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Washout of fuse plugs.

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WASHOUT OF FUSE PLUGS

A Thesis

Submitted to the Faculty of Graduate Studies through the Department of Civil Engineering in Partial Fulfilment of the Requirements for the Degree of Master of Applied Science at the University of Windsor

by

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ABSTRACT

Washout experiments have been carried out under different conditions, and empirical formulae for washout rates were derived from which the time of washout can be estimated.

A study has also been made to compare the results obtained from the time-scales derived from the experimental formulae with those obtained from the time-scales obtained from the well known bed load formulae of Sheilds, Einstein, and Kalinske.

Finally, a comparison of the observed washout rates with those computed by the Einstein and Kalinske's bed load formulae, has been made.

ACKNOWLEDGEMENTS

The author wishes to express his sincere gratitude to Dr. S. P. Chee, Associate Professor in Civil Engineering, University of Windsor for his guidance and encouragement during this study.

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NOMENCLATURE

$q_{con.}$	Constant water discharge in cubic feet per second / foot width of channel.
$q_{cri.}$	Critical water discharge in cubic feet per second/foot width of channel.
q_s	Sediment discharge in cubic feet per second per foot width of channel.
D	Water depth at upstream toe of the dam in ft.
y_c	Critical water depth in ft.
S_s	Specific gravity of the material used.
α	Angle of repose of the material used in radians.
H	Height of dam in ft.
$\bar{B}$	Average length of dam in ft.
d	Particle size of the material in ft.
S	Energy slope.
T	Time of washout in seconds.
N	Manning's roughness coefficient.
τ_o	Shear stress in lb/ft^2.
τ_c	Critical shear stress in lb/ft^2.
g	Acceleration due to gravity in ft/sec^2.
γ	Specific weight of water in lb/ft^3.
Φ	Bed load function.
$1/\Psi$	Entrainment function.
n	Porosity of the material used.
ρ	Density of water in $slug/ft^3$.
ν	Kinematic viscosity in ft^2/sec.
C_s	Du Boys' coefficient.

CHAPTER 1

INTRODUCTION

1.1 Description and Object of the Investigation

Generally, a fuse plug is simply a rockfill dam. It has a factor of safety equal to that for ordinary rockfill or earth dams when it functions as a dam. It will be washed out by the reservoir water automatically at a suitable rate when the spillway capacity is required to pass an extraordinary flow. Normally, laboratory experiments using model techniques are undertaken to demonstrate the feasibility of a fuse plug in a spillway of a major dam before it is constructed.

The fuse plug is often designed according to theoretical computations based mainly upon bed load transportation principles and modern concepts of soil mechanics.

Laboratory investigations, were performed to determine

a) The mechanics of the washout process.

b) The similitude relationship for the rate of washout.

The study involved two approaches:-

1) Empirical formulae, that permit the application of model test results to rates of washout, were based on the experiments which were carried out in four series as follows:-

   a) Washout at constant upstream water level with downstream supercritical flow.

b) Washout at constant upstream water level with downstream subcritical flow.

c) Washout at constant discharge with downstream supercritical flow.

d) Washout at constant discharge with downstream subcritical flow.

The washout time scale was then derived from the previously mentioned empirical formulae. This time scale was compared with those derived from Sheilds, Einstein, and Kalinske's bed load formulae.

A study of side effects has been made by using dams of different widths.

2) Rates of washout were calculated from successive photos taken during the experiments. These rates were compared with those obtained by substituting in the bed load formulae suggested by Einstein and Kalinske.

CHAPTER 2

THEORETICAL BACKGROUND

2.1 Significance of sediment properties:-

The entrainment, transportation, and deposition of sediment depend fully as much upon the properties of the sediment as upon the hydraulic characteristics of the flow.

Such properties may be classed as those which are typical

a) of the individual particle (such as size, shape, and specific gravity),

b) of the particle distribution,

c) of the sediment in bulk (such as porosity, and specific weight).

2.2 Bed load formulae

Many such formulae have been developed, some purely empirical, others having a background of semi-rational and/or semi-dimensional argument. They usually involve the difference, or the ratio between the actual bed shear stress τ_0 and the critical shear stress τ_c , at which movement begins.

Some of the better known formulae will now be described

a) Du Boys' classical formula:-

For many years, transport functions for bed load have been based on this formula [8]

$$q_s = C_s\ (\tau_o - \tau_c) \quad \ldots \quad (2.1)$$

in which q_s is the rate of sediment transport along the bed in volume of material per unit time per unit width of section; $\tau_o = \gamma y S$ is the intensity of bed shear, and τ_c is that value of τ_o at which the function intersects the $q_s = 0$ axis. Although Du Boys based his analysis on the over simplified picture of sliding layers of bed material kept in motion by the shear of the moving fluid, in effect the shear terms express the complex system of forces exerted by the flow upon the bed and the term C_s expresses the relative susceptibility of the given sediment to movement. If the formula is correct in principle, its successful use evidently depends upon correct evaluation of the parameter Cs. Straub found by examining the work of many investigators that for grain water systems C_s is equal to $0.173/d^{3/4}$, where d is the grain size in millimeters.

b) Shields' formula:-

Shields [7] put forward a bed load formula.

$$\frac{q_s(S_s-1)}{q\ S} = 10\ \frac{(\tau_o - \tau_c)}{\gamma(S_s-1)d} \qquad (2.2)$$

where q, S, and γ are defined in the normal way as water discharge per unit width, bed slope, and water specific weight. The equation is dimensionally homogeneous, so that any consistent system of units can be used. Also, it includes the specific gravity as a variable. It fits fairly well to a wide range of experimental data.

c) Einstein's formula:-

Einstein[6] departed radically from Du Boys type of analysis through the following combination of physical, dimensional, and statistical considerations. He first concluded on the basis of observations that a given size of particle moves in a series of steps of definite length and frequency, and that the rate of transport depends upon the number of particles moving at any time. The probability that any one particle will begin to move in a given unit of time was thus assumed to be expressible in terms of the rate of transport, the size and relative weight of the particles, and a time factor equal to the ratio of the particle diameter to its velocity of fall. The same probability was expressed again in terms of the ratio of the forces exerted by the flow to the resistance of the particle to movement. The two forms of the probability relationship were then equated to yield the general function

$$\Phi = f\left(\frac{1}{\Psi}\right)$$

The terms Φ is known as the bed load function; it involves the rate of movement, the particle size and weight in water, and a dimensionless function F of the fall velocity:

$$\Phi = \frac{q_s}{\sqrt{g(S_s - 1)}\ F\ d^{3/2}}$$

where

$$F = \sqrt{\frac{2}{3} + \frac{36\nu^2}{gd^3(S_s-1)}} - \sqrt{\frac{36\nu^2}{gd^3(S_s-1)}}$$

The quantity Ψ involves essentially the same particle characteristics and the bed shear $\tau_o = \gamma y S$:

$$\frac{1}{\Psi} = \frac{\tau_o}{\gamma(S_s-1)d}$$

The empirical Φ - $1/\Psi$ relation is plotted in Fig.1 , in a form due to Brown[8], who also deduced the equation

$$\Phi = 40\left[\frac{1}{\Psi}\right]^3$$

or

$$\frac{q_s}{\sqrt{g(S_s-1)}\ F\ d^{3/2}} = 40\left[\frac{\tau_o}{\gamma(S_s-1)\ d}\right]^3 \quad \ldots\ldots (2.3)$$

for the upper straight line portion of the curve. At low values of Φ, and hence of q_s, the curve swings away from this straight line to the asymptote

$$\frac{1}{\Psi} = 0.056$$

Experimental data relating to uniform sand and gravel sizes fit moderately well to the curve in Fig.1.

d) Kalinske's formula:-

Kalinske [6,8] likewise sought to improve upon the purely empirical type of formulation by incorporating relationships between bed shear and turbulence. His development, like that of Einstein, proceeded from the simple statement that the volume rate of sediment movement per unit width must be equal to the product of the particle volume $A_2 d^3$, the mean particle velocity $\bar{v}_s$, and the average number of particles moving per unit bed area $P/A_1 d^2$

$$q_s = A_2 d^3 \times \bar{v}_s \times P/A_1 d^2 = \frac{A2}{A_1} \bar{v}_s \; Pd$$

where the coefficients A_1, A_2 are dependent on the geometry of the particle.

As a conclusion to Kalinske's argument, the particle velocity $\bar{v}_s$ would be proportional to the shear velocity $\sqrt{\tau_o/\rho}$, and that the coverage factor P would be a function of the ratio τ_o/τ_c, which is directly proportional to the entrainment function $1/\Psi$. It follows that

$$\frac{q_s}{\sqrt{\tau_o/\rho}\; d} \propto P = f\left(\frac{1}{\Psi}\right)$$

The line plotted in Fig.2. has been fitted to a number of experimental data, whcih show about the same degree of scatter as for the Einstein function.

The upper straight line portion of the curve has the equation

$$\frac{q_s}{\sqrt{\tau_o/\rho}\; d} = 10 \left[\frac{1}{\Psi}\right]^2$$

or

$$\frac{q_s}{\sqrt{\tau_0/\rho}\; d} = 10 \left[\frac{\tau_0}{\gamma (S_s - 1)\; d} \right]^2 \quad ....(2.4)$$

and as in Fig.1 the lower part curves away to the asymptote $\frac{1}{\Psi} = 0.056$.

2.3 Washout of fuse plug:-

The washout process starts when the water overtops the crest level of the fuse plug. The washout process was conducted under two different conditions:

a) Constant upstream water elevation, during which the water level upstream of the fuse plug was kept constant. The experiments were carried out for different constant water levels starting from the crest level.

b) Constant discharge, during which the experiments were carried out for different constant discharges.

2.4 Evaluation of variables:-

a) Constant upstream water level case:- (Fig.7)

The sediment discharge per unit width q_s depends upon the critical water discharge q_{cri}, height of dam H, mean length of dam $\bar{B}$, depth of water upstream of dam D, mean diameter of grains d, angle of repose of grains in radians α, and specific gravity S_s of the material used.

$$q_s = f(q_{cri}, H, \bar{B}, D, d, \alpha, Ss)$$

By dimensional analysis [3,4] the above function can be written as

$$\frac{q_s}{q_{cri}} = f(g(D-0.5H)^3/q_{cri}^2, H/\bar{B}, 1/(Ss-1), D/d\alpha)$$

(D-0.5H) is known as the effective head of water above the washout material, $H/\bar{B}$ is representative of the shape of the dam, and $q_{cri} = 3.09\ D^{3/2}$

An equation of the form

$$\frac{q_s}{q_{cri}} = K_1\ (g(D-0.5H)^3/q_{cri}^2)^{a_1}(D/d\ )^{a_2}\ (1/Ss-1)^{a_3}\ (H/\bar{B})^{a_4} \quad ..(2.5$$

where the exponents a_1, a_2, a_3 and a_4 and the coefficient K_1 are constants, which are to be found by statistical methods [1,2] based on the experimental data, can be written.

b) <u>Constant discharge case:-</u> (Fig.7) The sediment discharge per unit width q_s depends upon the constant water discharge q_{con}, height of dam H, mean length of dam $\bar{B}$, critical water depth y_c, and the properties of material such as d, α and S_s.

$$q_s = f(q_{con}, H, \bar{B}, y_c, d, \alpha, S_s)$$

Again by dimensional analysis [3,4] the above function can be written as

$$\frac{q_s}{q_{con}} = f(gH^3/q_{con}^2, H/\bar{B}, 1/(Ss-1), y_c/d\alpha)$$

The term gH^3/q_{con}^2 represents the reciprocal of the Froude number.

An equation of the form

$$\frac{q_s}{q_{con}} = C_1\ (gH^3/q_{con}^2)^{b_1} (y_c/d\alpha)^{b_2}\ (1/S_s - 1)^{b_3}\ (H/\bar{B})^{b_4} \quad ..(2.6)$$

where the exponents b_1, b_2, b_3 and b_4 and the coefficient C_1 are constants, which are to be found from statistical methods [1,2] based on the laboratory observations, can be formulated.

CHAPTER 3

EXPERIMENTAL APPARATUS AND PROCEDURE

3.1 Fig.3 shows the 9" wide channel used for the washout experiments. The discharge was measured by an electronic flow meter.

Fig.4 shows the 6" wide flume used for another series of washout experiments. The discharge was measured by vertical and sloping manometers.

Finally, a series of experiments (using fuse plug widths of 18", 36" and 60") were conducted using the 60" wide channel shown in figs 5,6. The discharge was measured by a triangular notch.

3.2 Material Used:

a) Mechanical analysis:

The purpose of the mechanical analysis is to determine the sizes of the grains which constitute the material and the percentage of the total weight represented by the grains in various size ranges. A series of mechanical analysis were conducted for different gravels and sands excluding materials No 3,5. The diameter of a particle than which 50% (by weight) of the material is finer, was used (see Fig.9).

Material No 3 refers to particle size that passed a sieve with ¼" openings and retained by sieve No 4 (Tyler).

Material No 5 refers to particle size that passed both ¼" and No 4 and retained by sieve No 8 (Tyler).

b) Specific gravity, porosity, and angle of repose:

Specific gravity and porosity were determined experimentally for each of the materials used.

The angle of repose was obtained from the curves prepared by the U.S.B.R., and used in the derived equations to indicate the angularity of each material (see Fig.8).

Table No 1 shows the mean diameter in millimeter, specific gravity, porosity and angle of repose in radians for the different materials used.

3.3 Experimental investigation:

14 types of dams of different shapes and sizes have been used (Fig.7).

a) In the 9" wide channel, materials of specific gravities ranging from 2.57 to 2.77 have been used to build 14 types of embankments, and the experiments were conducted under both constant upstream water level and constant discharge, with two different washout conditions,

(1) supercritical, by building the dam near

the downstream end of the channel, and

(2) Subcritical, by building the dam within the mid-panel of the channel.

b) In the 6" wide flume, materials of specific gravities raging from 2.65 to 4.5 have been used to build 7 (type 2) dams, and the experiments were carried out under the case of constant upstream water level with the subcritical washout condition.

c) In the 60" wide channel, a material of 2.57 specific gravity has been used in building 3 (type 2) dams of widths 18", 36" and 60" to study the effect of the change in width. The experiments were conducted under the constant discharge case with the supercritical washout condition.

In all the previously mentioned experiments, the time of washout was recorded starting at the moment the water overtops the fuse plug. Photographs were taken during the washout process.

3.4 Experimental Errors:

The possible errors which might have occured during the experiments could be due either to errors in the instruments or errors of observation.

The instrument errors are related to the electronic flow meter and its degree of accuracy, to the air bubbles inside the manometers, and to the calibration of the clock. The observational errors are many and sometimes compensating. The flow chart is graduated to read to a minimum value of 50 gallons per minute and can be interpolated to read to within an accuracy of about 10 gallons per minute. The clock's scale is graduated to read directly to 1 second. The water levels over the weir were measured to within an accuracy of 1/100 of an inch. In the washout experiments for the case of constant upstream water level, there were difficulties in controlling the gate valve to maintain a constant upstream water level during the washout process. Thus, it is anticipated that the derived empirical formulae based on these experimental data will show more scatter than those derived from the washout experiments for the case of constant discharge.

CHAPTER 4

ANALYSIS AND DISCUSSION

4.1 Evaluation of Constants:

Based on statistical analysis [1,2], the constants in equations (2,5 and 2.6) were found using the experimental data.

The most satisfactory empirical equations obtained are as follows:

a) Constant upstream water level, supercritical case:

$$\frac{q_s}{q_{cri}} = \frac{1}{73.50} \left[g(D-0.5H)^3/q_{cri}^2\right]^{.052} \left[D/d\alpha\right]^{.125} \left[1/S_s-1\right]^{2.0} \left[H/\bar{B}\right]^{.22} \quad ..(4.1$$

b) Constant upstream water level, subcritical case:

$$\frac{q_s}{q_{cri}} = \frac{1}{295.72} \left[g(D-0.5H)^3/q_{cri}^2\right]^{.052} \left[D/d\alpha\right]^{.125} \left[1/S_s-1\right]^{2.0} \left[H/\bar{B}\right]^{.22} \quad ..(4.2$$

c) Constant discharge, supercritical case:

$$\frac{q_s}{q_{con}} = \frac{1}{73.39} \left[gH^3/q_{con}^2\right]^{.082} \left[y_c/d\alpha\right]^{.125} \left[1/S_s-1\right]^{2.0} \left[H/\bar{B}\right]^{.22} \quad ..(4.3$$

d) Constant discharge, subcritical case:

$$\frac{q_s}{q_{con}} = \frac{1}{477.74} \left[gH^3/q_{con}^2\right]^{.082} \left[y_c/d\alpha\right]^{.125} \left[1/S_s-1\right]^{2.0} \left[H/\bar{B}\right]^{.22} \quad ..(4.4$$

where

q_s = Sediment discharge in c.f.s/ft.

D = Depth of water at upstream toe of the dam in ft.

q_{cri} = Critical water discharge = $3.09\ D^{3/2}$ c.f.s/ft.

q_{con} = Constant discharge during the washout process. c.f.s/ft.

y_c = Critical water depth = $\sqrt[3]{\frac{q_{con}^2}{g}}$ in ft.

(S_s-1) = Submerged specific gravity of the material.

H = Height of dam in ft.

$\bar{B}$ = Average length of dam in ft.

α = Angle of repose of the material used in radians.

d = Mean particle size of the material used in ft.

From the previous equations the time of washout could be calculated as $T = \frac{V_s}{q_s}$

where

V_s = the effective volume of the dam

= volume of dam $\times\ (1- \frac{n}{100})$

where n is the porosity of the material.

The observed times of washout versus those computed from the above equations are plotted in Figs.58 to 61.

The correlation coefficients of equations 4.1, 4.2, 4.3 and 4.4 were calculated and the results are 0.31, 0.40, 0.78 and 0.42 respectively.

It can be seen from figs. 58 to 61, that, the washout time values obtained from the experimentally derived equations for the case of downstream subcritical flow exhibit more scatter than those obtained from the derived equation for the case of downstream supercritical flow.

The reason for this is obvious. In the case of the washout experiments with downstream subcritical flow, after the water overtopped the dam crest, the dam started to lengthen in the downstream direction and the washed out material were transported to the downstream end of the channel forming ripples, dunes and antidunes which affect the washout of the dam.

After the initial rapid failure and breakthrough, a much slower sediment transport state followed. The remaining part of the dam continued to be washed out as in the case of bed load transport.

It took a relatively much longer time to complete this final phase of washout. However, in the case of the washout experiments with downstream supercritical flow, the dam was built near the downstream end of the channel; all the washed out material fall immediately into the collecting box without leaving any behind to impede the transporting process.

4.2 Time-scales:

a) Derived from the experimental formulae:

$$\frac{T_p}{T_m} = S^{.375}\left[\frac{(S_s-1)p}{(S_s-1)m}\right]^{2.0}\left[\frac{dp}{dm}\right]^{.125}\left[\frac{\alpha p}{\alpha m}\right]^{.125} \quad \ldots(4.5)$$

where S is the model scale = L_p/L_m

The above equation can be derived from either the constant upstream water level equations or the constant discharge equations as well.

b) Derived from the bed load formulae:

i) Shields' formula

$$\frac{T_p}{T_m} = S^{1/6}\left[\frac{(S_s-1)p}{(S_s-1)m}\right]^{2.0}\left[\frac{dp}{dm}\right]^{1/3} \quad \ldots(4.6)$$

ii) Einstein's formula

$$\frac{T_p}{T_m} = \left[\frac{(S_s-1)p}{(S_s-1)m}\right]^{2.5}\left[\frac{dp}{dm}\right]^{1/2}\left[\frac{Fm}{Fp}\right] \quad \ldots(4.7)$$

It is obvious from the Einstein equation that the time scale does not depend on the length scale (S) as it is a function of the properties of the material only.

iii) Kalinske's formula

$$\frac{T_p}{T_m} = S^{1/3}\left[\frac{(S_s-1)p}{(S_s-1)m}\right]^{2.0}\left[\frac{dp}{dm}\right]^{1/6} \quad \ldots(4.8)$$

A comparison of the above different time-scales can be found in table 10 and Fig.62.

4.3 Application of the bed load formulae to the fuse plug washout:

The data obtained from the 6" wide flume were used for this application. Successive photos were taken during the washout process at various times.

From the photos,

i) The absolute time (T) since the start of washout and the water discharge at that time were recorded.

ii) The depths of water flowing over the dam were measured; hence the average flow depth over the dam was obtained for any given time.

iii) The cross-sectional area of the dam still remaining behind was measured by a planemeter at that given time.

The observed sediment discharges were calculated as follows:

a) Both the time interval and the washout area between two successive absolute times were calculated from

$\Delta T = T_2 - T_1$

$\Delta A = A_2 - A_1$ in sq.ft./ft width of channel.

b) The sediment discharge q_s was estimated from

$$q_s = \frac{\Delta A}{\Delta T} \times \left(1 - \frac{n}{100}\right) \quad \text{c.f.s/ft.}$$

The computed values of q_s were obtained as follows:

a) The value of shear stress(τ_o) was calculated from

$\tau_o = \gamma y S$

where y = average water depth over the dam at the corresponding absolute time.

S and N are obtained from the Manning and the Strickler equations [9] that is $S = \frac{q^2 N^2}{2.21\ y^{10/3}}$ and $N = 0.034\ d^{1/6}$

b) q_s was determined by substituting in both the Einstein and the Kalinske bed load formulae; the average $q_s = \frac{q_{s1} + q_{s2}}{2}$ was taken.

The values of q_s (observed), q_s (calculated) and the ratios of q_s obs to q_s comp. are given in tables 11 to 17 and tables 18 to 24.

CHAPTER 5

CONCLUSION.

5.1 From the tests conducted in the laboratory it appears that the shape of the dam (upstream and downstream slopes of the dam) has no appreciable effect on the time of washout if the volume of the dam is kept constant.

5.2 The results obtained from the time scale relation derived from the experimental formulae were found to be closer to those obtained from the time scale equation derived from the Kalinske formula rather than those from the Sheilds and the Einstein formulae.

5.3 Results of washout experiments for fuse plugs of widths 18", 36", and 60" showed that there were no significant side effects resulting from the 6" & 9" wide fuse plugs.

5.4 The application of the bed load formulae to the fuse plug washout indicated that this method lacked the accuracy desired. These formulae deal with the bed load only and do not cover the suspended load range. It appears from tables (22 to 24), (where the particles of the materials used are very small) that the ratios of q_s obs : q_s cal. are very large. It can be concluded, thus that most of the sediment was washed out as suspended load. In addition, the bed load formulae were based on experimental data conducted under steady flow conditions, while the washout experiments were conducted under the case of spatially varied flow.

5.5 Equations 4.1, 4.2, 4.3 and 4.4, can be used to calculate the sediment discharge q_s c.f.s/ft; knowing q_s and the effective volume of dam (ft^3/ft), the time of washout of that dam can be estimated.

5.6 Equation 4.5 can be used to calculate the time scale for the washout problem.

5.7 Two different types of erosion occured during the washout process. In the case of gravels, erosion progressed with a flat or mild slope while in the case of sands the process of washout was accompanied by a steep slope.

APPENDICES

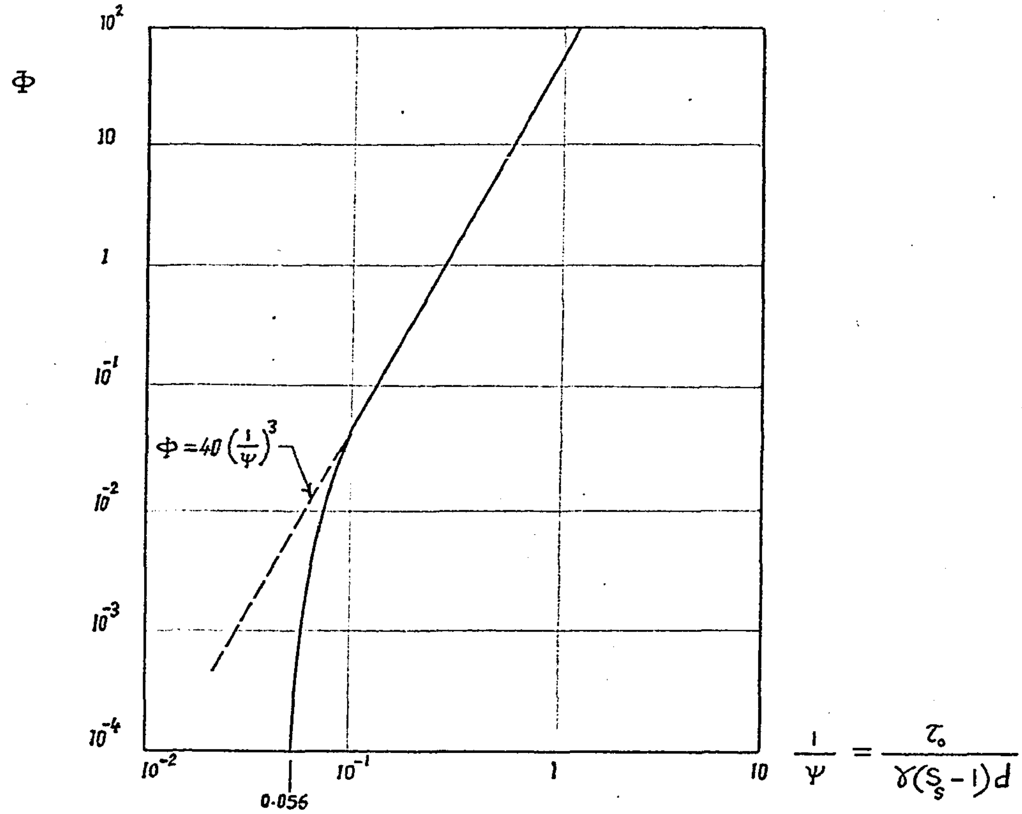


Fig. 1 The Einstein bed load function

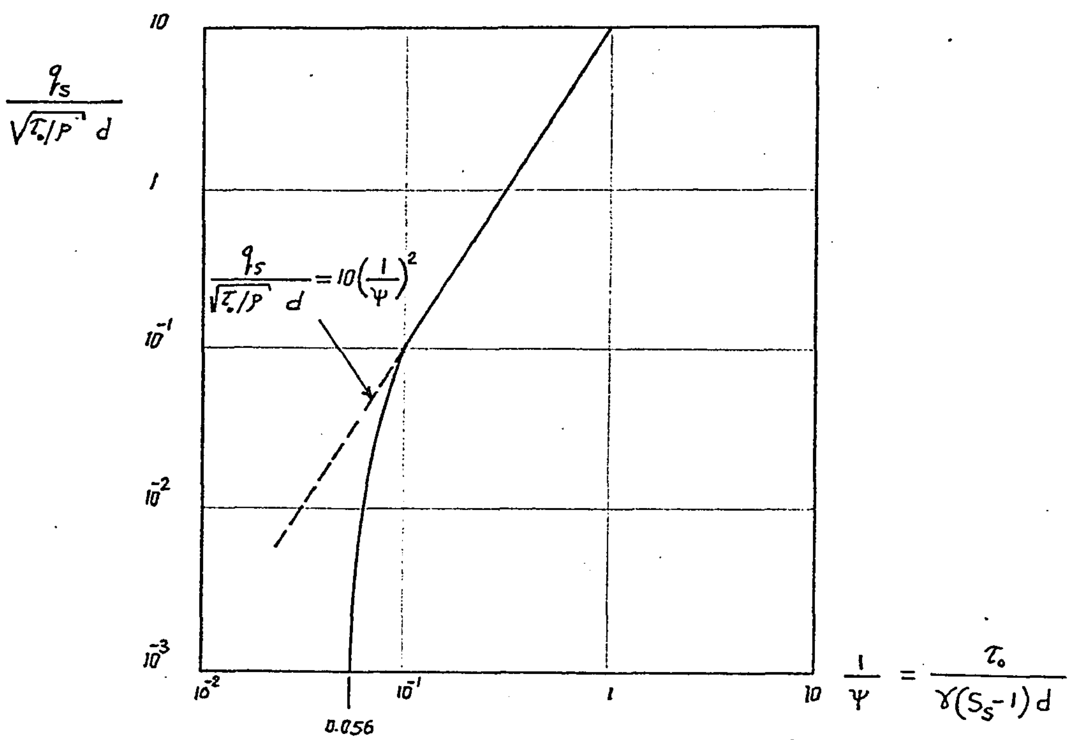
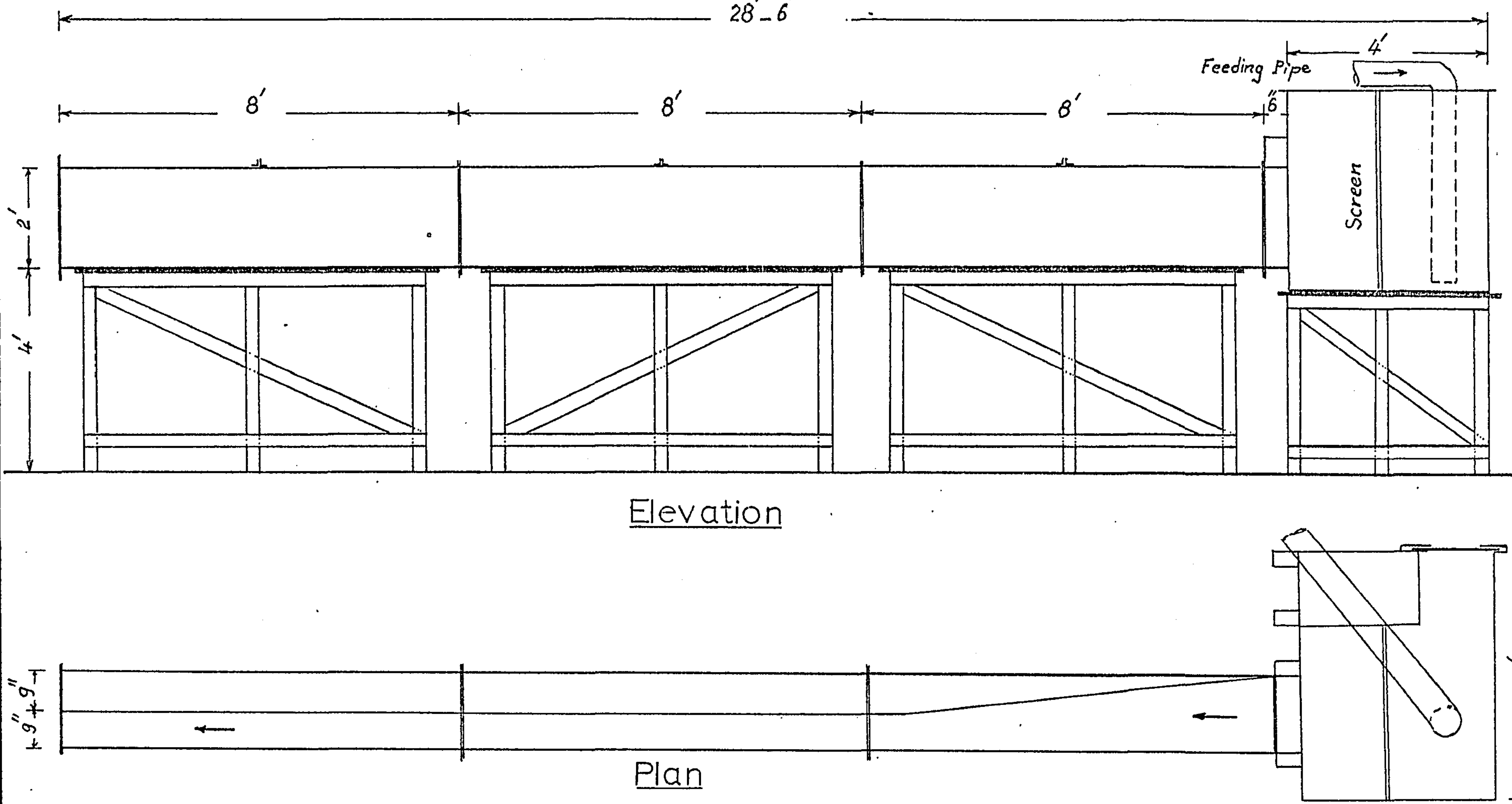


Fig. 2 The Kalinske bed load function



Scale 3 ft. to 1 in.

Fig. 3 9" Wide Channel

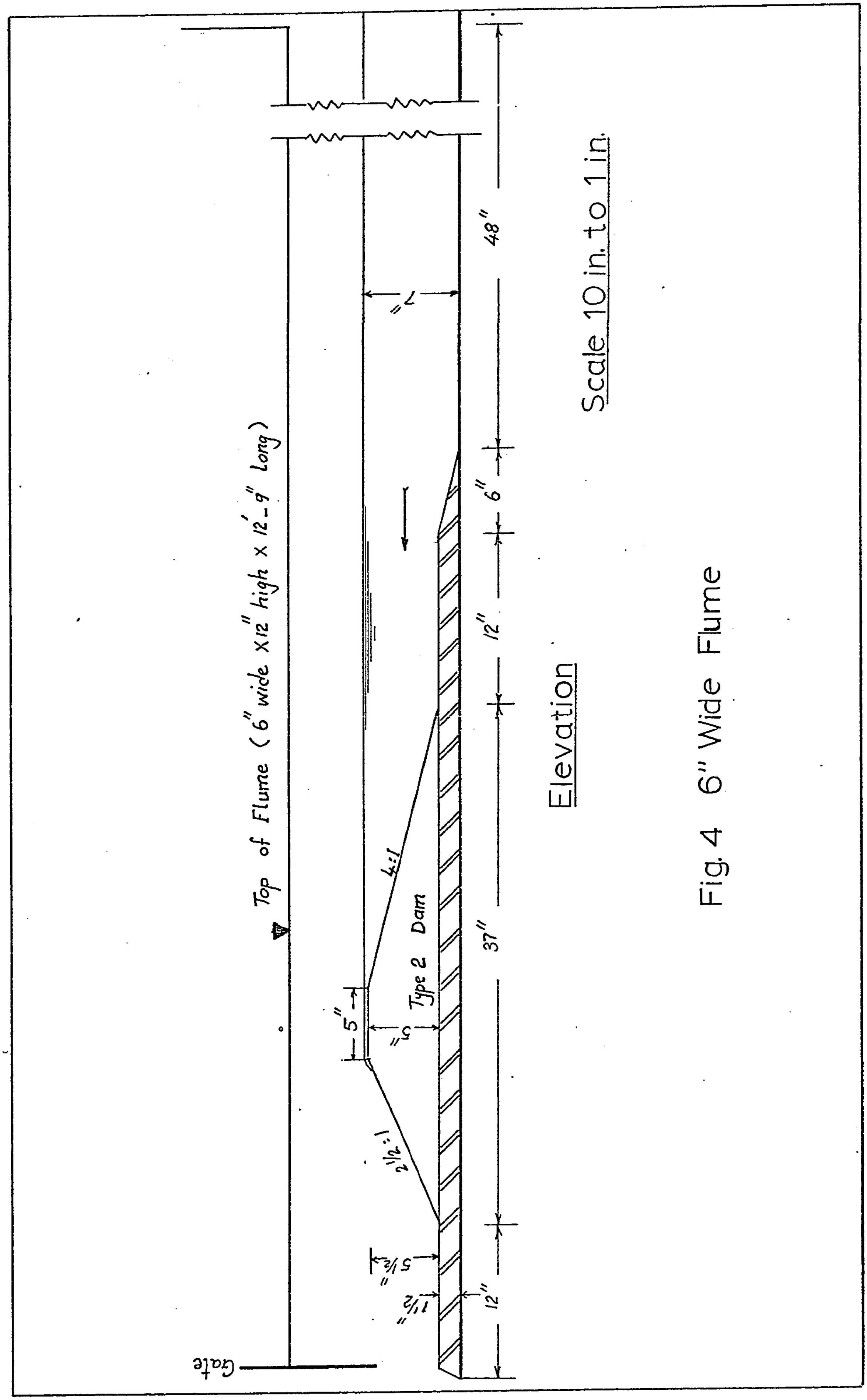
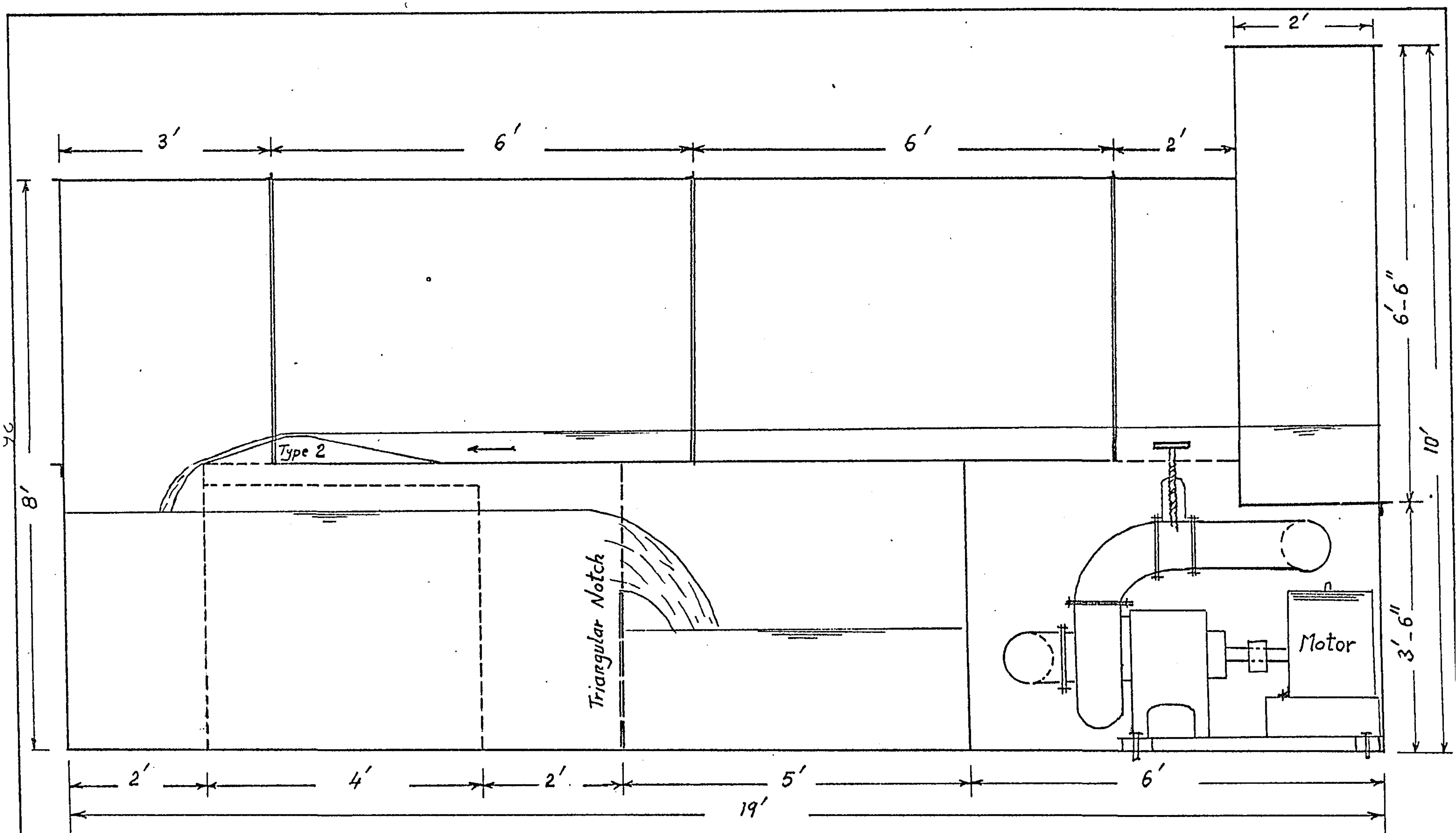
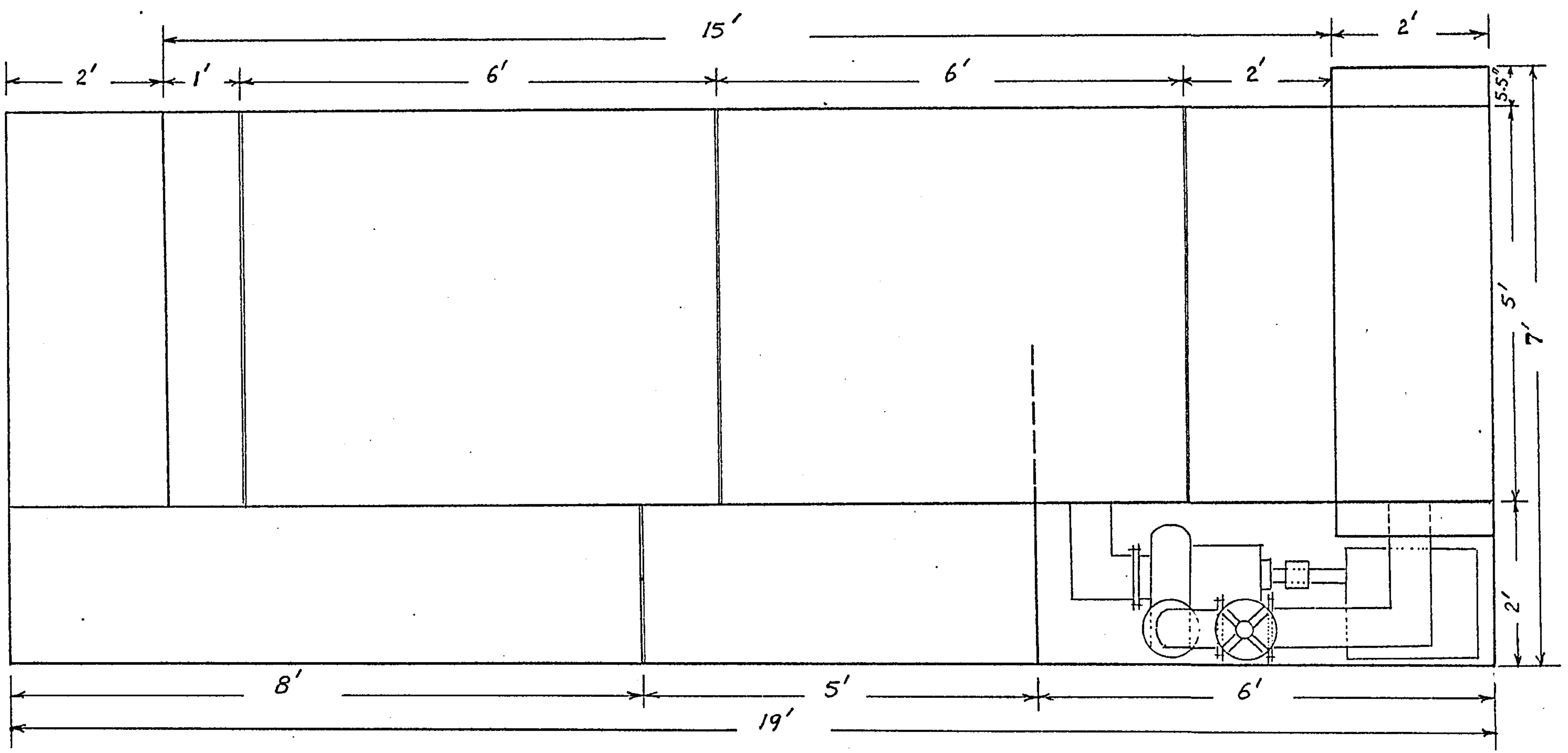


Fig. 4 6" Wide Flume



Scale 2 ft. to 1 in.

Fig. 5 Elevation Of 60" Wide Channel



Scale 2ft. to 1in.

Fig. 6 Plan Of 60" Wide Channel

Fig. 7 Shapes Of Fuseplugs Tested

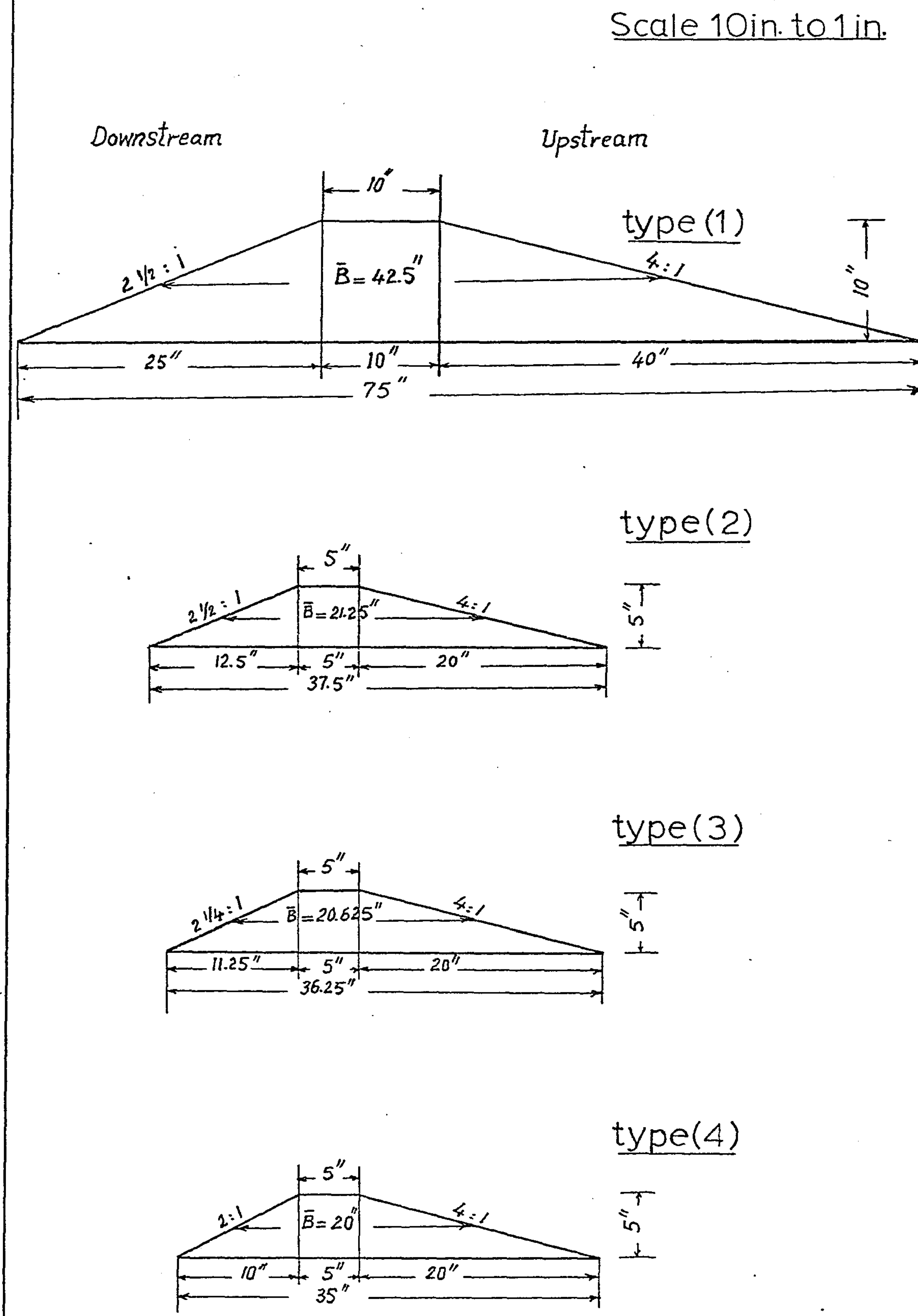


Fig. 7

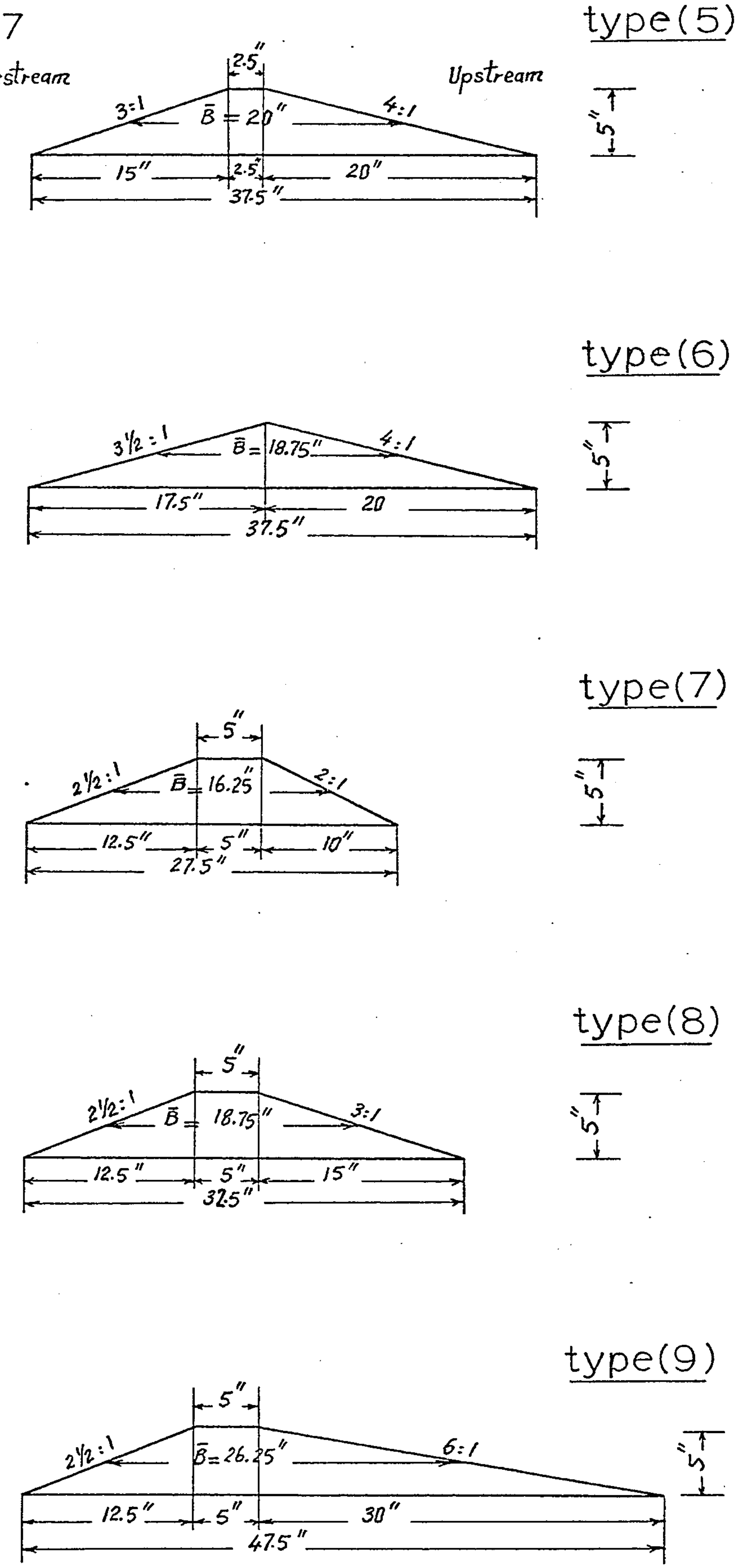
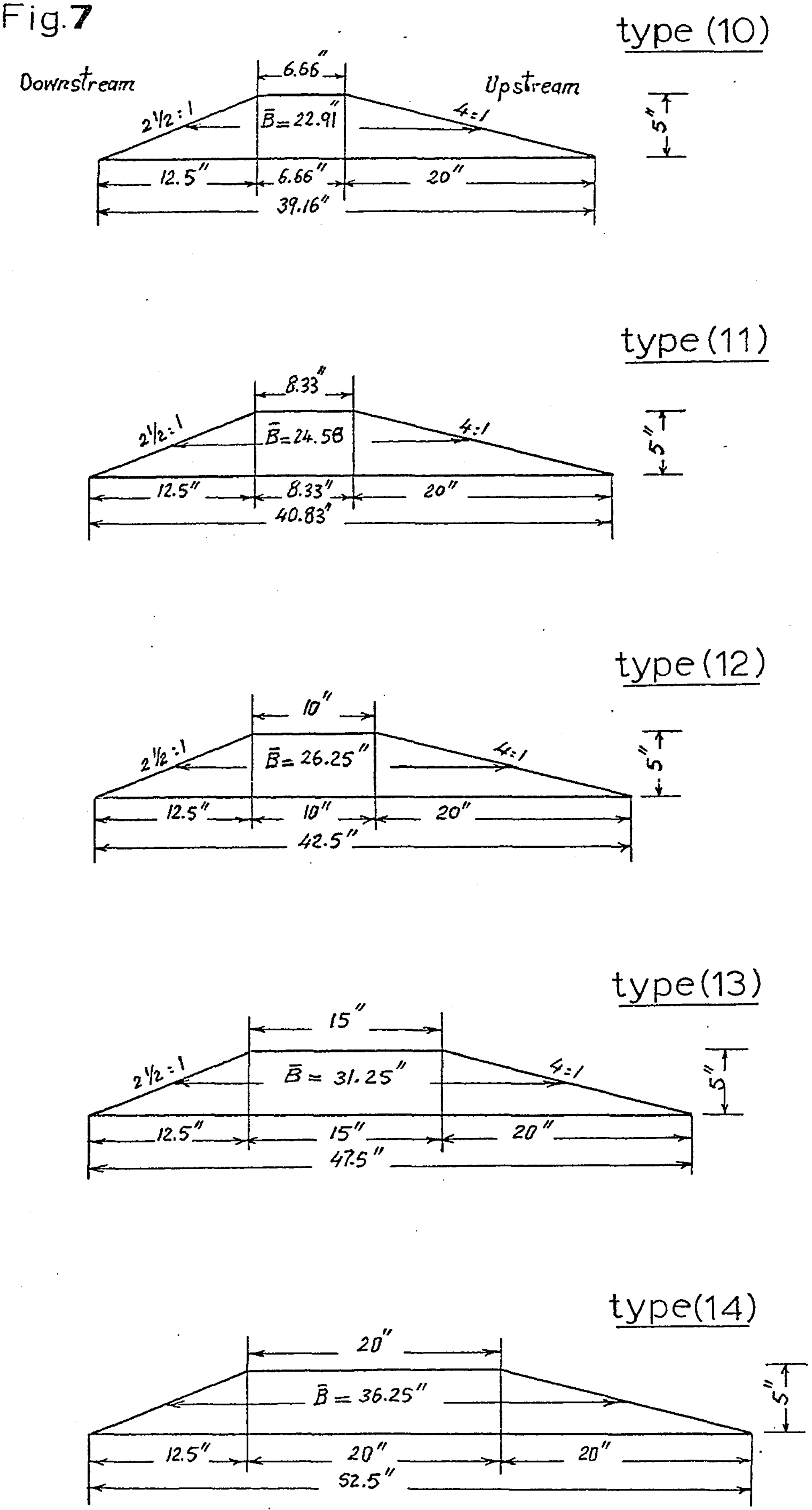

type(5)
Downstream
Upstream
2.5"
3:1
4:1
B̄ = 20"
5"
15"
2.5"
20"
37.5"
type(6)
3½ : 1
B̄ = 18.75"
4:1
5"
17.5"
20
37.5"
type(7)
5"
2½ : 1
B̄ = 16.25"
2:1
5"
12.5"
5"
10"
27.5"
type(8)
5"
2½ : 1
B̄ = 18.75"
3:1
5"
12.5"
5"
15"
32.5"
type(9)
5"
2½ : 1
B̄ = 26.25"
6:1
5"
12.5"
5"
30"
47.5"

Fig.7


type (10)
Downstream
Upstream
6.66"
2½:1
B̄=22.91"
4:1
5"
12.5"
6.66"
20"
39.16"
type (11)
8.33"
2½:1
B̄=24.58
4:1
5"
12.5"
8.33"
20"
40.83"
type (12)
10"
2½:1
B̄= 26.25"
4:1
5"
12.5"
10"
20"
42.5"
type (13)
15"
2½:1
B̄ = 31.25"
4:1
5"
12.5"
15"
20"
47.5"
type (14)
20"
B̄ = 36.25"
5"
12.5"
20"
20"
52.5"

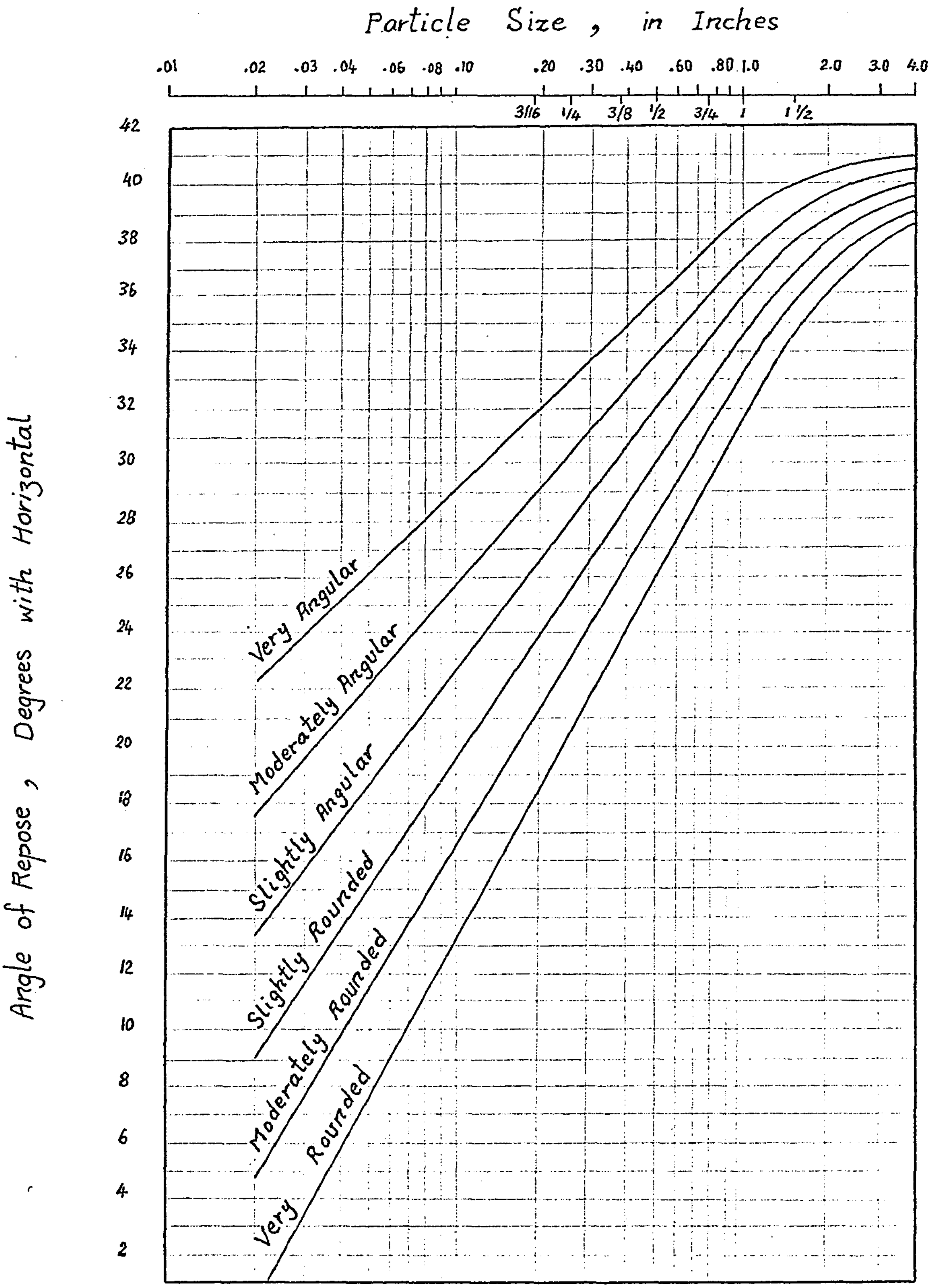


Fig. 8 Angle of repose of non-cohesive material

(U.S.Bureau of Reclamation)

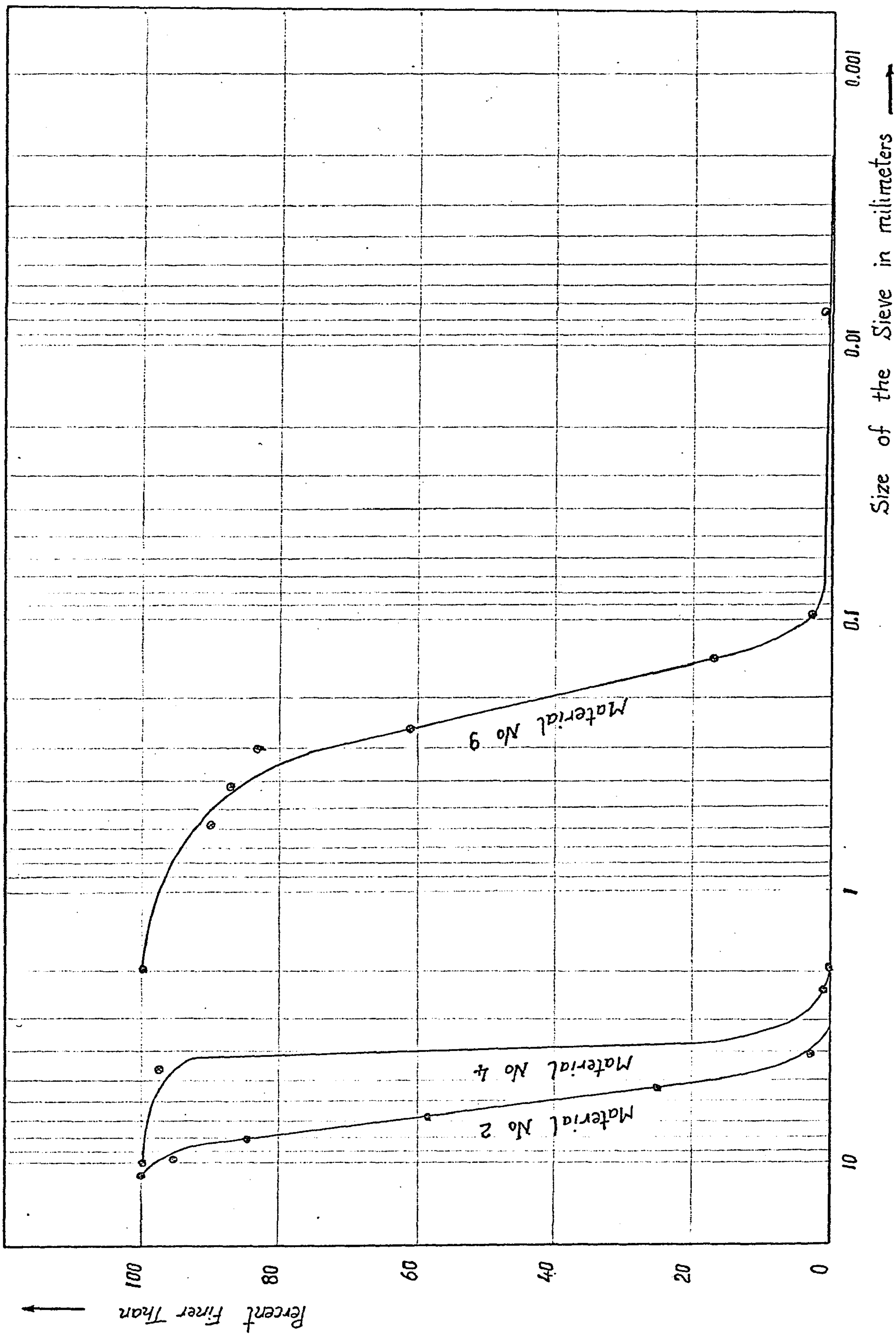


Fig.9 Sieve analysis of the materials used

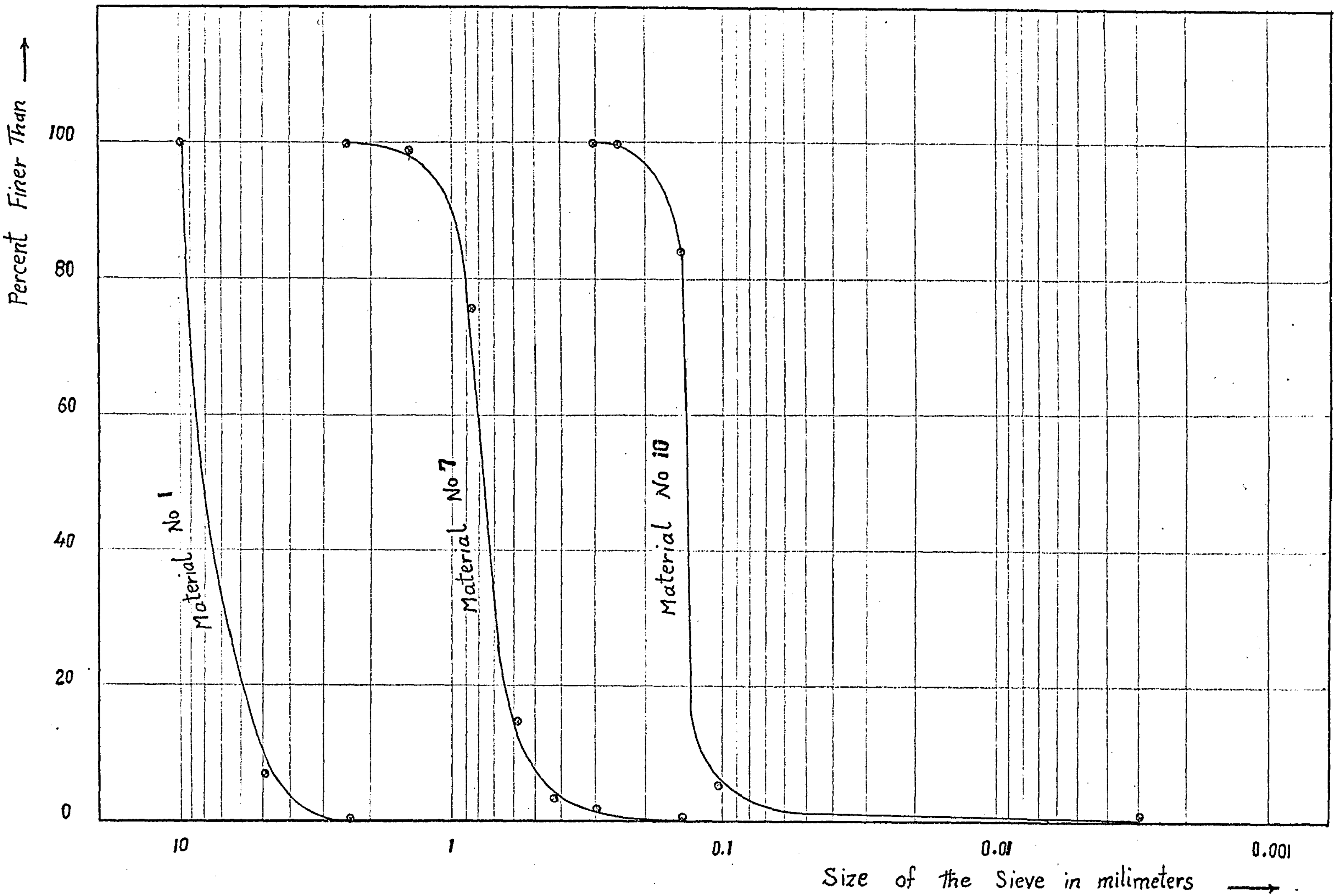


Fig.9 Sieve analysis of the materials used

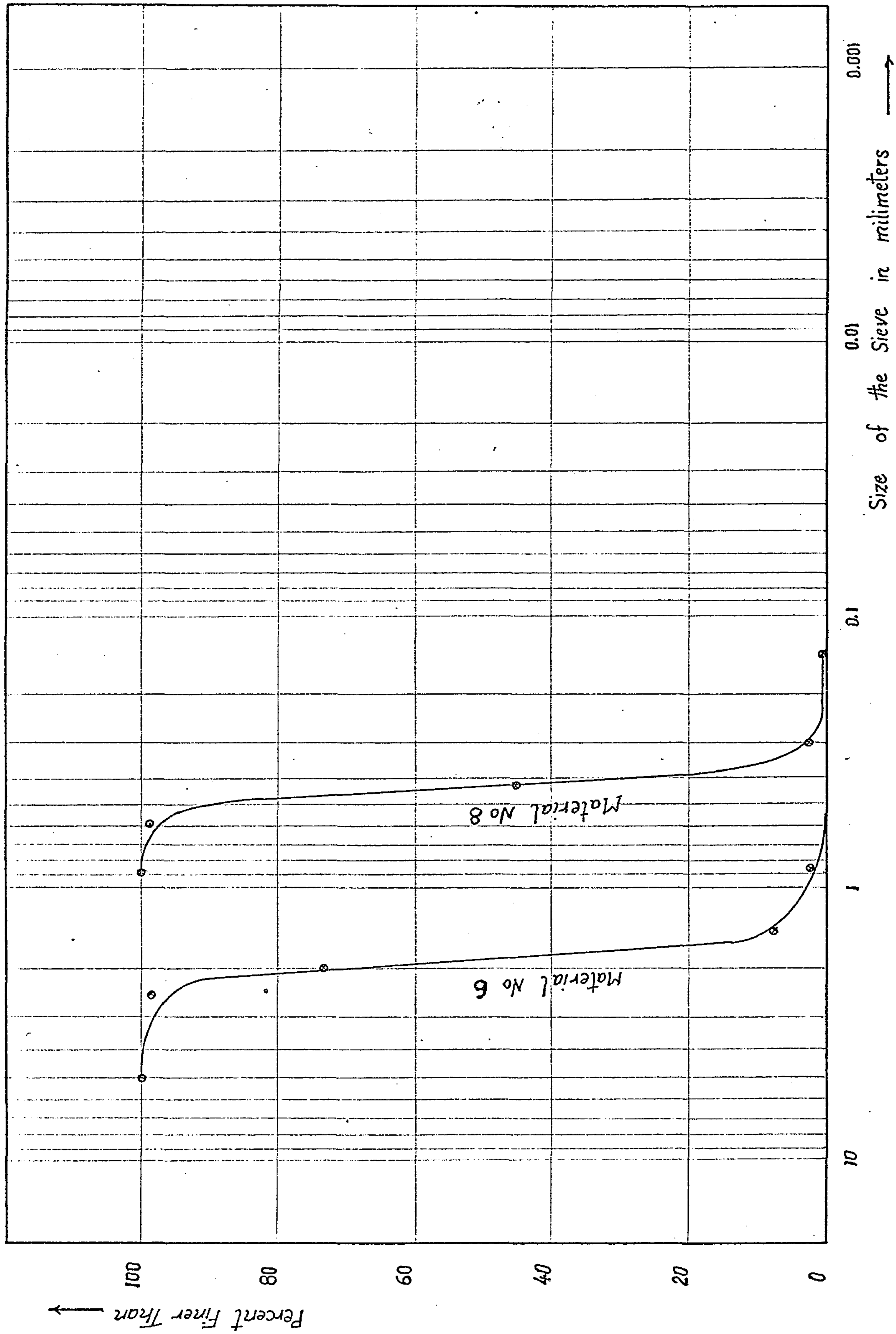


Fig.9 Sieve analysis of the materials used

Fig.10

Exp. No. 2-HO-9"

EROSION OF DAM AT CONSTANT UPSTREAM WATER LEVEL WITH DOWNSTREAM SUPERCRITICAL FLOW.

Type (1) dam

Upstream water level maintained 0" above fuse plug crest

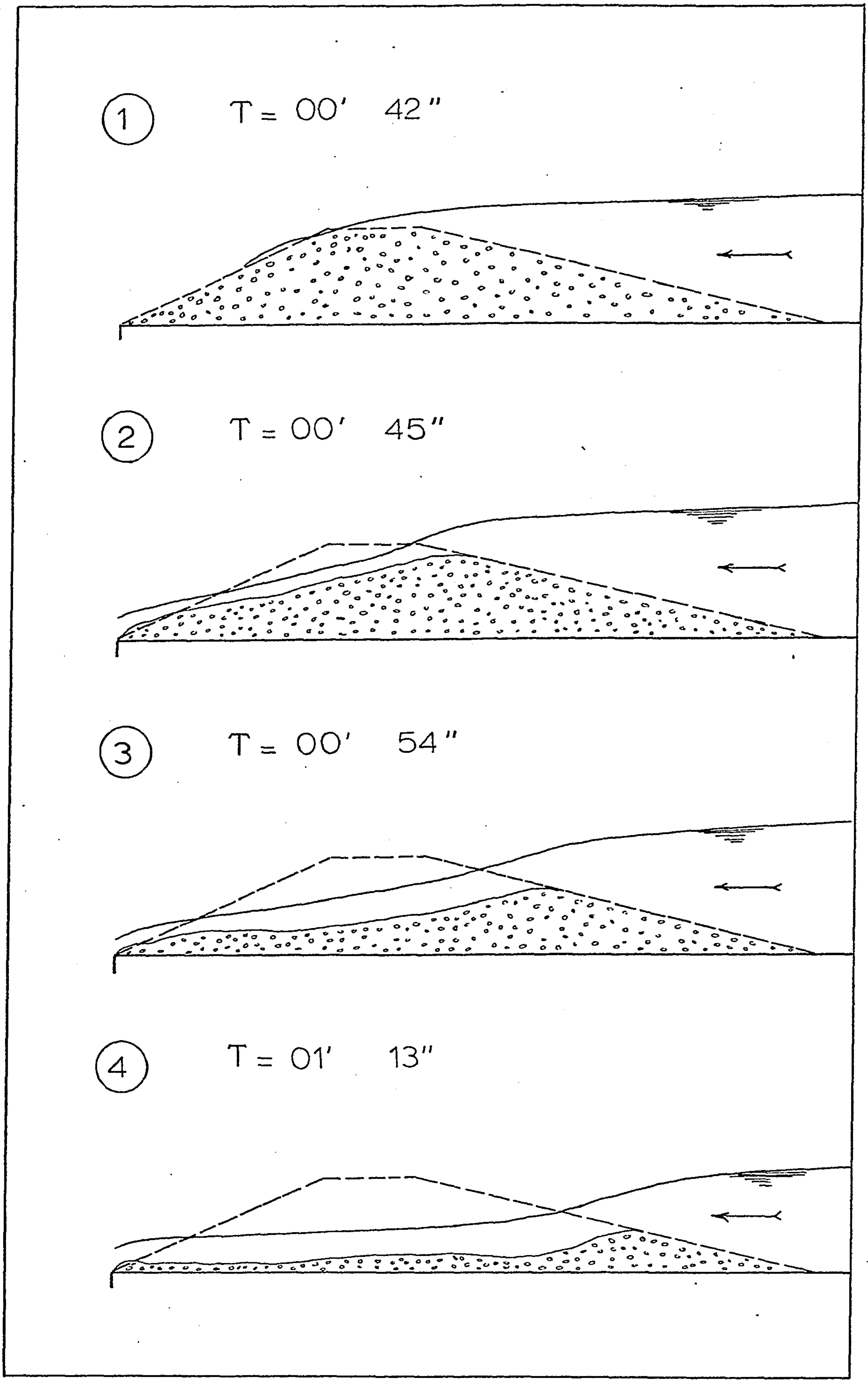
Material No. 2

$S_s = 2.57$

$n = 41.0\%$

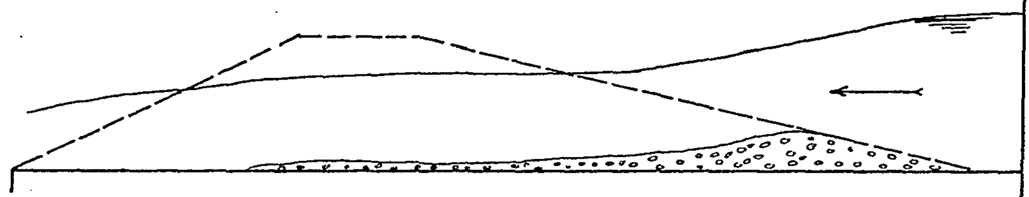
$\alpha = 0.532$

$d = 6.35$ mm.



1
T = 00' 42"
2
T = 00' 45"
3
T = 00' 54"
4
T = 01' 13"

(5) T = 01' 53''



(6) T = 02' 17''

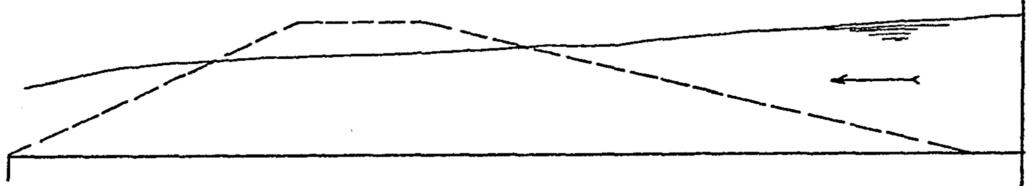


Fig.11

Exp. No. 2-H2-9"

EROSION OF DAM AT CONSTANT UPSTREAM WATER LEVEL WITH DOWNSTREAM SUPERCRITICAL FLOW.

Type (1) dam

Upstream water level maintained 2" above fuse plug crest

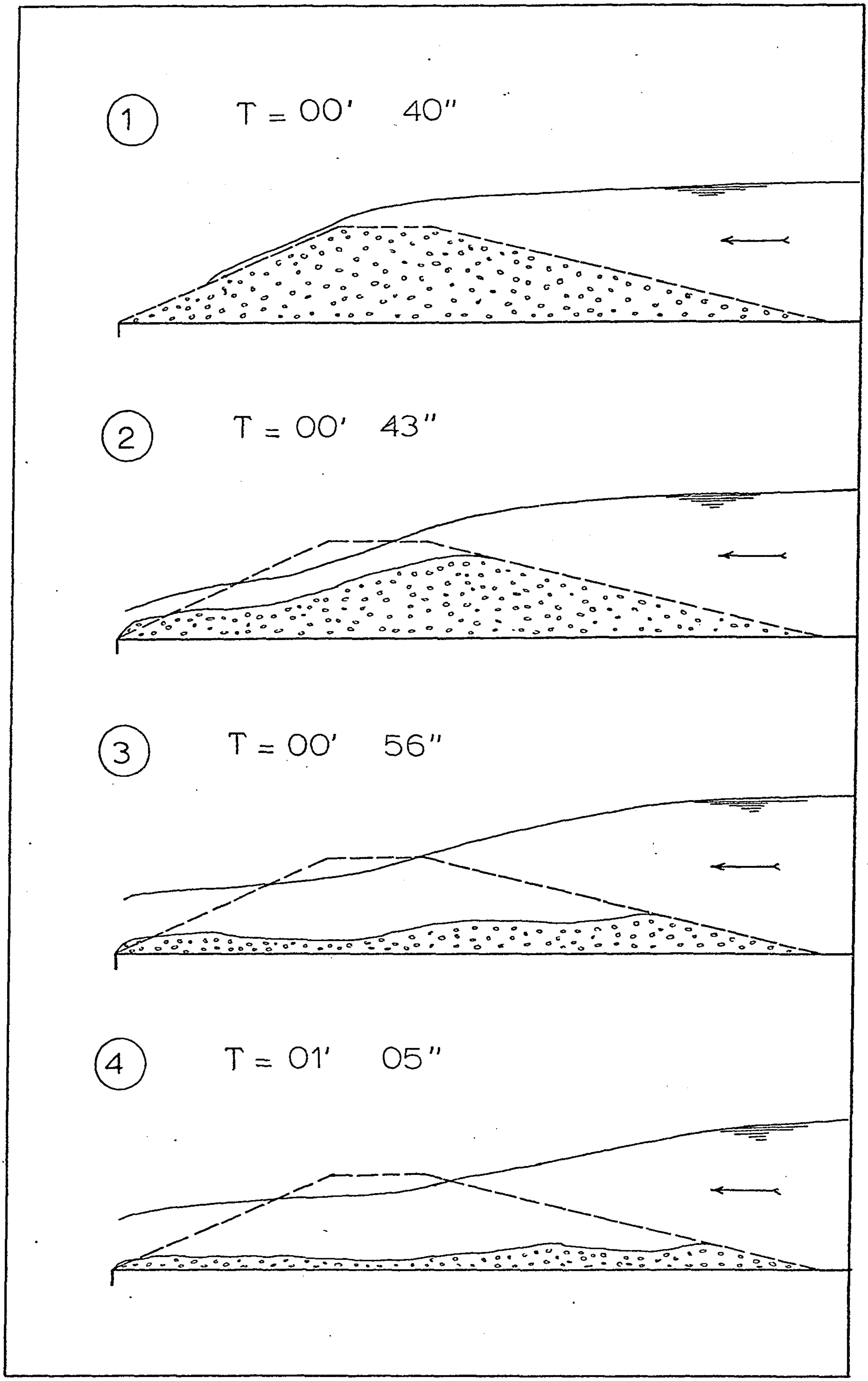
Material No. 2

S_s = 2.57

n = 41.0%

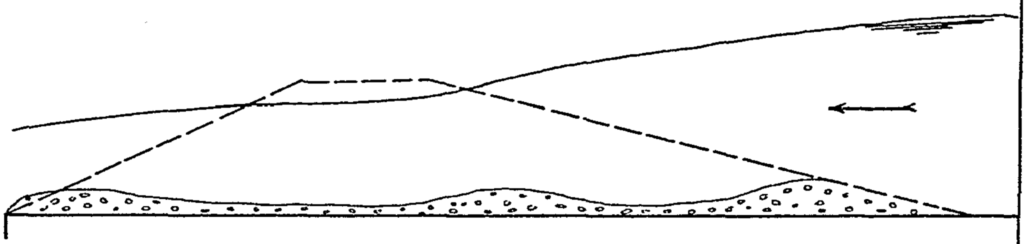
α = 0.532

d = 6.35 mm.



1
T = 00' 40"
2
T = 00' 43"
3
T = 00' 56"
4
T = 01' 05"

(5) T = 01' 15"



(6) T = 00' 22"

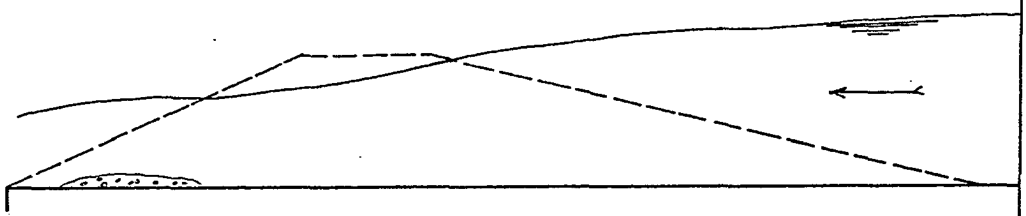


Fig. 12

Exp. No. 2-H4-9"

EROSION OF DAM AT CONSTANT UPSTREAM WATER LEVEL WITH DOWNSTREAM SUPERCRITICAL FLOW.

Type (1) dam

Upstream water level maintained 4" above fuse plug crest

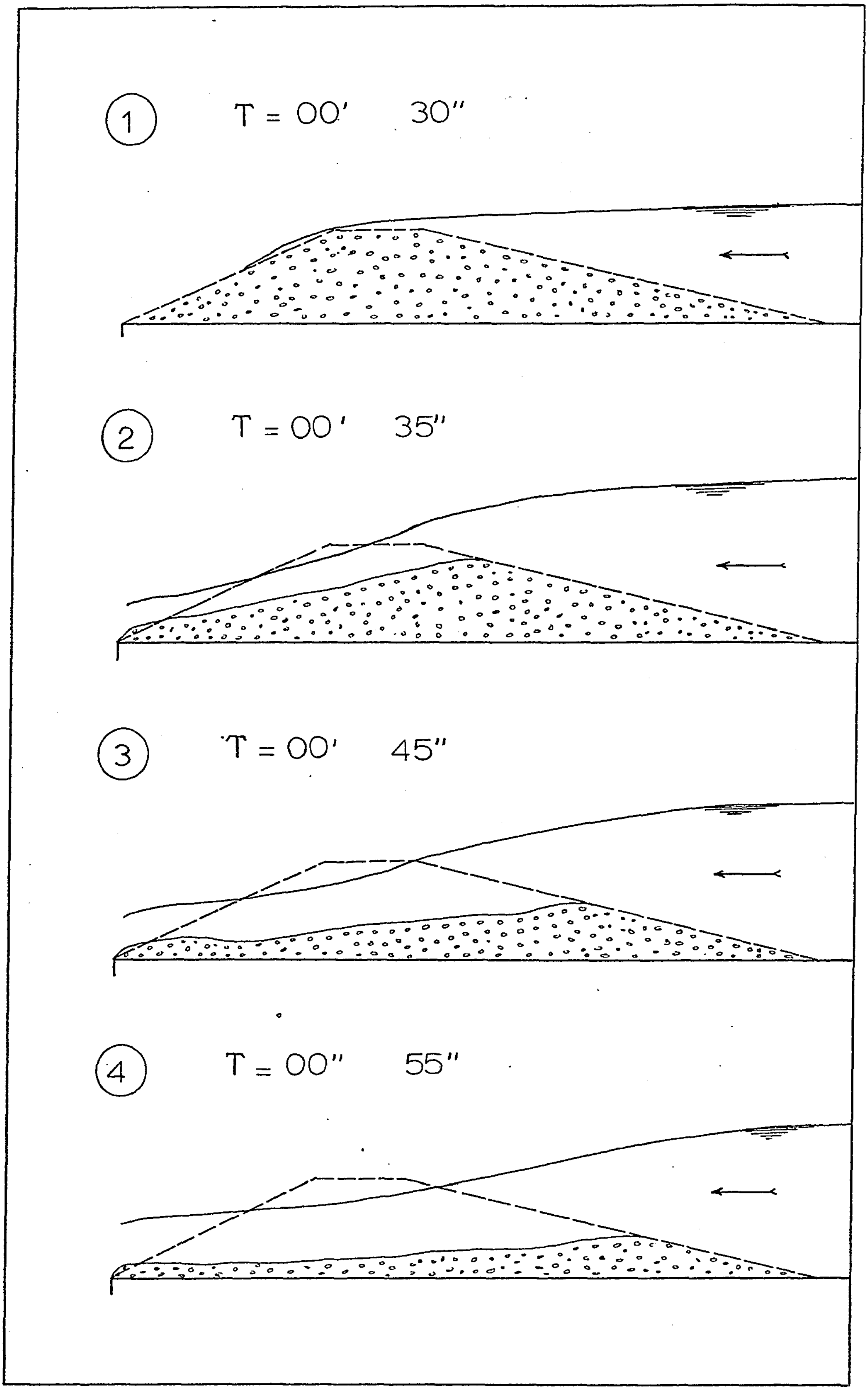
Material No. 2

$S_s = 2.57$

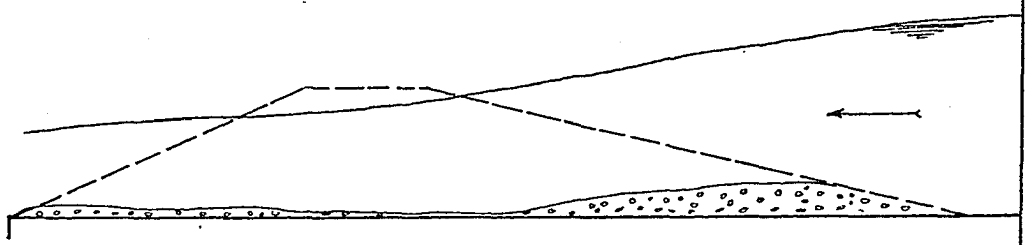
$n = 41.0\%$

$\alpha = 0.532$

$d = 6.35$ mm.


1
T = 00' 30"
2
T = 00' 35"
3
T = 00' 45"
4
T = 00" 55"

(5) T = 01' 03"



(6) T = 01' 15"

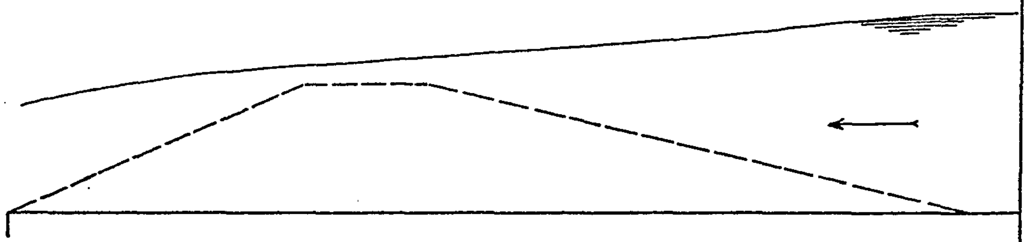


Fig.13

Exp. No. 3-HO-9"

EROSION OF DAM AT CONSTANT UPSTREAM WATER LEVEL WITH DOWNSTREAM SUPERCRITICAL FLOW.

Type (1) dam

Upstream water level maintained 0" above fuse plug crest

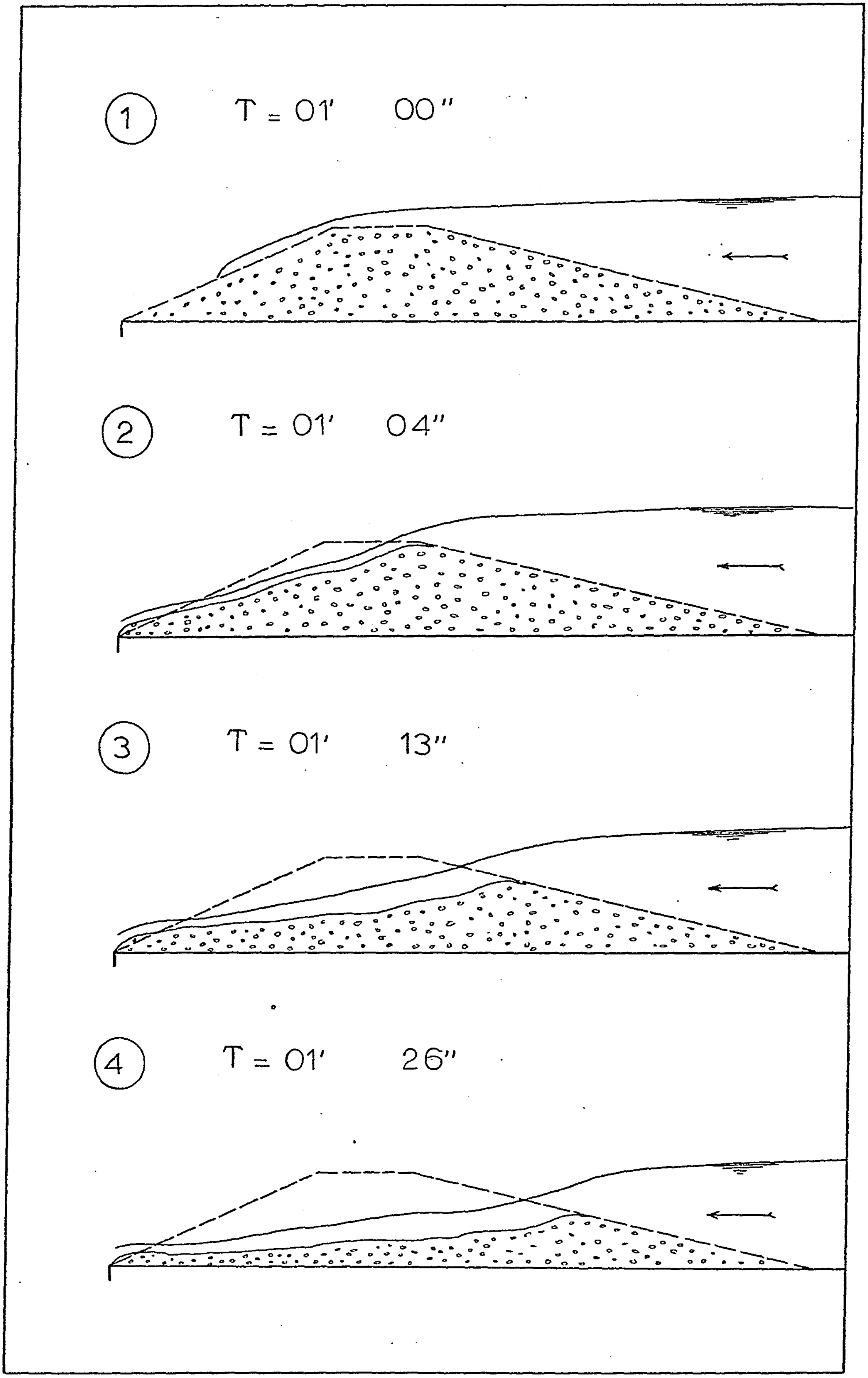
Material No. 3

S_s = 2.70

n = 40.0%

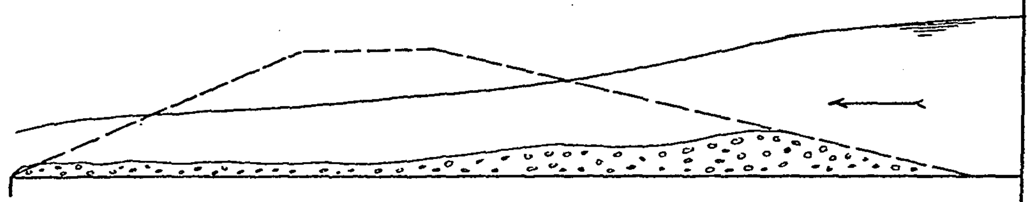
α = 0.454

d = 4.60 mm.



1 T = 01' 00"
2 T = 01' 04"
3 T = 01' 13"
4 T = 01' 26"

(5) T = 01' 56"



(6) T = 02' 53"

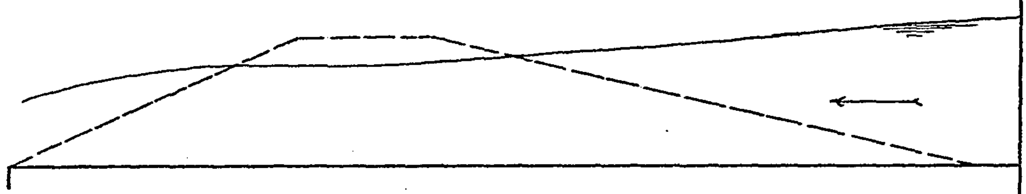


Fig.14

Exp. No. 3-H2-9"

EROSION OF DAM AT CONSTANT UPSTREAM WATER LEVEL WITH DOWNSTREAM SUPERCRITICAL FLOW.

Type (1) dam

Upstream water level maintained 2" above fuse plug crest

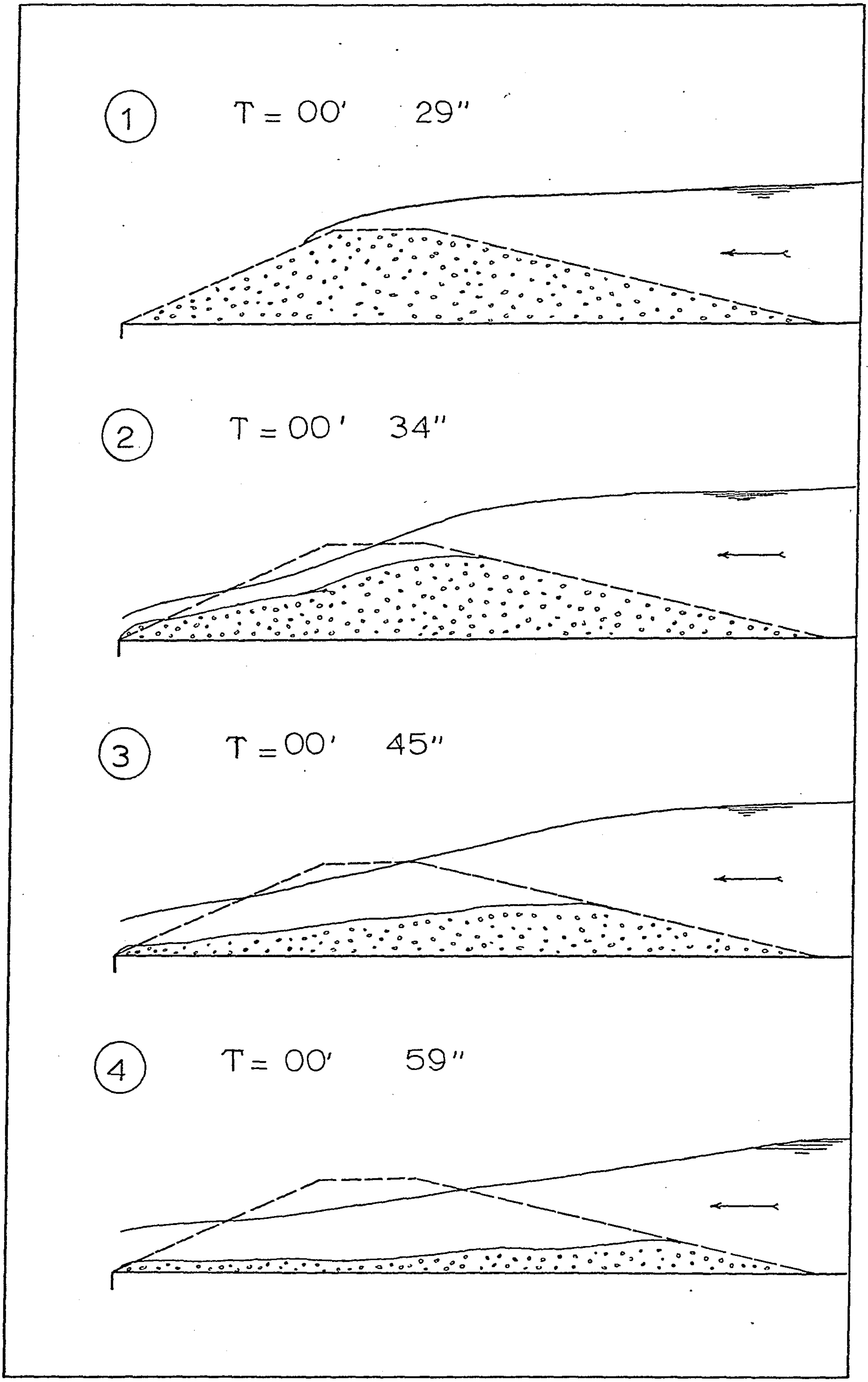
Material No. 3

S_s = 2.70

n = 40.0%

α = 0.454

d = 4.60 mm.


1 T = 00' 29"
2 T = 00' 34"
3 T = 00' 45"
4 T = 00' 59"

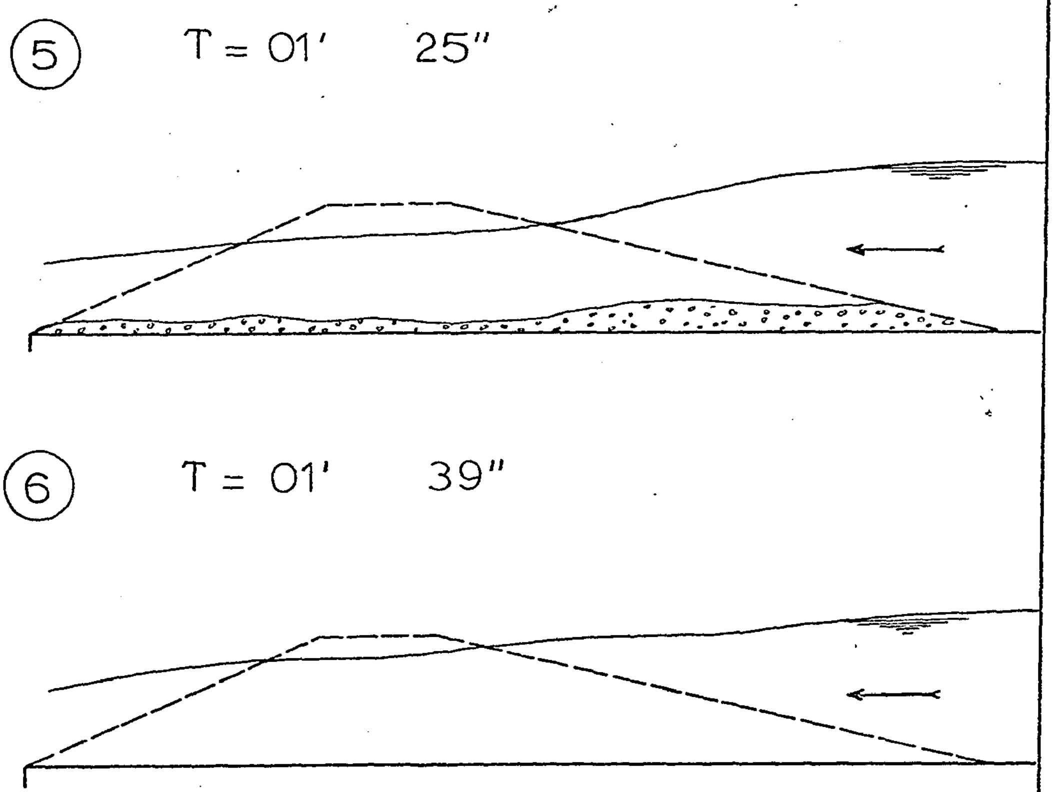

5
T = 01' 25"
6
T = 01' 39"

Fig.15

Exp. No. 3-H4-9"

EROSION OF DAM AT CONSTANT UPSTREAM WATER LEVEL WITH DOWNSTREAM SUPERCRITICAL FLOW.

Type (1) dam

Upstream water level maintained 4" above fuse plug crest

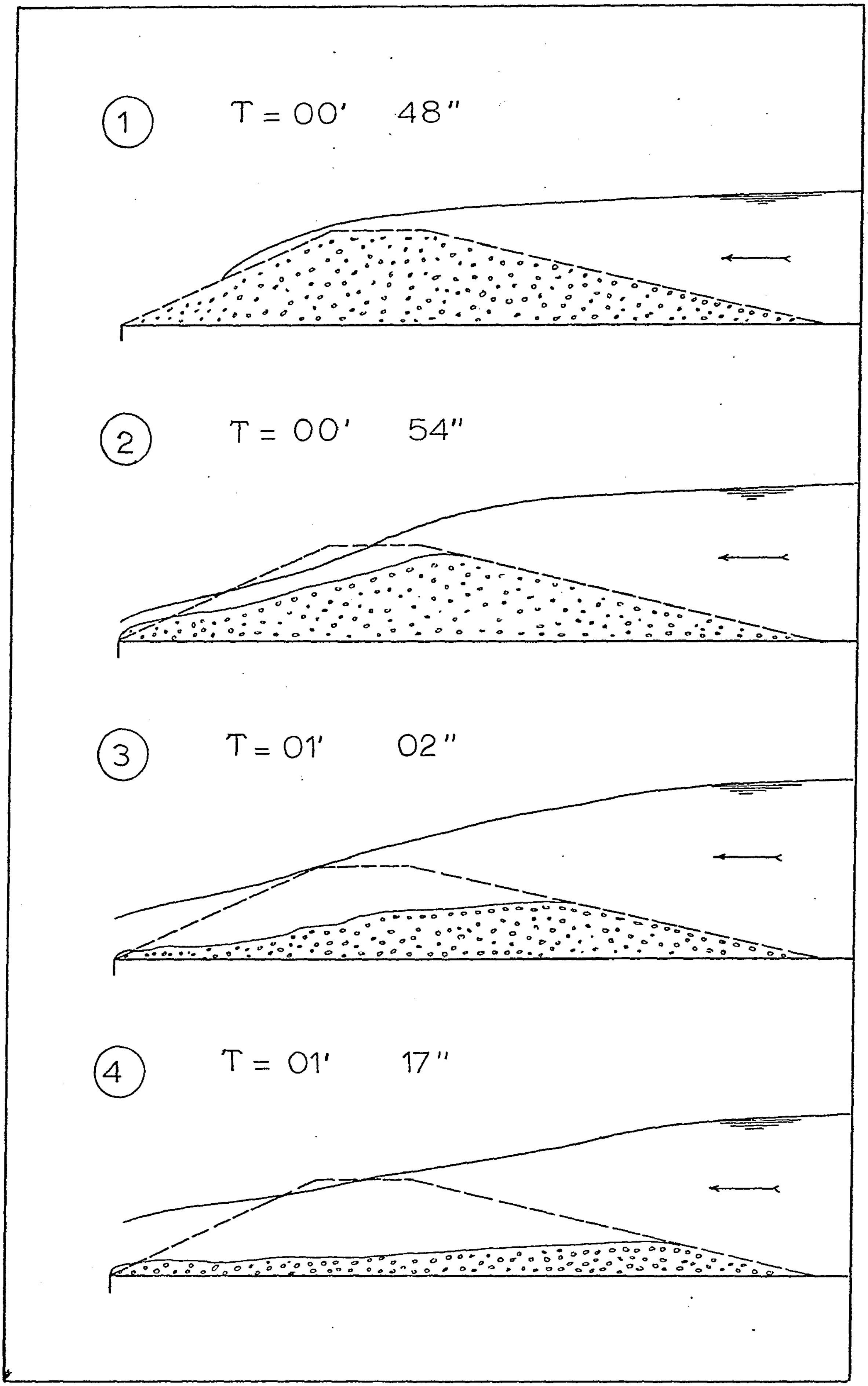
Material No. 3

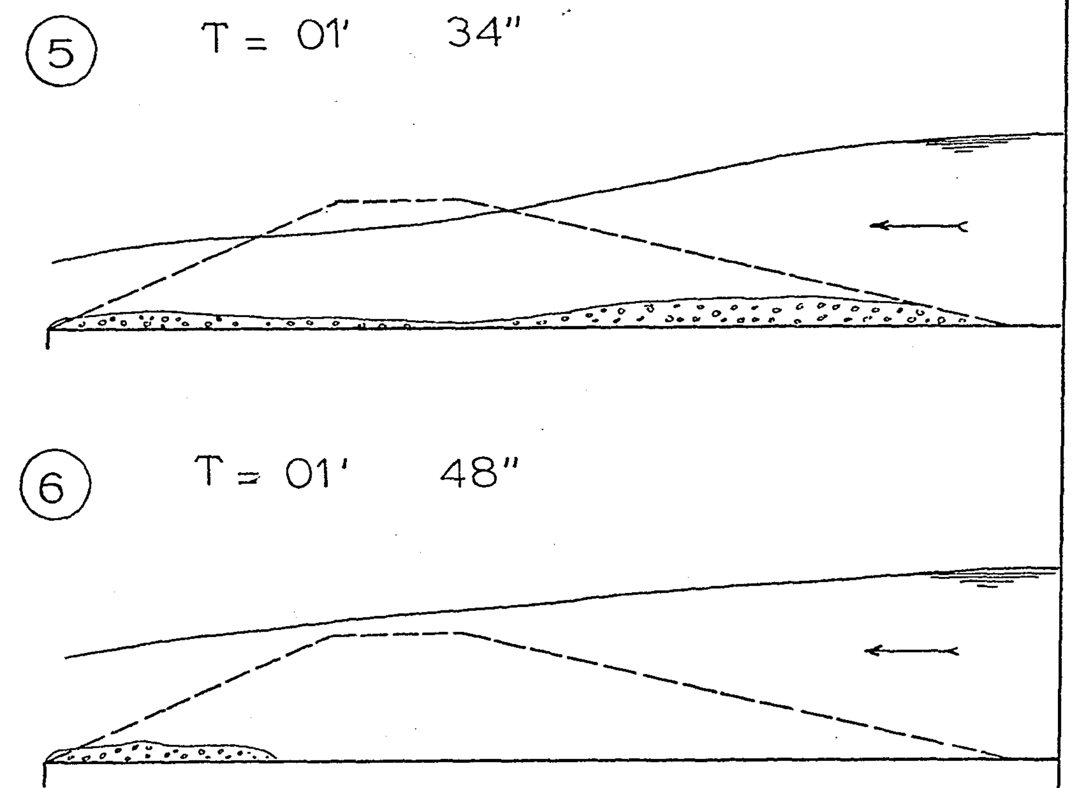
$S_s = 2.70$

$n = 40.0\%$

$\alpha = 0.454$

$d = 4.60$ mm.


1
T = 00' 48"
2
T = 00' 54"
3
T = 01' 02"
4
T = 01' 17"



5
T = 01' 34"
6
T = 01' 48"

Fig.16

Exp. No. 5-HO-9"

EROSION OF DAM AT CONSTANT UPSTREAM WATER

LEVEL WITH DOWNSTREAM SUPERCRITICAL FLOW.

Type (1) dam

Upstream water level maintained 0" above fuse plug crest

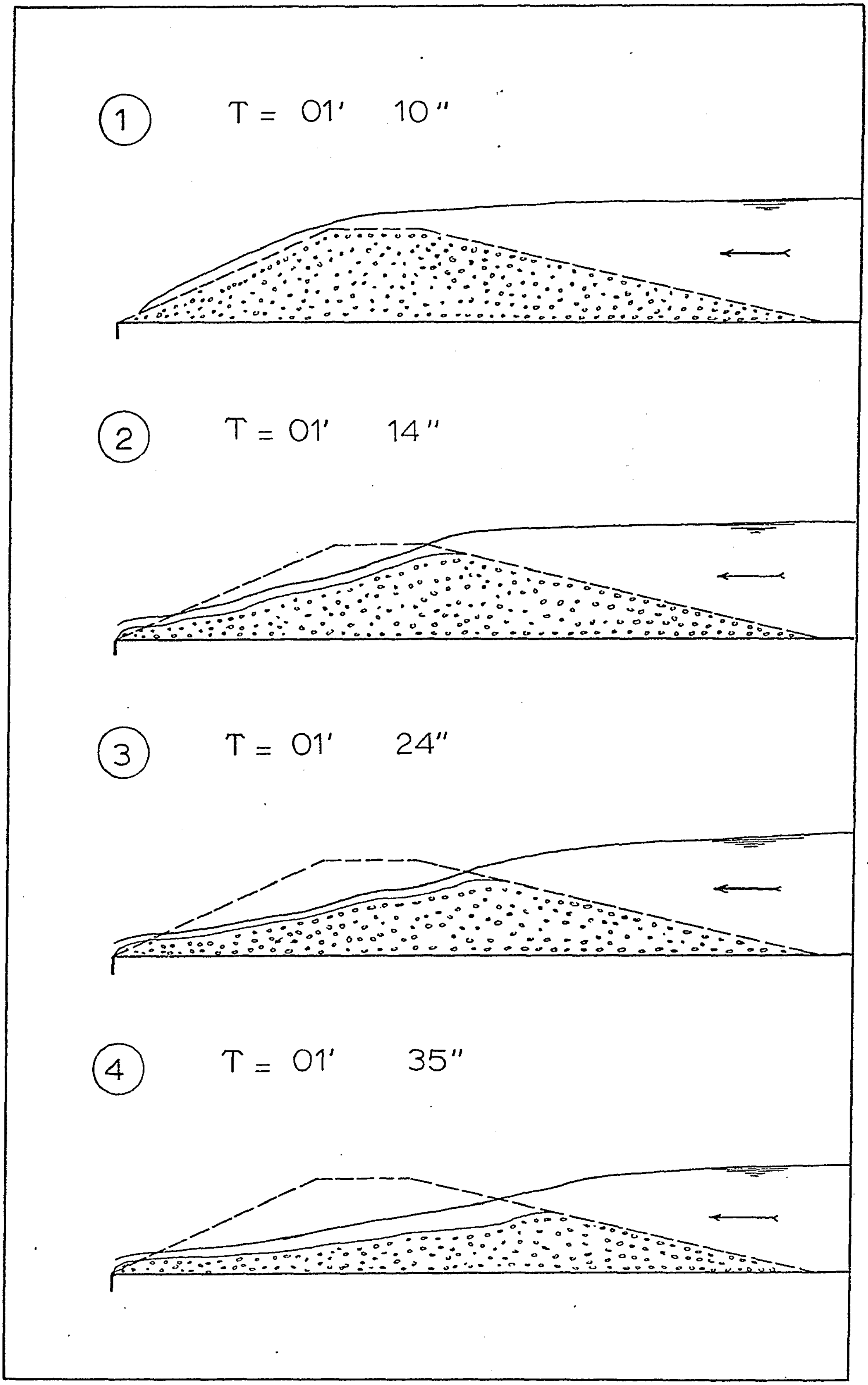
Material No. 5

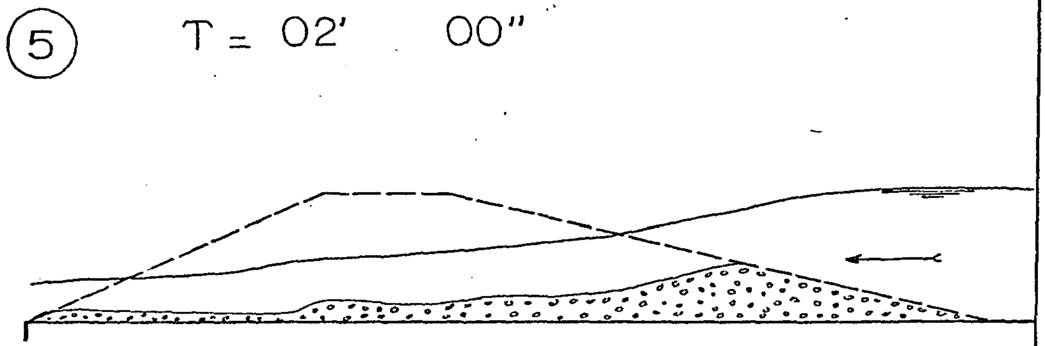
$S_s = 2.77$

$n = 40.0\%$

$\alpha = 0.267$

$d = 2.20$ mm.


1
T = 01' 10"
2
T = 01' 14"
3
T = 01' 24"
4
T = 01' 35"


5
T = 02' 00"

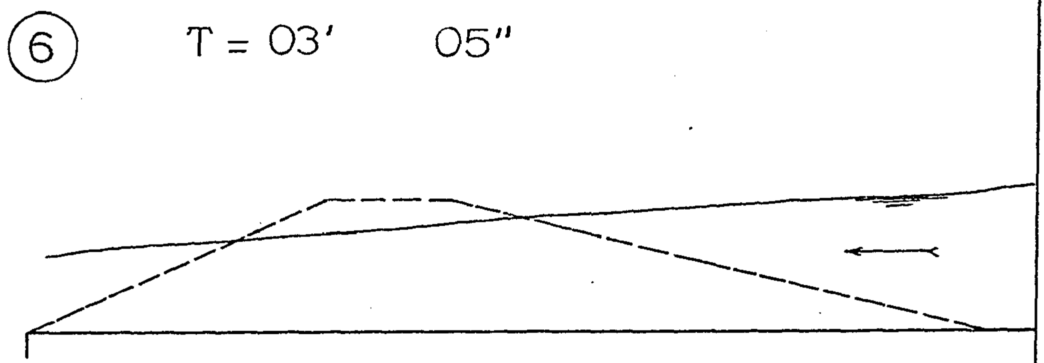

6
T = 03' 05"

Fig.17

Exp. No. 5-H2-9"

EROSION OF DAM AT CONSTANT UPSTREAM WATER LEVEL WITH DOWNSTREAM SUPERCRITICAL FLOW.

Type (1) dam

Upstream water level maintained 2" above fuse plug crest

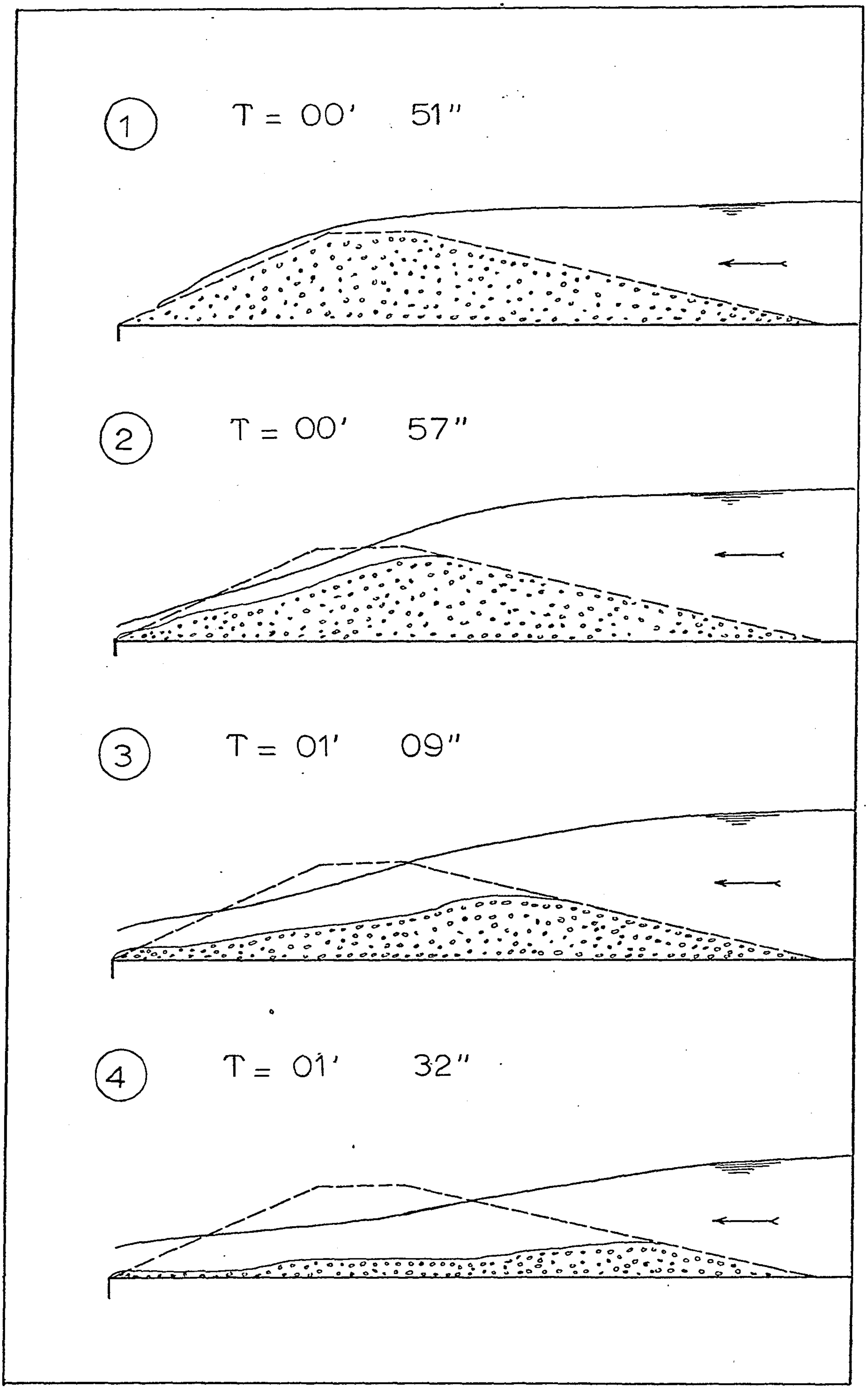
Material No. 5

S_s = 2.77

n = 40.0%

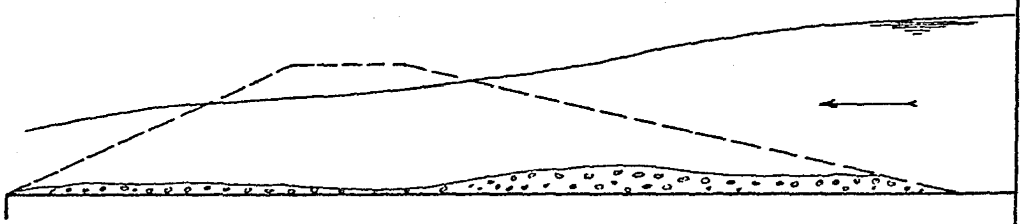
α = 0.267

d = 2.20 mm.



1 T = 00' 51"
2 T = 00' 57"
3 T = 01' 09"
4 T = 01' 32"

(5) T = 02' 00"



(6) T = 02' 21"

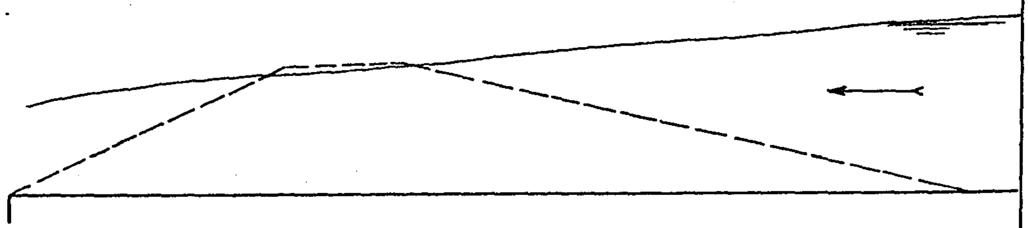


Fig.18

Exp. No. 5-H4-9"

EROSION OF DAM AT CONSTANT UPSTREAM WATER LEVEL WITH DOWNSTREAM SUPERCRITICAL FLOW.

Type (1) dam

Upstream water level maintained 4" above fuse plug crest

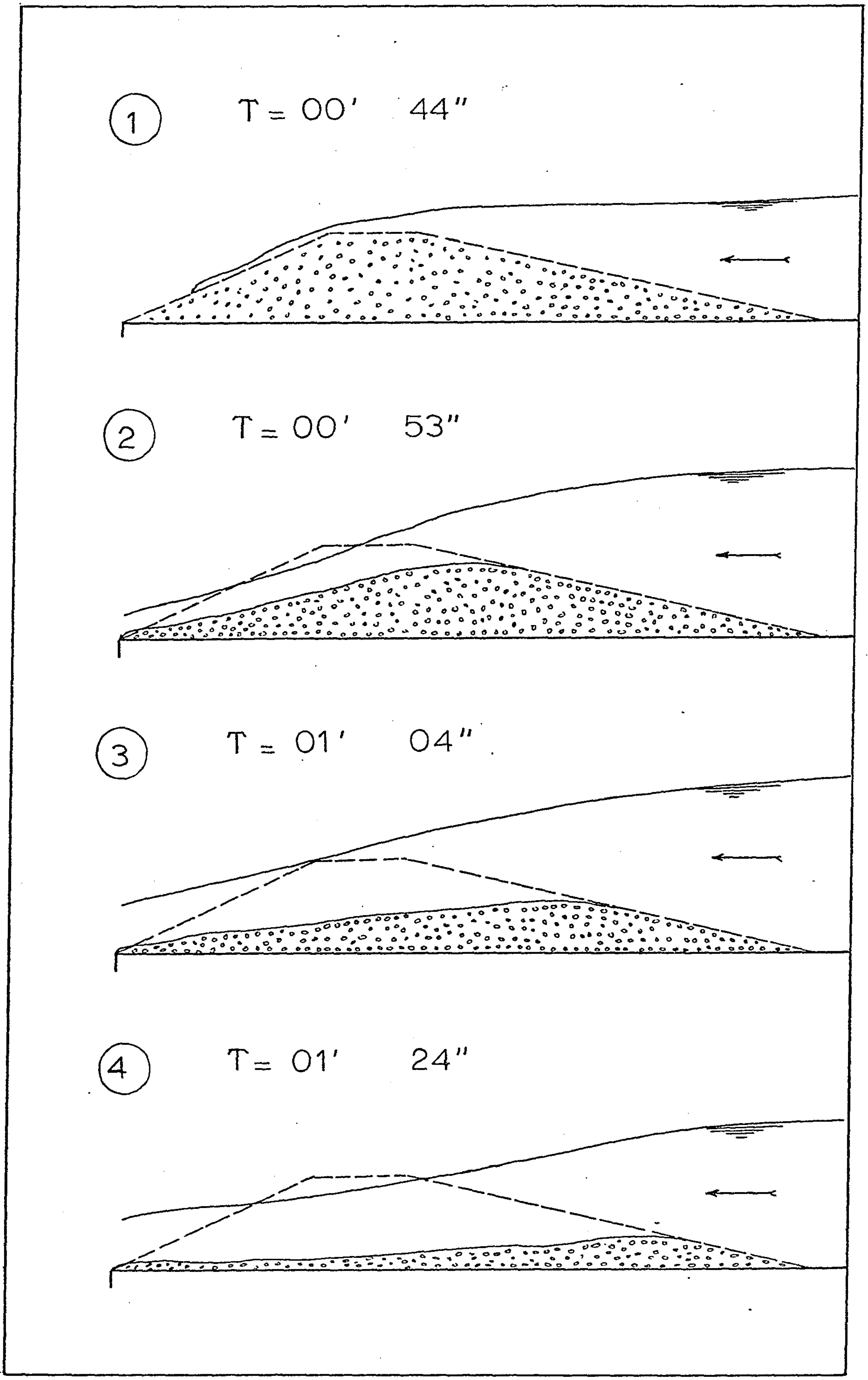
Material No. 5

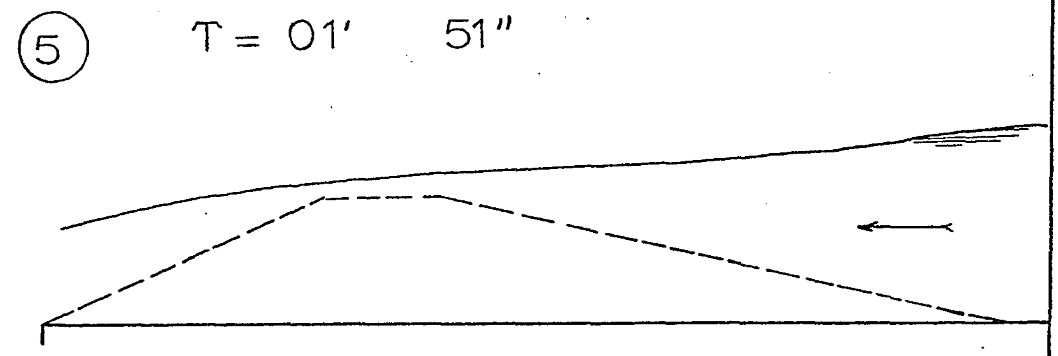
S_s = 2.77

n = 40.0%

$\propto$ = 0.267

d = 2.20 mm.


1
T = 00' 44"
2
T = 00' 53"
3
T = 01' 04"
4
T= 01' 24"



5
T = 01' 51"

Fig.19

Exp. No. 7-HO-9"

EROSION OF DAM AT CONSTANT UPSTREAM WATER LEVEL WITH DOWNSTREAM SUPERCRITICAL FLOW.

Type (1) dam

Upstream water level maintained 0" above fuse plug crest

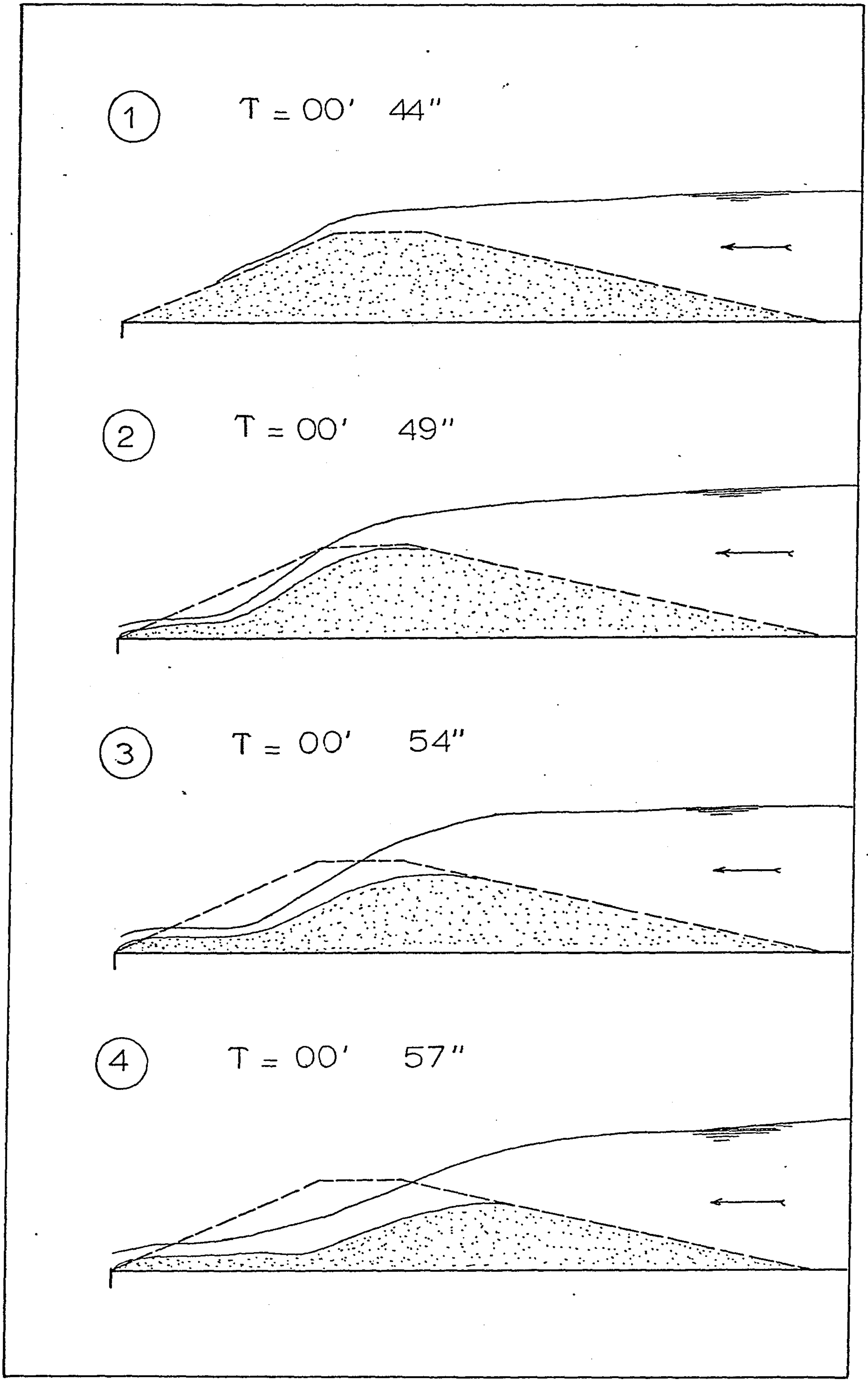
Material No. 7

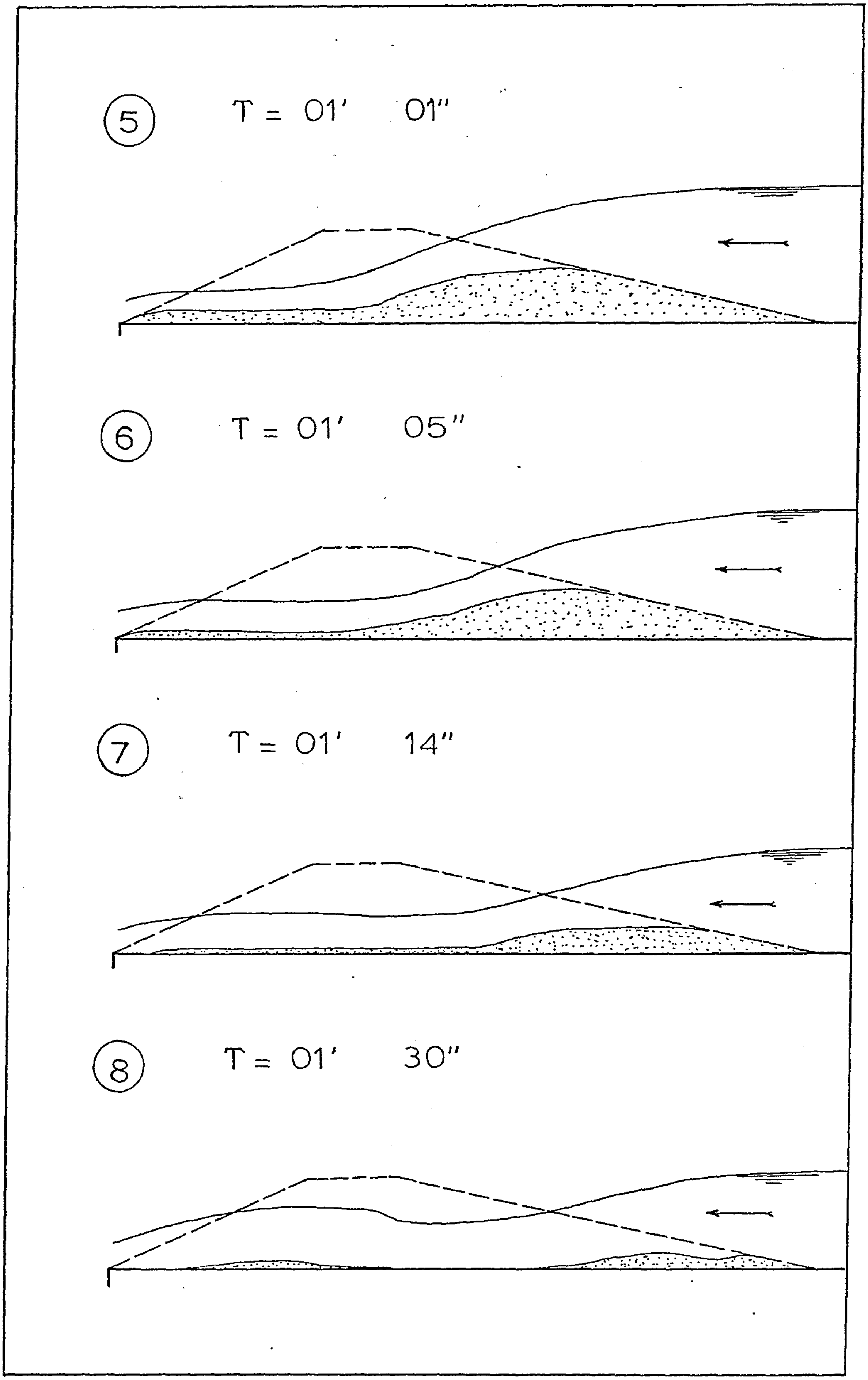
$S_s = 2.65$

$n = 41.0\%$

$\alpha = 0.066$

$d = 0.80$ mm.


1
T = 00' 44"
2
T = 00' 49"
3
T = 00' 54"
4
T = 00' 57"


5
T = 01' 01"
6
T = 01' 05"
7
T = 01' 14"
8
T = 01' 30"

(9) T= 02' 04"

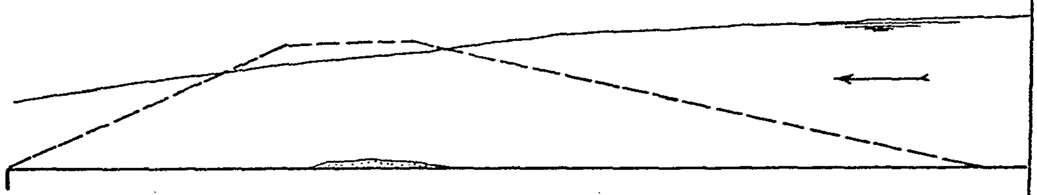


Fig.20

<u>Exp. No. 7-H2-9"</u>

EROSION OF DAM AT CONSTANT UPSTREAM WATER LEVEL WITH DOWNSTREAM SUPERCRITICAL FLOW.

Type (1) dam

Upstream water level maintained 2" above fuse plug crest

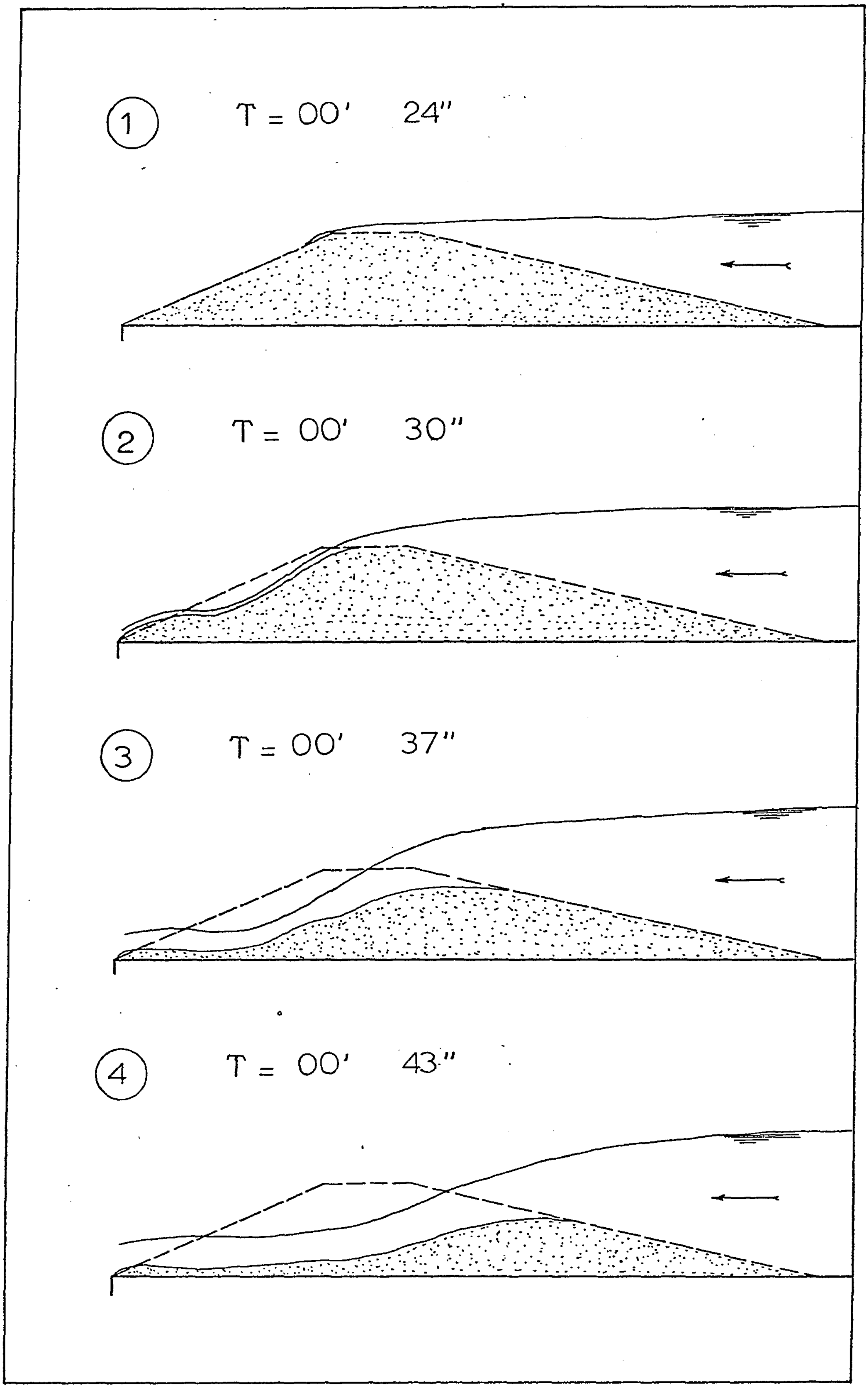
Material No. 7

S_s = 2.65

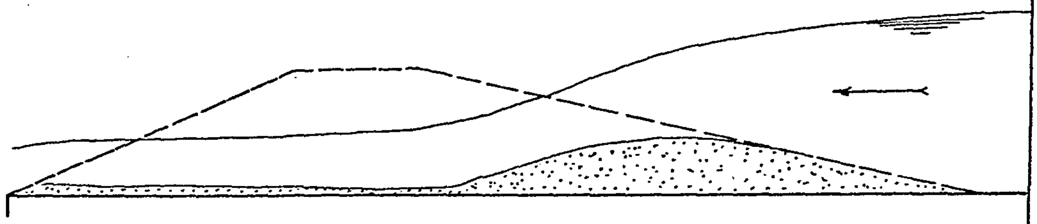
n = 41.0%

α = 0.066

d = 0.80 mm.


1
T = 00' 24"
2
T = 00' 30"
3
T = 00' 37"
4
T = 00' 43"

(5) T = 00' 50"



(6) T = 01' 24"

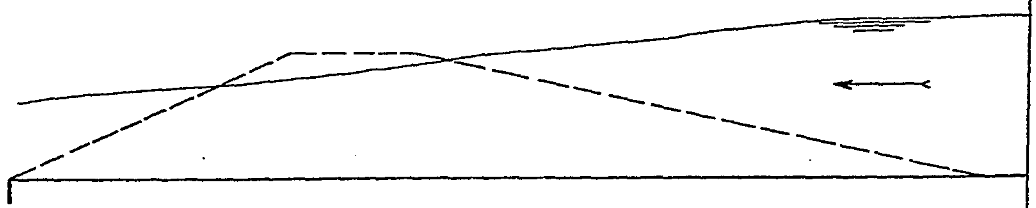


Fig.21

<u>Exp. No. 2-HO-9"</u>

EROSION OF DAM AT CONSTANT UPSTREAM WATER LEVEL WITH DOWNSTREAM SUBCRITICAL FLOW.

Type (1) dam

Upstream water level maintained 0" above fuse plug crest

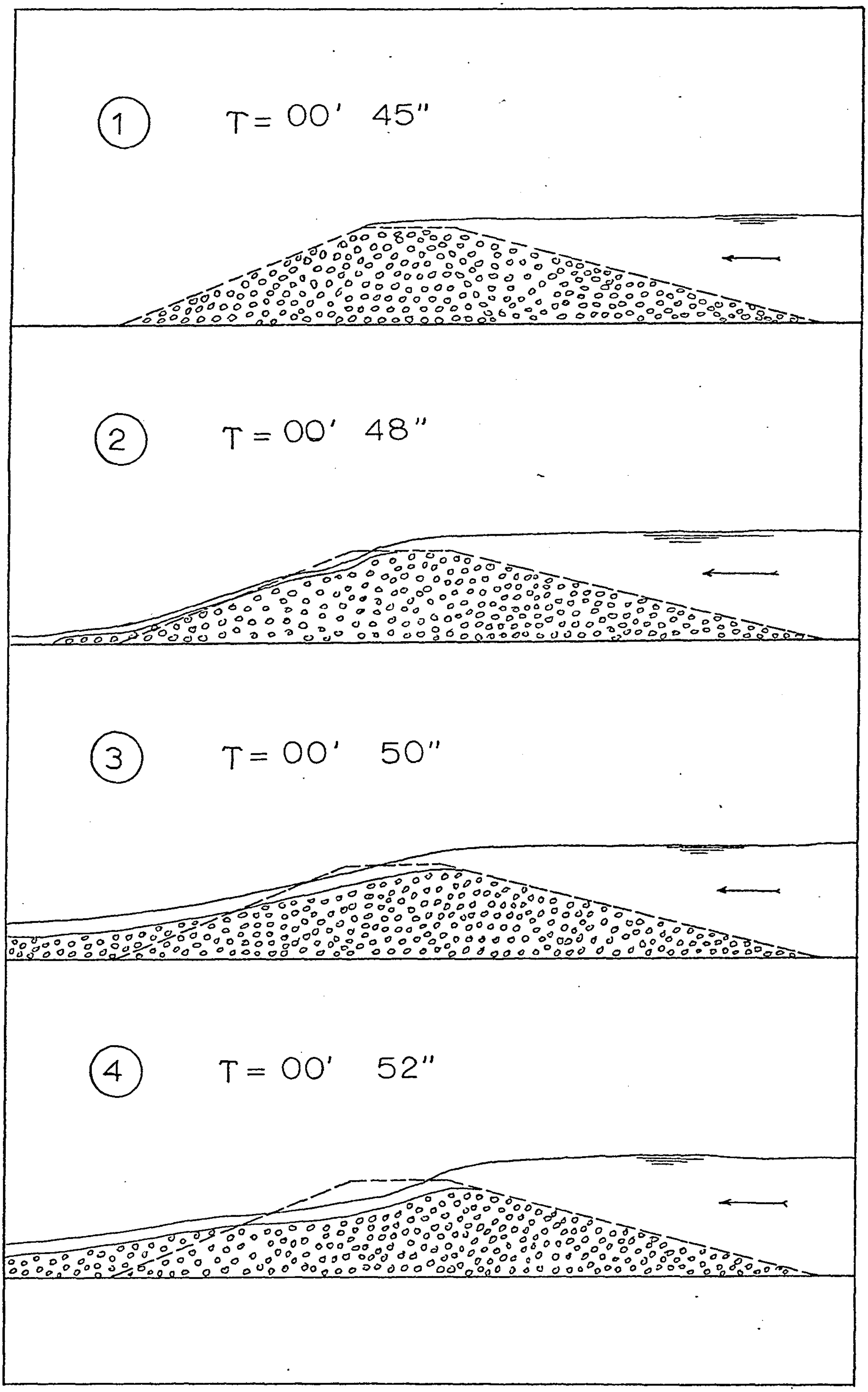
Material No. 2

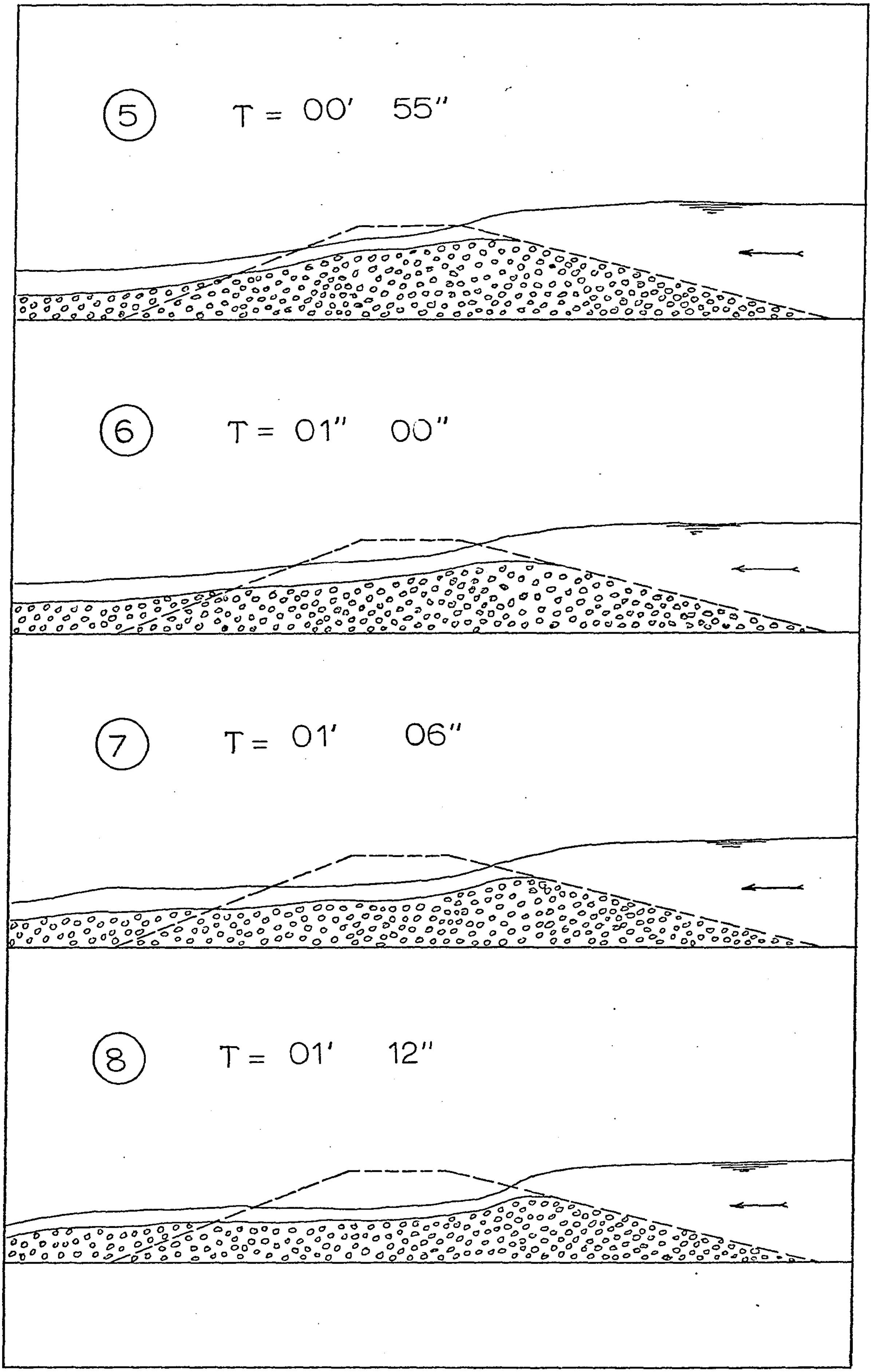
$S_s = 2.57$

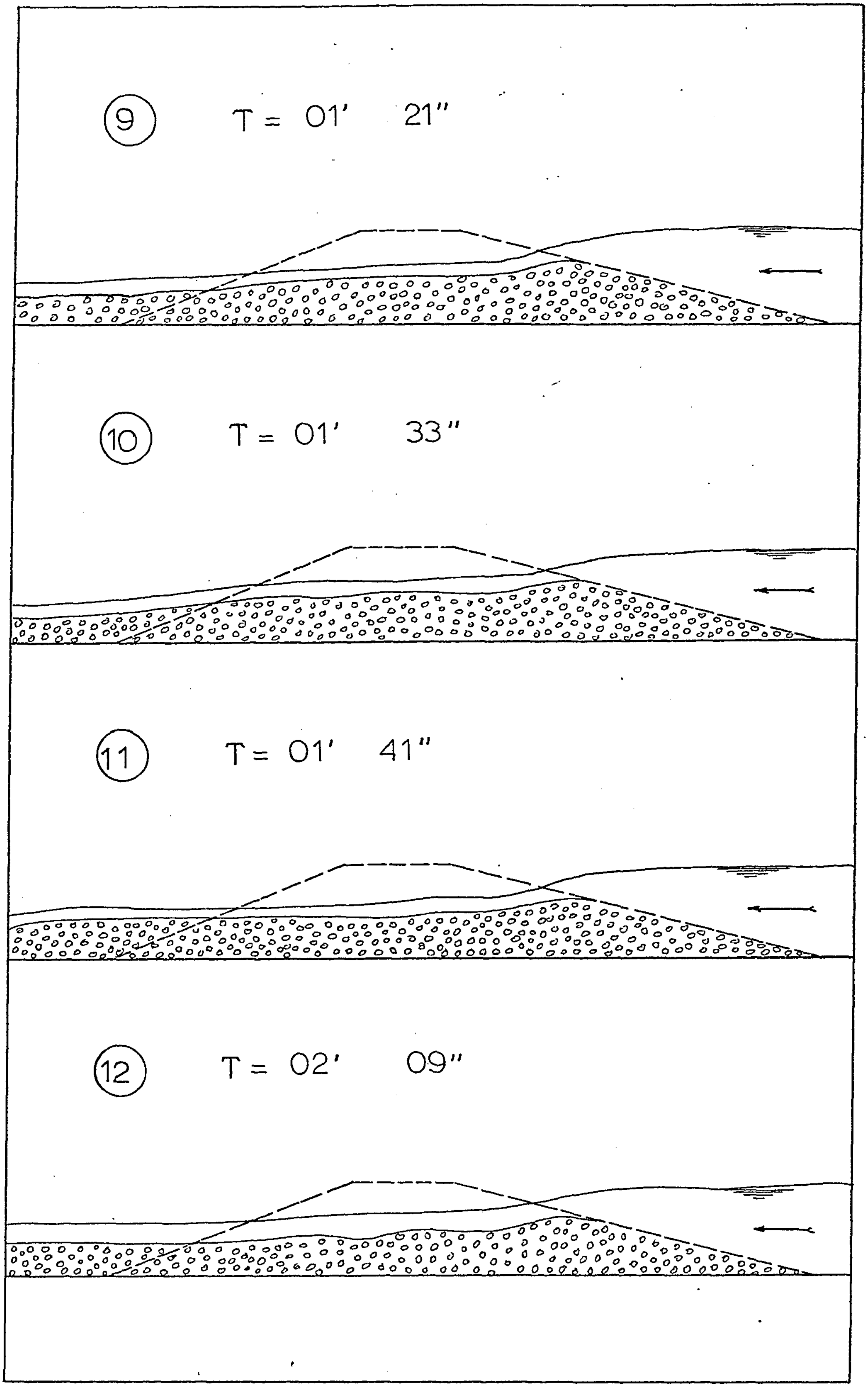
$n = 41.0\%$

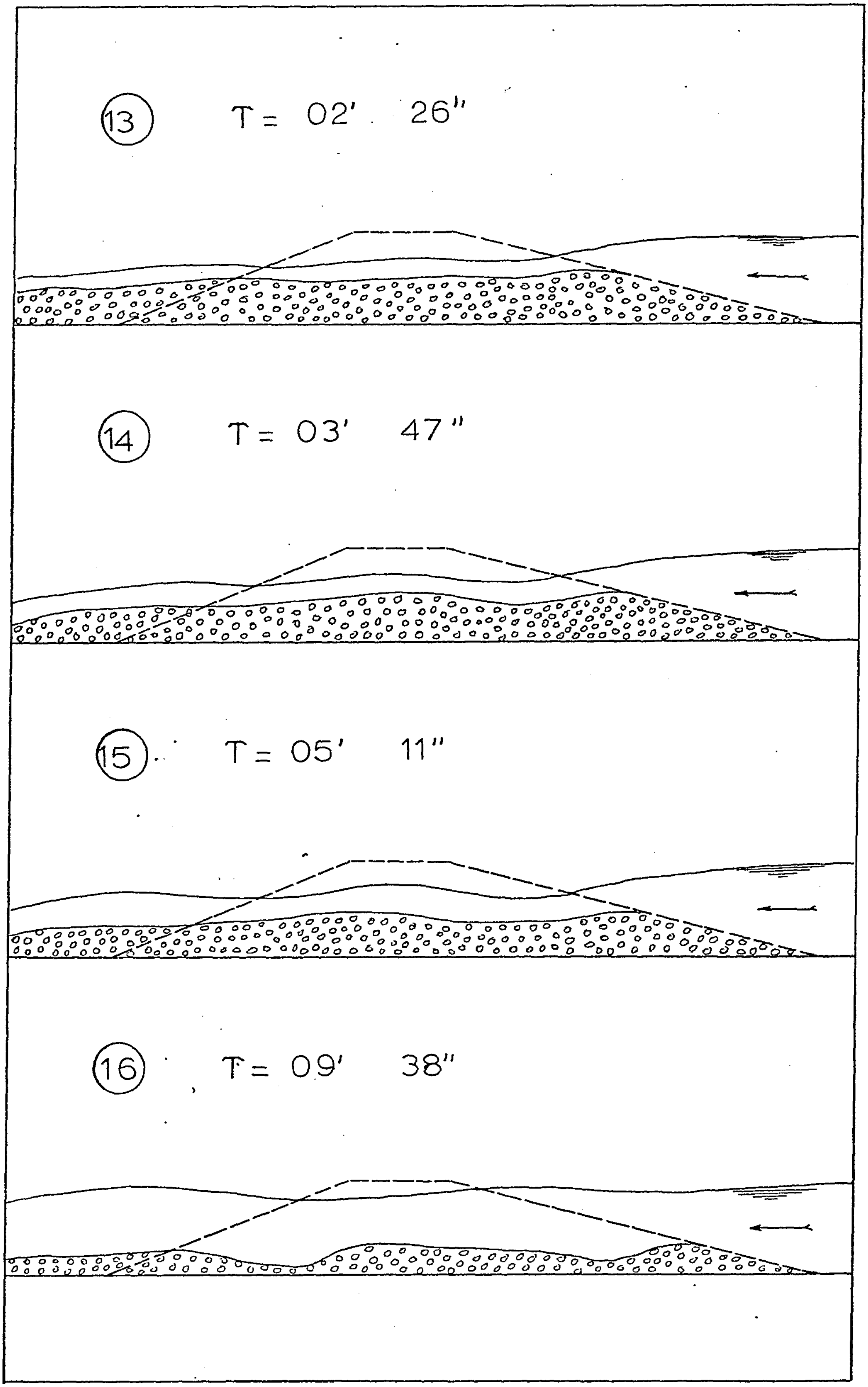
$\alpha = 0.532$

$d = 6.35$ mm.

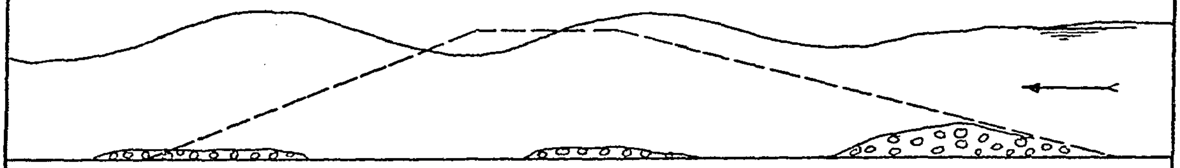

1
T= 00' 45"
2
T = 00' 48"
3
T= 00' 50"
4
T= 00' 52"


5
T = 00' 55"
6
T = 01" 00"
7
T = 01' 06"
8
T = 01' 12"


9
T = 01' 21"
10
T = 01' 33"
11
T = 01' 41"
12
T = 02' 09"


13 T = 02' 26"
14 T = 03' 47"
15 T = 05' 11"
16 T = 09' 38"

(17) T = 13' 38"



(18) T = 16' 15"

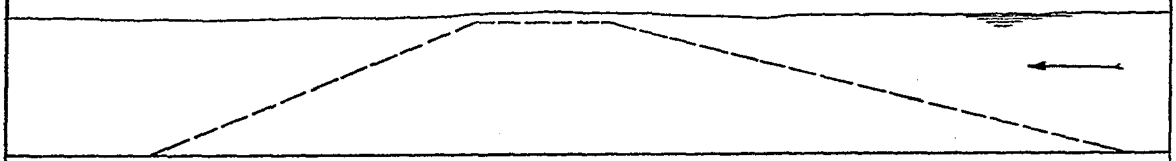


Fig.22

Exp. No. 2-H2-9"

EROSION OF DAM AT CONSTANT UPSTREAM WATER LEVEL WITH DOWNSTREAM SUBCRITICAL FLOW.

Type (1) dam

Upstream water level maintained 2" above fuse plug crest

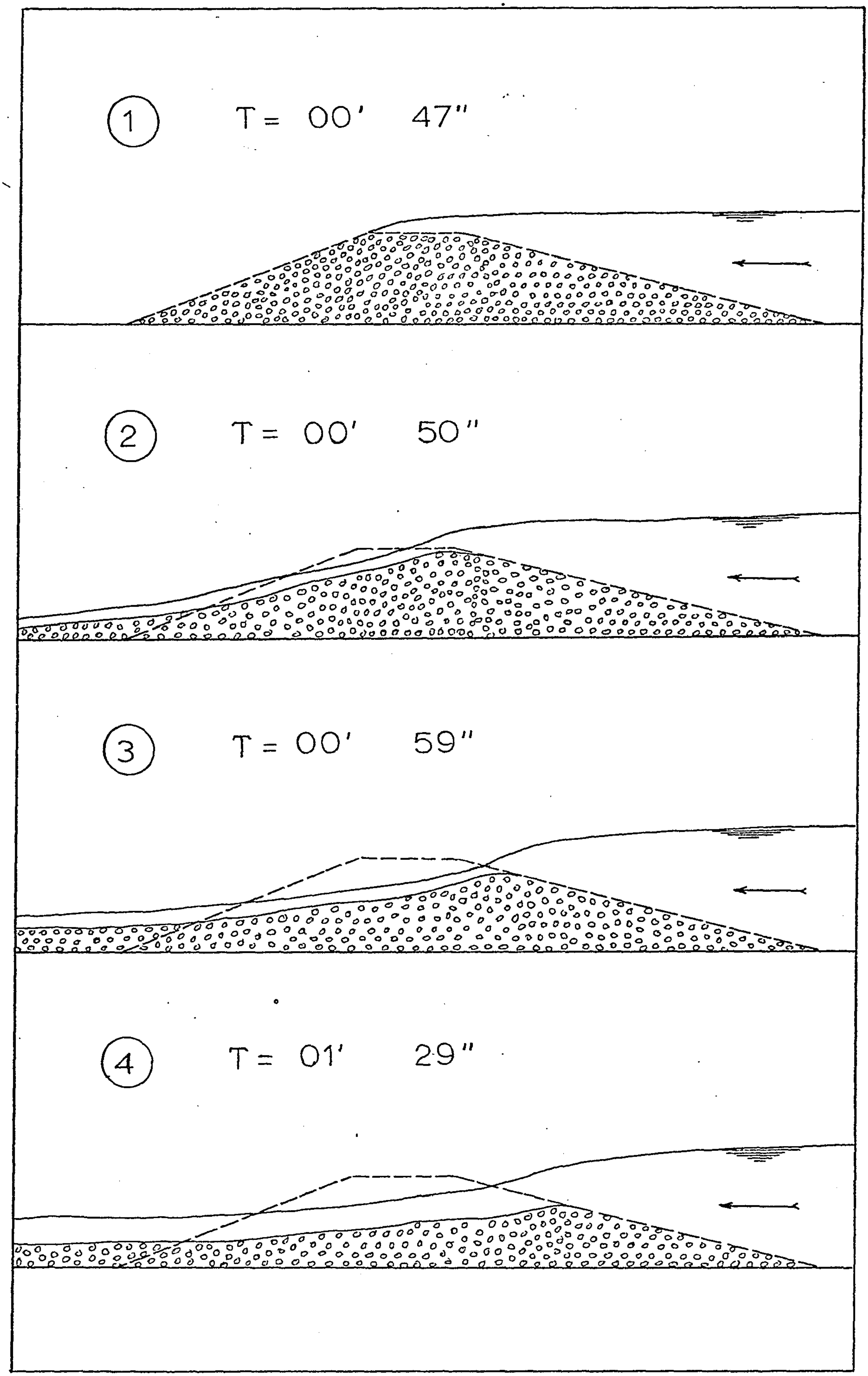
Material No. 2

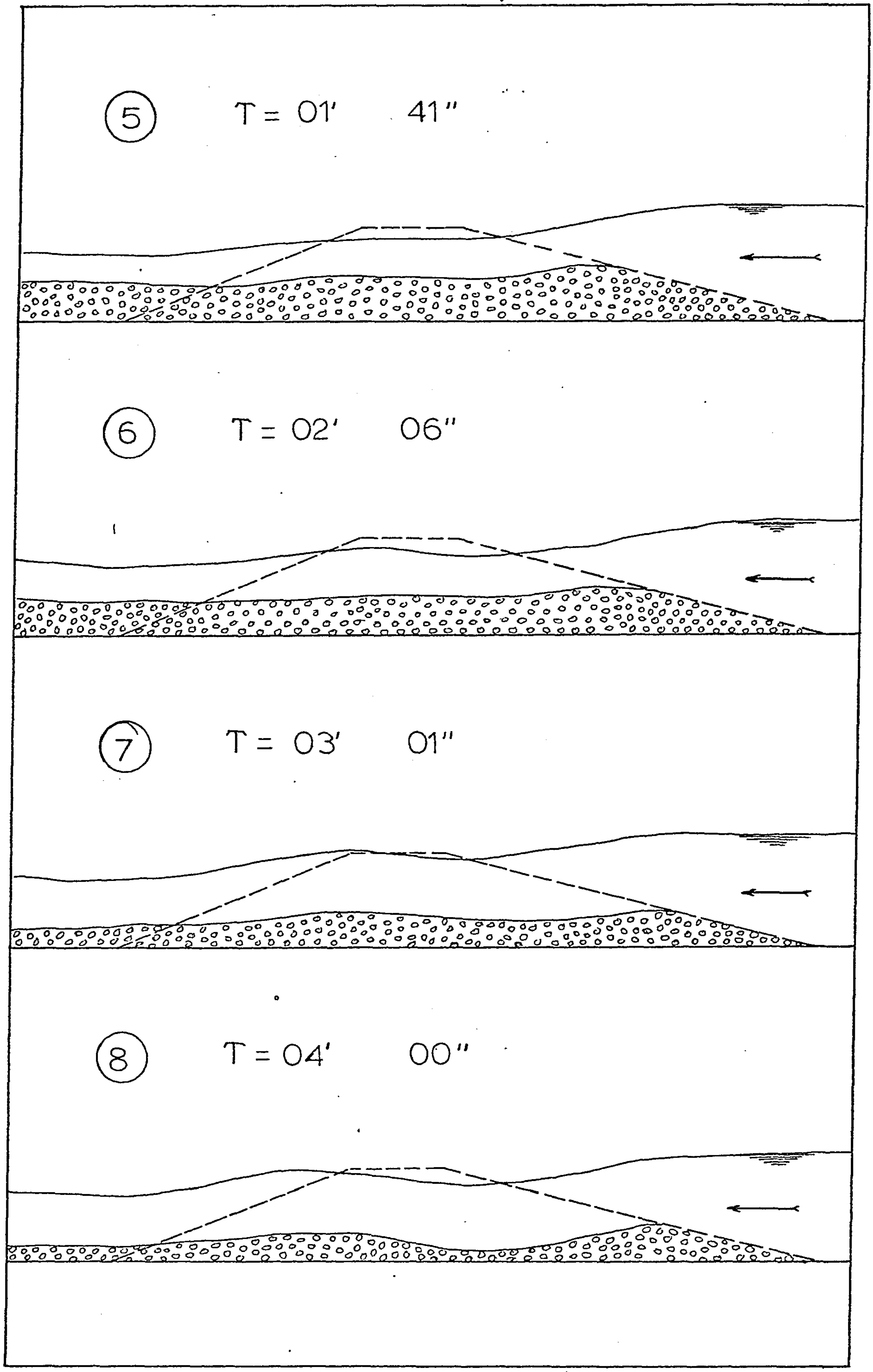
$S_s = 2.57$

$n = 41.0\%$

$\alpha = 0.532$

$d = 6.35$ mm.


1
T = 00' 47"
2
T = 00' 50"
3
T = 00' 59"
4
T = 01' 29"



5
T = 01' 41"
6
T = 02' 06"
7
T = 03' 01"
8
T = 04' 00"

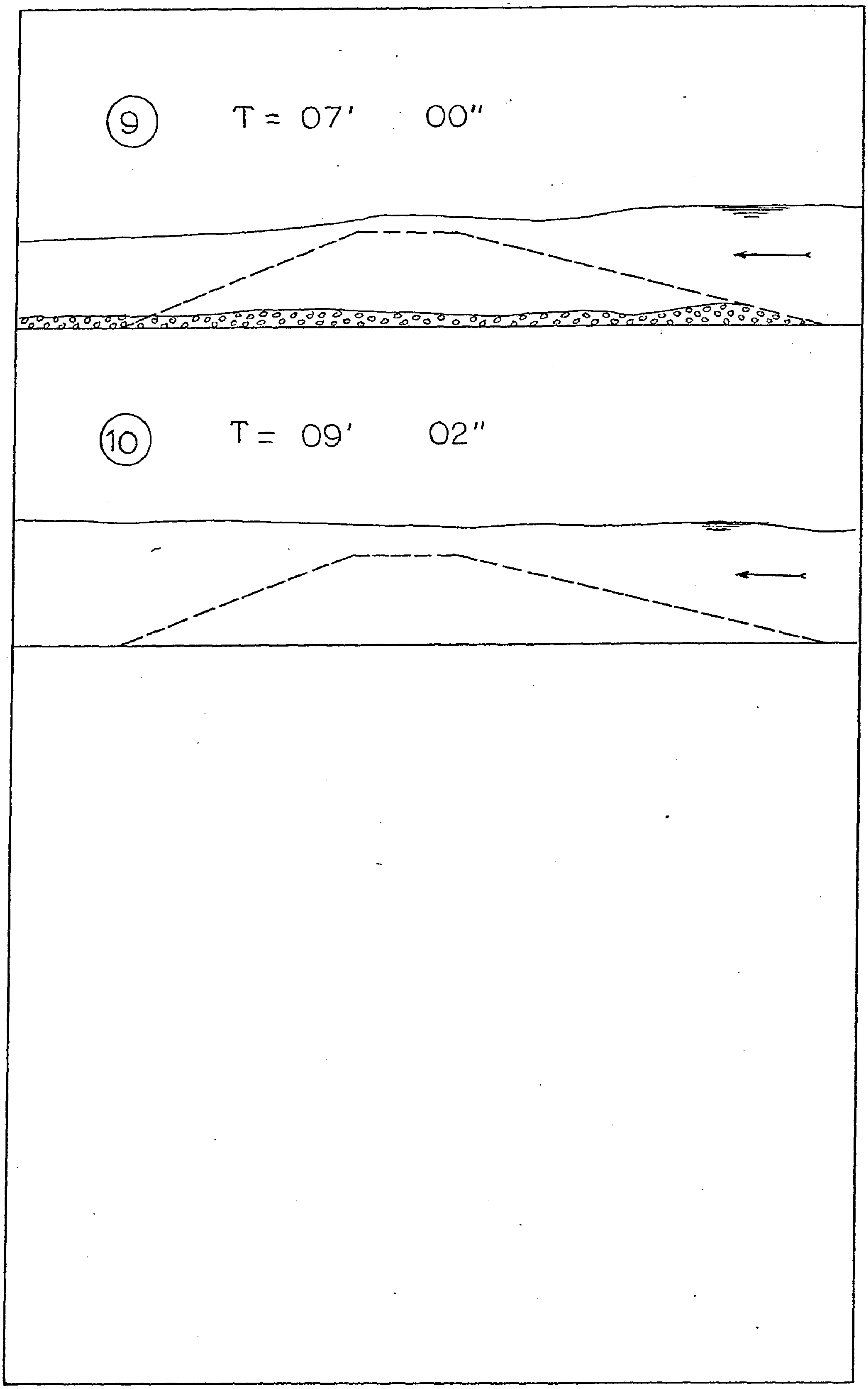

9
T = 07' 00"
10
T = 09' 02"

Fig.23

Exp. No. 2-H4-9"

EROSION OF DAM AT CONSTANT UPSTREAM WATER LEVEL WITH DOWNSTREAM SUBCRITICAL FLOW.

Type (1) dam

Upstream water level maintained 4" above fuse plug crest

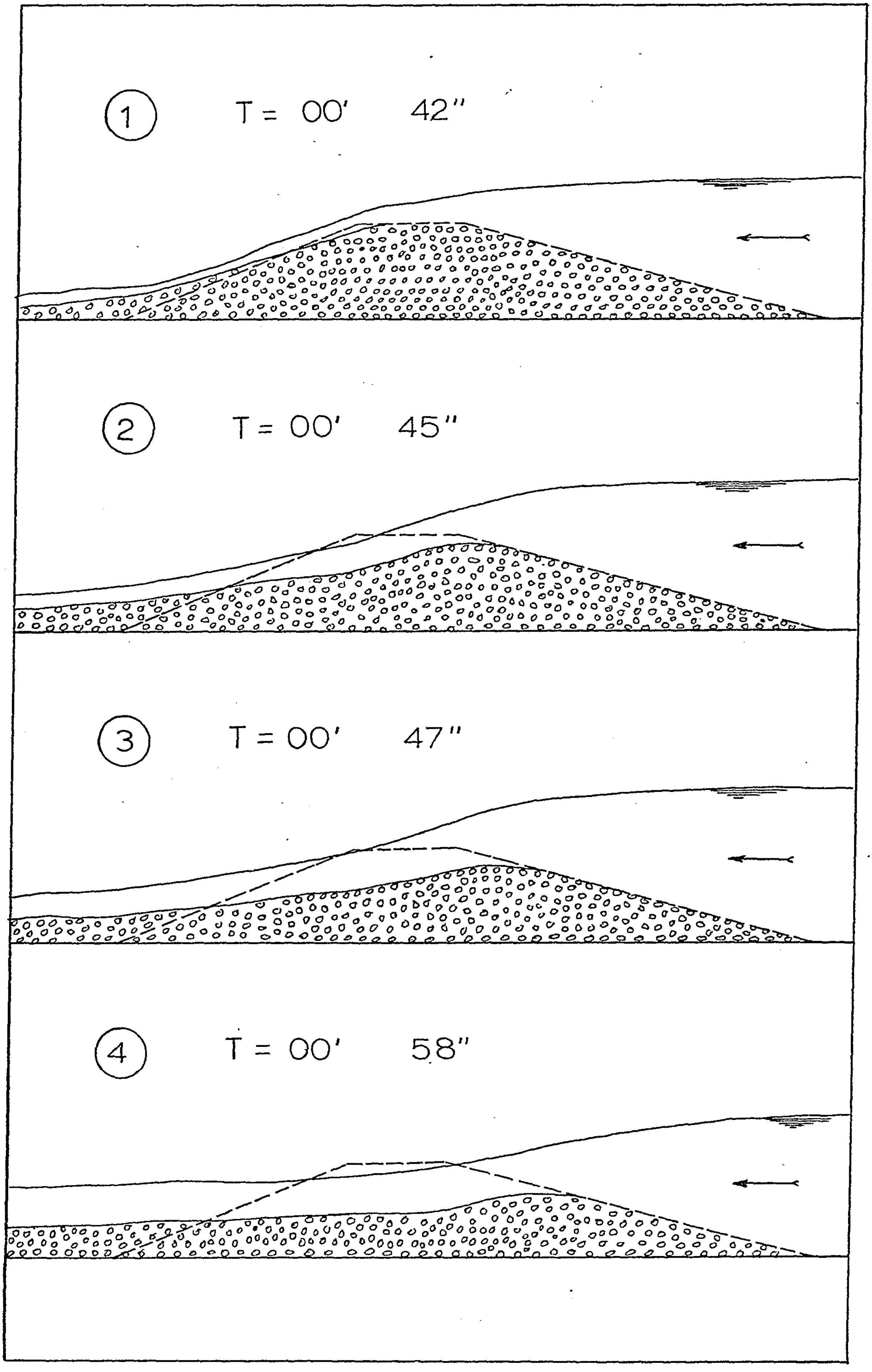
Material No. 2

$S_s = 2.57$

$n = 41.0\%$

$\propto = 0.532$

$d = 6.35$ mm.


1
T = 00' 42"
2
T = 00' 45"
3
T = 00' 47"
4
T = 00' 58"

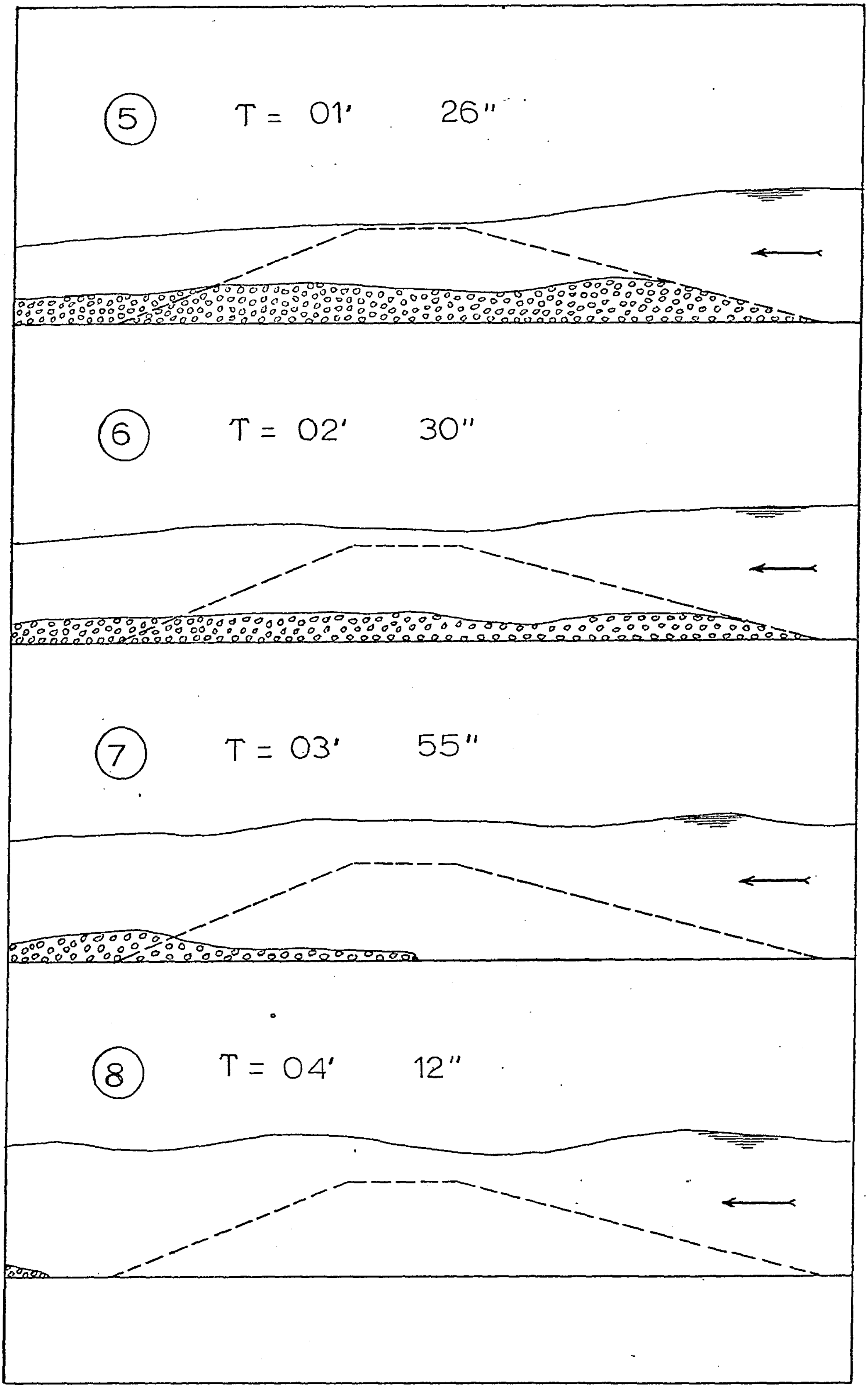

5
T = 01' 26"
6
T = 02' 30"
7
T = 03' 55"
8
T = 04' 12"

Fig.24

Exp. No. 3-HO-9"

EROSION OF DAM AT CONSTANT UPSTREAM WATER LEVEL WITH DOWNSTREAM SUBCRITICAL FLOW.

Type (1) dam

Upstream water level maintained 0" above fuse plug crest

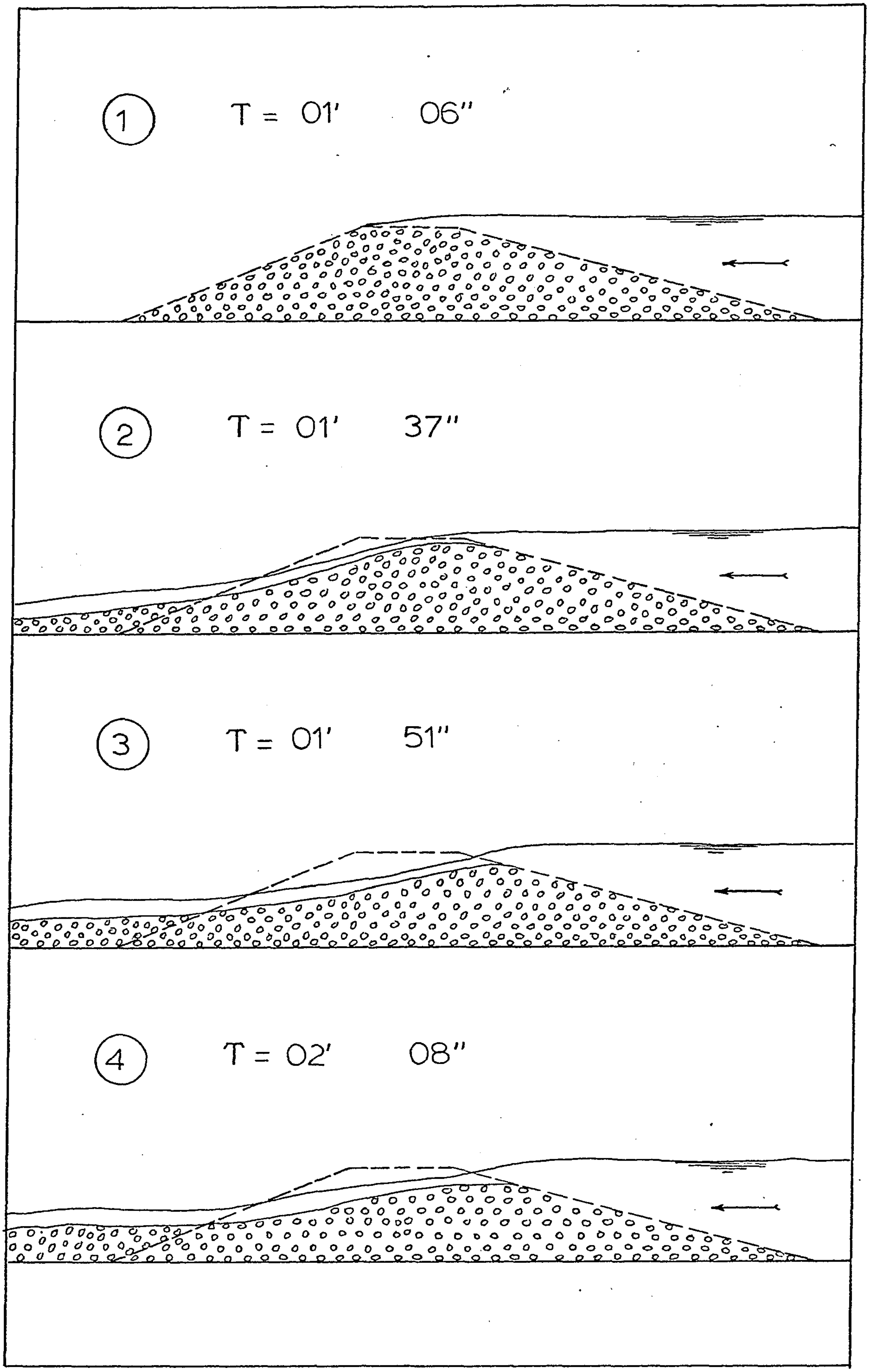
Material No. 3

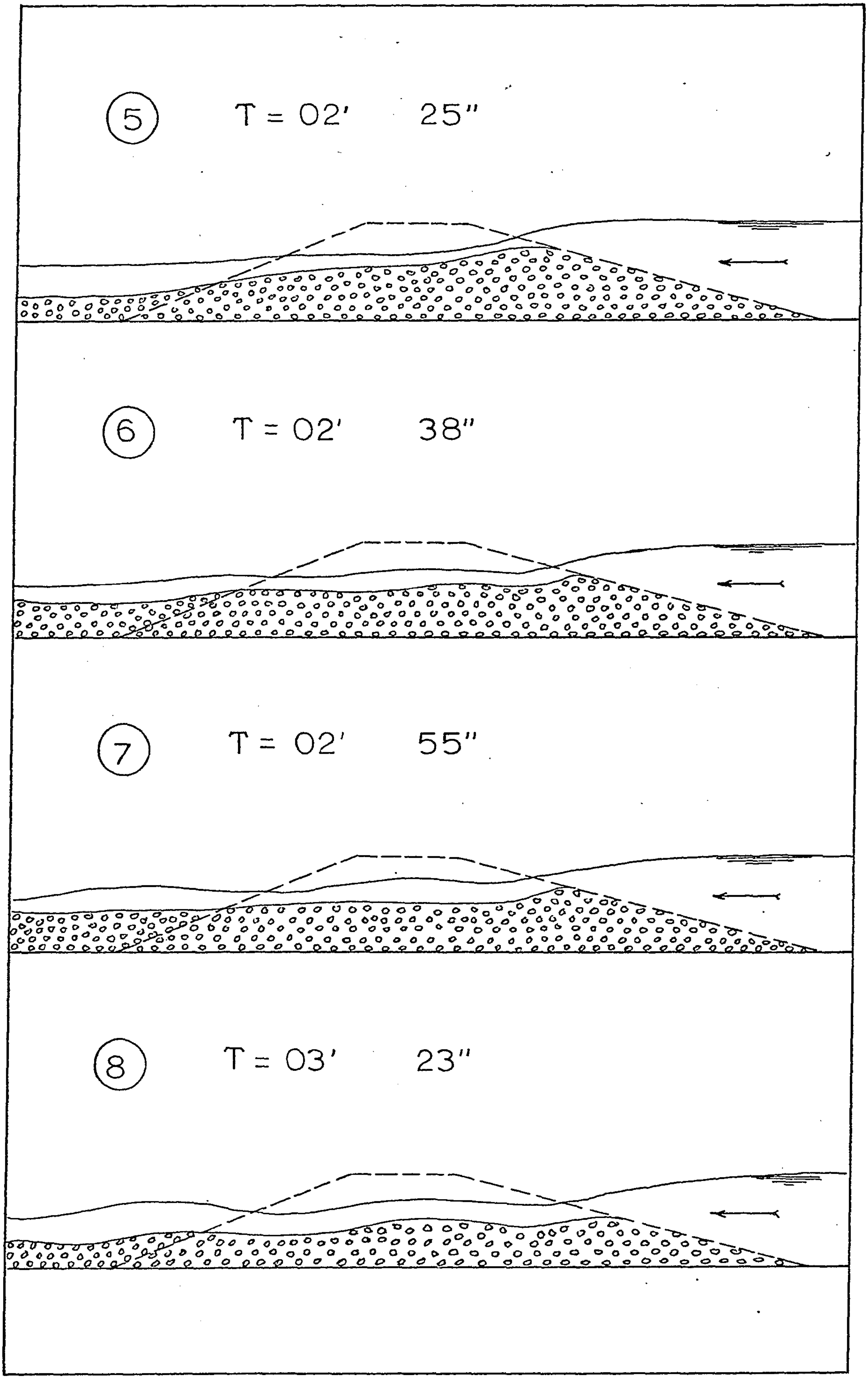
S_s = 2.70

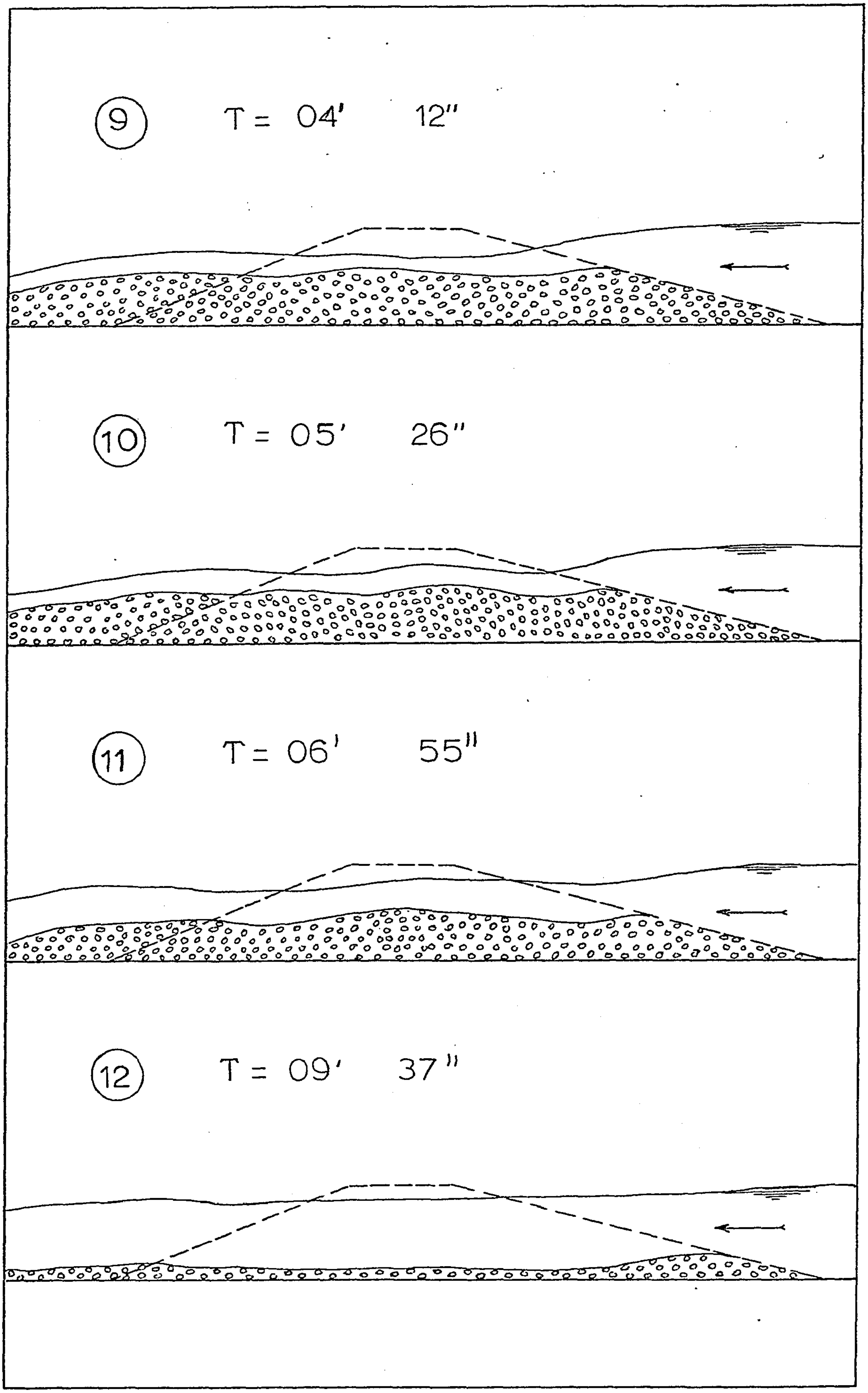
n = 40.0%

α = 0.454

d = 4.60 mm.


1
T = 01' 06"
2
T = 01' 37"
3
T = 01' 51"
4
T = 02' 08"


5
T = 02' 25"
6
T = 02' 38"
7
T = 02' 55"
8
T = 03' 23"


9 T = 04' 12"
10 T = 05' 26"
11 T = 06' 55"
12 T = 09' 37"

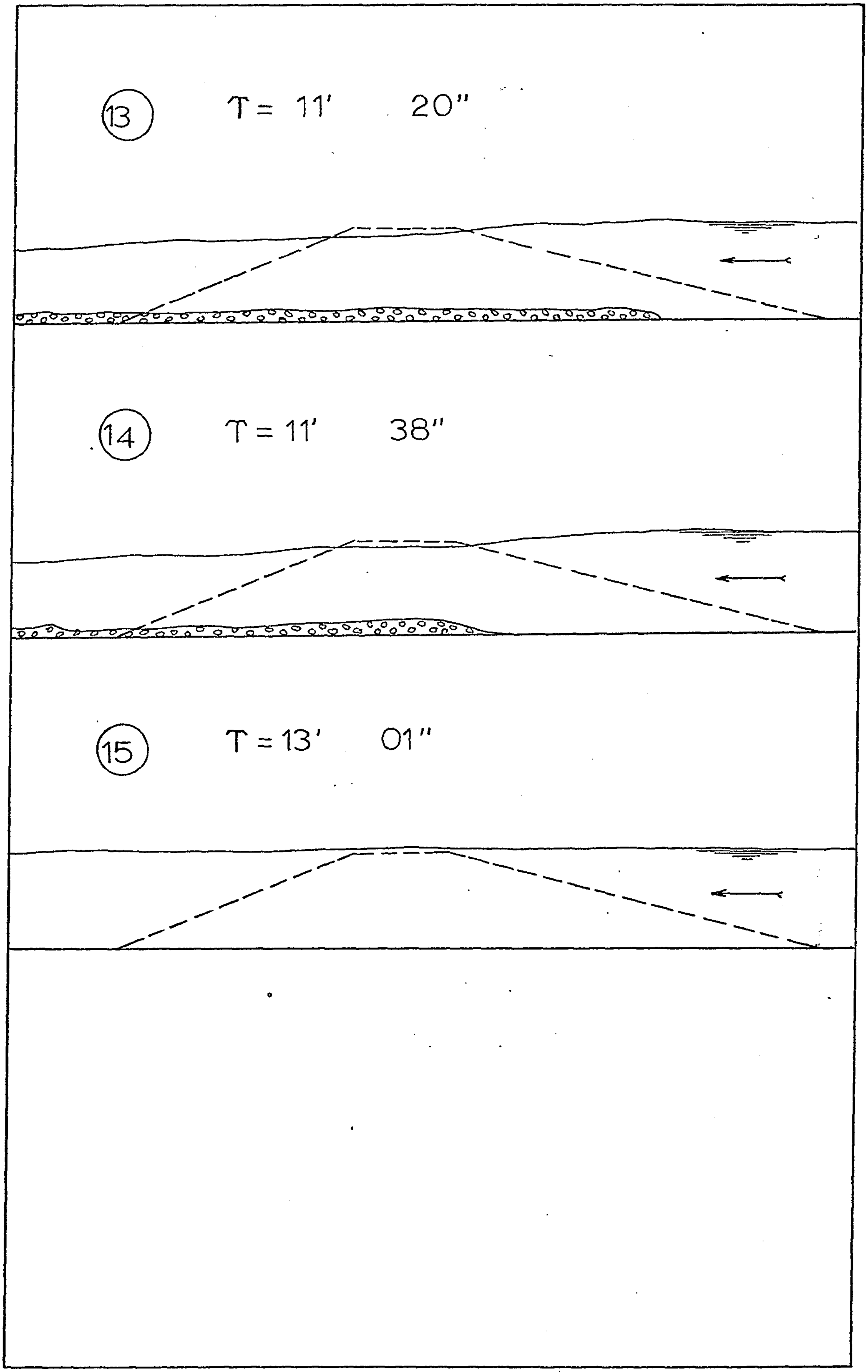

13 T = 11' 20"
14 T = 11' 38"
15 T = 13' 01"

Fig.25

Exp. No. 3-H2-9"

EROSION OF DAM AT CONSTANT UPSTREAM WATER LEVEL WITH DOWNSTREAM SUBCRITICAL FLOW.

Type (1) dam

Upstream water level maintained 2" above fuse plug crest

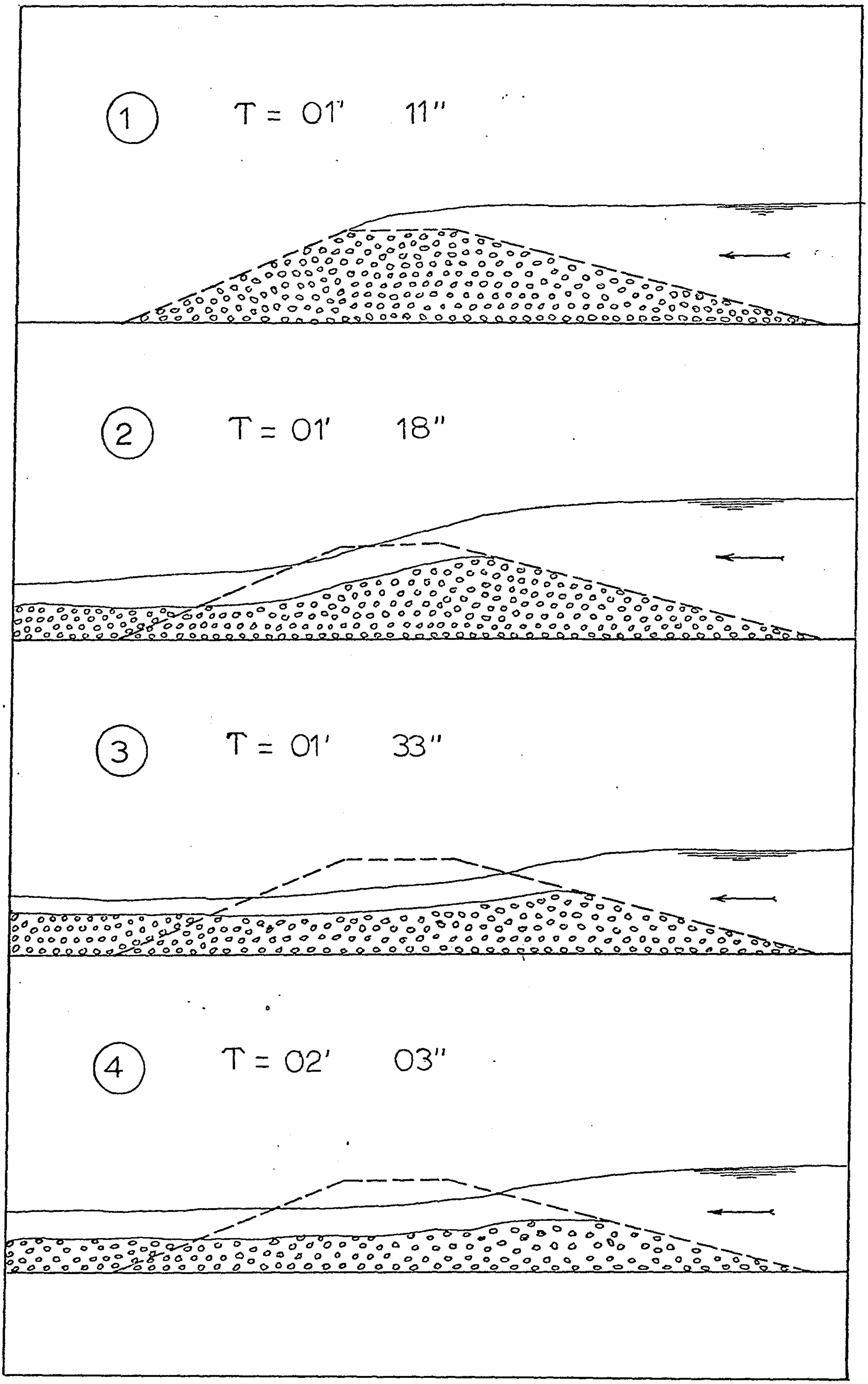
Material No. 3

$S_s = 2.70$

$n = 40.0\%$

$\alpha = 0.454$

$d = 4.60$ mm.


1 T = 01' 11"
2 T = 01' 18"
3 T = 01' 33"
4 T = 02' 03"

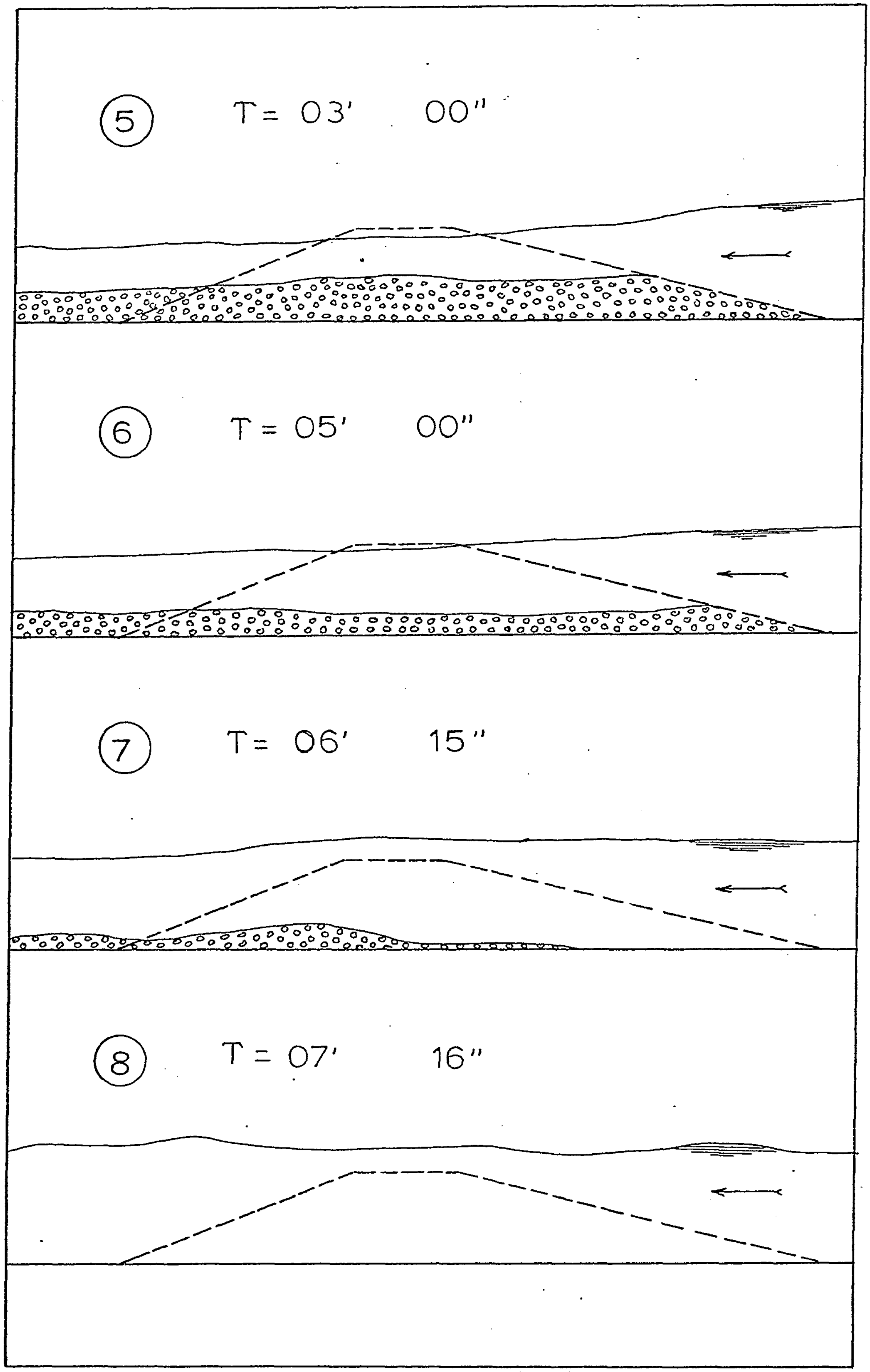

5
T= 03' 00"
6
T = 05' 00"
7
T= 06' 15"
8
T = 07' 16"

Fig.26

Exp. No. 3-H4-9"

EROSION OF DAM AT CONSTANT UPSTREAM WATER LEVEL WITH DOWNSTREAM SUBCRITICAL FLOW.

Type (1) dam

Upstream water level maintained 4" above fuse plug crest

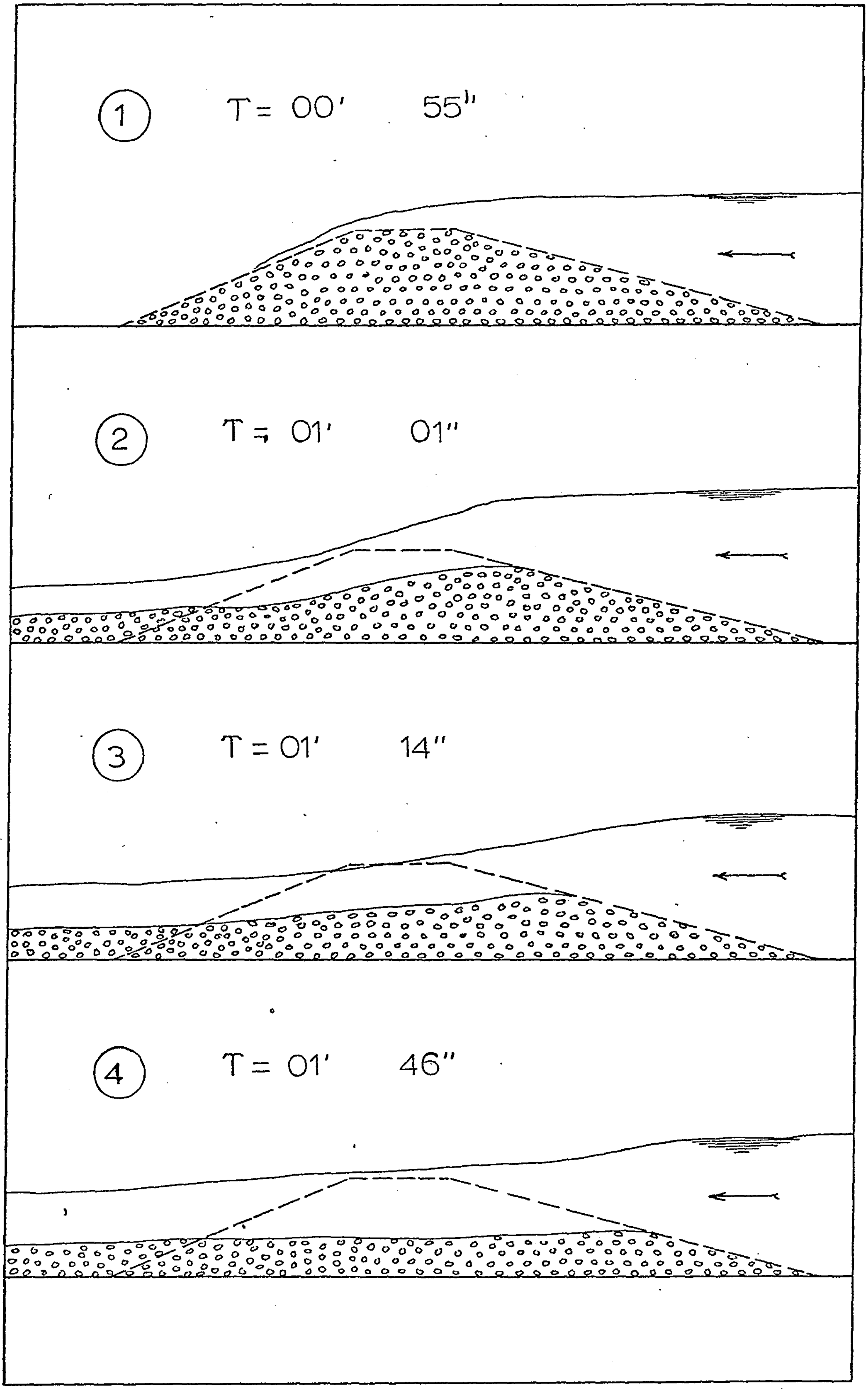
Material No. 3

S_s = 2.70

n = 40.0%

α = 0.454

d = 4.60 mm.


1
T= 00' 55"
2
T= 01' 01"
3
T = 01' 14"
4
T= 01' 46"

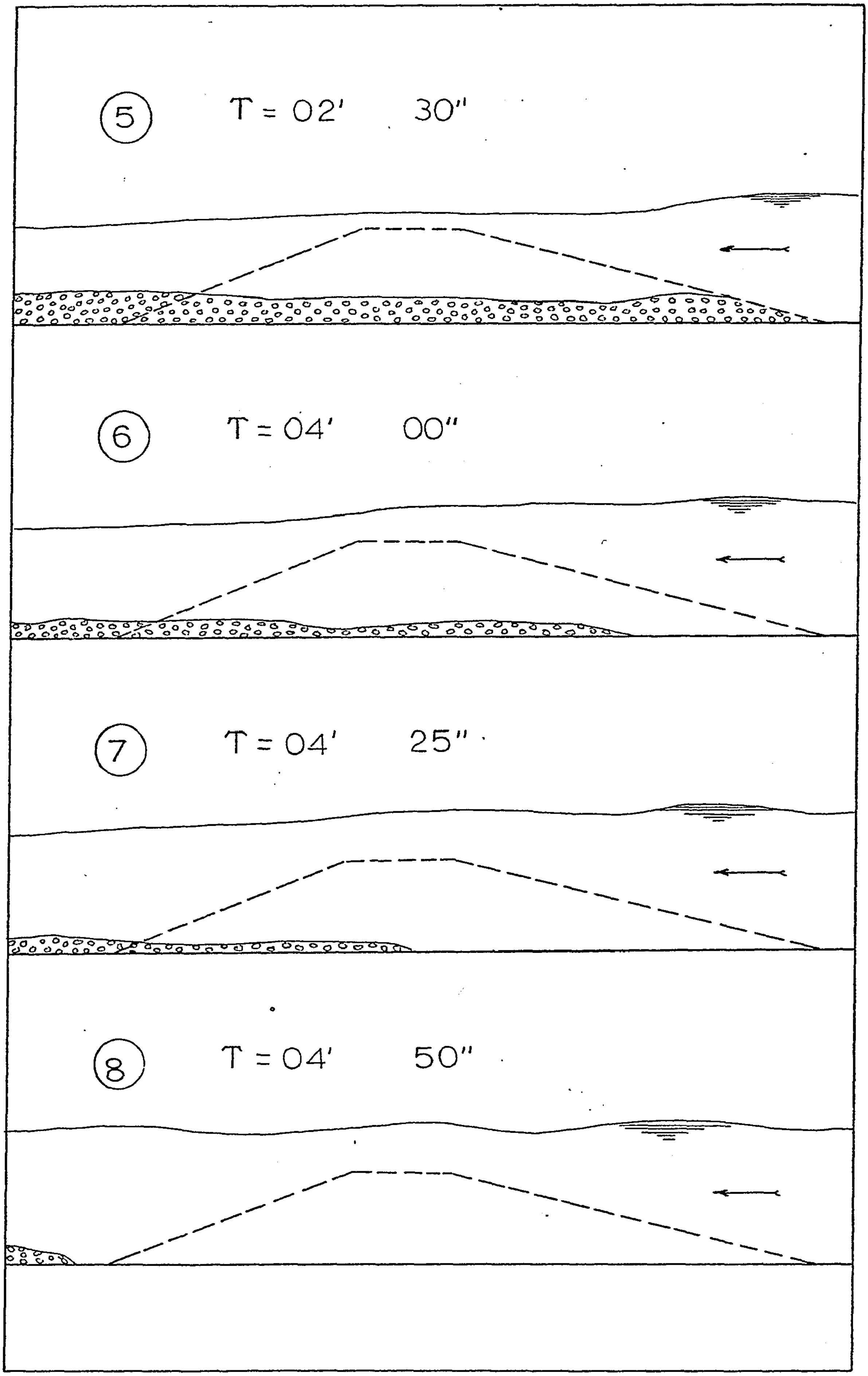

5
T = 02' 30"
6
T = 04' 00"
7
T = 04' 25"
8
T = 04' 50"

Fig.27

Exp. No. 5-HO-9"

EROSION OF DAM AT CONSTANT UPSTREAM WATER LEVEL WITH DOWNSTREAM SUBCRITICAL FLOW.

Type (1) dam

Upstream water level maintained 0" above fuse plug crest

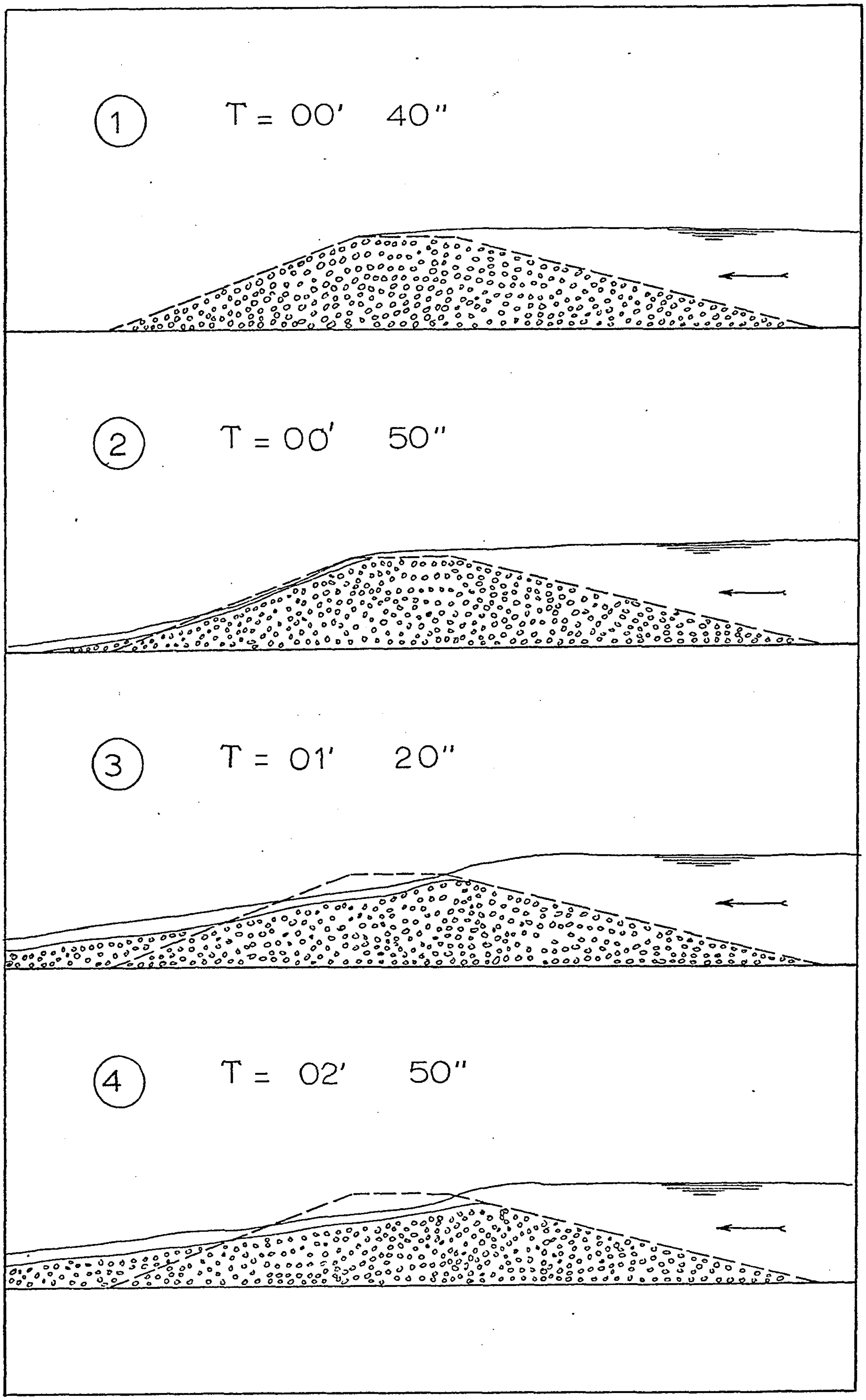
Material No. 5

$S_s = 2.77$

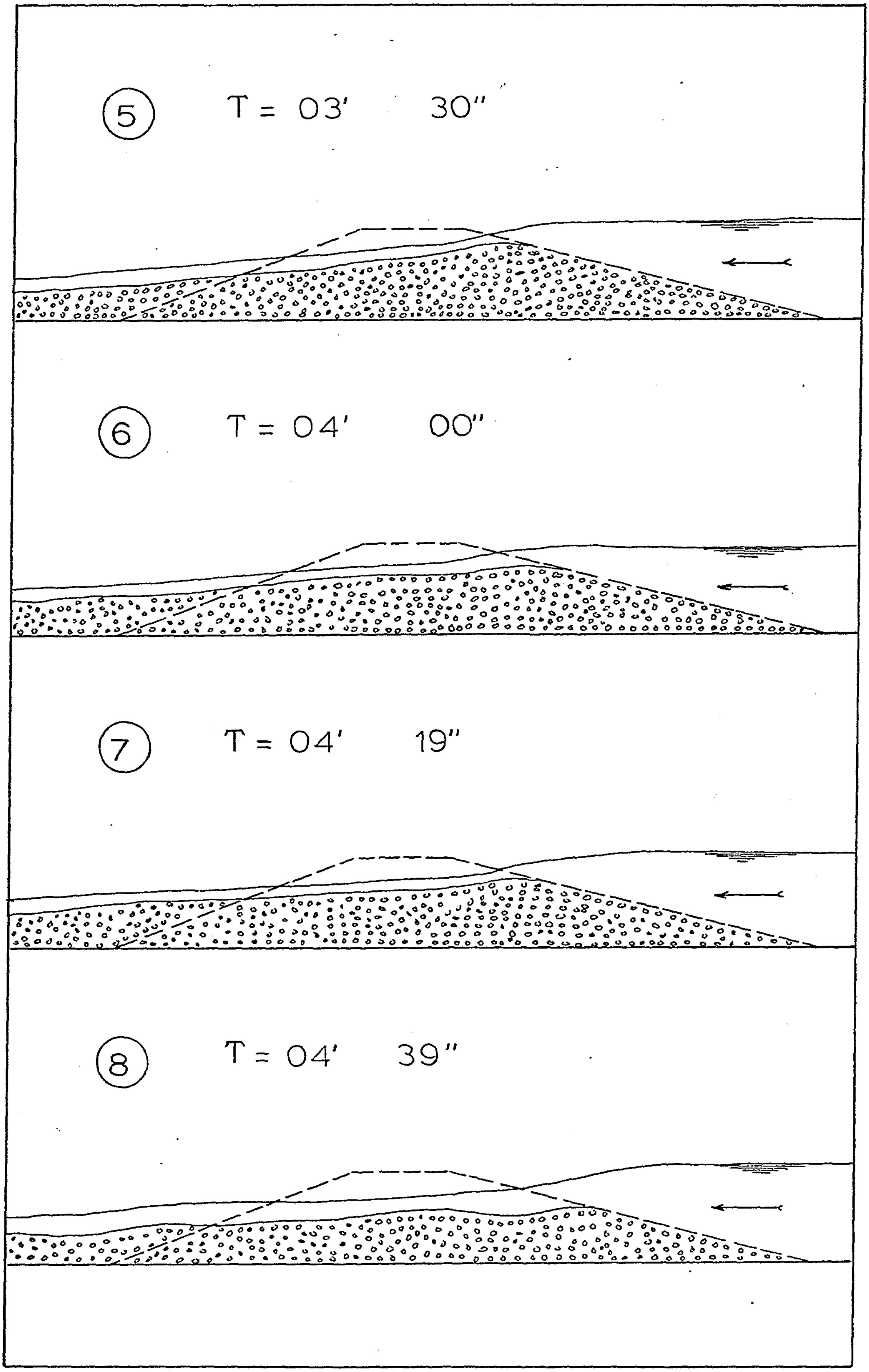
$n = 40.0\%$

$\alpha = 0.267$

$d = 2.20$ mm.



1
T = 00' 40"
2
T = 00' 50"
3
T = 01' 20"
4
T = 02' 50"


5
T = 03' 30"
6
T = 04' 00"
7
T = 04' 19"
8
T = 04' 39"

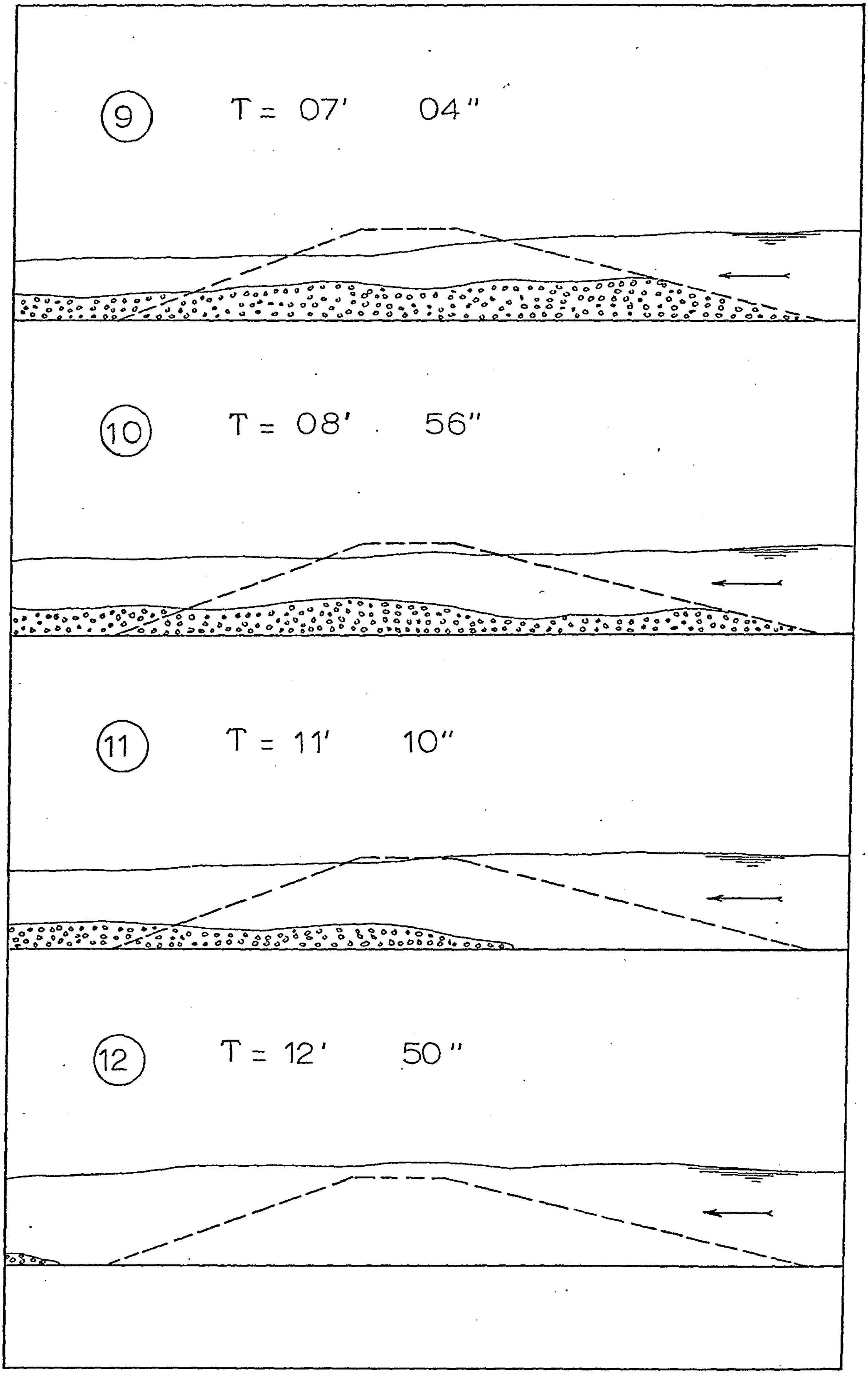

9
T = 07' 04"
10
T = 08' 56"
11
T = 11' 10"
12
T = 12' 50"

Fig.28

<u>Exp. No. 5-H2-9"</u>

EROSION OF DAM AT CONSTANT UPSTREAM WATER

LEVEL WITH DOWNSTREAM SUBCRITICAL FLOW.

Type (1) dam

Upstream water level maintained 2" above fuse plug crest

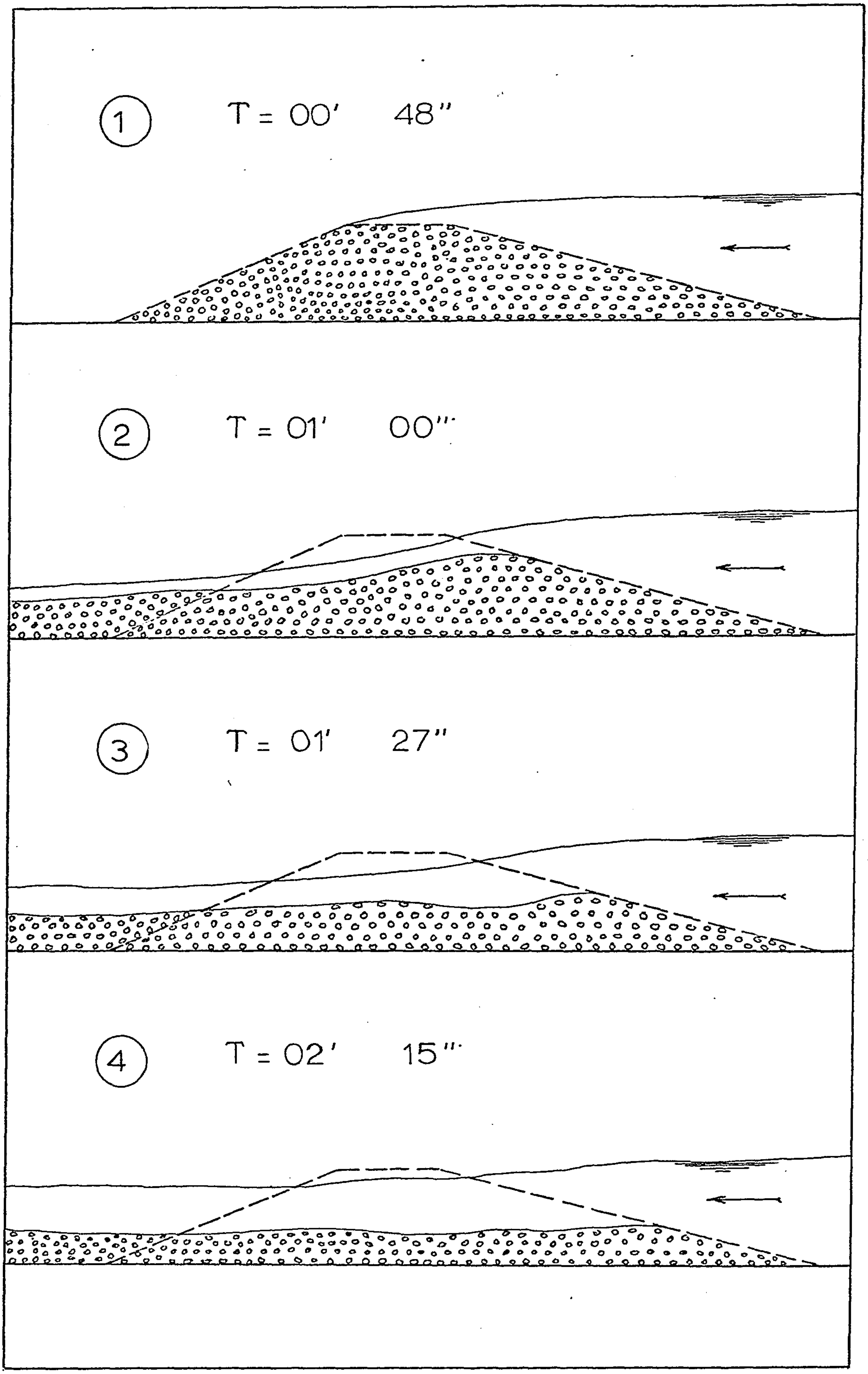
Material No. 5

$S_s = 2.77$

$n = 40.0\%$

$\alpha = 0.267$

$d = 2.20$ mm.


1
T = 00' 48"
2
T = 01' 00"
3
T = 01' 27"
4
T = 02' 15"

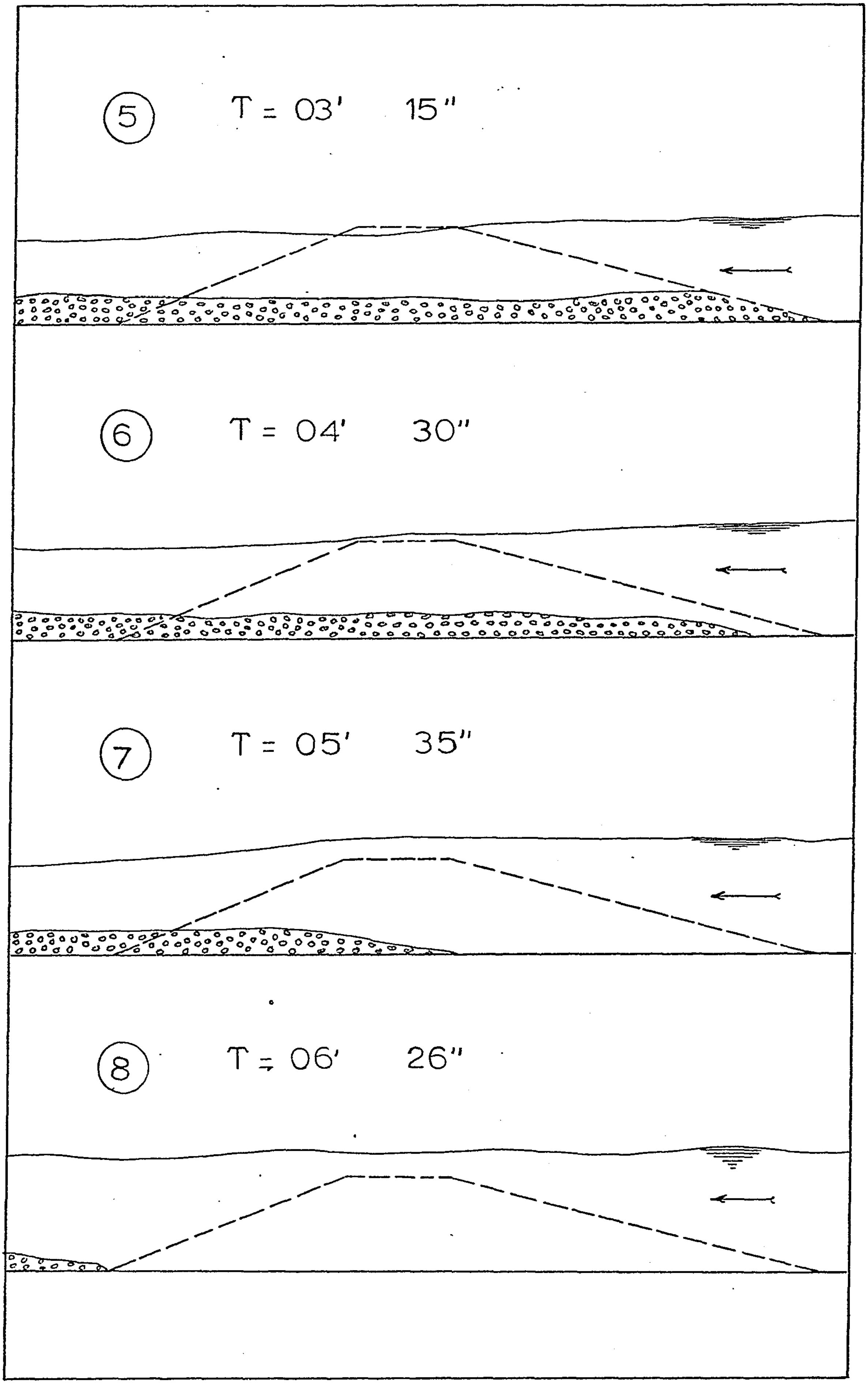

5
T = 03' 15"
6
T = 04' 30"
7
T = 05' 35"
8
T = 06' 26"

Fig.29

Exp. No. 5-H4-9"

EROSION OF DAM AT CONSTANT UPSTREAM WATER LEVEL WITH DOWNSTREAM SUBCRITICAL FLOW.

Type (1) dam

Upstream water level maintained 4" above fuse plug crest

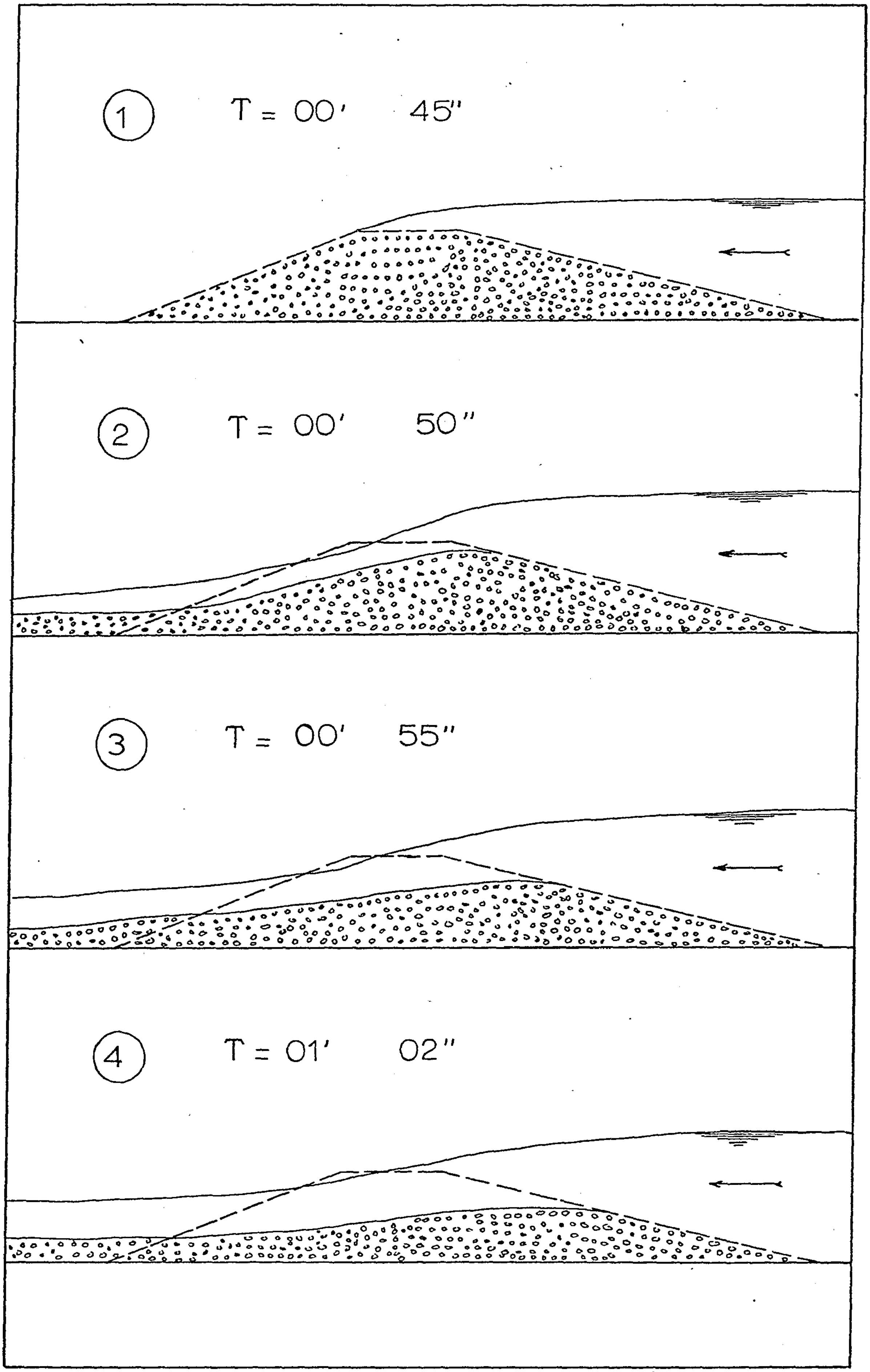
Material No. 5

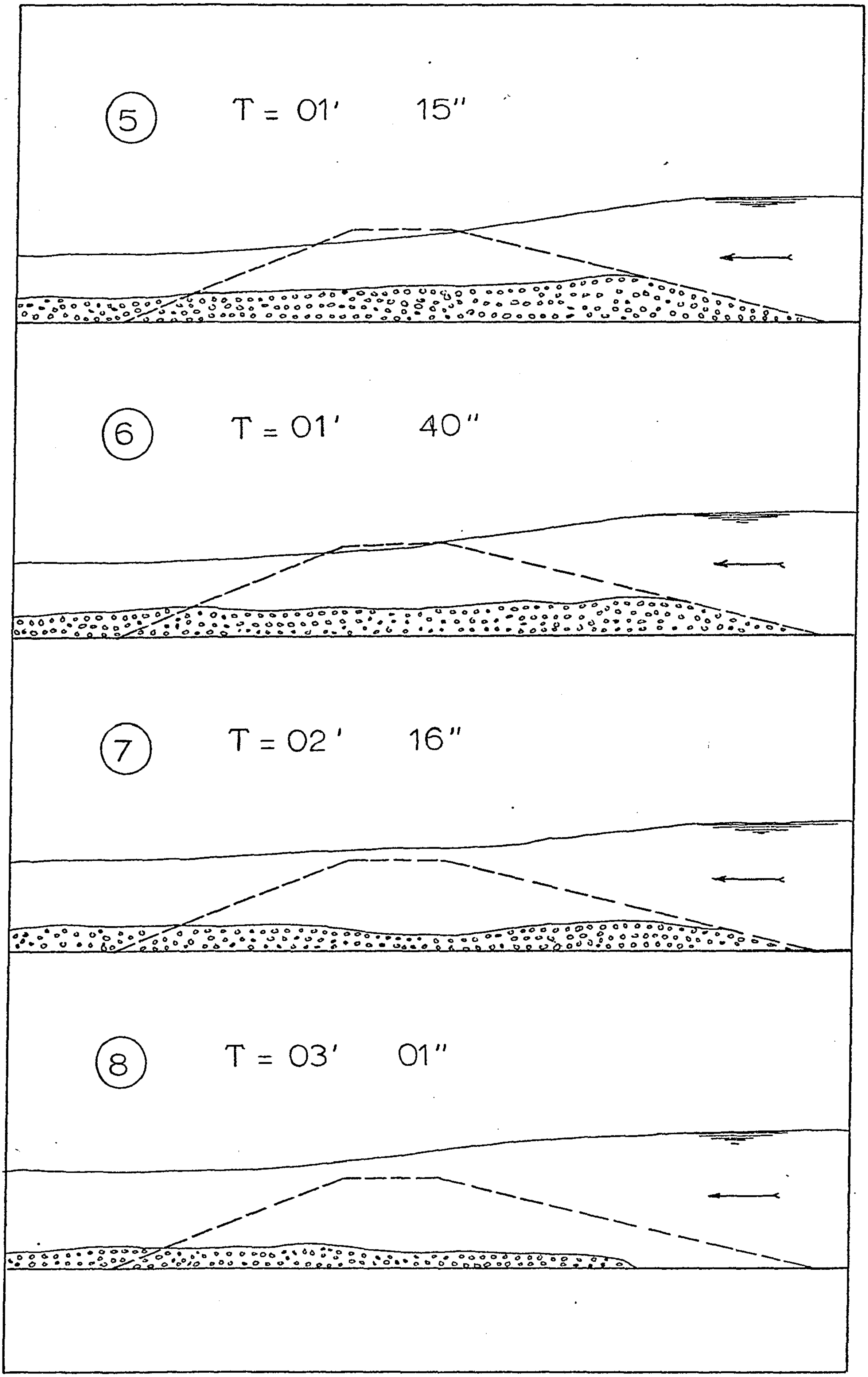
$S_s = 2.77$

$n = 40.0\%$

$\alpha = 0.267$

$d = 2.20$ mm.


1
T = 00' 45"
2
T = 00' 50"
3
T = 00' 55"
4
T = 01' 02"


5
T = 01' 15"
6
T = 01' 40"
7
T = 02' 16"
8
T = 03' 01"

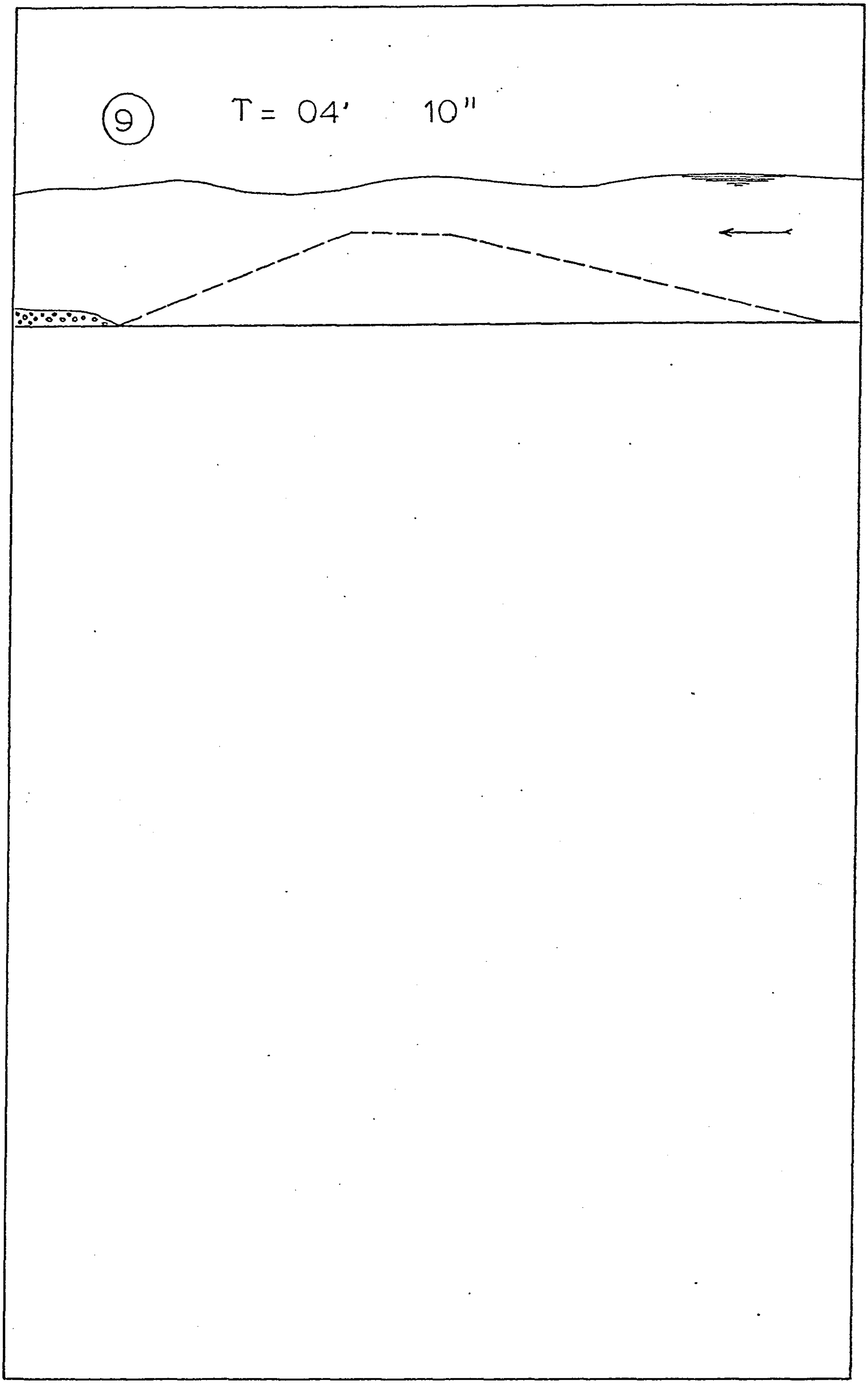

9
T = 04' 10"

Fig.30

Exp. No. 7-HO-9"

EROSION OF DAM AT CONSTANT UPSTREAM WATER LEVEL WITH DOWNSTREAM SUBCRITICAL FLOW.

Type (1) dam

Upstream water level maintained 0" above fuse plug crest

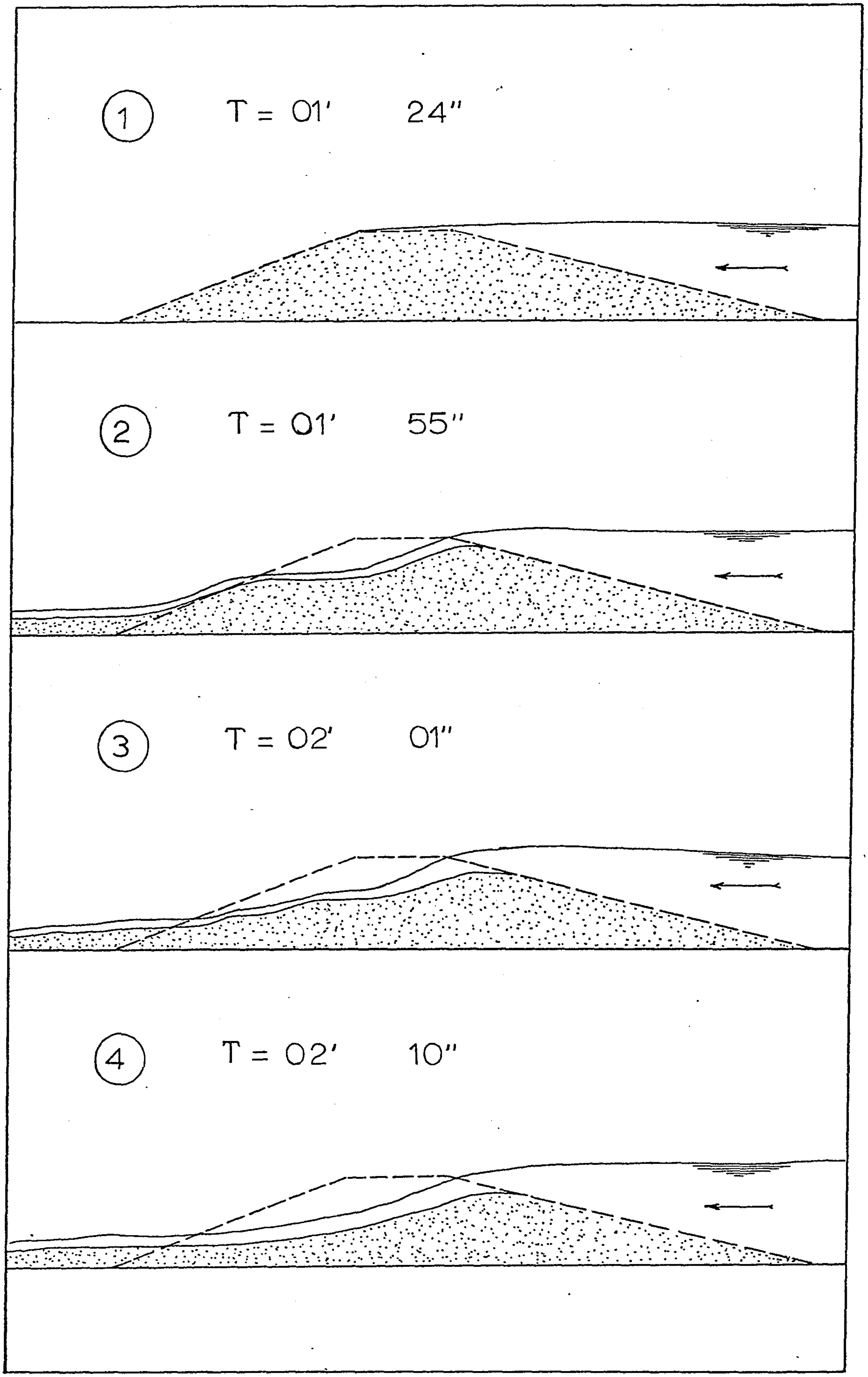
Material No. 7

$S_s = 2.65$

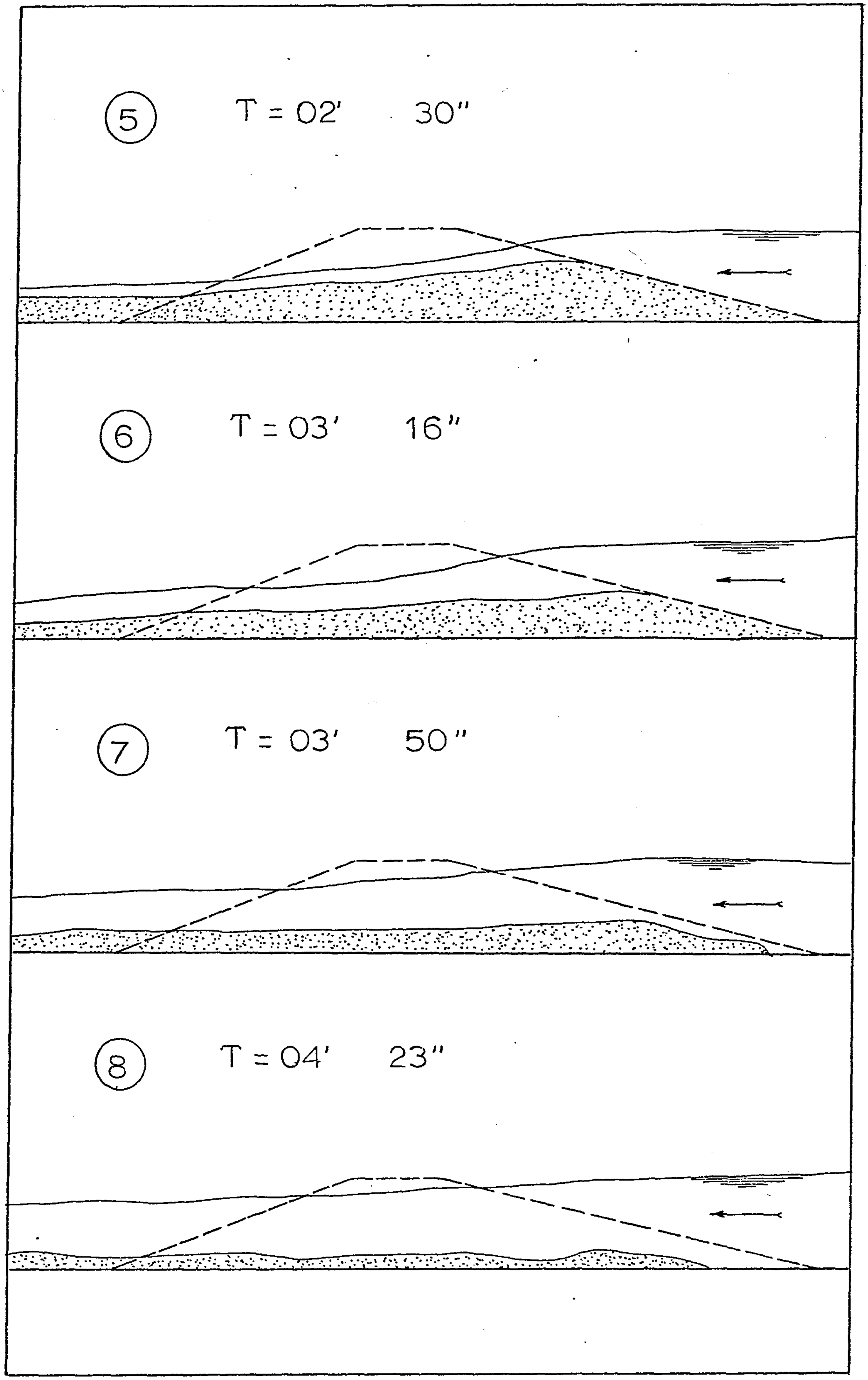
$n = 41.0\%$

$\alpha = 0.066$

$d = 0.80$ mm.



1
T = 01' 24"
2
T = 01' 55"
3
T = 02' 01"
4
T = 02' 10"



5
T = 02' 30"
6
T = 03' 16"
7
T = 03' 50"
8
T = 04' 23"

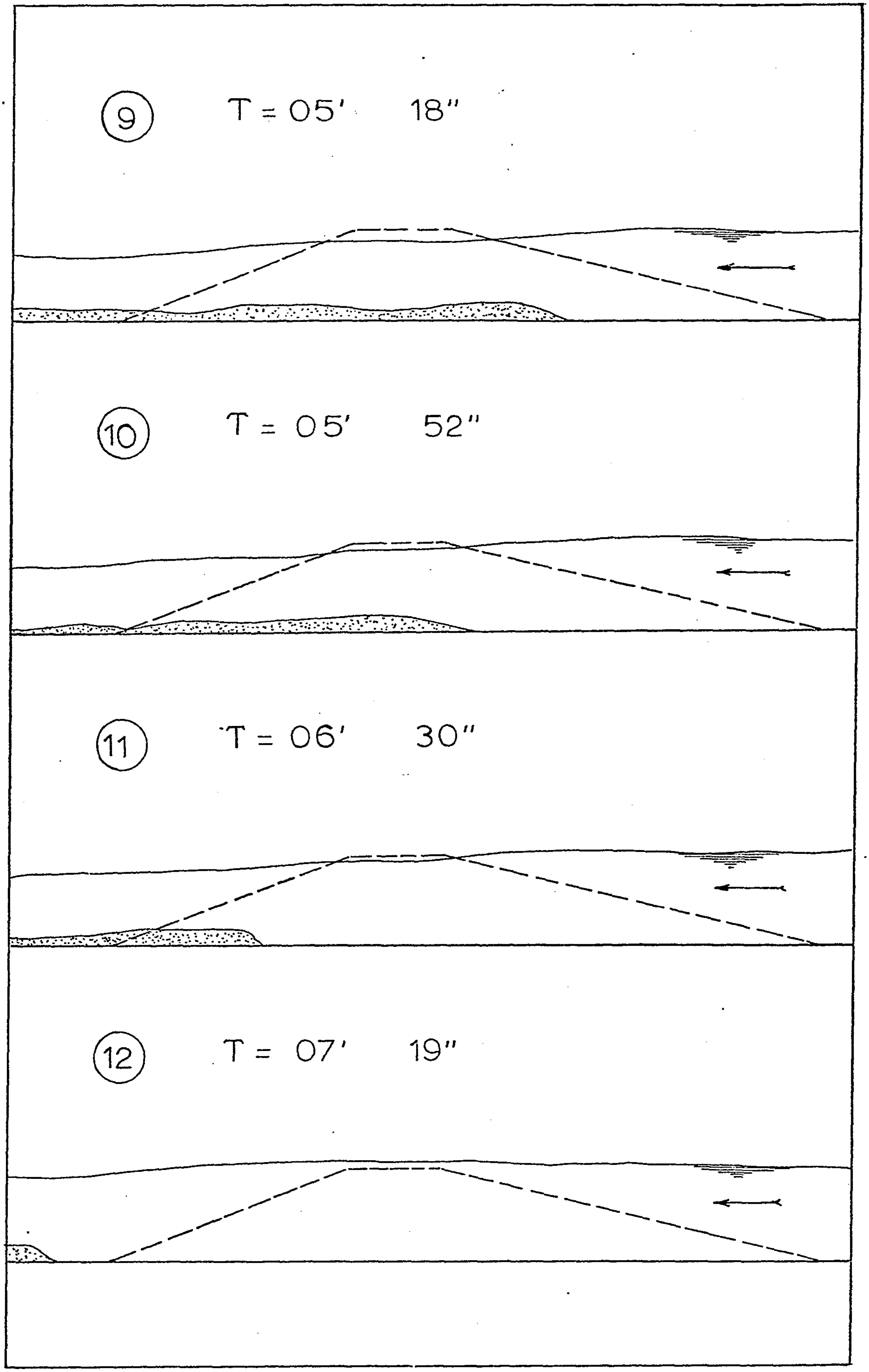

9 T = 05' 18"
10 T = 05' 52"
11 T = 06' 30"
12 T = 07' 19"

Fig.31

Exp. No. 7-H2-9"

EROSION OF DAM AT CONSTANT UPSTREAM WATER LEVEL WITH DOWNSTREAM SUBCRITICAL FLOW.

Type (1) dam

Upstream water level maintained 2" above fuse plug crest

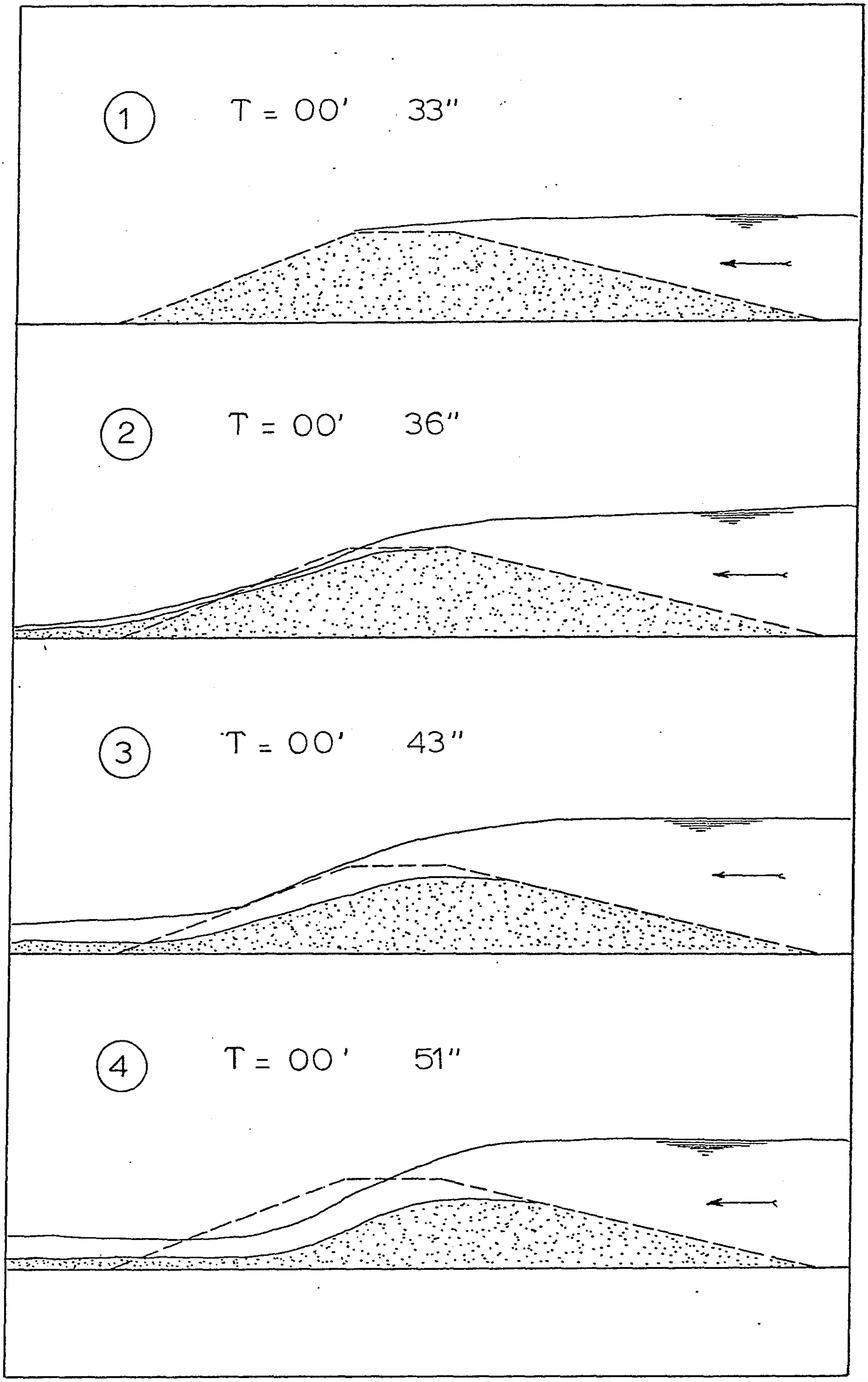
Material No. 7

$S_s = 2.65$

$n = 41.0\%$

$\alpha = 0.066$

$d = 0.80$ mm.



1
T = 00' 33"
2
T = 00' 36"
3
T = 00' 43"
4
T = 00' 51"

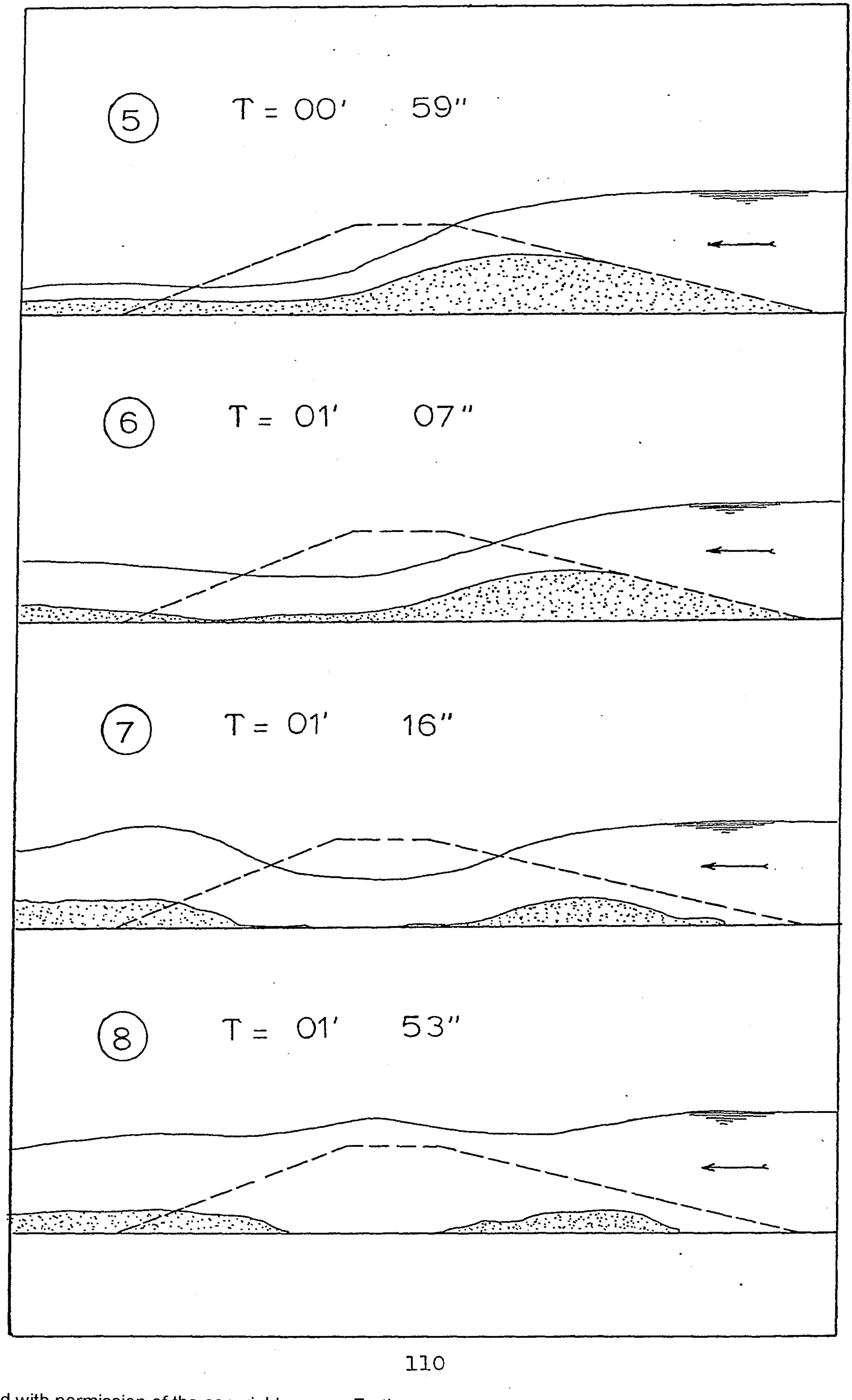

5 T = 00' 59"
6 T = 01' 07"
7 T = 01' 16"
8 T = 01' 53"

Fig.32

Exp. No. 1-HO-6"

EROSION OF DAM AT CONSTANT UPSTREAM WATER LEVEL WITH DOWNSTREAM SUBCRITICAL FLOW.

Type (2) dam

Upstream water level maintained 0" above fuse plug crest

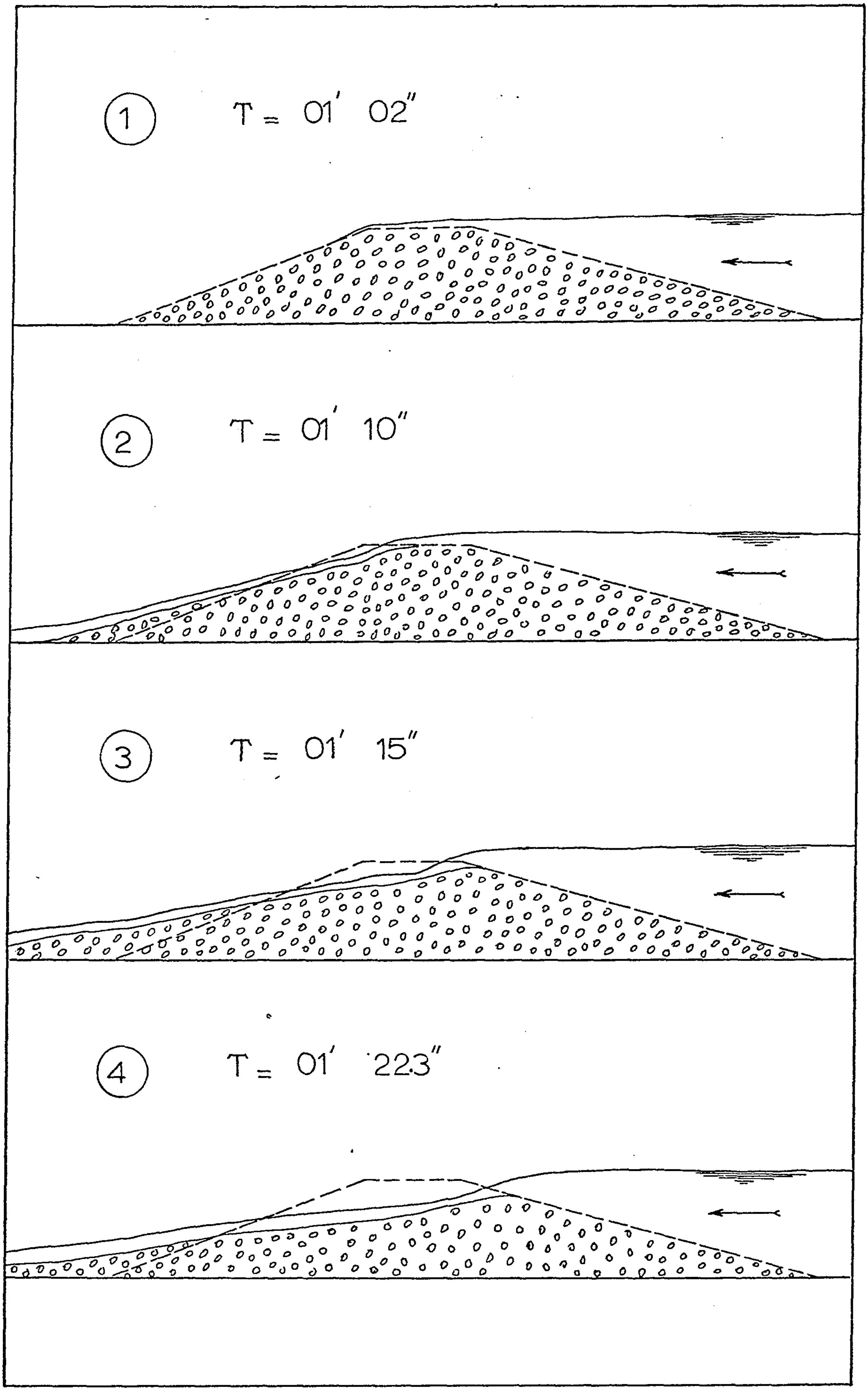
Material No. 1

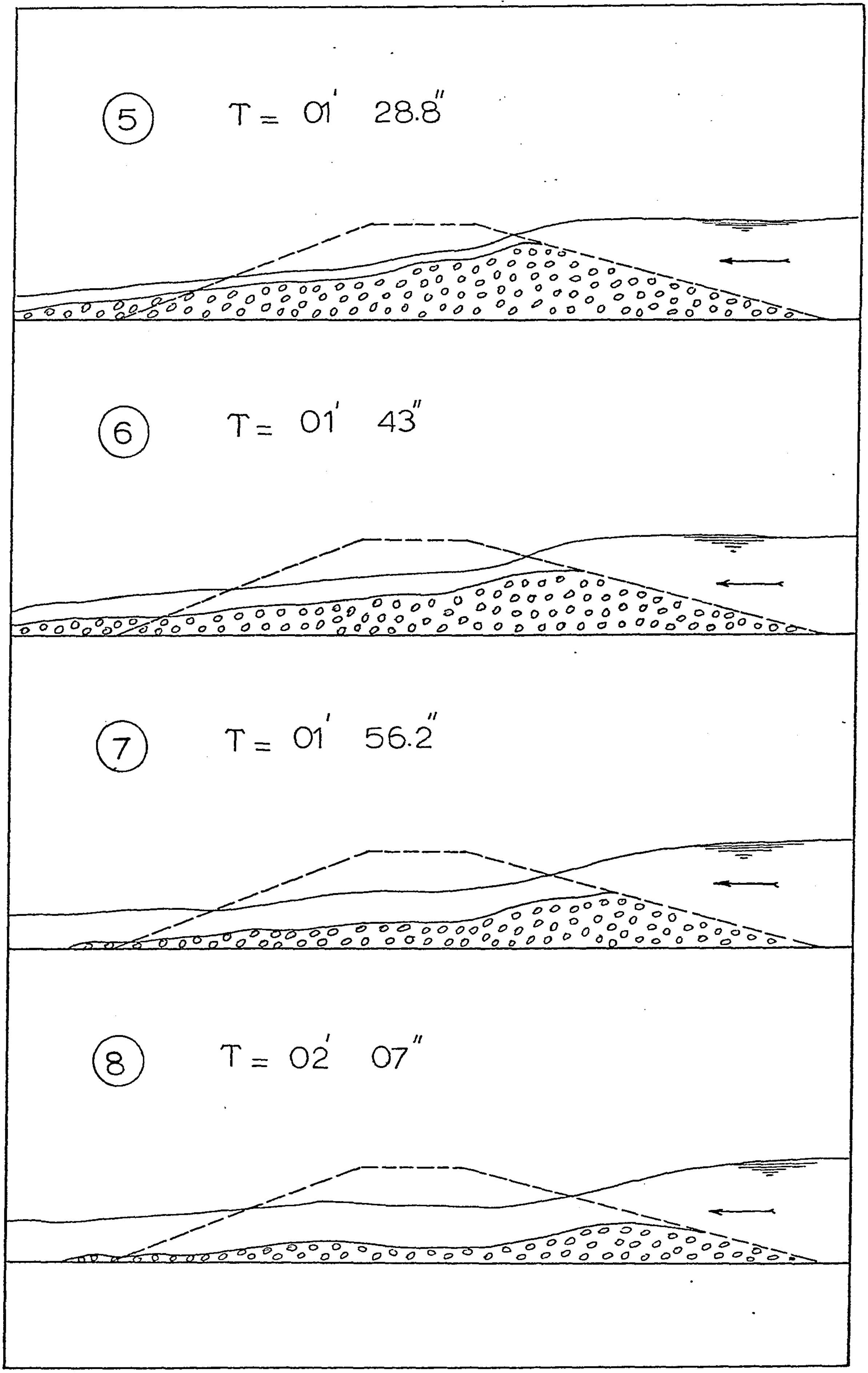
S_s = 2.76

n = 40.2%

$\propto$ = 0.596

d = 8.40 mm.


1
T = 01′ 02″
2
T = 01′ 10″
3
T = 01′ 15″
4
T = 01′ 22.3″



5
T = 01' 28.8"
6
T = 01' 43"
7
T = 01' 56.2"
8
T = 02' 07"

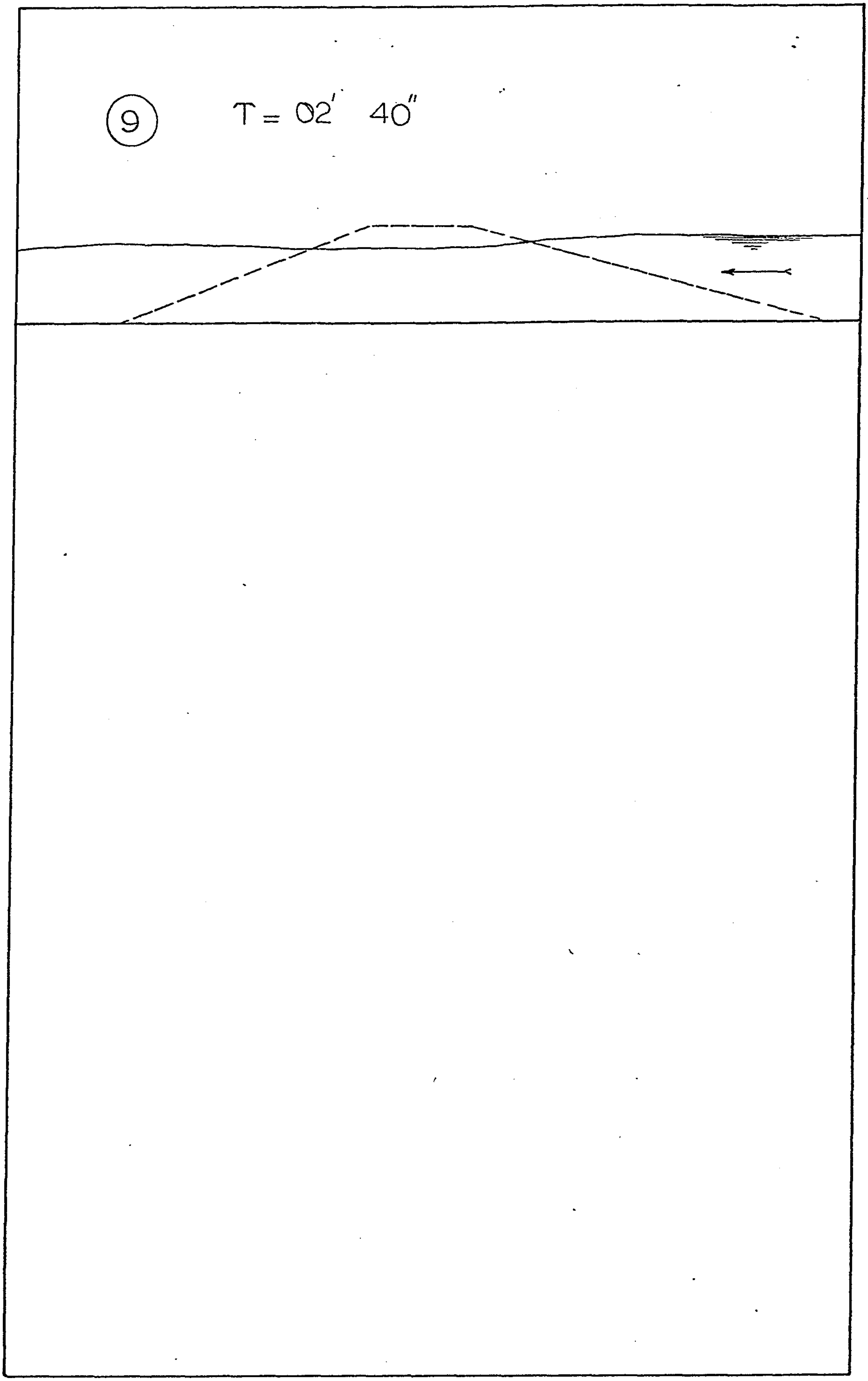

9
T = 02' 40"

Fig.33

<u>Exp. No. 4-HO-6"</u>

EROSION OF DAM AT CONSTANT UPSTREAM WATER LEVEL WITH DOWNSTREAM SUBCRITICAL FLOW.

Type (2) dam

Upstream water level maintained 0" above fuse plug crest

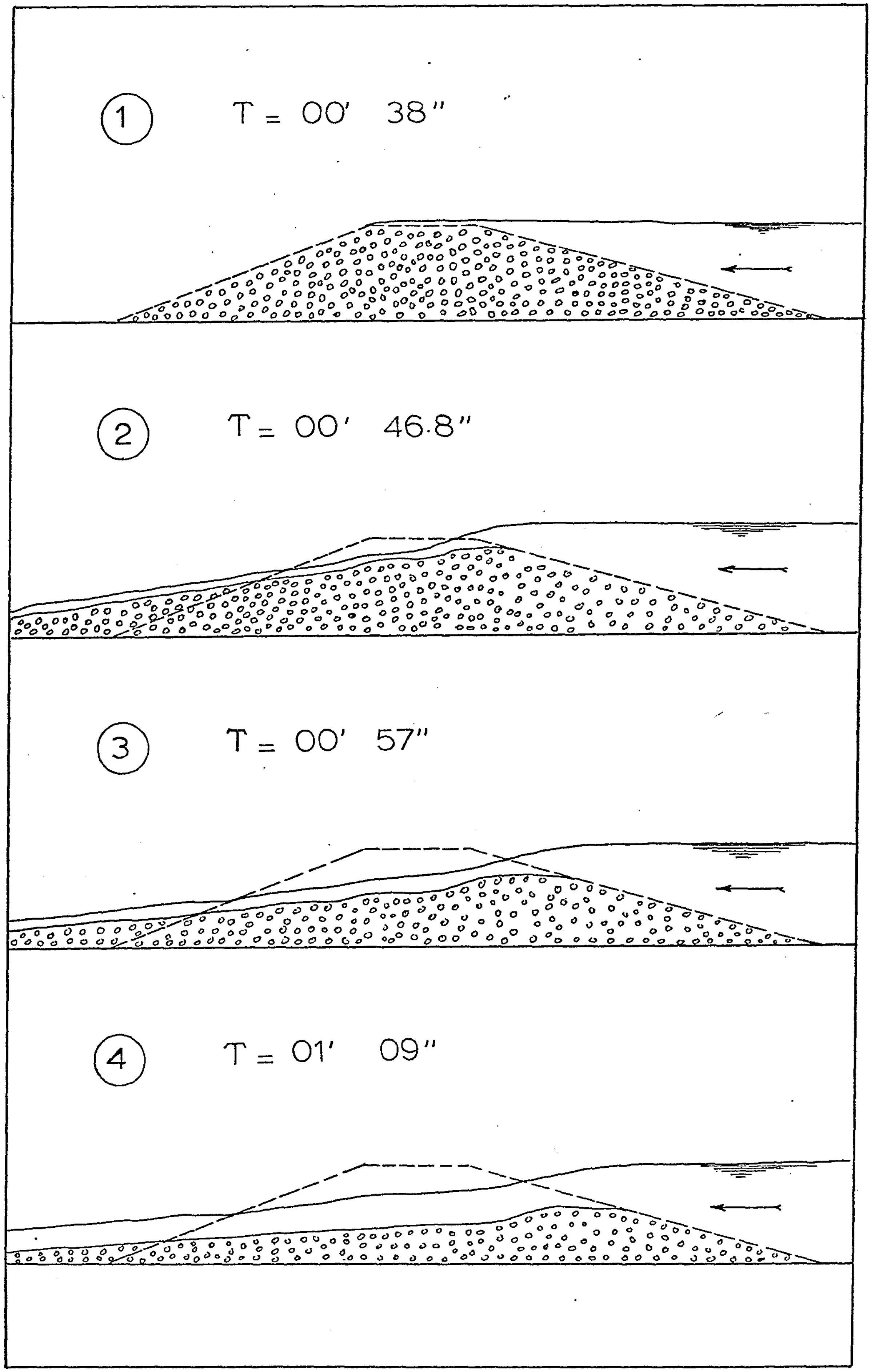
Material No. 4

S_s = 2.76

n = 40.2%

α = 0.438

d = 4.00 mm.


1
T = 00' 38"
2
T = 00' 46.8"
3
T = 00' 57"
4
T = 01' 09"

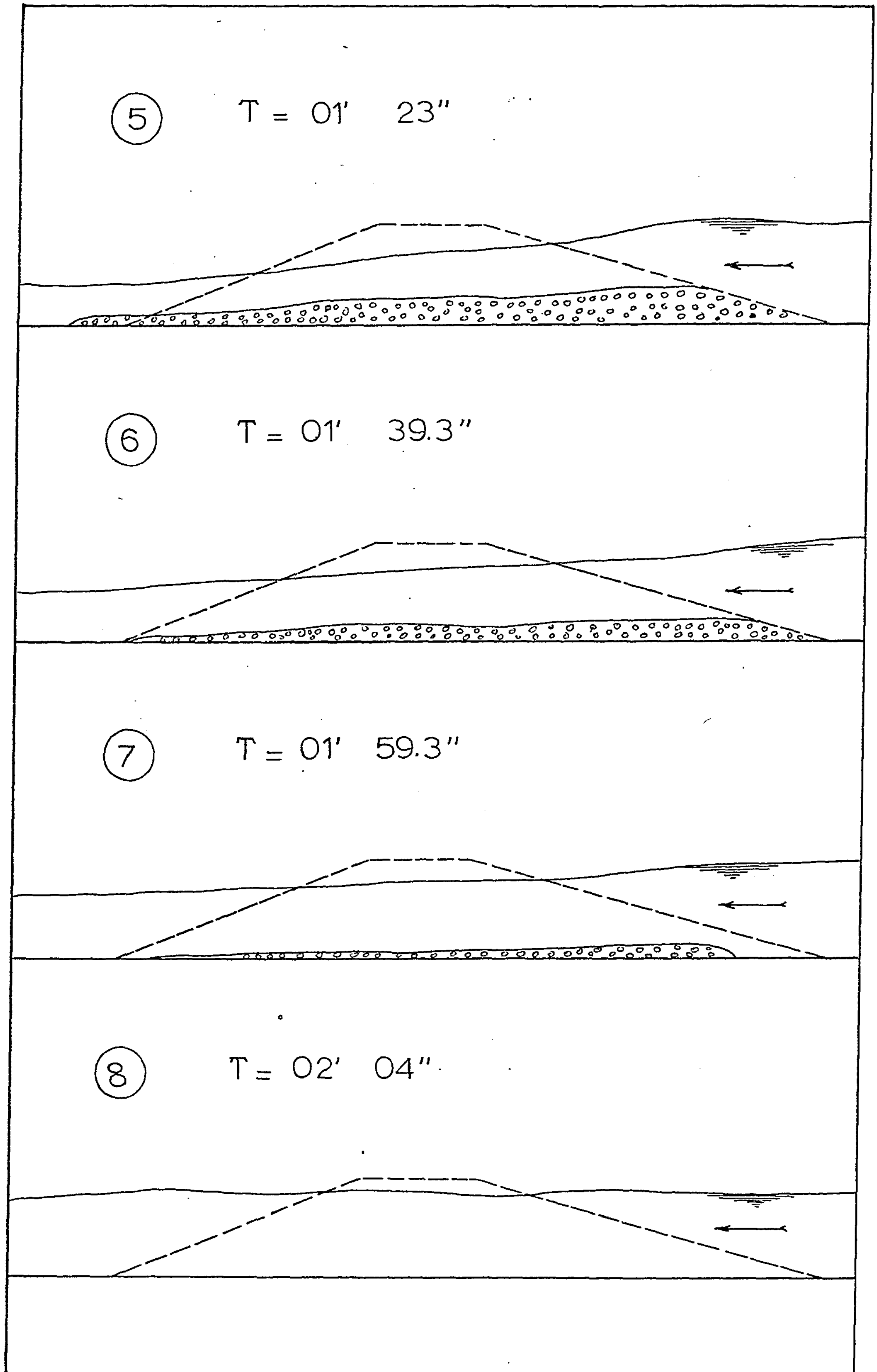

5
T = 01' 23"
6
T = 01' 39.3"
7
T = 01' 59.3"
8
T = 02' 04"

Fig.34

<u>Exp. No. 6-HO-6"</u>

EROSION OF DAM AT CONSTANT UPSTREAM WATER LEVEL WITH DOWNSTREAM SUBCRITICAL FLOW.

Type (2) dam

Upstream water level maintained 0" above fuse plug crest

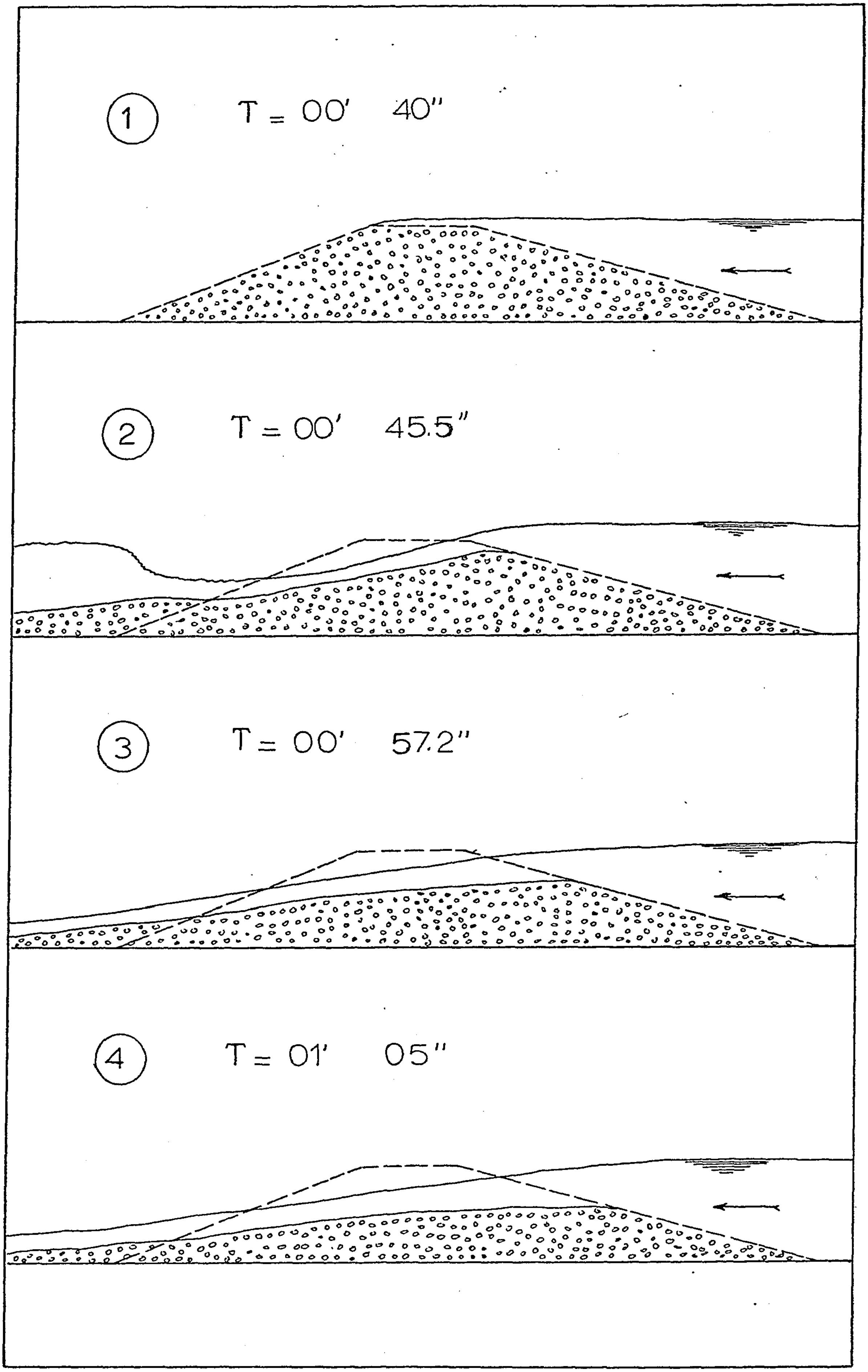
Material No. 6

S_s = 2.74

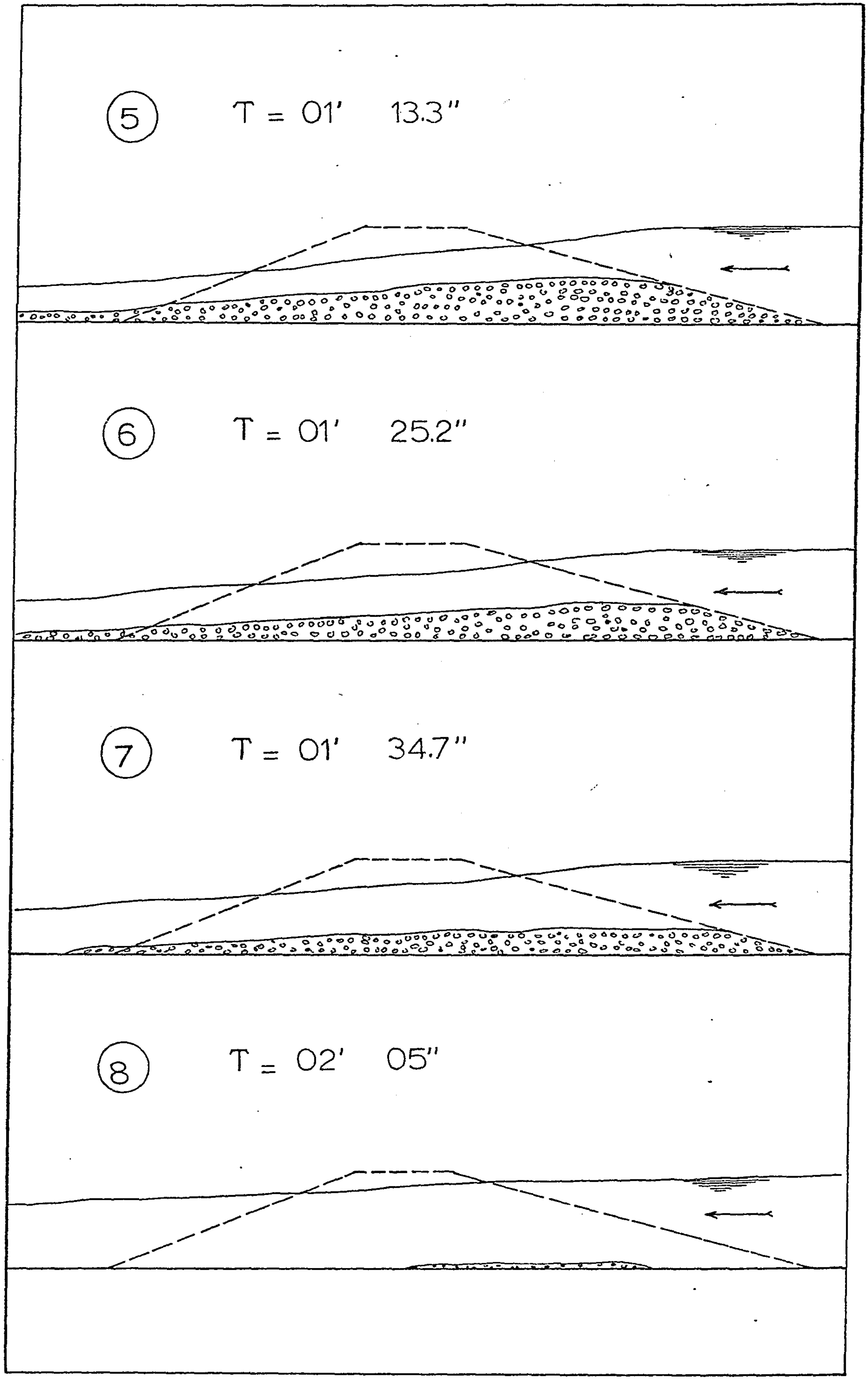
n = 35.0%

α = 0.251

d = 1.90 mm.



1
T = 00' 40"
2
T = 00' 45.5"
3
T = 00' 57.2"
4
T = 01' 05"



5
T = 01' 13.3"
6
T = 01' 25.2"
7
T = 01' 34.7"
8
T = 02' 05"

Fig.35

Exp. No. 7-HO-6"

EROSION OF DAM AT CONSTANT UPSTREAM WATER LEVEL WITH DOWNSTREAM SUBCRITICAL FLOW.

Type (2) dam

Upstream water level maintained 0" above fuse plug crest

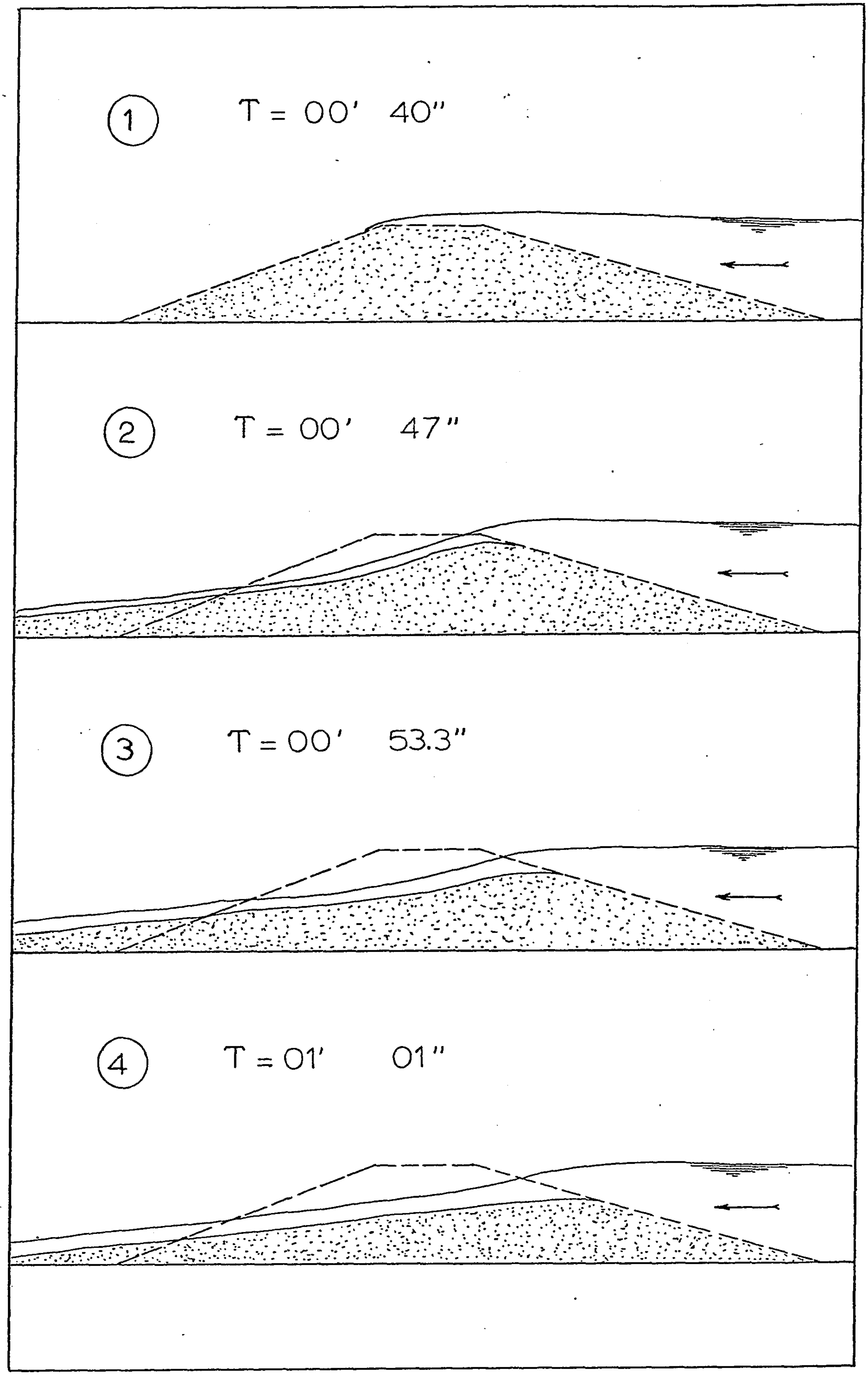
Material No. 7

$S_s = 2.65$

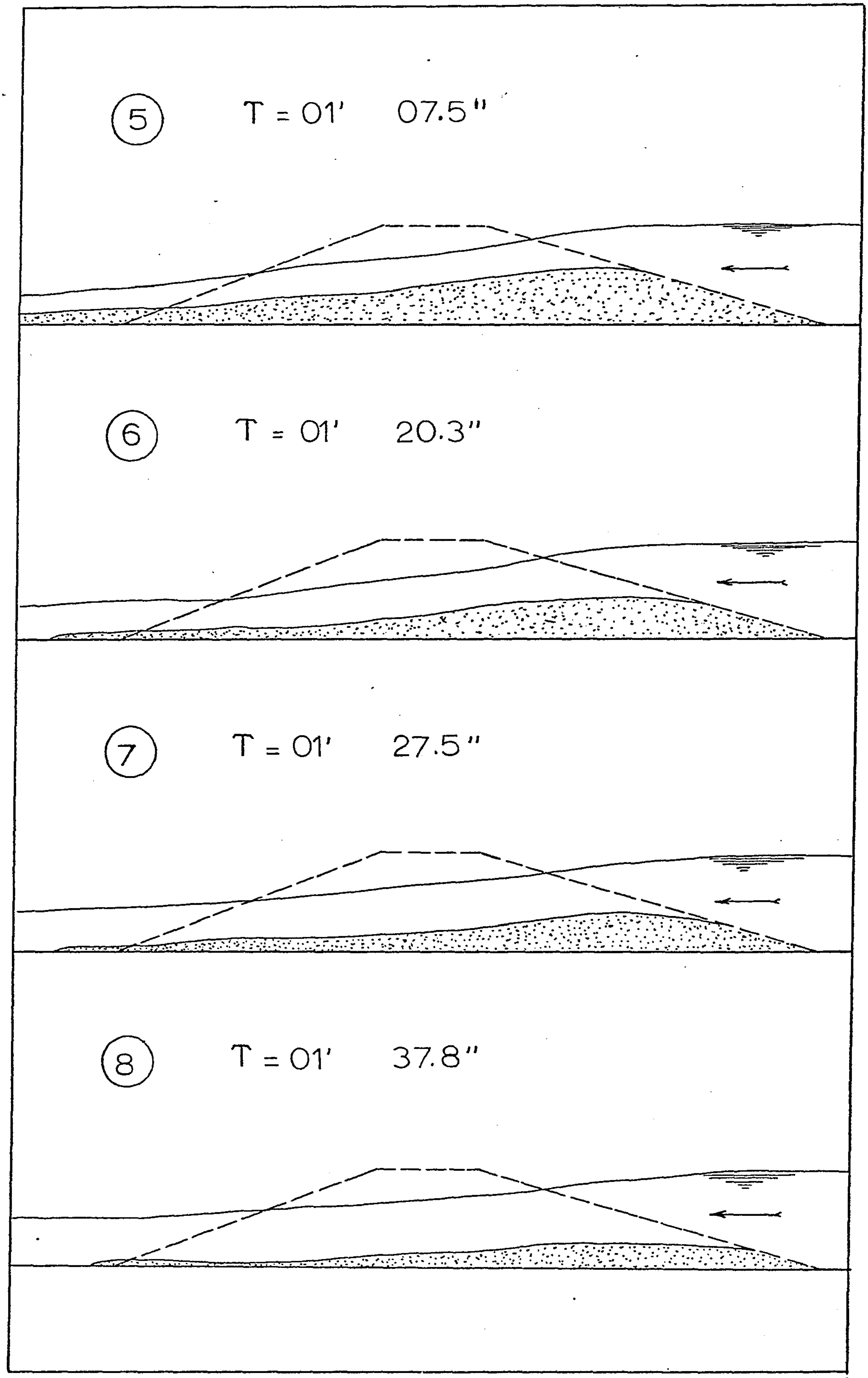
$n = 41.0\%$

$\alpha = 0.066$

$d = 0.80$ mm.



1
T = 00' 40"
2
T = 00' 47"
3
T = 00' 53.3"
4
T = 01' 01"



5
T = 01' 07.5"
6
T = 01' 20.3"
7
T = 01' 27.5"
8
T = 01' 37.8"

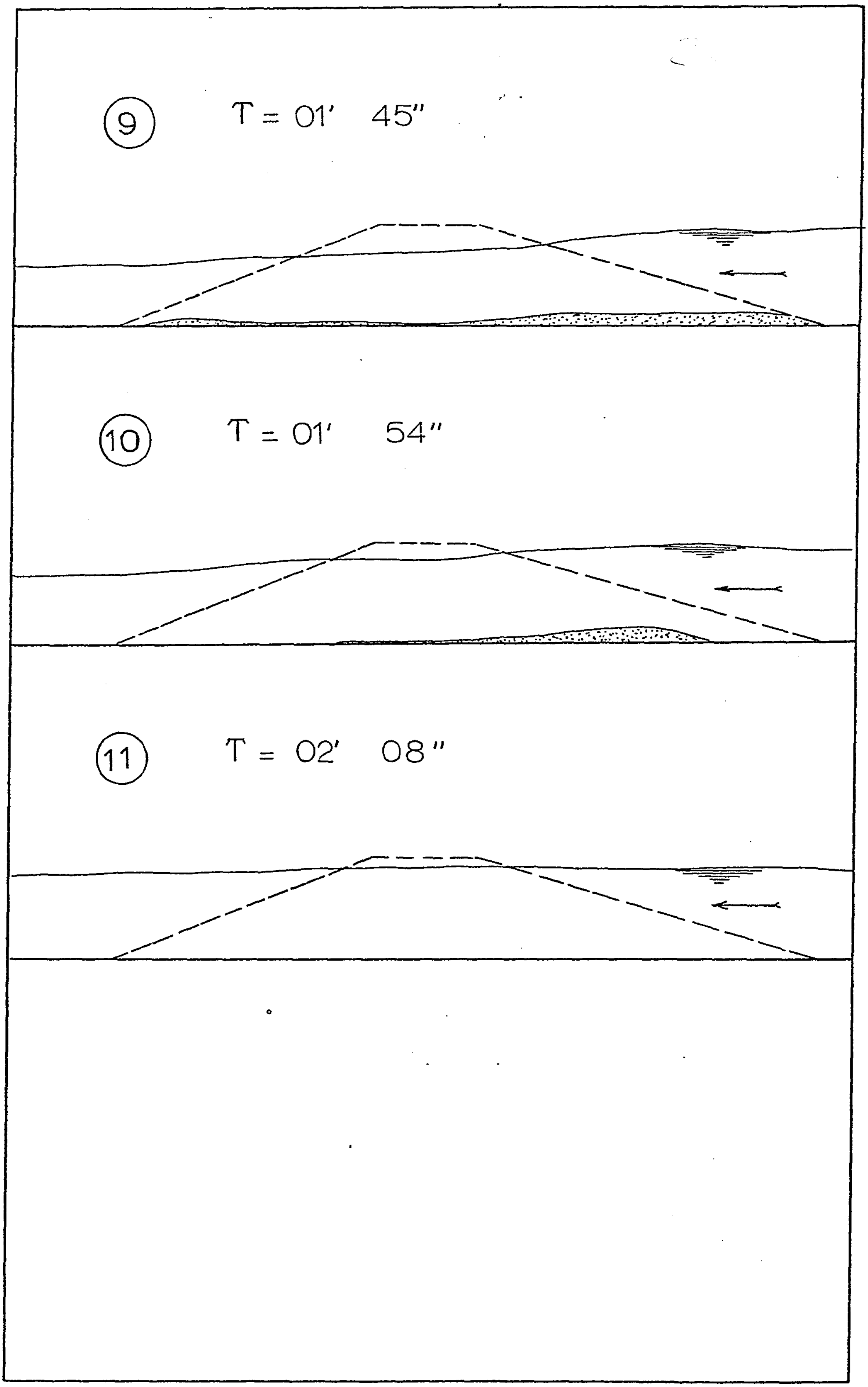

9
T = 01' 45"
10
T = 01' 54"
11
T = 02' 08"

Fig.36

Exp. No. 8-HO-6"

EROSION OF DAM AT CONSTANT UPSTREAM WATER LEVEL WITH DOWNSTREAM SUBCRITICAL FLOW.

Type (2) dam

Upstream water level maintained 0" above fuse plug crest

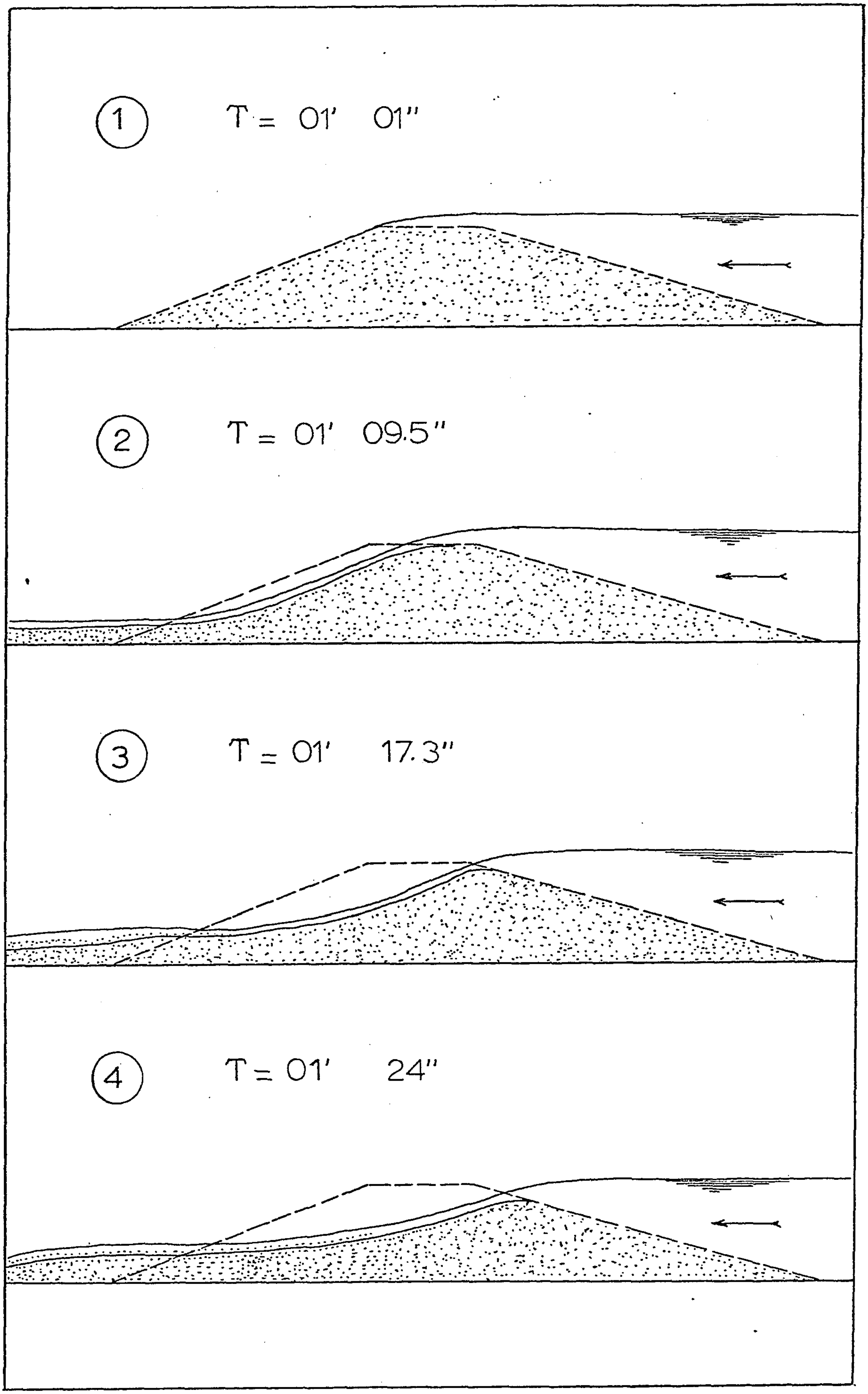
Material No. 8

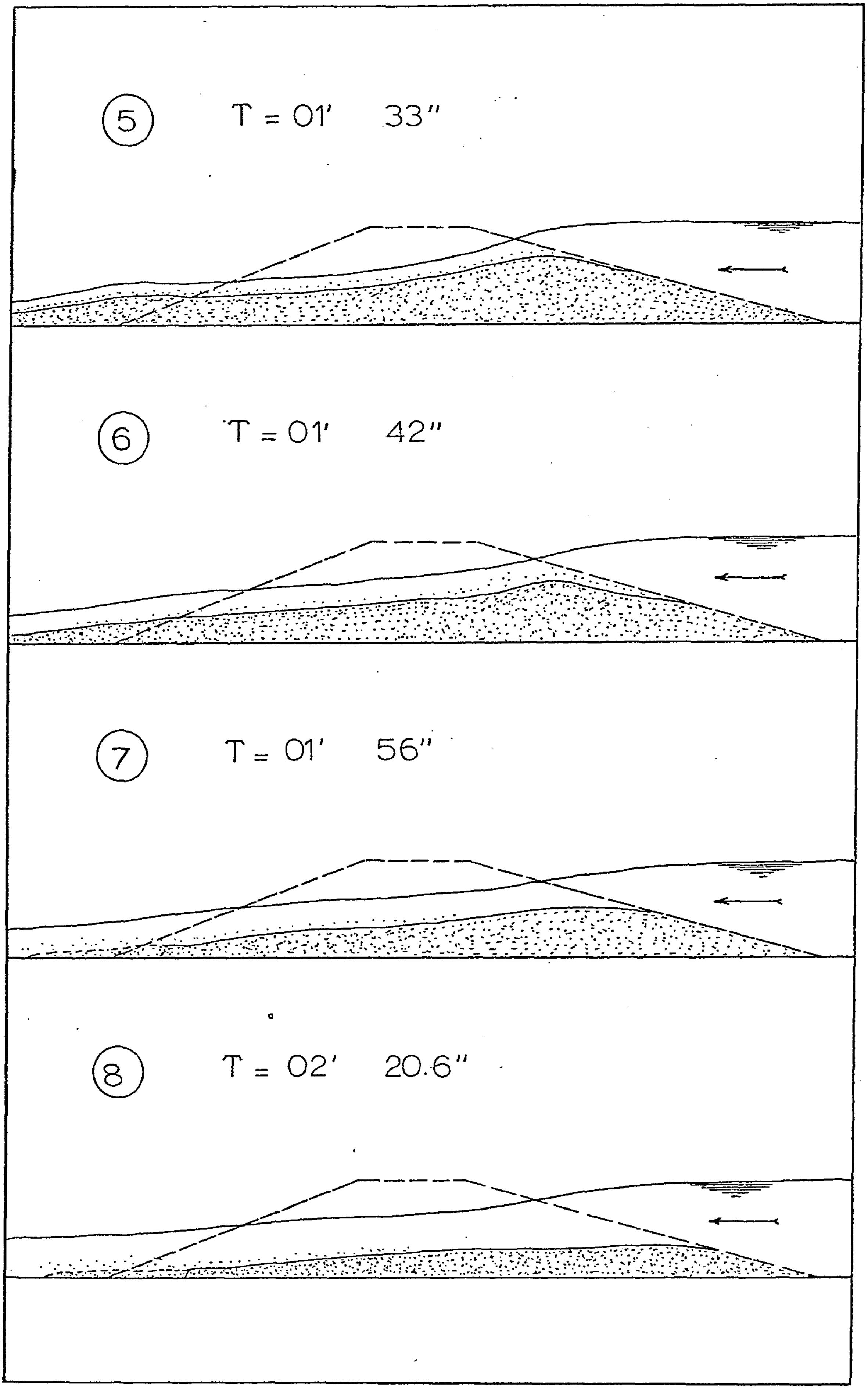
$Ss = 3.26$

$n = 37.6\%$

$\alpha = 0.035$

$d = 0.43$ mm.


1
T = 01' 01"
2
T = 01' 09.5"
3
T = 01' 17.3"
4
T = 01' 24"


5 T = 01' 33"
6 T = 01' 42"
7 T = 01' 56"
8 T = 02' 20.6"

(9) T = 02' 41"

(10) T = 03' 10"

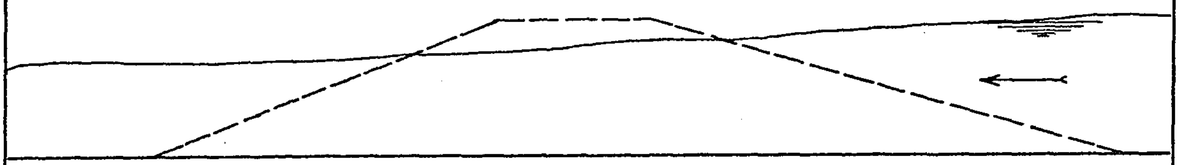


Fig.37

Exp. No. 9-HO-6"

EROSION OF DAM AT CONSTANT UPSTREAM WATER LEVEL WITH DOWNSTREAM SUBCRITICAL FLOW.

Type (2) dam

Upstream water level maintained 0" above fuse plug crest

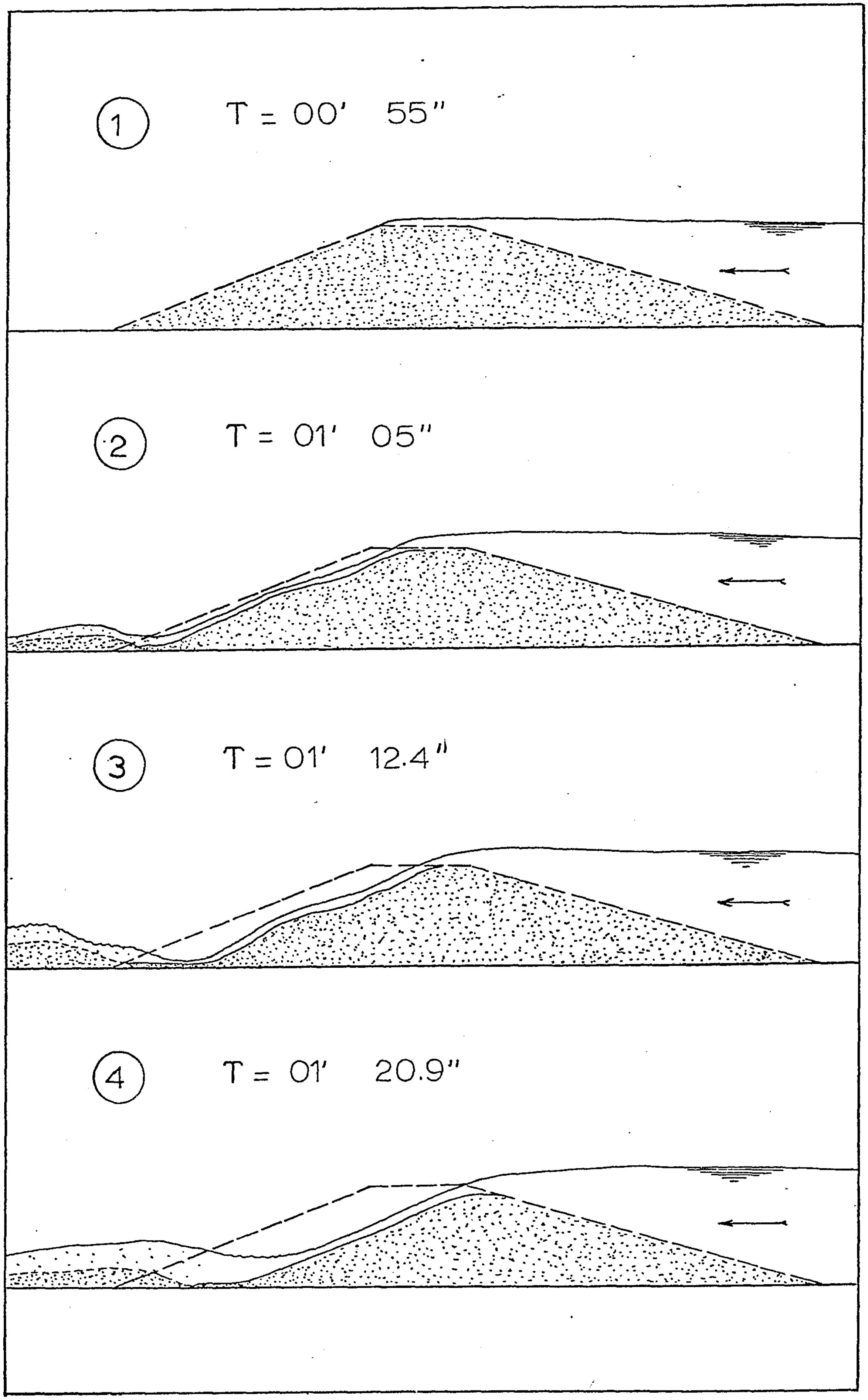
Material No. 9

$S_s = 2.65$

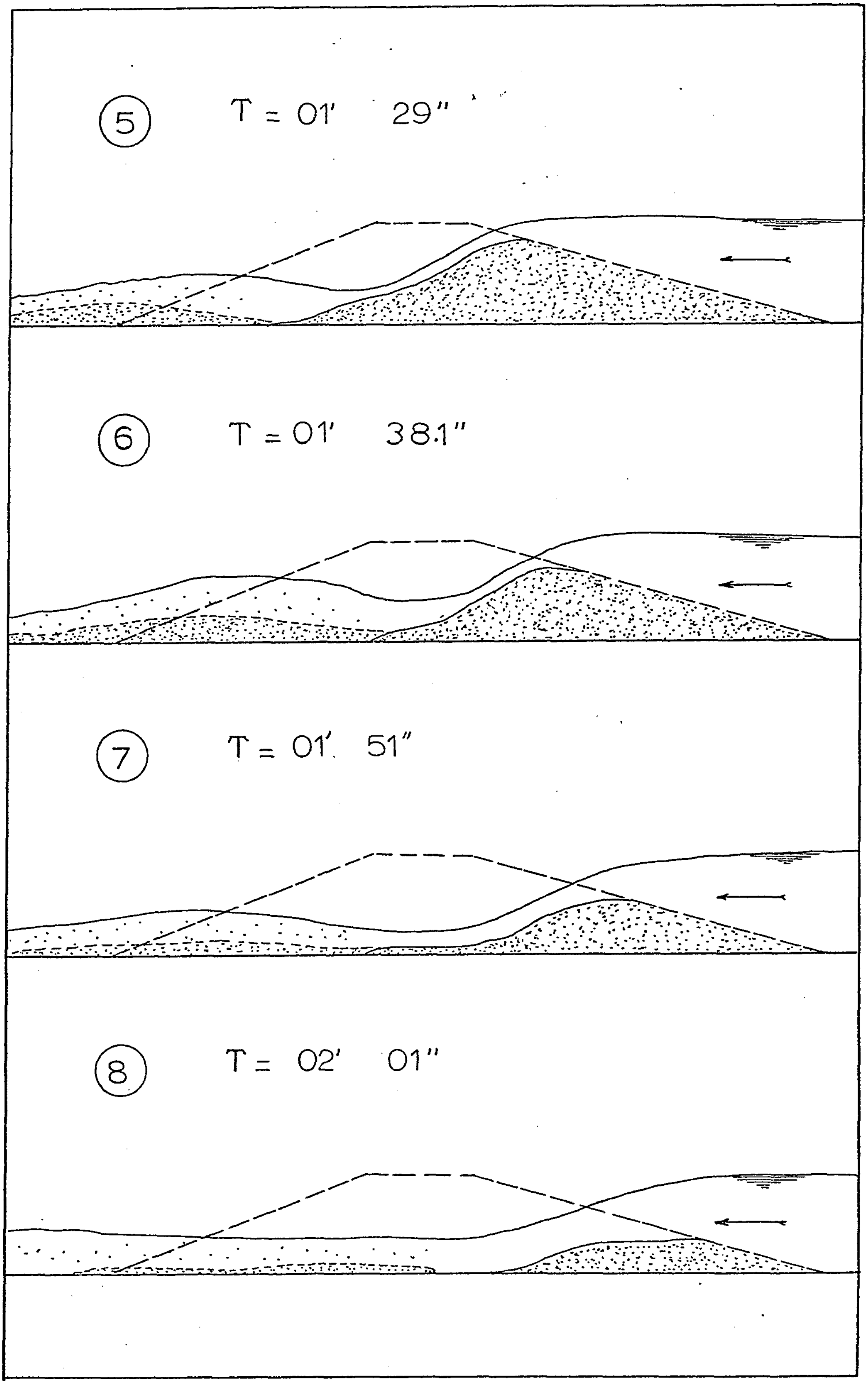
$n = 32.1\%$

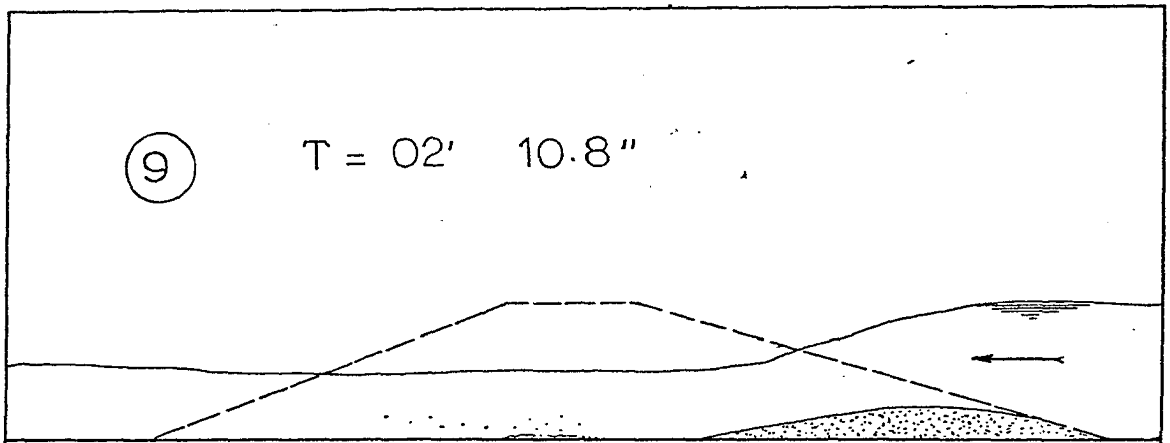
$\alpha = 0.019$

$d = 0.23$ mm.



1
T = 00' 55"
2
T = 01' 05"
3
T = 01' 12.4"
4
T = 01' 20.9"


5
T = 01' 29"
6
T = 01' 38.1"
7
T = 01'. 51"
8
T = 02' 01"


9
T = 02' 10.8"

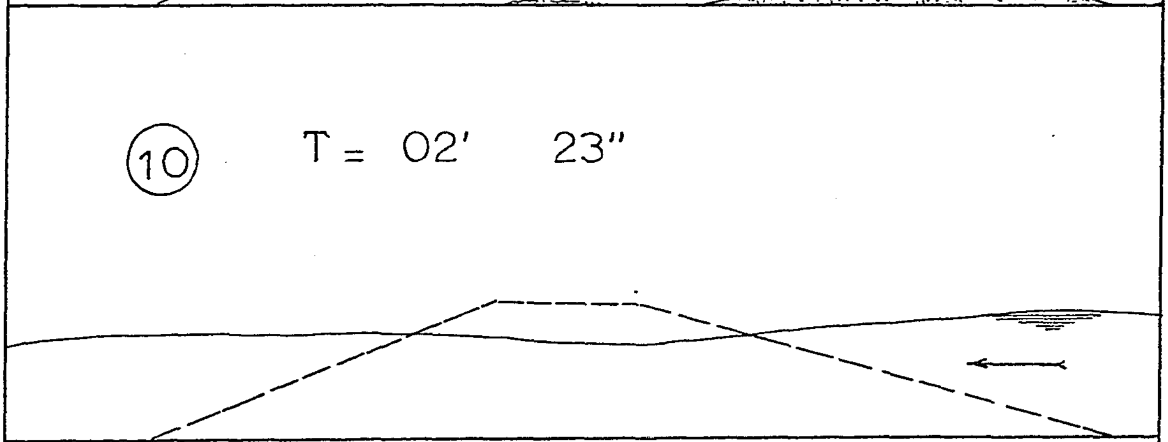

10
T = 02' 23"

Fig.38

Exp. No. 10-HO-6"

EROSION OF DAM AT CONSTANT UPSTREAM WATER LEVEL WITH DOWNSTREAM SUBCRITICAL FLOW.

Type (2) dam

Upstream water level maintained 0" above fuse plug crest

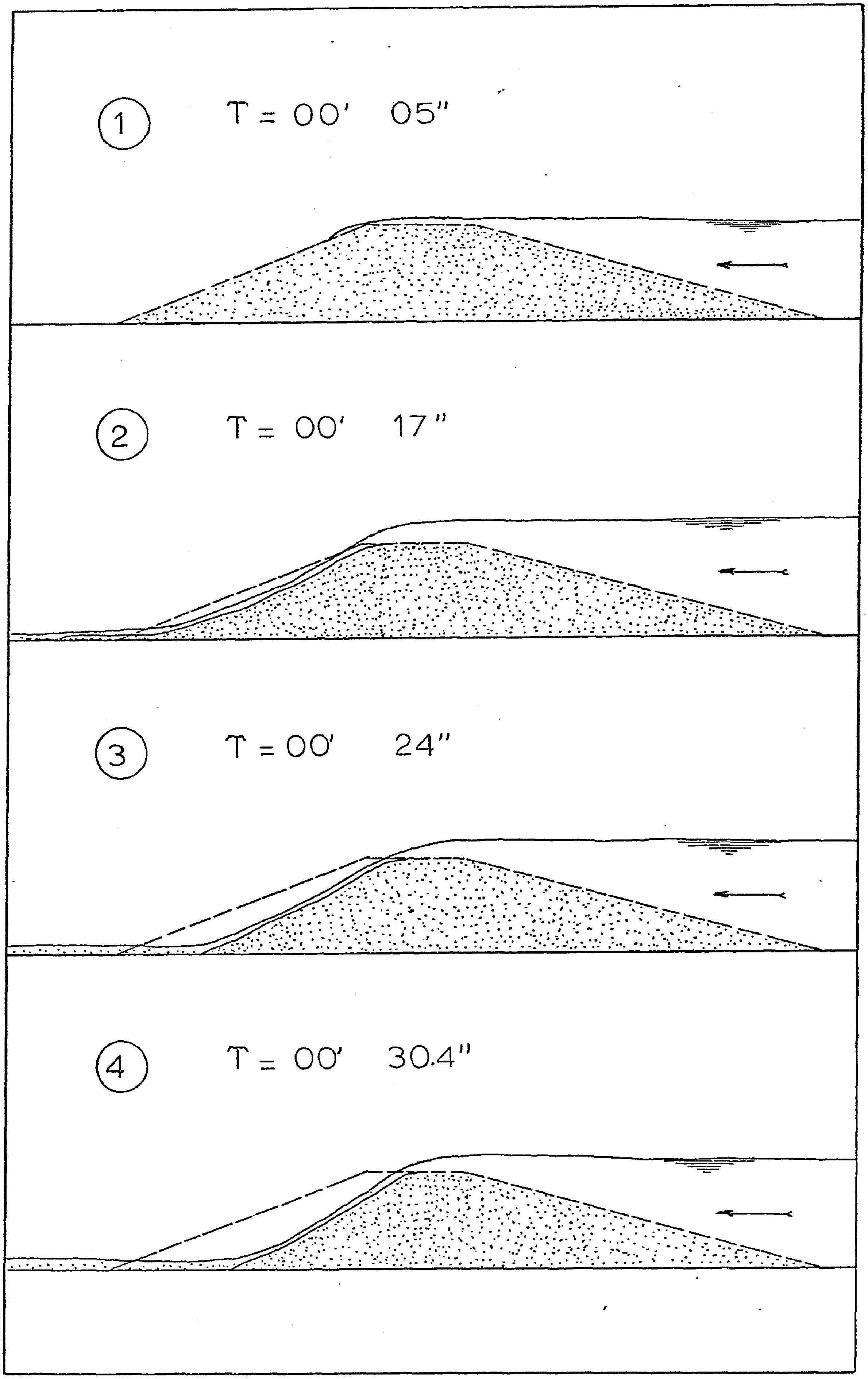
Material No. 10

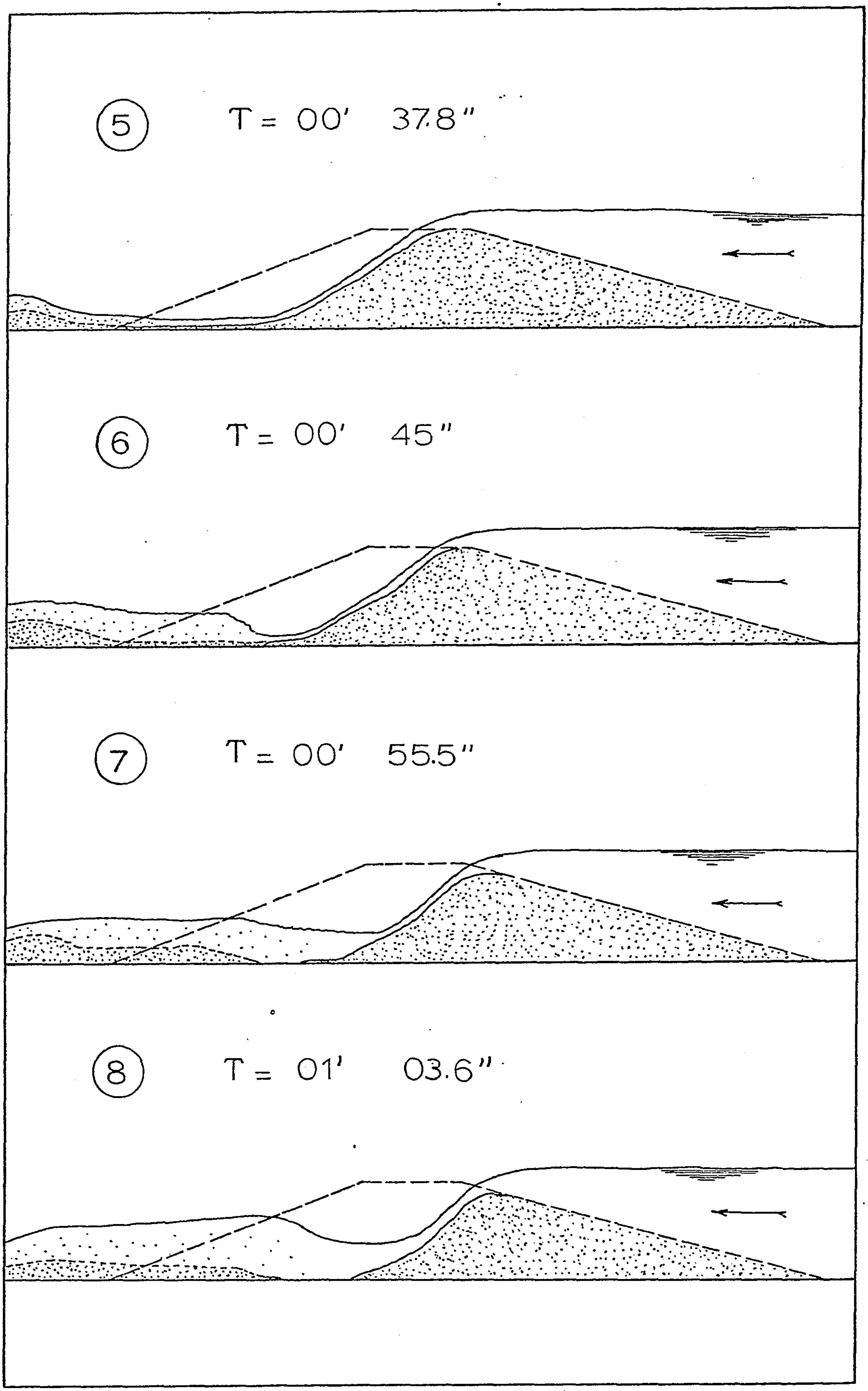
S_s = 4.50

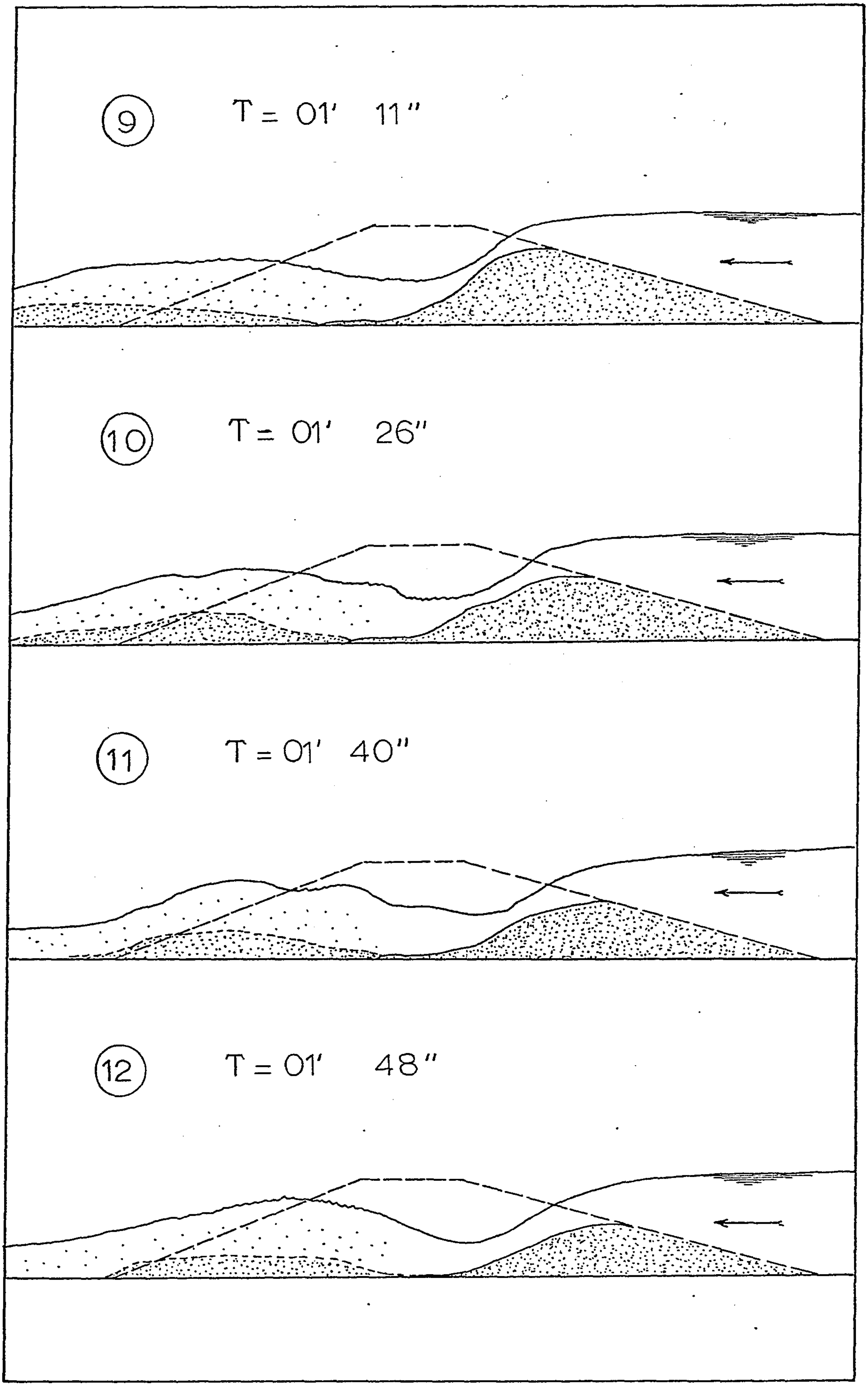
n = 32.1%

α = 0.012

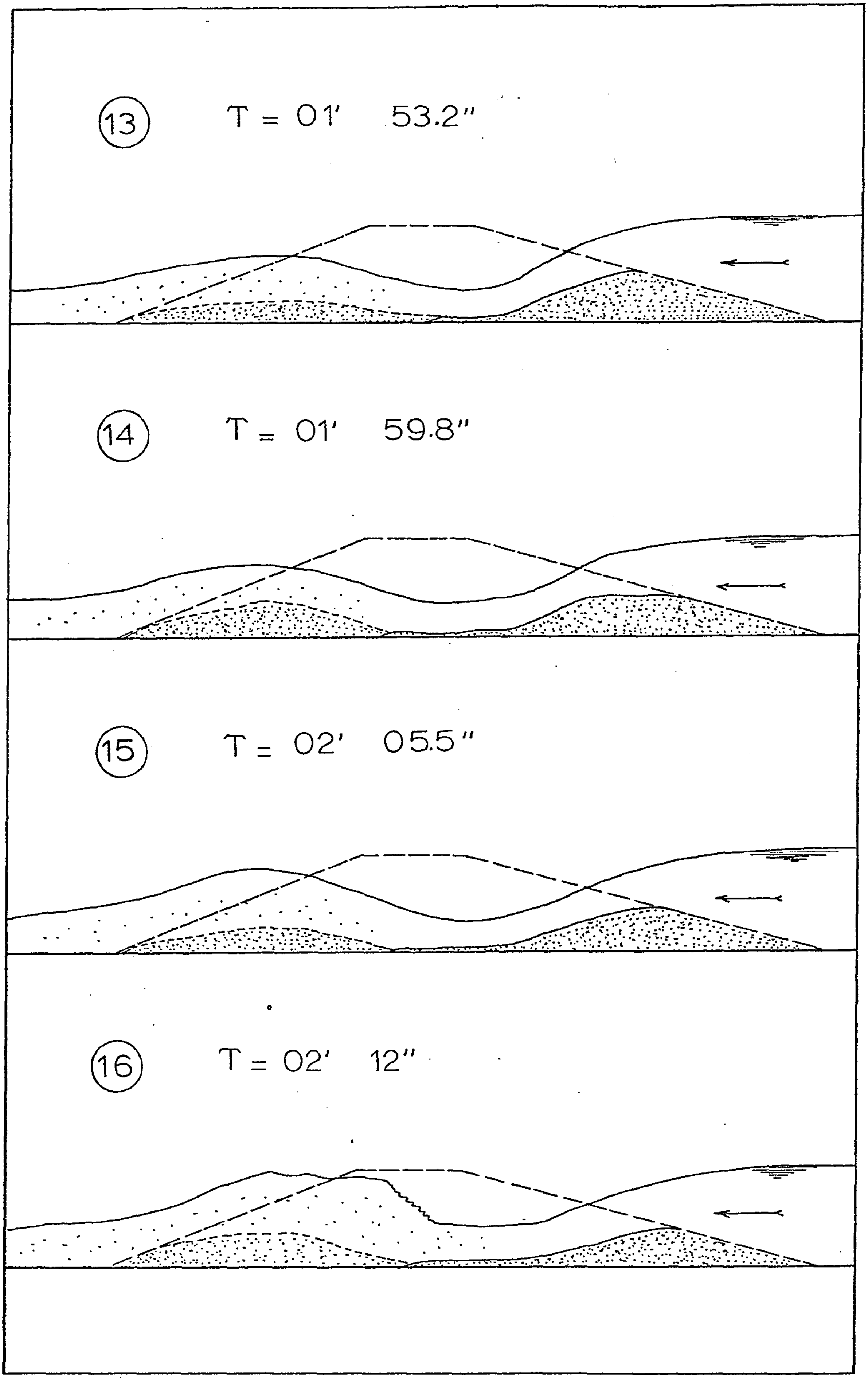
d = 0.14 mm.

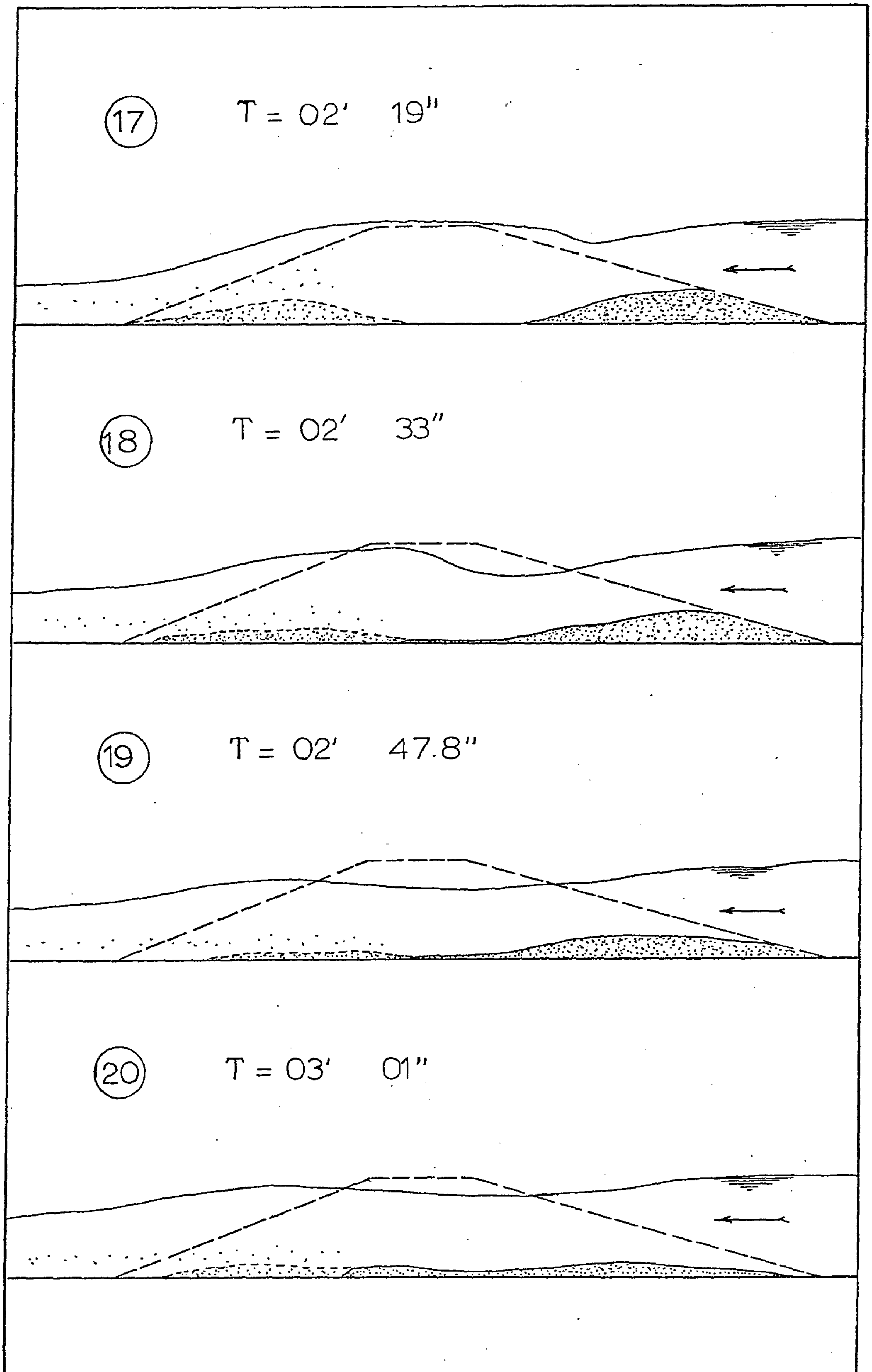

1
T = 00' 05"
2
T = 00' 17"
3
T = 00' 24"
4
T = 00' 30.4"


5
T = 00' 37.8"
6
T = 00' 45"
7
T = 00' 55.5"
8
T = 01' 03.6"



9
T = 01' 11"
10
T = 01' 26"
11
T = 01' 40"
12
T = 01' 48"


13
T = 01' 53.2"
14
T = 01' 59.8"
15
T = 02' 05.5"
16
T = 02' 12"



17
T = 02' 19"
18
T = 02' 33"
19
T = 02' 47.8"
20
T = 03' 01"

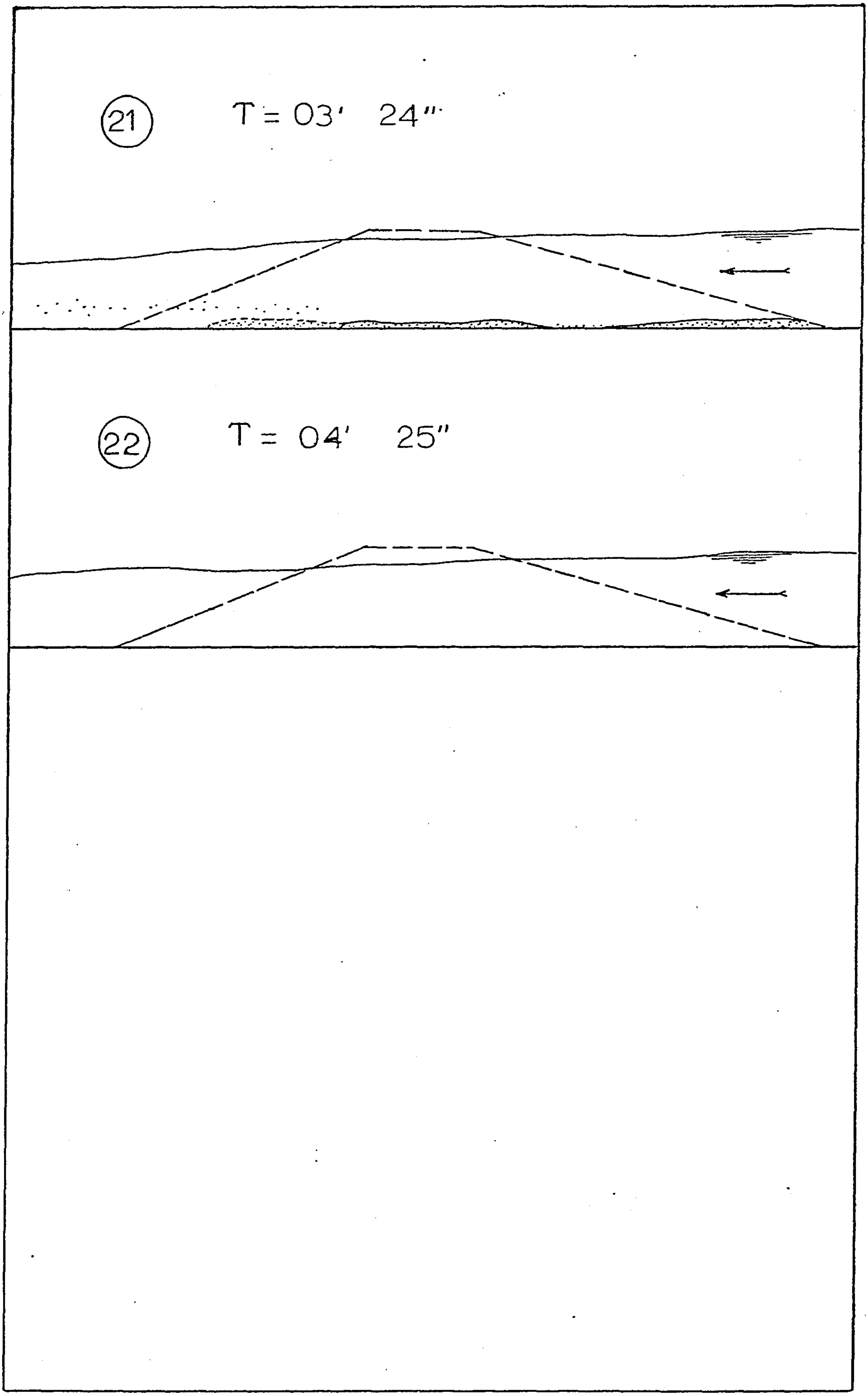

21
T = 03' 24"
22
T = 04' 25"

Fig.39

Exp. No. 3-Q750-9"

EROSION OF DAM AT CONSTANT DISCHARGE

WITH DOWNSTREAM SUPERCRITICAL FLOW.

Type (1) dam

Washout discharge = 2.27 cfs/ft

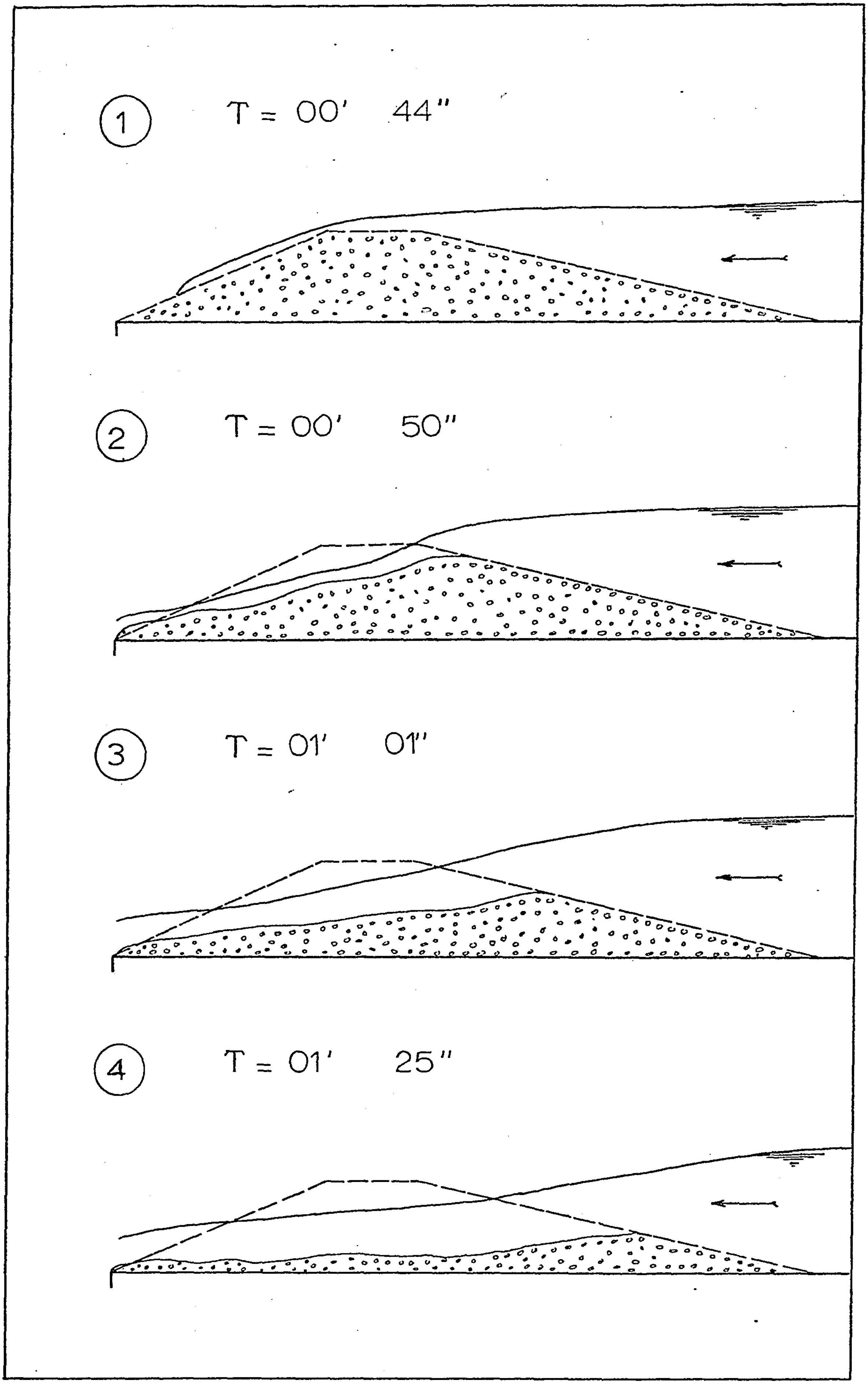
Material No. 3

S_s = 2.70

n = 40.0%

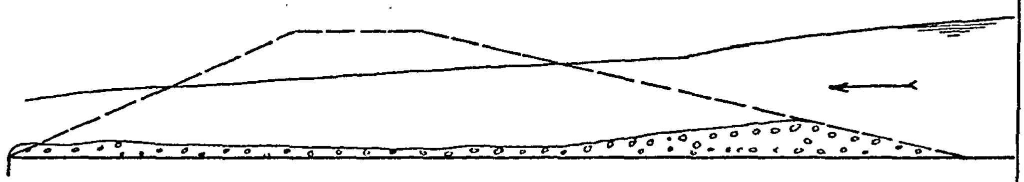
α = 0.454

d = 4.60 mm.



1
T = 00' 44"
2
T = 00' 50"
3
T = 01' 01"
4
T = 01' 25"

(5) T = 02' 05"



(6) T = 02' 32"

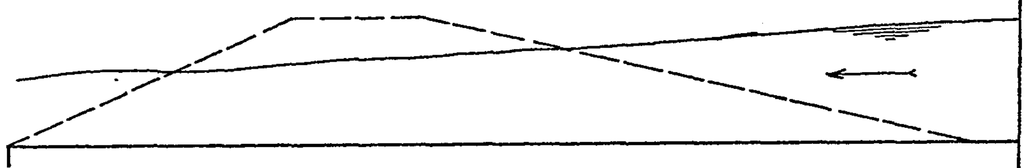


Fig. 40

Exp. No. 3-Q1000-9"

EROSION OF DAM AT CONSTANT DISCHARGE

WITH DOWNSTREAM SUPERCRITICAL FLOW.

Type (1) dam

Washout discharge = 3.03 cfs/ft

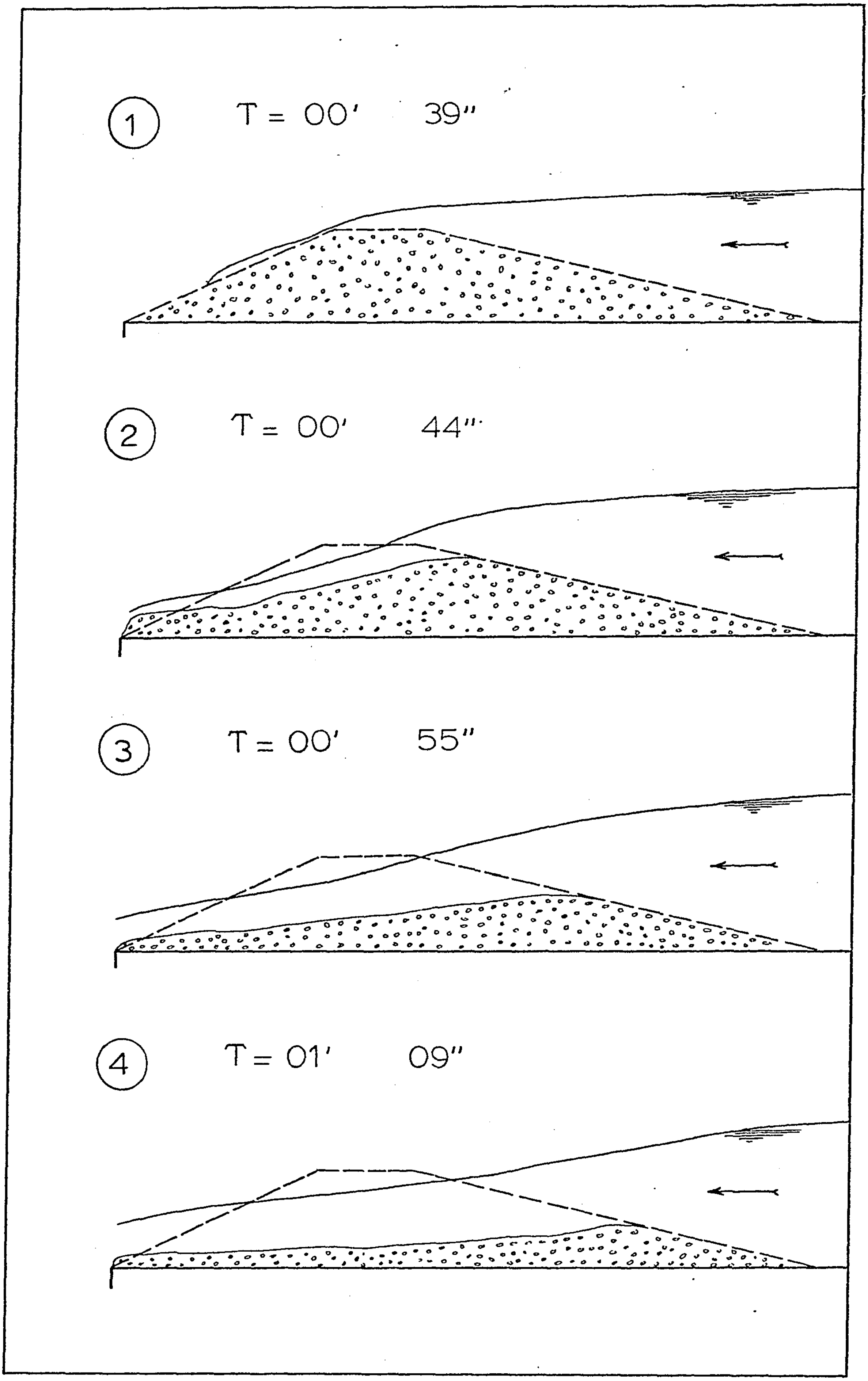
Material No. 3

S_s = 2.70

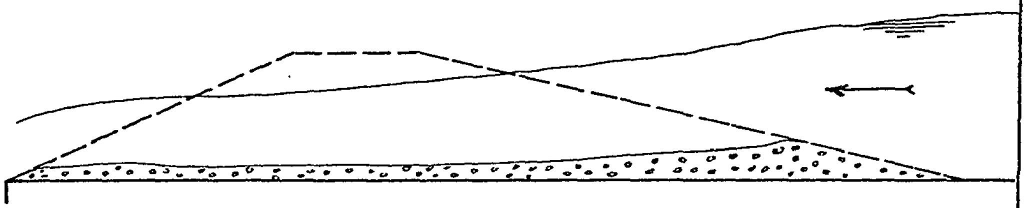
n = 40.0%

α = 0.454

d = 4.60 mm.


1 T = 00' 39"
2 T = 00' 44"
3 T = 00' 55"
4 T = 01' 09"

⑤ T = 01 ' 36"



⑥ T = 01' 46"

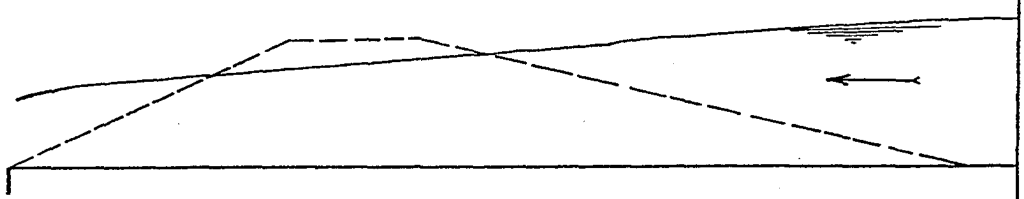


Fig.41

Exp. No. 3-Q1250-9"

EROSION OF DAM AT CONSTANT DISCHARGE

WITH DOWNSTREAM SUPERCRITICAL FLOW.

Type (1) dam

Washout discharge = 3.79 cfs/ft

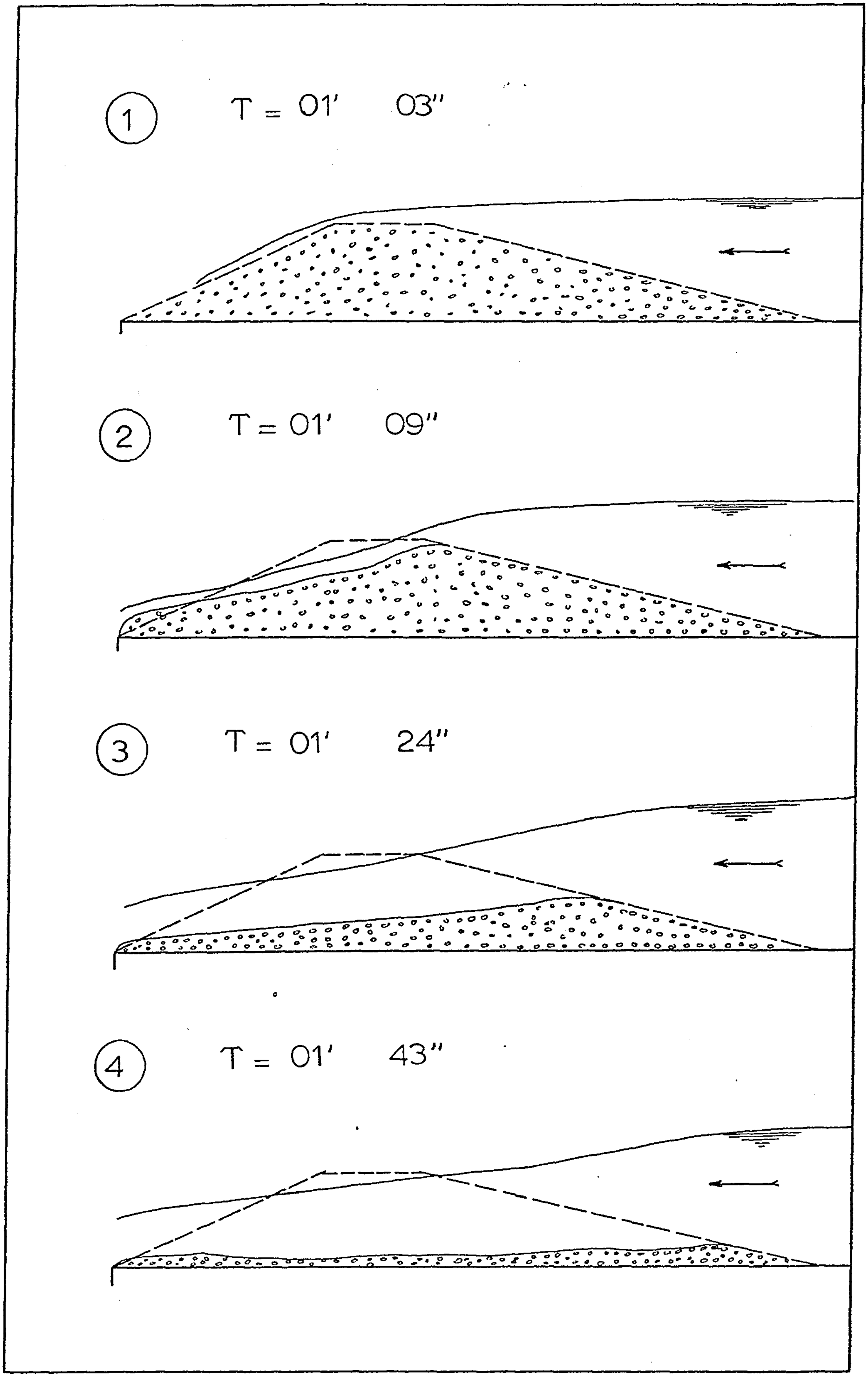
Material No. 3

$S_s = 2.70$

$n = 40.0\%$

$\alpha = 0.454$

$d = 4.60$ mm.


1
T = 01' 03"
2
T = 01' 09"
3
T = 01' 24"
4
T = 01' 43"

(5) T = 02' 03"

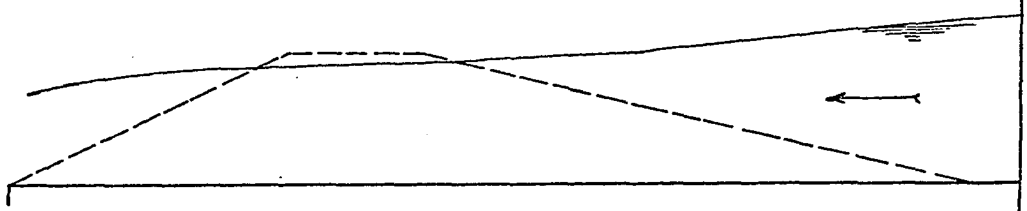


Fig.42

Exp. No. 5-Q750-9"

EROSION OF DAM AT CONSTANT DISCHARGE

WITH DOWNSTREAM SUPERCRITICAL FLOW.

Type (1) dam

Washout discharge = 2.27 cfs/ft

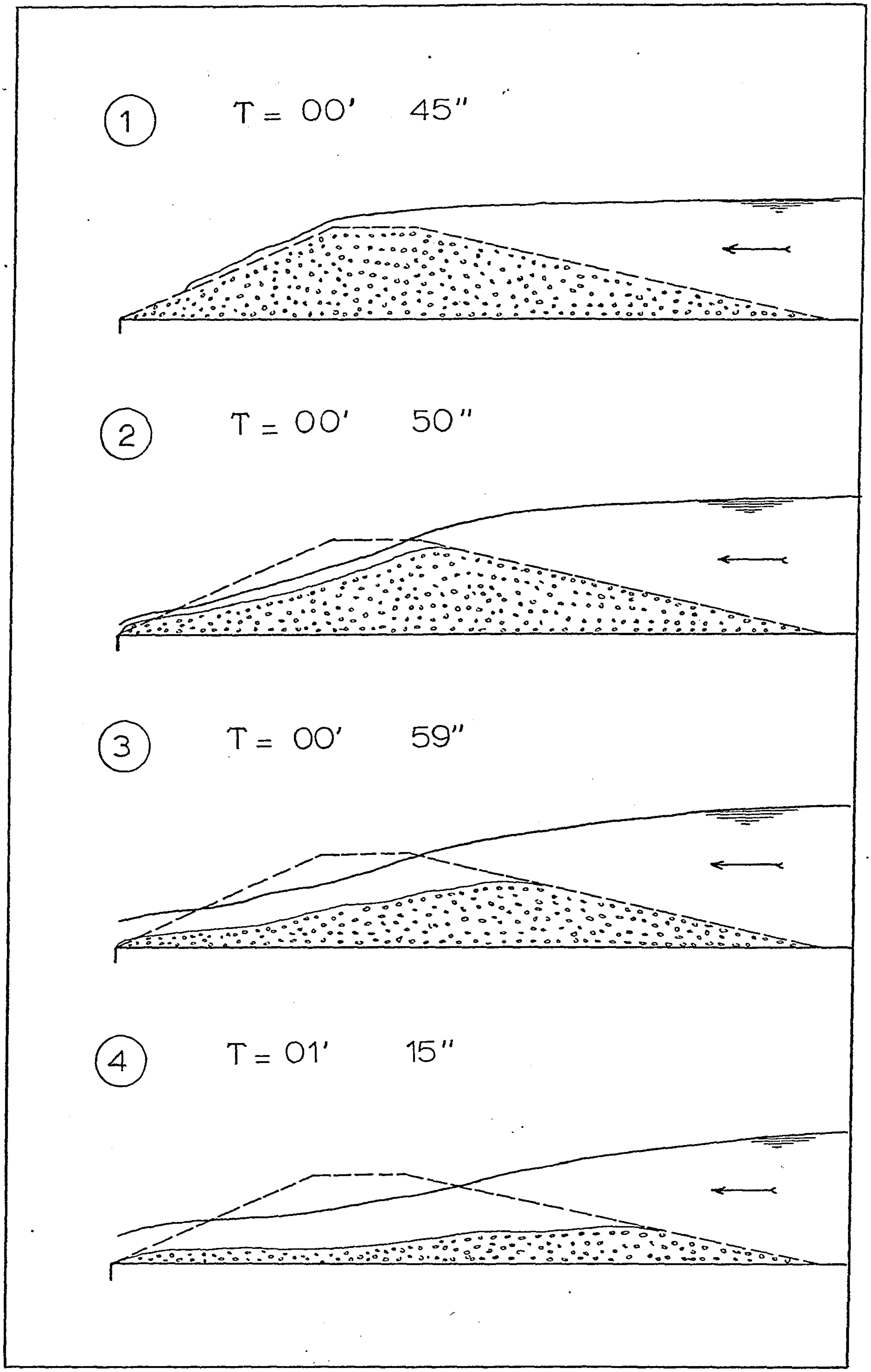
Material No. 5

$S_s = 2.77$

$n = 40.0\%$

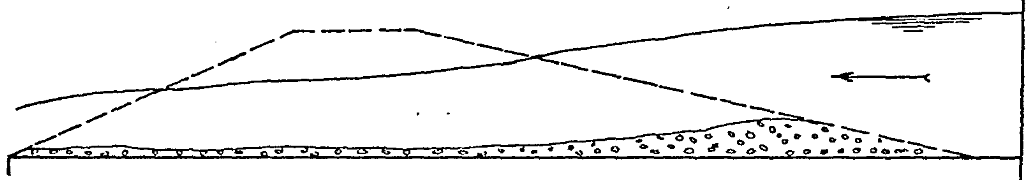
$\alpha = 0.267$

$d = 2.20$ mm.



1
T = 00' 45"
2
T = 00' 50"
3
T = 00' 59"
4
T = 01' 15"

(5) T = 01' 45"



(6) T = 02' 35"

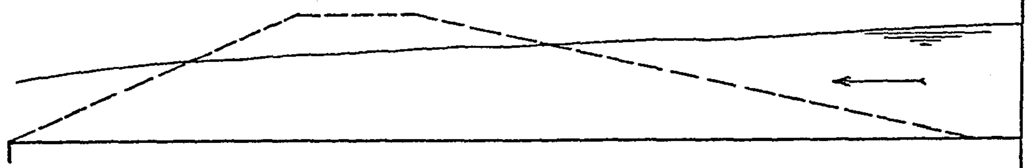


Fig.43

Exp. No. 5-Q1000-9"

EROSION OF DAM AT CONSTANT DISCHARGE

WITH DOWNSTREAM SUPERCRITICAL FLOW.

Type (1) dam

Wahsout discharge = 3.03 cfs/ft

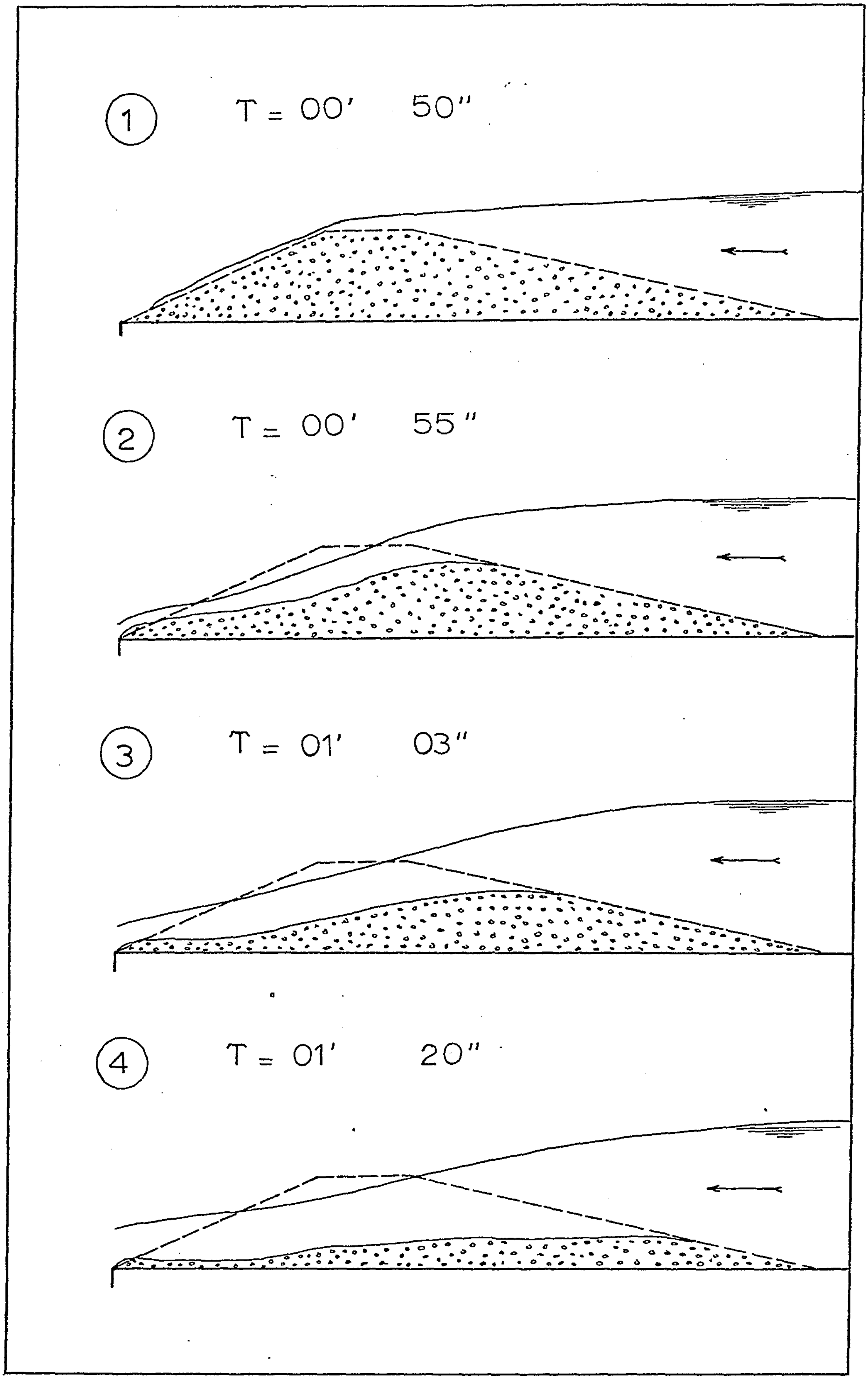
Material No. 5

S_s = 2.77

n = 40.0%

α = 0.267

d = 2.20 mm.


1
T = 00' 50"
2
T = 00' 55"
3
T = 01' 03"
4
T = 01' 20"

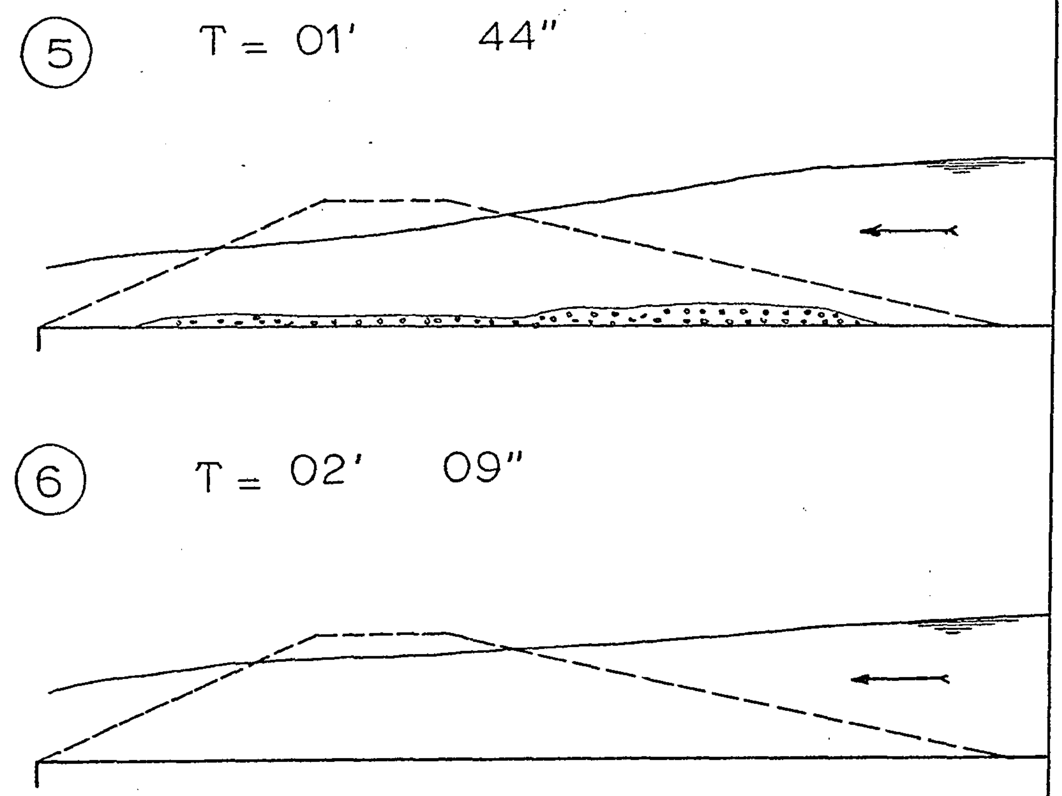

5
T = 01' 44"
6
T = 02' 09"

Fig. 44

Exp. No. 5-Q1250-9"

EROSION OF DAM AT CONSTANT DISCHARGE

WITH DOWNSTREAM SUPERCRITICAL FLOW.

Type (1) dam

Wahout discharge = 3.79 cfs/ft

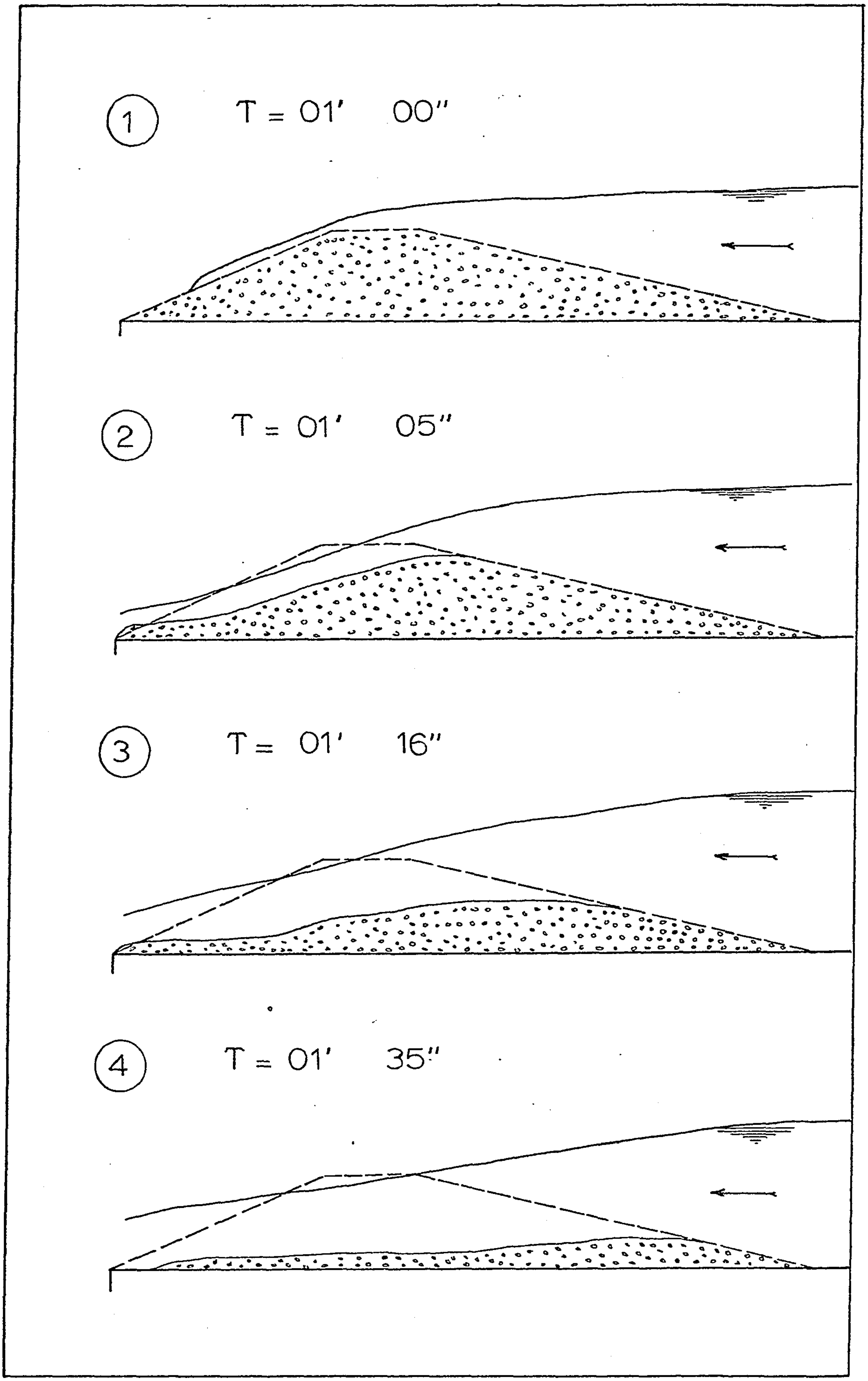
Material No. 5

S_s = 2.77

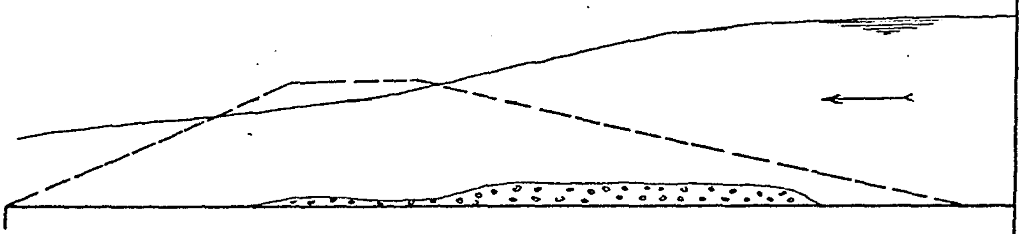
n = 40.0%

α = 0.267

d = 2.20 mm.


1
T = 01' 00"
2
T = 01' 05"
3
T = 01' 16"
4
T = 01' 35"

(5) T = 01' 45"



(6) T = 02' 09"

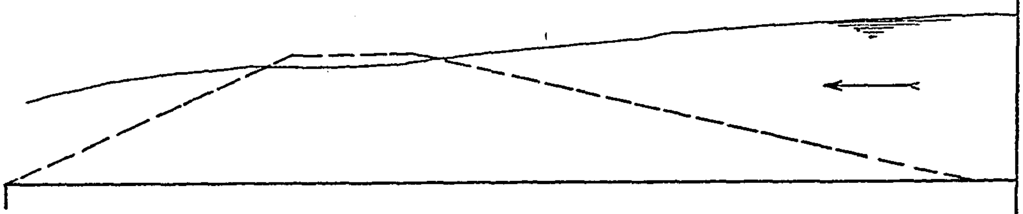


Fig. 45

Exp. No. 7-Q250-9"

EROSION OF DAM AT CONSTANT DISCHARGE

WITH DOWNSTREAM SUPERCRITICAL FLOW.

Type (1) dam

Washout discharge = 0.76 cfs/ft

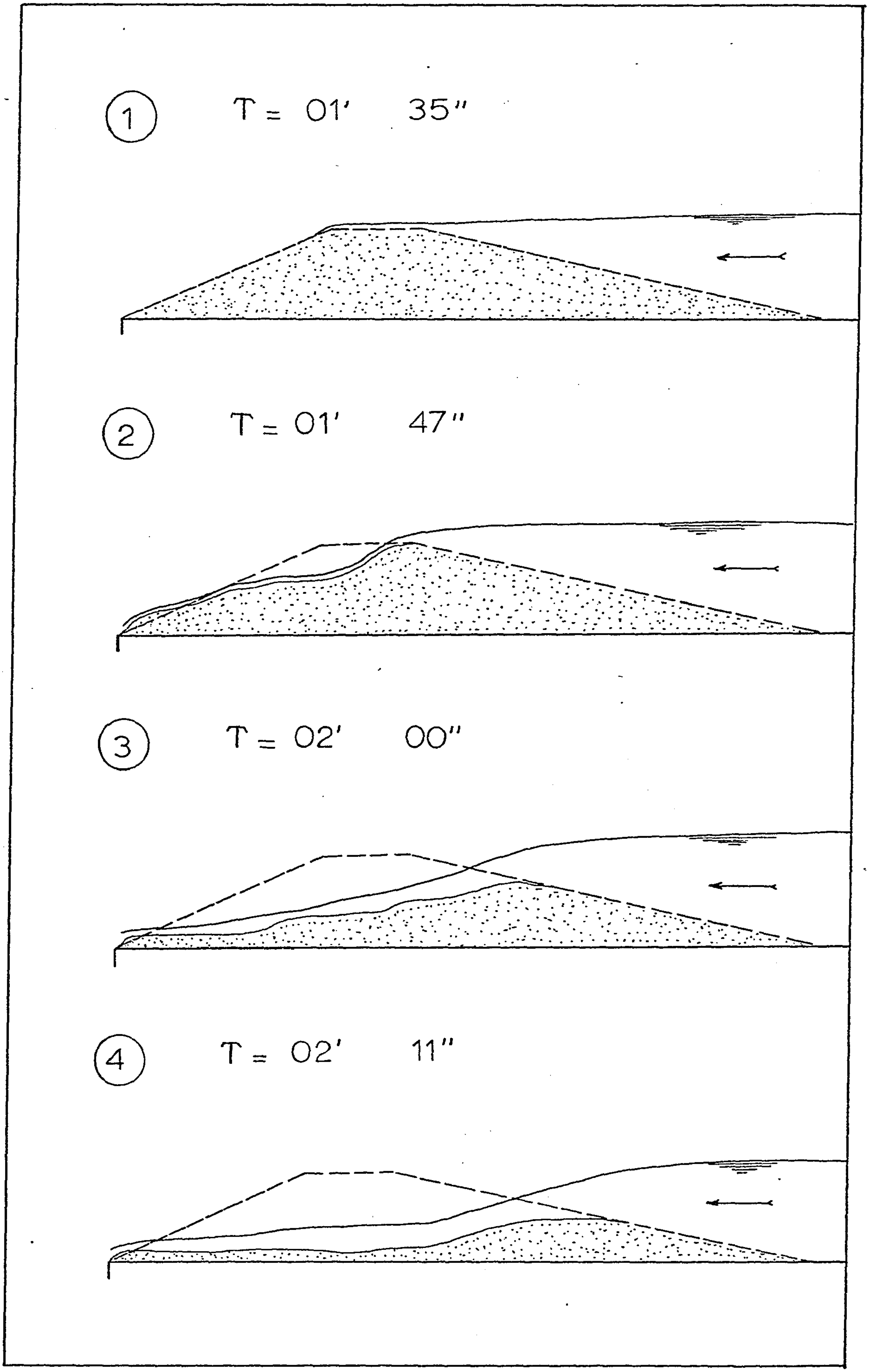
Material No. 7

S_s = 2.65

n = 41.0%

$\propto$ = 0.066

d = 0.80 mm.


1 T = 01' 35"
2 T = 01' 47"
3 T = 02' 00"
4 T = 02' 11"

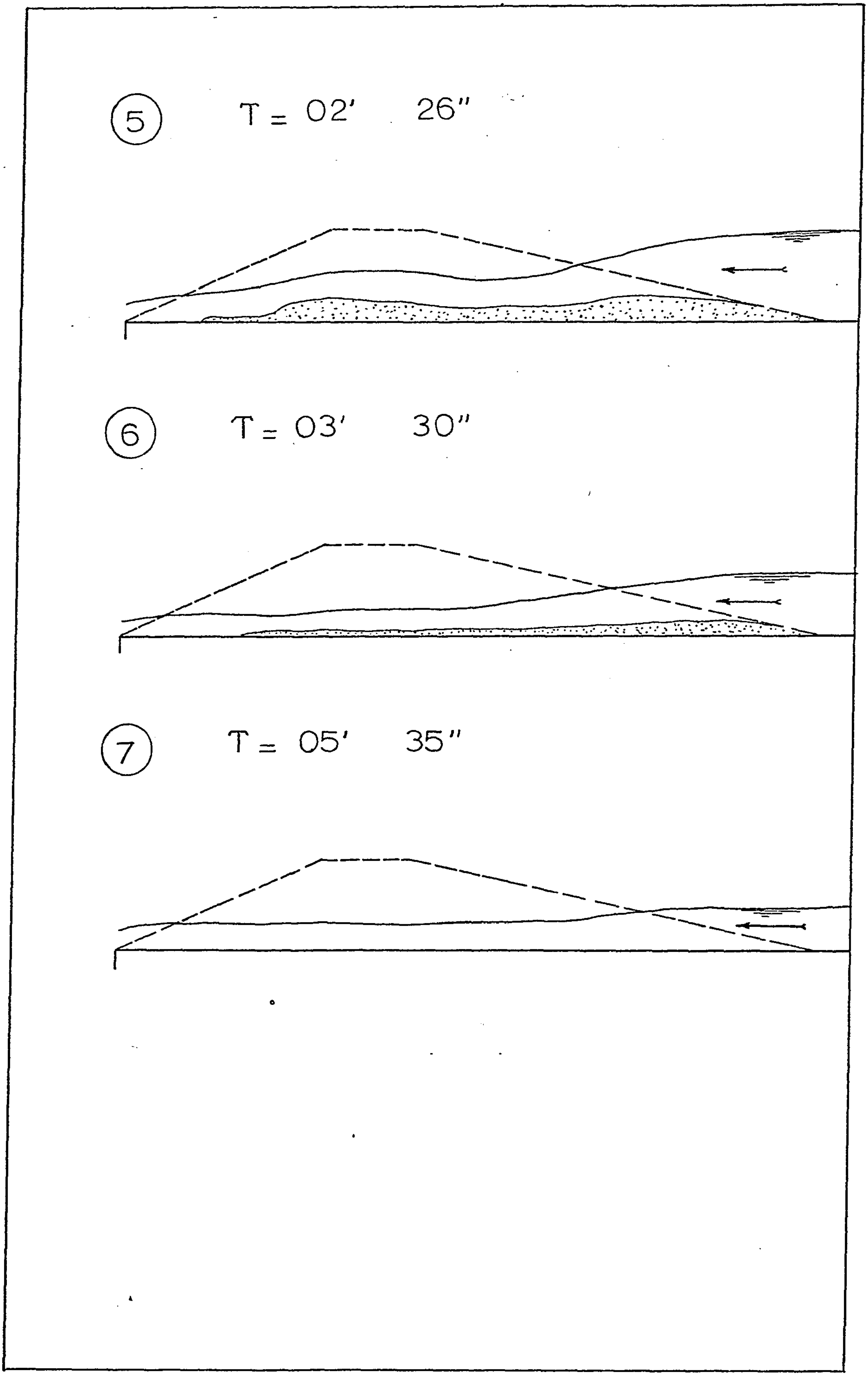

5
T = 02' 26"
6
T = 03' 30"
7
T = 05' 35"

Fig.46

Exp. No. 7-Q500-9"

EROSION OF DAM AT CONSTANT DISCHARGE

WITH DOWNSTREAM SUPERCRITICAL FLOW.

Type (1) dam

Washout discharge = 1.51 cfs/ft

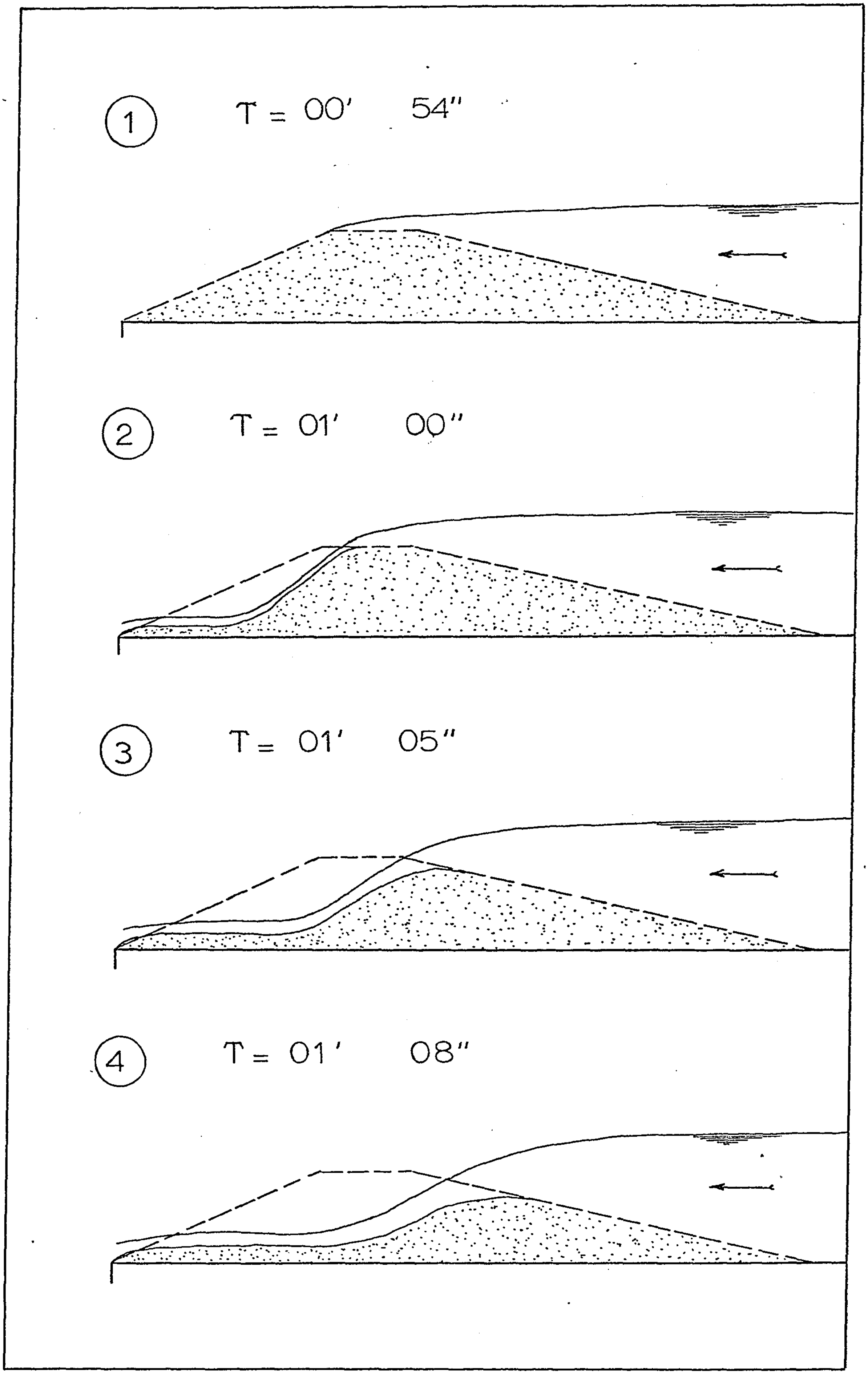
Material No. 7

S_s = 2.65

n = 41.0%

α = 0.066

d = 0.80 mm.



1
T = 00' 54"
2
T = 01' 00"
3
T = 01' 05"
4
T = 01' 08"

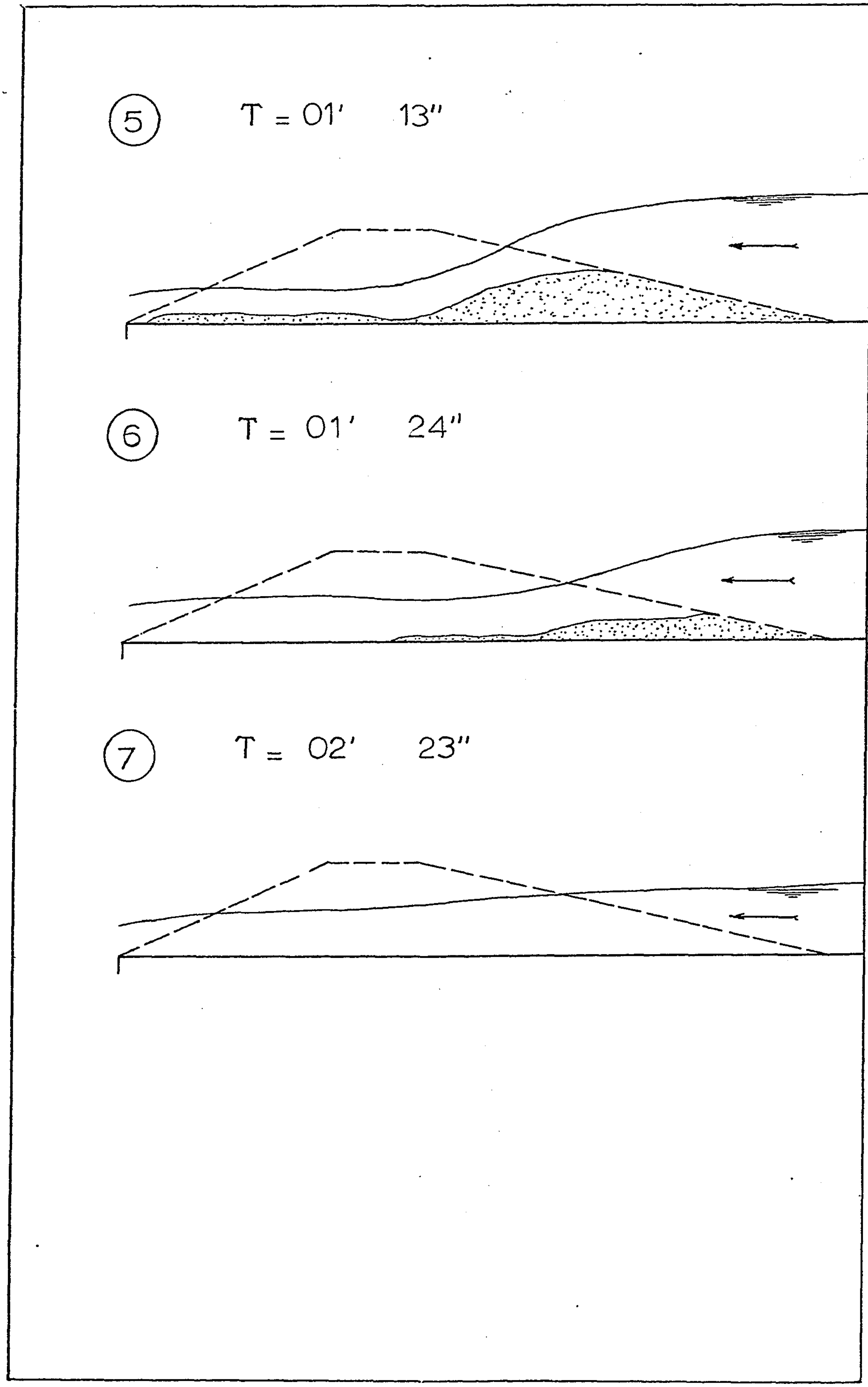

5
T = 01' 13"
6
T = 01' 24"
7
T = 02' 23"

Fig.47

Exp. No. 7-Q750-9"

EROSION OF DAM AT CONSTANT DISCHARGE

WITH DOWNSTREAM SUPERCRITICAL FLOW.

Type (1) dam

Washout discharge = 2.27 cfs/ft

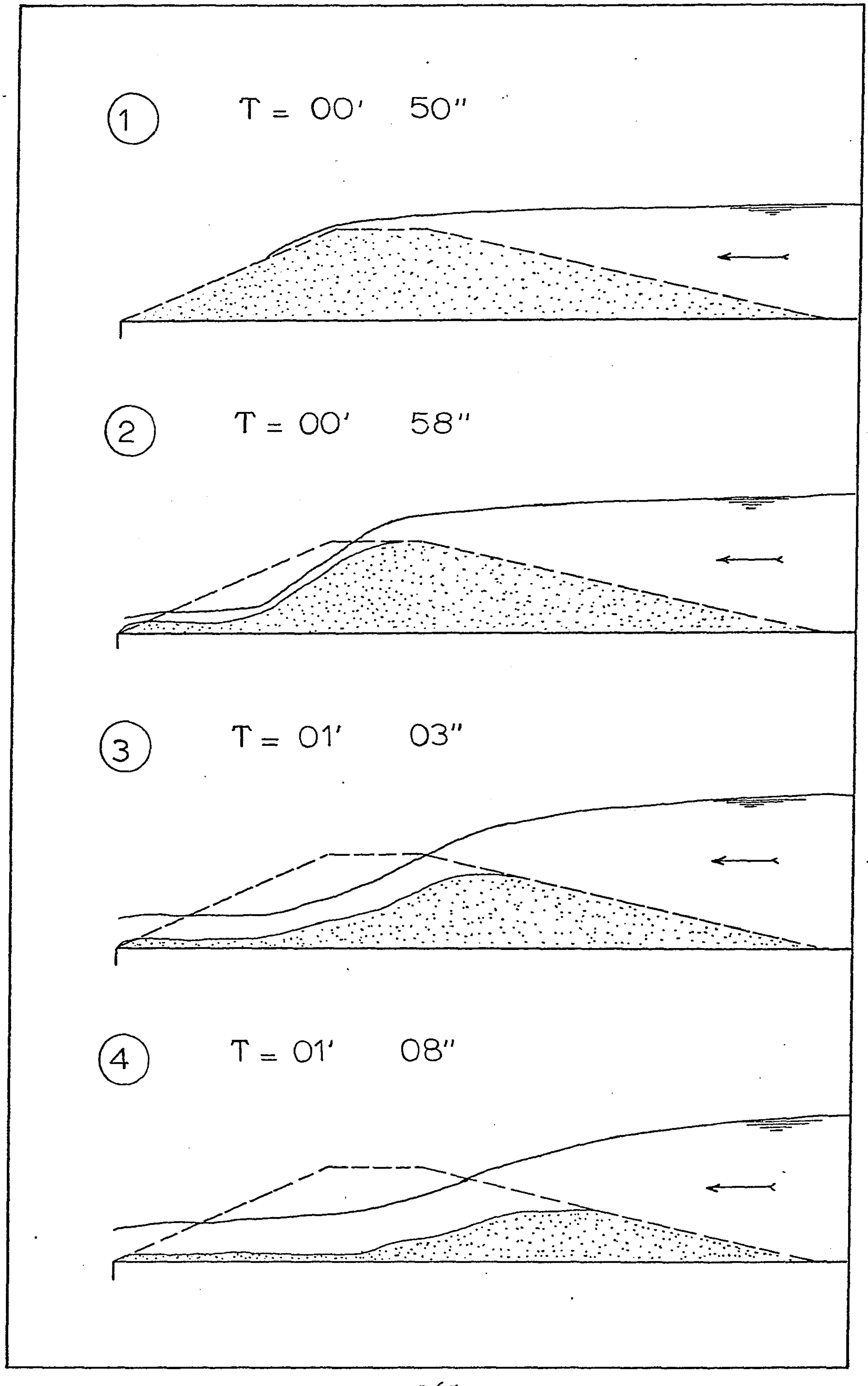
Material No. 7

S_s = 2.65

n = 41.0%

$\propto$ = 0.066

d = 0.80 mm.


1
T = 00' 50"
2
T = 00' 58"
3
T = 01' 03"
4
T = 01' 08"

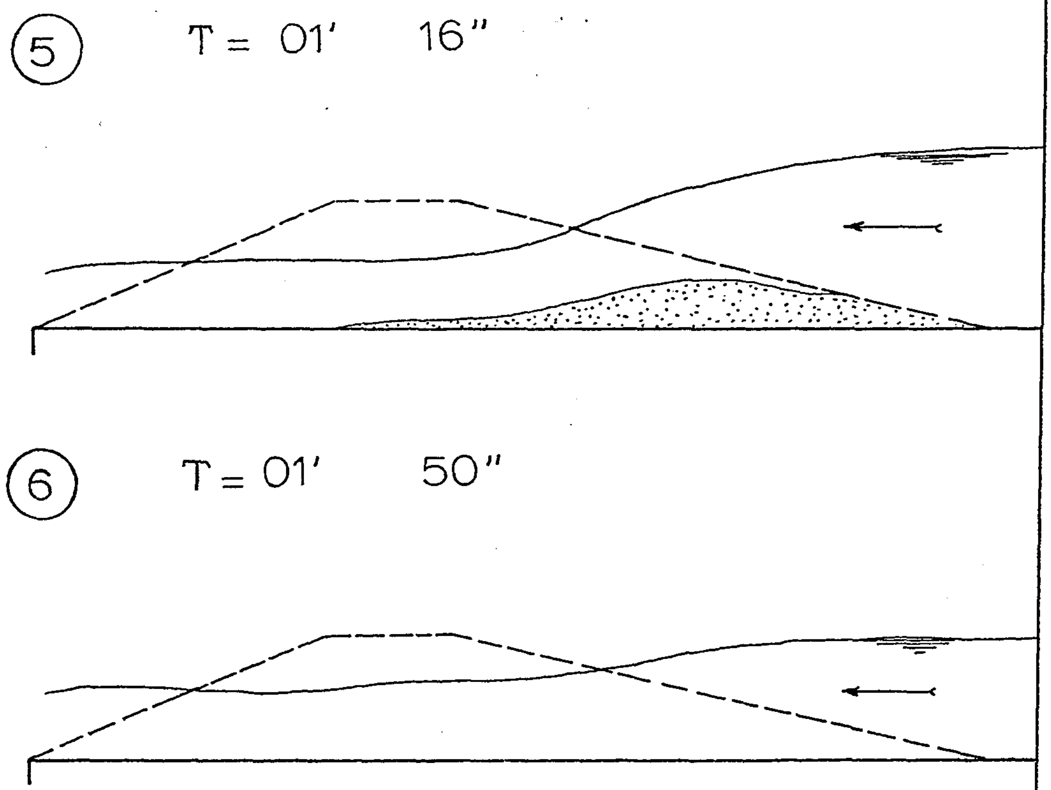

5
T = 01' 16"
6
T = 01' 50"

Fig.48

Exp. No. 2-Q500-9"

EROSION OF DAM AT CONSTANT DISCHARGE

WITH DOWNSTREAM SUBCRITICAL FLOW.

Type (1) dam

Washout discharge = 1.51 cfs/ft

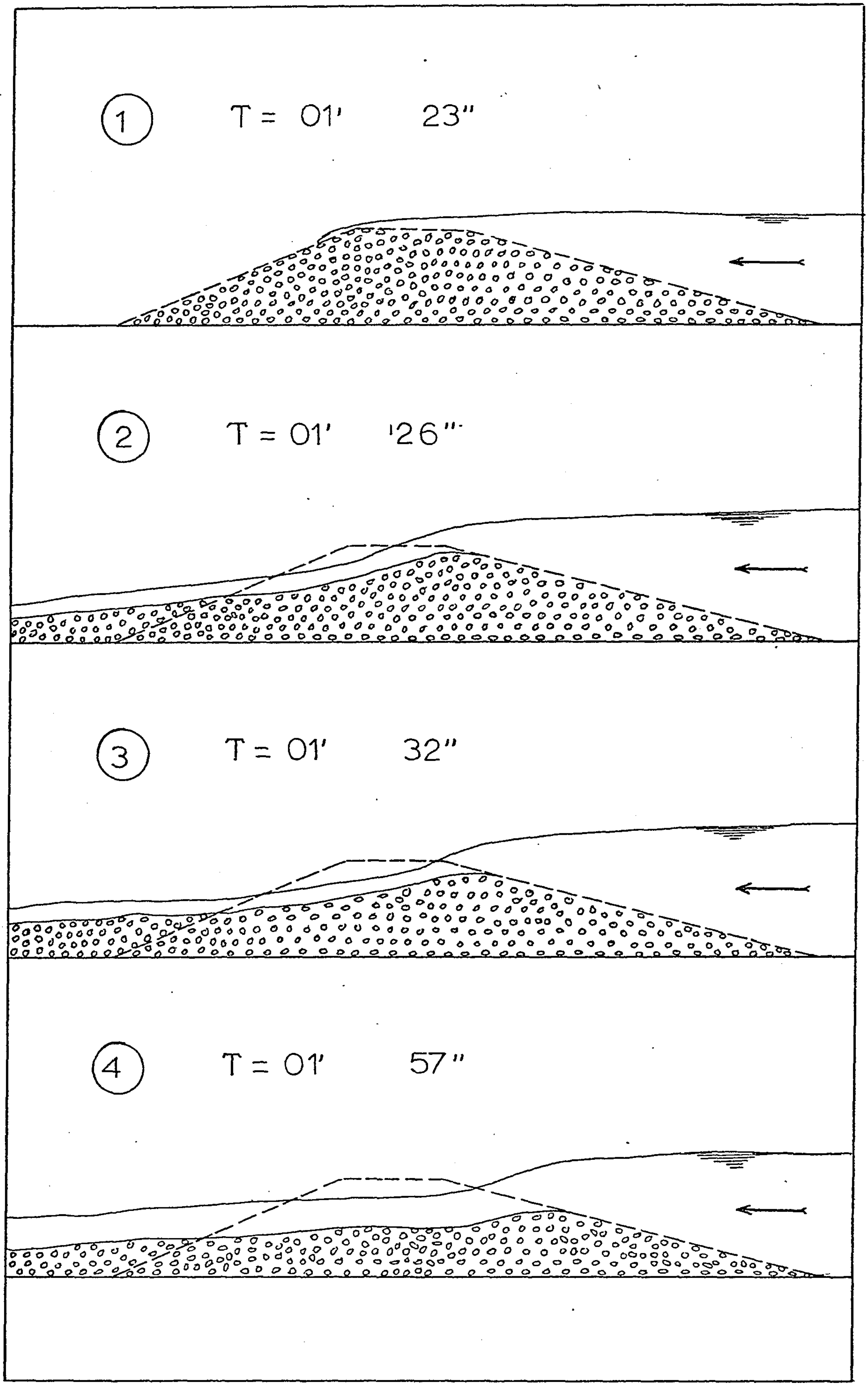
Material No. 2

S_s = 2.57

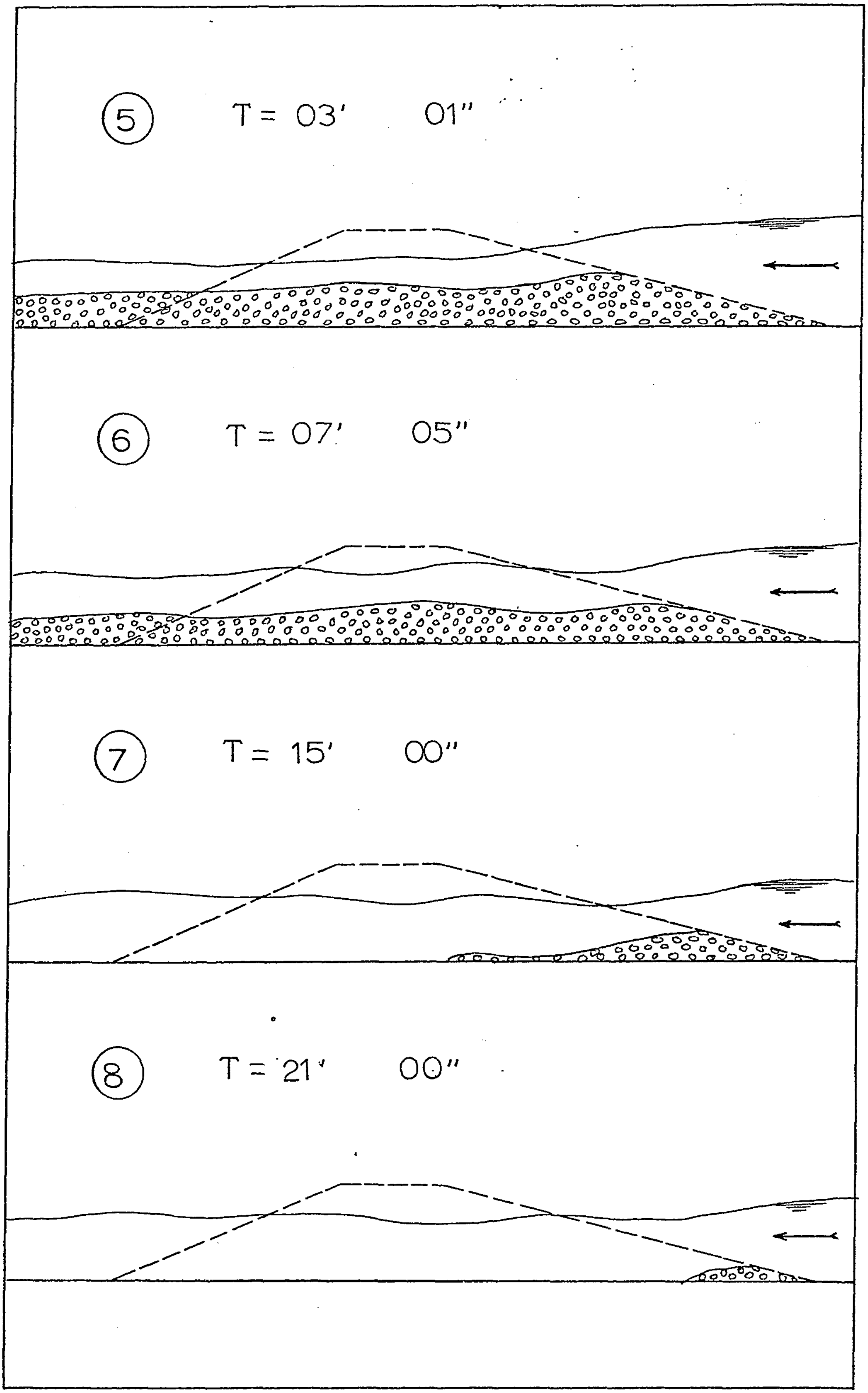
n = 41.0%

α = 0.532

d = 6.35 mm.



1
T = 01' 23"
2
T = 01' '26"
3
T = 01' 32"
4
T = 01' 57"



5
T = 03' 01"
6
T = 07' 05"
7
T = 15' 00"
8
T = 21' 00"

Fig. 49

<u>Exp. No. 2-Q1250-9"</u>

EROSION OF DAM AT CONSTANT DISCHARGE

WITH DOWNSTREAM SUBCRITICAL FLOW.

Type (1) dam

Washout discharge = 3.79 cfs/ft

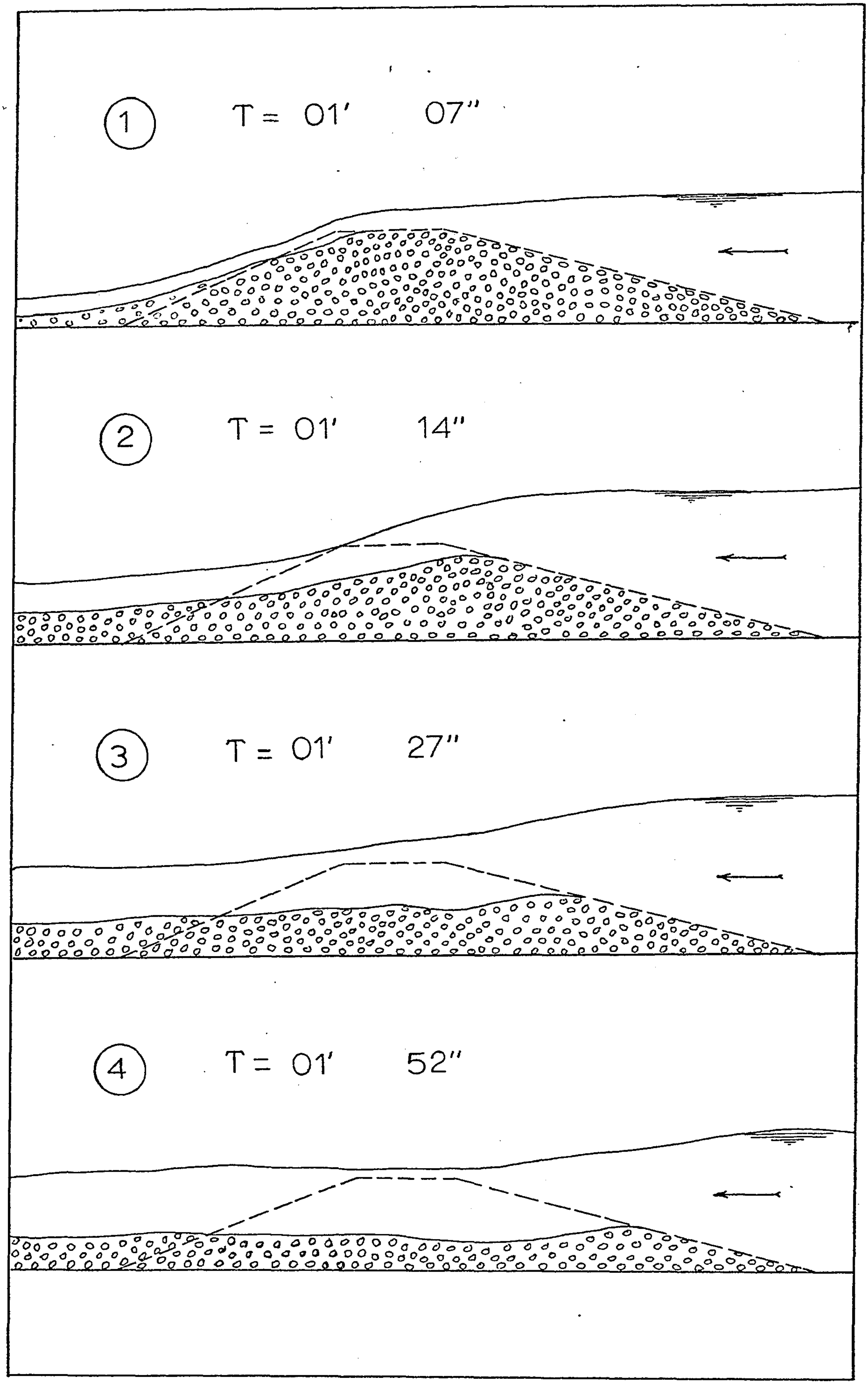
Material No. 2

S_s = 2.57

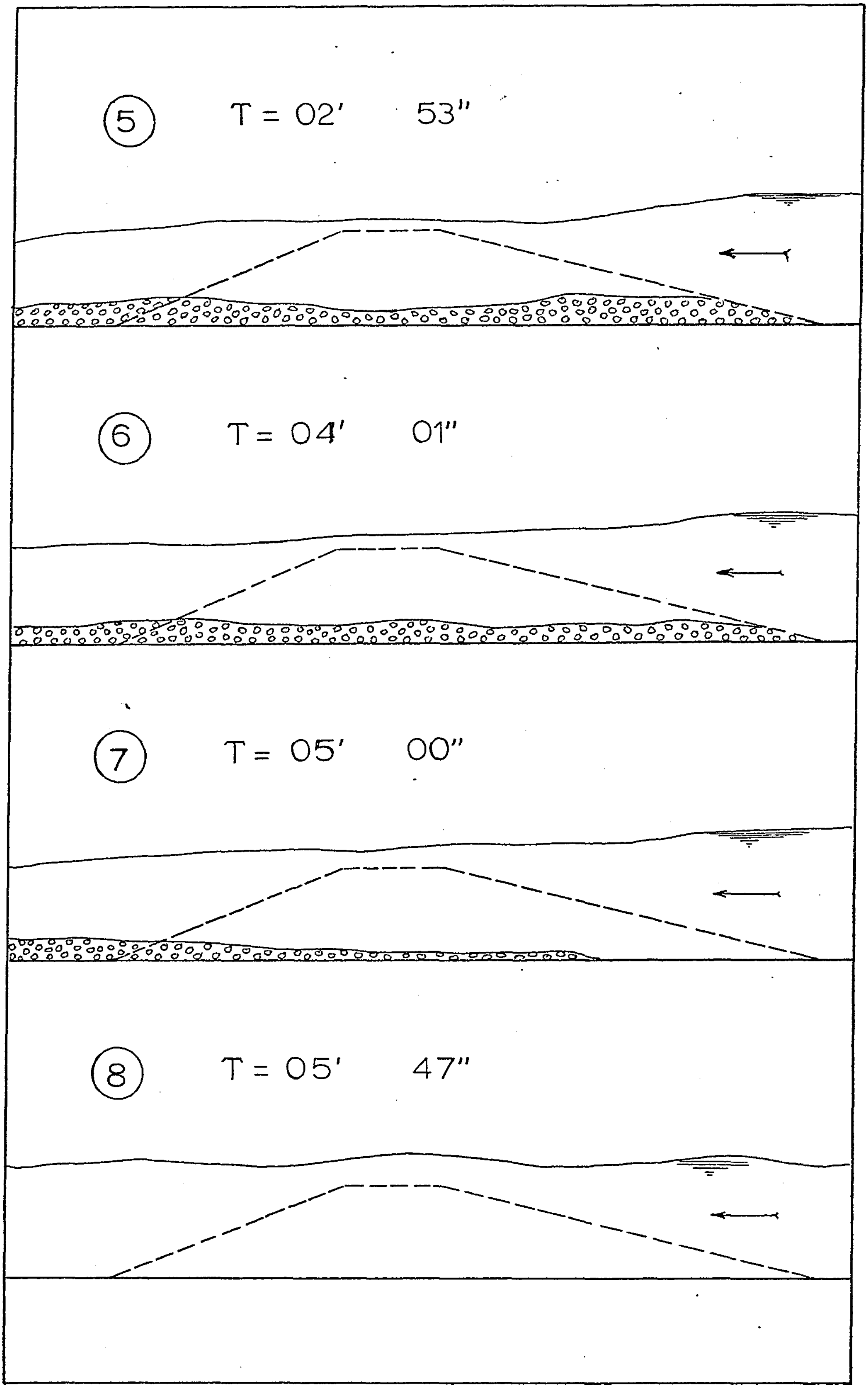
n = 41.0%

α = 0.532

d = 6.35 mm.



1
T = 01' 07"
2
T = 01' 14"
3
T = 01' 27"
4
T = 01' 52"



5
T = 02' 53"
6
T = 04' 01"
7
T = 05' 00"
8
T = 05' 47"

Fig.50

Exp. No. 3-Q750-9"

EROSION OF DAM AT CONSTANT DISCHARGE

WITH DOWNSTREAM SUBCRITICAL FLOW.

Type (1) dam

Washout discharge = 2.27 cfs/ft

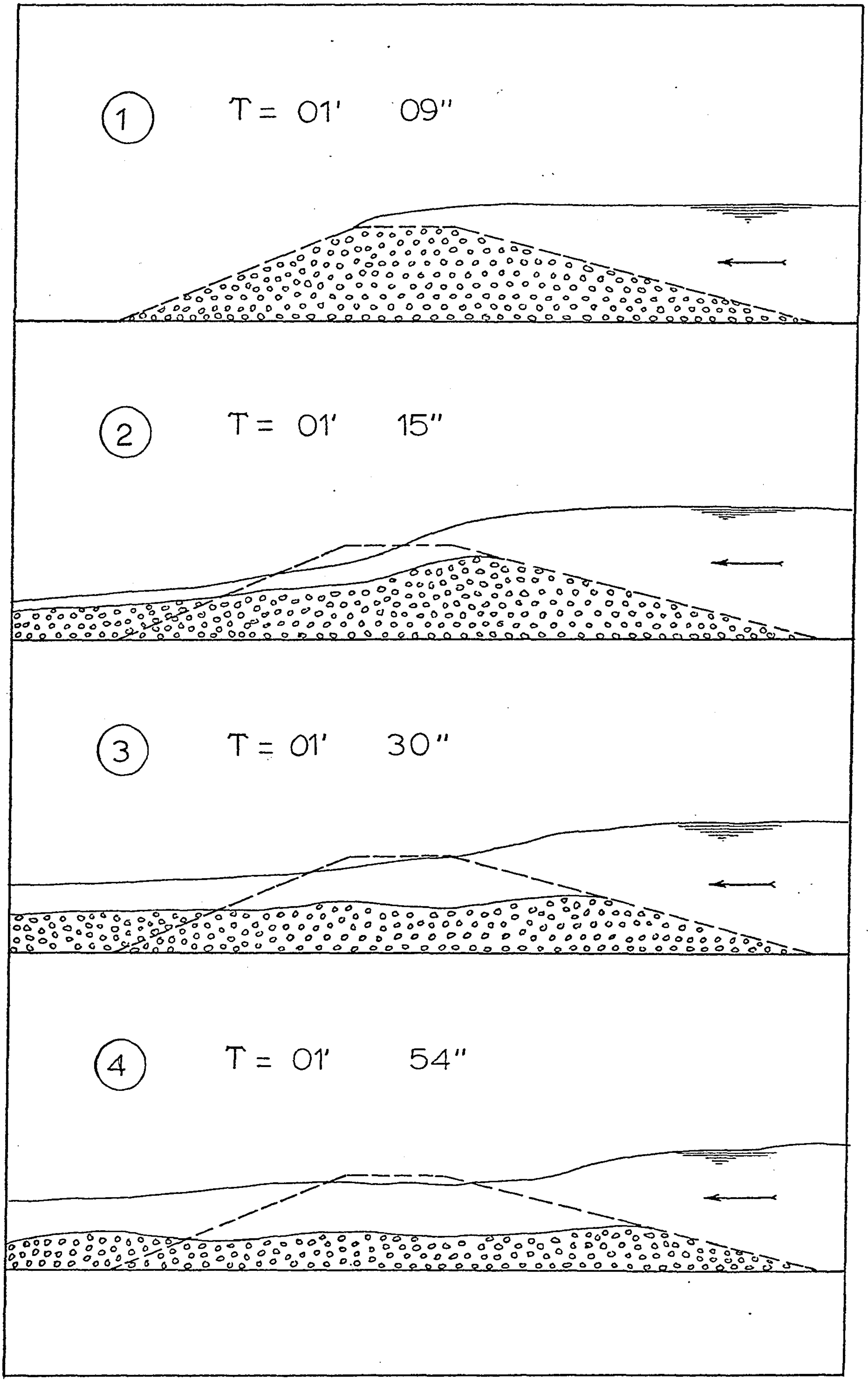
Material No. 3

S_s = 2.70

n = 40.0%

α = 0.454

d = 4.60 mm.


1
T = 01' 09"
2
T = 01' 15"
3
T = 01' 30"
4
T = 01' 54"

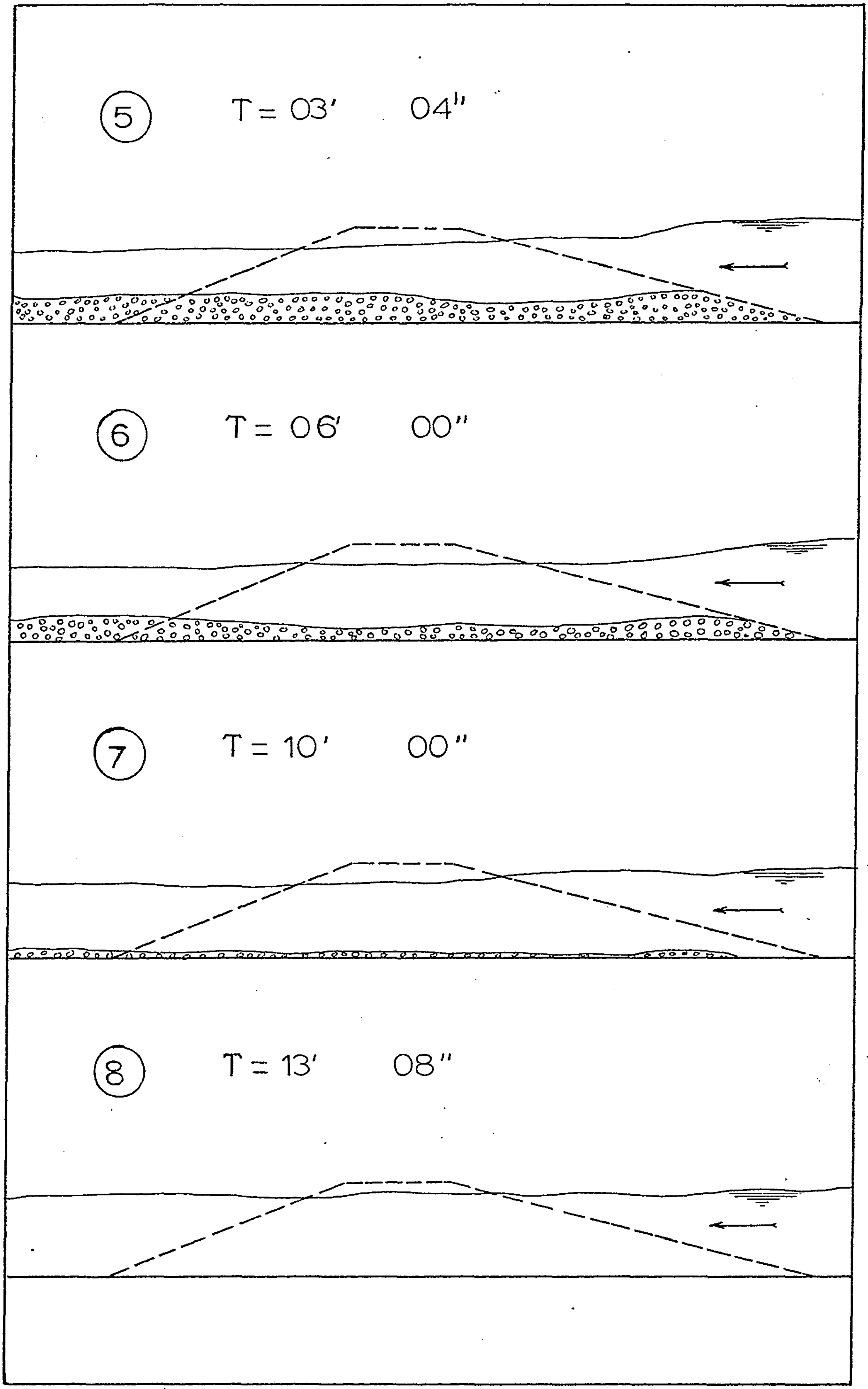

5
T = 03' 04"
6
T = 06' 00"
7
T = 10' 00"
8
T = 13' 08"

Fig.51

Exp. No. 3-Q1000-9"

EROSION OF DAM AT CONSTANT DISCHARGE

WITH DOWNSTREAM SUBCRITICAL FLOW.

Type (1) dam

Washout discharge = 3.03 cfs/ft

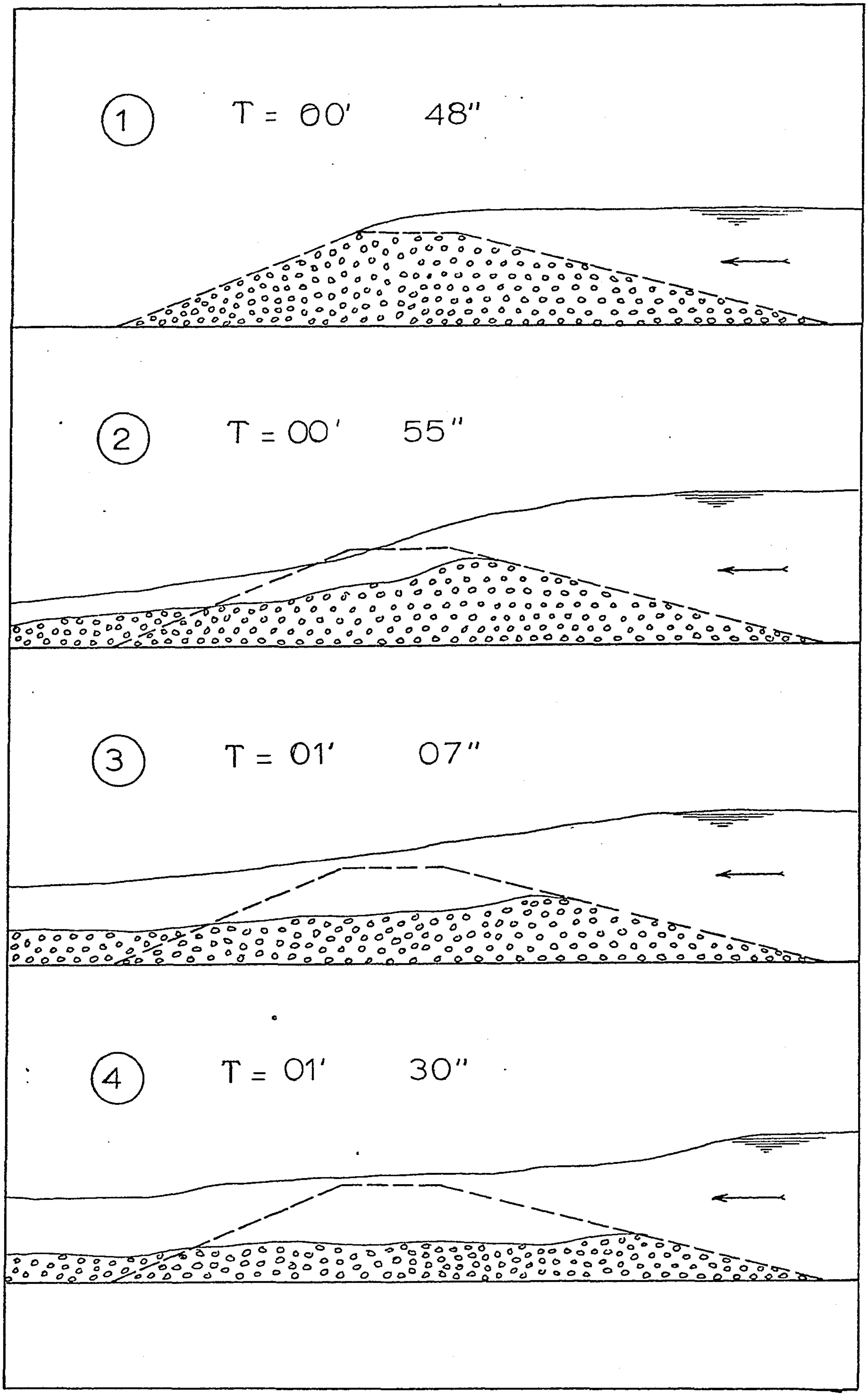
Material No. 3

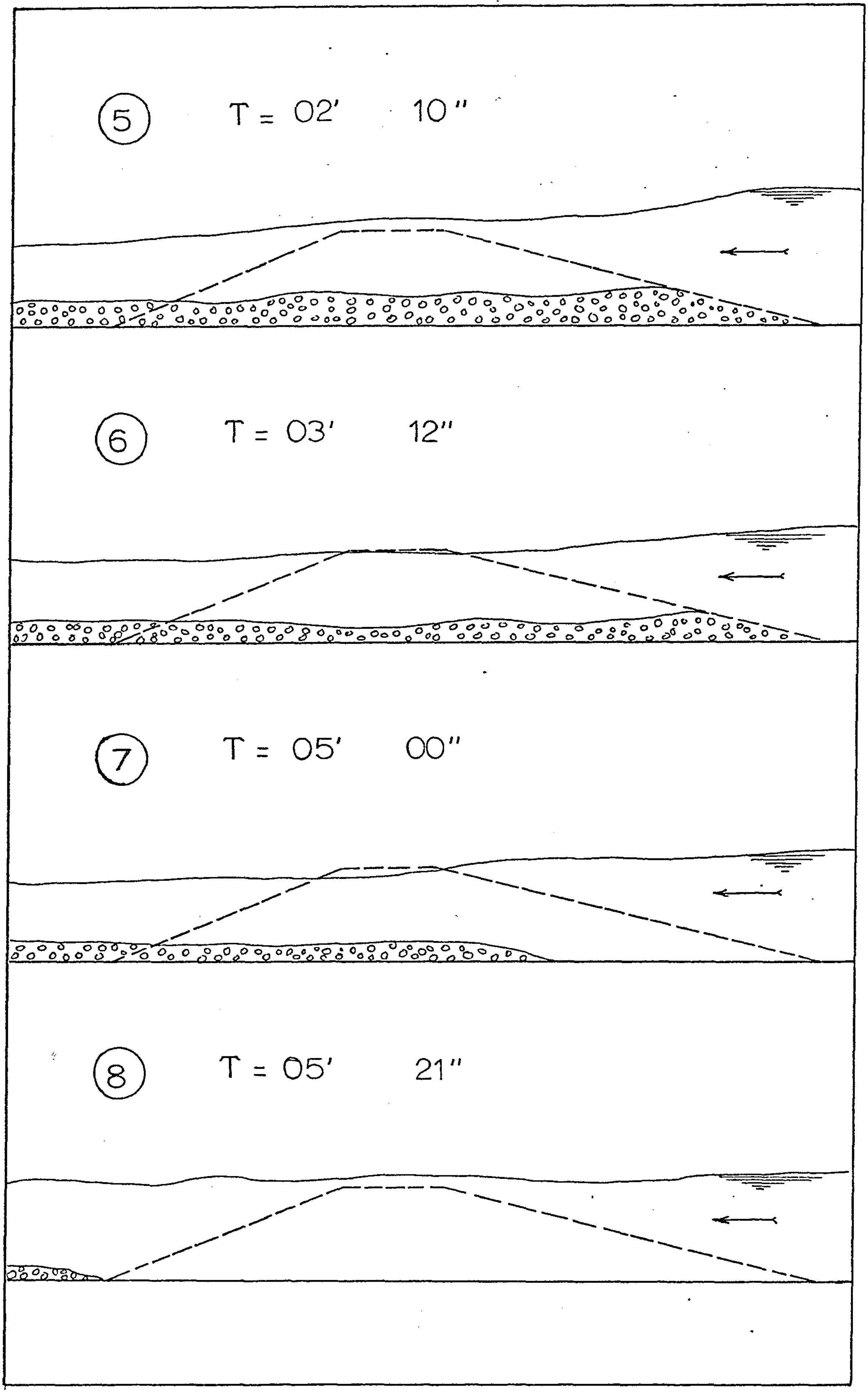
S_s = 2.70

n = 40.0%

α = 0.454

d = 4.60 mm.


1
T = 00' 48"
2
T = 00' 55"
3
T = 01' 07"
4
T = 01' 30"



5
T = 02' 10"
6
T = 03' 12"
7
T = 05' 00"
8
T = 05' 21"

Fig.52

Exp. No. 3-Q1250-9"

EROSION OF DAM AT CONSTANT DISCHARGE

WITH DOWNSTREAM SUBCRITICAL FLOW.

Type (1) dam

Washout discharge = 3.79 cfs/ft

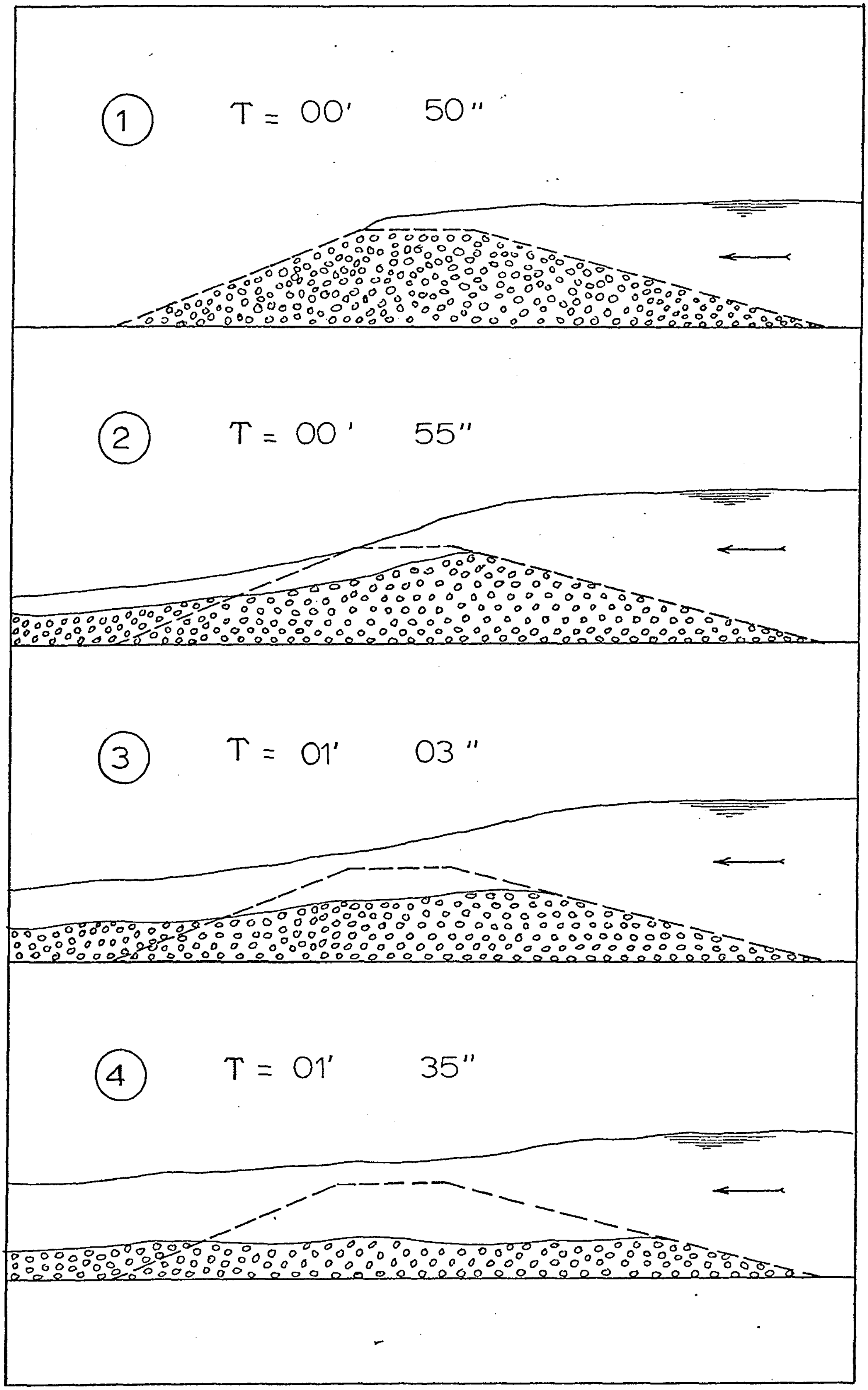
Material No. 3

S_s = 2.70

n = 40.0%

α = 0.454

d = 4.60 mm.


1
T = 00' 50"
2
T = 00' 55"
3
T = 01' 03"
4
T = 01' 35"

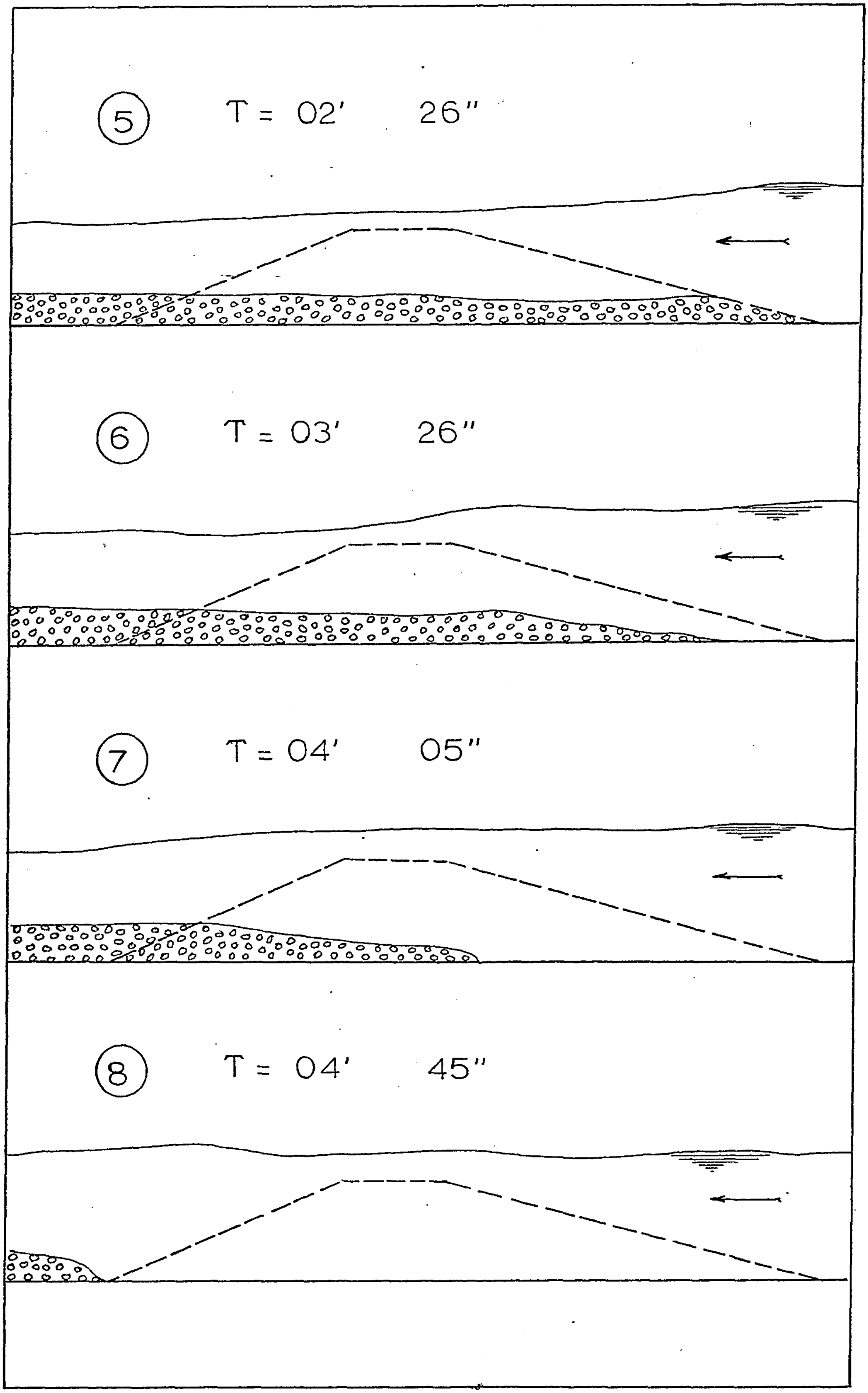

5
T = 02' 26"
6
T = 03' 26"
7
T = 04' 05"
8
T = 04' 45"

Fig.53

Exp. No. 5-Q750-9"

EROSION OF DAM AT CONSTANT DISCHARGE

WITH DOWNSTREAM SUBCRITICAL FLOW.

Type (1) dam

Washout discharge = 2.27 cfs/ft

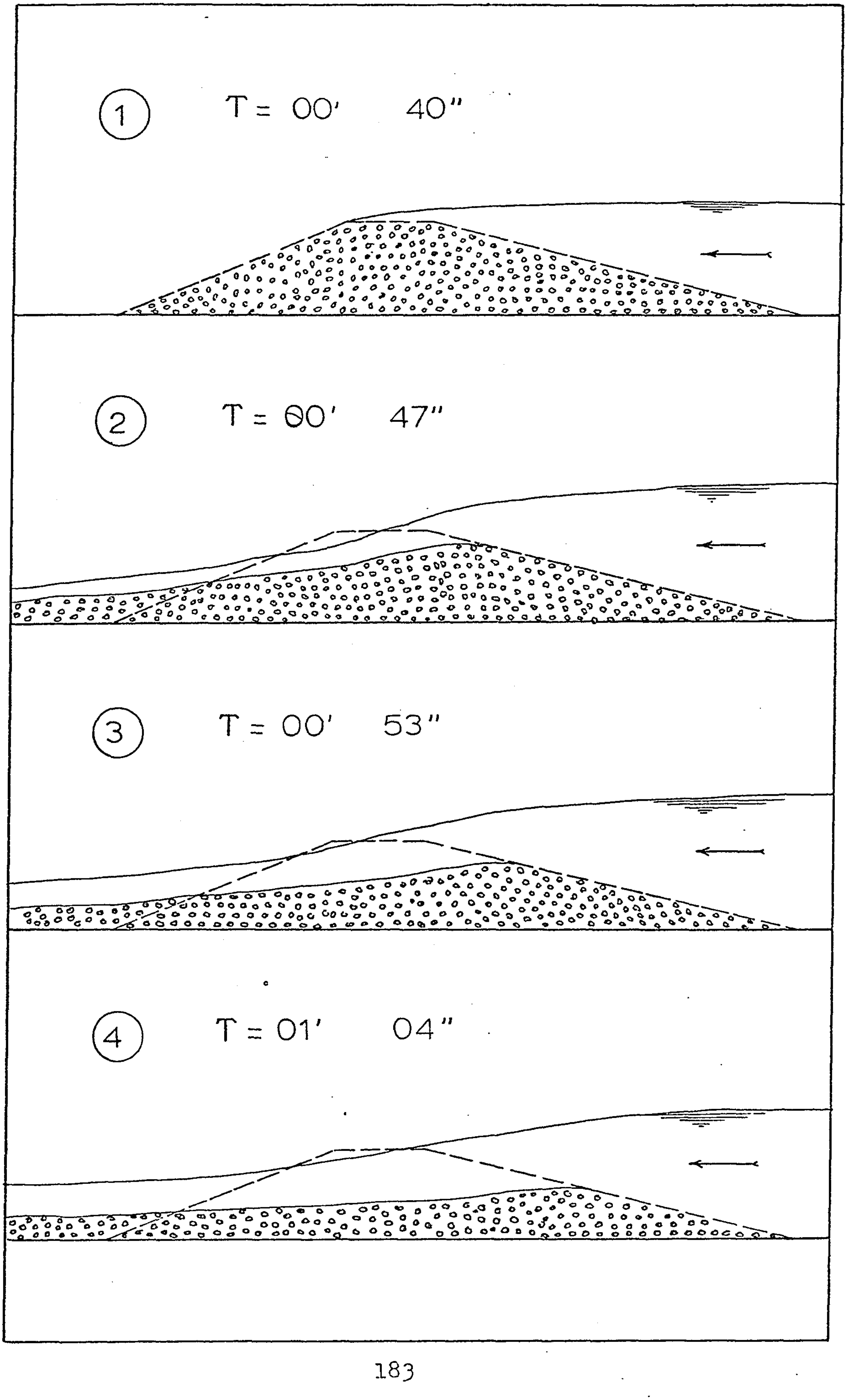
Material No. 5

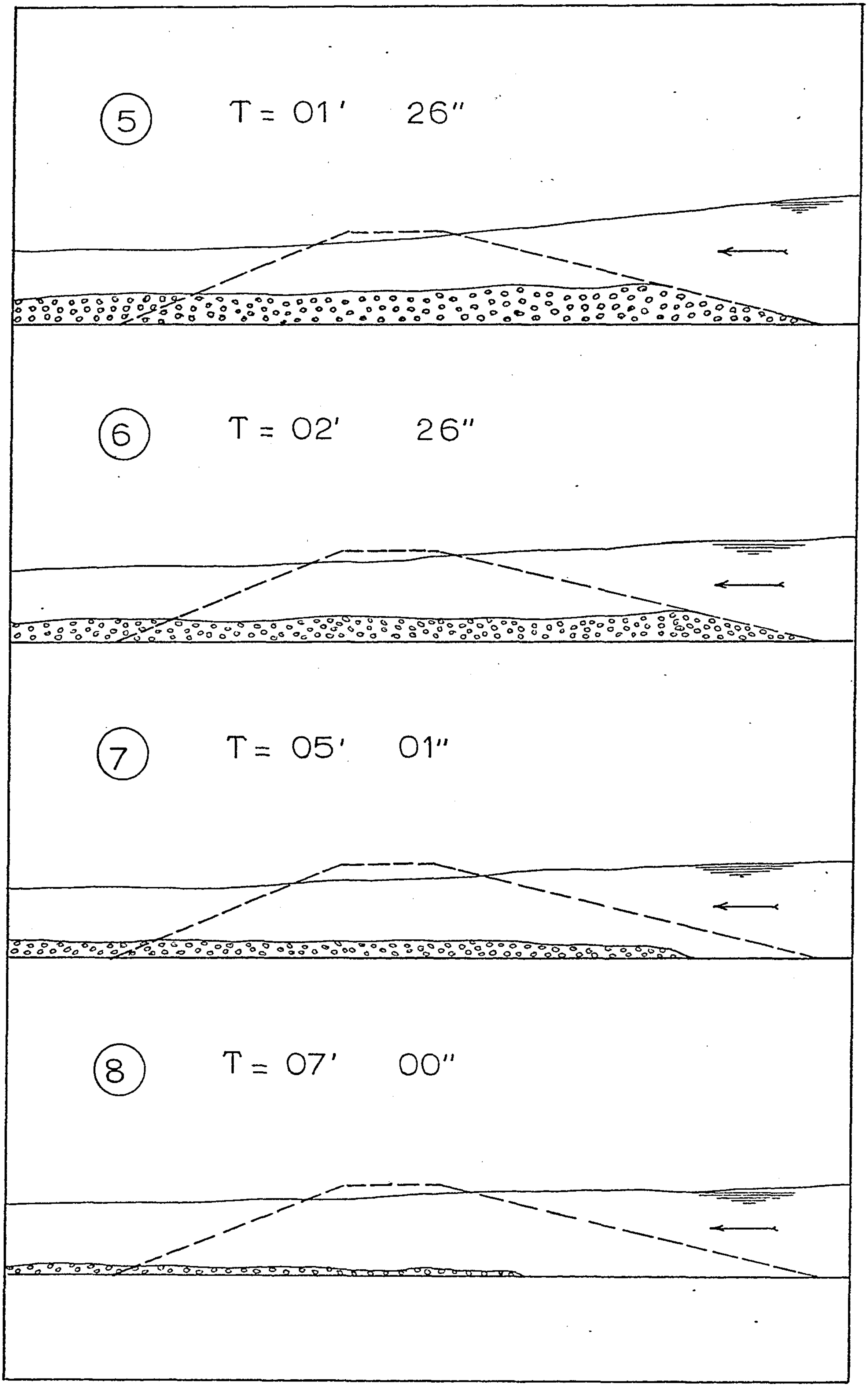
S_s = 2.77

n = 40.0%

α = 0.267

d = 2.20 mm.


1
T = 00' 40"
2
T = 00' 47"
3
T = 00' 53"
4
T = 01' 04"


5
T = 01' 26"
6
T = 02' 26"
7
T = 05' 01"
8
T = 07' 00"

(9) T = 08' 30"

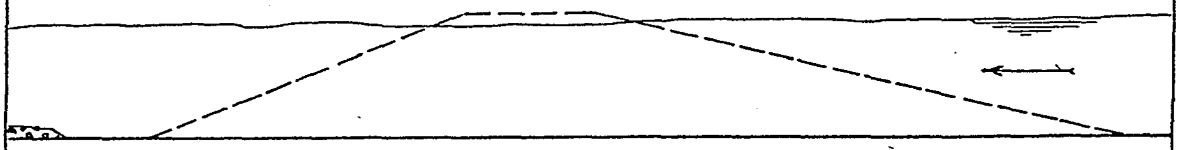


Fig.54

Exp. No. 5-Q1000-9"

EROSION OF DAM AT CONSTANT DISCHARGE

WITH DOWNSTREAM SUBCRITICAL FLOW.

Type (1) dam

Washout discharge = 3.03 cfs/ft

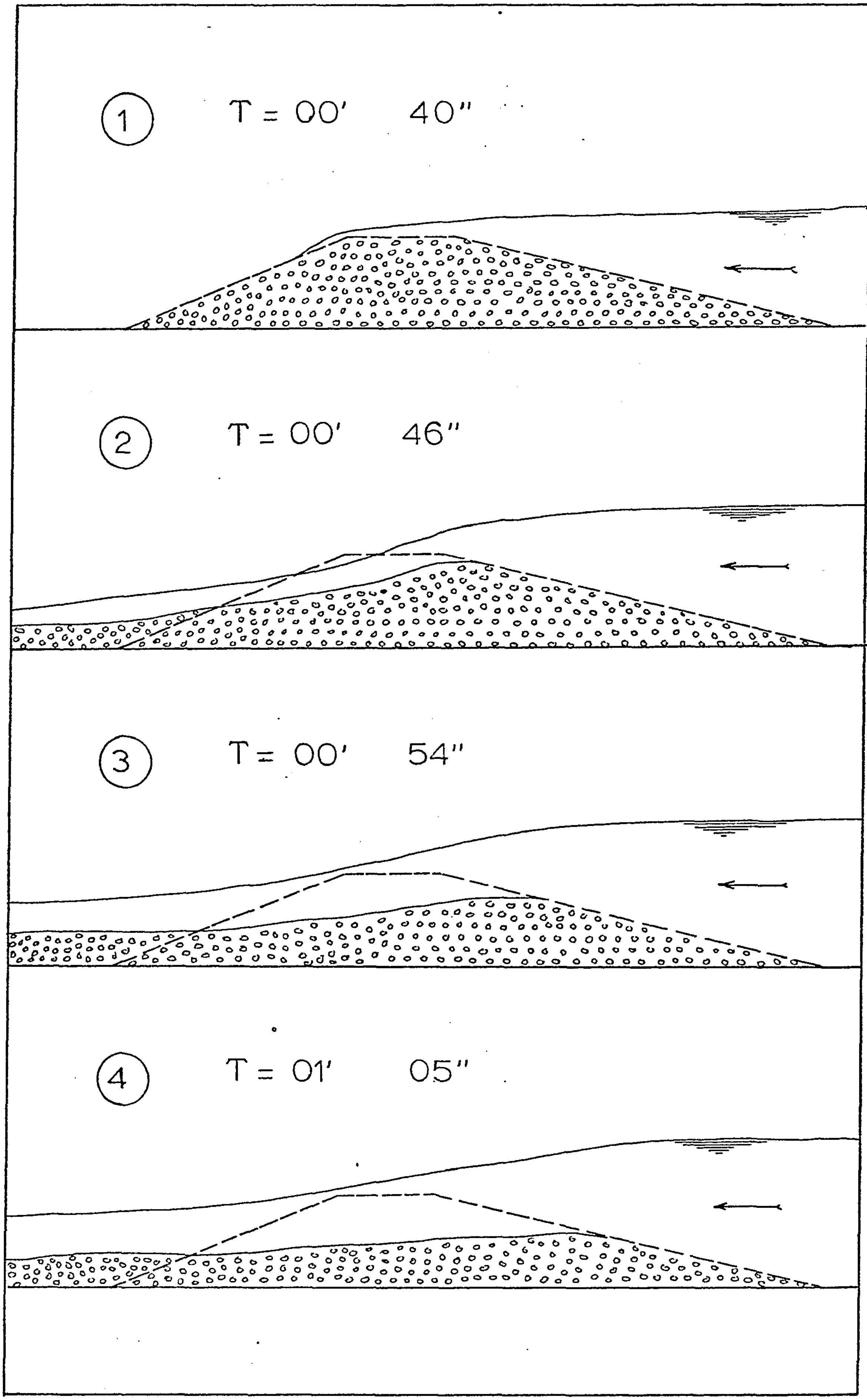
Material No. 5

S_s = 2.77

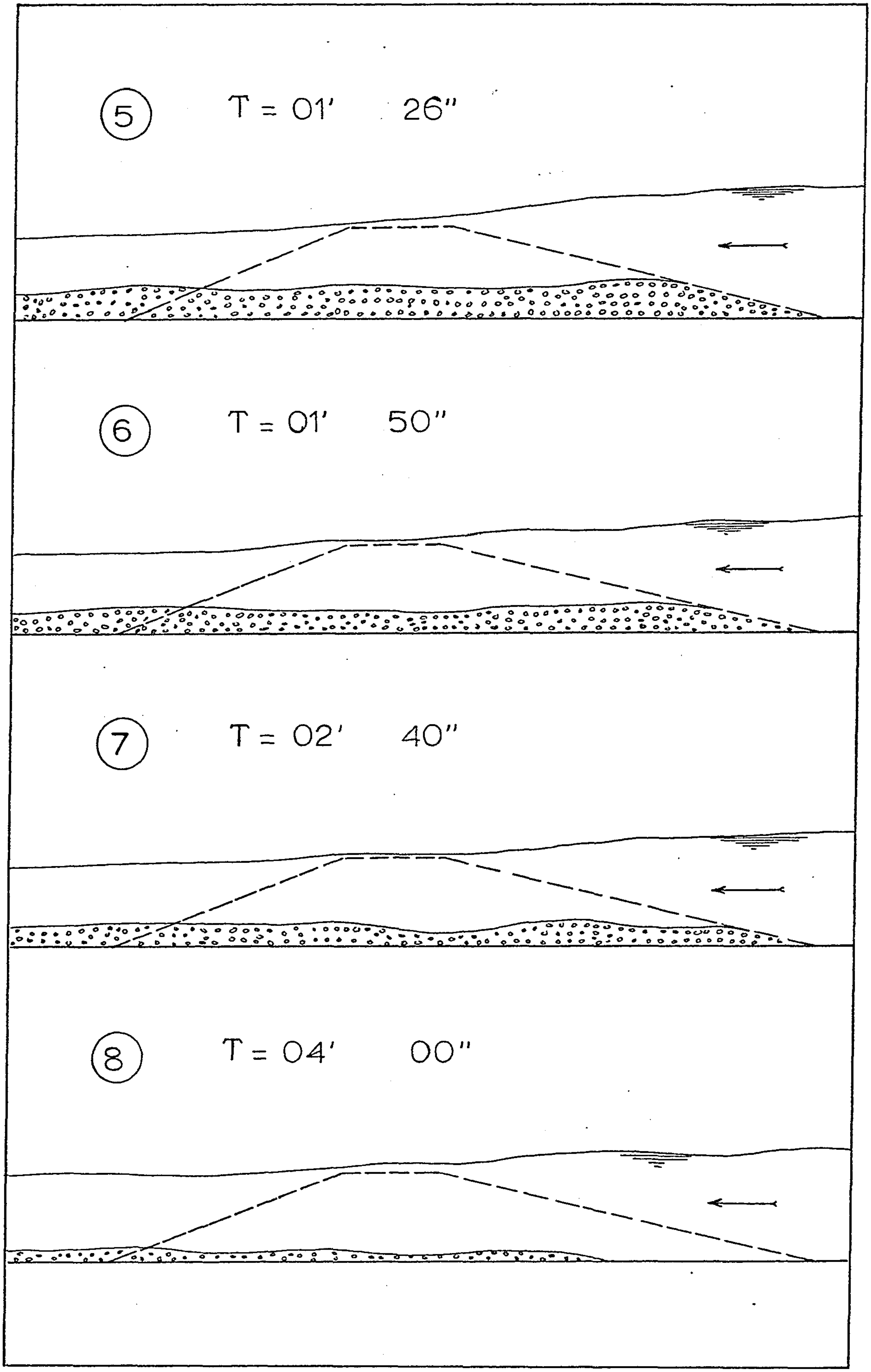
n = 40.0%

α = 0.267

d = 2.20 mm.



1
T = 00' 40"
2
T = 00' 46"
3
T = 00' 54"
4
T = 01' 05"


5
T = 01' 26"
6
T = 01' 50"
7
T = 02' 40"
8
T = 04' 00"

(9) T = 05' 30"

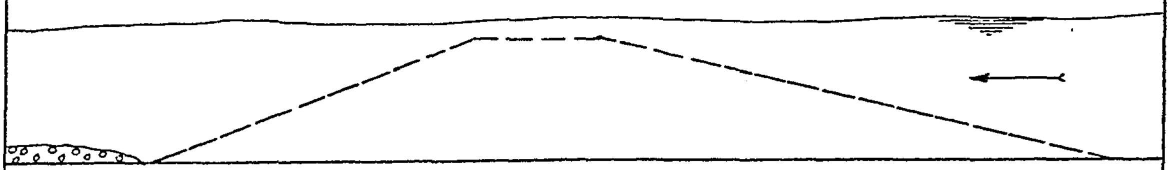


Fig.55

Exp. No. 5-Q1250-9"

EROSION OF DAM AT CONSTANT DISCHARGE

WITH DOWNSTREAM SUBCRITICAL FLOW.

Type (1) dam

Washout discharge = 3.79 cfs/ft

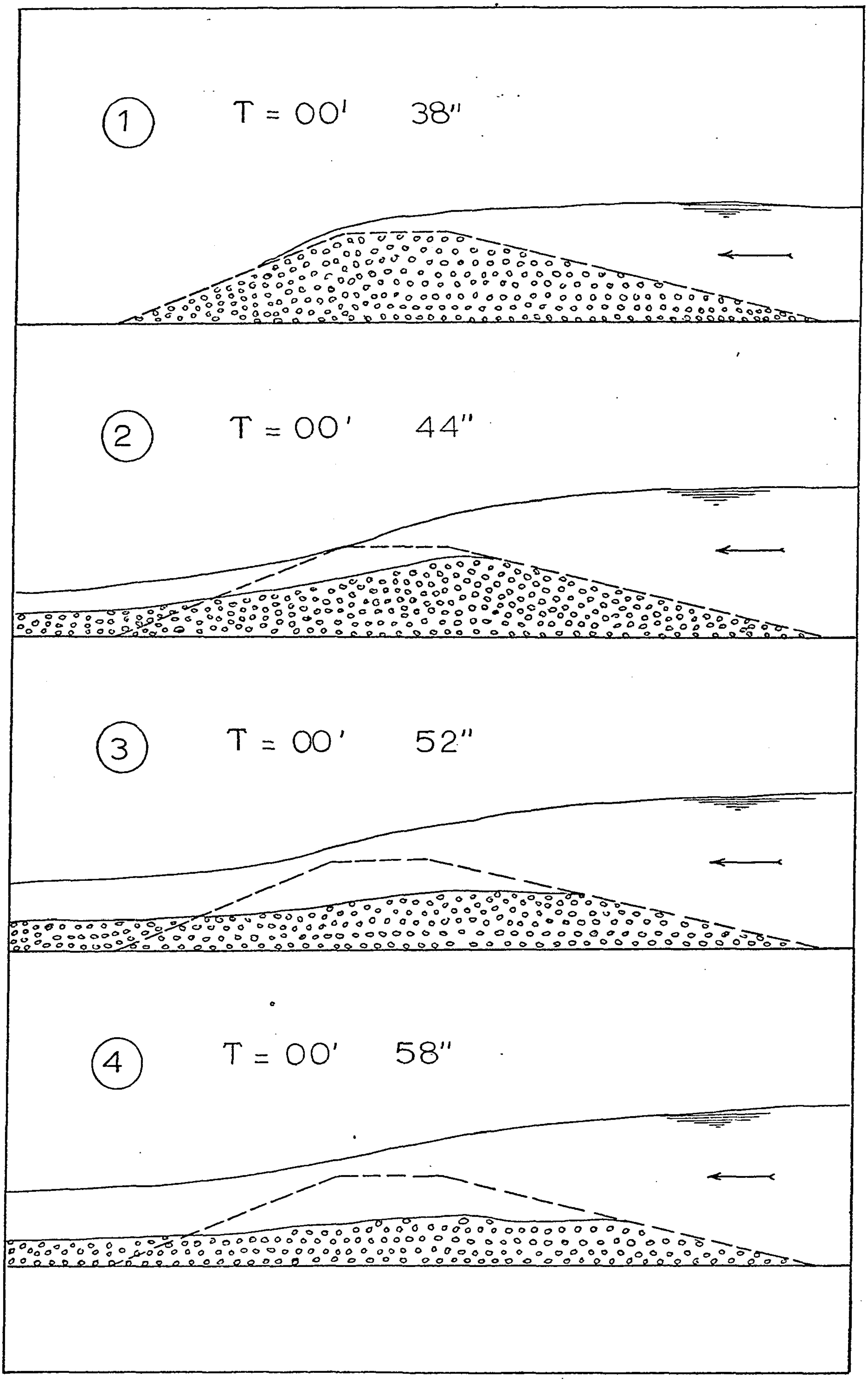
Material No. 5

S_s = 2.77

n = 40.0%

α = 0.267

d = 2.20 mm.



1
T = 00' 38"
2
T = 00' 44"
3
T = 00' 52"
4
T = 00' 58"

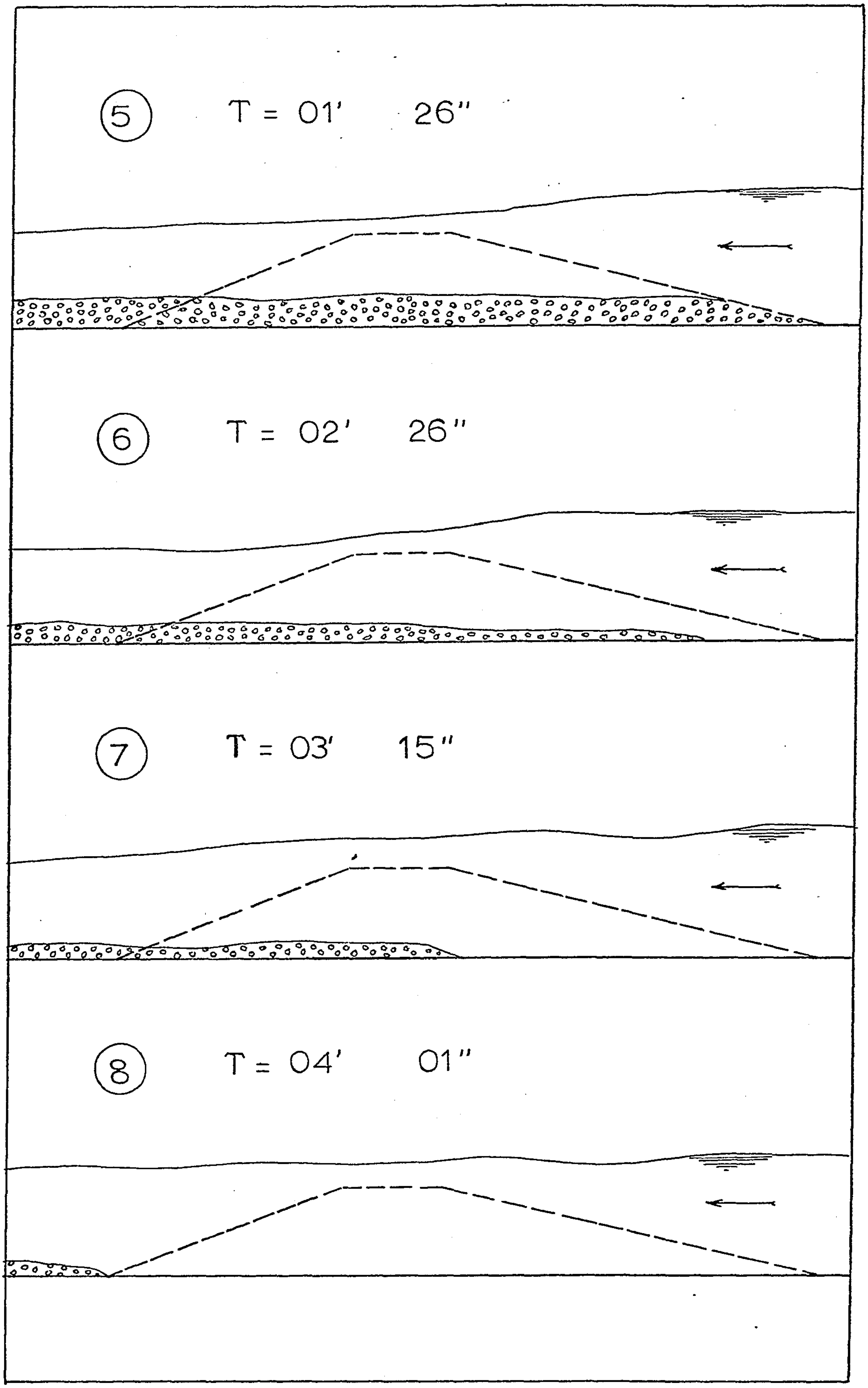

5
T = 01' 26"
6
T = 02' 26"
7
T = 03' 15"
8
T = 04' 01"

Fig.56

<u>Exp. No. 7-Q250-9"</u>

EROSION OF DAM AT CONSTANT DISCHARGE

WITH DOWNSTREAM SUBCRITICAL FLOW.

Type (1) dam

Washout discharge = 0.76 cfs/ft

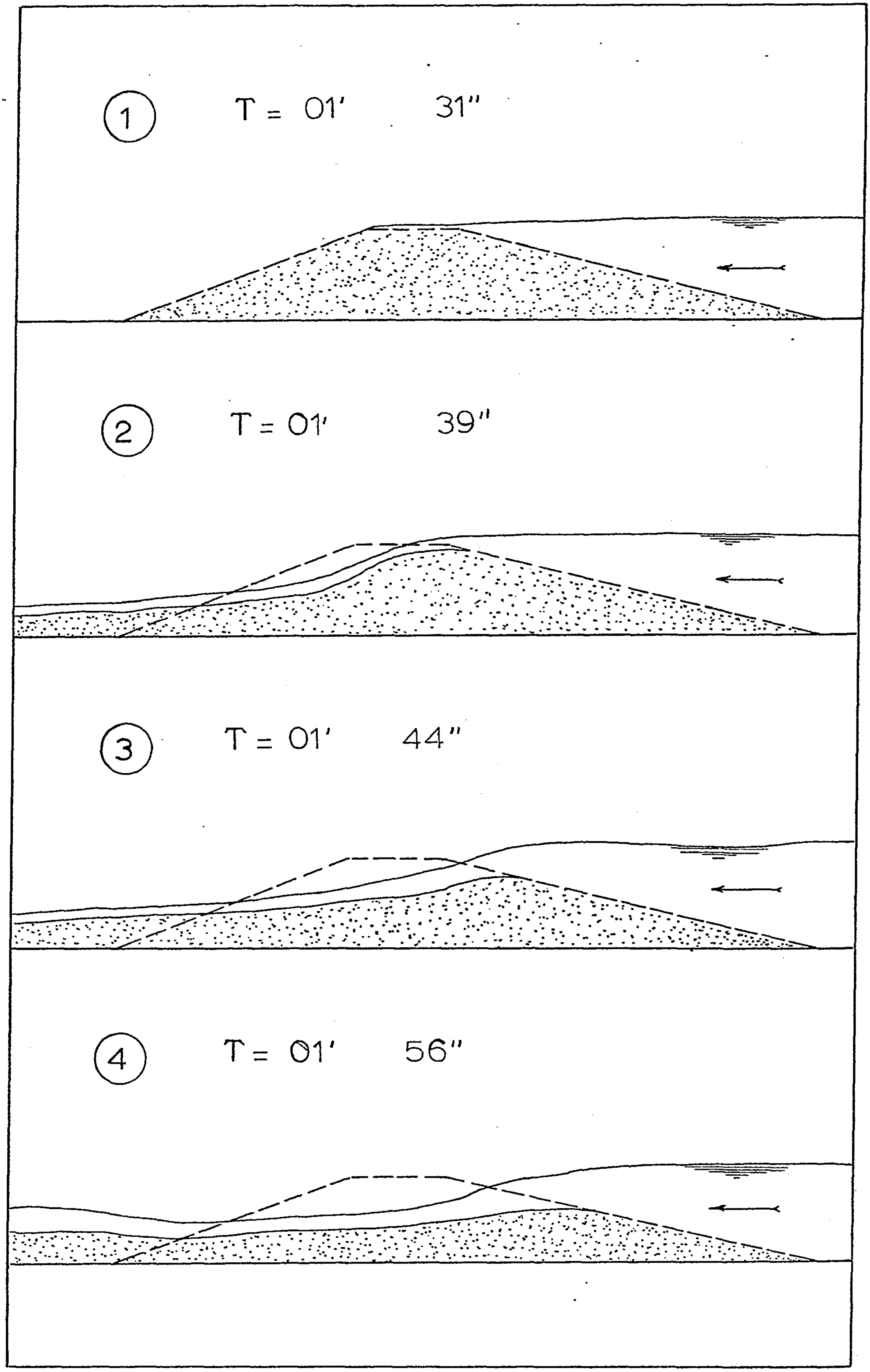
Material No. 7

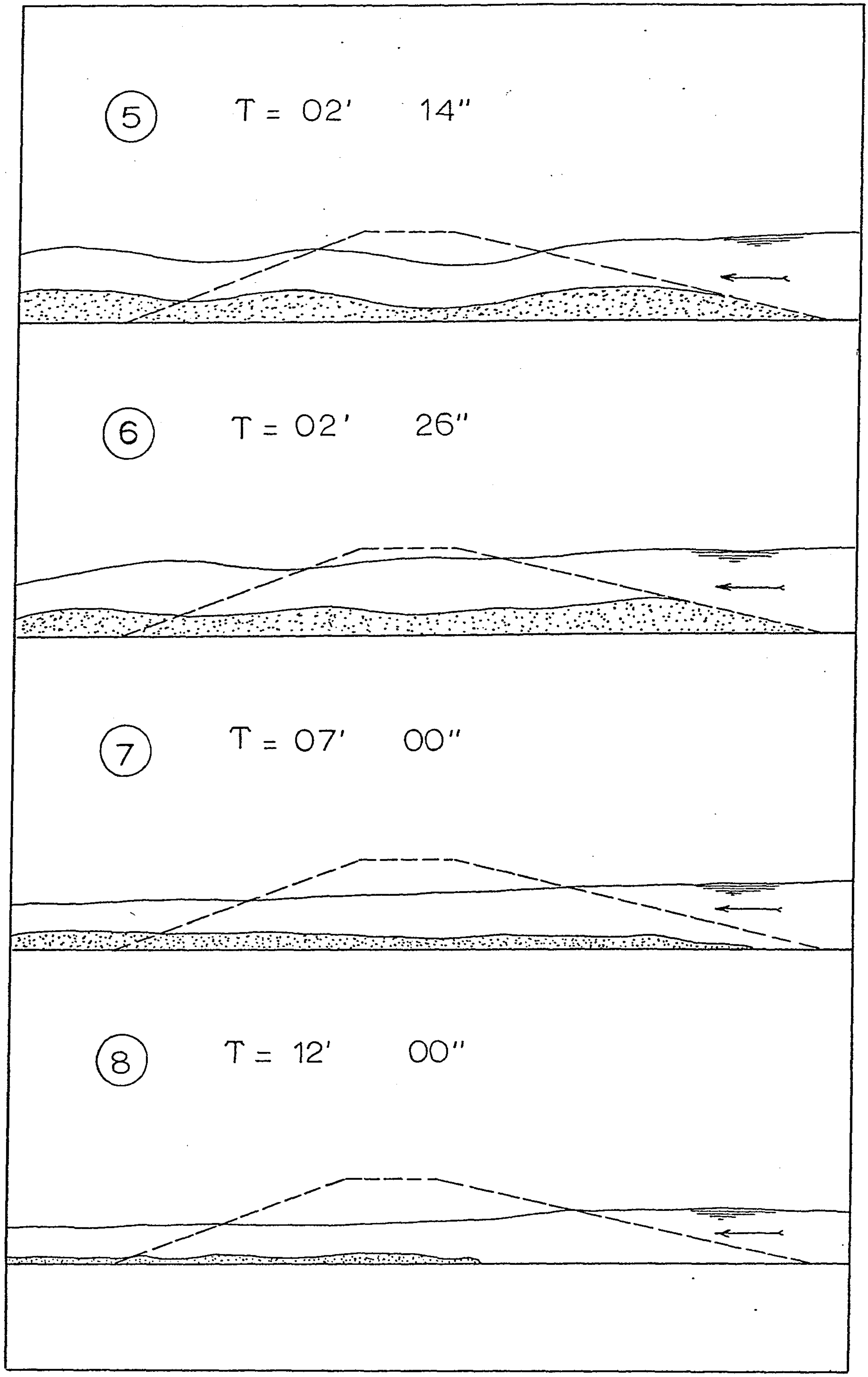
S_s = 2.65

n = 41.0%

α = 0.066

d = 0.80 mm.


1
T = 01' 31"
2
T = 01' 39"
3
T = 01' 44"
4
T = 01' 56"


5
T = 02' 14"
6
T = 02' 26"
7
T = 07' 00"
8
T = 12' 00"

(9) T = 19' 01"

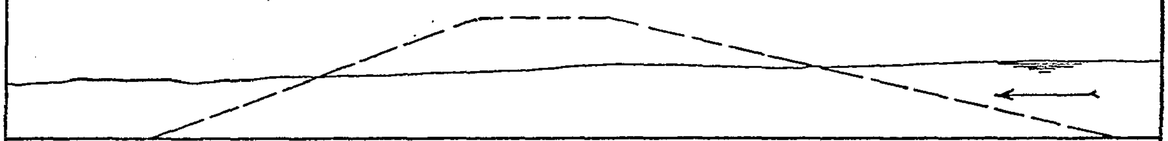


Fig.57

Exp. No. 7-Q500-9"

EROSION OF DAM AT CONSTANT DISCHARGE

WITH DOWNSTREAM SUBCRITICAL FLOW.

Type (1) dam

Washout discharge = 1.51 cfs/ft

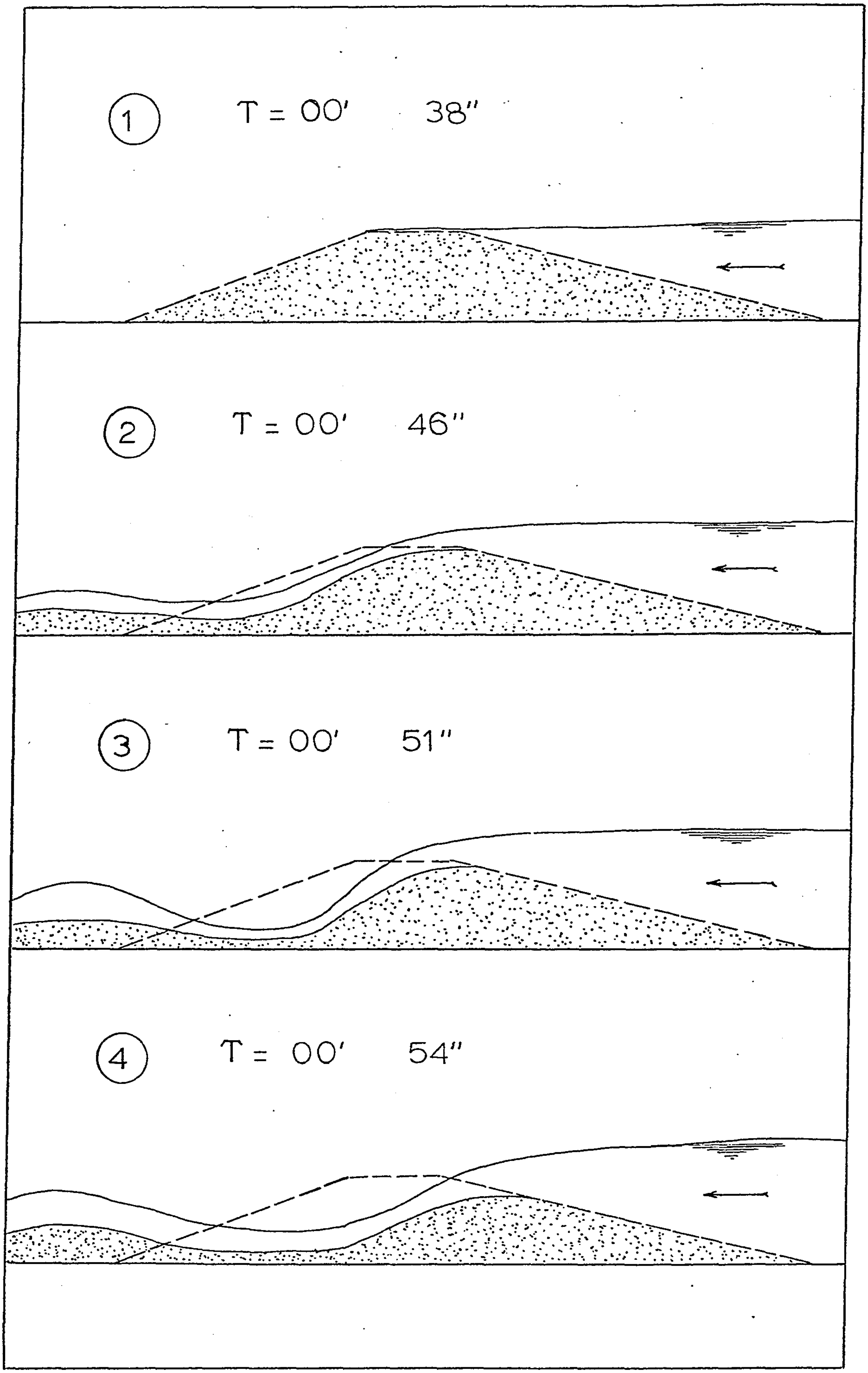
Material No. 7

$S_s = 2.65$

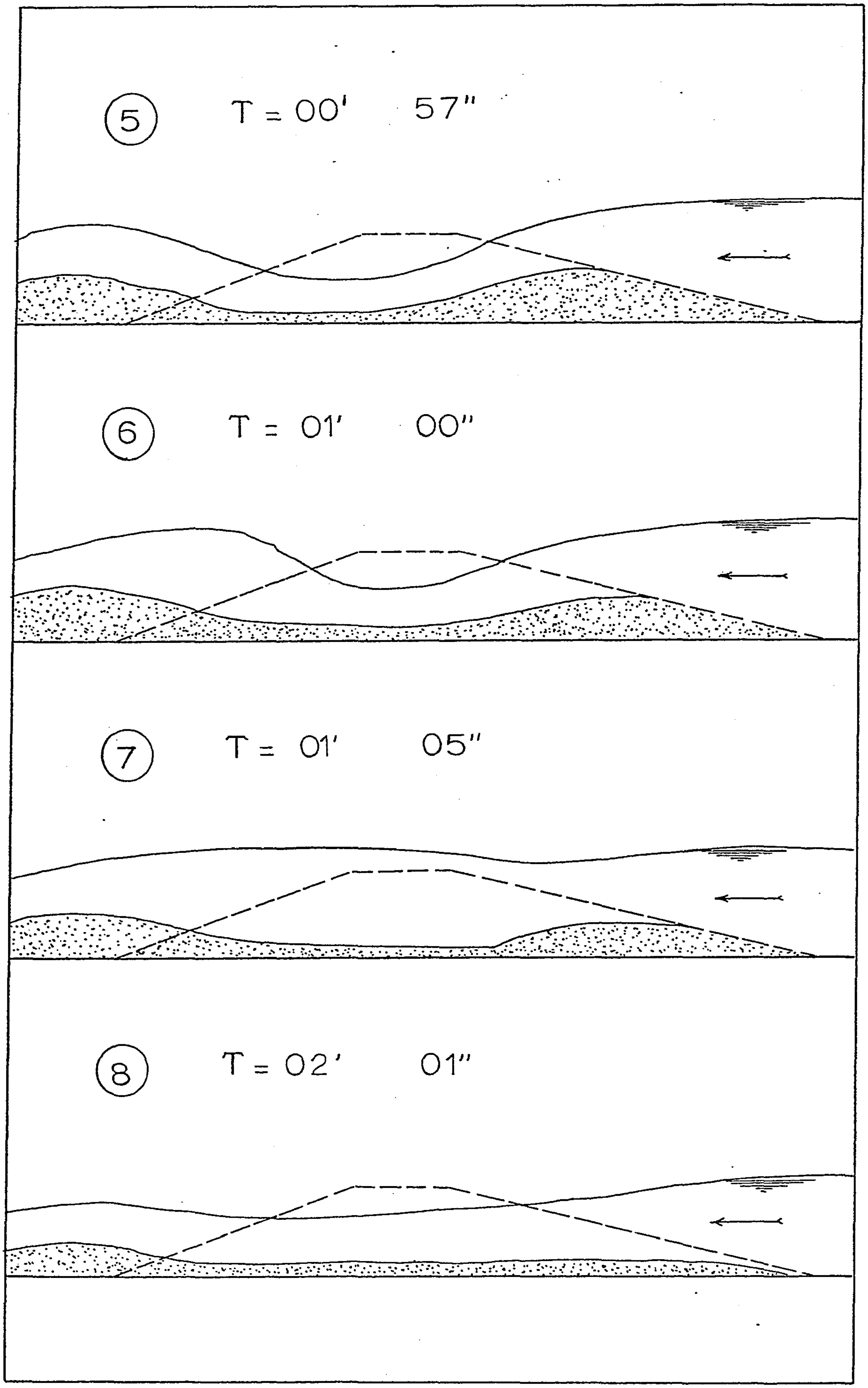
$n = 41.0\%$

$\alpha = 0.066$

$d = 0.80$ mm.

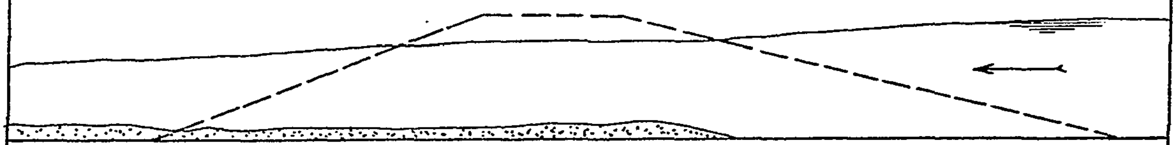


1
T = 00' 38"
2
T = 00' 46"
3
T = 00' 51"
4
T = 00' 54"

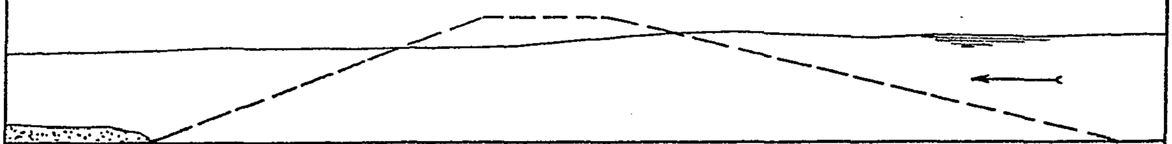


5
T = 00' 57"
6
T = 01' 00"
7
T = 01' 05"
8
T = 02' 01"

(9) T = 03' 38"



(10) T = 06' 31"



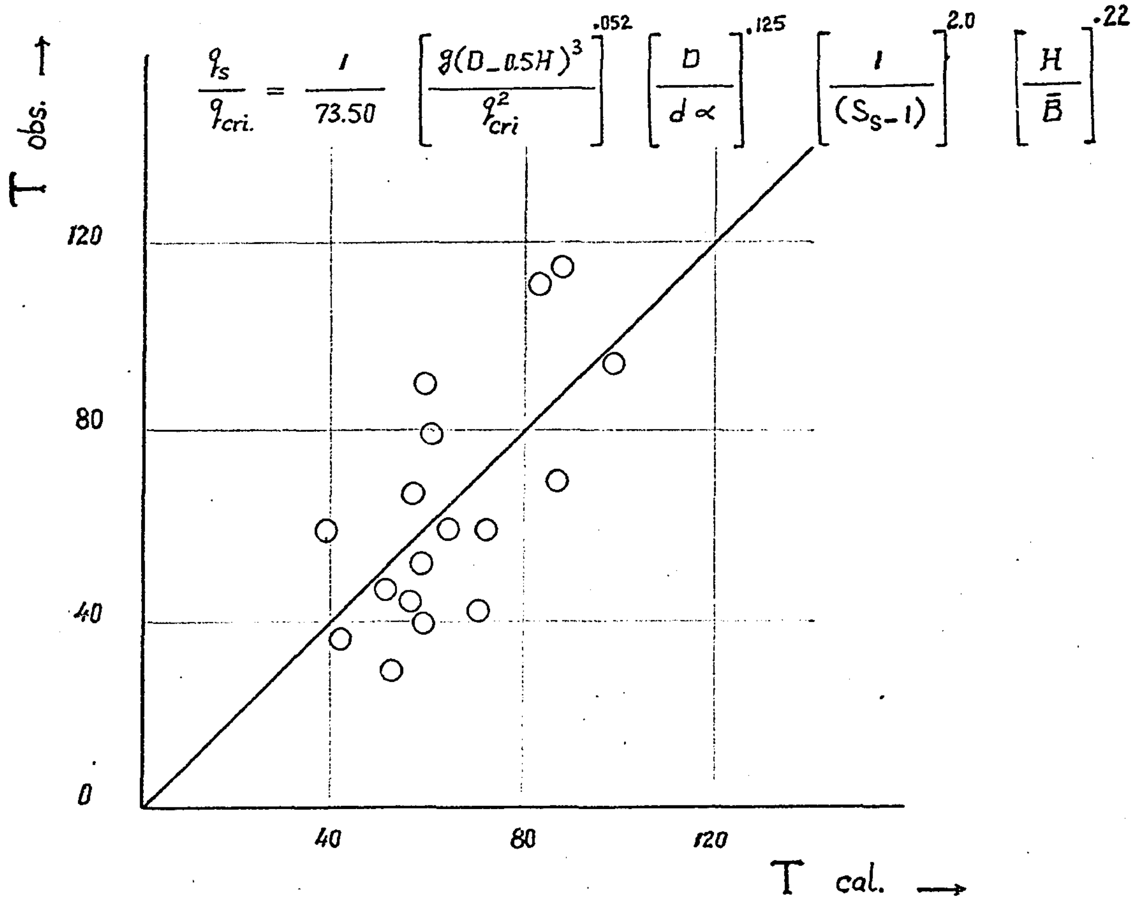


Fig. 58 Observed versus calculated values of time of washout at constant upstream water level with downstream supercritical flow.

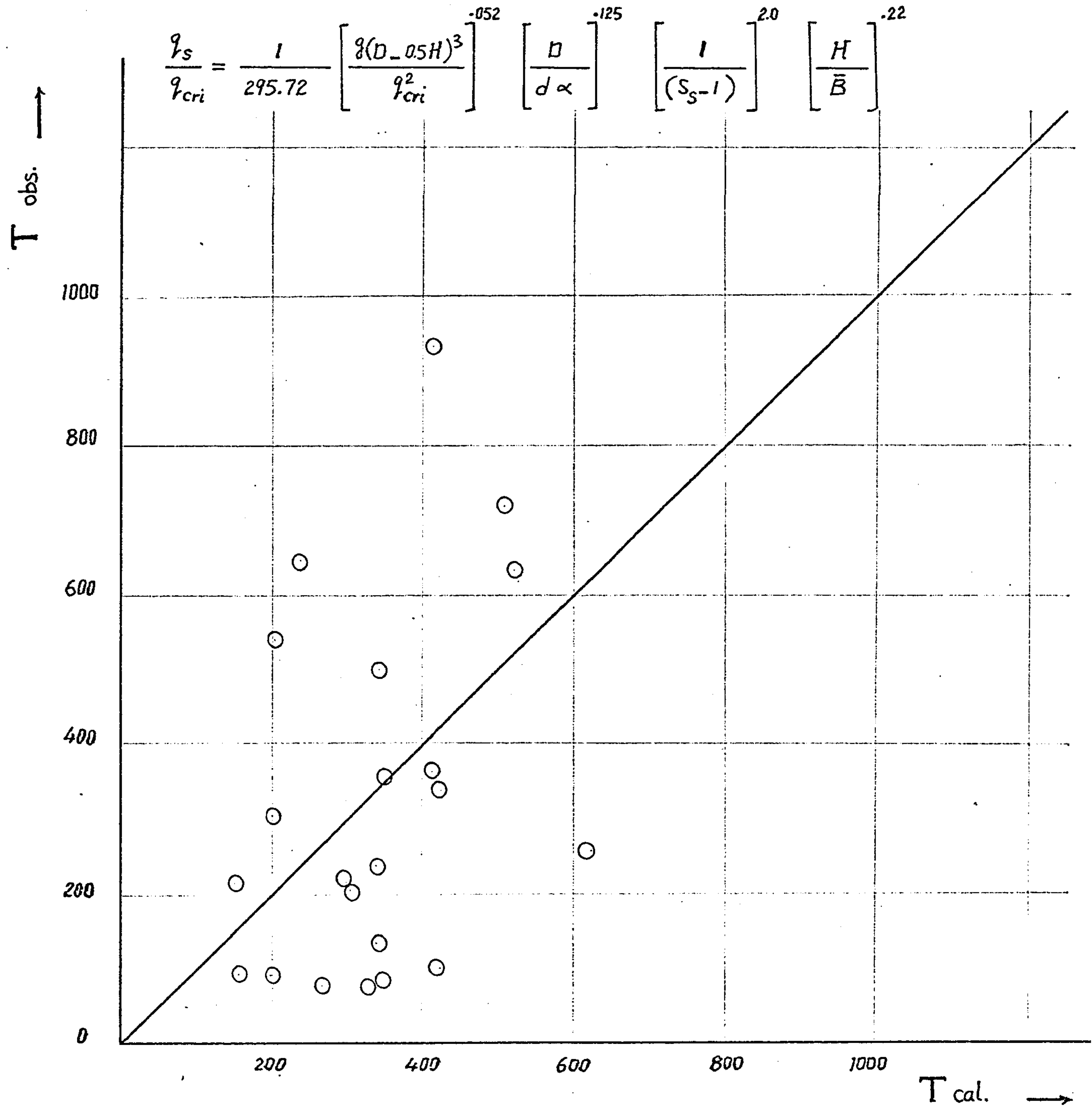


Fig. 59 Observed versus calculated values of time of washout at constant upstream water level with downstream subcritical flow.

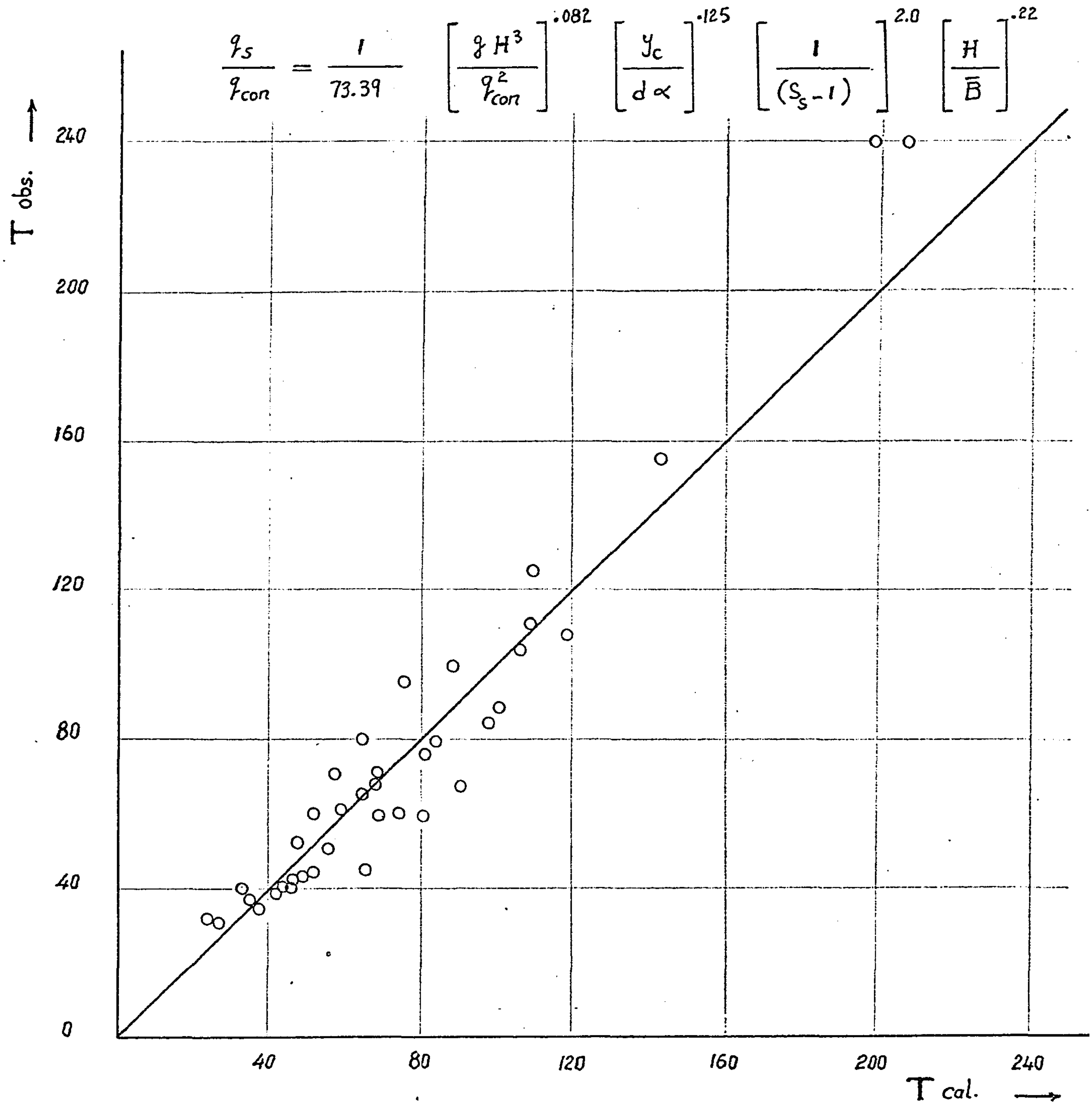


Fig. 60 Observed versus calculated values of time of washout at constant discharge with downstream supercritical flow.

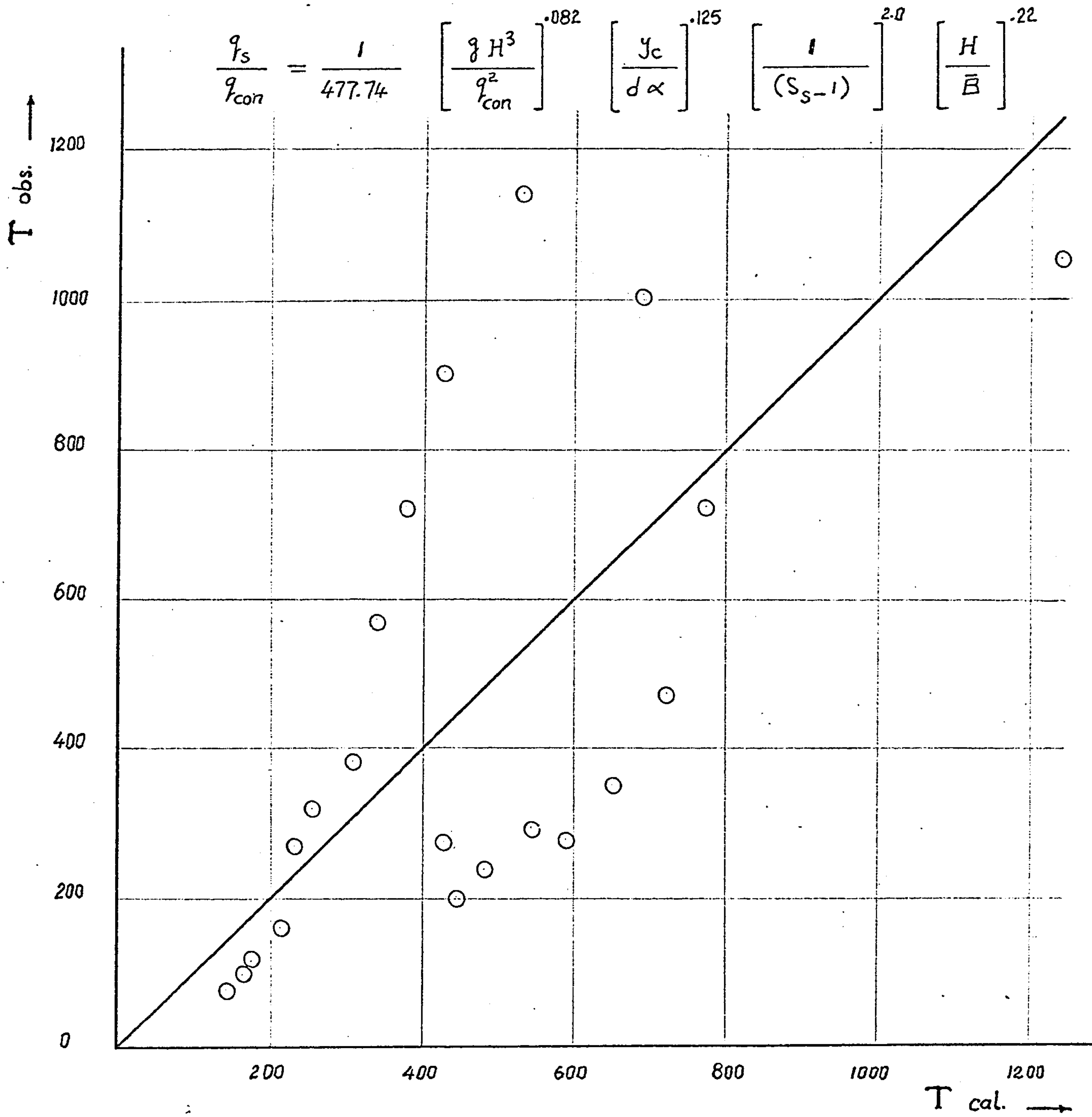


Fig. 61 Observed versus calculated values of time of washout at constant discharge with downstream subcritical flow.

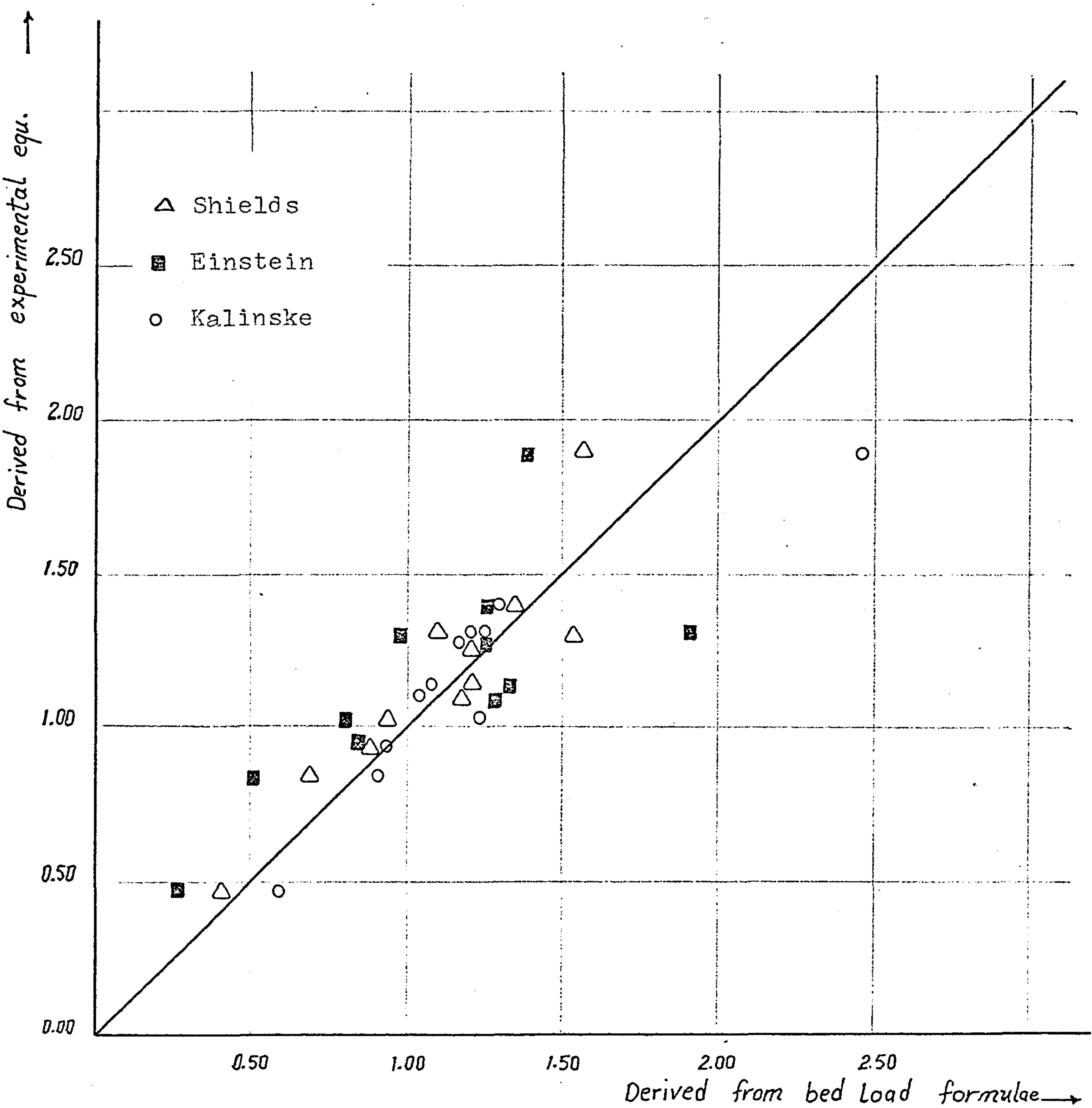


Fig. 62 Time scale values from derived experimental equation versus calculated values from bed load formulae.

TABLE No.1

Material No	Diam. d mm.	Types of materials	Angle of repose		Sp. gr. Ss	Porosity n%	Remarks
			Degrees	Radians			
1	8.40	very angular	34.0	0.596	2.76	40.2%	Gravels
2	6.35	moderately angular	30.5	0.532	2.57	41.0%	
3	4.60	slightly angular	26.0	0.454	2.70	40.0%	
4	4.00	slightly angular	25.0	0.438	2.76	40.2%	
5	2.20	moderately rounded	15.3	0.267	2.77	40.0%	
6	1.90	moderately rounded	14.3	0.251	2.74	35.0%	
7	0.80	very rounded	3.8	0.066	2.65	41.0%	large silica
8	0.43	very rounded	2.0	0.035	3.26	37.6%	olivine
9	0.23	very rounded	1.1	0.019	2.65	32.1%	small silica
10	0.14	very rounded	0.7	0.012	4.50	32.1%	zircon

TABLE No.2

Exp. No.	Diam. d mm.	Observed time of washout T sec.	Volume of dam Vs ft^3/ft	Sediment discharge $q_s = \frac{V_s(1-n/100)}{T}$ c.f.s./ft	$q_{max.}$ c.f.s/ft	Constant U/S * depth D inch.	Remarks
2-H0-9"	6.35	95	2.95	0.01831	3.15	9.950	type (1)
2-H2-9"	6.35	42	2.95	0.04142	4.24	11.50	"
2-H4-9"	6.35	40	2.95	0.03866	5.60	13.00	"
3-H0-9"	4.60	112	2.95	0.01580	4.09	11.20	"
3-H2-9"	4.60	70	2.95	0.02528	4.07	10.90	"
3-H4-9"	4.60	60	2.95	0.02950	5.69	12.90	"
5-H0-9"	2.20	115	2.95	0.01539	3.80	10.40	"
5-H2-9"	2.20	90	2.95	0.01966	5.60	13.00	"
5-H4-9"	2.20	67	2.95	0.02641	5.75	13.25	"
7-H0-9"	0.80	80	2.95	0.02175	3.36	9.85	"
7-H2-9"	0.80	60	2.95	0.02900	4.98	12.60	"
3-H0-9"	4.60	41	0.738	0.01080	2.12	5.80	type (2)
3-H2-9"	4.60	30	0.738	0.01476	2.57	6.25	"
5-H0-9"	2.20	60	0.738	0.00738	1.82	5.00	"
5-H1-9"	2.20	47	0.738	0.00942	2.42	6.00	"
5-H2-9"	2.20	37	0.738	0.01197	2.88	6.85	"

* U/S = upstream

TABLE No.3

Exp. No.	Diam. d mm.	Observed time of washout T sec.	Volume of dam Vs ft^3/ft	Sediment discharge $q_s = \frac{Vs(1-n/100)}{T}$ c.f.s/ft	$q_{max.}$ c.f.s/ft	Constant U/S depth D inch.	Remarks
2-H0-9"	6.35	930	2.95	0.00187	3.45	10.45	type (1)
2-H2-9"	6.35	495	2.95	0.00351	4.09	11.70	"
2-H4-9"	6.35	210	2.95	0.00828	4.72	12.60	"
3-H0-9"	4.60	715	2.95	0.00247	3.27	10.00	"
3-H2-9"	4.60	365	2.95	0.00484	3.94	11.20	"
3-H4-9"	4.60	235	2.95	0.00753	4.69	12.50	"
5-H0-9"	2.20	630	2.95	0.00280	2.95	9.40	"
5-H2-9"	2.20	338	2.95	0.00523	3.48	10.50	"
5-H4-9"	2.20	205	2.95	0.00863	4.75	12.70	"
7-H0-9"	0.80	355	2.95	0.00490	2.79	9.00	"
7-H2-9"	0.80	80	2.95	0.02175	3.48	10.50	"
3-H2-9"	4.60	540	0.738	0.00082	1.97	7.25	type (2)
3-H3-9"	4.60	210	0.738	0.00210	2.50	8.50	"
5-H1-9"	2.20	645	0.738	0.00068	1.59	6.35	"
5-H2-9"	2.20	305	0.738	0.00145	1.82	7.00	"
1-H0-6"	8.40	100	0.738	0.00443	0.875	5.25	"
4-H0-6"	4.00	86	0.738	0.00515	0.907	5.50	"
6-H0-6"	1.90	85	0.738	0.00565	0.867	5.20	"
7-H0-6"	0.80	88	0.738	0.00496	0.900	5.40	"
8-H0-6"	0.43	129	0.738	0.00355	0.891	5.35	"
9-H0-6"	0.23	88	0.738	0.00571	0.925	5.55	"
10-H0-6"	0.14	260	0.738	0.00193	0.933	5.60	"

TABLE No. 4

Exp. No.	Diam. d mm.	Observed time of washout T sec.	Volume of dam Vs ft³/ft	Sediment discharge $q_s = \frac{V_s(1-n/100)}{T}$ cfs/ft	Constant water discharge Q U.S.GPM	$q_{con.}$ cfs/ft	Remarks
2-Q750 -9"	6.35	105	2.95	0.01657	750	2.27	type (1)
2-Q1000-9"	6.35	59	2.95	0.02949	1000	3.03	"
2-Q1250-9"	6.35	45	2.95	0.03866	1250	3.79	"
3-Q750 -9"	4.60	108	2.95	0.01638	750	2.27	"
3-Q1000-9"	4.60	67	2.95	0.02641	1000	3.03	"
3-Q1250-9"	4.60	60	2.95	0.02950	1250	3.79	"
5-Q750 -9"	2.20	110	2.95	0.01609	750	2.27	"
5-Q1000-9"	2.20	79	2.95	0.02240	1000	3.03	"
5-Q1250-9"	2.20	69	2.95	0.02565	1250	3.79	"
7-Q250 -9"	0.80	240	2.95	0.00725	250	0.76	"
7-Q500 -9"	0.80	89	2.95	0.01955	500	1.51	"
7-Q750 -9"	0.80	60	2.95	0.02900	750	2.27	"
3-Q500 -9"	4.60	45	0.738	0.00984	500	1.51	type (2)
3-Q750 -9"	4.60	37	0.738	0.01197	750	2.27	"
3-Q1000-9"	4.60	30	0.738	0.01476	1000	3.03	"
5-Q100 -9"	2.20	240	0.738	0.00184	100	0.30	"
5-Q150 -9"	2.20	155	0.738	0.00285	150	0.46	"
5-Q200 -9"	2.20	125	0.738	0.00354	200	0.61	"
5-Q250 -9"	2.20	100	0.738	0.00443	250	0.76	"
5-Q300 -9"	2.20	95	0.738	0.00466	300	0.91	"
5-Q350 -9"	2.20	80	0.738	0.00553	350	1.06	"
5-Q400 -9"	2.20	70	0.738	0.00632	400	1.21	"
5-Q450 -9"	2.20	60	0.738	0.00738	450	1.36	"

Continued

5-Q500 -9"	2.20	52	0.738	0.00851	500	1.51	type (2)
5-Q750 -9"	2.20	40	0.738	0.01107	750	2.27	"
5-Q1000-9"	2.20	31	0.738	0.01429	1000	3.03	"
3-Q500 -9"	4.60	44	0.716	0.00976	500	1.51	type (3)
3-Q500 -9"	4.60	42	0.695	0.00992	500	1.51	type (4)
3-Q500 -9"	4.60	42	0.695	0.00992	500	1.51	type (5)
3-Q500 -9"	4.60	41	0.651	0.00952	500	1.51	type (6)
3-Q500 -9"	4.60	41	0.651	0.00952	500	1.51	type (7)
3-Q500 -9"	4.60	35	0.564	0.00967	500	1.51	type (8)
3-Q500 -9"	4.60	66	0.912	0.00828	500	1.51	type (9)
3-Q500 -9"	4.60	51	0.796	0.00935	500	1.51	type (10)
3-Q500 -9"	4.60	61	0.854	0.00839	500	1.51	type (11)
3-Q500 -9"	4.60	66	0.912	0.00828	500	1.51	type (12)
3-Q500 -9"	4.60	75	1.085	0.00868	500	1.51	type (13)
3-Q500 -9"	4.60	85	1.259	0.00888	500	1.51	type (14)
2-Q500 -18"	6.35	85	0.436	0.00512	500	0.76	type (2)
2-Q1300-36"	6.35	70	0.436	0.00622	1300	0.98	"
2-Q1300-60"	6.35	110	0.436	0.00396	1300	0.59	"

TABLE No.5

Exp. No.	Diam. d mm.	Observed time of washout T sec.	Volume of dam Vs ft^3/ft	Sediment discharge $q_s = \frac{Vs(1-n/100)}{T}$ c.f.s/ft	Constant water discharge Q U.S.GPM	$q_{con.}$ cfs/ft	Remarks
2-Q750 -9"	6.35	1135	2.95	0.00173	750	2.27	type (1)
2-Q1000-9"	6.35	1005	2.95	0.00153	1000	3.03	"
2-Q1250-9"	6.35	280	2.95	0.00621	1250	3.79	"
3-Q750 -9"	4.60	719	2.95	0.00246	750	2.27	"
3-Q1000-9"	4.60	273	2.95	0.00648	1000	3.03	"
3-Q1250-9"	4.60	235	2.95	0.00753	1250	3.79	"
5-Q750 -9"	2.20	470	2.95	0.00376	750	2.27	"
5-Q1000-9"	2.20	290	2.95	0.00610	1000	3.03	"
5-Q1250-9"	2.20	203	2.95	0.00871	1250	3.79	"
7-Q250 -9"	0.80	1050	2.95	0.00165	240	0.76	"
7-Q500 -9"	0.80	353	2.95	0.00687	500	1.51	"
3-Q750 -9"	4.60	266	0.738	0.00166	750	2.27	type (2)
3-Q1000-9"	4.60	116	0.738	0.00381	1000	3.03	"
3-Q1250-9"	4.60	79	0.738	0.00560	1250	3.79	"
5-Q350 -9"	2.20	900	0.738	0.00049	350	1.06	"
5-Q400 -9"	2.20	720	0.738	0.00061	400	1.21	"
5-Q450 -9"	2.20	570	0.738	0.00077	450	1.36	"
5-Q500 -9"	2.20	382	0.738	0.00115	500	1.51	"
5-Q600 -9"	2.20	315	0.738	0.00140	610	1.85	"
5-Q750 -9"	2.20	158	0.738	0.00280	750	2.27	"
5-Q1000-9"	2.20	97	0.738	0.00456	1000	3.03	"

TABLE No.6

Exp. No.	Diam. d mm.	Sediment discharge q_s cfs/ft.		Time of washout seconds		Remarks
		Observed	Calculated	Observed	Calculated	
2-H0-9"	6.35	0.01831	0.01746	95	99.62	type (1)
2-H2-9"	6.35	0.04142	0.02448	42	71.05	"
2-H4-9"	6.35	0.03866	0.03028	40	57.46	"
3-H0-9"	4.60	0.01580	0.02117	112	83.57	"
3-H2-9"	4.60	0.02528	0.02019	70	87.65	"
3-H4-9"	4.60	0.02950	0.02706	60	65.39	"
5-H0-9"	2.20	0.01539	0.02009	115	88.08	"
5-H2-9"	2.20	0.01966	0.02965	90	59.70	"
5-H4-9"	2.20	0.02641	0.03063	67	57.77	"
7-H0-9"	0.80	0.02175	0.02837	80	61.32	"
7-H2-9"	0.80	0.02900	0.04369	60	39.83	"
3-H0-9"	4.60	0.01080	0.00730	41	60.68	type (2)
3-H2-9"	4.60	0.01476	0.00831	30	53.30	"
5-H0-9"	2.20	0.00738	0.00607	60	72.90	"
5-H1-9"	2.20	0.00942	0.00837	47	52.92	"
5-H2-9"	2.20	0.01197	0.01051	37	42.11	"

TABLE No.7

Exp. No.	Diam. d mm.	Sediment discharge q_s cfs/ft.		Time of washout seconds.		Remarks
		Observed	Calculated	Observed	Calculated	
2-H0-9"	6.35	0.00187	0.00416	930	418.06	type (1)
2-H2-9"	6.35	0.00351	0.00507	495	342.92	"
2-H4-9"	6.35	0.00828	0.00576	210	301.57	"
3-H0-9"	4.60	0.00247	0.00348	715	507.64	"
3-H2-9"	4.60	0.00484	0.00425	365	415.64	"
3-H4-9"	4.60	0.00753	0.00515	235	343.39	"
5-H0-9"	2.20	0.00280	0.00337	630	524.63	"
5-H2-9"	2.20	0.00523	0.00410	338	430.70	"
5-H4-9"	2.20	0.00863	0.00572	205	309.08	"
7-H0-9"	0.80	0.00490	0.00484	355	358.79	"
7-H2-9"	0.80	0.02175	0.00639	80	272.26	"
3-H2-9"	4.60	0.00082	0.00215	540	205.46	type (2)
3-H3-9"	4.60	0.00210	0.00282	210	156.84	"
5-H1-9"	2.20	0.00068	0.00185	645	238.61	"
5-H2-9"	2.20	0.00145	0.00219	305	201.82	"
1-H0-6"	8.40	0.00443	0.00103	100	429.71	"
4-H0-6"	4.00	0.00515	0.00127	86	347.28	"
6-H0-6"	1.90	0.00565	0.00139	85	345.03	"
7-H0-6"	0.80	0.00496	0.00217	88	200.23	"
8-H0-6"	0.43	0.00355	0.00133	129	342.92	"
9-H0-6"	0.23	0.00571	0.00311	88	160.91	"
10-H0-6"	0.14	0.00193	0.00079	260	632.40	"

TABLE No.8

Exp. No.	Diam. d mm.	Sediment discharge q_s cfs/ft		Time of washout seconds.		Remarks
		Observed	Calculated	Observed	Calculated	
2-Q750 -9"	6.35	0.01657	0.01648	105	105.52	type (1)
2-Q1000-9"	6.35	0.02949	0.02148	59	80.97	"
2-Q1250-9"	6.35	0.03866	0.02638	45	65.94	"
3-Q750 -9"	4.60	0.01638	0.01493	108	118.51	"
3-Q1000-9"	4.60	0.02641	0.01946	67	90.94	"
3-Q1250-9"	4.60	0.02950	0.02390	60	74.05	"
5-Q750 -9"	2.20	0.01609	0.01614	110	109.63	"
5-Q1000-9"	2.20	0.02240	0.02103	79	84.13	"
5-Q1250-9"	2.20	0.02565	0.02583	69	68.51	"
7-Q250 -9"	0.80	0.00725	0.00913	240	190.52	"
7-Q500 -9"	0.80	0.01955	0.01728	89	100.66	"
7-Q750 -9"	0.80	0.02900	0.02510	60	69.30	"
3-Q500 -9"	4.60	0.00984	0.00868	45	51.03	type (2)
3-Q750 -9"	4.60	0.01197	0.01260	37	35.13	"
3-Q1000-9"	4.60	0.01476	0.01643	30	26.96	"
5-Q100 -9"	2.20	0.00184	0.00213	240	207.68	"
5-Q150 -9"	2.20	0.00285	0.00309	155	142.99	"
5-Q200 -9"	2.20	0.00354	0.00403	125	109.72	"
5-Q250 -9"	2.20	0.00443	0.00495	100	89.35	"
5-Q300 -9"	2.20	0.00466	0.00586	95	75.55	"
5-Q350 -9"	2.20	0.00553	0.00675	80	65.55	"

Continued

5-Q400 -9"	2.20	0.00632	0.00764	70	57.97	type (2)
5-Q450 -9"	2.20	0.00738	0.00851	60	52.02	"
5-Q500 -9"	2.20	0.00851	0.00938	52	47.20	"
5-Q750 -9"	2.20	0.01107	0.01363	40	32.51	"
5-Q1000-9"	2.20	0.01429	0.01776	31	24.94	"
3-Q500 -9"	4.60	0.00976	0.00873	44	49.21	type (3)
3-Q500 -9"	4.60	0.00992	0.00879	42	47.40	type (4)
3-Q500 -9"	4.60	0.00992	0.00879	42	47.40	type (5)
3-Q500 -9"	4.60	0.00952	0.00892	41	43.82	type (6)
3-Q500 -9"	4.60	0.00952	0.00892	41	43.82	type (7)
3-Q500 -9"	4.60	0.00967	0.00920	35	36.81	type (8)
3-Q500 -9"	4.60	0.00828	0.00828	66	66.00	type (9)
3-Q500 -9"	4.60	0.00935	0.00853	51	55.86	type (10)
3-Q500 -9"	4.60	0.00839	0.00840	61	60.90	type (11)
3-Q500 -9"	4.60	0.00828	0.00828	66	66.00	type (12)
3-Q500 -9"	4.60	0.00868	0.00797	75	81.63	type (13)
3-Q500 -9"	4.60	0.00888	0.00771	85	97.94	type (14)
2-Q500 -18"	6.35	0.00512	0.00506	85	86.03	type (2)
2-Q1300-36"	6.35	0.00622	0.00645	70	67.59	"
2-Q1300-60"	6.35	0.00396	0.00403	110	108.11	"

TABLE No.9

Exp. No.	Diam. d mm.	Sediment discharge q_s cfs/ft		Time of washout seconds.		Remarks
		Observed	Calculated	Observed	Calculated	
2-Q750 -9"	6.35	0.00173	0.00330	1135	527.10	type (1)
2-Q1000-9"	6.35	0.00153	0.00253	1005	686.90	"
2-Q1250-9"	6.35	0.00621	0.00405	280	429.23	"
3-Q750 -9"	4.60	0.00246	0.00229	719	771.45	"
3-Q1000-9"	4.60	0.00648	0.00298	273	591.98	"
3-Q1250-9"	4.60	0.00753	0.00367	235	482.06	"
5-Q750 -9"	2.20	0.00376	0.00248	470	713.67	"
5-Q1000-9"	2.20	0.00610	0.00323	290	547.64	"
5-Q1250-9"	2.20	0.00871	0.00396	203	445.95	"
7-Q250 -9"	0.80	0.00165	0.00140	1050	1240.20	"
7-Q500 -9"	0.80	0.00687	0.00265	353	655.23	"
3-Q750 -9"	4.60	0.00166	0.00193	266	228.70	type (2)
3-Q1000-9"	4.60	0.00381	0.00252	116	175.50	"
3-Q1250-9"	4.60	0.00560	0.00309	79	142.91	"
5-Q350 -9"	2.20	0.00049	0.00103	900	426.71	"
5-Q400 -9"	2.20	0.00061	0.00117	720	377.36	"
5-Q450 -9"	2.20	0.00077	0.00130	570	338.59	"
5-Q500 -9"	2.20	0.00115	0.00144	382	307.29	"
5-Q600 -9"	2.20	0.00140	0.00173	315	255.90	"
5-Q750 -9"	2.20	0.00280	0.00209	158	211.57	"
5-Q1000-9"	2.20	0.00456	0.00272	97	162.35	"

TABLE No.10

Material No.	Diam. d mm.	Model scale	Time scale values according to			
			Derived eqn. (4.5)	Kalinske	Sheilds	Einstein
1	8.40	1	1.29	1.24	1.55	1.93
2	6.35	2	1.27	1.18	1.26	1.26
3	4.60	2	1.40	1.32	1.33	1.31
3	4.60	1	1.10	1.05	1.18	1.31
4	4.00	1	1.13	1.09	1.21	1.33
* 5	2.20	2	1.30	1.26	1.22	1.00
6	1.90	1	0.94	0.94	0.92	0.89
7	0.80	2	0.84	0.93	0.70	0.51
8	0.43	1	1.03	1.24	0.95	0.82
9	0.23	1	0.47	0.60	0.41	0.27
10	0.14	1	1.88	2.47	1.56	1.39

* Material No.5 is used as a model.

TABLE No.11

Exp. No. 1-HO-6"

d= 8.4 mm., S_s= 2.76, n= 40.2%

Photo No.	Remaining Area A sq.in.	Rec* abs. time T. sec	Water discharge q cfs/ft	Mean water depth ft	Time interval ΔT sec.	ΔA sq. in.	Sediment discharge cfs/ft $q_s = \frac{\Delta A(1-n/100)}{144\Delta T}$	Calculated sediment duscgarge cfs/ft Kalinske	Calculated sediment duscgarge cfs/ft Einstein
4	98.28	82.3	0.438	0.034				.0000013	.000000350
					6.5	9.29	.0059		
5	88.99	88.8	0.536	0.042				.00087	.00086
					14.2	13.89	.0040		
6	75.10	103.0	0.988	0.077				.00075	.00072
					13.2	29.33	.0092		
7	45.77	116.2	1.674	0.131				.00074	.00071
					11.7	11.48	.0040		
8	34.29	127.9	2.325	0.183				.00062	.00057

TABLE No.18

Exp. No. 1-HO-6"

d= 8.4 mm., S_s= 2.76, n= 40.2%

Photo No.	Observed sediment discharge q_s cfs/ft	Calculated sediment discharge cfs/ft		q_s obs./q_s cal.	
		Kalinske	Einstein	Kalinske	Einstein
4-5	0.0059	0.00044	0.00043	13.57	13.76
5-6	0.0040	0.00081	0.00079	4.99	5.12
6-7	0.0092	0.00074	0.00071	12.30	12.84
7-8	0.0040	0.00068	0.00064	5.95	6.32
			average	9.20	9.51

* Rec. abs. = recorded absolute

TABLE No.12

Exp. No. 4-HO-6"

d= 4.0 mm., S_s= 2.76, n= 40.2%

Photo No.	Remaining Area A sq.in.	Rec. abs. time. T.sec.	Water discharge q cfs/ft	Mean water depth ft	Time interval ΔT sec.	ΔA sq. in.	Sediment discharge cfs/ft $q_s=\frac{\Delta A(1-n/100)}{144\Delta T}$	Calculated sediment discharge cfs/ft Kalinske	Einstein
3	91.50	57.0	0.160	0.049				.00117	.00153
					12.0	22.40	.0077		
4	69.10	69.0	0.374	0.113				.00075	.00090
					14.0	25.34	.0075		
5	43.76	83.0	0.559	0.163				.00075	.00090
					16.3	16.34	.0041		
6	27.42	99.3	0.806	0.220				.00091	.00114
					20.0	14.65	.0030		
7	12.77	119.3	0.920	0.302				.00037	.00039
					4.7	12.77	.0079		
8	00.00	124.0	0.950	0.417				.00006	.00004

TABLE No.19

Exp. No. 4-HO-6"

d= 4.0 mm., S_s= 2.76, n= 40.2%

Photo No.	Observed sediment discharge q_s cfs/ft	Calculated sediment discharge cfs/ft		q_s obs./q_s cal.	
		Kalinske	Einstein	Kalinske	Einstein
3-4	0.0077	0.00096	0.00122	8.01	6.34
4-5	0.0075	0.00075	0.00090	9.93	8.31
5-6	0.0041	0.00083	0.00102	4.96	4.05
6-7	0.0030	0.00064	0.00076	4.69	3.96
7-8	0.0079	0.00022	0.00022	35.61	35.84
			average	12.64	11.70

TABLE No.13

Exp. No. 6-HO-6"

d= 1.9 mm ., S_s= 2.74, n= 35.0%

Photo No.	Remaining Area A sq.in.	Rec. abs. time T.sec.	Water discharge cfs/ft	Mean water depth ft	Time interval ΔT	ΔA sq. in.	Sediment discharge cfs/ft $q_s=\frac{\Delta A(1-n/100)}{144\Delta T}$	Calculated sediment discharge cfs/ft: Kalinske	Calculated sediment discharge cfs/ft: Einstein
3	86.31	57.2	0.191	0.071				.00040	.00053
					16.1	35.01	.0098		
5	51.30	73.3	0.473	0.134				.00111	.00178
					11.9	17.01	.0064		
6	34.29	85.2	0.579	0.171				.00080	.00119
					9.5	14.96	.0071		
7	19.33	94.7	0.693	0.217				.00053	.00074
					30.3	6.16	.0008		
8	13.17	125.0	0.874	0.296				.00032	.00040

TABLE No.20

Exp. No. 6-HO-6"

d= 1.9 mm., S_s= 2.74, n= 35.0%

Photo No.	Observed sediment discharge q_s cfs/ft	Calculated sediment discharge cfs/ft		q_s obs./q_s cal.	
		Kalinske	Einstein	Kalinske	Einstein
3-5	0.0098	0.00076	0.00115	12.89	8.46
5-6	0.0064	0.00095	0.00149	6.73	4.32
6-7	0.0071	0.00066	0.00097	10.63	7.32
7-8	0.0008	0.00042	0.00057	2.07	1.55
			average	8.08	5.41

TABLE No.14

Exp. No. 7-HO-6"

d= 0.8 mm., S_s= 2.65, n= 41.1%

Photo No.	Remaining Area A sq.in.	Rec. abs. time T.sec.	Water deschargre cfs/ft	Mean water depth ft	Time interval ΔT	ΔA sq. in.	Sediment discharge cfs/ft $q_s=\frac{\Delta A(1-n/100)}{144\,\Delta T}$	Calculated sediment discgarge cfs/ft Kalinske	Calculated sediment discgarge cfs/ft Einstein
3	86.85	53.3	0.116	0.049				.00034	.00053
					34.2	48.85	.0058		
7	38.00	87.5	0.541	0.178				.00059	.00105
					10.3	11.70	.0046		
8	26.30	97.8	0.709	0.235				.00050	.00086
					26.2	19.60	.0026		
10	6.70	114.0	0.955	0.334				.00033	.00052

TABLE No.21

Exp. No. 7-HO-6"

d= 0.8 mm., S_s= 2.65, n= 41.1%

Photo No.	Observed sediment discharge q_s cfs/ft	Calculated sediment discharge cfs/ft		q_s obs./q_s cal.	
		Kalinske	Einstein	Kalinske	Einstein
3-7	0.0058	0.00046	0.00079	12.50	7.35
7-8	0.0046	0.00054	0.00095	8.53	4.89
8-10	0.0026	0.00041	0.00069	6.30	3.80
			average	9.11	5.34

TABLE No.15

Exp. No. 8-HO-6"

d= 0.43 mm., S_s= 3.26, n= 37.6%

Photo No.	Remaining Area A sq.in.	Rec. abs. time T.sec.	Water discharge cfs/ft	Mean water depth ft	Time interval ΔT	ΔA sq. in.	Sediment discharge cfs/ft $q_s=\frac{\Delta A(1-n/100)}{144\,\Delta T}$	Calculated sediment discharge cfs/ft	
								Kalinske	Einstein
3	84.12	77.3	0.057	0.038				.0000268	.0000279
					6.7	5.67	.0036		
4	78.45	84.0	0.079	0.051				.0000249	.0000257
					9.0	13.35	.0064		
5	65.10	93.0	0.212	0.165				.0000049	.0000036
					9.0	8.79	.0042		
6	56.31	102.0	0.329	0.168				.0000554	.0000668
					14.0	18.04	.0055		
7	38.27	116.0	0.437	0.189				.0000867	.0001145

TABLE No.22

Exp. No. 8-HO-6"

d= 0.43 mm., S = 3.26, n= 37.6%

Photo No.	Observed sediment discharge q_s cfs/ft	Calculated sediment discharge cfs/ft		q_s obs./q_s cal.	
		Kalinske	Einstein	Kalinske	Einstein
3-4	0.0036	0.0000258	0.0000268	141.61	136.68
4-5	0.0064	0.0000149	0.0000147	429.23	437.26
5-6	0.0042	0.0000301	0.0000352	140.16	119.97
6-7	0.0055	0.0000711	0.0000906	78.52	61.57
			average	197.38	188.87

TABLE No. 16

Exp. No. 9-HO-6"

$d = 0.23$ mm., $S_s = 2.65$, $n = 32.1\%$

Photo No.	Remaining Area A sq.in.	Rec. abs. time T.sec.	Water discharge cfs/ft	Mean water depth ft	Time interval ΔT	ΔA sq. in.	Sediment discharge cfs/ft $q_s = \frac{\Delta A(1-n/100)}{144\ \Delta T}$	Calculated sediment discharge cfs/ft	
								Kalinske	Einstein
3	81.44	72.4	0.074	0.039				.000167	.000249
					8.5	22.50	.0124		
4	85.94	80.9	0.088	0.062				.000029	.000031
					8.1	5.58	.0032		
5	53.36	89.0	0.095	0.071				.000019	.000018
					9.1	13.36	.0069		
6	40.00	98.1	0.210	0.094				.000218	.000344
					22.9	21.74	.0044		
8	18.26	121.0	0.594	0.181				.001071	.002321

TABLE No.23

Exp. No. 9-HO-6"

$d = 0.23$ mm., $S_s = 2.65$, $n = 32.1\%$

Photo No.	Observed sediment discharge q_s cfs/ft	Calculated sediment discharge cfs/ft		q_s obs./q_s cal.	
		Kalinske	Einstein	Kalinske	Einstein
3-4	0.0124	0.000098	0.000140	126.72	88.75
4-5	0.0032	0.000024	0.000025	132.58	129.59
5-6	0.0069	0.000118	0.000181	58.25	38.16
6-8	0.0044	0.000645	0.001332	6.93	3.35
			average	81.12	64.96

TABLE No.17

Exp. No. 10-HO-6"

d= 0.14 mm., S_s= 4.5 , n= 32.1%

Photo No.	Remaining Area A sq.sec	Rec. abs. time T.sec.	Water dicharge cfs/ft	Mean Water depth ft	Time interval ΔT	ΔA sq. in.	Sediment discharge cfs/ft $q_s = \frac{\Delta A(1-n/100)}{144\,\Delta T}$	Calculated sediment discharge cfs/ft: Kalinske	Calculated sediment discharge cfs/ft: Einstein
4	75.68	30.4	0.034	0.028				.0000206	.0000189
					14.6	10.89	.0035		
6	64.79	45.0	0.062	0.038				.0000052	.0000036
					18.6	16.30	.0041		
8	48.49	63.6	0.150	0.075				.0000349	.0000356
					36.4	20.27	.0026		
11	28.22	100.0	0.392	0.143				.0001182	.0001537
					25.5	7.90	.0014		
15	20.32	125.5	0.572	0.166				.0003364	.0005391

TABLE No.24

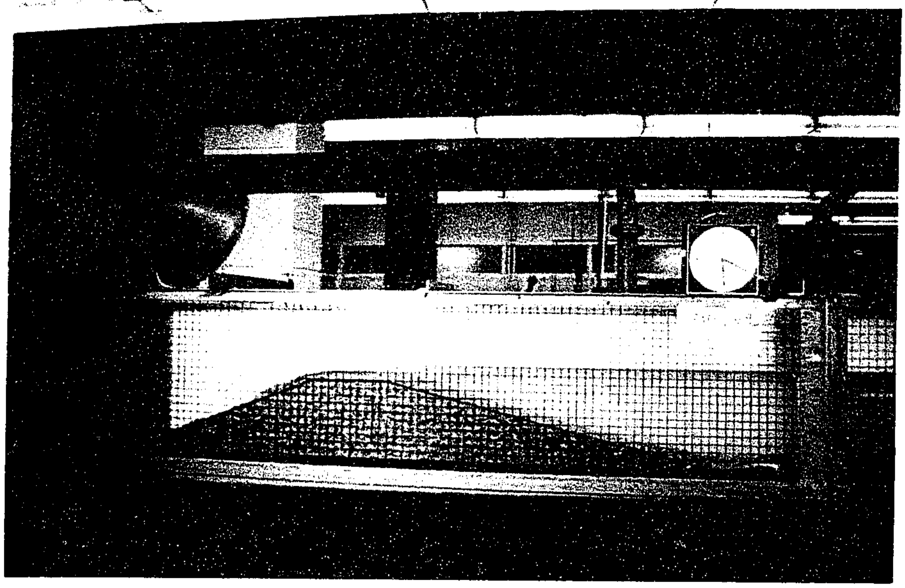
Exp. No. 10-HO-6"

d= 0.14 mm., S_s= 4.5 , n= 32.1%

Photo No.	Observed sediment discharge q_s cfs/ft	Calculated sediment discharge cfs/ft		q_s obs./q_s cal.	
		Kalinske	Einstein	Kalinske	Einstein
4-6	0.0035	0.0000129	0.0000113	271.69	311.24
6-8	0.0041	0.0000200	0.0000196	205.83	210.66
8-11	0.0026	0.0000766	0.0000946	34.27	27.73
11-15	0.0014	0.0002273	0.0003464	6.42	4.21
			average	129.55	138.46

EROSION OF DAM AT CONSTANT DISCHARGE WITH DOWNSTREAM SUPERCRITICAL FLOW FOR EXPERIMENT No. 2-Q1250-9"

(1)



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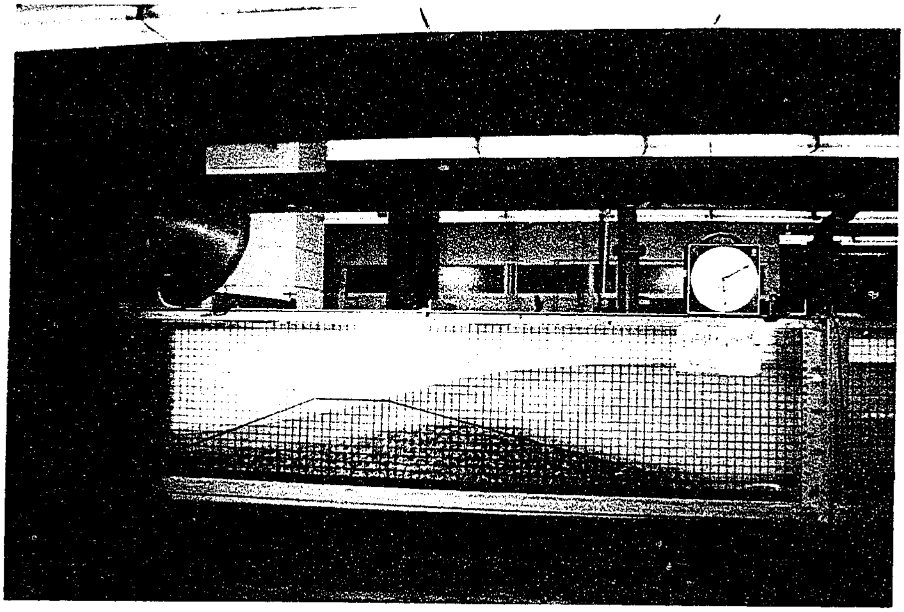

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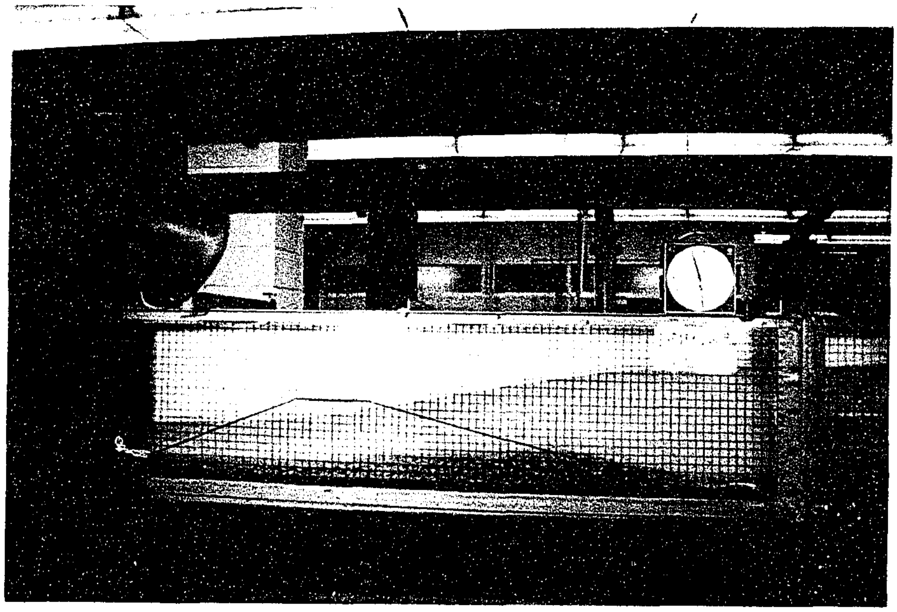

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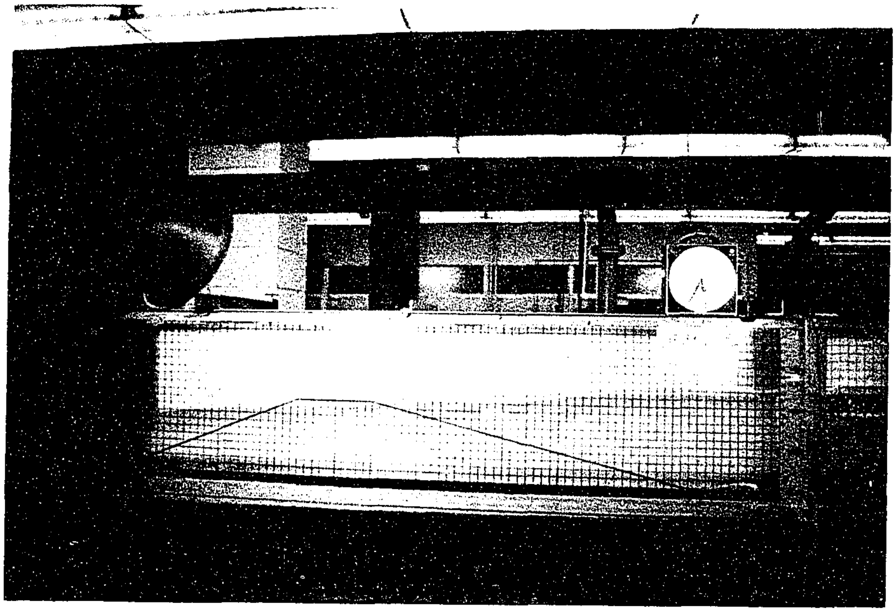

BIBLIOGRAPHY

1- Kennedy, J.B, and A.M. Neville, Basic Statistical Methods for Engineers and Scientics, 1966.

2- Hoel, P.G, Introduction to Mathematical Statistics, 1954.

3- Langhaar, H.L, Dimensional Analysis and Theory of Models.

4- Rouse, H, Fluid Mechanics for Hydraulic Engineers.

5- Roy Tinney, E, and H.Y. HSU, Mechanics of Washout of an Erodible Fuse Plug, Journal of the Hydraulics Division, Proceeding: of the American Society of Civil Engineers, vol 87, No HY3, May 1961.

6- Einstein, H.A, Formulas for the Transportation of Bed Load. Trans. American Society of Civil Engineers, vol. 107, 1942.

7- Henderson, F.M, Open Channel Flow, 1966.

8- Rouse, H, Engineering Hydraulics, 1949.

9- Lane, E.W, and Carlson, E.J, Some Factors Affecting the Stability of Canals Constructed in Coarse Granular Materials, International Association of Hydraulic Research, August, 1953.

10- Straub, L.G, Dredge Fill Closure of Missouri River at Fort Randall, International Association of Hydraulic Research, August 1953.

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