LONGITUDINAL BED FORMATIONS OF DAMIETTA NILE BRANCH

Kassem S. Abd El-Wahab El-Alfy

Associate Prof., Irrigation & Hydraulics Dept., Faculty of Engineering,
Mansoura University, Egypt

ABSTRACT

Predictions of both type and geometrical characteristics of the bed formations in Damietta Nile branch are the main objectives of this research paper. The results indicate that most of the bed forms in Damietta Nile branch are dunes, while a little of these formations are ripples, where Froude number varies between 0.1 and 0.4 (lower regime). Also, the results illustrate that there are big differences between the measured dimensions of the bed formations in Damietta Nile branch and corresponding ones calculated by using other approaches and formulas. The analysis of results shows that the dunes height (Δ) increases weakly with the increase of the particles diameters for a given water depth. It is found that the bed form height in Damietta Nile branch increases as the flow depth increases, which is compatible with Allen [2], Yalin (27], Gill [8], and Saad et al. [18]. Also, the increase of the densimetric Froude number results in increasing the bed formation length and decreasing the bed formation height. By using the analytical regression of the nonlinear relationships, three formulas are developed for computing both the length and the height of the bed formations in Damietta Nile branch, in terms of both flow and bed properties. It should be mentioned that these developed formulas could be valid with good accuracy for the channels with circumstances similar to that existed in Damietta Nile branch. The comparison of the present measured data of Damietta Nile branch and the new developed formulas shows that formula (3), which based on particle mobility parameter (θ), Froude number (F_r), median grain size of the bed particles (D_{50}), and flow depth (d) is the nearest to the field mensurations.

1. INTRODUCTION

The study of the geometric properties of the bed forms is an important factor to understand the effect of the geometric elements of the bed forms on both flow resistance and sediment transport in the alluvial channels. When the flow velocity increases more than the critical velocity by (10%-20%), small ripples are generated at the bed surface by a length much smaller than the flow depth [21]. The mini ripples have asymmetric profile with a relatively steep downstream face and a relatively gentle upstream face. As the velocity increases, the ripples become more irregular in shape and height. The largest ripple may have a length up to the water depth, and is commonly called mega-ripples. The length of mega-ripples ranges between (0.5-1)d, and the height ranges from 0.02d to 0.06d. As the velocity is increased more, the dune-type bed forms are formed with the length related to the water depth with values (3-15) d [21].

The most extensive experimental studies on bed forms in alluvial channels were made by U.S.A. Geological Survey at Colorado State University. Guy et al. [10] stated that the work on predicting bed forms had involved both theoretical and empirical studies, but many researchers stated that the empirical study had been more successful than the theoretical study. In 1957, based on the flume data, Liu [14] described the type of the bed forms in terms of the suspension parameter (U_*/W_s) and the particle-related Reynolds number (U_*D_{50}/ν).

Bed form type $= f\ [U_*/W_s,\ U_*D_{50}/\nu]$,

in which:

U_*	shear-velocity
D_{50}	median grain size of bed particles.
W_s	particle fall velocity of bed material
ν	kinematic viscosity

In 1965, Simons et al. [20] used Froude number (F_r) and the measure of the relative roughness (R/D_{50}) in the classification of the bed forms. In 1968, based on the flume data, Simons and Richardson [21] used the stream power ($\tau_b U$) and the median fall diameter (D_f) as basic parameters in predicting the bed forms. In 1982, Van Rijn, [24] used the dimensionless bed shear stress parameter ($T= (\tau_b^{'} - \tau_b)/\tau_b$) and the dimensionless particle parameter ($D_* = D_{50}[(s-1)g/\nu^2]^{1/3}$) in bed forms classification, in which U is the mean flow velocity, τ_b is the shear-bed stress, and $\tau_b^{'}$ is the shear-bed stress due to surface drag . Also, In 1989, Van den Berg et al. [23] used the mobility parameter ($\theta^{'} = \tau_b/(\rho_s-\rho)D_{50}$) and the particle parameter (D_*) in bed form classifications.

The geometry of the bed forms was investigated by Tsubaki et al. [11], who used the dimensional consideration to show that both the length (λ) and the height (Δ) of the bed forms depend on both flow characteristics and bed material properties. Yalin [26] studied the geometrical properties of the bed forms with the help of the theory of dimensional analysis. By analysing the mechanical process of bed load movement, He suggested the following relationship:

$$\frac{\Delta}{d} = f\left(\frac{\tau_o - \tau_c}{\tau_c}\right)$$

in which: τ_o is the bottom shear, and τ_c is the critical boundary shear.

Also, Yalin [26] proposed that, for large values of a particle-related Reynolds number ($U_*D_{50}/\nu>20$), the dunes are formed with length λ proportional to the flow depth (λ = 5d) , while for small values of $U_*D_{50}/\nu<20$, ripples are formed and λ is proportional to the median diameter of the bed material ($\lambda = 1000D_{50}$). In 1967 Goswami [9] suggested that $d/\lambda = f\ (S,\ d/D_{50})$ and $d/\Delta = f(S,\ d/D_{50})$. Also, He concluded that $\Delta = 0.55\lambda^{0.87}$. Allen [2] proposed that $\lambda/d = d^{0.6}$ and $\Delta/d = 0.086\ d^{0.19}$. Ranga [15] suggested that λ/D_{50} and Δ/D_{50} are functions in $\theta^{'}$, D_{50}, F_r, and d. Based on a few field data of the Nile River, Saad et al. [18] proposed that Δ=0.1d. Also, the effect of bed form on velocity distribution in Nile River was studied by Abdel-Aal et al. [1].

2. THEORETICAL STUDY

Most of the theoretical studies up to date have essentially made use of the two-dimensional potential flow assumptions [15], which are based on the sediment continuity equation:

$$\gamma_s \, dy/dt + dg_s/dx = 0, \tag{1}$$

in which:

- γ_s specific weight of the bed material.
- y height of the bed form at position x along the channel at time t.
- g_s sediment discharge in weight per unit width and time (kg/m-sec).

In 1925, Exner [5] assumed that:

$$g_s = A_o \, U_o \,, \tag{2}$$

in which:

- A_o constant.
- U_o flow velocity near the bed.

Substituting for g_s in Eq. (1) gives Exener's equation as follows:

$$\gamma_s \, dy/dt + A_o \, dU_o /dx = 0 \tag{3}$$

Other theoretical treatments were presented by Anderson [3], Kennedy [13], Simons-Richardson [20], Reynolds [16], Engelund [4], Von Kàrmàn [25], Hayashi [11], Fredsoe [6], [7]. The theoretical analysis of the dune migration was given by Fredsoe [6], [7], based on the continuity equation of sediment, as follows:

$$\frac{\partial z_b}{\partial t} + \frac{1}{(1-p)} \frac{\partial g_s}{\partial x} = 0 \,, \tag{4}$$

in which:

- Z_b the bed level.
- g_s the sediment transport rate in weight per unit width and time (kg/m-sec).
- p the porosity factor.
- t time.

and, the migration velocity (a) of the dunes is given as follows:

$$a = \frac{q_D}{(1-p)\Delta_d} \,, \tag{5}$$

in which:

- q_D amount of sediment transported per unit width in unit time.
- Δ_d dune height.

3. FIELD MENSURATIONS

Since, the predicting of the bed formations in the Nile River is a highly complex subject, an extensive field survey along the entire length of Damietta Nile branch between Zefta city and Damietta city was carried out. Series of both flow parameters and cross-sections characteristics in Damietta Nile branch were measured for nine reaches are located between Zefta Barrages (km 90 from Delta barrages) to Damietta city (km 195). These reaches are located at kms 90.500, 91.0, 91.750, 92.750, 120.700, 124.500, 143.00, 154.600, and 194.00, respectively. The samples of the longitudinal bed profiles of these reaches are illustrated through Figures (1) to (6). The following precautions were considered at the measuring process:

a- The cross-section was selected in stable and straight part.
b- The water surface slope was determined by measuring the water levels at two points with a distance of about 1.0 km.
c- During the measuring period, the local water surface slope, water level and flow discharge at the measuring sites were almost constant.

The measured data in this study were carried out by the writer in co-operation with Hydraulic Research Institute (HRI). The field mensurations of flow properties, bed profiles, velocity profiles, and bed material properties were carried out at the centerline of the cross-sections. At each measuring station, the mensurations were carried out to cover a length ranging between 550m to 1250m. At each location the following mensurations were performed:

1- The bed surface profiles were measured by using echo sounder.
2- Flow velocity profile was determined along the flow depth by using propeller current-meter. The flow velocity was measured at 0.18 m, 0.37 m and 0.50 m above the bed level by using three Braystoke current-meters attached to the Nile Delft Fish sampler. For the height equals to 0.50 m above the bed level to the water surface, the flow velocity was measured by using Braystoke current-meter attached to the Delft Fish apparatus.
3- One sample of the bed material was taken at each measuring station by using Van Veen grab sampler.
4- The bed load samples, taken at each location in the measuring station, were separately dried, weighed and put together to obtain a bulk sample, which represents the bed load material at this measuring station. Grain size distribution of the bed material at each measuring station was also analysed.

4. ANALYSIS AND DISCUSSION OF THE RESULTS

Some samples of the bed profiles are illustrated through Figures (1) to (6). Both the bed form length (λ) and the bed form height (Δ), of the different reaches are measured from these bed profiles.

Figure (7) shows the relationship between the bed forms height and the bed forms length. From Figure (7), it can be concluded that the bed form height increases when the bed form length increases, which was verified by Allen [2], Yalin [26], Gill [8], and Saad et al. [17]. Figures (8) and (9) show the relationships between both the bed forms length (λ) and bed forms height (Δ) versus the densimetric Froude number (F_{ND}). The figures show that increase the values of the densimetric Froude number causes increase in both the bed form length and the bed form height. The foregoing result could be explained due to the fact that the increase of F_{ND} means an increase in the flow velocity and a decrease in D_{50} of the bed material. The high velocity carries the bed particles to a long distance, which increasing the bed form length and hence, the bed form height, which depending on the angle of repose of the bed material. Figures (10) and (11) show the relationships between the flow depth and both the bed form length and the bed form height respectively. These figures demonstrate that both the bed form length and the bed form height are directly proportional to the flow depth.

4.1 Types of bed forms in Damietta Nile branch

The theoretical approaches illustrate that the length of ripples bed forms ranges from 0.5d to d, and their height ranges from 0.02d to 0.06d [24], while the dunes-type bed form length is strongly related to the water depth with values of the range 3d to 15d. The field measurements in Damietta Nile branch illustrate that most values of the bed forms length are larger than the corresponding flow depth. This means that from the theoretical view, the bed forms in Damietta Nile branch could be classified as dunes. Also, the graphical classification is used in the investigation the type of the bed forms in Damietta Nile branch. As a result of this investigation, Figures (12) and (13) introduce a classification of bed forms in Damietta Nile branch according to Simons and Richardson [20], and Simons and Sentürk [19] respectively, which are widely accepted. Also, Figure (14) shows the classification of the bed forms as described by Simon and Senturk [19] in terms of the suspension parameter (U_*/W_s) and the particle-related Reynolds number (U_*D_{50}/ν). The bed forms could be classified depending on F_r and R/D_{50} as shown in Figure (15), because Froude number (F_r) is the best for describing the effect of the inertia and the gravitational forces on the system and R/D_{50} is a measure for the relative roughness. As shown in the aforementioned figures most of the bed forms in Damietta Nile branch are dunes, while very small forms are ripples.

4.2 Comparative study between the predicted and the measured bed forms in Damietta Nile branch

The dimensions of the bed forms (height and length) in Damietta Nile branch are computed by using the formulas derived by Allen [2], Gill [8], Yalin [27], Van Rijn [24] and Saad et al. [18]. Figures (16) and (17) show the comparison between measured and computed values of the bed forms length (λ) and the bed forms height (Δ) at the different measured reaches. From these figures, it is found that there are discrepancies between both the measured and the predicted bed forms dimensions. These discrepancies could be explained due to the fact that the derivation of those formulas based mainly on the flume data or few field data, with boundary conditions different from that existed in Damietta Nile branch. Also, the figures show that Van Rijin [24] and Saad et al. [18] approaches are the nearest to Damietta Nile branch data. This can be explained due to the fact that Van Rijin [24] formula was derived from the field data, and Saad et al. [18] formula which was derived depending on the data of Nile River, in Egypt.

4.3 Developed formulas for bed forms characteristics in Damietta Nile branch

Based on the analytical regression of the non-linear relationships, the following formulas are derived for Damietta Nile branch for both bed form length (λ) and the bed form height (Δ):

Approach (1)

These formulas were derived in terms of different factors affecting the bed form characteristics as the densimetric Froude number (F_{ND}), the measure of the relative roughness (R/D_{50}), the Froude number (F_r), and the mobility parameter (θ^-) related to the bed form:

$$\frac{\lambda}{d} = 2.95\,[F_{ND}]^{0.21}\left[\frac{R}{D_{50}}\right]^{0.21}[F_r]^{0.72}[\theta^-]^{-0.06} \tag{6}$$

$$\frac{\Delta}{d} = 9.64\,[F_{ND}]^{-0.23}\left[\frac{R}{D_{50}}\right]^{-0.51}[F_r]^{-0.51}[\theta^-]^{0.30} \tag{7}$$

Approach (2)

The following formulas were derived according to Ranga approach [15] in terms of the mobility parameter (θ^-), the bed median grain size (D_{50}), Froude number (F_r), and the flow depth (d) as follows:

$$\frac{\lambda}{D_{50}} = 8.277\,[\theta^-]^{-0.284}[D_{50}]^{-1.15}[F_r]^{0.258}\,d^{0.786} \tag{8}$$

$$\frac{\Delta}{d} = 0.42\,[\theta^-]^{-0.035}[D_{50}]^{0.0031}[F_r]^{-0.116}\,d^{0.66} \tag{9}$$

Approach (3)

Also, the following simple formulas were derived based on the flow depth [18].

$$\Delta = 0.427\ d^{0.57} \tag{10}$$

$$\lambda = 99\ \Delta^{1.45} \tag{11}$$

in which

- θ' particle mobility parameter related to grains.
- F_r Froude number.
- d flow depth.
- R/D_{50} the measure of the relative roughness.
- F_{ND} densimetric Froude number = $\dfrac{U}{\sqrt{gd_{50}(G_s-1)}}$.

The comparisons between the results of applying the derived formulas and the corresponding measured field data for both bed form length and bed form height are shown in Figures (18) and (19) respectively. The figures show that formulas of approach (1) and approach (2), which depend on densimetric Froude number, particle mobility parameter, Froude number, bed particles, and flow depth are the nearest to the field measurements. It should be recorded that the aforementioned formulas can only be valid with good accuracy for the channels having the similar circumstances to that existed in Damietta Nile branch.

5. CONCLUSIONS

From this paper, the following points can be concluded:

1- Most of the bed forms in Damietta Nile branch are dunes, while the small forms are ripples.
2- There are big differences between the measured bed forms dimensions in Damietta Nile branch and those calculated by using the other approaches and formulas except those of Van Rijin [24] and Saad et al. [18] formulas.
3- The analysis of the present measured data in Damietta Nile branch shows that the dunes height increases weakly with the increase of the particle diameter for a given flow depth.
4- The increase of densimetric Froude number results in increasing both the bed form length and the bed form height for dune forms.
5- The bed form height in Damietta Nile branch increases as the flow depth increases, which was verified by Gill [8], Yalin [27], Allen [2], and Saad et al. [18].
6- Based on the analytical regression of the non-linear relationships, three formulas were developed to calculate both the bed form length and the bed forms height in Damietta Nile Branch in terms of both flow properties and bed material characteristics.
7- The comparison between the present measured data in Damietta Nile branch and the results of applying the new derived formulas shows that, formulas of approach (1) and approach (2), which are based on particle mobility parameter, Froude number, bed particles, and flow depth are the nearest to the field measurements.

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LIST OF SYMBOLS

The following symbols are used in this paper:

A_o constant;
D_{50} particle diameter of which 50% of the sediment mixture is finer;
d flow depth;
p porosity factor;
F_r Froude number;
F_{ND} densimetric Froude number;
g_s sediment discharge in weight per unit width and time (kg/m-sec);
q_D amount of sediment transport per unit width in unit time;

R/D_{50} measure of the relative roughness;
U mean flow velocity;
U_o flow velocity near the bed;
U_* shear velocity;
W_s particles fall velocity of bed material;
z_b bed level;
γ_s specific weight of the bed material;
λ bed form length;
Δ bed form height;
ν kinematics viscosity;
τ_o bottom shear;
τ_c critical boundary shear; and
θ' particle mobility parameter related to grains.

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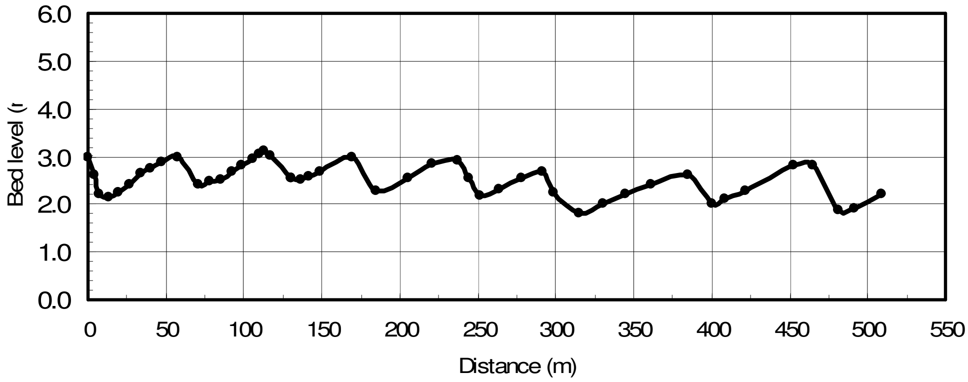

Fig. (1) Bed formation in Damietta Nile branch (Km 90.000-90.600).

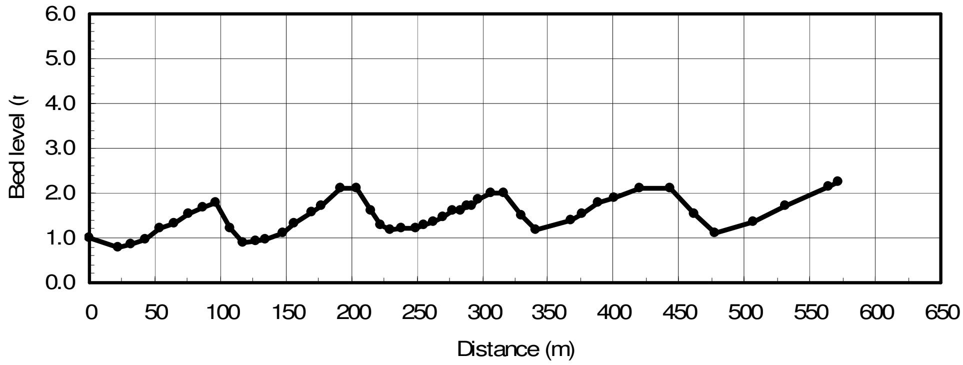

Fig. (2) Bed formation in Damietta Nile branch (Km 91.500-92.000).

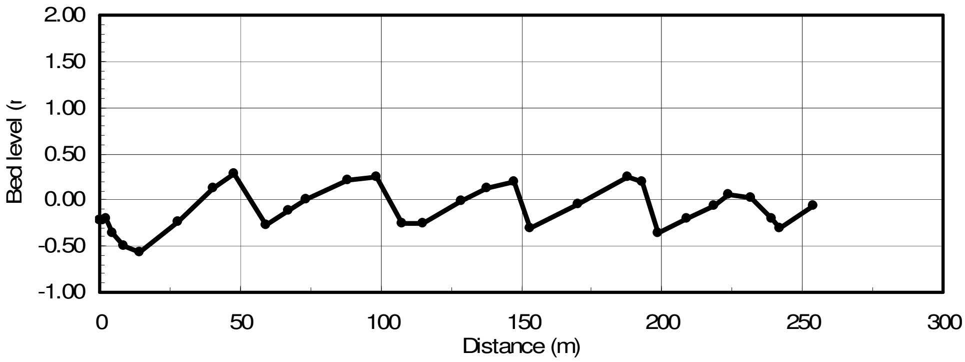

Fig. (3) Bed formation in Damietta Nile branch (Km 105.50-05.355).

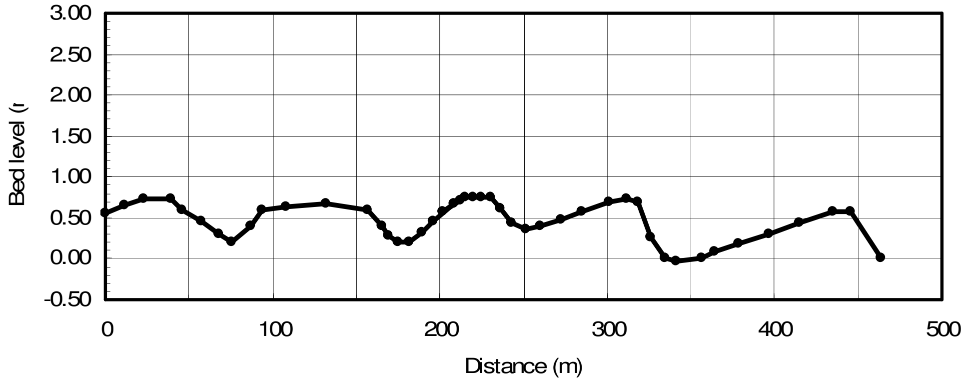

Fig. (4) Bed formation in Damietta Nile branch (Km 142.500-143.170).

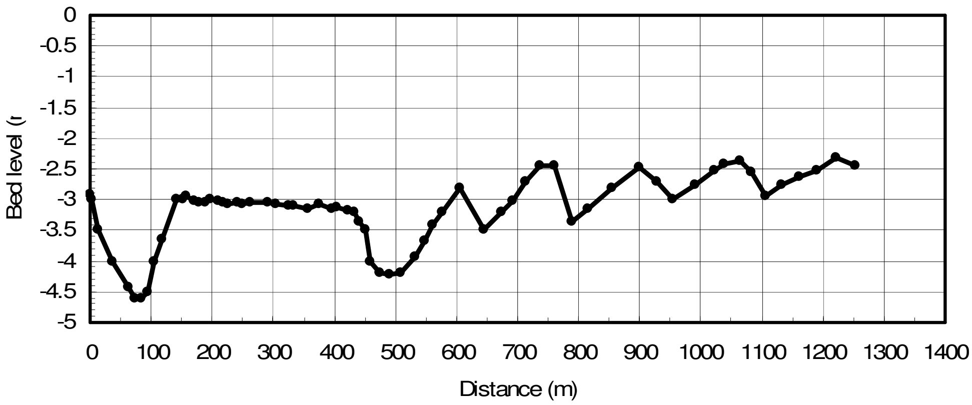

Fig. (5) Bed formation in Damietta Nile branch (Km 154.250-55.340)

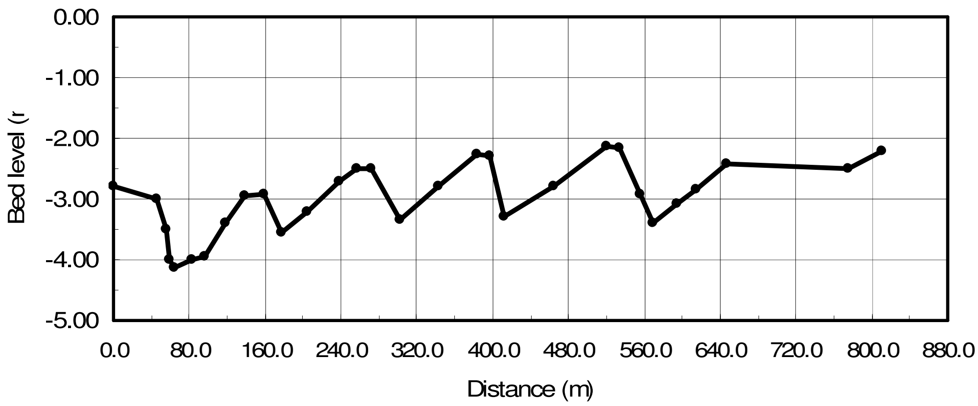

Fig. (6) Bed formation in Damietta Nile branch (Km 183.100-183.910)

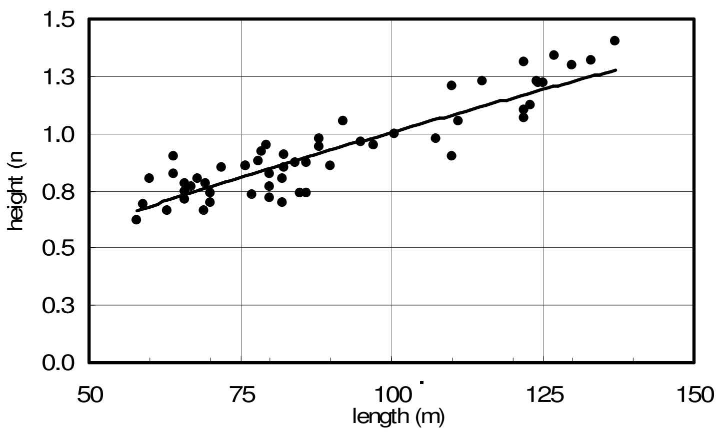

Fig. (7) Relationship between bed form height and bed form length.

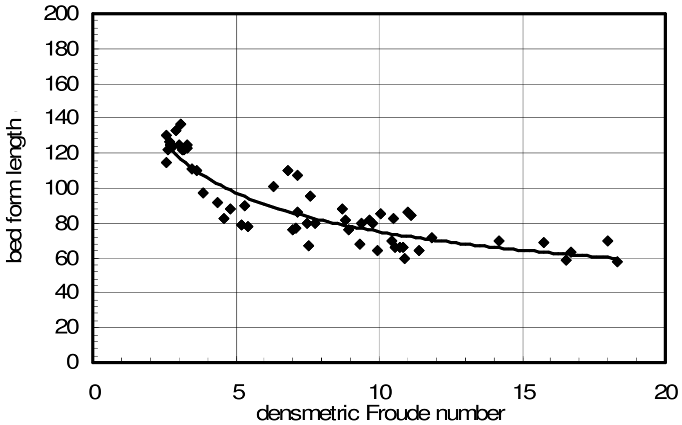

Fig. (8) Relationship between bed form length and densimetric Froude number.

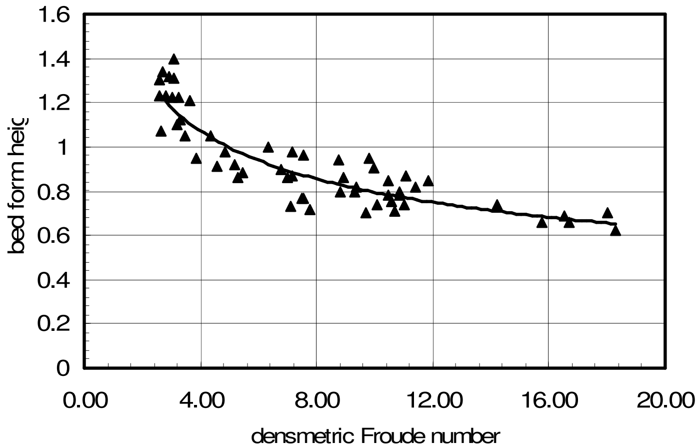

Fig (9) Relationship between bed form height and densimetric Froude number.

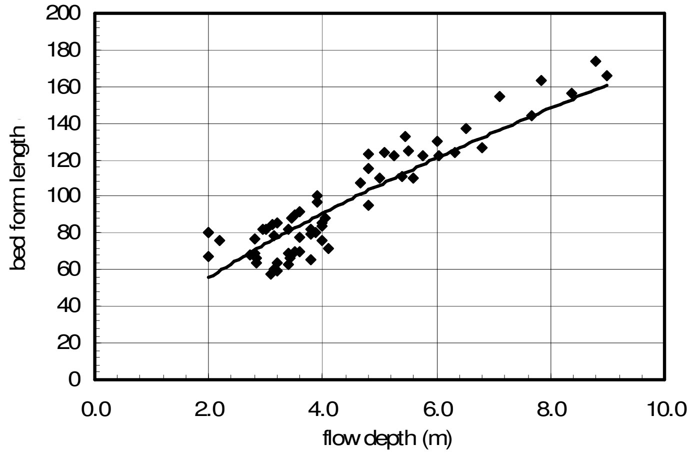

Fig (10) Relationship between bed form length and flow depth.

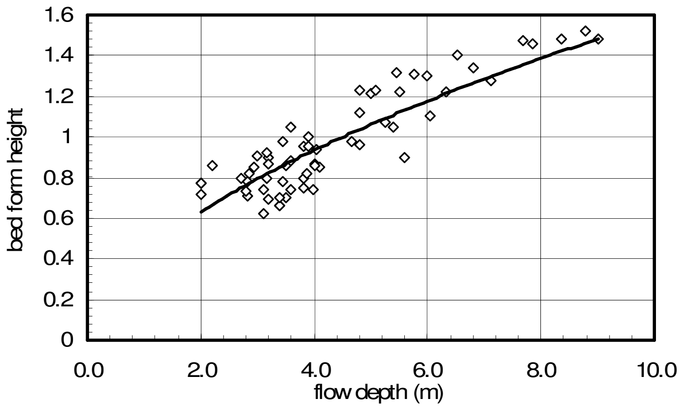

Fig (11) Relationship between bed form height and flow depth.

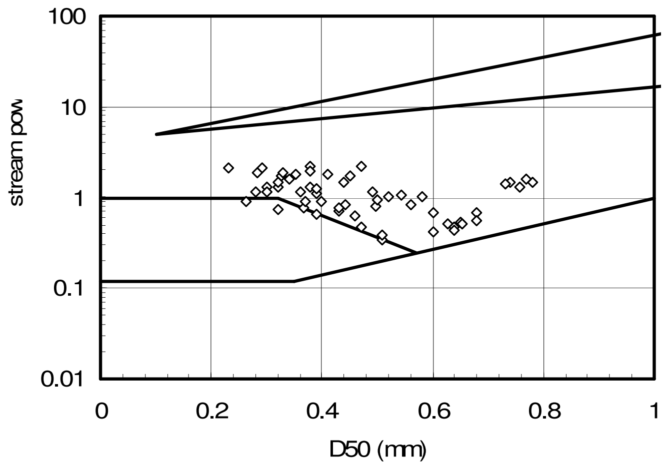

Fig (12) Bed form classifications of Damietta Nile branch according to stream power and median diameter (after Simon and Richardson [20]).

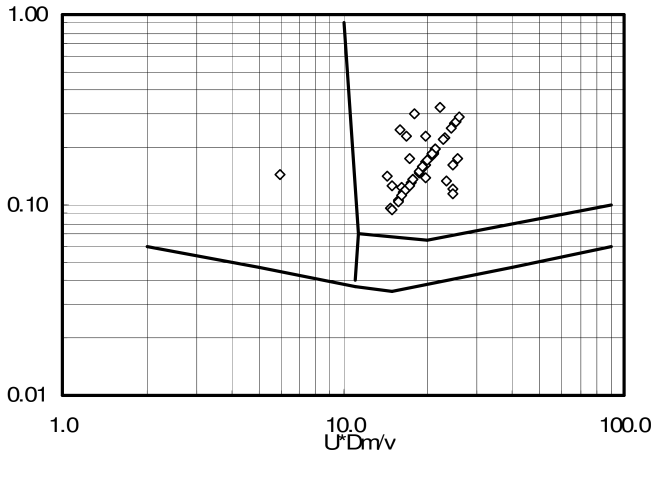

Fig (13) Bed form classifications of Damietta Nile branch (after Simon and Senturk [19]).

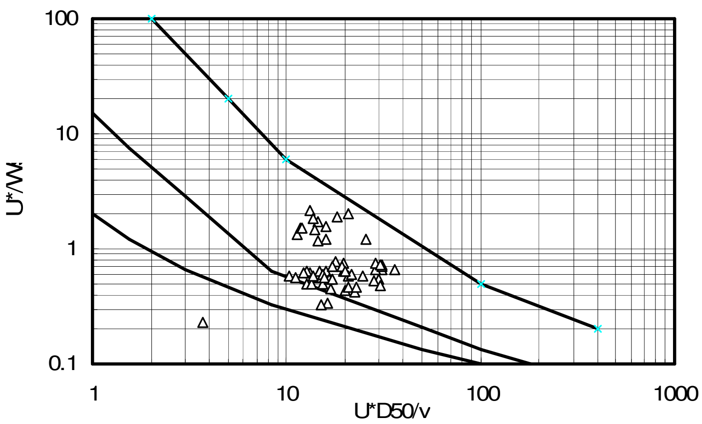

Fig (14) Bed form classifications of Damietta Nile branch (after Simon and Senturk, 1969).

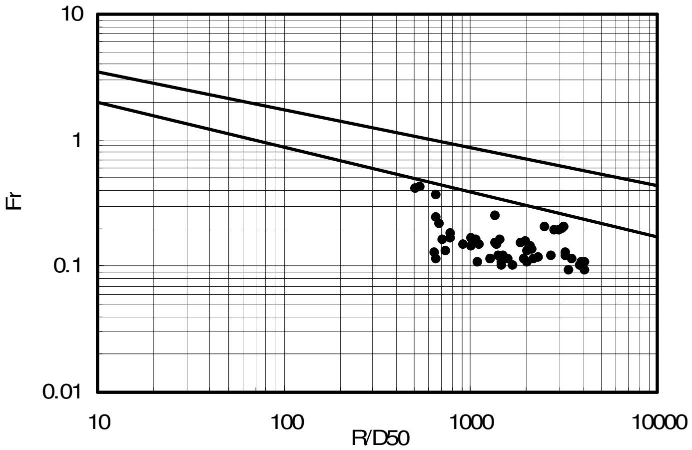

Fig (15) Classification of bed forms in Damietta Nile branch as a function of Froude number and measure of relative roughness (after Simon, 1968)

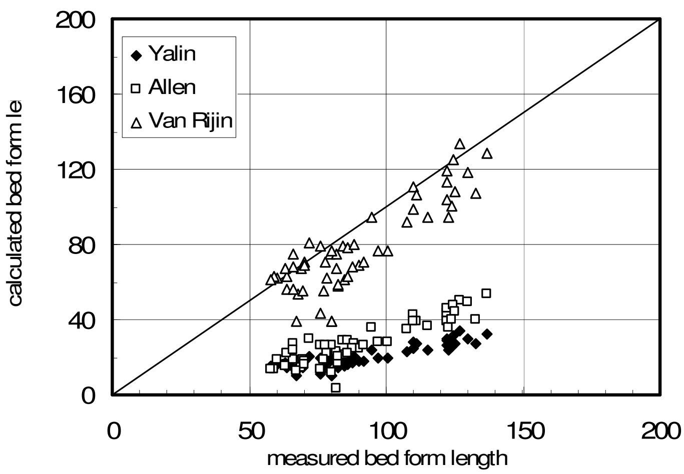

Fig (16) A comparison between calculated and measured values of the bed form length.

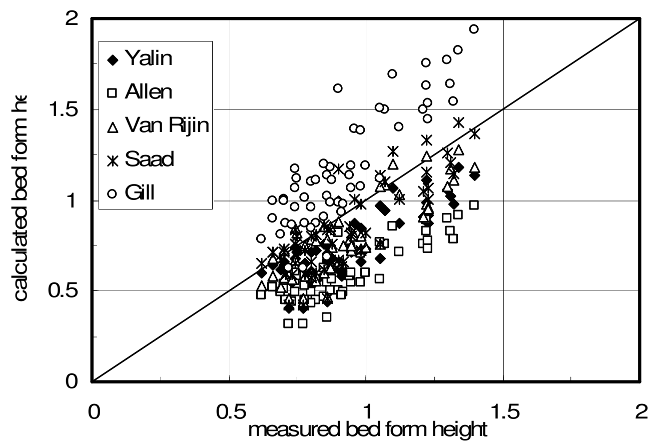

Fig (17) A comparison between calculated and measured values of the bed form height.

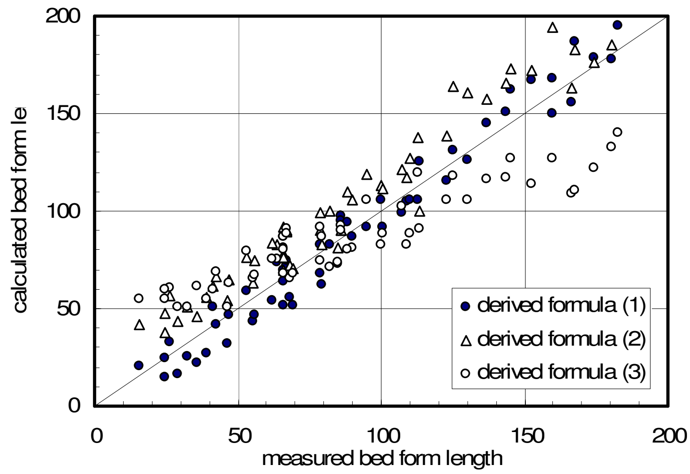

Fig (18) A comparison between calculated and measured values of the bed form length.

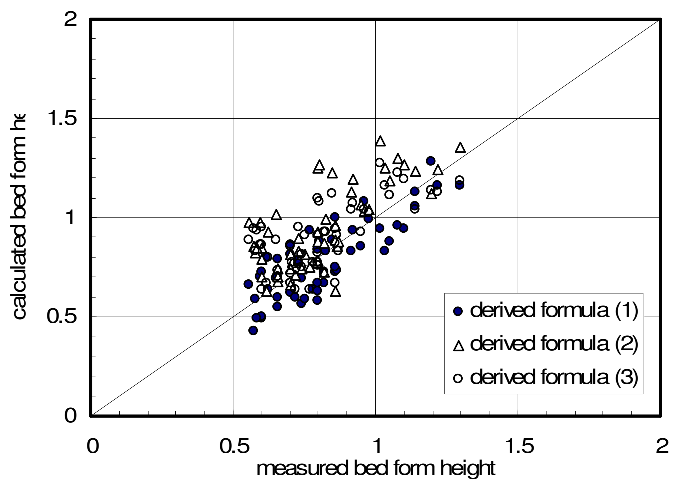

Fig (19) A comparison between calculated and measured values of the bed form height.