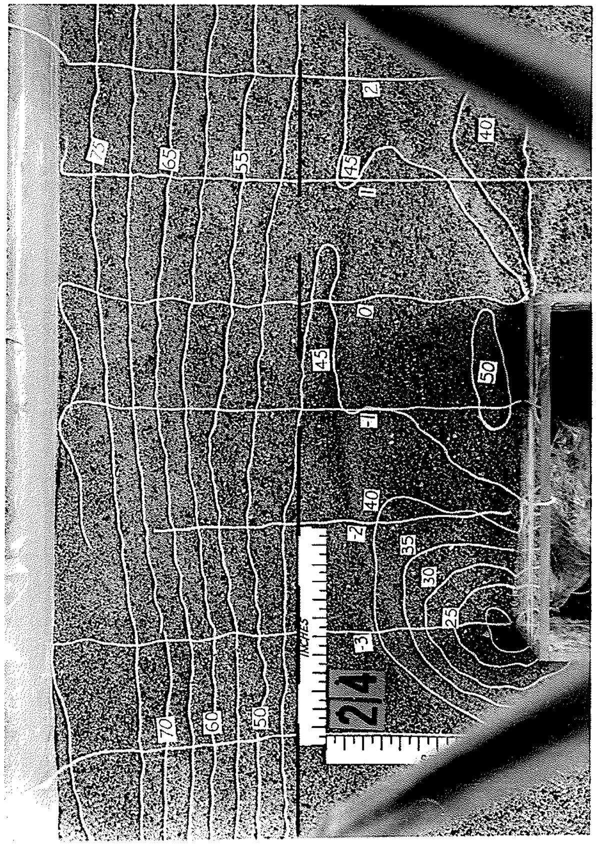






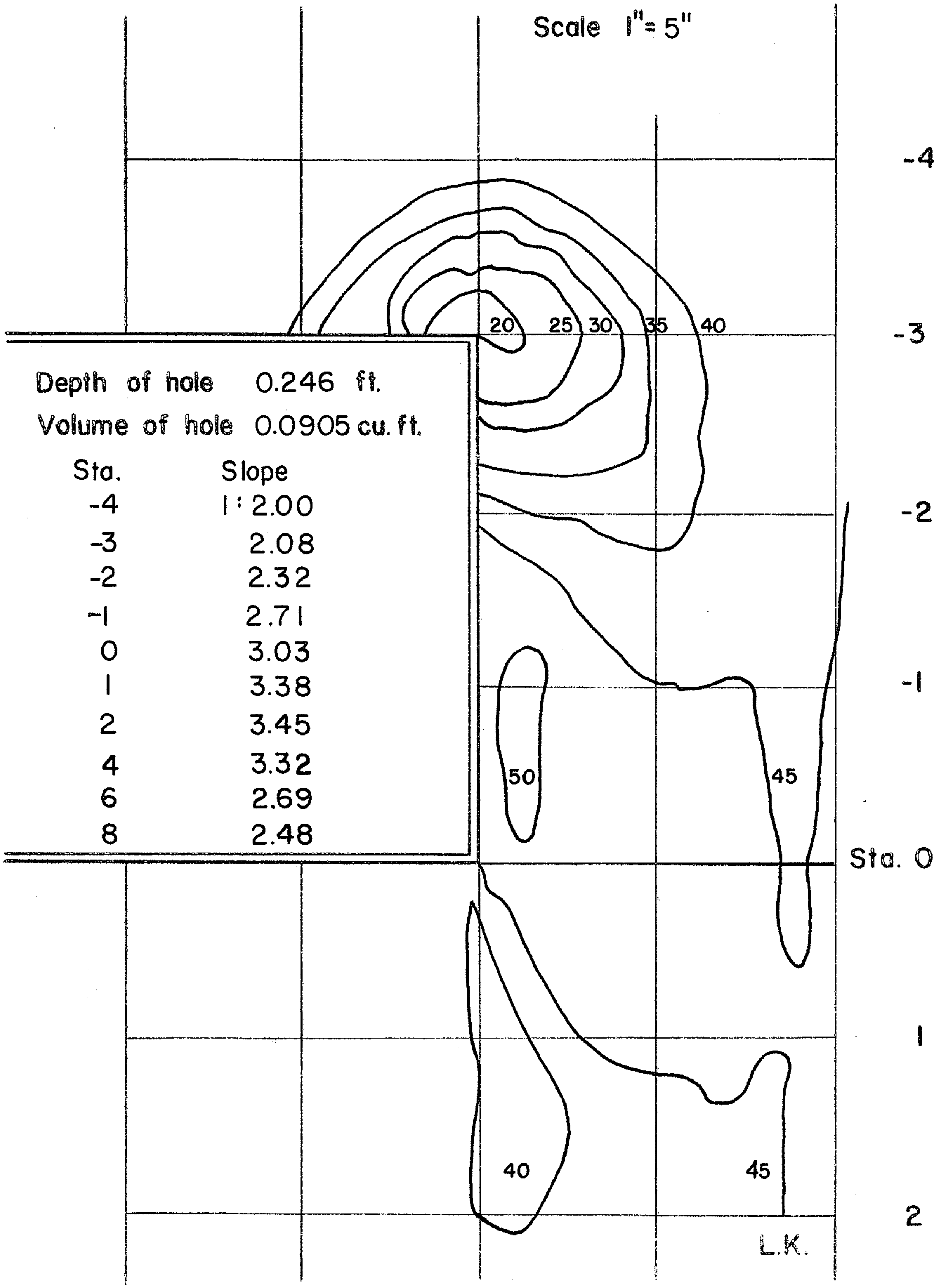

75
65
55
45
8
7
6
5
4
3
2
0
55
45

JUL • 64


75
65
55
45
2
40
1
0
45
50
-1
40
-2
35
30
25
-3
INCHES
24
70
60
50

JUL • 64

TEST 24



Depth of hole 0.246 ft.

Volume of hole 0.0905 cu. ft.

Sta.	Slope
-4	1 : 2.00
-3	2.08
-2	2.32
-1	2.71
0	3.03
1	3.38
2	3.45
4	3.32
6	2.69
8	2.48

TEST DATA SHEET

TEST NO. 25

DATE July 7/64

MODEL SCALES: HORIZ. 1:100

VERT. 1:100

MATERIAL: SIEVED COARSE

	MODEL	PROTOTYPE
Gauge Height (ft.)	0.595	
Discharge (CFS)	0.657	50,500.
Depth of Flow (ft.)	0.400	40.
Area (sq.ft.)	1.120	11,200.
Mean Velocity in Channel (ft/sec)	0.587	4.51
Time of Run	42.5 minutes	7.07 hours
Number of Photos Taken	1	

REMARKS:

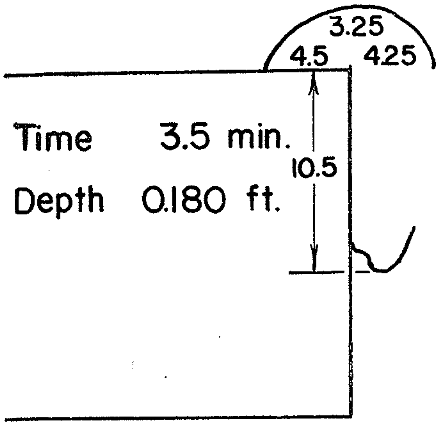
No erosion of left bank.

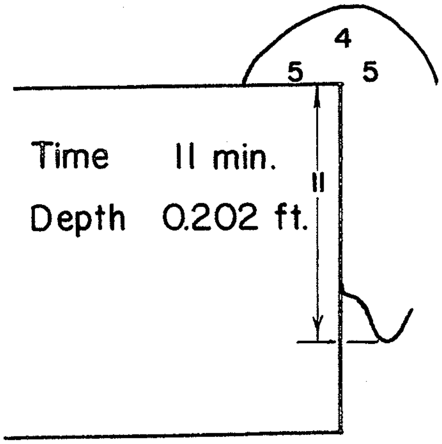
No erosion of right bank.

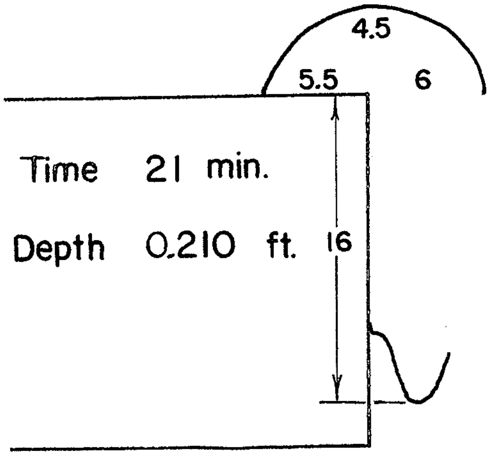
Hole reaches full depth in 20 minutes.

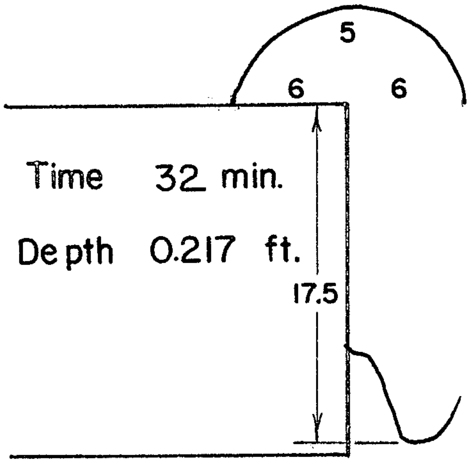
Test Performed by: lk

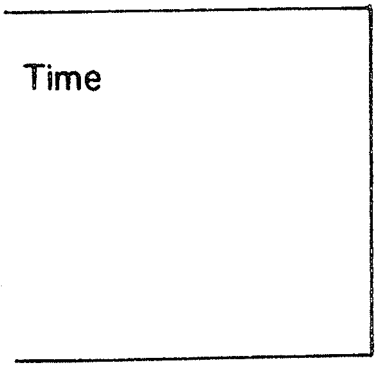
Scale: 1" = 10"

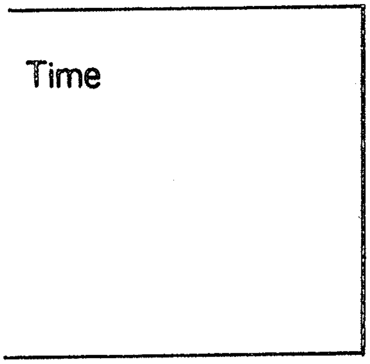

3.25
4.5
4.25
Time 3.5 min.
Depth 0.180 ft.
10.5


4
5
5
Time 11 min.
Depth 0.202 ft.
11

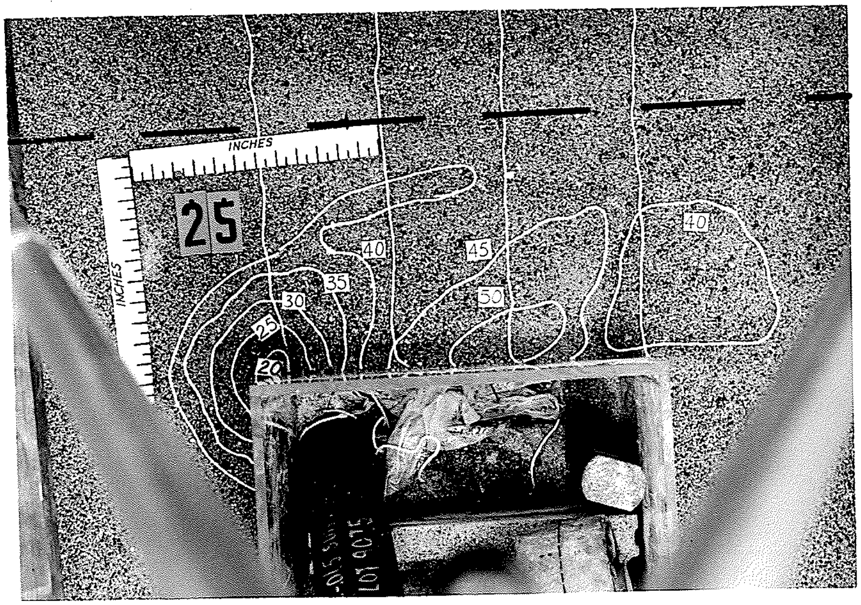

4.5
5.5
6
Time 21 min.
Depth 0.210 ft.
16


5
6
6
Time 32 min.
Depth 0.217 ft.
17.5

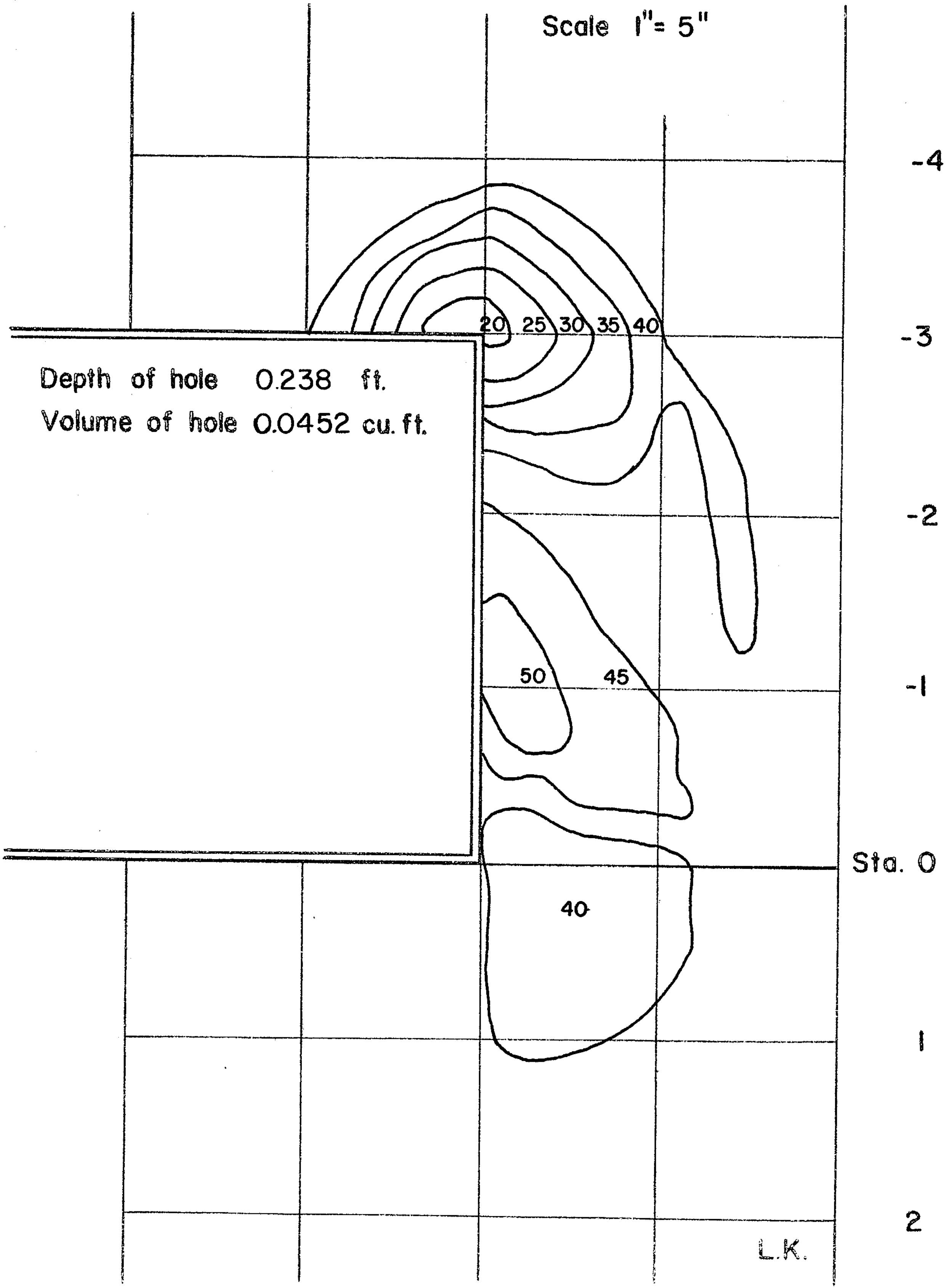

Time


Time

JUL • 64



TEST 25


Scale 1" = 5"
Depth of hole 0.238 ft.
Volume of hole 0.0452 cu. ft.
20
25
30
35
40
50
45
40
-4
-3
-2
-1
Sta. 0
1
2
L.K.

TEST DATA SHEET

TEST NO. 26

DATE July 8/64

MODEL SCALES: HORIZ. 1:100

VERT. 1:100

MATERIAL: SIEVED COARSE

	MODEL	PROTOTYPE
Gauge Height (ft.)	0.586	
Discharge (CFS)	0.682	50,500.
Depth of Flow (ft.)	0.400	40.
Area (sq.ft.)	1.120	11,200.
Mean Velocity in Channel (ft/sec)	0.609	4.51
Time of Run	42.4 minutes	7.07 hours

Number of Photos Taken 2

REMARKS:

No erosion of left bank.

Rapid erosion of right bank.

Hole reaches full depth in 20 minutes.

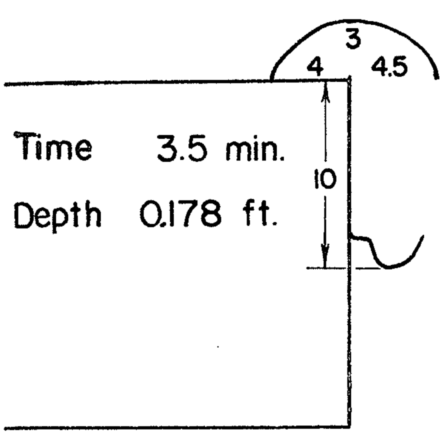
A distortion of 35% is not quite enough while 40% is considerably too great.

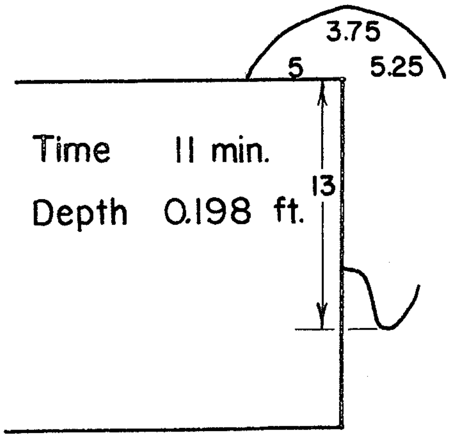
Proper side slope erosion is estimated to occur at 37%.

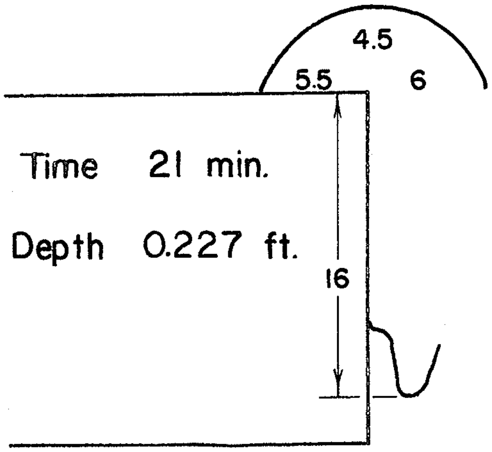
Discharge distortion.

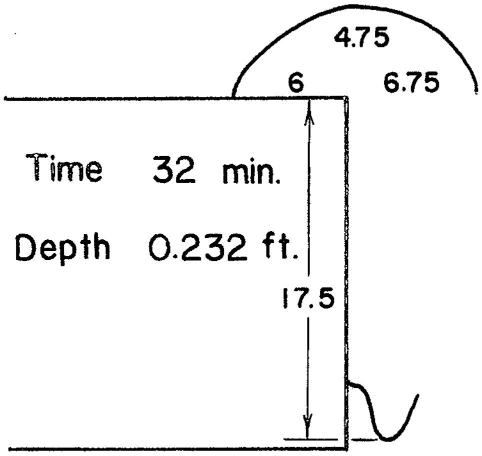
Test Performed by: lk

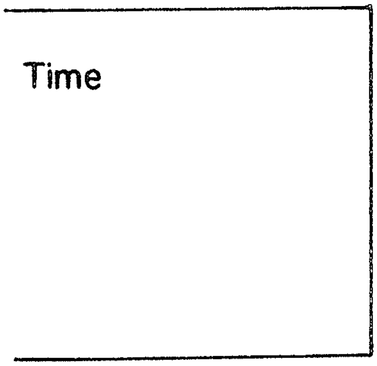
Scale: 1" = 10"

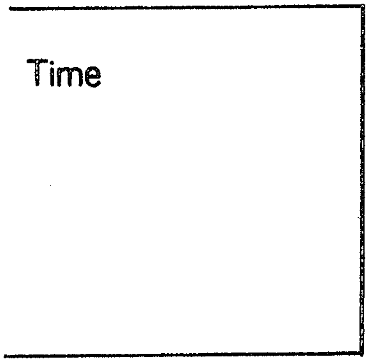

3
4
4.5
Time 3.5 min.
Depth 0.178 ft.
10


3.75
5
5.25
Time 11 min.
Depth 0.198 ft.
13


4.5
5.5
6
Time 21 min.
Depth 0.227 ft.
16

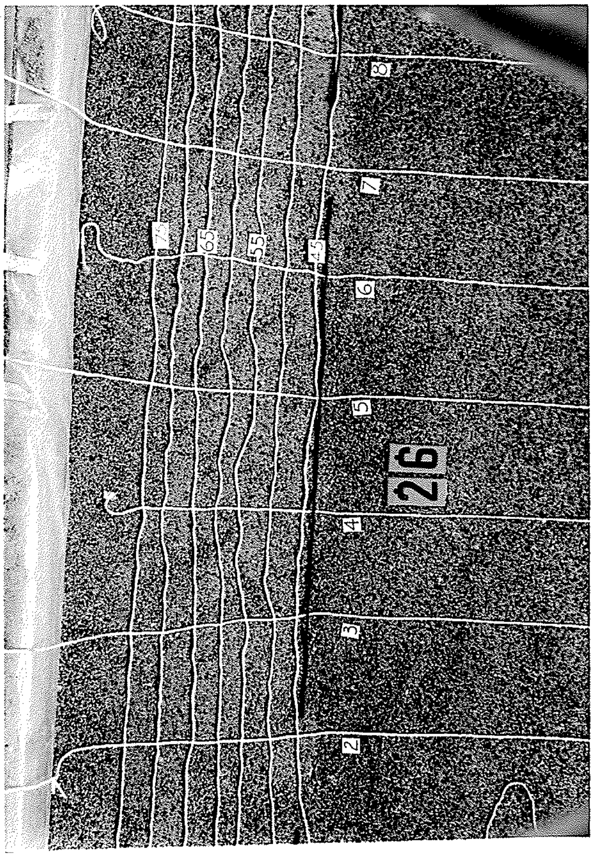

4.75
6
6.75
Time 32 min.
Depth 0.232 ft.
17.5


Time

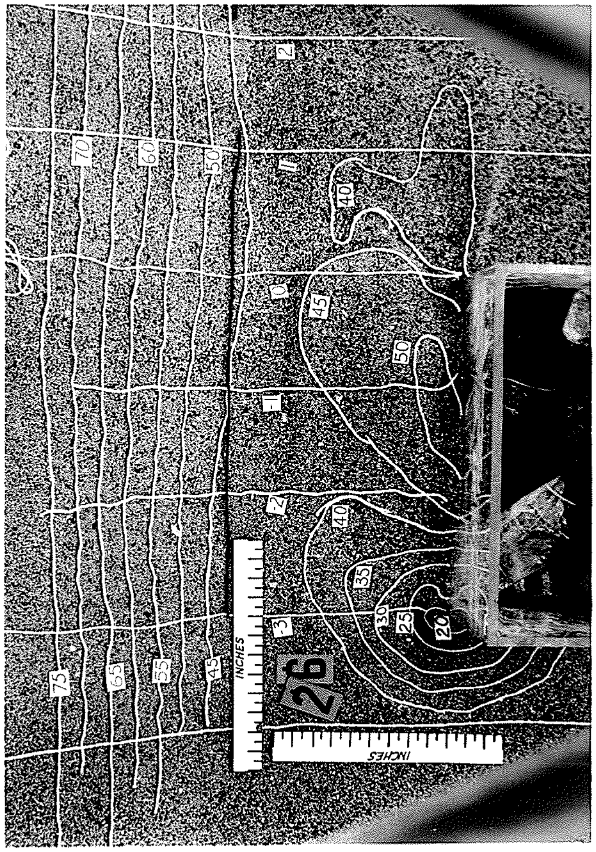

Time

192.

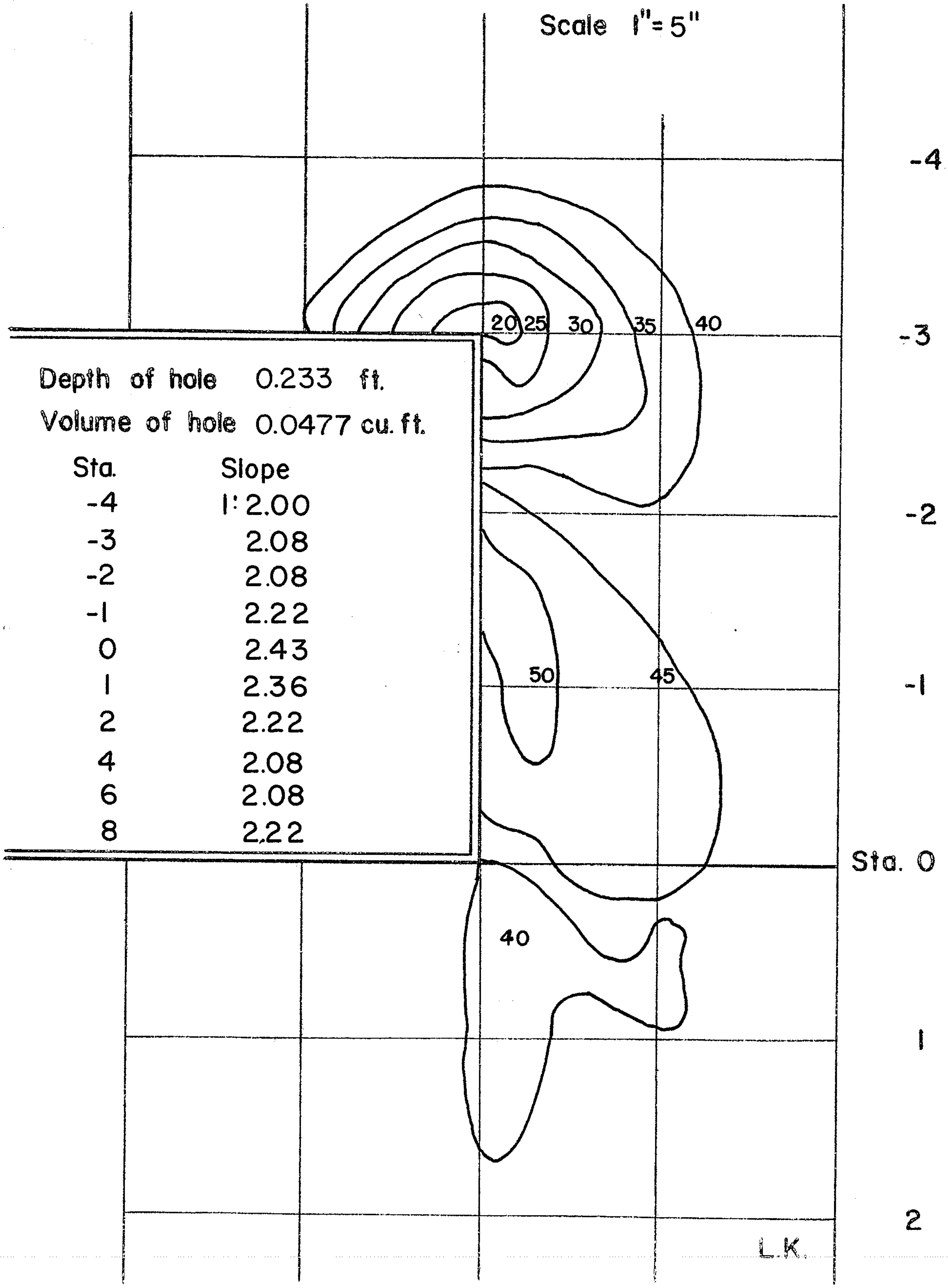
JUL • 64



JUL • 64



TEST 26



Depth of hole 0.233 ft.

Volume of hole 0.0477 cu. ft.

Sta.	Slope
-4	1:2.00
-3	2.08
-2	2.08
-1	2.22
0	2.43
1	2.36
2	2.22
4	2.08
6	2.08
8	2.22

TEST DATA SHEET

TEST NO. 27

DATE July 8/64

MODEL SCALES: HORIZ. 1:100

VERT. 1:100

MATERIAL: SIEVED COARSE

	MODEL	PROTOTYPE
Gauge Height (ft.)	0.586	
Discharge (CFS)	0.682	50,500.
Depth of Flow (ft.)	0.400	40.
Area (sq.ft.)	1.120	11,200.
Mean Velocity in Channel (ft/sec)	0.609	4.51
Time of Run	84.8 minutes	14.14 hours
Number of Photos Taken		2

REMARKS:

No erosion of left bank.

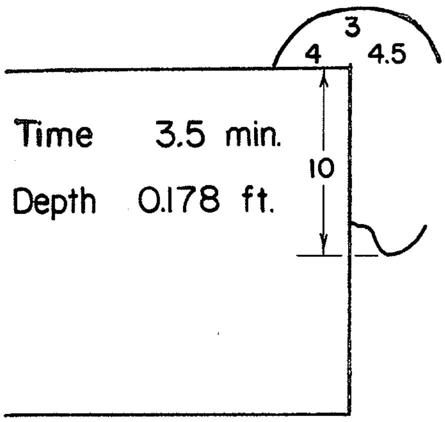
Rapid erosion of right bank throughout.

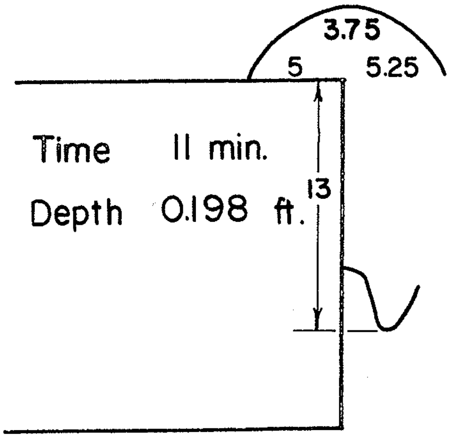
Hole reaches full depth in 20 minutes.

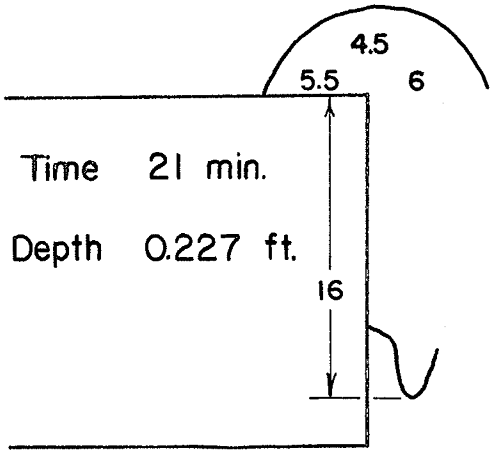
Test Performed by: lk

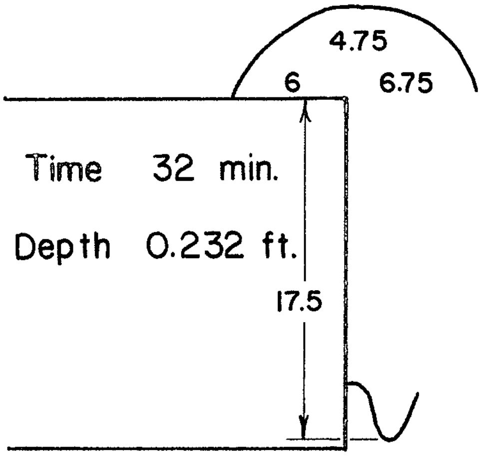
TEST 27

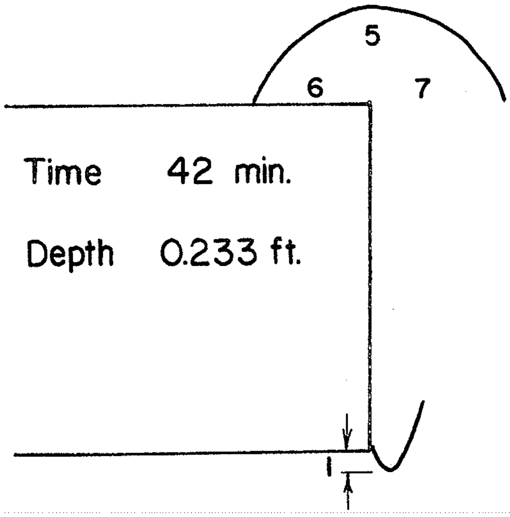
Scale: 1" = 10"

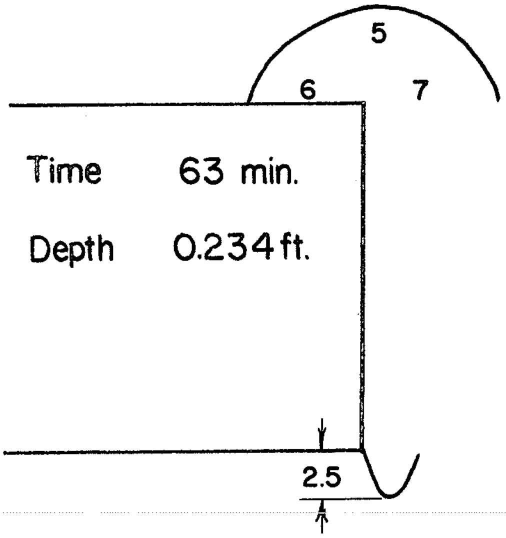




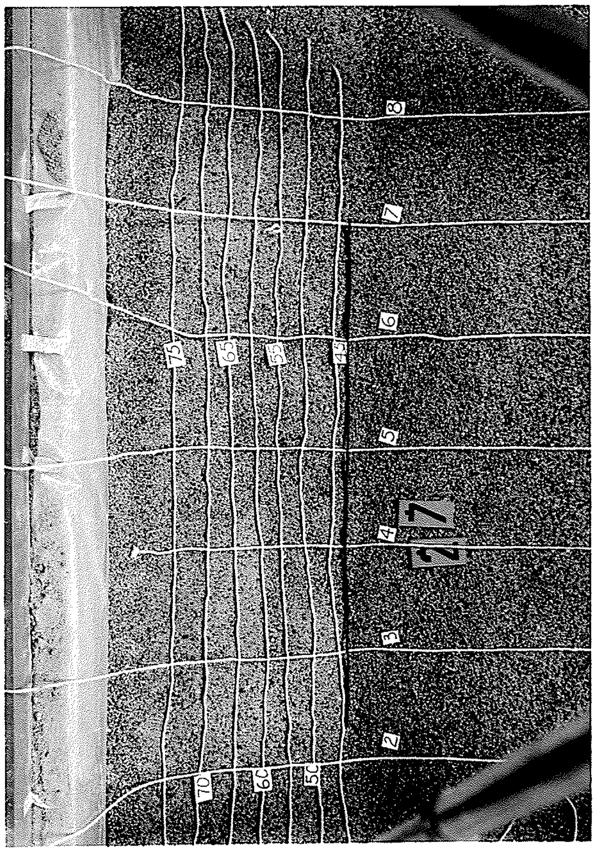




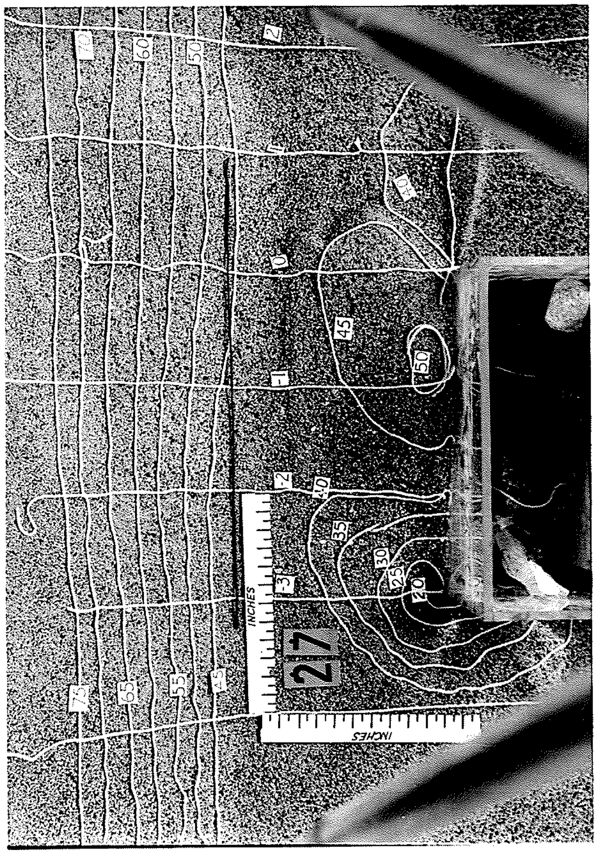




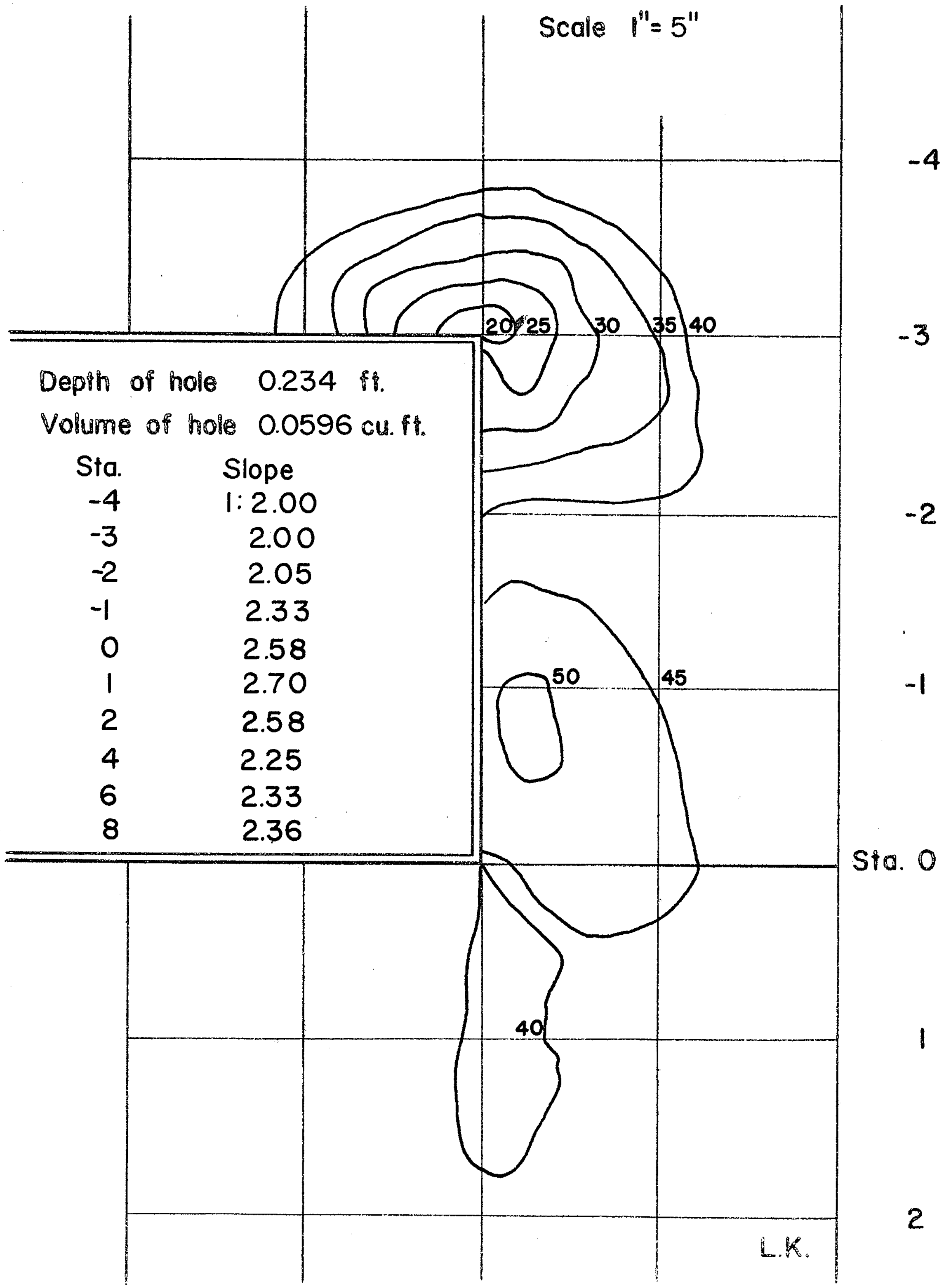
JUL • 64


75
65
55
45
70
60
50
2
3
4
5
6
7
8
27

JUL • 64


70
60
50
2
75
65
55
45
27
INCHES
INCHES
1
2
3
0
45
50
40
35
30
25
20

TEST 27



Depth of hole 0.234 ft.

Volume of hole 0.0596 cu. ft.

Sta.	Slope
-4	1: 2.00
-3	2.00
-2	2.05
-1	2.33
0	2.58
1	2.70
2	2.58
4	2.25
6	2.33
8	2.36

TEST DATA SHEET

TEST NO. 28 (A)

DATE July 9/68

MODEL SCALES: HORIZ. 1:100

VERT. 1:79.3

MATERIAL: SIEVED COARSE MORTAR SAND FROM RED RIVER FLOODWAY MODEL

	MODEL	PROTOTYPE
Gauge Height (ft.)	0.606	
Discharge (CFS)	0.715	50,500.
Depth of Flow (ft.)	0.505	40.
Area (sq.ft.)	1.505	11,200.
Mean Velocity in Channel (ft/sec)	.475	4.51
Time of Run	47.6 minutes	7.07 hours

Number of Photos Taken 2

REMARKS:

No erosion of left bank.

Moderate erosion of right bank from Sta. -2.5 and downstream.

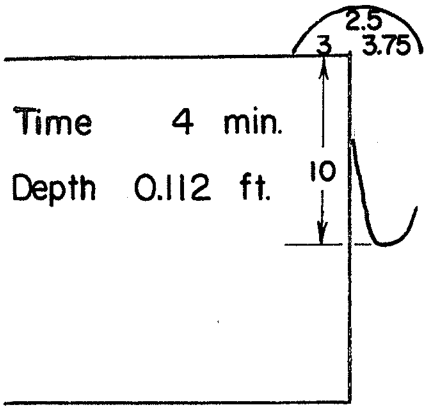
Main erosion of the banks occurs between Sta. (-1.5) to (-2).

The hole is very shallow and reaches full depth in 25 minutes.

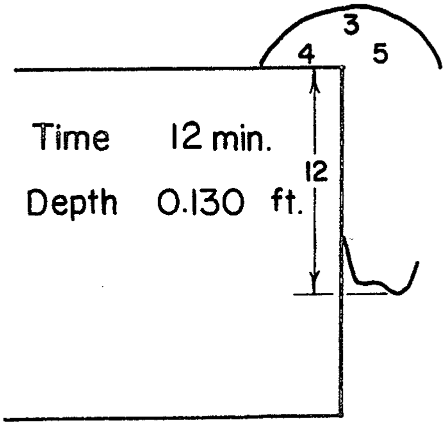
Test Performed by: lk

TEST 28

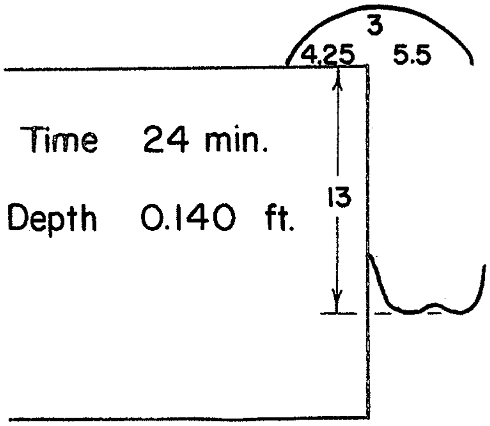
Scale: 1" = 10"



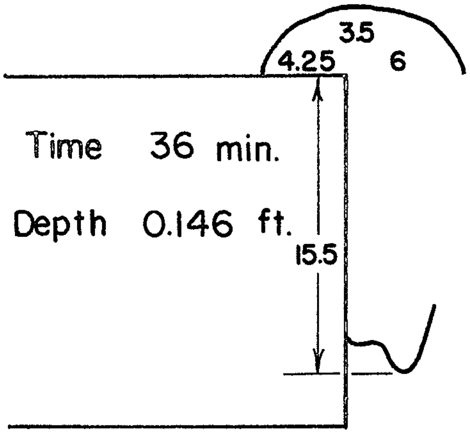
Time 4 min.
Depth 0.112 ft.



Time 12 min.
Depth 0.130 ft.



Time 24 min.
Depth 0.140 ft.

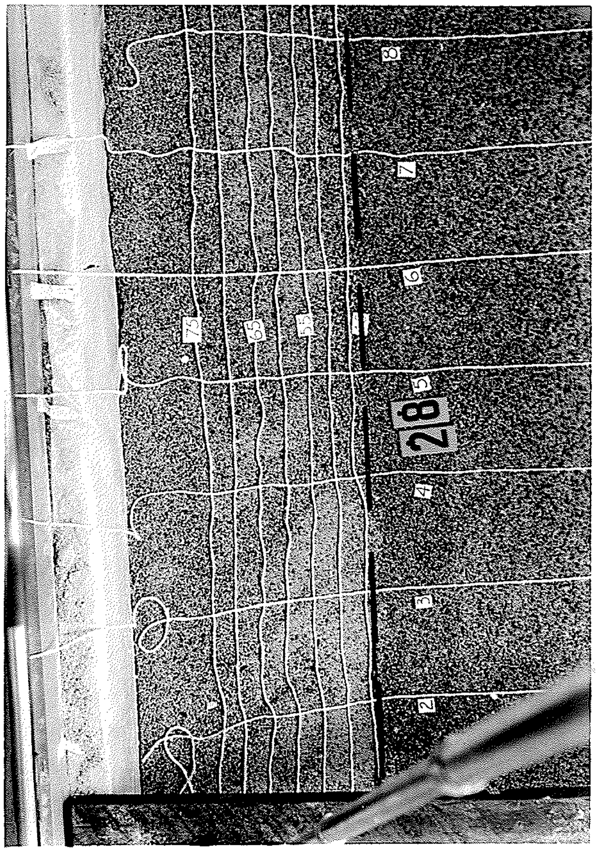


Time 36 min.
Depth 0.146 ft.

Time

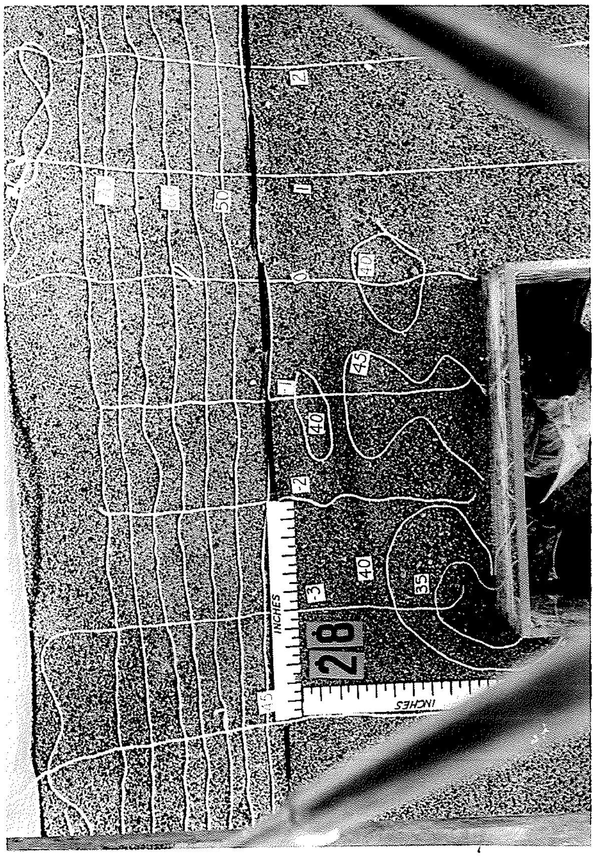
Time

JUL • 64

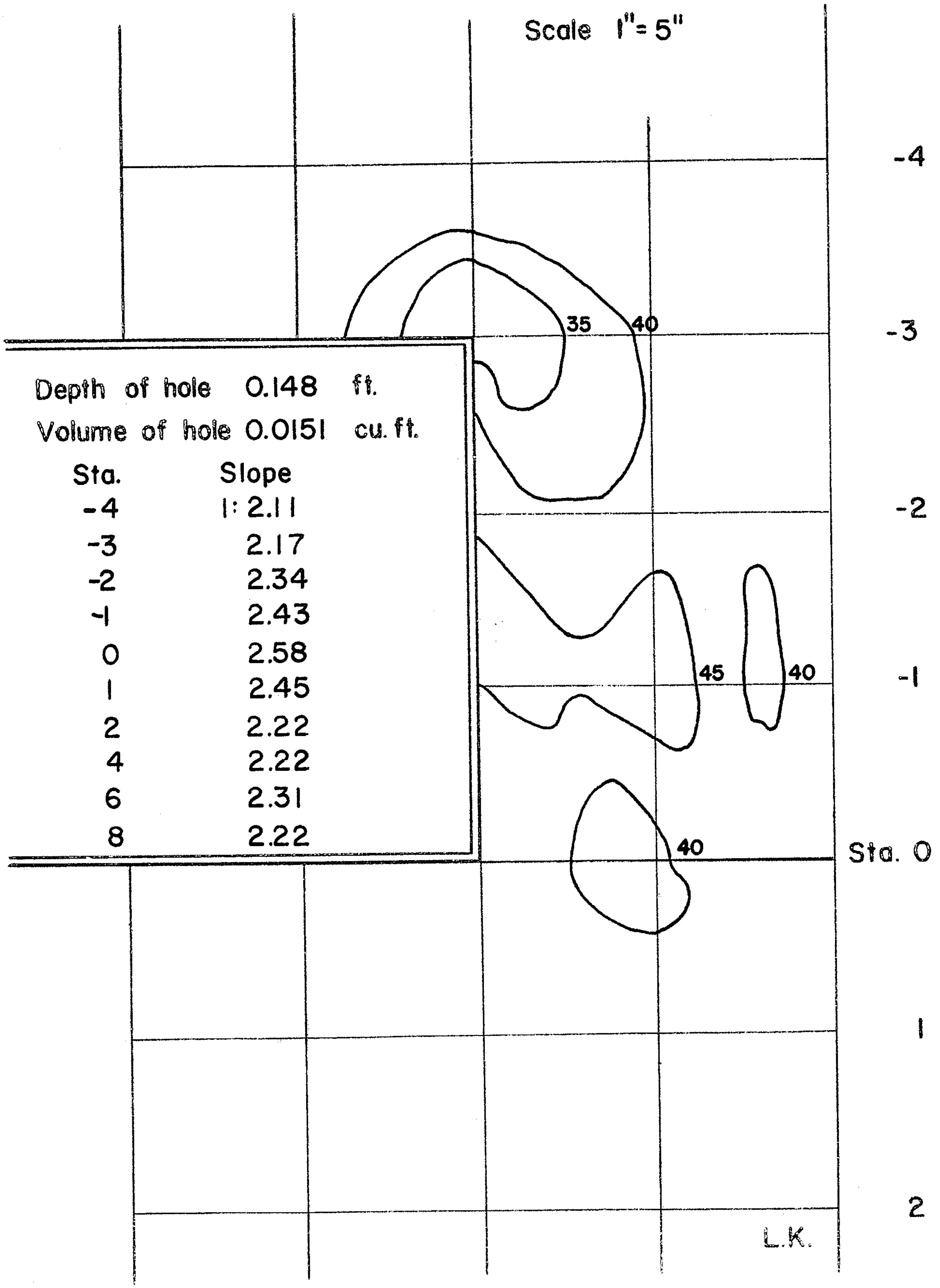


TEST 28(A)

JUL • 64



TEST 28 (A)



Depth of hole 0.148 ft.

Volume of hole 0.0151 cu. ft.

Sta.	Slope
-4	1: 2.11
-3	2.17
-2	2.34
-1	2.43
0	2.58
1	2.45
2	2.22
4	2.22
6	2.31
8	2.22

TEST DATA SHEET

TEST NO. 28(B)

DATE July 12/64

MODEL SCALES: HORIZ. 1:100

VERT. 1:50

MATERIAL: SIEVED COARSE MORTAR SAND FROM RED RIVER FLOODWAY MODEL

	MODEL	PROTOTYPE
Gauge Height (ft.)	0.800	
Discharge (CFS)	1.430	50,500.
Depth of Flow (ft.)	0.800	40.
Area (sq.ft.)	2.240	11,200.
Mean Velocity in Channel (ft/sec)	0.639	4.51
Time of Run		

Number of Photos Taken 1

REMARKS:

The banks would not hold up at side slopes of 1:1 (vertical distortion 2:1). Thus the test was discontinued.

Test Performed by:

JUL • 64

TEST 28 (B)

TEST DATA SHEET

TEST NO. 29

DATE July 13/64

MODEL SCALES: HORIZ.1 1:100

VERT. 1:100

MATERIAL: MEDIUM MORTAR SAND

	MODEL	PROTOTYPE
Gauge Height (ft.)	0.557	
Discharge (CFS)	0.586	50,500.
Depth of Flow (ft.)	0.400	40.
Area (sq.ft.)	1.120	11,200.
Mean Velocity in Channel (ft/sec)	0.524	4.51
Time of Run	42.5 minutes	7.07 hours

Number of Photos Taken 2

REMARKS:

No erosion of left bank.

Constant moderate erosion of right bank.

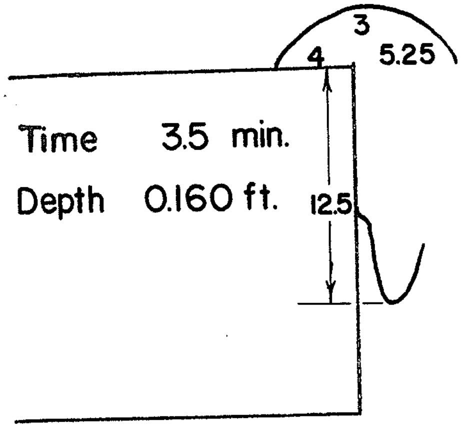
Considerable paring occurs.

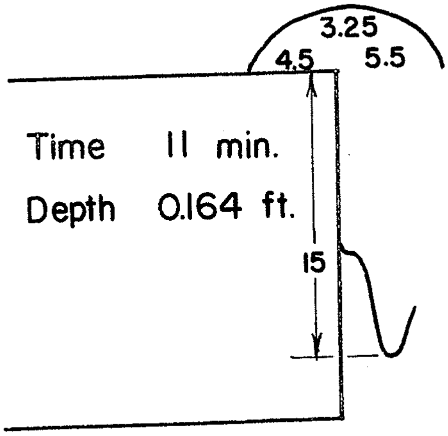
Hole reaches full depth in 25 minutes.

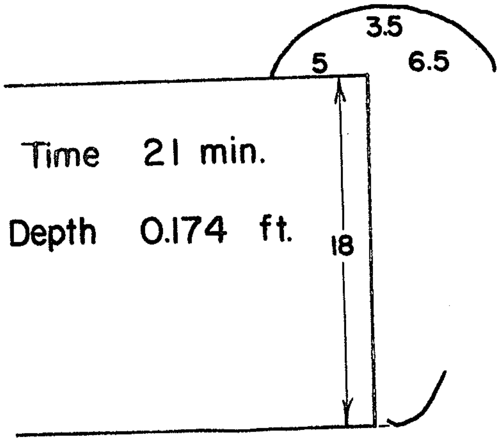
Test Performed by: lk

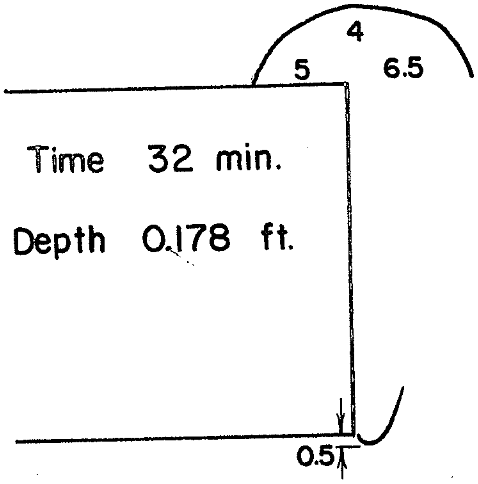
TEST 29

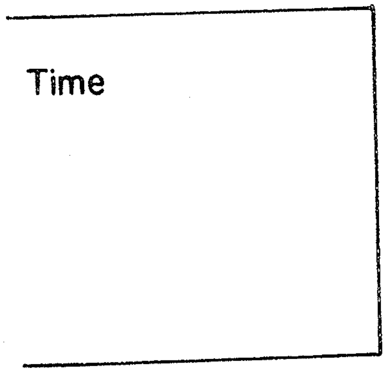
Scale: 1" = 10"

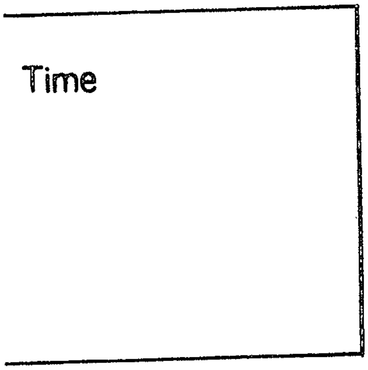




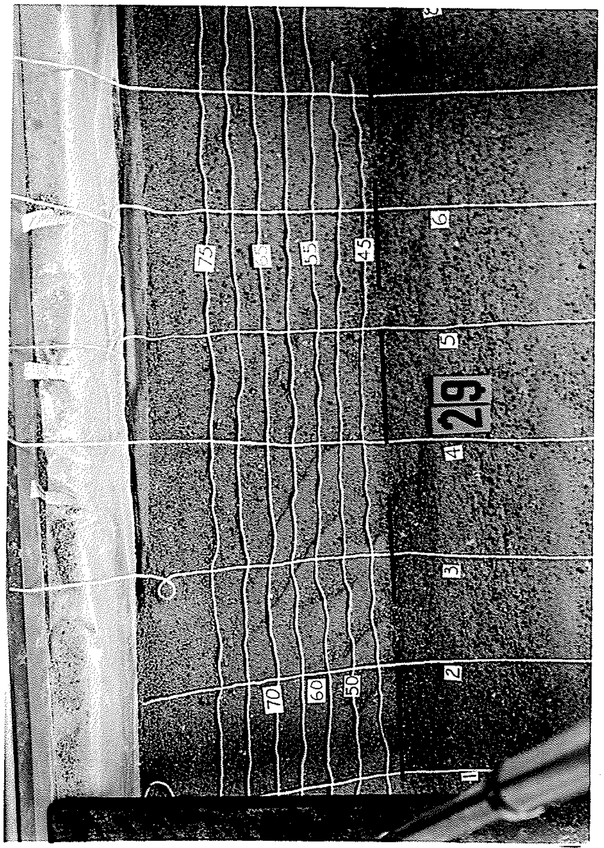




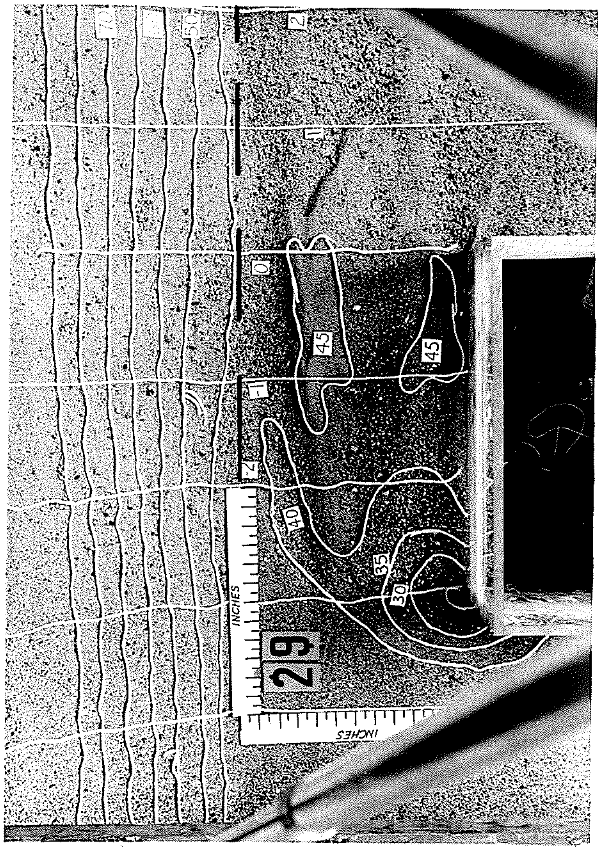




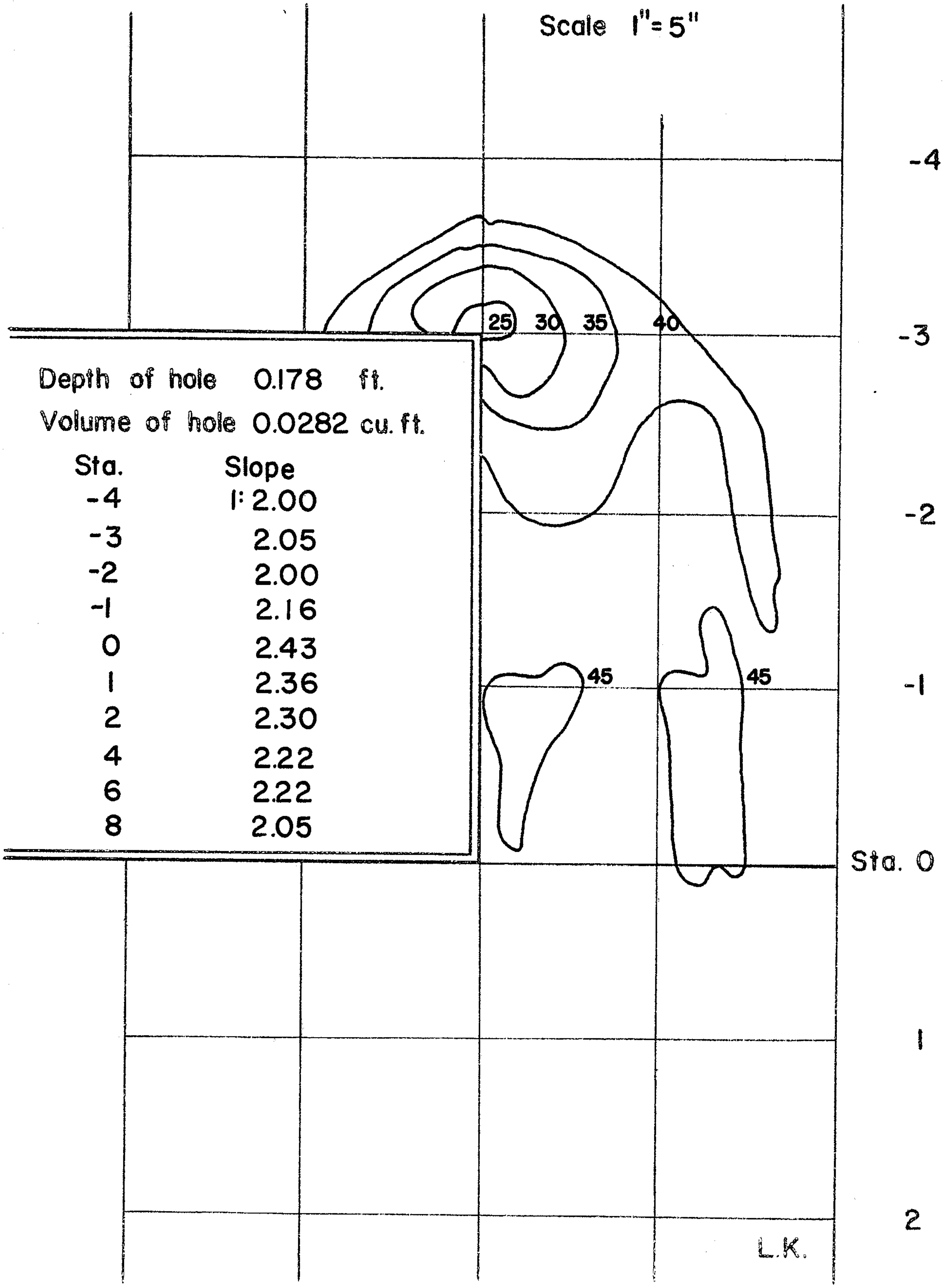
JUL • 64


75
65
55
45
70
60
50
1
2
3
4
5
6
29

JUL • 64


70
50
2
1
0
-1
-2
45
45
40
35
30
29
INCHES
INCHES

TEST 29



Depth of hole 0.178 ft.

Volume of hole 0.0282 cu. ft.

Sta.	Slope
-4	1: 2.00
-3	2.05
-2	2.00
-1	2.16
0	2.43
1	2.36
2	2.30
4	2.22
6	2.22
8	2.05

TEST DATA SHEET

TEST NO. 30

DATE July 14/64

MODEL SCALES: HORIZ. 1:100

VERT. 1:100

MATERIAL: MEDIUM MORTAR SAND

	MODEL	PROTOTYPE
Gauge Height (ft.)	0.568	
Discharge (CFS)	0.606	50,500.
Depth of Flow (ft.)	0.400	40.
Area (sq.ft.)	1.120	11,200.
Mean Velocity in Channel (ft/sec)	0.542	4.51
Time of Run	42.5 minutes	7.07 hours
Number of Photos Taken	2	

REMARKS:

No erosoin of the left bank.

Rapid erosion of the right bank occurred.

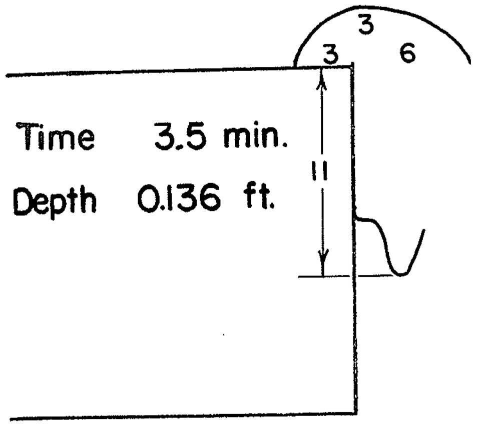
Considerable paving occurred causing the hole to be hsallower than in the previous test.

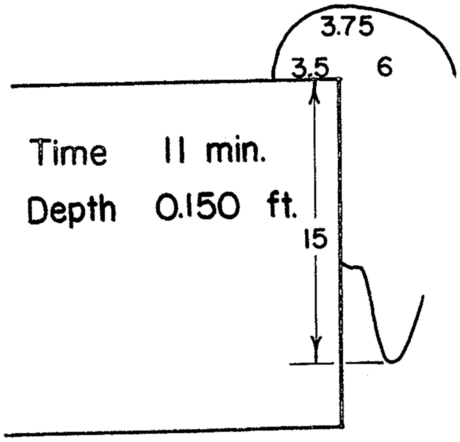
The holw reached full depth in 30 minutes.

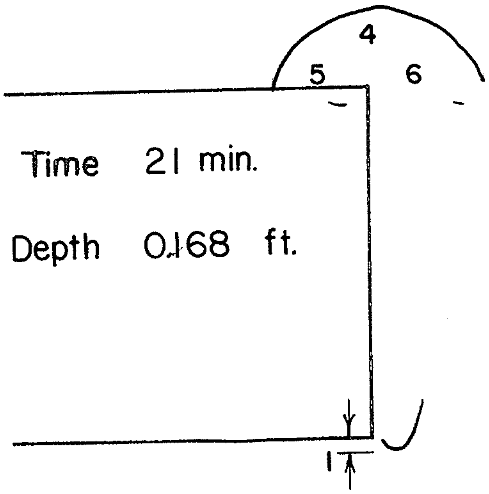
Test Performed by: 1k

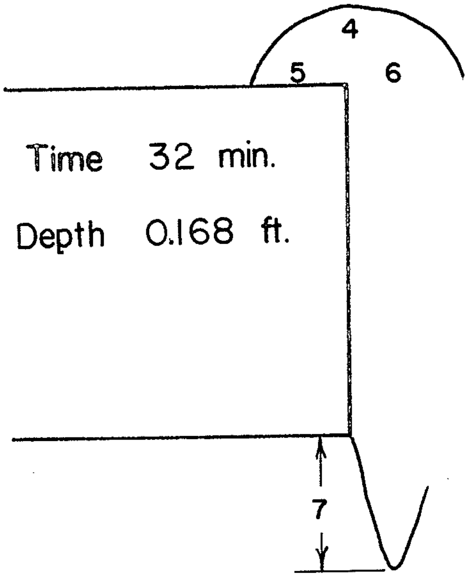
TEST 30

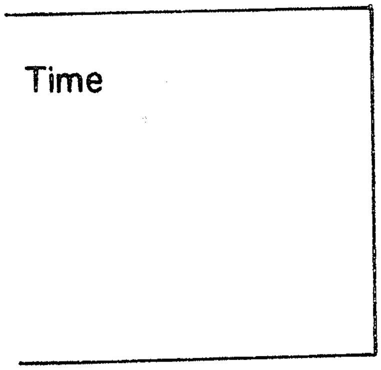
Scale: 1" = 10"

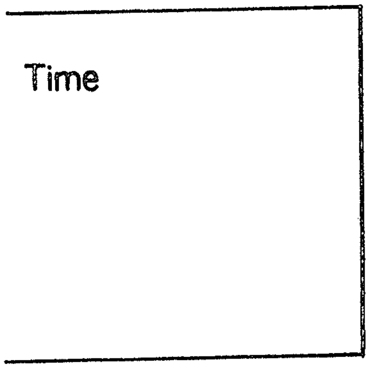




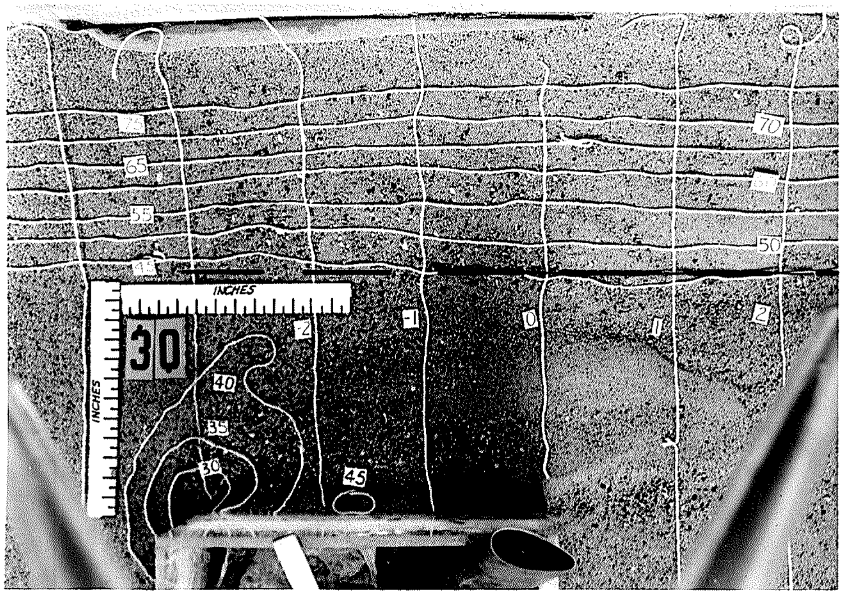




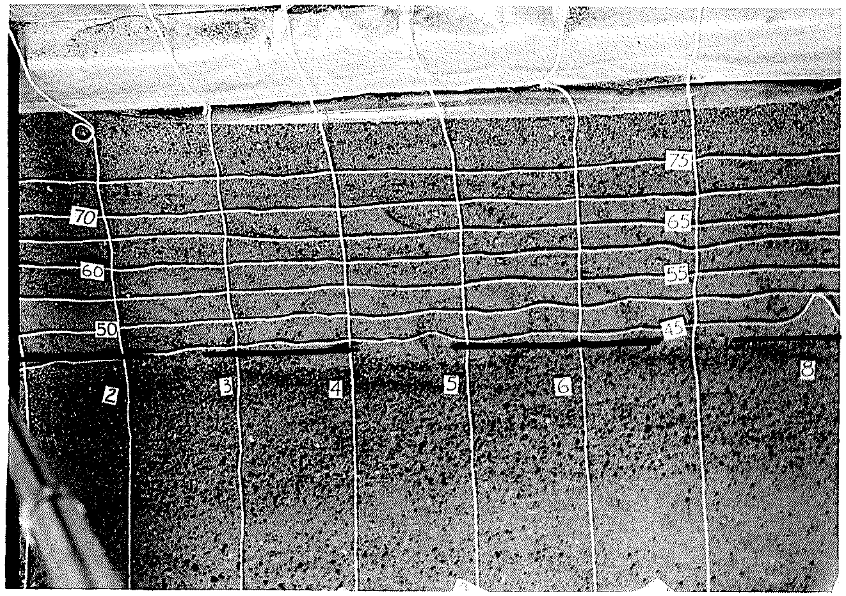




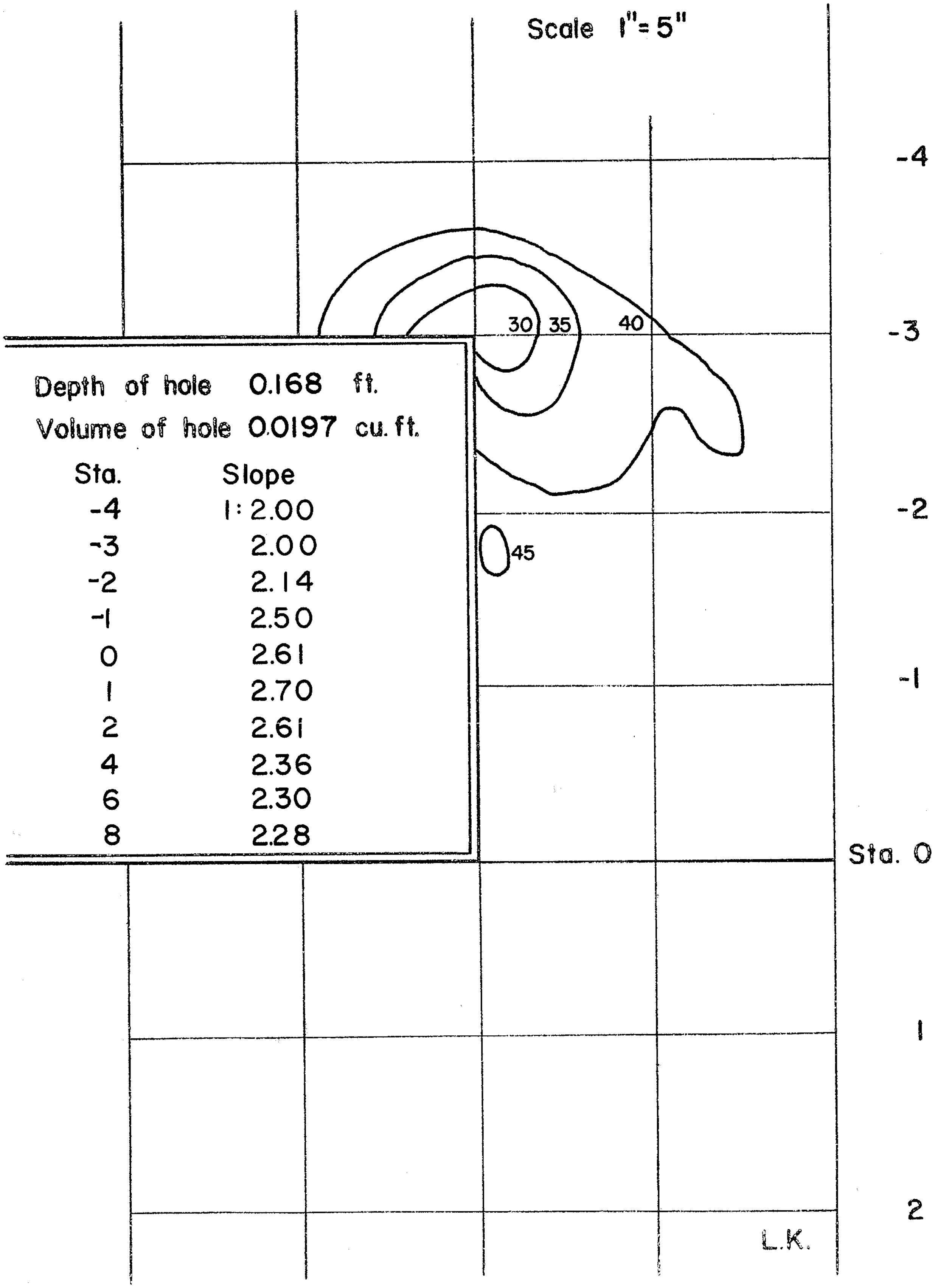
JUL • 64


75
65
55
45
70
50
2
1
0
-1
-2
INCHES
INCHES
30
40
35
30
45

JUL • 64


70
60
50
75
65
55
45
2
3
4
5
6
8

TEST 30



Depth of hole 0.168 ft.

Volume of hole 0.0197 cu. ft.

Sta.	Slope
-4	1:2.00
-3	2.00
-2	2.14
-1	2.50
0	2.61
1	2.70
2	2.61
4	2.36
6	2.30
8	2.28

TEST DATA SHEET

TEST NO. 31(A)

DATE July 15/64

MODEL SCALES: HORIZ. 1:100

VERT. 1:100

MATERIAL: FINE MORTAR SAND

	MODEL	PROTOTYPE
Gauge Height (ft.)	0.528	
Discharge (CFS)	0.505	50,500.
Depth of Flow (ft.)	0.400	40.
Area (sq.ft.)	1.120	11,200.
Mean Velocity in Channel (ft/sec)	0.451	4.51
Time of Run	13 minutes	2.17 hours

Number of Photos Taken 2

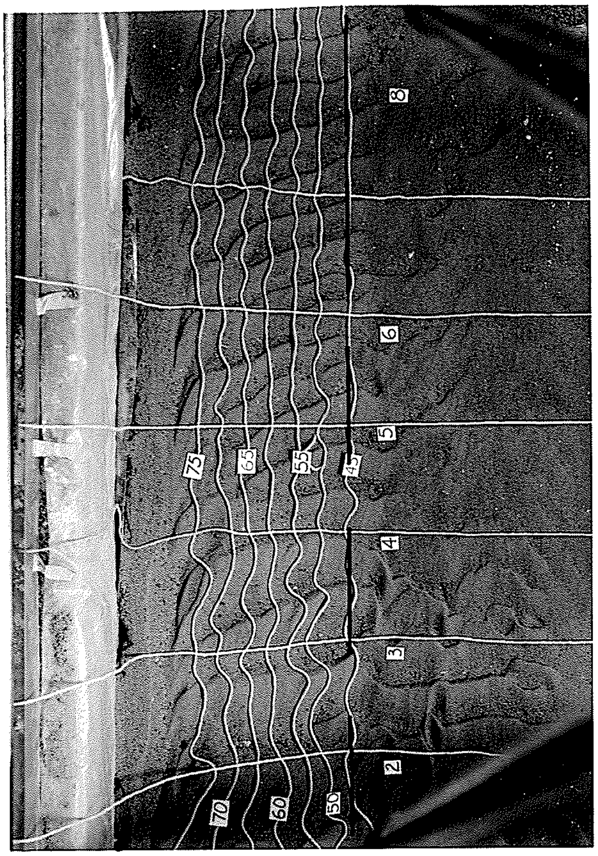
REMARKS:

No erosion of left bank.

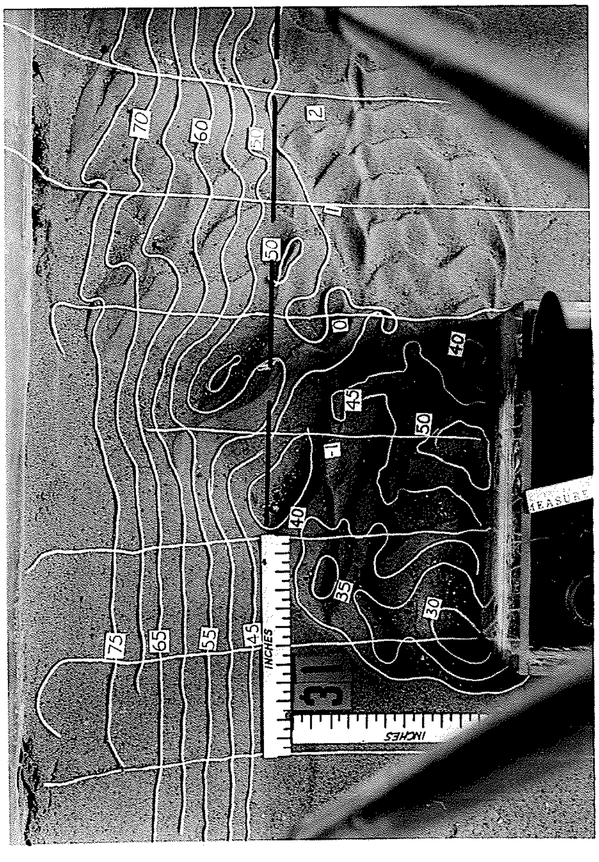
The right bank had eroded sufficiently to give the proper side slope at Sta. 1 in 13 minutes.

The erosion of slopes at 20% Q. Distortion is not quite enough and it is assumed 24% is sufficient.

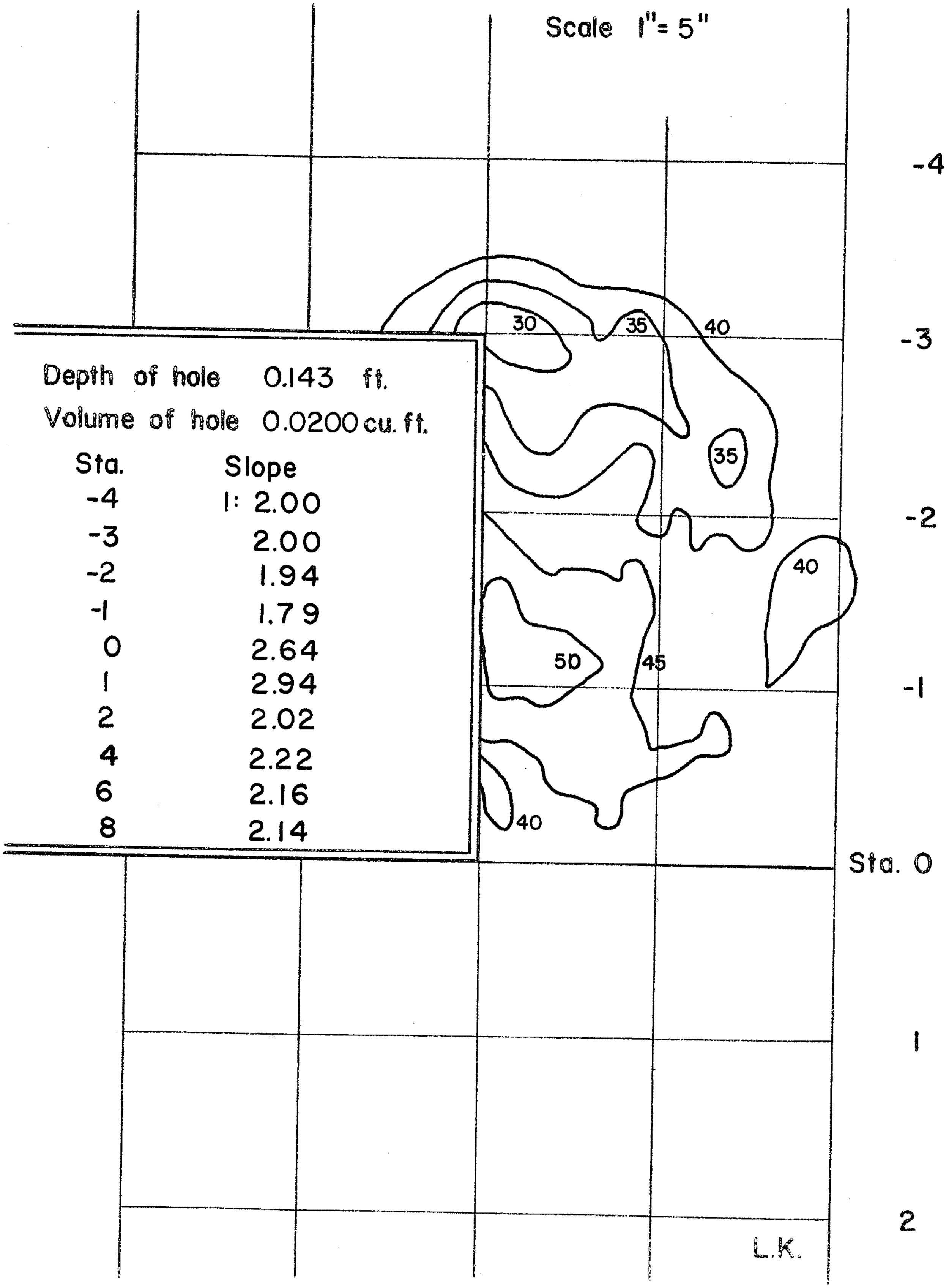
Test Performed by: lk


8
6
5
4
3
2
75
65
55
45
70
60
50
JUL • 64

TEST 31(A)


70
60
50
2
1
50
0
40
45
50
-1
40
35
30
75
65
55
45
INCHES
MEASURE
JUL • 64

TEST 31 (A)



Depth of hole 0.143 ft.

Volume of hole 0.0200 cu. ft.

Sta.	Slope
-4	1: 2.00
-3	2.00
-2	1.94
-1	1.79
0	2.64
1	2.94
2	2.02
4	2.22
6	2.16
8	2.14

TEST DATA SHEET

TEST NO. 31(B)

DATE July 16/64

MODEL SCALES: HORIZ. 1:100

VERT. 1:100

MATERIAL: FINE MORTAR SAND

	MODEL	PROTOTYPE
Gauge Height (ft.)		
Discharge (CFS)		
Depth of Flow (ft.)		
Area (sq.ft.)		
Mean Velocity in Channel (ft/sec)		
Time of Run		

Number of Photos Taken 2

REMARKS:

At a discharge distortion of about -25% the hole formed and riffles progressed diagonally across the bottom from the furthest right side of the hole. Initially there was no erosion of the side slopes, and after 15 minutes, no erosion occuring yet, the test was shut down.

At a distortion of -5% the hole grew very rapidly but erosion of the side slopes only began when riffles formed from the hole reached the bottom of the slope. The resulting erosion pattern was completly different from that of the other mortar sand as the erosion began at the foot of the slope and progressed upward. The resulting riffles were very excessive. (Photo 1 after 15 minutes).

At a decrease of discharge of 15%, it took considerably longer for the erosion to begin and the pattern was much further downstream than that of 5% distortion. As illistrated by Photo 2 (at 25 minutes) considerable paving occurred on the slope of the hole and also at the foot of the riffles.

It was decided that the trend in erosion pattern was undesirable and no further testing was done on this material.

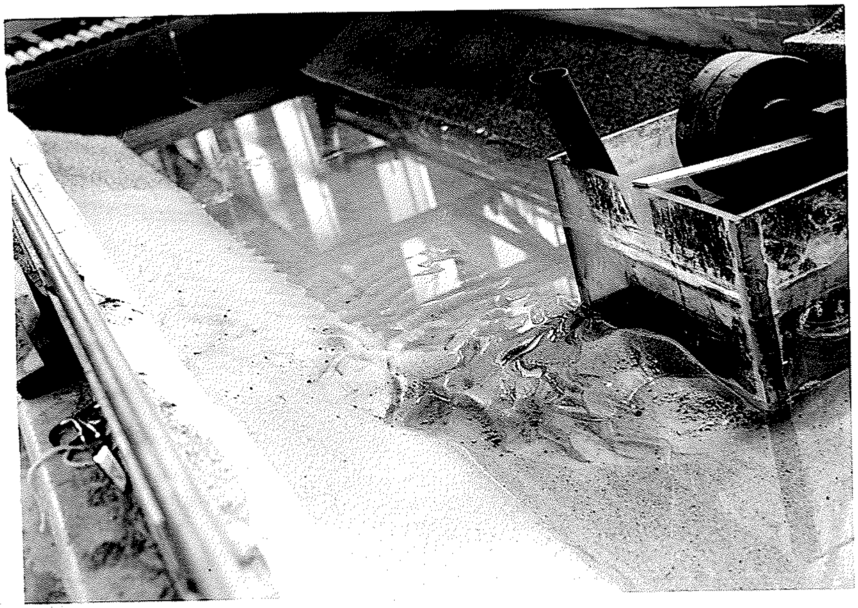
NOTICE - The change in flow pattern with each different distortion caused the diagonal travel of the riffles to be considerably further downstream at greater discharges.

Test Performed by: lk

AUG • 64

TEST 31 (B)

AUG • 64



217.

TEST DATA SHEET

TEST NO. 32

DATE July 20/64

MODEL SCALES: HORIZ. 1:200

VERT. 1:200

MATERIAL: SIEVED COARSE MORTAR SAND FROM RED RIVER FLOODWAY MODEL

	MODEL	PROTOTYPE
Gauge Height (ft.)	0.330	
Discharge (CFS)	0.1560	50,500.
Depth of Flow (ft.)	0.200	40.
Area (sq.ft.)	0.280	11,200.
Mean Velocity in Channel (ft/sec)	0.558	4.51
Time of Run	30 minutes	7.07 hours
Number of Photos Taken	1	

REMARKS:

No erosion of left bank.
Rapid erosion of right bank.
The proper amount of erosion was obtained by varying discharge in the correct amount of erosion on the slopes seemed to occur and then the test was rerun at this setting.

Erosion of the slopes of the hole continues throughout the test.

Erosion particles from the sides are carried considerably far downstream.

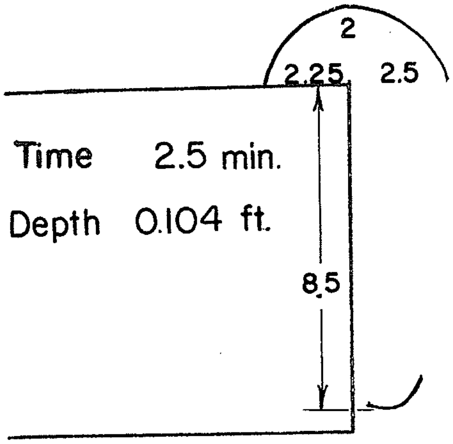
Full depth of hole is reached in 8 minutes.

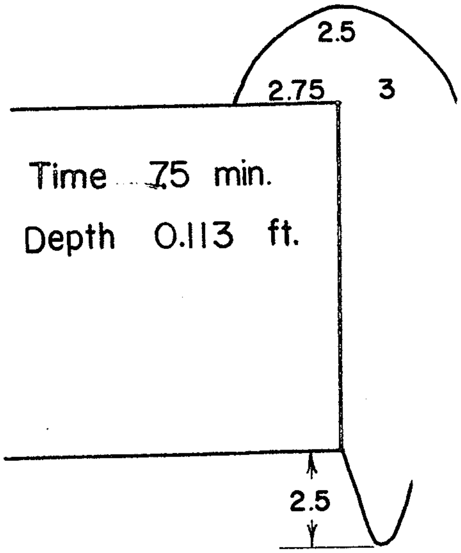
Q distortion = 1.75

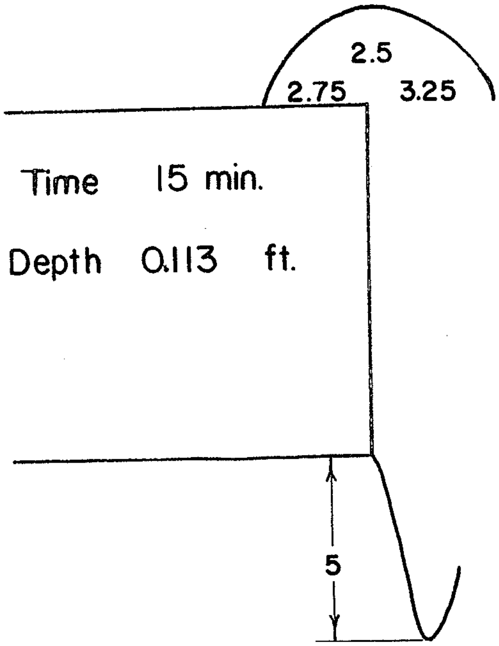
Test Performed by: lk

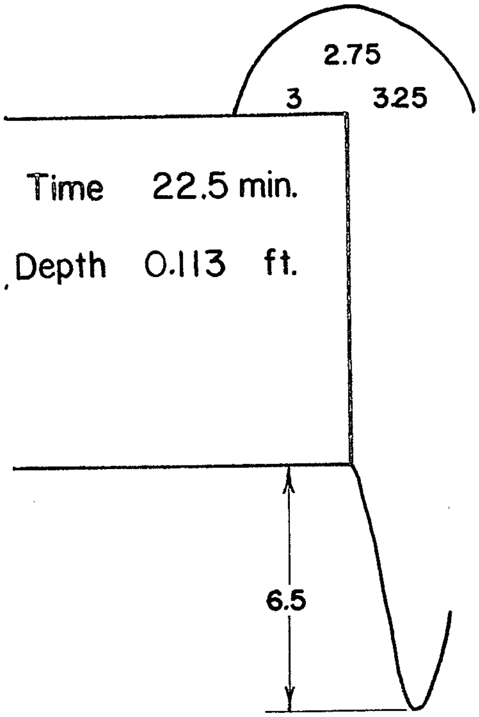
TEST 32

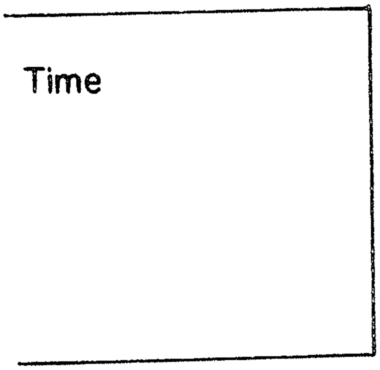
Scale: 1" = 5"

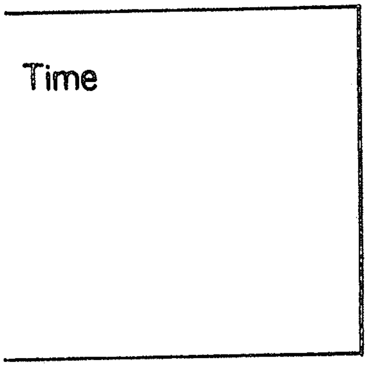












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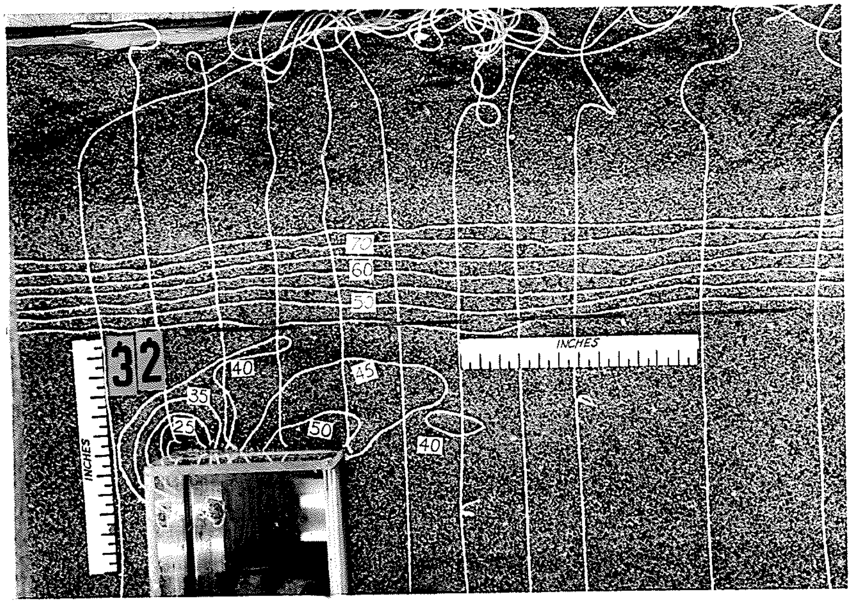
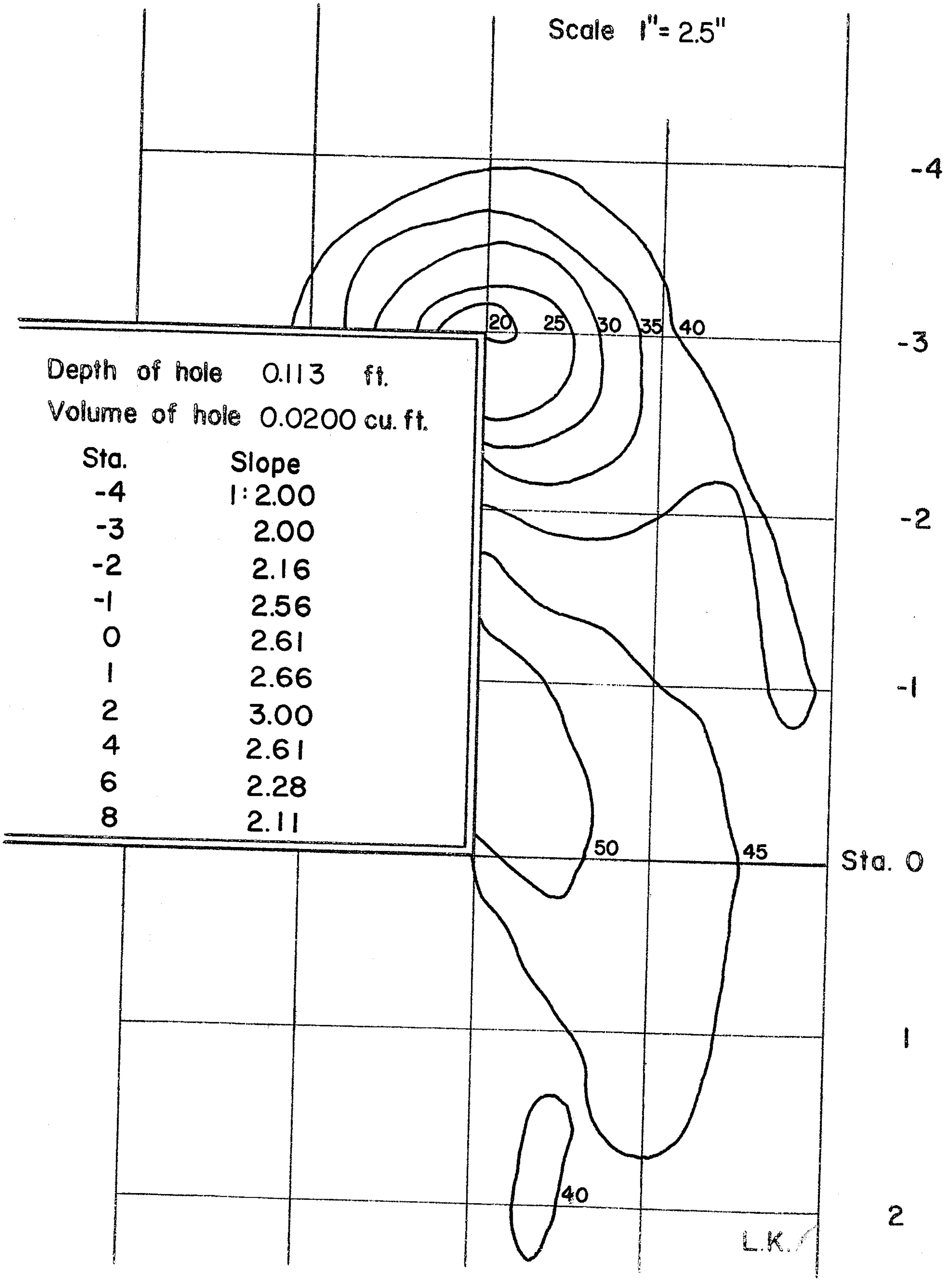


TEST 32



Depth of hole 0.113 ft.

Volume of hole 0.0200 cu. ft.

Sta.	Slope
-4	1:2.00
-3	2.00
-2	2.16
-1	2.56
0	2.61
1	2.66
2	3.00
4	2.61
6	2.28
8	2.11

TEST DATA SHEET

TEST NO. 33(A) and 33(B)

DATE July 20/64

MODEL SCALES: HORIZ. 1:200

VERT. 1:200

MATERIAL: 33(a) MEDIUM MORTAR SAND 33(b) FINE MORTAR

	MODEL	PROTOTYPE
Gauge Height (ft.)	0.307	
Discharge (CFS)	0.130	50,500.
Depth of Flow (ft.)	0.200	40.
Area (sq.ft.)	0.280	11,200.
Mean Velocity in Channel (ft/sec)	0.465	4.51
Time of Run	30 minutes	7.07 hours

Number of Photos Taken 1

REMARKS:

33(A):

The proper amount of erosion was obtained by varying discharge until the correct amount of erosion seemed to occur and then the test was rerun at this setting.

No erosion of left bank.
Rapid erosion of right bank.
Full depth of hole is reached in 10 minutes.
Q distortion = 1.46

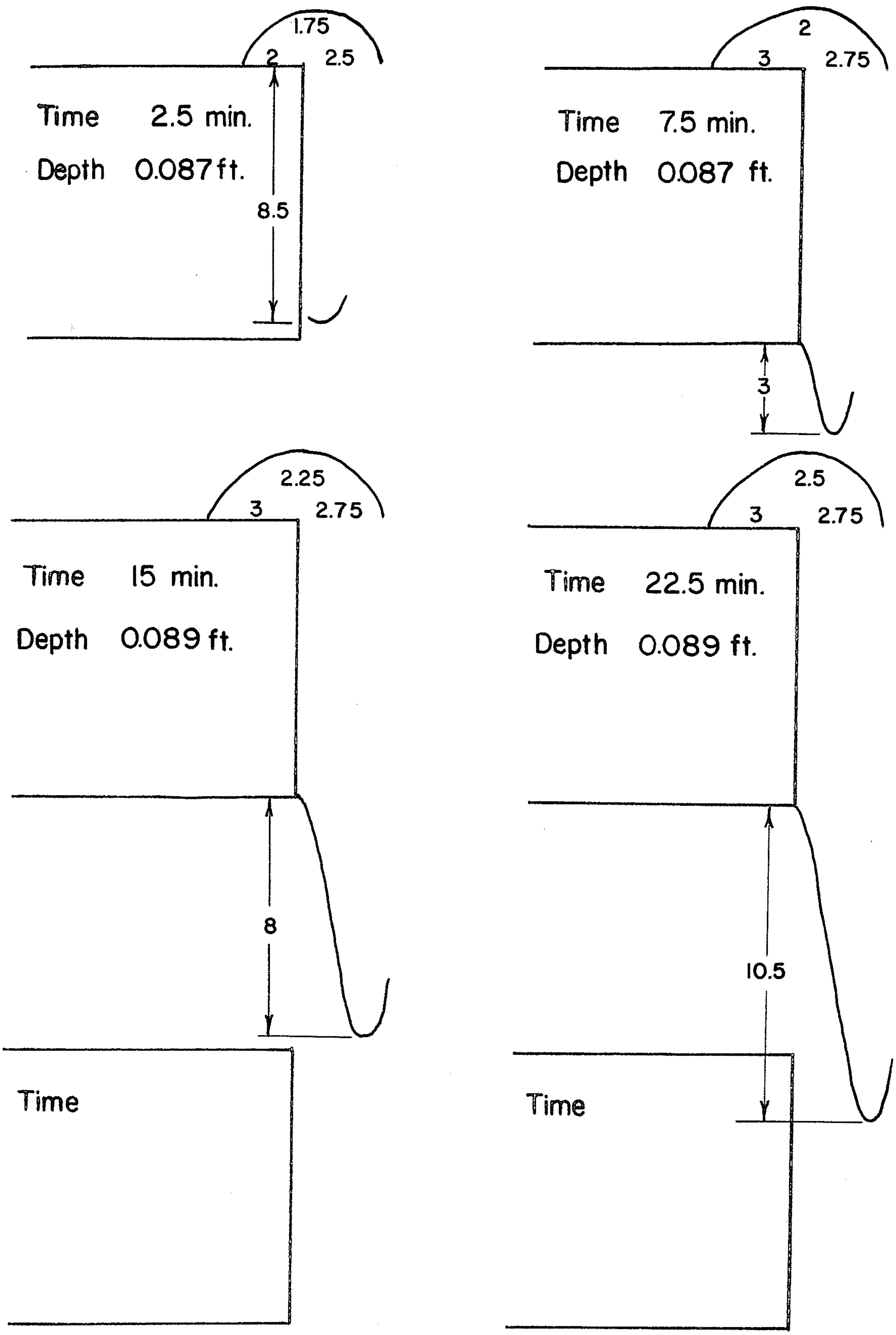
33(B):

As previously experienced, the pattern of erosion obtained from fine mortar sand was unsuitable due to formation of large riffles and paving thus further testing on fine mortar sand was discontinued.

Test Performed by: 1k

TEST 33

Scale: 1" = 5"



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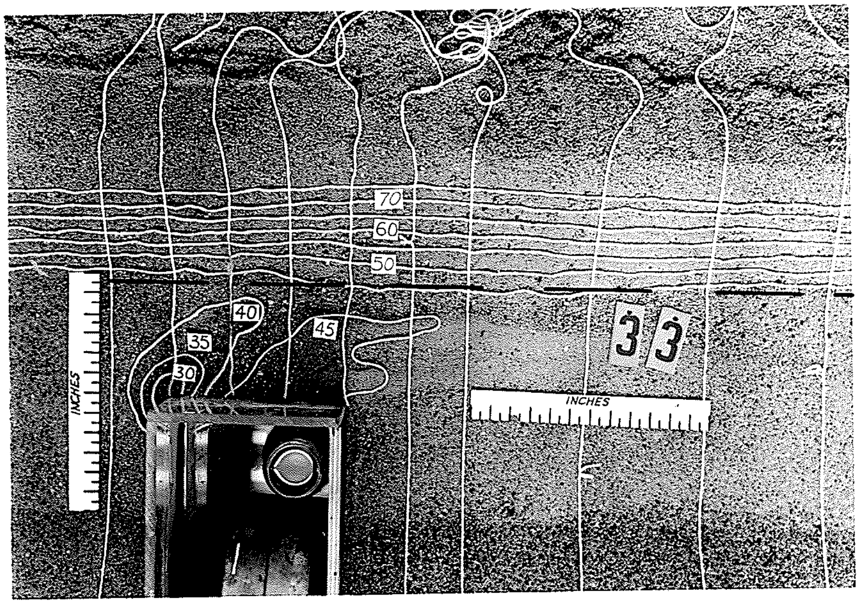
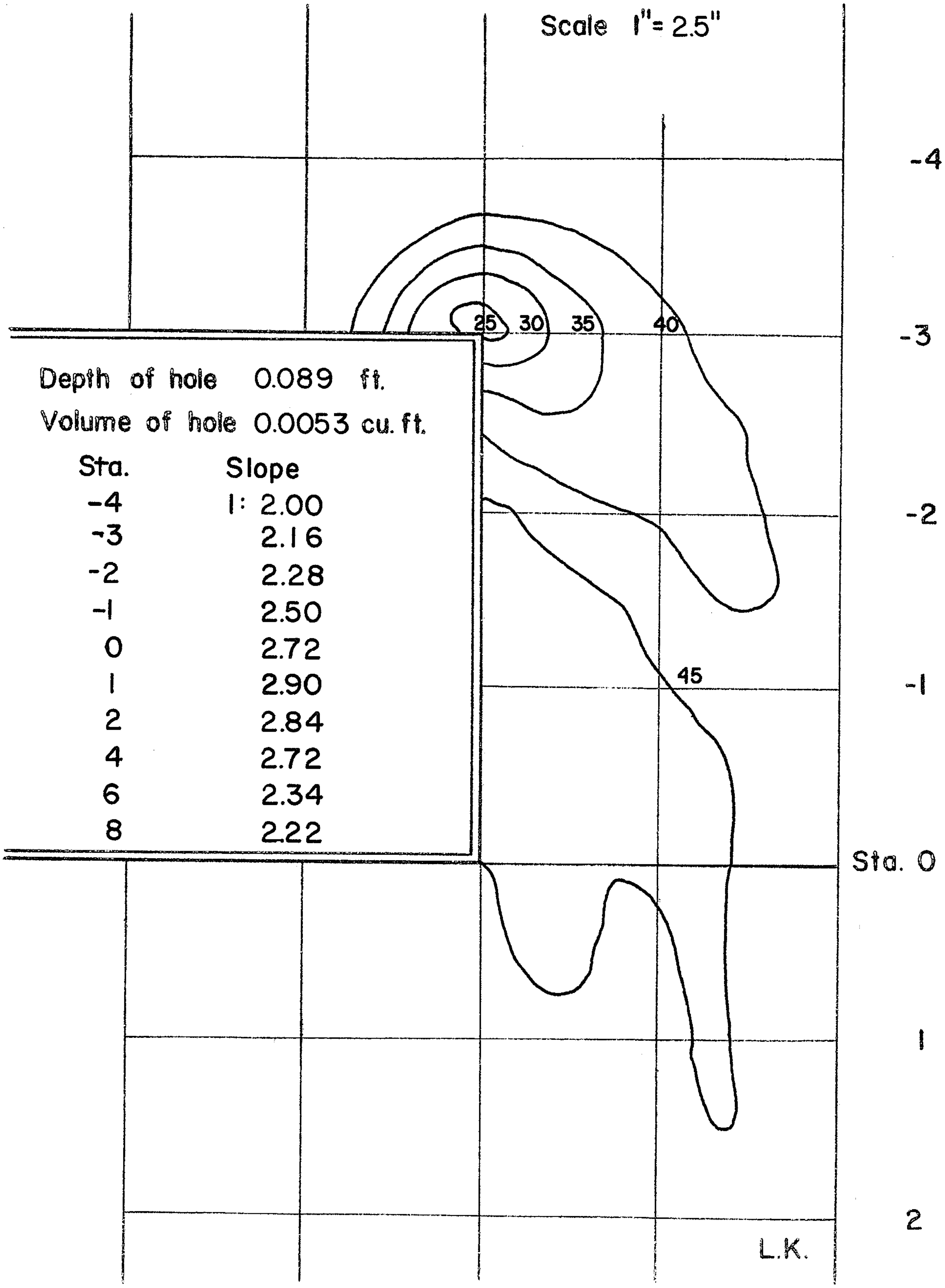


TEST 33(A)

TEST 33



Depth of hole 0.089 ft.

Volume of hole 0.0053 cu. ft.

Sta.	Slope
-4	1: 2.00
-3	2.16
-2	2.28
-1	2.50
0	2.72
1	2.90
2	2.84
4	2.72
6	2.34
8	2.22

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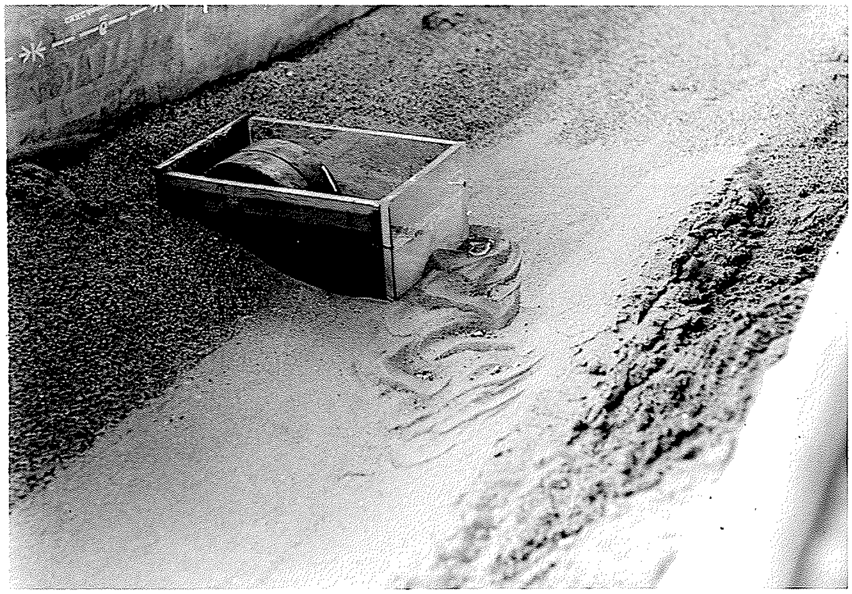

TEST 33 (B).

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