A REGIME STUDY OF EGYPTIAN IRRIGATION CANALS

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ABSTRACT

The derivation of new general regime equations, which could help in the design of the different degrees of Egyptian irrigation canals, is the main objective of this research paper. This objective was achieved by bringing on the relationships between the major data of the stable cross-section parameters and between these parameters and discharge of the irrigation canals. The used canals were selected to represent the different degrees of the Egyptian irrigation canals. The selected canals are Rayahat, main canals, branch canals, and distribution canals, which are mostly distributed throughout the Egyptian Delta region, while some of these canals are existed out of that region. These new formulas were resulted from three hundred and fifty five cross-sections for Rayahat and main carrier canals and seventy cross-sections of distribution canals in the period between 1980 and 1995. Using the analytical regression of the non-linear relationships, the bed width (B), the flow depth (D), wetted perimeter (P), and the hydraulic radius, (R) of both the distribution and the carrier canals were formulated in terms of discharge. A comparison between the measured field data and the corresponding resulting ones from both derived and some familiar formulas in this field by using statistical analysis (F-test & sloping-test) was carried out. The comparison showed that the formulas based on the Egyptian canals data were nearest to the derived formulas than the others for the same range of discharge and soil type. Application of the derived formulas on both designed and measured cross-sections of El-Salam canal, in Egypt, showed that the computed values of different parameters of the cross-section were closer to the measured values than the corresponding designed ones. It may be concluded that the present derived formulas could help in the design of silty distribution canals having a discharge ranges from 0.22 to 4.9 m^3/s and main carrier canals (silty or silty sand) having a discharge ranges from 2.5 to 322 m^3/s.

1. INTRODUCTION

The regime method is considered one of the important methods, which could be used in derivation the practical design equations depending on field data of the stable canals [3], [7]. The tractive force method can be used in the design of the channels depending on drag force exerted on the cross-section by the flow [6]. Also, the live bed approach method can be used in designing the stable channels cross-sections depending on both flow resistance equation and sediment transport formula [5]. The study of regime equations for the Egyptian canals started from about fifty years ago. For the Egyptian canals, some of these formulas were estimated before the construction of the High Dam, which can not be valid now due to the change in sediment conditions. The other formulas, which were derived after the construction of the High Dam, may not be accurate due to either the lack of data or lowly computer facilities at the time in which these formulas were derived. It is found that the derived formulas after the construction of the High Dam have a right trend to be used, but it is required to derive more accurate formulas by using a big amount of data, in addition to the development in computer facilities. Application of conventional regime equations (Lacey, Blench and Simon-Albertson) on Egyptian canals revealed differences between observed field data and calculated properties of the canal cross-section [15].

2. LITERATURE REVIEW

The study of the regime theory have begun since 1895 by Kennedy, who used the balanced canals measurements to develop the following formula:

$$V = C\,D^{m},$$

in which:

V flow velocity (ft/sec)
C factor depends on sediment size
m factor depends on location
D water depth in feet

Many researchers had studied the regime theory. The regime channel was first defined by Lindley [10]. He stated that both the cross-section width and depth could be considered as regime variables. Lacey [9] studied the relationships between the different parameters of the cross-section and the discharge. He concluded that the variations of both the constant and exponent depend mostly on the locality and not on the channels under consideration. Also, the regime of the irrigation canals was studied by Marshall [11]. Simon and Richardson [14] derived some formulas, which describe the relationships between the different parameters of the cross-section and the discharge. In 1970 Blench [2] modified the lacey equations by studying the effect of canal sides and bed on flow parameters and canal geometrical elements. The regime theory of the Egyptian canals was studied either before or after the construction of the High Dam. Moleworth and Yenidonia [12] presented the following formulas to design the Egyptian canals: -

$$V_0 = 0.26\,y^{0.66} \qquad (1)$$

$$y = 0.1(S/2 + 4.0)B^{0.5} \qquad (y > 1.62\text{ m}) \qquad (2)$$

$$y = 0.00154(S + 8)^{2.0} \qquad (y < 1.62\text{ m}) \qquad (3)$$

in which:

S hydraulic gradient slope.
V flow velocity (m/sec).
y flow depth (m).

Also, the study of the regime theory in Egypt was carried out by Ghaleb [4] on non-silting, and non-scouring channels. He developed the following relationship:

$$V_0 = 0.39\,y^{0.73}, \qquad (4)$$

in which:

V_0 flow velocity (ft/sec)
y flow depth (ft)

In 1957. Moustafa et al. [13] suggested the following relationship between the mean depth, water surface slope, and bed width in the River Nile and discharge ($Q/B=130D^2S^{0.66}$), but this derived formula became invalid and new design for the present regime is needed. In 1987 Khattab et al. [8] studied the regime of twenty-three stable canals after the construction of the High Dam. They derived some formulas, which could be used for designing the stable earthen canals having sand loam bed with discharges ranged from 2 m^3/sec to 200 m^3/sec. In 1985, Bakery [1] studied the practical design of the Egyptian irrigation canals. Also, Zidan [16] derived regime equations for some irrigation canals in Irrigation Dakahlyia Directorate.

3. CANALS UNDER STUDY

In this paper, the cross-sections data of thirty-five canals are used. Twenty-five canals represent the main canals, while ten canals represent distribution canals, respectively. The main canals under study in this paper are rayahat, main carrier canals, and branch canals. Some of these canals locate in upper Egypt as Ibrahemia canal and Nagh Hammady canal, while the big number of these canals locate in south and in midst of Egyptian Nile Delta. Also, some of these canals extend to both the east and the west of Delta region like Tawfiky rayah and El-Behary rayah. Representative soil samples were collected from some of these canals. The analysis of these samples illustrated that, most of these canals are silty soil and silty sand soil as shown in Appendix. The discharges for every cross-section at the different periods were obtained from the Ministry of Water Resources and Irrigation. Also, the main characteristics of the canal cross-sections under study were collected from the Ministry of Water Resources and Irrigation in the period 1980 to 1995. Also, some of these data were collected in co-operation with the Hydraulic Research Institute (HRI), the National Water Research Center, Ministry of Water Resources and Irrigation.

4. ANALYSIS AND DISCUSSION OF THE RESULTS

The relationships between different properties of the cross-section and between these properties and discharge for distribution canals are shown through Figures (1) to (11). From the derived formulas illustrated in Figures (1) to (4), some parameters of the cross-section (R, B, Y, D) could be computed in the distribution canals of silty soil with discharge ranges from 0.22 m^3/sec. to 4.9 m^3/sec. It is found that the values of correlation factor of most derived formulas increase than 0.92, which indicate that these relationships could be used with an accepted accuracy. Also, Figures (5) through (11) show the relationships between the different properties of the cross-section and discharge. It is found that the values of correlation factor for the derived formulas illustrated on figures ranged from 0.91 to 0.943. From these figures, the wetted perimeter (P), the average depth (D), the bed width of the cross-section (B), the hydraulic radius (R), the area of the cross-section (A), the maximum depth (Y), and the water surface slope (S) could be computed for silty soil distribution canals having a discharge ranges from 0.22 m^3/sec. to 4.9 m^3/sec as follows:

$P = 7.2737\ Q^{0.5712}$ $\qquad$ $D = 0.9966\ Q^{0.4034}$

$B = 6.2691\ Q^{0.5}$ $\qquad$ $R = 0.8557\ Q^{0.5574}$

$A = 5.5538\ Q^{0.72}$ $Y = 1.062\ Q^{0.424}$
$S = 11.689\ Q^{0.6346}$

Figures (12) to (19) show a comparison between the present investigation of the distribution canals and the relationships derived by Lacy [9], Marshall [11], Simon [14], and Zidan [16]. From these figures it is found that the calculated values from the derived formulas are consistent with the measured values. By using statistical analysis (F-test, $F_{0.05,\ 1,\ 70} = 3.98$ & sloping test), it is found that the cross-section properties computed by the derived formulas are very close to the computed values by Zidan [16], especially at low values of discharge. This could be explained due to the fact that Zidan formulas [16] were derived from the data of the Egyptian distribution canals with relatively small cross-sections and small values of discharge. Also, from Figures and by using F-test and sloping-test, it is found that the corresponding values of the cross-section properties computed in relation to discharge by using Lacy [9], Marshall [11], and Simon [14] are either overestimated or underestimated the measured ones. This can be explained due to the fact that those formulas were derived for canals with the boundary conditions differ from those existed in the Egyptian canals.

Figures (20) through (30) show the relationships between the cross-section parameters and between these parameters and discharge for the main and carrier silty sand soil canals. Also, the relationships between the cross-section parameters and between these parameters and discharge for the main and carrier silty soil canals are shown through Figures (31) to (41). A set of equations for the relationships between the cross section properties and between these properties and the discharge are illustrated through Figures (20) to (30) for silty sand soil canals and through Figures (31) to (41) for silty soil canals respectively. These formulas were derived for branch and main carrier canals with discharge ranged from 2.50 m^3/sec to 322 m^3/sec. It was found that the values of correlation factor for most relationships ranging from 0.9 to 0.96, which indicate that these relationships could be used in computing the different parameters of the cross-section with an acceptable accuracy.

From these figures, the wetted perimeter (P), the average depth (D), the bed width of the cross-section (B), the hydraulic radius (R), the area of the cross-section (A), the maximum depth (Y), and the water surface slope (S) could be computed for carrier canals having a discharge ranges from 2.50 m^3/sec. to 322 m^3/sec as follows:

A- silty sand soil canals

$P = 8.2134\ Q^{0.4331}$ $D = 1.0909\ Q^{0.2019}$
$B = 9.6387\ Q^{0.3238}$ $R = 0.7842\ Q^{0.2611}$
$A = 5.513\ Q^{0.7187}$ $Y = 0.5481\ Q^{0.4049}$
$S = 2.12\ Q^{0.29}$

B- silty soil canals

$P = 8.102\ Q^{0.3927}$ $D = 1.0628\ Q^{0.1759}$
$B = 12.71\ Q^{0.2122}$ $R = 0.756\ Q^{0.1786}$
$A = 5.413\ Q^{0.632}$ $Y = 0.567\ Q^{0.3739}$
$S = 2.16\ Q^{0.279}$

A comparative study was carried out between the different measured parameters of the cross-section and the corresponding computed values from both the derived formulas and the formulas derived by Lacey [9], Marshall [11], Simon [14], and Khattab [8] as shown through Figures (42) to (47) for silty sand soil canals. Also, the comparison between measured parameters and computed ones by the aforementioned formulas for silty soil canals are shown through Figures (48) to (53). The figures show that the computed values by the derived formulas versus the measured values locate around the line of equality. This can be attributed due to the fact that these formulas were derived from the data of these canals. The comparison between the cross-sections parameters, which computed by other formulas such as by Lacey [9], Marshall [11], Simon [14], and Khattab [8] versus the corresponding measured values showed that some of these formulas were overestimated while the others were underestimated. By using the statistical analysis (F-test, $F_{0.05,\,1,\,133}$ =3.84 & sloping test), it was found that the values computed by using Khattab formulas [8] were the nearest to both the measured values and the derived formulas than the others. This could be explained due to the fact that Khattab formulas [8] were derived depending on the data of the Egyptian sand loam main canals, while the others were derived for the canals with characteristics and flow properties may be different from that existed in the Egyptian canals.

Also, the discharge for silty sand soil carrier canals and rayahat was calculated by using the analytical regression of the nonlinear relationship in terms of cross-sectional area (A), longitudinal slope (S), and hydraulic radius (R) as illustrated in the following relationship:

$$Q = 0.127 A^{1.11} S^{0.442} R^{0.244}$$

From the aforementioned analysis, it could be concluded that the derived formulas presented in this research paper give practical and acceptable design procedures for the Egyptian canals after the construction of the High Dam. Also, if the discharge, velocity, water surface slope and the type of boundaries of the cross-section are known, the cross-sectional characteristics could be obtained for both the main and distribution canals in case of silty and silty sand soil cross-sections. It should be mentioned that the derived formulas could be valid for main and branch silty and silty sand canals of discharge ranging from 2.50 to 322 m^3/sec and for the silty soil distribution canals of discharge ranging from 0.22 to 4.9 m^3/sec.

Application of the Derived Formulas on El-Salam Canal

The derived formulas were applied on the western part of El-Salam canal, in which its first stage was operated in 1996. The different properties were measured at nine cross-sections distributed from km 1.0 to km 75.0. A comparative study was carried out between calculated values of different parameters of the cross-section and both designed and measured corresponding values of these parameters as shown through Figures (54) to (58). Although the working period of the canal is small (five year), the profiles of some measured cross-sections showed that there is a big difference between both measured and designed parameters of these cross-sections.

operated with its full capacity, it takes a part of its regime. It could be concluded that the application of the derived formulas on the selected cross-sections of western part of El-Salam canal showed that the computed values of the different parameters were closer to measured values than designed values of these parameters. The aforementioned observation means that the canal may be obtained a big part of its regime in this small period of operation.

5.CONCLUSIONS

From this paper the following points could be concluded:

1-New regime formulas for rayahat, main canals, and branch canals of silty and silty sand soil having a discharge ranging from 2.50 to 322 m^3/s after the High Dam construction were derived.

2-The regime formulas of the stable distribution canals after the construction of the High Dam were derived to represent silty soil Egyptian canals of discharge ranging from 0.22 to 4.9 m^3/sec.

3-The derived formulas presented in this paper give practical and acceptable design procedures for the Egyptian canals after the construction of High Dam. From these formulas, the cross-sectional area (A), average depth (D), hydraulic radius (R), bed width (B), maximum depth (Y), wetted perimeter (P), and water surface slope (S) could be computed.

4-Since the derived formulas do not contain sediment load term, they should be used when sediment load is too low as the case of the Egyptian canals after the construction of the High Dam.

5-The derived formulas for the silty soil distribution canals having a discharge ranged from 0.22 to 4.9 m^3/sec are as follows:

$P = 7.2737\ Q^{0.5712}$ $D = 0.9966\ Q^{0.4034}$
$B = 6.2691\ Q^{0.5}$ $R = 0.8557\ Q^{0.5574}$
$A = 5.5538\ Q^{0.72}$ $Y = 1.062\ Q^{0.424}$
$S = 11.689\ Q^{0.6346}$

6- The derived formulas for the carrier canals having a discharge ranges from 2.50 m^3/sec. to 322 m^3/sec are as follows:

A- silty sand soil canals

$P = 8.2134\ Q^{0.4331}$ $D = 1.0909\ Q^{0.2019}$
$B = 9.6387\ Q^{0.3238}$ $R = 0.7842\ Q^{0.2611}$
$A = 5.513\ Q^{0.7187}$ $Y = 0.5481\ Q^{0.4049}$
$S = 2.12\ Q^{0.29}$

B- silty soil canals

$P = 8.102\ Q^{0.3927}$ $D = 1.0628\ Q^{0.1759}$
$B = 12.71\ Q^{0.2122}$ $R = 0.756\ Q^{0.1786}$
$A = 5.413\ Q^{0.632}$ $Y = 0.567\ Q^{0.3739}$
$S = 2.16\ Q^{0.279}$

7- The comparison between the derived formulas and some familiar existing formulas in this field by using statistical analysis (F-test & sloping test) led to:

a-The parameters computed by formulas derived Lacey [9], Marshall [11], and Simon [14] are either overestimated or underestimated the corresponding computed values by present derived formulas.

b-The derived formulas by Khattab [8] and Zidan [16] for the Egyptian canals are very close to the corresponding computed values by present derived formulas for the same values of discharge and the same soil type .

8- Application of the derived formulas on both designed and measured cross-sections of El-Salam canal showed that:

a- The computed values of the different parameters of the cross-section are closer to the corresponding measured values than the corresponding designed ones.

b- Although the canal has partially operated from five years only, it has obtained a part of its regime.

9- It may be concluded that the present formulas could help in the design of silty distribution canals, and silty and silty sand main canals for a discharge ranges from 0.22 to 4.9 m^3/s and 2.5 to 322 m^3/s respectively.

NOTATION

The following symbols are used in this research paper:

A cross-sectional area;
B bed width;
C factor depends on sediment size;
D mean water depth;
m factor depends on location;
r correlation coefficient;
R hydraulic radius;
P wetted perimeter of the water cross-section;
Q discharge;
S water surface slope;
T top width of the cross-section;
V flow velocity;
y flow depth; and
Y maximum water depth.

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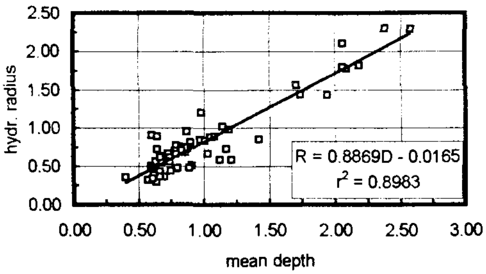


Fig. (1) Relationship between hydraulic radius and mean depth.

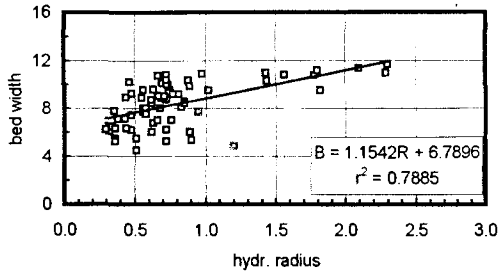


Fig. (2) Relationship between bed width and hydraulic radius.

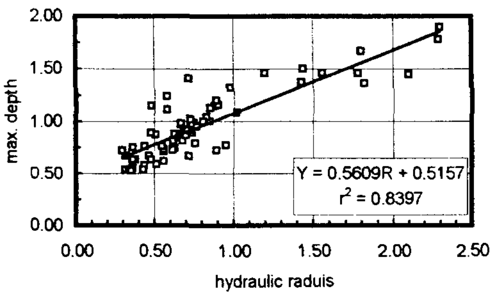


Fig. (3) Relationship between maximum depth and hydraulic raduis.

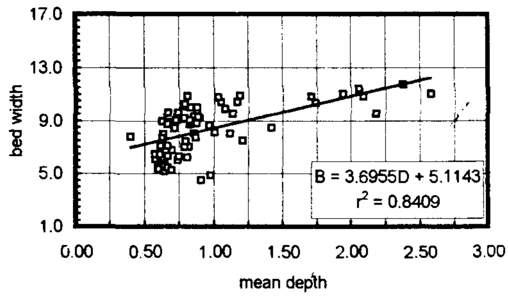


Fig. (4) Relationship between bed width and mean depth.

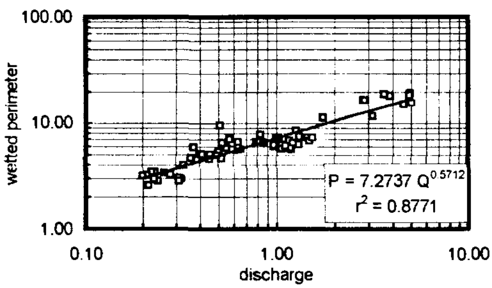


Fig. (5) Relationship between wetted perimeter and discharge.

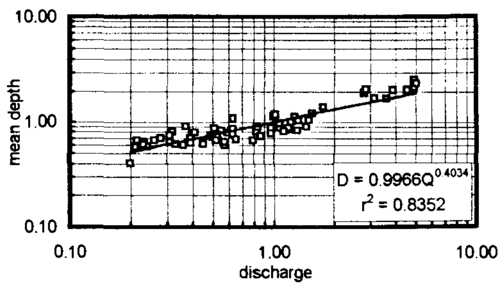


Fig. (6) Relationship between mean depth and discharge.

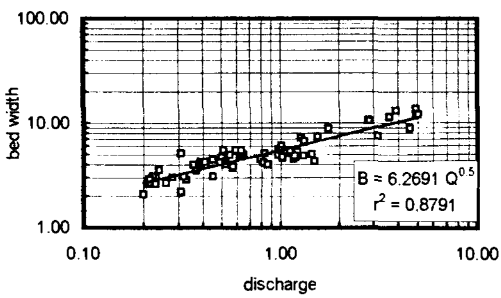


Fig. (7) Relationship between bed width and

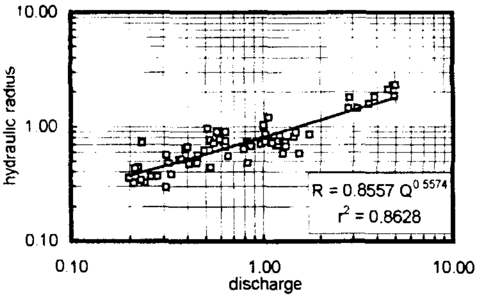


Fig. (8) Relationship between hydraulic radius and discharge

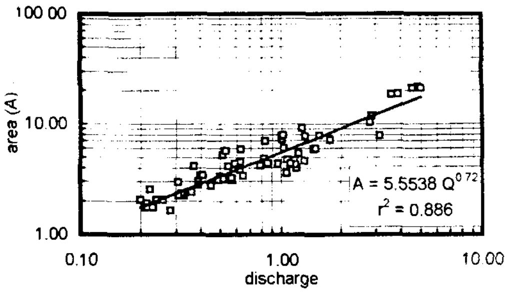


Fig. (9) Relationship between cross-sectional area and discharge

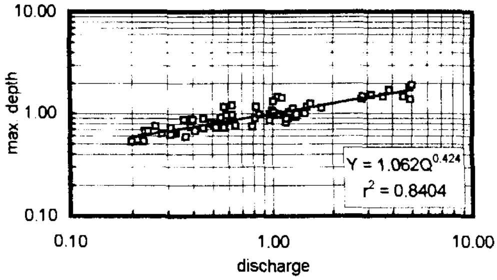


Fig. (10) Relationship between maximum depth and discharge

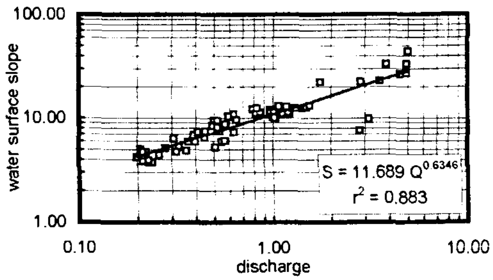


Fig. (11) Relationship between water surface slope and discharge.

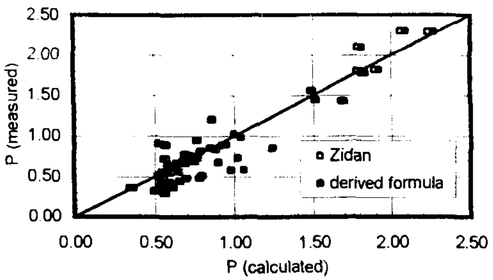


Fig. (12) A comparison betweenmeasured and calculated values of wetted perimeter

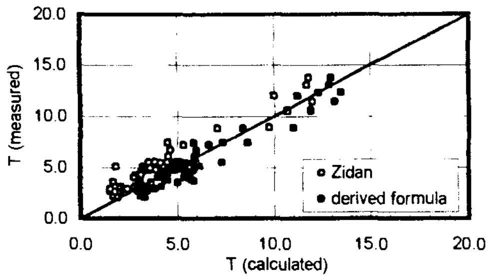


Fig. (13) A comparison between measured and calculated values of top width.

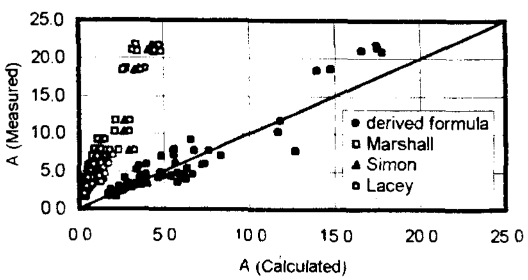


Fig. (14) A comparison between measured and calculated values of cross-sectional area

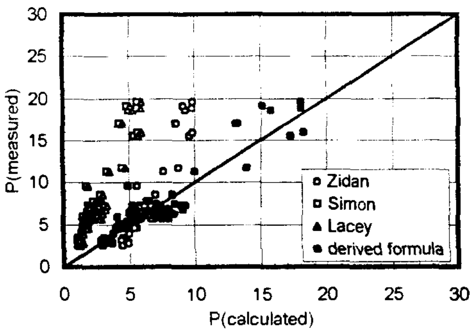


Fig. (15) A comparison between measured and calculated values of wetted perimeter

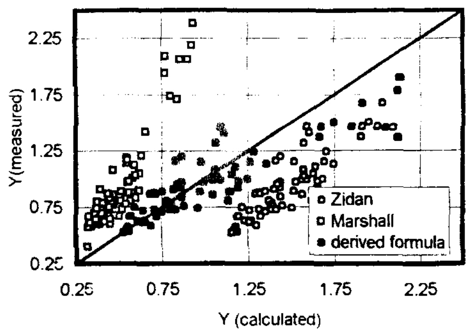


Fig. (16) A comparison between measured and calculated values of maximum depth.

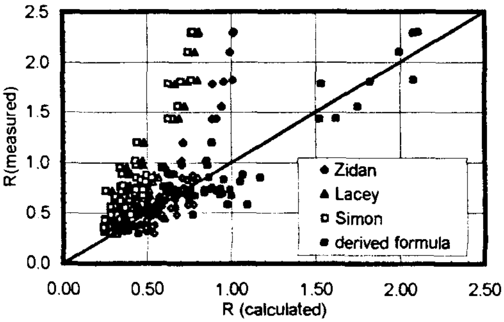


Fig. (17) A comparison between measured and calculated values of hydraulic raduis.

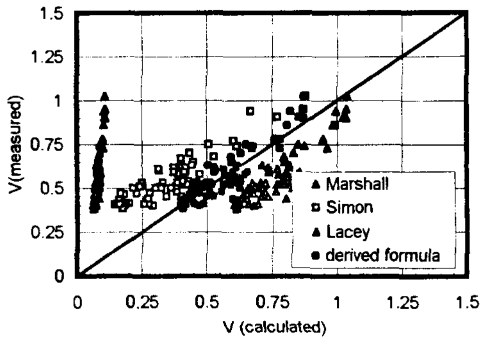


Fig. (18) A comparison between measured and calculated values of mean velocity.

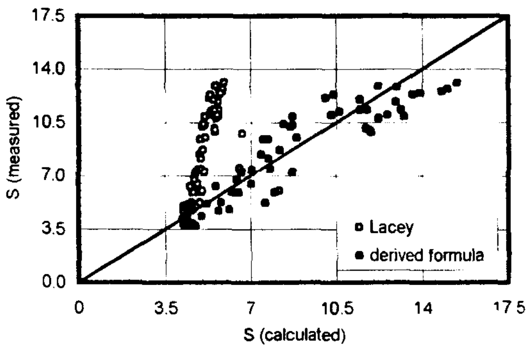


Fig (19) A comparison between measured and calculated values of water surface slope

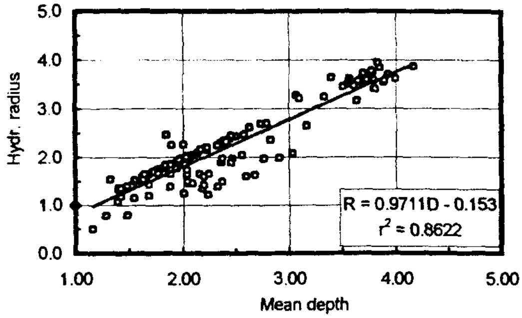


Fig. (20) Relationship between hydraulic radius and mean depth.

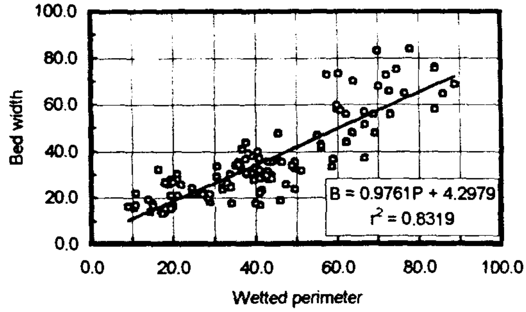


Fig. (21) Relationship between bed width and wetted perimeter.

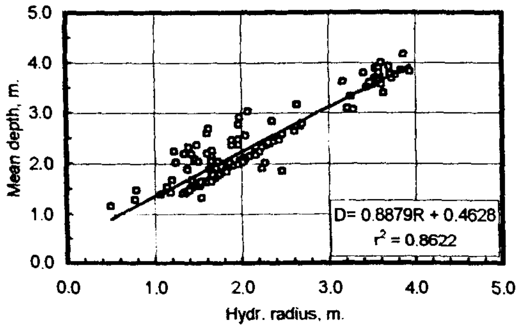


Fig. (22) Relationship between mean depth and hydraulic radius.

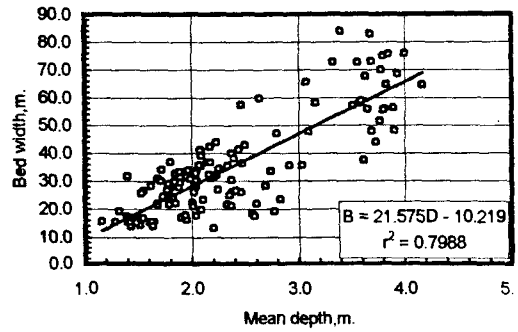


Fig. (23) Relationship between bed width and mean depth.

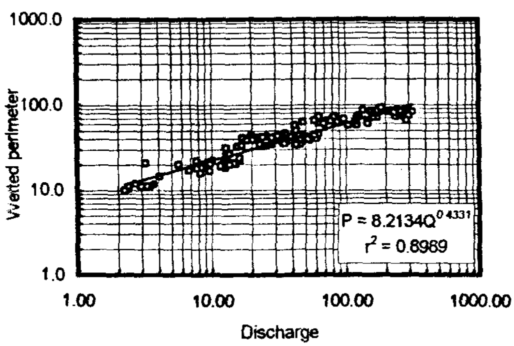


Fig. (24) Relationship between wetted

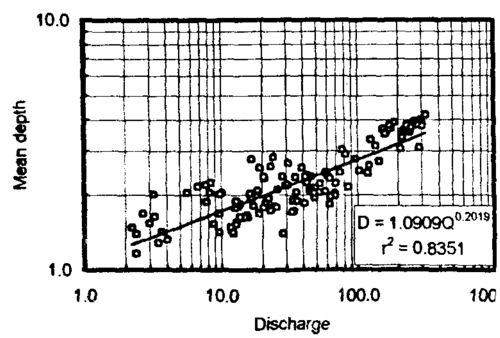


Fig.(25) Relationship between mean depth

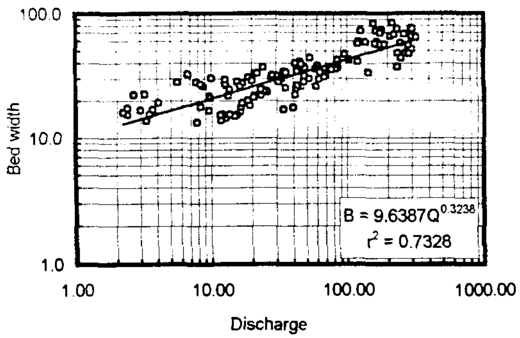


Fig.(26) Relationship between bed width and discharge.

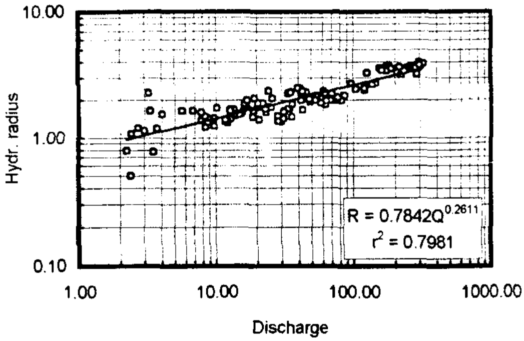


Fig.(27) Relationship between hydraulic radius and discharge.

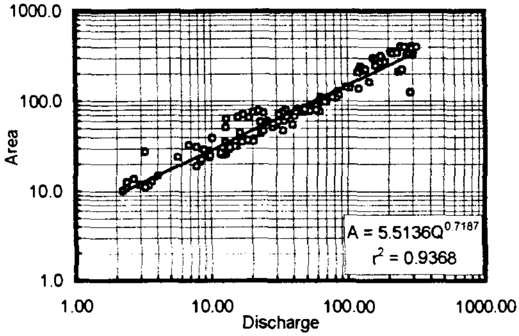


Fig. (28) Relationship between water area and discharge.

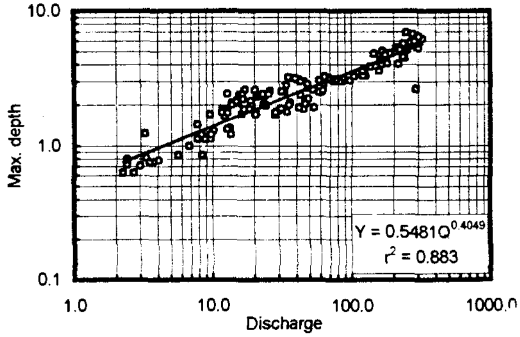


Fig. (29) Relationship between maximum depth and discharge.

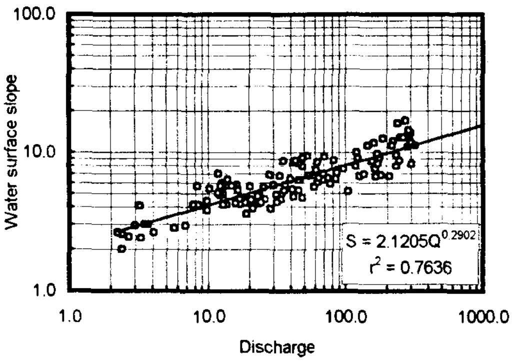


Fig. (30) Relationship between water surface

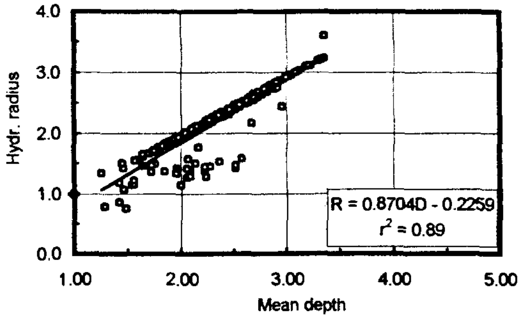


Fig. (31) Relationship between hydraulic radius and mean depth.

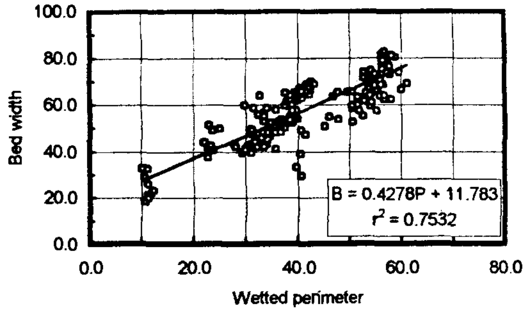


Fig. (32) Relationship between bed width and wetted perimeter.

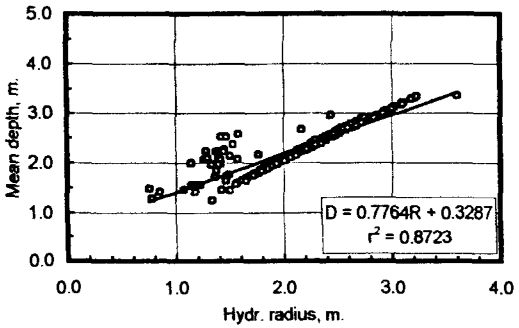


Fig. (33) Relationship between mean depth and hydraulic radius.

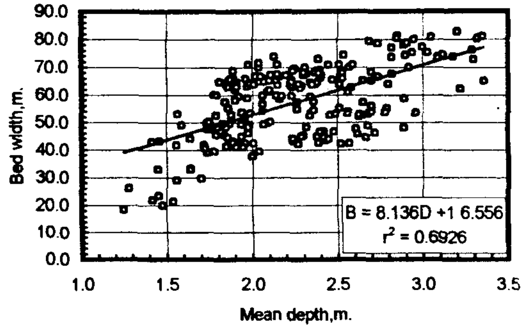
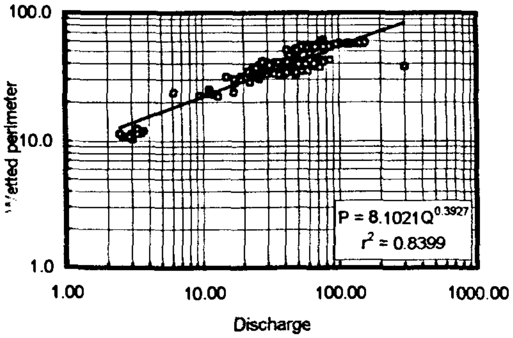
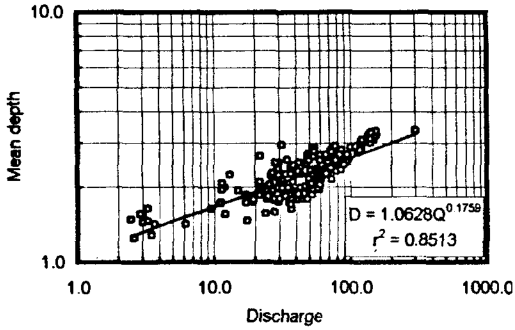


Fig. (34) Relationship between bed width and mean depth.





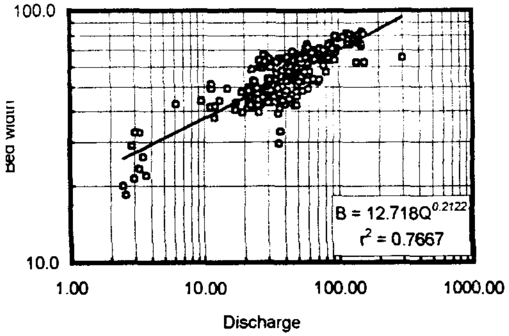


Fig.(37) Relationship between bed width and discharge.

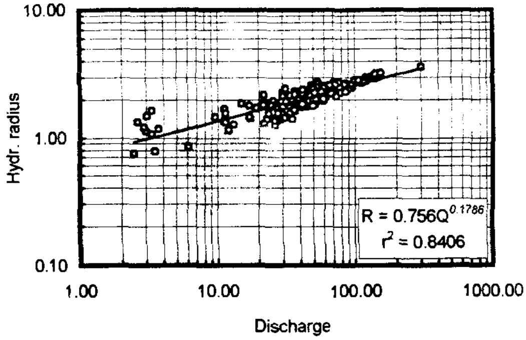


Fig.(38) Relationship between hydraulic radius and discharge.

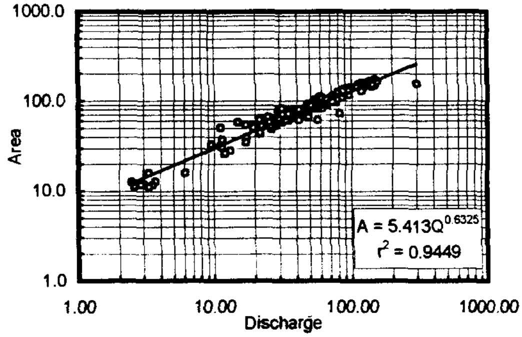


Fig. (39) Relationship between cross-sectional area and discharge.

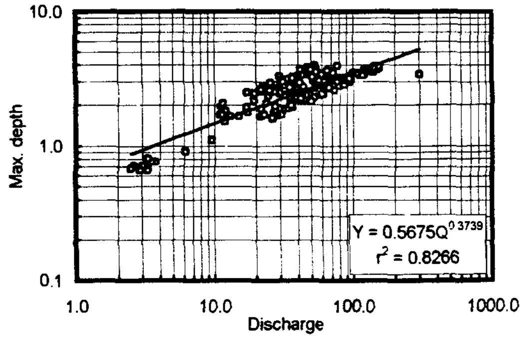


Fig. (40) Relationship between the maximum depth and discharge.

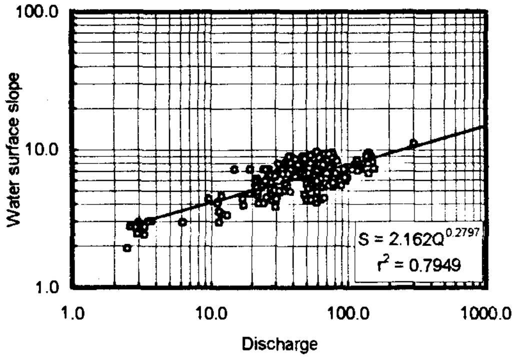


Fig. (41) Relationship between water surface

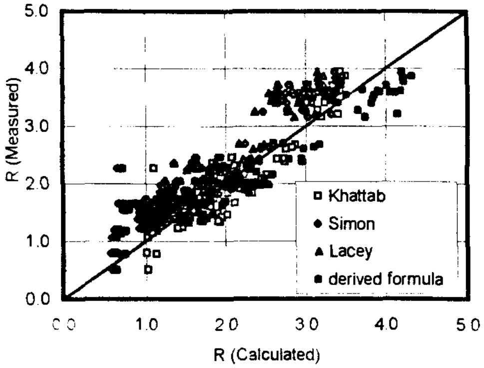


Fig. (42) A comparison between measured and calculated values of the hydraulic radius.

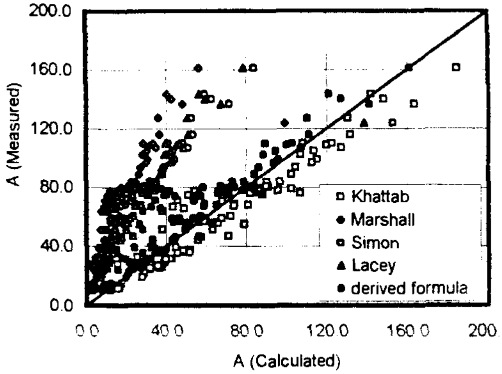


Fig. (43) A comparison between measured and calculated values of the cross-sectional area.

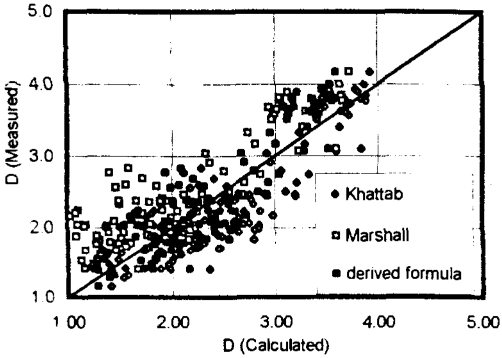


Fig. (44) A comparison between measured and calculated values of the mean depth.

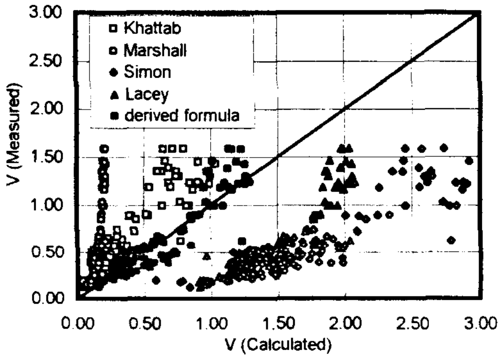
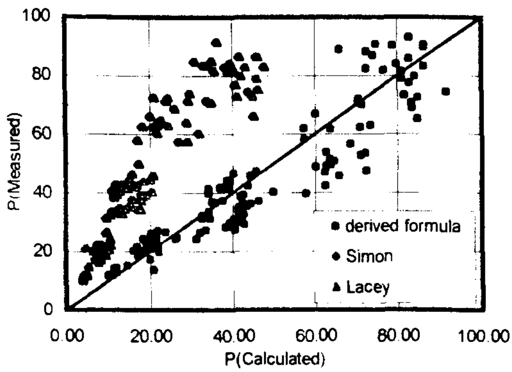


Fig. (45) A comparison between the measured and calculated values of the mean velocity.



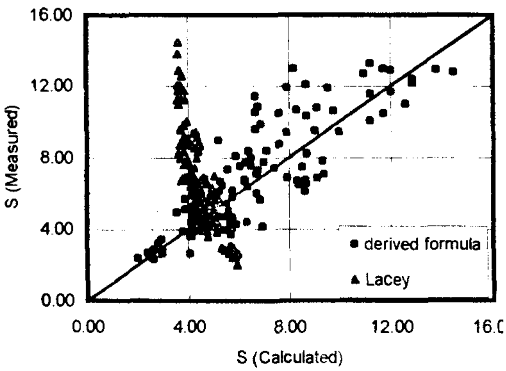


Fig. (46) A comparison between measured

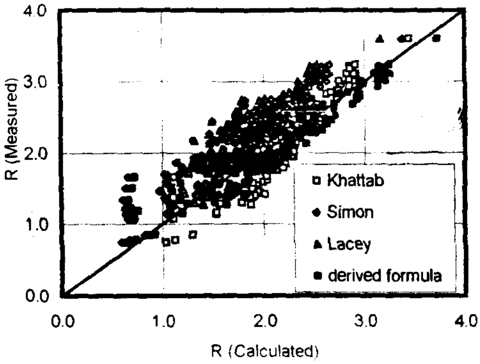


Fig. (48) A comparison between measured and calculated values of the hydraulic radius.

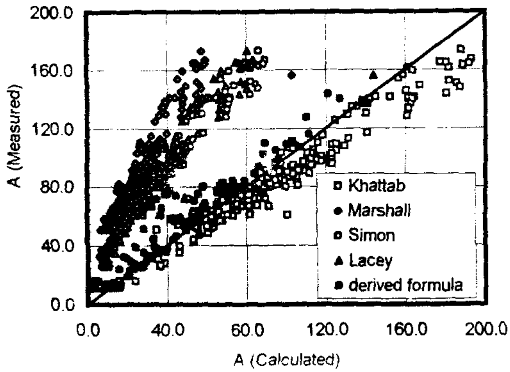


Fig. (49) A comparison between measured and calculated values of the cross-sectional area.

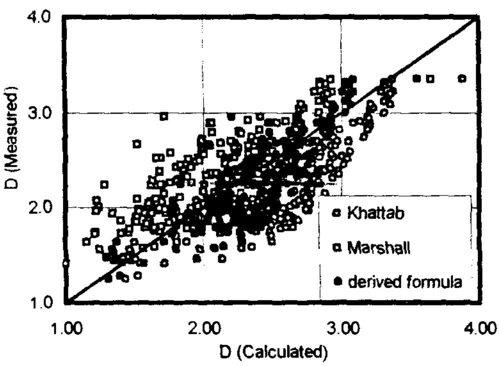


Fig. (50) A comparison between measured and calculated values of the mean depth.

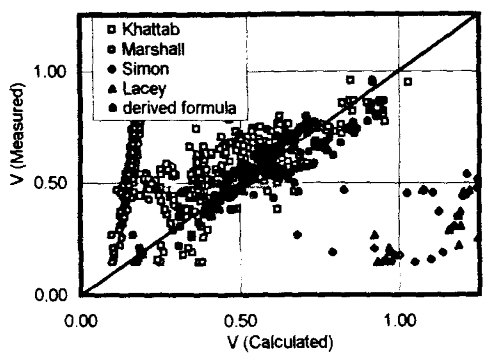


Fig. (51) A comparison between measured and calculated values of the mean velocity.

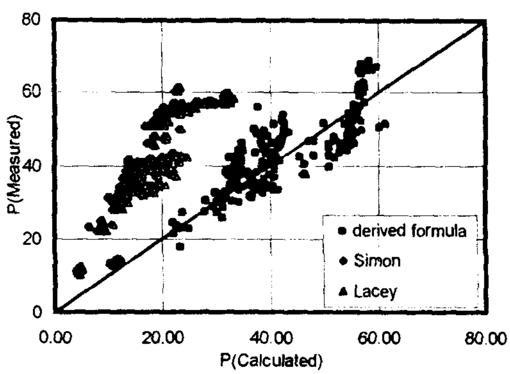


Fig (52) A comparison between measured and calculated values of the wetted

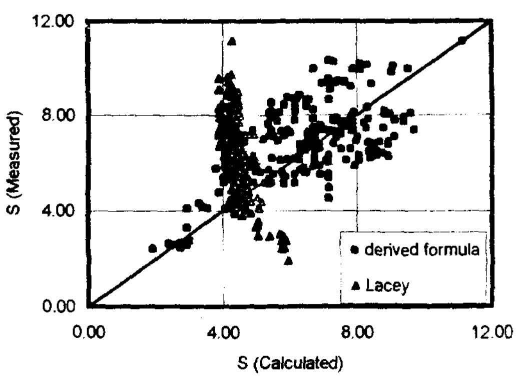


Fig (53) A comparison betwen measured and calculated values of the water surface slope

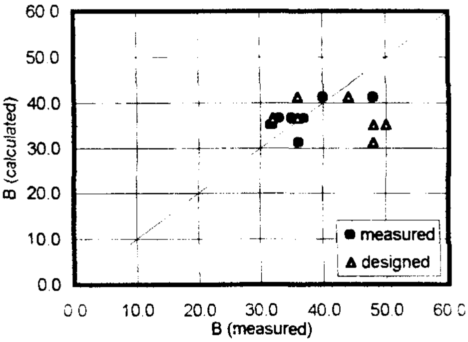


Fig. (54) Relationship between calculated and measured bed width

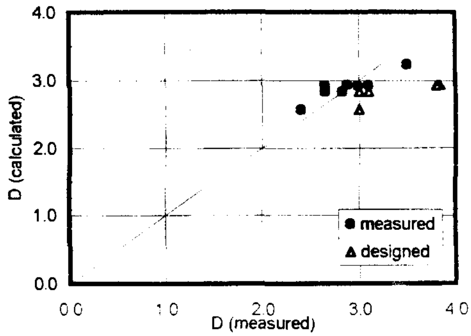


Fig. (55) Relationship between calculated and measured mean depth.

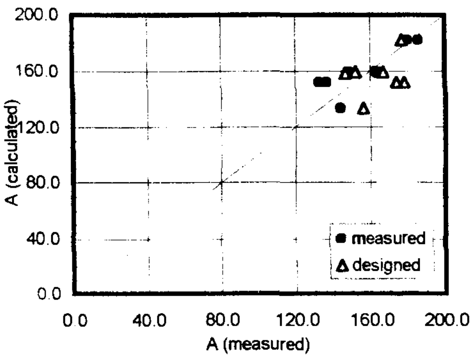


Fig. (56) Relationship between calculated and measured area

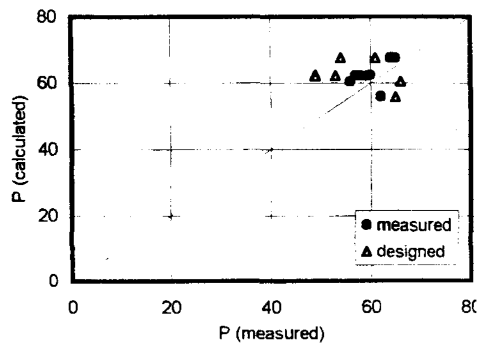


Fig. (57) Relationship between calculated and measured wetted perimeter.

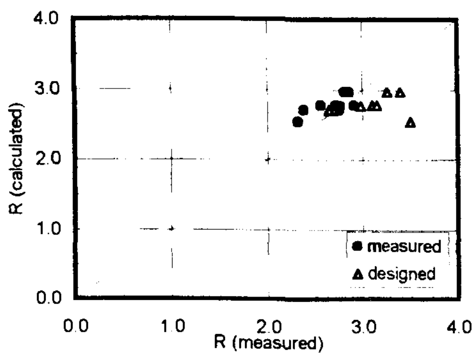


Fig (58) Relationship between calculated

Appendix

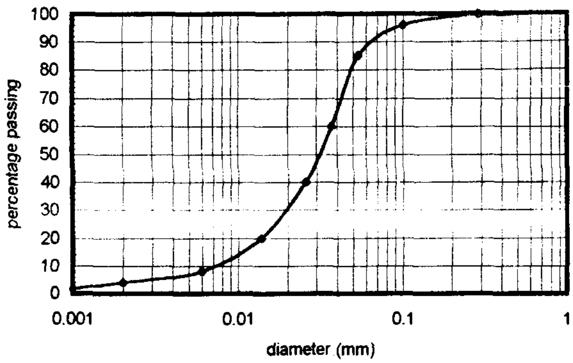


Fig. (1) Grain size distribution of silty soil canals

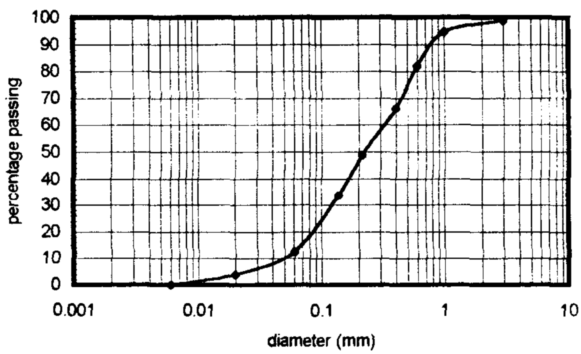


Fig. (2) Grain size distribution of silty sand soil canals