INFLUENCE OF WATER TEMPERATURE AND SIDE SLOPE ON SAND BED CHANNELS

Zidan, Abdel Razik Ahmed

Dept. of Agricultural Engrg, College of Agriculture and Veterinary Medicine, Al-Qassim, Saudi Arabia

تاثير درجة حرارة المياه والميل الجانبى على القنوات الرملية

خلاصة

استخدم نموذج رياضي لمعرفة مدى تاثير كل من درجة حرارة المياه وكذلك الميل الجانبى للقطاع المائي على خصائص القطاع فى الأراضي الرملية ، أثبتت الدراسة أن عمق المياه وعرض القطاع لا يتاثران بإرتفاع درجة الحرارة وذلك لجميع القنوات التى حجم حبيباتها المتوسط يساوى أو يقل عن ٥ر مم ، أما فى التصرفات الكبيرة ومع الرمال الخشنة قد يقل عرض القاع ويزداد عمق المياه خاصة إذا ما تغيرت درجة الحرارة فوق الصفر المئوى إلى حوالى عشرين درجة مئوية

كما اثبت البحث ان إنحدار القناة يقل بصورة منتظمة بإرتفاع درجة الحرارة وذلك لجميع القنوات تحت الدراسة . هذا وقد أجرى تحليل إحصائي لإمكانية إيجاد العلاقة بين الإنحدار (الميل الطولى للقاع) ودرجة الحرارة

إزدياد الميل الجانبي للقطاع المائي قد يقلل كل من عرض القطاع وعمق المياه ويزيد من إنحدار القناة

ABSTRACT

A mathematical model was used to study the effect of both water temperature and side slope on sand bed channel geometry and longitudinal slope. The study has revealed no responses occurred for both mean width and water depth due to the change in water temperature over $0^{\circ}C$ for canal having median particle size $\leqslant 0.5$ mm.

For canals having $d_{50} \geqslant 0.6$ mm, mean width decreased and water depth increased especially from $0^{\circ}C$ to about $20^{\circ}C$.

Bed slopes decreased regularly with the increasing value of water temperature. Statistical analysis was used to fit this variation.

Both mean width and water depth decreased and bed slope increased with the increase of the channel side slope.

INTRODUCTION

The design of stable canal in alluvial material is the optimum aim of the irrigation engineer. Many different methods are given in literature, among these methods are the tractive force method, the regime theory and the live bed approach.

In contrast to the regime theory, Chang (1980) has proposed the minimum stream power concept. His method underpredict appreciably the mean width for large canals, but it provides representative answer to smaller streams(14). The designed bed channel is flatter than the actual bed, slope and the design bed level is generally below (3).

White et al (1982) stated that the mean width, water depth and bed slope have adopted themselves so that the transport sediment is maximized. This hypothesis is equivalent to the minimum stream power concept, it underpredict the width of large canal but agreement is much better for small canal (14).

However an important objective in the channel design is to reach a hydraulic geometry that will minimize potential channel bed changes.

The live bed approach for the design of stable cross section was used in this research work. Calculations were based on Einstein-Brown's formula and liu-Hwang's equation.

Although lacey considered canals to be elliptical in cross sectional shape, other hydraulicians assumed to be parabolic in shape (4). Kennedy (1894), Inglis (1930) and Blench (1957) confirmed that the regime section has a horizontal bed and steep side slope (14). However the trapezoidal section is an appropriate representation. and the value of side slope depends on he type of bank soil.

In this research work, trapezoidal section was considered with side slope (horizontal: vertical) 2:1, other side slopes were also considered for canal having d_{50} = 0.05 mm to show the influence of side slope on the section properties of channel in regime.

Ten values of actual discharge ranged from 0.15 m^3/sec. to 9.33 m^3/.sec. and their corresponding mean width, water depth were incorporated into the model these section properties having median particle size varied between 0.05 mm and 0.1 mm (very fine sand).

Different degrees of sand bed roughness were also tried, i.e. fine sand, medium sand and coarse sand (9). The actual mean widths and water depths were used as initial values for computations to get the designed mean width, water depth and bed slope for every corresponding median particle size. For the study of water temperature effect, the sediment concentration was considered to be 50 p.p.m.

THEORETICAL CONSIDERATION

Two equations were used in the design of stable cross section as mentioned before, Einstein- Brown's formula (6) and Liu- Hwang equation (10,11).

1-Einstein- Brown's formula is given by:

$$\phi = \frac{q_s}{F\sqrt{g\left(\frac{\gamma_s}{\gamma} - 1\right) d_s^3}} \qquad \text{.................... (1)}$$

in which;

ϕ = dimensionless measure of bed load;
q_s = sediment discharge in volume per unit time and width;
d_s = bed material size;
γ = specific weight of water;
γ_s = specific weight of bed material; and
F = settling velocity representation term which is given by:

$$F = \sqrt{\frac{2}{3} + \frac{36\,\nu^2}{g d_s^3 \left(\frac{\gamma_s}{\gamma} - 1\right)}} - \sqrt{\frac{36\,\nu^2}{g d_s^3 \left(\frac{\gamma_s}{\gamma} - 1\right)}} \qquad \text{.... (2)}$$

where, (ν) is kinematic viscosity of water and it is based on water temperature. Values of dynamic viscosity and specific weight of water decrease with the increasing value of water temperature.

ϕ is related to the entrainment function ψ, which is given by:

$$\psi = \left(\frac{\gamma_s - \gamma}{\tau_o}\right) d_s \qquad \text{.............................. (3)}$$

where , τ_o = average shear stress on the channel wetted perimeter.

$$\Phi = K_1 \Psi^{-K_2} \quad \ldots\ldots\ldots\ldots \quad (4)$$

K_1 and K_2 are constants to be determined from field data

2- Liu and Hwang's formula is given by:

$$V = C_a R^x S^y \quad \ldots\ldots\ldots\ldots \quad (5)$$

in which;

V = mean velocity of water in m/sec.;
R = hydraulic radius m;
S = non-dimensional slope; and
C_a, x, y are coefficients depend on the median particle size of bed material and bed formation and are obtained from charts.

The bed material d_s was considered to be the median particle size (d_{50}), the model was based on lower regime (ripples and dunes) , although ripples and dunes show some differences, but their geometric appearances show remarkable similarities (8). However there is still considerable interest in investigating the relationship between suspendid sediment and bed forms (1) .

The two equations have provided simulated mean width, water depth and bed slope, for large extensive field data, to an acceptable degree of accuracy (12).

RESULTS AND ANALYSES:

Generally no responses occurred in both mean width and water depth due to the change of water temperature over 0°C for canals having d_{50} = 0.05, 0.1, 0.2, 0.3, 0.4 and 0.5 mm Canals having median particle size d_{50} = 0.6 mm and 0.7 mm showed no change in both mean width and water depth over 10°C for any value of water discharge .

Mean Width:

The minimum width of straight alluvial channel with or without sediment load is a function of the tractive force and sliding strength of the bank soil, i.e. it depends on specific weight of water and viscosity.

For Q = 9.33 m^3/sec. and d_{50} = 0.6 mm, the mean width decreased from 10.26 m at 0°C to 10.01 m at 10°C (2.4 %). Canal having d_{50} = 0.7 mm with the same discharge, the mean width decreased from 12.26 m at 0°C to 12.01 m at 10°C (2.1%).

Canals having d_{50} = 0.8 mm and Q = 8.5 m^3/sec, the mean width decreased from 11.26 m at 0°C to 11.03 m at 10°C (2.2 %) and at 50°C the mean width became 10.78 m (4.4%). For Q = 7.0 m^3/sec, the mean width decreased from 8.75 m at 0°C to 8.5 m at 10°C (2.9 %) to 8.25 m at 50°C (5.7 %), and for Q = 6.19 m^3/sec. the mean width decreased from 7.14 m at 0°C to 6.88 m at 10°C (3.5 %).

Water Depth:

For Q = 9.33 m^3/sec. and d_{50} = 0.6 mm, the water depth increased from 1.49 m at 0°C to 1.57 m at 10°C (5.4 %) for d_{50} = 0.7 mm with the same discharge, the water depth increased from 0.94 m at 0°C to 0.95 m at 10°C (1.1%).

Canals having d_{50} = 0.8 mm, as the water temperature canals from 0°C to 20°C the water depth increased from 0.69 m to 0.71 m (2 %) for Q = 8.5 m^3/sec., from 0.71 m to 0.74 m (4.2 %) for Q = 7.0 m^3/sec. and from 0.74 m to 0.76 m (2.7%) for Q = 6.19 m^3/sec.

No changes occurred in both mean width and water depth for canals having discharges less than 6.19 m^3/sec. and median particle size > 0.6 mm.

It may be concluded that a decrease in mean width and increase in water depth occurred due to the increase of water temperature. However these changes in section properties did not exceed 6% for discharges and median particle sizes under study.

Bed Slope:

Bed slope decreased regularly with the increasse of water temperature for any value of discharge and median poarticle size. Specific function could be tried to fit this variation, logarithmic, polynomial from the first degree to the fifth degree, exponential and power functions were tried, using the statistical computer program "SAS". Polynomials from the fourth degree and fifth degree were excluded from this analysis for providing parameters having no significance.

For fine sand (d_{50} = 0.1 mm) cubic polynomial is not suitable to fit the data, its parameters have no significance seven discharge values out of ten, variation of bed slope with temperature, could not be fitted by this function. at Q = 9.33 m^3/sec. prob > T = 0.1595 for X^2 and prob > T = 0.9052 for X^3 (X represent water temperature) Table (1). At Q = 0.15 m^3/sec (minimum value) prob >T = 0.0958 for X^2 and prob > T = 0.2156 for X^3. Table (2).

If Durbin-Watson statistic (d) is close to 2 the errors are uncorrelated i.e each error is not correlated with the error immediately before it, (d) is used to test that the auto-correlation is zero and good fit of the data (13). Quadratic polynomial has the biggest multiple correlation coefficient (R^2) for Q = 9.33 m^3/sec. and for Q = 0.15 m^3/sec. and Durbin- Watson (d) is close to (2). The alternative function could be the logarithmic function it has R^2 = 0.9257 for Q = 0.15 m^3/sec, d = 1.628 and R^2 = 0.8401, d = 1.367 for Q = 9.33 m^3/sec. Other functions exhibited smaller values of Durbin - Watson coefficients.

For medium sand (d_{50} = 0.3 mm), statistical analyses showed that more than one value of water discharge, decrease of bed slope with temperature, could not be fitted by any of the statistical function under study. Four values of water discharge, variation of bed slope with temperature, could not be fitted by cubic polynomial for providing parameters having no significance. Quadratic polynomial, logarithmic and power functions could be used, but logarithmic function has higher values of R^2 and Durbin Watson (d) is close to (2) Tables (3,4).

For coarse sand (d_{50} = 0.5 mm), statistical program SAS showed, the change of bed slope with temperature, for two values of discharge had poor correlation, using any of the functions under study. Cubic polynomial, quadratic polynomial, logarithmic and power functions could be used to fit the data,cubic polynomial had the biggest value of R^2 but logrithmic had the biggest value of (d) close to 2 for Q = 9.33 m^3/sec. For Q = 0.15 m^3/sac. cubic polynomial exhibited the biggest values of both R^2 and (d). Tables (5,6). It seems suitable to fit the variation of bed slope and temperature either by cubic polynomial or logarithmic function.

The logarithmic function is given by:

$$Y = a - b\,LN(X) \qquad (6)$$

in which; y = bed slope(S) and X = water temperatur (T) it was found that there was no significant difference between coefficient (a) and the bed slope at zero temperature degree centigrade, the error between (a) and S_o decreased with the increase of median particle size, it reached a maximum value of 7.7 % at d_{50} = 0.05 mm and 3 % at d_{50} = 0.5 mm. So equation (6) could be written as:

$$S = S_o - b\ LN\ (T) \qquad (7)$$

where, b = coefficient depends on median particle size and water discharge and section properties. Values of (b) are given in Table (7).

Quadratic polynomial is given by:

$$Y = a + b_1\ X + b_2\ X^2 \qquad (8)$$

$$\text{or } S = a + b_1\ T + b_2\ T^2 \qquad (9)$$

No significant difference was found between bed slope at zero degree and coefficient (a), equation (9) could be written as:

$$S = S_o - b_1 T + b_2 T^2 \qquad (10)$$

Coefficients b_1, b_2 depend on water discharge, median particle size and section properties.

In the same manner cubic polynomial could be written as:

$$S = S_o - b_1 T + b_2\ T^2 - b_3\ T^3 \qquad (11)$$

Values of some polynomial coefficients are given in Table (8)

Figs (1) through (6) provided logarithmic variation between bed slope and water temperature for different values of median particle size under various values of discharges. The corresponding quadratic polynomial functions are given in Figs (7) through (12). Cubic polynomial variations are demonstrated in Figs (13) through (16). The figures on the graphs are the discharge numbers, Table (9). These figures show that quadratic polynomial is the best fit for d_{50} = 0.05, 0.1 and 0.2 mm and the cubic polynomial is convenient for d_{50} = 0.5 mm.

Side Slope

For the same values of water discharge, median particle size (d_{50} = 0.05 mm) and water temperature (T = 20°C), side slope z = 2.0 could exhibit smaller Values of both mean width and water depth and bigger values of bed slope than the corresponding values at side slope z = 1.5 Table (9).

Figs (17) through (20) give the variation of relative bedslope S/S_o with temperature for different values of discharges, side slope z = 2.0 could provide higher values of S/S_o than z = 1.5 for bigger values of discharge Figs. (17,18) Smaller values of discharge may exhibit the reverse answer Figs.(19) . However for some discharges, side slope has no effect on the variation of S/S_o with temperature Fig. (20). The rate of decrease of S/S_o decreased with the smaller values of median particle size Fig. (21).

Fig. (22) shows the influence of side slope on the relative bed slope S/S_{100} , in which S_{100} is the bed slope at sediment concentration C_s = 100 p.p.m.,the difference between the two curves decresed with the decrease of discharge.

Type of Flow:

The flow was in subcritical condition, canals having median particle size d_{50} = 0.05, 0.1, and 0.2 mm showed negligible change in the value of Froude's number (F_r) with temperature. Other values of median particle size showed decrease in the value of F_r with temperature Table (10). The decrease of F_r due to the increase of temperature may make lower regime (ripples and dunes) to exist at bigger values of median particle size. Simon and Senturk (1977), stated that ripples do not form in sand bed sediments greater than about 0.6 mm in diameter (7). However lower regime could exist at d_{50} = 0.8 mm with maximum value of F_r = 0.37. A review of the extensive literature on alluvial channels, suggests that little is known about the transition from the lower flow regime to the upper (flat and antidunes) flow regime (2).

Reynold's frictional number R_f increased with the increase of water temperature Table (10) , when R_f < 5 the bed is described as hydraulically smooth when R_f > 70 the bed is described as hydraulically rough and the mobility of sediment particles becomes independent of R_f (5,15). The increase of R_f may change the condition of flow from smooth turbulent to transitional turbulent R_f > 5 < 70 for very fine, fine and medium sand and from transitional turbulent to rough turbulent condition for coarse sand.

CONCLUSIONS:

Water temperature may have no effect on mean width and water depth of canal established in, very fine, fine and medium sand.

Increase of water temperature could decrease the mean width and increase the water depth, especially from 0°C to about 20°C for canals having median particle size d_{50} = 0.6, 0.7 and 0.8 mm (coarse sand). These changes of section properties could be of a negligible influence.

Bed slope decreased regularly with the increasing value of water temperature. Quadratic polynomial was found to fit this variation for very fine and fine sand, while in coarse sand cubic polynomial was the most convenient. However it was found that logarithmic function could be suitable to fit the variation of bed slope with temperature for the different degrees of median particle size.

Side slope has an effect on a channel in regime, the bigger value of side slope (horizonatal : vertical) may give smaller values of both mean width and water depth and higher values of bed slope.

Increase of water temperature decreased the value of Froude's number and increased Reynold's frictional number . The decrease in Froude's number could give a chance to lower regime (ripples and durnes) to exist for canals having bigger median particle size. The increase of Reynold's frictional number could change the condition of flow from smooth turbulent to rough turbulent condition.

It is hoped that the analyses presented in this work are of some interest to researchers in the same field for developing a more comprehensive study.

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NOTATION

The following symbols are used in this paper:

a = coefficient;
b = mean width;

b_1, b_2, b_3 = coefficients;
C_a = coefficient;
C_s = sediment concentration p.p.m;
C = degree centigrade;
D = water mean depth;
d = Durbin - Watson statistic;
d_s = bed material size;
d_{50} = median particle size;
F = settling velocity representation term;
F = statistical parameter F - test;
F_r = Froude's number;
g = acceleration of gravity;
K_1, K_2 = constants;
Q = water discharge;
q_s = sediment discharge in volume /unit width;

R = hydraulic radius;
R_f = Reynold's number of friction;
R^2 = multiple correlation coefficient of determination,

R^2_{adj} = adjustable multiple correlation coefficient of determination;
S = non-dimensional slope;
S_o = bed slope at zero temperature degree;
T = statistical parameter t-test;
T = temperature;
V = mean velocity of water;
X = parameter = temperature T;
x = coefficient;
Y = function = S;
y = coefficient; and
z = side slope (horizontal : vertical);

Greek letters:

γ = specific weight of water;
γ_s = specific weight of bed materials;
ν = kinematic viscosity of Water;
τ_o = average bed shear stress;
Φ = dimensionless measure of the bed load; and
Ψ = entrainment function.

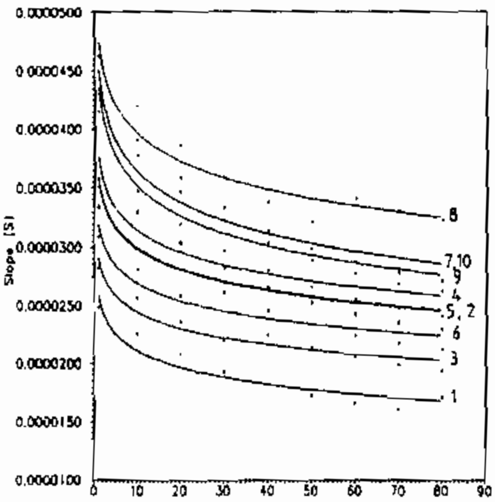

Fig (1) Variation of Bed Slope with Temperature for Different Values of Discharges, d_{50}=0.05 mm

Logarithmic

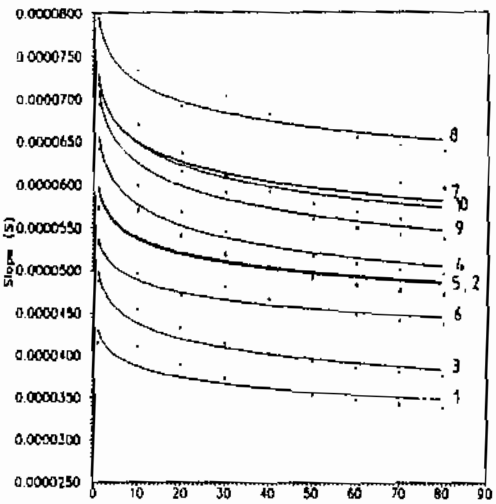

Fig (2) Variation of Bed Slope with Temperature for Different Values of Discharges, d_{50}=0.1 mm

Logarithmic

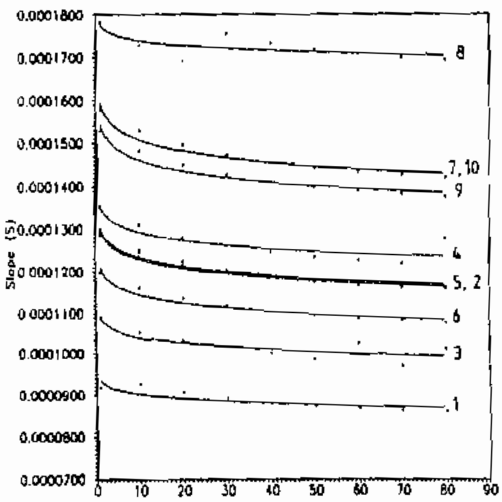

Fig (3) Variation of Bed Slope with Temperature for Different Values of Discharges, d_{50}=0.2 mm

Logarithmic

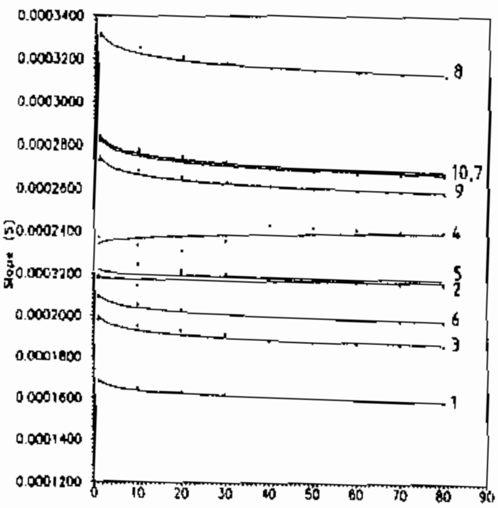

Fig (4) Variation of Bed Slope with Temperature for Different Values of Discharges, d_{50}=0.3 mm

Logarithmic

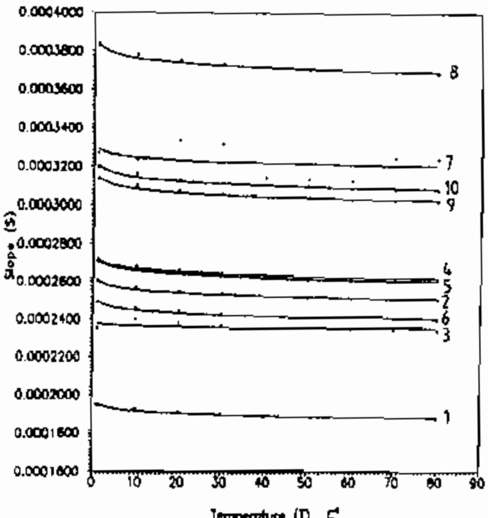

Fig (5) Variation of Bed Slope with Temperature for Different Values of Discharges, d_{50}=0.4 mm

Logarithmic

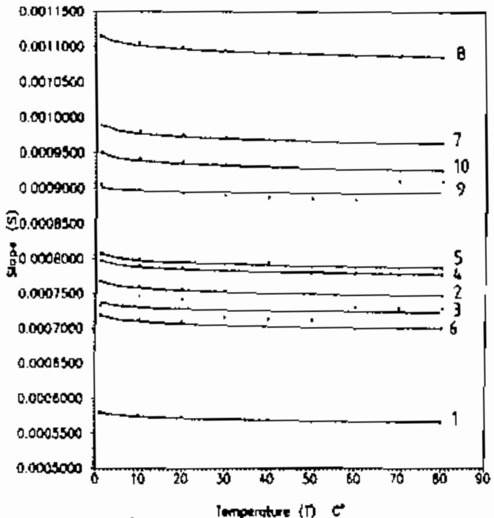

Fig (6) Variation of Bed Slope with Temperature for Different Values of Discharges, d_{50}=0.5 mm

Logarithmic

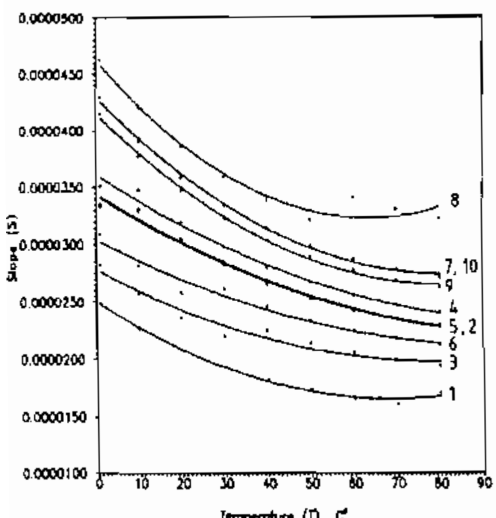

Fig (7) Variation of Bed Slope with Temperature for Different Values of Discharges, d_{50}=0.05 mm

Quadratic polynomial

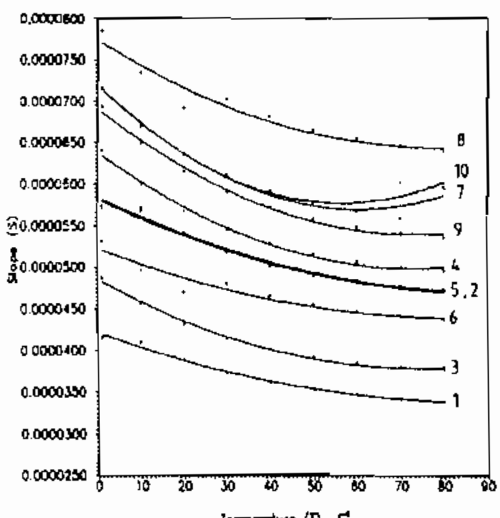

Fig (8) Variation of Bed Slope with Temperature for Different Values of Discharges, d_{50}=0.1 mm

Quadratic polynomial

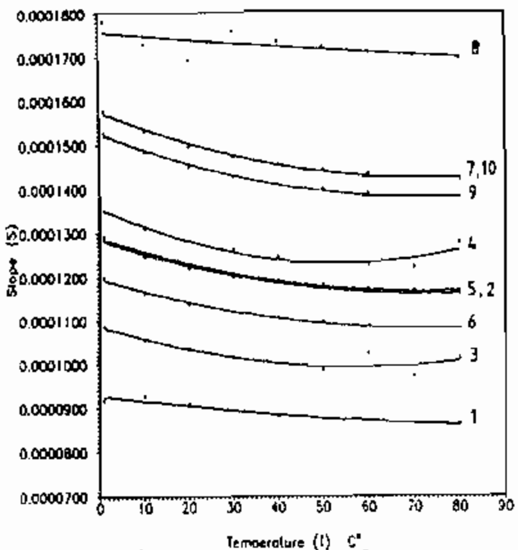

Fig (9) Variation of Bed Slope with Temperature for Different Values of Discharges, d_{50}=0.2 mm

Quadratic polynomial

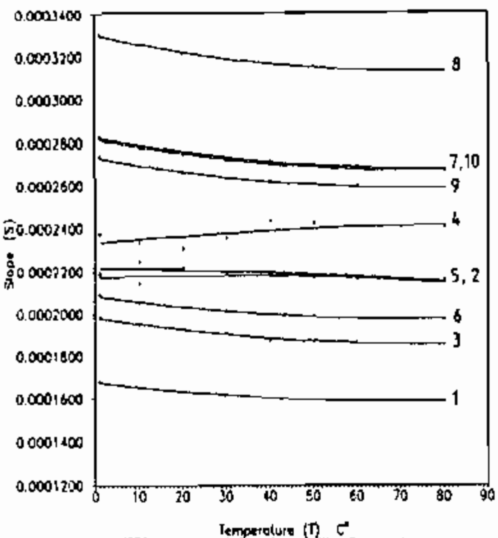

Fig (10) Variation of Bed Slope with Temperature for Different Values of Discharges, d_{50}=0.3 mm

Quadratic polynomial

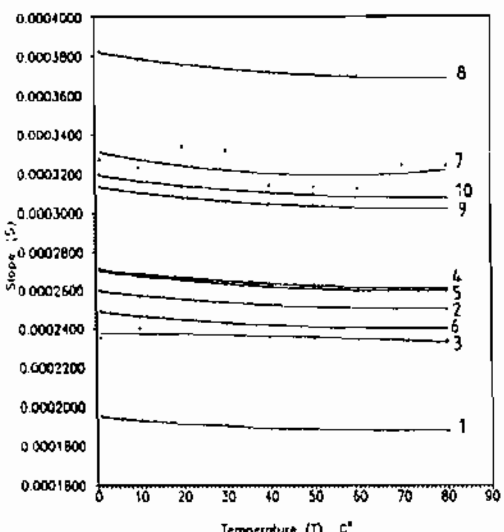

Fig (11) Variation of Bed Slope with Temperature for Different Values of Discharges, d_{50}=0.4 mm

Quadratic polynomial

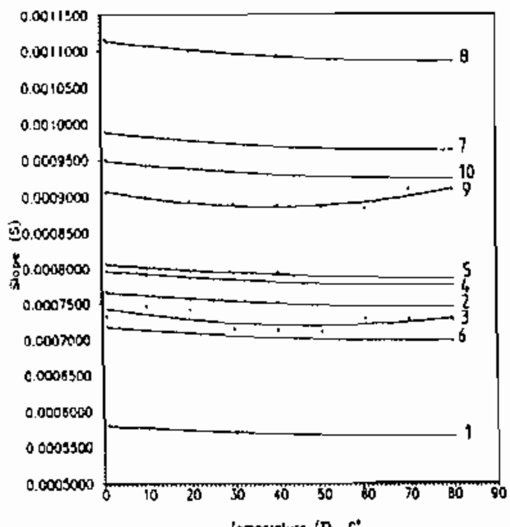

Fig (12) Variation of Bed Slope with Temperature for Different Values of Discharges, d_{50}=0.5 mm

Quadratic polynomia

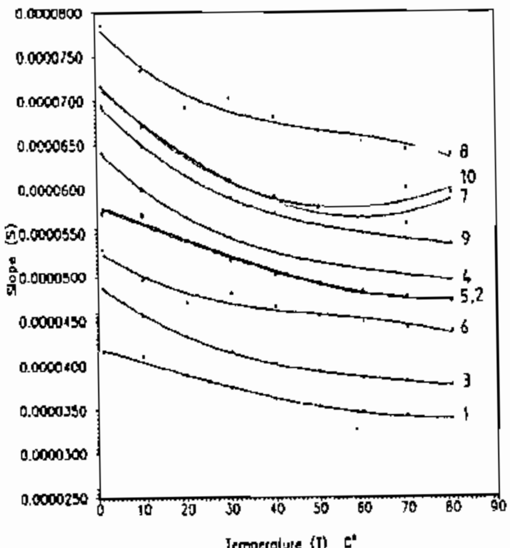

Fig (13) Variation of Bed Slope with Temperature for Different Values of Discharges, d_{50}=0.1 mm

Cubic polynomial

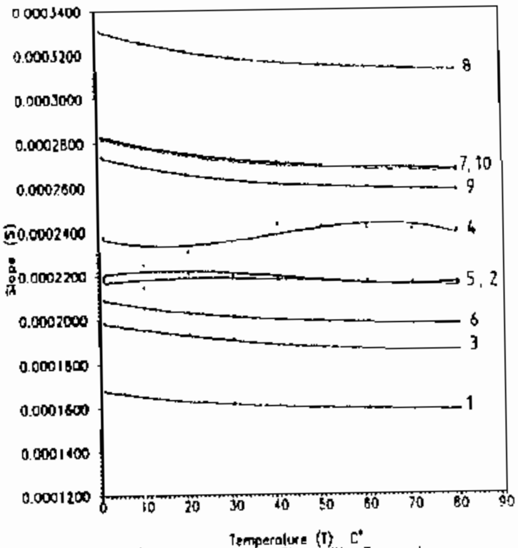

Fig (14) Variation of Bed Slope with Temperature for Different Values of Discharges, d_{50}=0.3 mm

Cubic polynomial

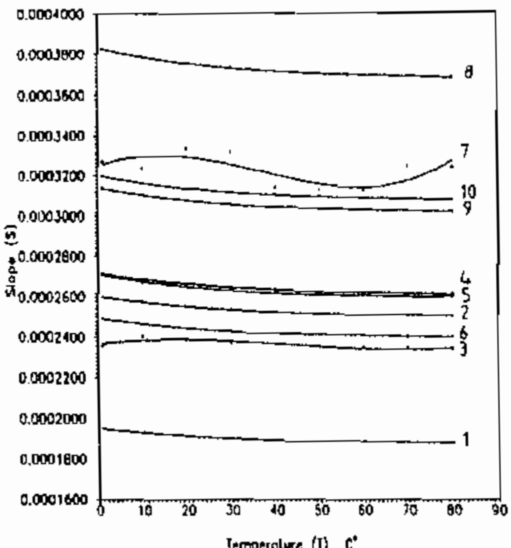

Fig (15) Variation of Bed Slope with Temperature for Different Values of Discharges, d_{50}=0.4 mm

Cubic polynomial

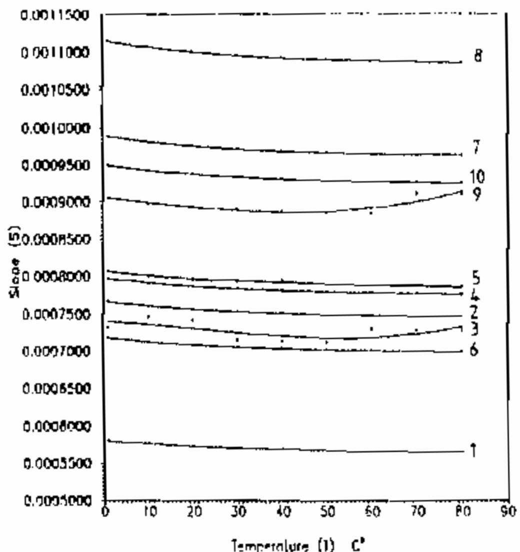

Fig (16) Variation of Bed Slope with Temperature for Different Values of Discharges, d_{50}=0.5 mm

Cubic polynomial

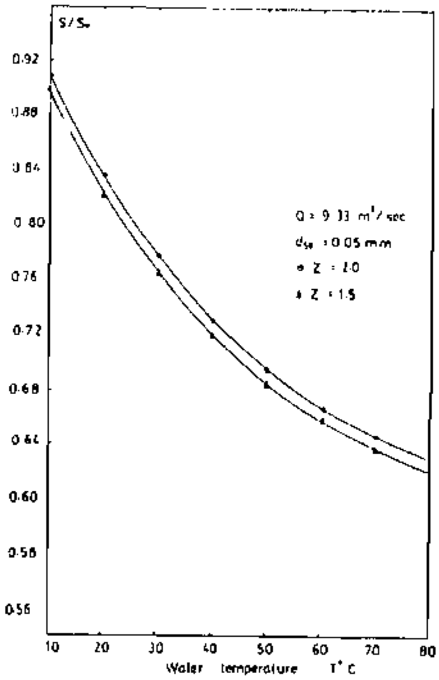

Fig (17) Variation of S/S₀ with temperature for different values of side slope (Z)

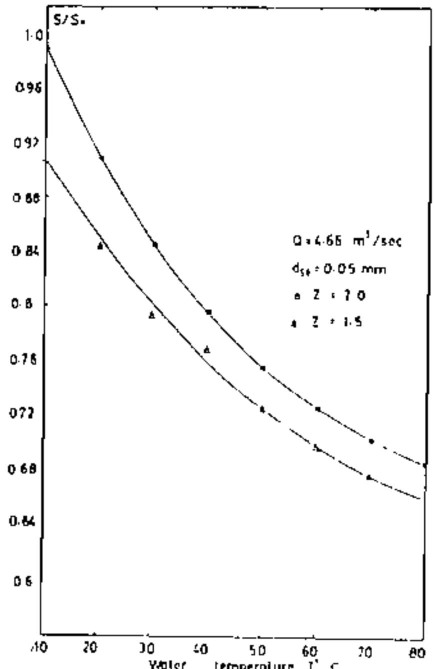

Fig (18) Variation of S/S₀ with temperature for different values of side slope (Z)

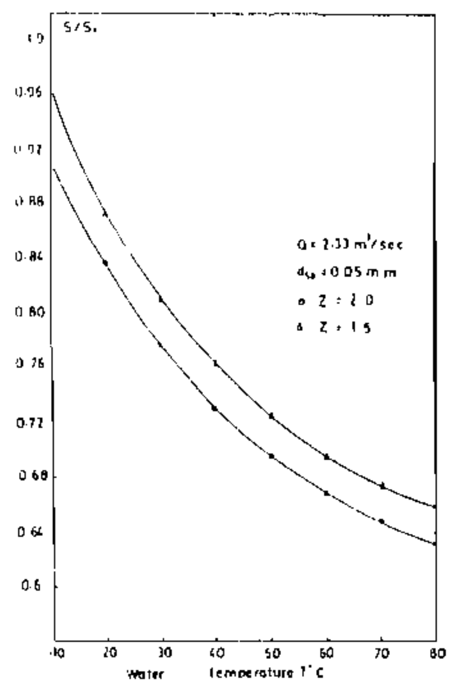

Fig (19) Variation of S/S₀ with temperature for different values of side slope (Z)

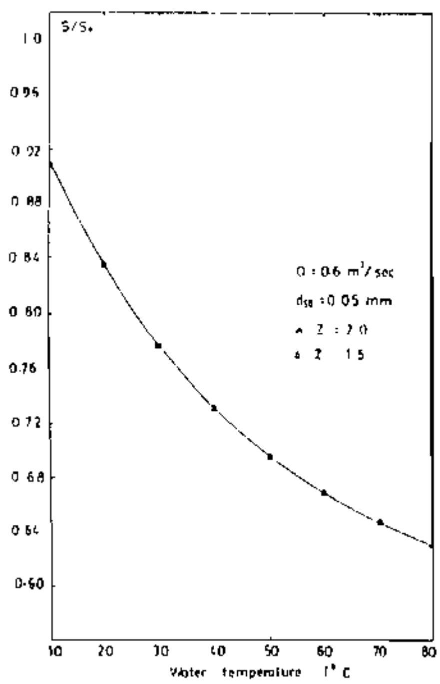

Fig (20) Variation of S/S₀ with temperature for different values of side slope (Z)

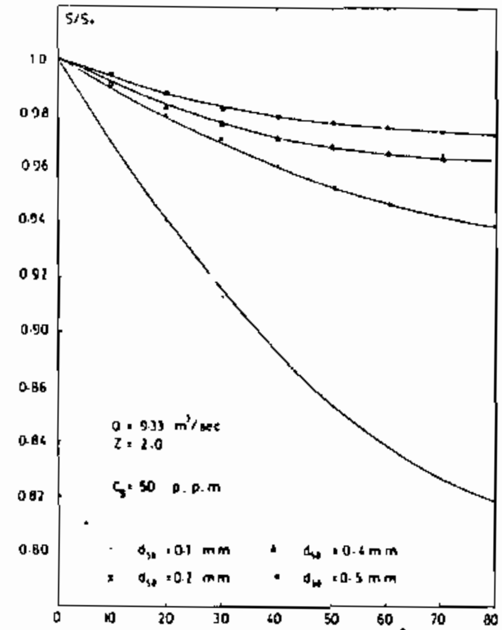

Fig (21) Variation of S/S_o with water temperature for different values of median particle size d_{50}

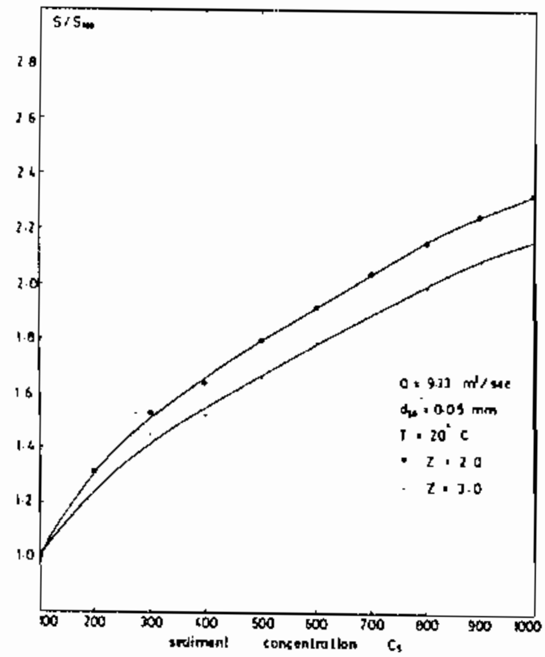

Fig (22) Variation of S/S_{100} with sediment concentration (Cs) for different values of side slope (Z)

Table (1) Statistical analysis, "SAS" program
$Q_{max} = 9.33\ m^3/sec.$ $d_{50} = 0.1$ mm

Function	Analysis of variance				Parameter estimate			Durbin-Watson (d)	1st order auto-correlation
	F	prob>F	R^2	R^2 adj		T	prob>T		
Logarithmic Y	47.296	0.0001	0.8401	0.8224	Intercep LN (X)	40.541 - 6.877	0.0001 0.0001	1.367	0.181
Exponential LN(Y)	100.745	0.0001	0.918	0.9089	Intercep X	-756.456 - 10.037	0.0001 0.0001	0.437	0.626
Polynomial 1st degree Y	87.563	0.0001	0.9068	0.8964	Intercep X	77.554 - 9.357	0.0001 0.0001	0.433	0.626
Polynomial 2nd degree Y	463.127	0.0001	0.9914	0.9893	Intercep X X^2	179.186 - 16.390 9.026	0.0001 0.0001 0.0001	2.207	-0.22
Polynomial 3rd degree	270.752	0.0001	0.9915	0.9878	Intercep X X^2 X^3	139.021 - 6.614 1.574 - 0.124	0.0001 0.003 0.1595 0.9052	2.234	-0.24
power LN(Y)	43.769	0.0001	0.8294	0.8105	Intercep LN(X)	-339.367 - 6.616	0.0001 0.0001	0.437	0.626

Table (2) Statistical analysis, "SAS" program
$Q_{min} = 0.15\ m^3/sec.$ $d_{50} = 0.1$ mm

Function	Analysis of variance				Parameter estimate			Durbin-Watson (d)	1st order auto-correlation
	F	prob>F	R^2	R^2 adj		T	prob>T		
Logarithmic Y	125.676	0.0001	0.9332	0.9257	Intercep LN (X)	74.157 - 11.211	0.0001 0.0001	1.379	0.221
Exponential LN (Y)	67.140	0.0001	0.8818	0.8687	Intercep X	-746.430 - 8.194	0.0001 0.0001	1.207	0.100
Polynomial 1st degree Y	56.410	0.0001	0.8624	0.8471	Intercep X	74.438 - 7.511	0.0001 0.0001	1.157	0.117
Polynomial 2nd degree	62.801	0.0001	0.9401	0.9252	Intercep X X^2	79.612 - 5.945 3.222	0.0001 0.0003 0.0122	1.871	-0.071
Polynomial 3rd degree	46.952	0.0001	.9527	0.9324	Intercep X X^2 X^3	70.118 - 3.883 1.924 - 1.361	0.0001 0.0060 0.0958 0.2156	1.973	-0.052
power LN(Y)	101.938	0.0001	0.9189	0.9099	Intercep LN(X)	-582.974 - 10.096	0.0001 0.0001	1.242	0.278

Table (3) Statistical analysis, "SAS" program
Q_{max} = 9.33 m³/sec. d_{50} = 0.3 mm

Function	Analysis of variance				Parameter estimate			Durbin Watson (d)	1st order auto-correlation
	F	prob>F	R^2	R^2 adj	T		prob>T		
Logarithmic Y	164.964	0.0001	0.9483	0.9425	Intercep LN (X)	259.615 - 12.844	0.0001 0.0001	1.628	0.067
Exponential LN(Y)	50.810	0.0001	0.8495	0.8328	Intercep X	-1967.819 - 7.128	0.0001 0.0001	0.585	0.446
Polynomial 1st degree Y	48.751	0.0001	0.8442	0.8268	Intercep X	225.841 - 6.821	0.0001 0.0001	0.582	0.445
Polynomial 2nd degree Y	139.187	0.0001	0.9721	0.9651	Intercep X X^2	376.423 - 10.01 6.05	0.0011 0.0001 0.003	1.274	0.230
Polynomial 3rd degree Y	313.315	0.0001	0.9926	0.9894	Intercep X X^2 X^3	588.914 - 11.937 6.280 - 4.411	0.0001 0.0001 0.0004 0.0031	2.862	-0.452
power LN(Y)	154.729	0.0001	0.9450	0.9389	Intercep LN(X)	-2106.334 - 12.439	0.0001 0.0001	1.60	0.078

Table (4) Statistical analysis, "SAS" program
Q_{min} = 0.15 m³/sec. d_{50} = 0.3 mm

Function	Analysis of variance				Parameter estimate			Durbin-Watson (d)	1st order auto-correlation
	F	prob>F	R^2	R^2 adj	T		prob >T		
Logarithmic Y	173.866	0.0001	0.9508	0.9453	Intercep LN (X)	261.65 - 13.186	0.0001 0.0001	1.370	0.191
Exponantial LN(Y)	53.268	0.0001	0.8555	0.8394	Intercep X	-1922.877 - 7.290	0.0001 0.0001	0.455	0.492
Polynomial 1st degree Y	51.02	0.0001	0.8501	0.8334	Intercep X	226.249 - 7.143	0.0001 0.0001	0.461	0.488
Polynomial 2nd degree	334.159	0.0001	0.9882	0.9852	Intercep X X^2	568.802 - 15.758 9.665	0.0001 0.0001 0.0001	0.924	0.324
Polynomial 3rd degree	3467.681	0.0001	0.9993	0.9990	Intercep X X^2 X^3	1918.099 - 36.760 17.285 - 10.777	0.0001 0.0001 0.0001 0.0001	1.425	0.162
power LN(Y)	162.996	0.0001	0.9477	0.9419	Intercep LN(X)	-2067.276 - 12.676	0.0001 0.0001	1.345	0.201

Table (5) Statistical analysis, "SAS" program
Q_{max} = 9.33 m³/sec. d_{50} = 0.5 mm

Function	Analysis of variance				Parameter estimate			Durbin-Waston (d)	1st order auto-cor-relation
	F	prob>F	R^2	R^2 adj	T		prob>T		
Logarithmic Y	148.288	0.0001	0.9429	0.9364	Intercep LN (X)	517.576 - 12.177	0.0001 0.0001	1.364	0.191
Exponential LN(Y)	55.726	0.0001	0.8610	0.8455	Intercep X	-3747.83 2.466	0.0001 0.0001	0.434	0.511
Polynomial 1st degree Y	54.637	0.0001	0.8586	0.8429	Intercep X	502.284 - 7.392	0.0001 0.0001	0.436	0.509
Polynomial 2nd degree	427.901	0.0001	0.9907	0.9884	Intercep X X^2	1377.337 - 17.616 10.685	0.0001 0.0001 0.0001	0.852	0.371
Polynomial 3rd degree	8133.725	0.0001	0.9997	0.9996	Intercep X X^2 X^3	6282.431 - 54.311 24.571 - 14.800	0.0001 0.0001 0.0001 0.0001	1.27	0.26
power LN(Y)	144.347	0.0001	0.9413	0.9348	Intercep LN(X)	-3736.262 - 12.014	0.0001 0.0001	1.353	0.196

Table (6) Statistical analysis, "SAS" program
Q_{min} = 0.15 m³/sec. d_{50} = 0.5 mm

Function	Analysis of variance				Parameter estimate			Durbin-Watson (d)	1st order auto-cor-relation
	F	prob>F	R^2	R^2 adj	T		prob>T		
Logarithmic Y	171.239	0.0001	0.9501	0.9945	Intercep LN (X)	544.980 - 13.084	0.0001 0.0001	1.358	0.196
Exponential LN(Y)	52.716	0.0001	0.8542	0.8380	Intercep X	-3498.94 - 7.261	0.0001 0.0001	0.458	0.490
Polynomial 1st degree Y	51.666	0.0001	0.8516	0.8352	Intercep X	482.610 - 7.188	0.0001 0.0001	0.461	0.488
Polynomial 2nd degree	343.739	0.0001	0.9995	0.9885	Intercep X X^2	1216.414 - 15.943 9.756	0.0001 0.0001 0.0001	.927	0.322
Polynomial 3rd degree Y	3536.683	0.0001	0.9993	0.9991	Intercep X X^2 X^3	4078.784 - 36.922 17.274 - 10.730	0.0001 0.0001 0.0001 0.0001	1.45	0.148
power LN(Y)	166.128	0.0001	0.9486	0.9429	Intercep LN(X)	-3817.162 - 12.889	0.0001 0.0001	1.347	0.201

Table (7) Values of ($b \times 10^4$) in the equation
$S = S_o - b\ LN(T)$

Q m³/sec / d_{50} mm	9.33	8.50	7.00	6.19	4.66	2.71	2.33	1.35	0.6	0.15	Mean value
0.05	2.05	2.78	2.14	2.92	2.77	2.34	3.61	3.48	3.82	3.61	2.95
0.10	1.99	2.69	2.42	3.57	2.68	2.21	3.30	3.47	3.86	3.13	2.93
0.20	1.58	3.12	2.63	2.24	3.11	2.90	3.81	1.82	3.69	3.81	2.87
0.30	2.30	0.71	3.23	1.22	1.31	2.87	3.88	4.54	3.75	3.87	2.77
0.40	1.77	2.37	0.80	2.47	2.66	2.27	1.62	3.49	2.86	2.91	2.32
0.50	3.78	5.00	2.93	5.20	5.21	4.68	6.44	7.27	0.03	6.19	4.67

N.B. for $d_{50} \leqslant 0.4$ the mean value of (h) decreased with the increasing value of median particle size.

Table (8) Values of polynomial coefficients
$S = a - b_1\ T + b_2\ T^2$

d_{50}	0.05 mm			0.1 mm			0.2 mm			0.3 mm		
Q m³/sec	a x 10^5	h_1 x 10^7	h x 10^9	a x 10^5	h_1 x 10^7	h_2 x 10^9	a x 10^5	h_1 x 10^7	b_2 x 10^9	a x 10^5	h_1 x 10^7	h_2 x 10^9
9.33	2.50	2.48	1.80	4.20	1.79	0.95	9.28	1.31	0.57	16.76	2.48	1.71
8.5	3.44	2.34	1.12	5.83	2.41	1.25	12.88	3.37	2.32	21.70	-7.14	-1.38
7.0	2.78	2.03	1.28	4.86	2.97	2.11	10.87	3.21	2.74	19.83	3.41	2.24
6.19	3.61	2.45	1.17	6.34	3.38	1.98	13.55	4.63	4.30	23.32	-1.63	-8.28
4.66	3.43	2.33	1.11	5.81	2.40	1.25	12.82	3.35	2.31	22.17	0.43	-0.55
2.71	3.04	1.93	1.00	5.20	1.81	0.94	11.95	3.13	2.16	20.85	3.08	2.12
2.33	4.29	3.84	2.37	7.13	4.29	3.17	15.73	4.11	2.84	28.26	4.18	2.88
1.35	4.62	4.38	3.45	7.71	2.96	1.61	17.57	1.01	0.35	33.02	4.89	3.37
0.6	4.15	3.71	2.29	6.87	3.66	2.15	15.25	3.99	2.75	27.79	4.04	2.78
0.15	4.30	3.84	2.37	7.09	3.92	2.87	15.74	4.11	2.84	28.14	4.16	2.87

Table (8) Conted. Values of polynomial coefficients

	$S = a - b_1 T + b_2 T^2$						$S = a - b_1 T + b_2 T^2 - b_3 T^3$							
d_{50}	0.4 mm			0.5 mm			0.4 mm				0.5 mm			
Q m^3/sec	a x 10^5	b_1 x 10^7	b_2 x 10^9	a x 10^5	b_1 x 10^7	b_2 x 10^9	a x 10^5	b_1 x 10^7	b_2 x 10^9	b_3 x 10^{11}	a x 10^5	b_1 x 10^7	b_2 x 10^9	b_3 x 10^{11}
9.33	19.48	1.91	1.31	58.01	4.06	2.79	19.51	2.54	3.35	1.69	58.08	-5.4	7.12	3.56
8.50	25.98	2.54	1.75	76.64	5.37	3.69	26.02	3.39	4.46	2.23	76.74	7.1	9.41	4.71
7.00	23.78	0.09	-0.596	74.40	10.25	10.65	-23.64	-2.52	-9.02	-6.93	74.02	2.9	-13.08	-19.47
6.19	27.12	2.66	1.83	79.69	5.58	3.83	27.17	3.55	4.69	2.36	79.79	7.43	9.80	4.91
4.66	27.03	2.96	2.13	80.63	4.95	3.01	27.1	4.31	6.49	3.59	80.72	6.74	8.80	4.77
2.71	24.89	2.44	1.67	71.75	5.02	3.45	24.93	3.25	4.29	2.15	71.84	6.68	8.81	4.41
2.33	33.11	4.35	3.96	98.80	6.92	4.75	32.44	-8.49	-37.46	-34.09	98.92	9.20	12.11	6.06
1.35	38.23	3.75	2.57	111.45	7.80	5.36	38.29	4.99	6.58	3.30	111.58	10.4	13.67	6.84
0.60	31.34	3.07	2.11	90.82	11.67	14.96	31.39	4.09	5.40	2.71	90.62	7.68	2.10	-10.59
0.15	31.94	3.13	2.15	94.91	6.65	4.56	31.99	4.17	5.50	2.76	95.03	8.84	11.62	5.81

Table (9) Effect of side slope (z) on section properties. d_{50} = 0.05 mm, C_e = 50 p.p.m, T = 20° C

		side slope z = 3:2			side slope z = 2:1		
Disch. No.	Q m^3/sec	B metre	D metre	S x 10^5	B metre	D metre	S x 10^5
1	9.33	11.50	2.01	1.94	9.51	1.85	2.08
2	8.5	7.78	1.00	3.01	7.78	1.00	3.04
3	7.0	10.00	1.74	2.10	6.25	1.53	2.36
4	6.19	6.64	1.17	2.84	5.93	0.97	3.20
5	4.66	8.11	1.42	2.35	4.86	1.12	3.03
6	2.71	7.03	1.16	2.84	6.53	1.24	2.58
7	2.33	6.35	1.07	2.97	3.60	0.82	3.59
8	1.35	4.57	0.66	3.82	4.57	0.66	3.86
9	0.60	4.62	0.75	3.60	3.87	0.87	3.47
10	0.15	4.33	0.70	3.74	3.58	0.82	3.59

Table (10) Maximum and minimum (F_r and R_f) due the change in water temperature

d_{50} mm	0.05	0.01	0.2	0.3	0.4	0.5	0.6	0.7
F_r max	0.11	0.13	0.16	0.19	0.22	0.24	0.29	0.32
F_r min	0.11	0.13	0.16	0.18	0.20	0.23	0.26	0.30
R_{f_o} at 0° C	0.81	2.17	6.63	13.21	19.08	41.27	66.30	86.06
R_{f_o} at 80 C	2.40	6.71	21.46	43.29	62.86	101.30	219.47	280