INFLUENCE OF SEDIMENT LOAD ON STABLE SAND BED CHANNELS

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تأثير حمل المواد الرسوبية على القنوات الرملية المتزنة

خلاصة

يهدف البحث إلى دراسة تأثير حمل المواد الرسوبية على إتزان القنوات الرملية وإلى أى مدى يؤثر هذا الحمل علي كل من العرض المتوسط للقطاع المائي، عمق المياه والميل الطولي للقناة أثبت البحث أن ميل القاع يزداد بصورة منتظمة بازدياد حمل المواد الرسوبية هذا وقد أجرى تحليل إحصائي لإيجاد العلاقة التي تربط بين ميل القاع الطولي ودرجة تركيز المواد الرسوبية وذلك عند تصرفات مختلفة لقنوات رملية قطر حبيباتها المتوسط يتراوح ما بين ٠٥ر مم إلى ٥ر مم

قد يقل عرض القطاع وعمق المياه بازدياد درجة تركيز المواد الرسوبية للقنوات التي قطر حبيباتها المتوسط يساوي أو يقل عن ٤ر مم

استنتجت مجموعة من المنحنيات والمعادلات التي قد تفيد في تصميم القنوات في الأراضي الرملية

ABSTRACT

The main objective of this research work is study to what extent sediment load can affect the sand bed channel geometry i.e. mean width, water depth and bed slope. It was found in this study, the bed slope increased regularly with the increasing value of sediment concentration. Statistical analysis was performed to get the relationship between bed slope and sediment concentration at different values of discharges, for canals having median particle size varied between 0.05 mm and 0.5 mm.

Both water depth and mean width could decrease with the increasing value of sediment concentration for canals having median particle size $\leqslant$ 0.4 mm.

INTRODUCTION

Environmental considerations are the main difficulties that face the hydraulic engineer in dealing with the design of stable channel section. The major objective is to avoid totally lined channels, for economical, ground water recharge and preservation of wild life habits reasons (4).

A channel carrying water and accompanying sediment load in alluvial or erodible materials can adjust its width, depth and bed slope, depending on water discharge, sediment load and the strength of the bank soil.

However an important aim in the channel design is to reach a hydraulic geometry that will minimize potential channel bed changes (4).

The formation of bed forms has been investigated by many researchers. The first important contribution in the recent years was made by Anderson (1953) and followed by a significant development by Kennedy in 1963.

The study here in was in lower regime. The bed formations were ripples and dunes, although ripples and dunes show some differences but their geometrical appearance have remarkable similarities (8).

The understanding of sediment in suspension is still far from being satifactory. The suspended sediment has been related to the intensity of the vertical component of turbulent eddies. There is still considerable interest in investigating the relationship between suspended sediment and bed forms (1).

THEORETICAL CONSIDERATIONS

Although iacey (1930) considered the regime canals are elliptical in cross sectional shape, other hydraulicians assumed them to be parabolic in shape (5). Lindley (1930) and Blench (1957) assumed that the regime section has a horizontal bed and steep side slopes. However the trapezoidal section seems to be an appropriate representation to channel in regime. A trapezoidal sectional shape has been considered in this study, with side slope 2 (horizontal): 1 (vertical).

Computations were based on the following two equations:
1 - Einstein - Brown's formula (11) which is given by:

$$\Phi = \frac{q_s}{F\sqrt{g\,(\gamma_s/\gamma - 1)\, d_s^3}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

in which;

ϕ = dimensionless measure of bed load;
q_s = sediment discharge in volume per unit width and time;
d_s = bed material size = d_{50};
d_{50} = median particle size;
γ_s = specific weight of bed materials;
γ = specific weight of water;
g = acceleration due to gravity; and
F = settling velocity representation term.

$$\phi = K_1 \psi^{-K_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where ψ is the entrainment function

$$\psi = \left(\frac{\gamma_s - \gamma}{\tau_c}\right) d_s \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

in which ; τ_o = average shear stress

Values of K_1 and K_2 are constants which could be determined from field data

2 - Liu and Hwang's formula (10) which is given by:

$$V = C_3 R^x S^y \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

in which;
V = mean velocity in m/sec.
R = hydraulic radius m;
S = non-dimensional slope; and
C_3, x and y are coefficients depend on the median particle size of bed material and bed formation and could be obtained from charts (11).

Using the two equations, for various extensive data, has provided simulated water depths, mean widths and bed slopes to an acceptable degree of accuracy compared with the corresponding actual properties (12).

Ten values of actual discharges, which vary between 0.15 m^3/sec. and 9.33 m^3/sec; and the corresponding values of mean widths and water depths were incorporated into the model

Table (1). the median particle size d_{50} varied between 0.05 mm and 0.1 mm. Shape factors for these canals were in the range between 3.7 and 8.1.

Canals having median particle size 0.2, 0.3, 0.4 and 0.5 mm were incorporated in the model to get their section propoerties using the given actual properties as initial values for computations .

RESULTS AND ANALYSES

Mean Width

Many combinations of mean width, water depth and bed slope may provide stable canals for a given discharge and sediment load. i.e for a given depth, a channel may adjust its bed slope and mean width to reach an equilibrium condition according to water discharge and sediment load.

Most of canals under study, established in bed material having median particle size diameter (d_{50}) ranged between 0.05 mm and 0.4 mm, showed no change in mean width as the sediment concentration varied from 0.0 to 1000 p.p.m. This may mean the mean widths have the maximum designed values.

For $Q = 7.0$ m³/sec. and $d_{50} = 0.2$ mm , the mean width decreased from 6.25 m at $C_s = 0.0$ to 6.0 m at $C_s = 100$ p.p.m to 5.75 m at $C_s = 200$ p.p.m to 1000 p.p.m; for $d_{50} = 0.3$ mm a decrease in mean width occurred from 6.25 m at $C_s = 0.0$ to 5.75 m at $C_s = 100$ p.p.m to 5.5 m at $C_s = 200$ p.p.m and 300 p.p.m. to 5.25 at $C_s = 400$ p.p.m to 1000 p.p.m.; for $d_{50} = 0.4$ m the mean width decreased from 6.25 m at $C_s = 0.0$ to 5.25 m at $C_s = 100$ p.p.m to 5.0 m at $C_s = 200$ p.p.m to 1000 p.p.m.

For $Q = 0.15$ m³/sec and $d_{50} = 0.4$ mm the mean width decreased from 3.58 m at $C_s = 0.0$ to 3.33 m at $C_s = 100$ to 1000 p.p.m.

Canals having $d_{50} = 0.5$ mm, may show an increase in mean width with the increasing value of sediment concentration, Fig. (1), for $Q > 2.71$ m³/sec.

For $Q < 2.71$ m³/sec. no responses were observed in mean widths.

However the maximum width at which a channel can function well is not clear. It seems best to limit the channel width to a minimum value. 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 (14). Centrifugal forces in meander channels produces super elevation of the water surface and helicoidal flow, which has a great effect on erosion, deposition and sediment transport in channels (9).

Two contradicting views are given in literature concerning mean width. The first view states that the transport capacity of sediment is a decreasing function of width and the second view is the transport capacity increases as the channel width increases, the second view is shown to be inconsistent with sediment transport formulas (3).

Mean width is a decreasing function of sediment concentration till $d_{50} \leqslant 0.4$ mm and the channel width increases with sediment concentration at $d_{50} = 0.5$ mm.

Water Depth

Conventional formulas of predicting water depth in sand bed are being far from experience gained from both the laboratory and the field and they do not provide solutions for wide range of independent variables (2). The model tackled these problems by providing simulated water depths to an acceptable degree of accuracy.

Canals having median particle size equal to 0.05 mm and 0.1 mm showed negligible change in water depth due to the increase of sediment concentration from 0.0 to 100 p.p.m. and no responses in water depth occured at $Q = 0.15$ m^3/sec for any median particle size.

For $Q = 9.33$ m^3/sec and $d_{50} = 0.05$ mm the water depth decreased from 1.85 m to 1.77 m as the sediment concentration increased from 100 p.p.m to 1000 p.p.m. For $d_{50} = 0.1$ mm, water depth decreased from 1.144 m to 1.36 m at $Q = 7.0$ m^3/sec.; from 1.21 m to 1.01 m at $Q = 4.66$ m^3/sec.; from 0.82 m to 0.78 m at $Q = 2.33$ m^3/sec., and from 0.58 m to 0.54 m at 1.35 m^3/sec. For $d_{50} = 0.3$ mm as the value of C_e increased from 100 p.p.m. to 1000 p.p.m. , water depth decreased from 1.37 m to 1.28 m at $Q = 7.0$ m^3/sec., from 1.09 m to 1.0 m at $Q = 4.66$ m^3/sec, and from 0.80 m to 0.72 m at $Q = 2.33$ m^3/sec.

For $d_{50} = 0.4$ mm, water depth decreased from 1.129 m to 1.21 m at $Q = 7.0$ m^3/sec, from 1.09 m to 1.0 m at $Q = 4.66$ m^3/sec and from 0.76 m to 0.78 m at $Q = 2.33$ m^3/sec.

For canals having $d_{50} = 0.5$ mm and $Q > 2.71$ m^3/sec., the water depth decreased with the increasing value of sediment concentration from 100 p.p.m. to 600 p.p.m, for $Q = 9.33$ m^3/sec. the depth decreased from 1.73 m to 0.68 m; and from 1.08 to 0.69 m at $Q = 8.5$ m^3/sec. For $Q = 7.0$ m^3/sec. the water depth decreased from 1.21 m to 0.71 m and from 1.0 m to

0.73 m at $Q = 6.19\ m^3/sec$. No responses have been observed for other values of discharge less than $2.71\ m^3/sec$.

The percentage of decrease occured in water depths, for the given values of water discharge, in the range of 10% for $d_{50} \leqslant 0.4$ mm. It may reach 61% for $d_{50} = 0.5$ mm at $Q = 9.33\ m^3/sec$ and it decreases with the decreasing value of water discharge Fig. (2).

Bed Slope

Bed slope decreased with the increasing value of water discharge. The relationships between bed slope and sediment concentration are given in Figs (3)through (6). More deviation is observed for $d_{50} = 0.5$ mm than other particle sizes.

Figs (7) through (12) give the relationships between sediment concentration (C_s) and bed slope (S) at 20 C, for different values of median particle size under various values of discharges. The numbers in the figures are related to the discharge number Table (1).

The bed slope increases regularly with the increasing value of sediment concentration. A specific function could be fitted to these variations, logarithmic, polynomial from the first degree to the fifth degree, exponential and power functions were tried, using program SAS. It gave the biggest values of multiple corelation coefficient of determination (R^2). The parameter estimate exhibited also more significant values. It was found that the power function is the best fit to these relationships. Tables (2) through (5) give samples of the output of the statistical analyses. The power function is in the form :

$$S = a\, C_s^{\,b} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

Values of coefficient (a) and (b) are given in Table (6). The coefficient (a) decreases with the increasing value of water discharge and it increases with increasing value of median particle size. It does not significantly differ from the value of bed slope at clear water. The difference between values of coefficient (a) and bed slope at clear water is usually less than 10%. Slight variation of coefficient (b) was noticed with water discharge and median particle size. It could be adjusted to minimize the error between the equation given by analysis and the proposed relationship between bed slope and sediment concentration. So the bed slope at any sediment concentation could be given by :

$$S = S_c\, C_s^{\,b} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

where (b) may have the values for :

very fine sand (0.05 mm 0.1) = 0.33
fine sand (0.1 mm 0.2 mm) = 0.33
medium sand (0.3 mm 0.4) = 0.335
coarse sand (0.5 mm) = 0.34

Figs. (13) through (22) show the variations of S/S_{100} with the sediment concentration (C_s). The values of S/S_{100} versus C_s for d_{50} = 0.5 mm are shown in the figures as dashed curves. It is an increasing function, it was also found, using the statistical program "SAS", the best fit of S/S_{100} versus C_s is a power function. It takes the form:

$$S/S_{100} = a\ C_s^{\,b} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

Values of coefficients (a) and (b) are given in Table (7). Deviation was observed for d_{50} = 0.5 mm at values of discharges > 2.71 m³/sec.

The envelope curves have a maximum difference of 25 % at C_s = 1000 p.p.m. which give the designer the ability to estimate the bed slope at any sediment concentration in term of bed slope at C_s = 100 p.p.m.

Bed slope varied exponentially with the median particle size. For C_s = 50 p.p.m at 20° C the relationship between median particle size (d_{50}) and bed slope (S) is given by:

$$S = 2.69 \times 10^{-5}\ e^{6.68\, d_{50}} \quad \text{for } Q \geqslant 0.15 \leqslant 9.33\ \text{m}^3/\text{sec} \ldots (9)$$

$$S = 2.38 \times 10^{-5}\ e^{6.67\, d_{50}} \quad \text{for } Q \geqslant 2.71 \leqslant 9.33\ \text{m}^3/\text{sec} \ldots (10)$$

$$S = 3.17 \times 10^{-5}\ e^{6.70\, d_{50}} \quad \text{for } Q \geqslant 0.15 \leqslant 2.33\ \text{m}^3/\text{sec} \ldots (11)$$

Fig. (23) shows the variation of bed slope with median particle size for different values of discharges.

Type of Flow

The flow is a smooth turbulent flow for $d_{50} < 0.2$ mm the maximum value of Reynold's frictional number $R_f = 3.51 < 5.0$. For $d_{50} < 0.2$ mm the flow is transitional turbulent, maximum value of $R_f = 54.04 < 100$. Table (8) provides values of R_f at different values of sediment concentration, which could change the state of flow from smooth turbulent to transitional turbulent condition.

Regular increase in Froude's number (Fr) due to the increase in sediment concentration was noticed. Maximum value of (Fr) = 0.34, which could mean that the lower flow regime (ripples and dunes) do form in subcritical flow which has Froude's number less than 0.34. Kennedy concured with Simon-Albertson recommedation (8), that (Fr) should not be greater than 0.3.

Simon and Senturk (7) stated that, ripples do not form in bed sediment greater than about 0.6 mm in diameter. Lower flow regime occurred for canals under study having median particle size $d_{50} < 0.5$ mm with sediment concentration C_s = 1000 p.p.m. For canals having d_{50} = 0.5 mm ripples and dunes could occur on the condition that sediment concentration should be less than 600 p.p.m. lower flow regime may form in canals having $d_{50} \leqslant 0.7$ mm with $C_s \leqslant$ 50 p.p.m.

CONCLUSIONS

Based on this study the following conclusions can be written:

1 . A set of equations and curves are presented in this research work which could be of use in the design of stable canals in sandy bed formations.

2 . Ripples and dunes do form in canals having median particle size (d_{50}) less than 0.5 mm with sediment concentration (C_s) = 1000 p.p.m. They occur in canals having d_{50} = 0.5 mm in the condition that C_s do not exceed 600 p.p.m. For $d_{50} \leqslant 0.7$ mm lower flow regime may form at $C_s \leqslant$ 50 p.p.m.

3 . Lower flow regime occurs in sand bed channels which have Froude's number less than 0.34

4 . Bed slope is more sensitive to cope with the change in sediment concentration than mean width and water depth this could be observed in increasing the bed slope without noticeable change in both mean width and water depth.

5 . Channels carrying clear water and having $d_{50} < 0.5$ mm have wider breadths and deeper depths than those carrying sediment. Both the mean width and water depth decrease with the increasing sediment concentration. For $d_{50} \geqslant 0.5$ mm, increasing the sediment load may increase the mean width and decrease water depth.

6 . Bed slope increases regulary with sediment concentration the relationship between bed slope and sediment concentration is a power function in the form :

$$S = S_{0}\, C_{s}^{\,b}$$

where S_o is the bed slope for clear water and b coefficient depends mainly on the type of soil it ranges between 0.33 for very fine sand to 0.34 for coarse sand. Values of S/S_{100} versus (C_g) take also a power function.

7 . Bed slope has an exponential relationship with canals median particle size, equations are given for this relationship.

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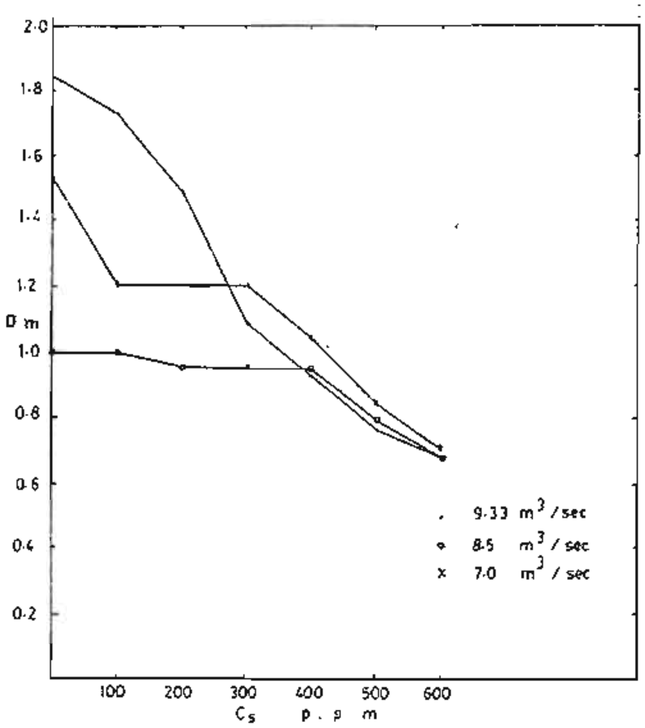
NOTATION

The following symbols are used in this paper:

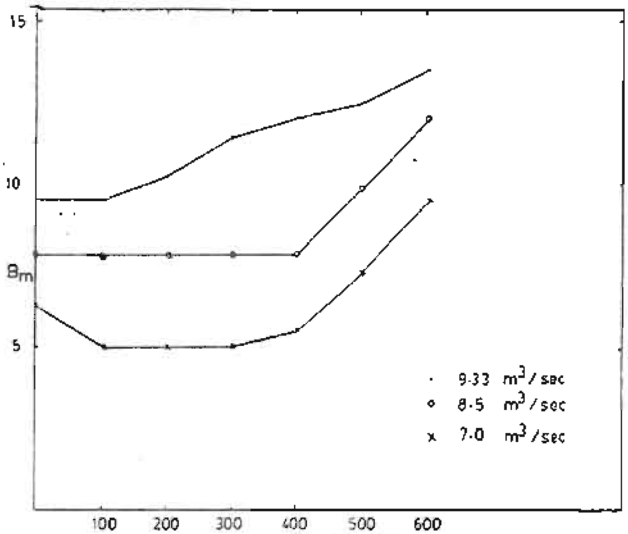
a = coefficient;
B = mean width;
b = exponent;
C_s = coefficient;
D = water mean depth;
d = Durbin - Watson statistic;
d_s = bed material size;
d_{50} = median particle size;
F = settling velocity representation term;
F = statistical parameter F-test;
F_r = Froude's number;
g = accelerlation of gravity;
K_1, X_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 clear water;
S_{100} = bed slope at C_c = 100 p.p.m;
T = statistical parameter t-test
V = mean velocity of water;
X = parameter = C_s ;
x = coefficient ;
Y = function = S ; and
y = coefficient.

Greek letters

γ = specific weight of water;
γ_s = specific weight of bed materials ;
τ_o = average bed shear stress;
ϕ = dimensionless measure of the bed load; and
ψ = entrainment function.



Fig(2) Variation of Water Depth (D) with Sediment Concentration (C_s) d_{50} = 0.5 mm



Fig(1) Variation of Mean Width(B) with Sediment Concentration (C_s) d_{50}= 0.5 mm

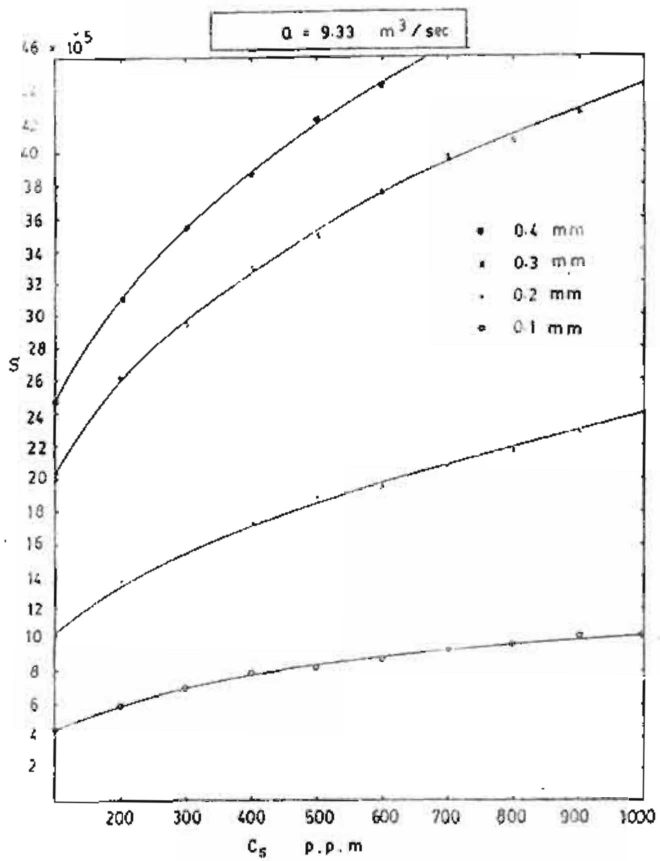


Fig (3) Variation of Bed Slope (S) with Sediment Concentration (C_s) for Different Values of d_{50} Q = 9.33 m^3/sec

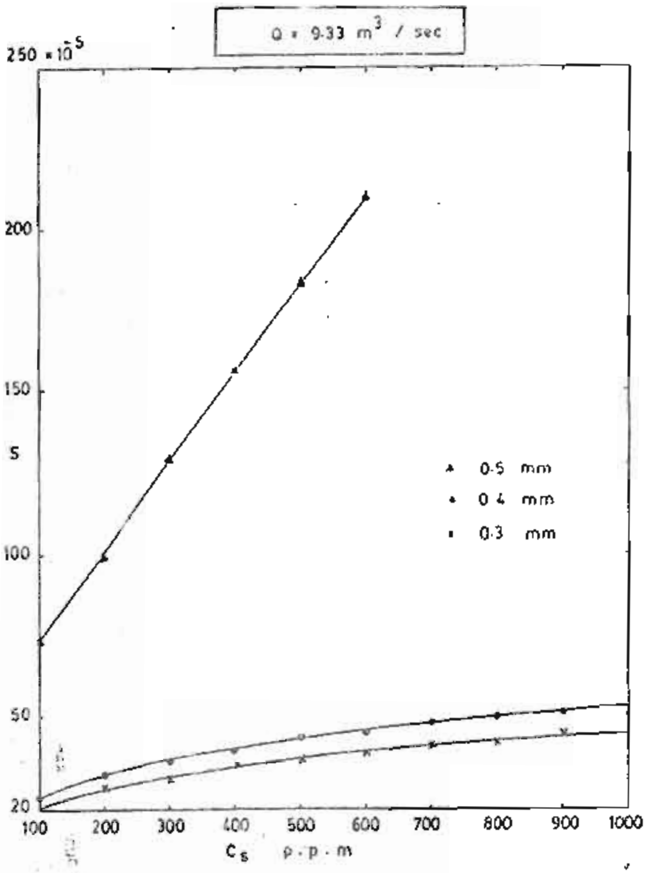


Fig (4) Variation of Bed Slope (S) with Sediment Concentration (C_s) for Different Values of d_{50} Q = 9.33 m^3/sec

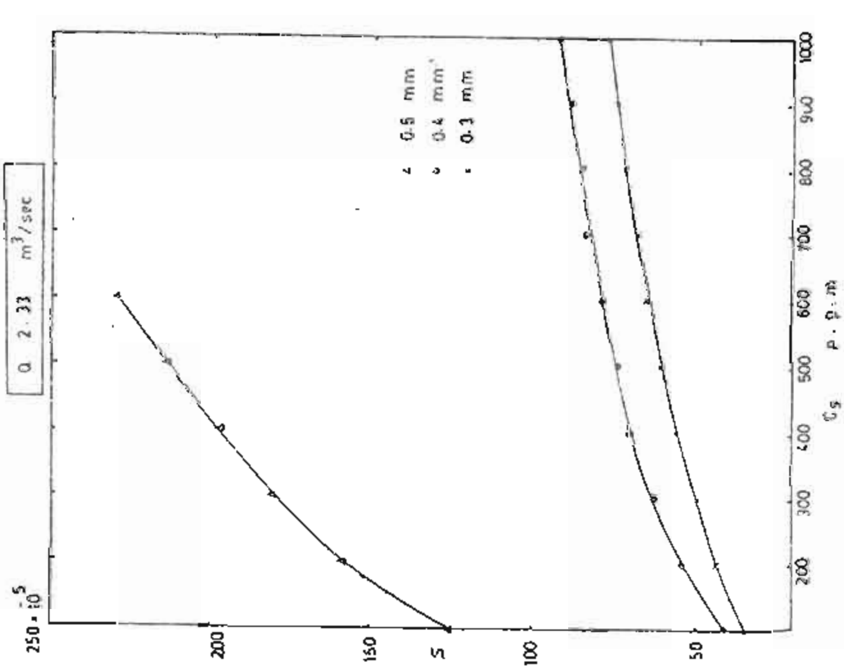


Fig (5) Variation of Bed Slope (S) with Sediment Concentration (C_s) for Different Values of d_{50}

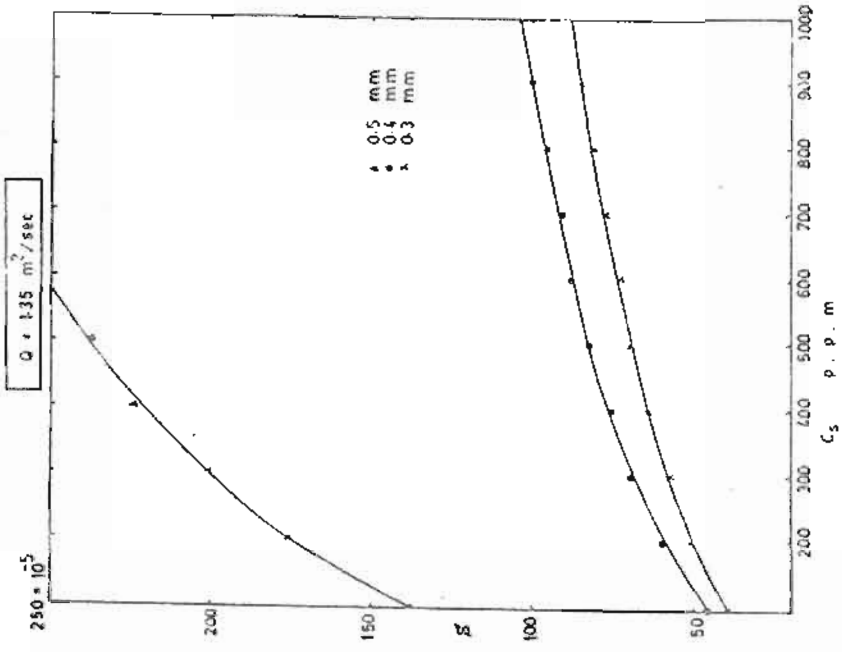
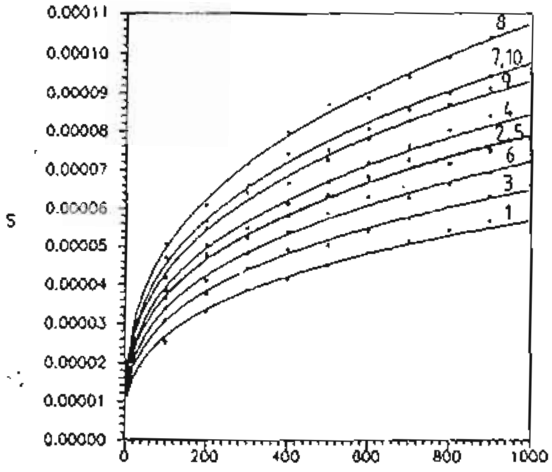
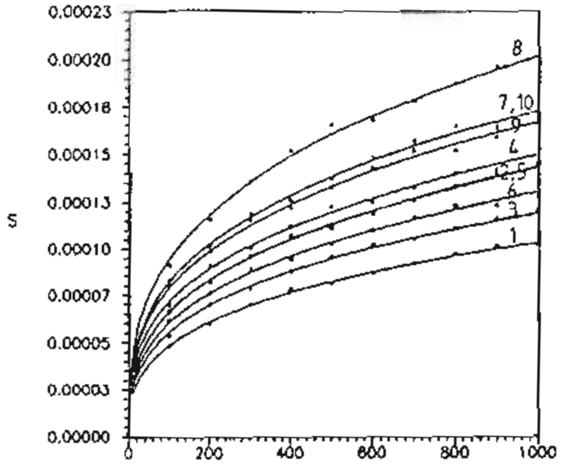


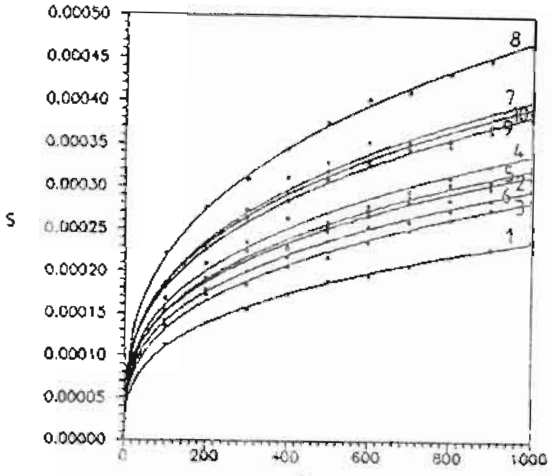
Fig (6) Variation of Bed Slope (S) with Sediment Concentration (C_s) for Different Values of d_{50}



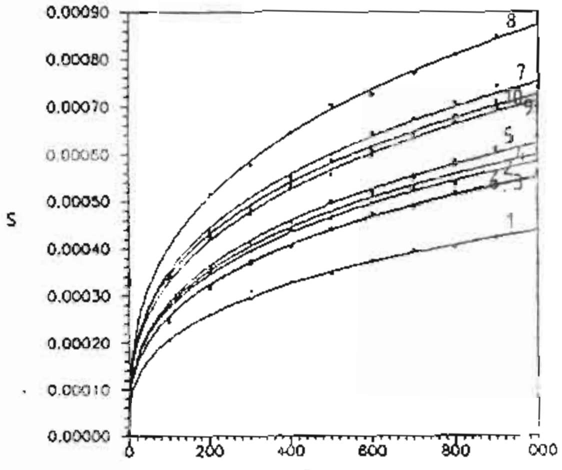
Fig(7) Relationships between Bed Slope (S) and Sediment Concentration (Cs) for Different Values of Discharges,d_{50}=0.05mm



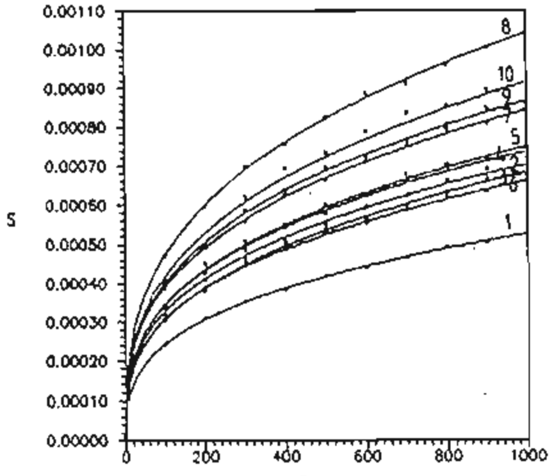
Fig(8) Relationships between Bed Slope (S) and Sediment Concentration (Cs) for Different Values of Discharges,d_{50}=0.1mm



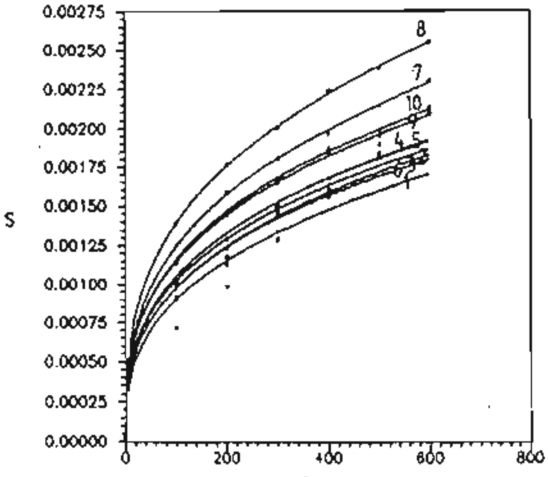
Fig(9) Relationships between Bed Slope (S) and Sediment Concentration (Cs) for Different Values of Discharges,d_{50}=0.2mm



Fig(10) Relationships between Bed Slope (S) and Sediment Concentration (Cs) for Different Values of Discharges,d_{50}=0.3mm



Fig(11) Relationships between Bed Slope (S) and Sediment Concentration (Cs) for Different Values of Discharges, d_{50}=0.4mm



Fig(12) Relationships between Bed Slope (S) and Sediment Concentration (Cs) for Different Values of Discharges, d_{50}=0.5mm

key notes :

(a) d_{50}=0.05mm

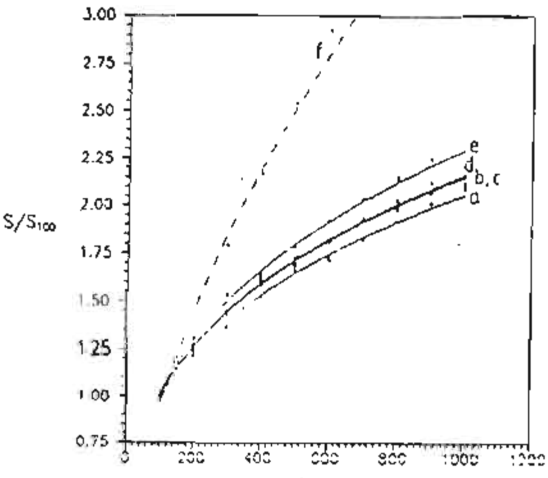
(b) d_{50} =0.1 mm

(c) d_{50} =0.2 mm

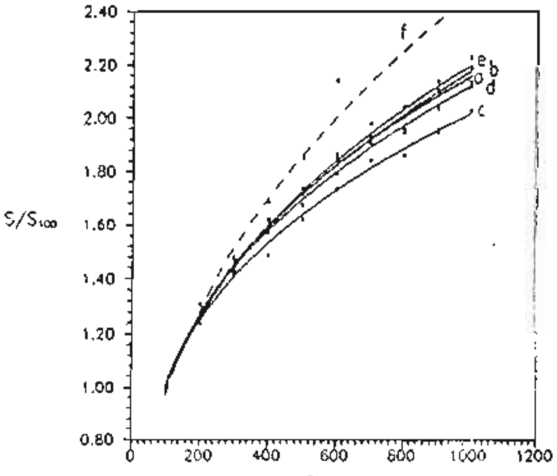
(d) d_{50} =0.3 mm

(e) d_{50} =0.4 mm

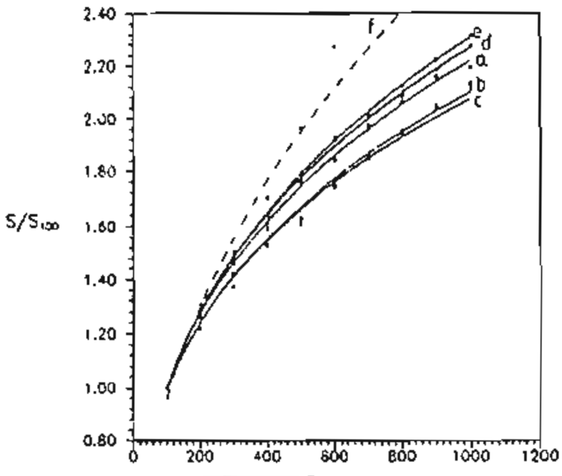
(f) d_{50} =0.5 mm



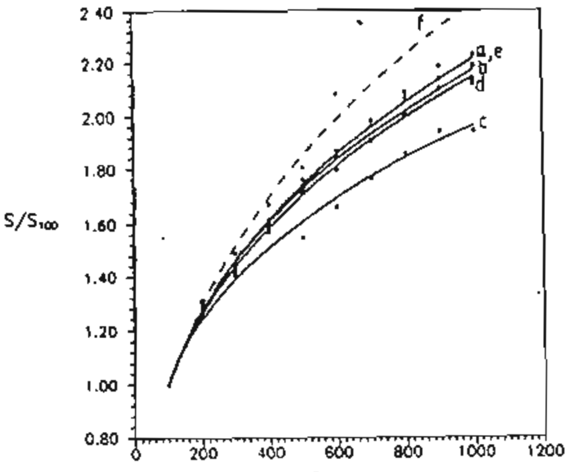
Fig(13) Variation of (S/S_{100}) with (Cs) for Different Values of Median Particle Size Q=9.33 m^3/sec



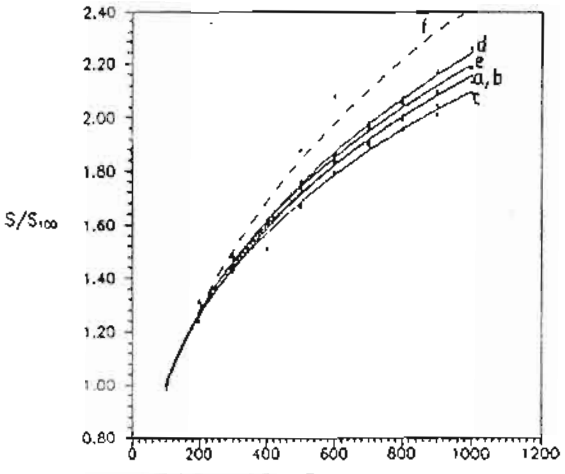
Fig(14) Variation of (S/S_{100}) with (Cs) for Different Values of Median Particle Size Q=8.50 m^3/sec.



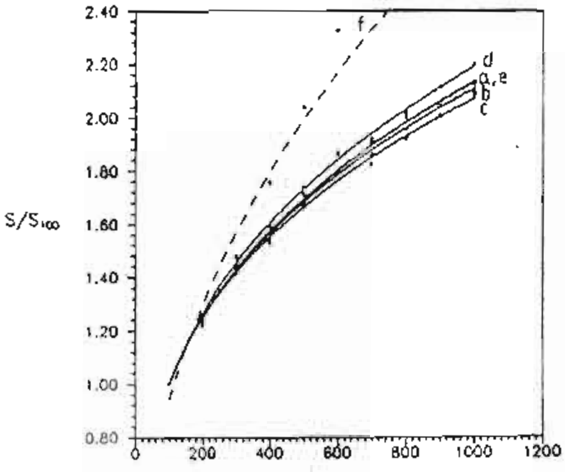
Fig(15) Variation of (S/S$_{100}$) with (Cs) for Different Values of Median Particle Size Q=7.00 m^3/sec.



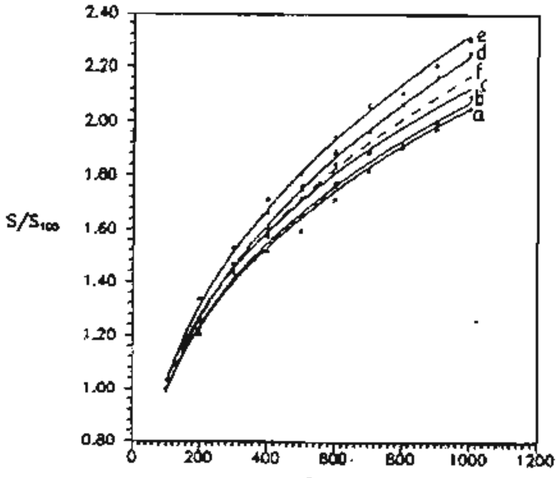
Fig(16) Variation of (S/S$_{100}$) with (Cs) for Different Values of Median Particle Size Q=6.19 m^3/sec.



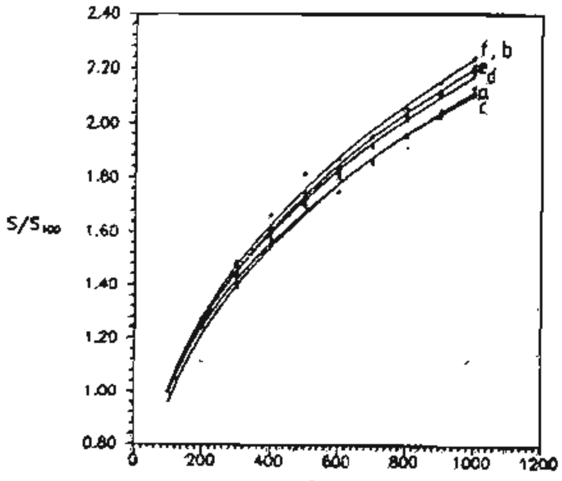
Fig(17) Variation of (S/S$_{100}$) with (Cs) for Different Values of Median Particle Size Q=4.66 m^3/sec.



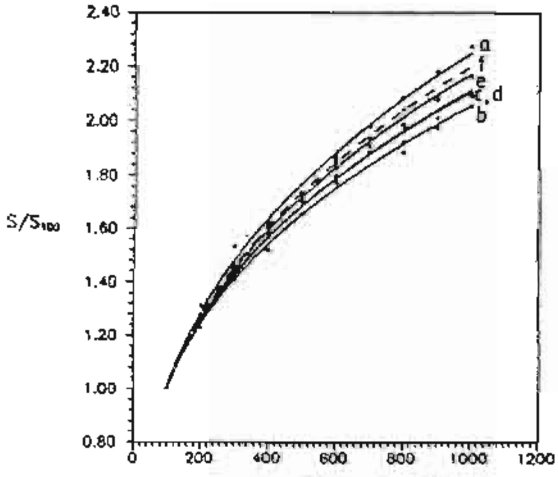
Fig(18) Variation of (S/S$_{100}$) with (Cs) for Different Values of Median Particle Size Q=2.71 m^3/sec.



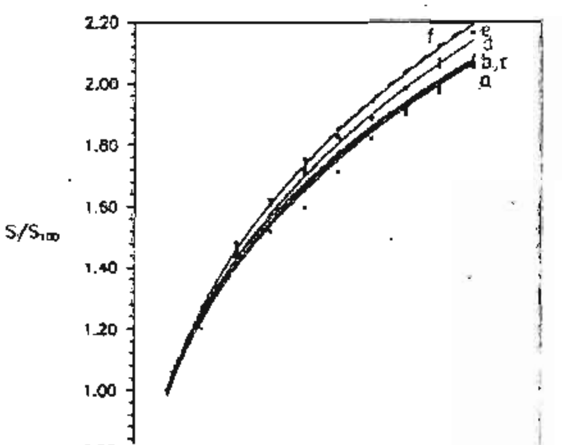
Fig(19) Variation of (S/S_{100}) with (Cs) for Different Values of Median Particle Size Q=2.33 m^3/sec.



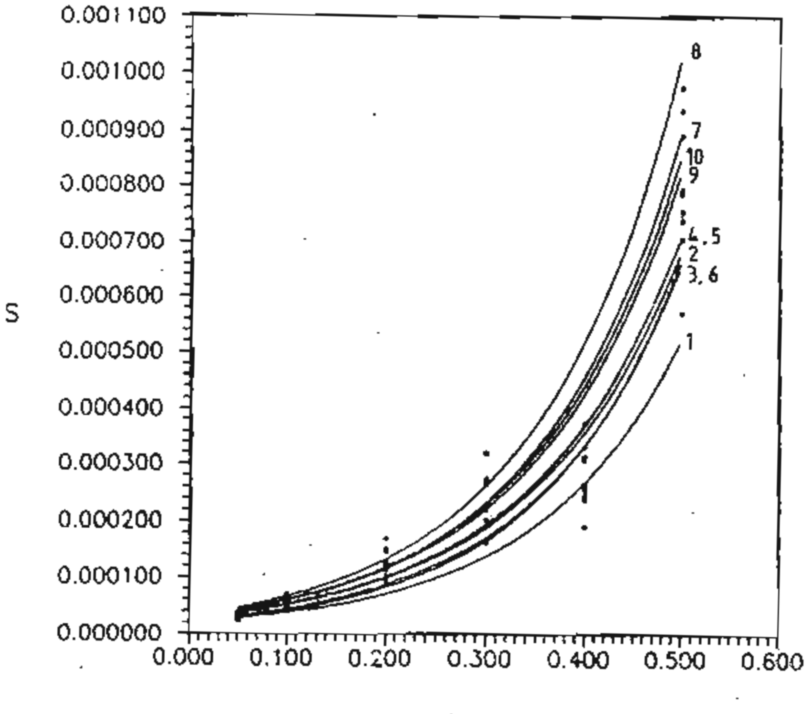
Fig(20) Variation of (S/S_{100}) with (Cs) for Different Values of Median Particle Size Q=1.35 m^3/sec.



Fig(21) Variation of (S/S_{100}) with (Cs) for Different Values of Median Particle Size Q=0.60 m^3/sec.



Fig(22) Variation of (S/S_{100}) with (Cs) for Different Values of Median Particle Size Q=0.15 m^3/sec.



Fig(23) Variation of (S) with Median Particle Size (d_{50})for Different Values of Discharges

Table (1) Input field data to computer program

Disch.No.	1	2	3	4	5	6	7	8	9	10
Q m^3/sec.	9.33	8.5	7.0	6.19	4.66	2.71	2.33	1.35	0.6	0.15
B metre	9.51	7.78	5.0	5.39	4.86	6.53	3.6	4.57	3.87	3.33
D metre	1.81	0.96	1.29	0.93	1.08	1.28	0.78	0.62	0.91	0.90

Table (2) Statistical analysis, "SAS" program

$Q_{max} = 9.33\ m^3/sec.$ $d_{50} = 0.1\ mm$

Function	Anaylysis of variance				Parameter estimate			Durbin-Watson (d)	1st order auto-correlation
	F	prob > F	R^2	R^2 adj	T		prob > T		
Logarithmic Y	40.121	0.0001	0.8168	0.7964	intercep LN(X)	6.188 6.334	0.0002 0.0001	0.713	0.571
Exponential LN(Y)	6.139	0.0351	0.4055	0.3394	intercep X	-18.269 2.478	0.0001 0.0361	1.247	0.018
Polynomial 1st degree Y	36.594	0.0002	0.8026	0.7807	intercep X	4.33 6.049	0.0019 0.0002	0.948	0.165
Polynomial 2nd degree Y	53.824	0.0001	0.9308	0.9135	intercep X X^2	2.526 6.300 -3.851	0.0355 0.0002 0.0049	1.519	0.022
Polynomial 3rd degree Y	75.27	0.0001	0.9699	0.9570	intercep X X^2 X^3	1.517 6.627 -3.932 3.017	1.173 0.003 0.0057 0.0195	1.987	-0.126
Power LN(Y)	89876.97	0.0001	0.9999	0.9999	intercep LN(X)	-1661.169 299.794	0.0001 0.0001	2.101	-0.161

Table (3) Statistical analysis, "SAS" program

$Q_{min} = 0.15\ m^3/sec.$ $d_{50} = 0.1$ mm

Function	Anaylysis of variance				Parameter estimate			Durbin-Watson (d)	1st order auto-correlation
	F	prob>F	R^2	R^2 adj	T		prob > T		
Logarithmic Y	44.219	0.0001	0.8309	0.8121	intercep LN (X)	6.576	0.0001 0.0001	0.713	0.562
Exponential LN(Y)	6.082	0.0358	0.4033	0.3370	intercep X	-17.892 2.466	0.0001 0.0358	1.252	0.017
Polynomial 1st degree Y	33.416	0.0003	0.7878	0.7642	intercep X	4.37 5.781	0.0018 0.0003	0.971	0.161
Polynomial 2nd degree Y	48.715	0.0001	0.9241	0.9052	intercep X X^2	2.553 6.103 -3.791	0.034 0.0003 0.0053	1.6	-0.029
Polynomial 3rd degree Y	62.905	0.0001	0.9642	0.9489	intercep X X^2 X^3	1.537 6.160 -3.668 2.802	0.1681 0.008 0.008 0.0265	1.885	-0.056
power LN(Y)	65437.61	0.0001	0.9999	0.9998	intercep LN(X)	-1392.06 255.808	0.0001 0.0001	2.165	-0.116

Table (4) Statistical analysis, "SAS" program

$Q_{max} = 9.33\ m^3/sec.$ $d_{50} = 0.5$ mm

Function	Anaylysis of variance				Parameter estimate			Durbin-Watson (d)	1st order auto-correlation
	F	prob > F	R^2	R^2 adj	T		prob > T		
Logarithmic Y	10.284	0.0238	0.6729	0.6074	intercep LN(X)	3.319 3.207	0.021 0.0238	0.761	0.44
Exponential LN(Y)	7.042	0.0452	0.5848	0.5017	intercep X	-11.013 2.654	0.0001 0.0452	1.517	-0.062
Polynomial 1st degree Y	148.402	0.0001	0.9674	0.9609	intercep X	2.562 12.182	0.0505 0.001	1.589	-0.096
Polynomial 2nd degree Y	147.688	0.0002	0.9866	0.9800	intercep X X^2	1.294 7.025 -2.40	0.2652 0.0022 0.0744	2.236	-0.267
Polynomial 3rd degree Y	229.12	0.0005	0.9957	0.9913	intercep X X^2 X^3	0.724 7.007 -3.095 2.495	0.5216 0.0060 0.0535 0.0881	2.786	-0.441
Power LN(Y)	610.219	0.0001	0.9919	0.9902	intercep LN(X)	-101.596 24.703	0.0001 0.0001	0.796	0.449

Table (5) Statistical analysis, "SAS" program

$Q_{min} = 0.15\ m^3/sec. \qquad d_{50} = 0.5\ mm$

Function	Anaylysis of variance				Parameter estimate			Durbin-Watson (d)	1st order auto-correlation
	F	prob > F	R^2	R^2 adj	T		prob > T		
Logarithmic Y	73.165	0.0017	0.8814	0.8577	intercep LN(X)	6.786 6.096	0.0011 0.0017	0.964	0.38
Exponential LN(Y)	4.961	0.0764	0.4981	0.4981	intercep X	-10.078 2.227	0.0002 0.0764	1.52	0.062
Polynomial 1st degree Y	21.789	0.0055	0.8134	0.7760	intercep X	2.47 4.668	0.0565 0.0055	1.317	0.033
Polynomial 2nd degree Y	35.897	0.0028	0.9472	0.928	intercep X X^2	1.253 5.238 -3.185	0.2786 0.0063 0.0334	2.041	-0.177
Polynomial 3rd degree Y	82.55	0.0022	0.988	0.9761	intercep X X^2 X^3	0.708 7.124 -4.165 -3.198	0.5298 0.0057 0.0252 0.0494	2.594	-0.347
Power LN(Y)	292078.4	0.0001	1.00	1.00	intercep LN(X)	-2265.3 540.44	0.0001 0.0001	2.561	-0.368

Table (6) Relationships between bed slope(S) and sediment concentration (C_s)

d_{50} mm	0.05		0.1		0.2		0.3		0.4		0.5	
Q m^3/sec.	$S_o \times 10^5$	$S \times 10^5$	$S_o \times 10^5$	$S \times 10^5$	$S_o \times 10^5$	$S \times 10^5$	$S_o \times 10^5$	$S \times 10^5$	$S_o \times 10^5$	$S \times 10^5$	$S_o \times 10^5$	$S \times 10^5$
9.33	6.2	$5.91\ C_s^{0.328}$	1.05	$1.04\ C_s^{0.333}$	2.40	$2.38\ C_s^{0.332}$	4.75	$4.57\ C_s^{0.328}$	5.12	$5.19\ C_s^{0.335}$	15.7	$17.53\ C_s^{0.356}$
8.5	8.3	$8.11\ C_s^{0.330}$	1.40	$1.42\ C_s^{0.334}$	3.65	$3.99\ C_s^{0.322}$	6.18	$6.02\ C_s^{0.329}$	7.44	$7.20\ C_s^{0.330}$	21.67	$21.79\ C_s^{0.336}$
7.0	7.0	$6.74\ C_s^{0.328}$	1.19	$1.19\ C_s^{0.334}$	2.70	$2.77\ C_s^{0.336}$	5.32	$5.50\ C_s^{0.334}$	5.74	$6.25\ C_s^{0.346}$	17.42	$19.38\ C_s^{0.351}$
6.19	8.7	$8.54\ C_s^{0.331}$	1.82	$1.65\ C_s^{0.319}$	3.82	$3.61\ C_s^{0.323}$	6.46	$6.21\ C_s^{0.330}$	7.77	$7.54\ C_s^{0.330}$	22.53	$22.55\ C_s^{0.335}$
4.66	8.3	$8.09\ C_s^{0.329}$	1.40	$1.41\ C_s^{0.335}$	3.64	$3.42\ C_s^{0.324}$	6.16	$6.18\ C_s^{0.335}$	7.41	$7.44\ C_s^{0.334}$	21.58	$22.13\ C_s^{0.338}$
2.71	7.5	$7.35\ C_s^{0.330}$	1.26	$1.29\ C_s^{0.336}$	3.30	$3.13\ C_s^{0.325}$	5.61	$5.57\ C_s^{0.333}$	6.76	$6.68\ C_s^{0.332}$	20.01	$20.45\ C_s^{0.340}$
2.30	9.8	$9.8\ C_s^{0.333}$	2.40	$1.88\ C_s^{0.321}$	4.25	$4.13\ C_s^{0.329}$	8.24	$7.83\ C_s^{0.327}$	8.62	$8.80\ C_s^{0.339}$	24.76	$25.97\ C_s^{0.340}$
1.35	1.05	$1.06\ C_s^{0.335}$	2.19	$2.09\ C_s^{0.328}$	4.55	$4.62\ C_s^{0.335}$	8.80	$8.75\ C_s^{0.333}$	9.21	$9.79\ C_s^{0.342}$	29.02	$29.61\ C_s^{0.336}$
0.6	9.1	$9.18\ C_s^{0.335}$	1.90	$1.78\ C_s^{0.324}$	4.12	$3.97\ C_s^{0.328}$	6.95	$7.05\ C_s^{0.335}$	8.37	$8.39\ C_s^{0.334}$	24.09	$24.41\ C_s^{0.335}$
0.15	9.8	$9.8\ C_s^{0.333}$	2.04	$1.88\ C_s^{0.321}$	4.25	$4.09\ C_s^{0.327}$	8.24	$7.72\ C_s^{0.324}$	8.63	$8.63\ C_s^{0.337}$	24.77	$24.95\ C_s^{0.335}$

Table (7) Values of coefficients (a) and (b) for $S/S100 = a\,Cs^{b}$

Q m³/sec	$Q \geq 4.66 \leq 9.33$		$Q \geq 2.33 \leq 4.66$		$Q \geq 0.15 \leq 2.33$		$Q \geq 0.15 \leq 9.33$	
d_{50} mm	a	b	a	b	a	b	a	b
0.05	0.220	0.337	0.233	0.326	0.208	0.338	0.214	0.334
0.1	0.210	0.340	0.220	0.328	0.224	0.326	0.217	0.332
0.2	0.244	0.307	0.235	0.317	0.232	0.319	0.238	0.314
0.3	0.213	0.337	0.199	0.350	0.216	0.333	0.209	0.340
0.4	0.206	0.342	0.210	0.341	0.210	0.339	0.209	0.341
0.5	0.124	0.460	0.160	0.400	0.209	0.340	0.160	0.406

Table (8) Values of (R_f) and (F_r) at different values of sediment concentration C_s

d_{50} mm	0.05	0.1	0.2	0.3	0.4	0.5
R_f C_s = 0.0 p.p.m	0.139	0.364	1.098	2.317	3.208	7.024
R_f C_s = 100 p.p.m	0.891	2.413	7.427	14.832	21.510	46.140
R_f C_s =1000 p.p.m	3.010	3.509	10.631	27.761	31.600	54.037
F_r C_s =50 p.p.m	0.036	0.147	0.193	0.212	0.240	0.260
F_r C_s =1000 p.p.m	0.148	0.198	0.220	0.260	0.320	0.340