Evaluation of closure depth along the northern Nile delta coast, Egypt

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The closure depth is defined as the minimum water depth at which no measurable changes in the sea bottom level are observed. The line of closure depth represents a boundary that separates the area characterized by cross-shore active sediment transport and the area of deep water where negligible sediment motion occurs. The present study used extensive records of cross-shore field data along the northern coast of Egypt; from Alexandria to Burullus, for three periods of 1920, 1976, and 1984, to develop a new equations for estimating the closure depth. Results from the obtained expressions are compared with results of several previous expressions of scientific evidences. The new developed expressions give a good agreement with field measurements compared with the previous published expressions.

يعتبر العمق الذى تبدأ عنده حركة الرسوبيات(closure depth) بأنه أقل عمق للمياه المقاسة والتى عندها يبدأ حدوث تغيرات فى قاع البحر. والخط الواصل لأعماق (line of closure depth) على طول اتجاه الساحل يمثل حدا فاصلا بين مناطق نشاط حركة الرسوبيات العمودية على الشواطئ ومنطقة المياه العميقة ذات النشاط الضئيل لحركة الرسوبيات. فى هذا البحث استخدمت قياسات مكثفة لبيانات القطاعات البحرية المتوافرة على طول الساحل الشمالى لجمهورية مصر العربية والتى تمتد من الاسكندرية الى البرلس لثلاث فترات زمنية لأعوام ١٩٢٠و١٩٧٦و١٩٨٤ وذلك بغرض استنتاج معادلات جديدة لتحديد (closure depth). قورنت النتائج المستنتجة فى هذا البحث مع العديد من النتائج المتاحة والمؤكدة علميا. وقد أعطيت المعادلات الجديدة توافقا طيبا مع البيانات الحقلية المقاسة بالمقارنة مع نتائج الأبحاث السابقة.

Keywords: Closure depth, Cross-shore, Seaward, Near shore, Line of closure depth

1. Introduction

Closure depth may be defined in several ways; it is defined as the depth at which the dynamic forces in the sea can no longer produce a measurable change in bottom, or the depth beyond which no significant longshore and cross-shore transport take place due to littoral transport processes, or the depth at the seaward boundary of the littoral zone. The closure depth is obviously deeper then that portion of the beach profile that changes seasonally or due to storm.

The measure of closure depth has an important use for a number of applications such as placement of mounds of dredged material to reduce wave action, beach fill, placement of ocean outfalls and sediment budget calculations.

In the past few decades, several researchers have studied closure depth. Among of them, Hallermeier [1], Birkemeier [2], Naffa [3] and Nicholls et al. [4]. The obtained expressions for closure depth have contained the effective parameters, such as significant wave height, the corresponding period, the median grain diameter and gravity acceleration.

Starting from 1971, a monitoring programs have been launched to study changes in the nearshore zone of the Nile Delta coast by the Coastal Research Institute (CoRI), Egypt. A series of annual beach profiles, covering the Nile delta coast and extending to 6.0 m depth, have been obtained. The analysis of these profiles for the last 30 years denoted the presence of a seaward limit (closure depth) beyond the 6.0 m depth. In this study, the field data are obtained from contour maps covering the coast from Alexandria to Burullus for the three periods 1920, 1976 and 1984 up to 50.0 m depth, and from profile surveys for Alexandria and Abu Quir Bay during the period of 2001 to 2003, which extends to approximately 15.0 m depth. In this research a new expression has been obtained for estimating the closure depth in front of the Egyptian delta coast by using the technique of statistical regression analysis. The effective parameters such as wave height, wave period, and grain size are presented in the analysis. A comparison between the developed expression and the well known previously equations for closure depth estimation was carried out. The developed expression gives much better agreement with the observed data rather than previous equations.

2. Background on closure depth expressions

Geological studies indicate that fine material in the bottom are winnowing from the surface sediments over the shelf, Shepard [5] and Dietz [6]. Silvester and Mogeride [7] noted that extreme waves are able to cause sand motion at water depths in the order of 100 m, far out from the continental shelf and beyond usual estimates of the wave dominated bottom. Komar et al. [8] showed that oscillatory ripple marks generated by surface waves have been observed on the interface of the continental shelf to depths of 100 m and as deep as 200 m during storms. The CERC [9] suggested that waves are able to move bottom sediments over most of the continental shelf (for depths of 30m to 130m or more) during the year.

A widely used expression for the depth of closure was derived by Hallermeier [1] and modified by Nicholls et al. [4] as follows:

$$dc = 2.28\, H_{s(12h,t)} - 68.5\ \frac{H^2_{s(12h,t)}}{g\, {T_s}^2}\ , \quad (1)$$

where *dc* is the depth of closure derived from the time of observation *t*, *g* is the gravitational acceleration, T_S is the associated wave period and $H_{s\,(12h,t)}$ is the extreme maximum wave height of non breaking waves that occur for more than 12 hours during time *t*, which occurs only 0.137 % of the time, in which.

$$H_{s\,(12h,\,t)} = H_s + 5.6\ \delta_H\ . \quad (2)$$

Where H_s is the mean significant wave height and δ_H is the standard deviation in annual wave heights. As time of observation increases, *dc* also increases (since the highest significant wave height is likely to increase), and this formulation is not valid in situations of accretion. Hands [11] measured a series of beach profiles from the east shore of Lake Michigan. His analysis has showed a wide envelope of profile changes in the shallower water of the nearshore pinching out in the offshore.

Based on wave and sediment characteristics, analytical model has been developed by Hallermeier [12]. He proposed that the extreme maximum wave height given by eq. (2) may be unrepresentative in defining the closure depth due to consideration involved in sampling rare events .Thus, he used the mean significant wave height H_s in eq. (4). Hallermeier divided the shore normal profile into three submarine zones parallel to the shoreline. The middle or shoal zone is intended to be a buffer region where expected surface waves have neither strong nor negligible effects on the sand bottom. The two water depths bounding the shoal zone are d_c and d_{cl}, where d_{cl} is the depth where significant alongshore transport and intense on/offshore transport by waves are restricted to water depths less than d_{cl} and significant on/offshore transport by waves is restricted to water depths less than d_c. He derived a generally more restrictive water depth independent of observation time as follows,

$$dc = H_{sm}\ T_S \sqrt{\frac{g}{5000\ D_{50}}}\ , \quad (3)$$

$$d_{cl} \cong 2H_s + 11\delta_H\ , \quad (4)$$

where H_{sm} is the mean of the annual distribution of significant wave height, T_s is the corresponding period, δ_H is the standard deviation and D_{50} the median grain diameter. Birkemeier [2] presented another approach for determining the closure depth based on the analysis on bathymetric data, which obtained in different seasons and different years. The following equation is derived as:

$$d_c = (1.5 \leftrightarrow 2.0)1.75H_s - 57.9(H_s^2/g\ T_s^2)\ . \tag{5}$$

A similar expression is presented by Nicholls et al. [4] as follows:

$$d_c = 2.28H_s - 68.5(H_s^2/gT_s^2)\ , \tag{6}$$

where H_s is the height of the local significant wave. Naffa [3] has estimated the closure depth at the Nile delta coast by using the standard deviation method.

3. Field observations and data processing

The data used in this study has been collected from various surveys. The collection program covers the northern coast of the Nile delta, which extends from Alexandria to Baltim resort (10 km east El-Burulls Outlet). In all surveys, profile lines were allocated perpendicular to the shoreline.

The first group of data has been collected by the Admiralty Survey Ship (Endeavour) during the period 1919/1922 for the area extended from Alexandria to Baltim. The data have been recorded on a map of scale of 1:235,410, fig. 1. The second survey has been done by the Woods Hole Oceanographic Institute during the period from 1975/1976 for the area extended from Abu Quir bay at west to Baltim Resort. They have used a research vessel called Chain and Le Surooit and established a map on scale of 1:100.000, fig. 1. The Shore Protection Authority (SPA) established the third map during the year 1986 on scale of 1:100.000, fig. 2.

For the present analysis, a baseline had been drawn to match the three maps and to extend more or less parallel to the shoreline. Sixteen profiles bordering the coastal zone from Alexandria in the west to Baltim resort in the east have been randomly selected perpendicular to shore and extended seaward from the baseline to 50 m contour depth. Fig. 3 shows the position of the beach profiles along the study area.

The Coastal Research Institute (CoRI) in 2001/2002 initiated a program to estimate the closure depth along the nile delta Coast. Seven hydrographic profiles have been collected along Alexandria area. They have extended from Miymi area to Cleopatra district for approximately 15.0 m depth during the period from 2001 to 2002, fig. 4. Also three profiles at Abu Quir bay have been chosen as shown in fig. 5. They have extended to approximately 15 m depth.

The sets of bathymetric maps were digitized into a worksheet file and compared together. Sixteen profiles were chosen along the study area. Along each individual profile line, distances from baseline and their corresponding depth were calculated. Analysis and results of the whole data show that:

1. *Alexandria Area*: analysis of nearshore profile data indicates the presence of seaward limit (depth of closure) beyond the 6m of water depth. figs from 6 to 12 show that the closure depth at Alexandria area ranges from 10.0 to 15.0 m. It may be due to the presence of rocky beds beyond Alexandria beach face.
2. *Abu Quir Bay*: beach profiles taken from the different maps in this area are shown in figs. 16 to 20 and the new survey of beach profiles during the year (2001/2002) in front of Abu Quir bay are shown in figs. 25 to 27. It is apparent that the closure depth at Abu Quir Bay and west of Rosetta ranges from 15.0 to 20.0m.
3. *Rosetta Promontory*: beach profiles west and east of Rosetta Nile branch are shown in figs. 21 to 24. The figures show that the closure depth at this stretch is approximately 50.0 m.
4. *West El-Burulus to Baltim*: at this area the estimated closure depth from the beach profiles, figs. 25 to 31, ranges from 40.0 to 45.0 m.

4. Developed expressions for closure depth

The closure depth is calculated using linear regression analysis considering waves parameters such as H_s and T_s, and sediment parameter represented by mean grain size, D_{50}. Regression analysis is tested for different forms of expressions. The parameters in the equation terms are calibrated by using the observed data. On the other hand, the closure depth is estimated from the different profiles of the contour maps covering the coast

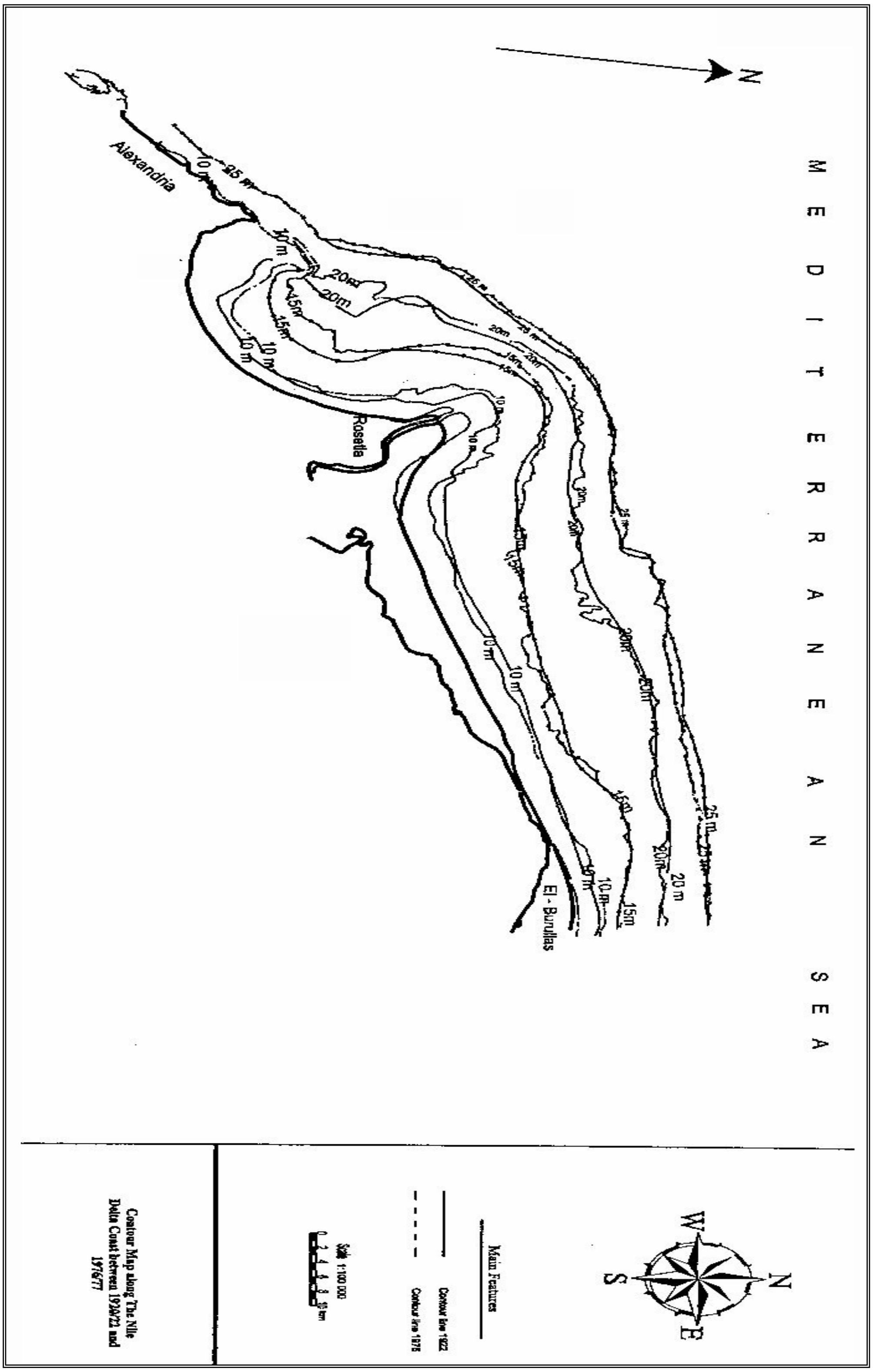

Fig. 1. Contour map of Nile delta. (1922-1976).

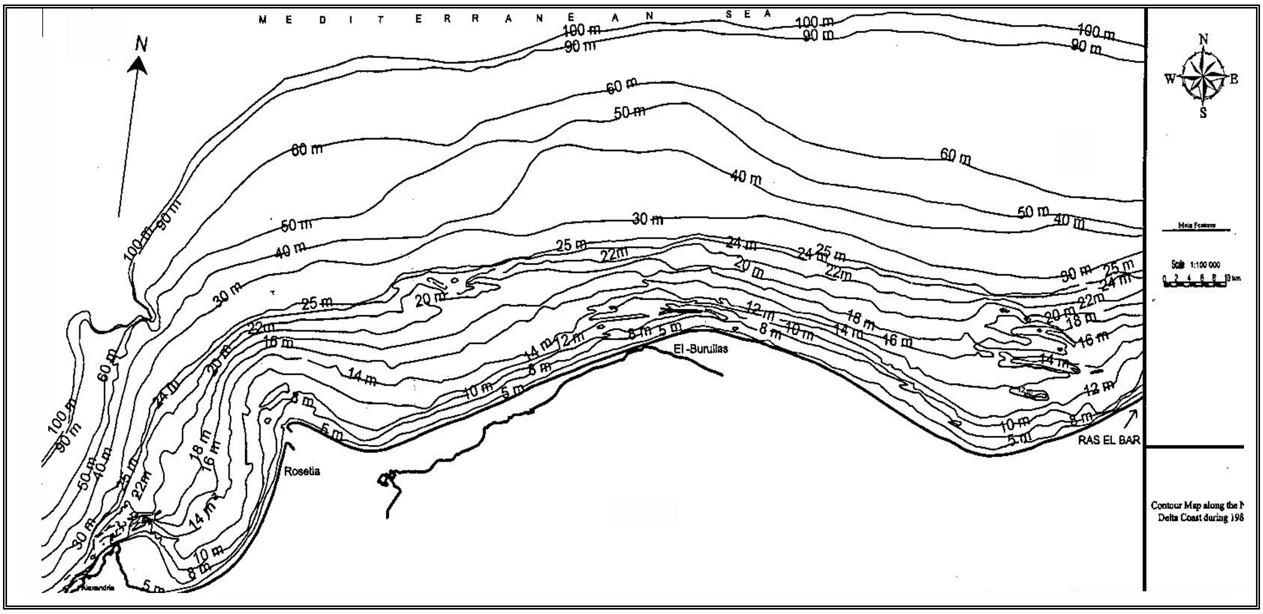

Fig. 2. Contour map of nile delta. (1986).

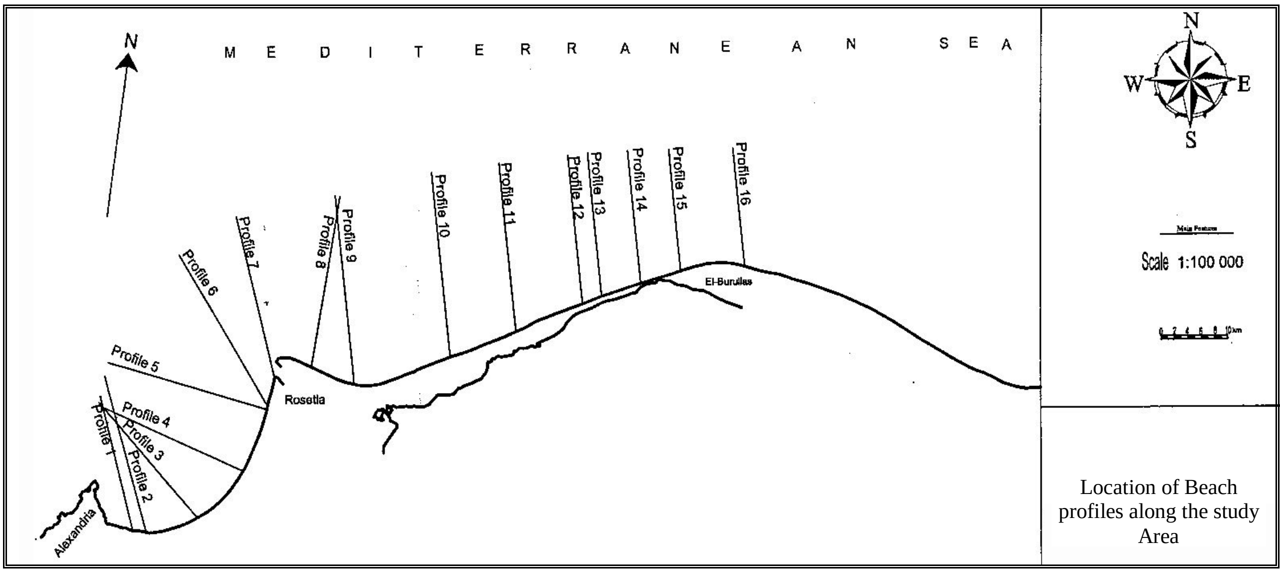

Fig. 3. Map of nile delta showing the position of beach profiles.

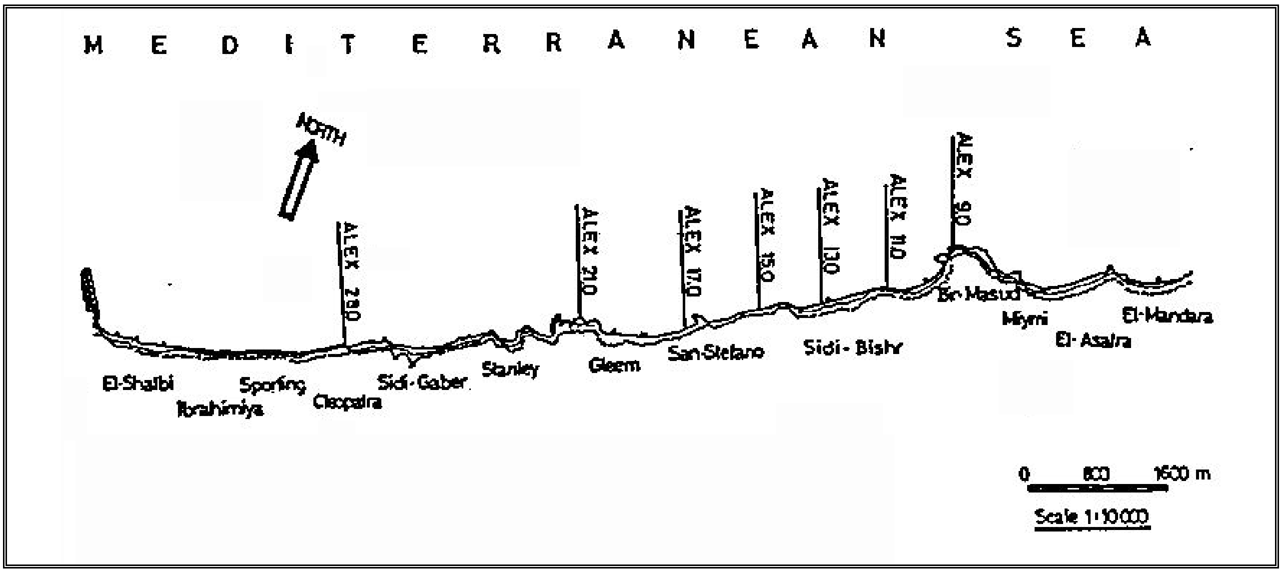

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Fig. 4. Alexandria profiles location.

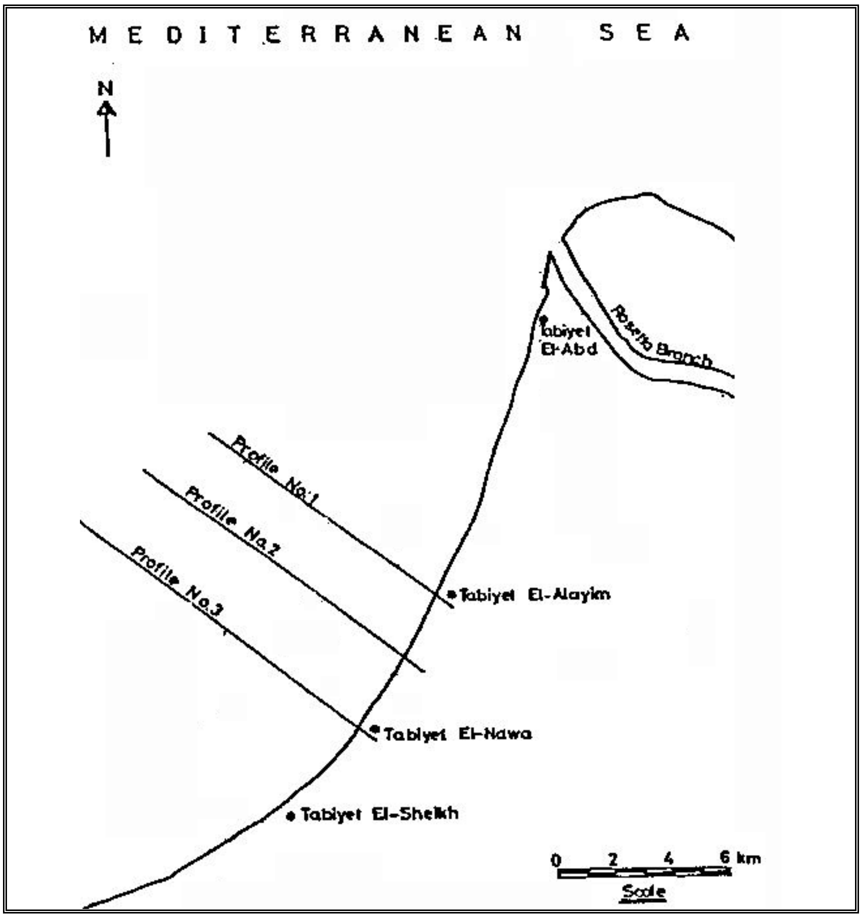

Fig. 5. Profiles location of Abu-Quir bay.

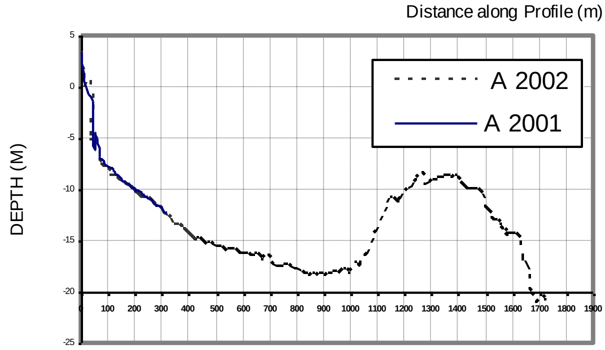

Fig. 6. Profile no.9.0 along the Alexandria coast.

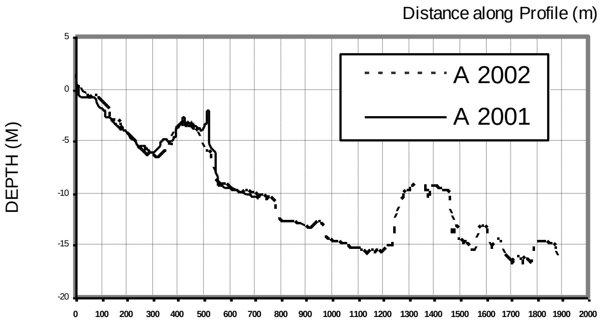

Fig. 7. Profile no.11.0 along the Alexandria coast.

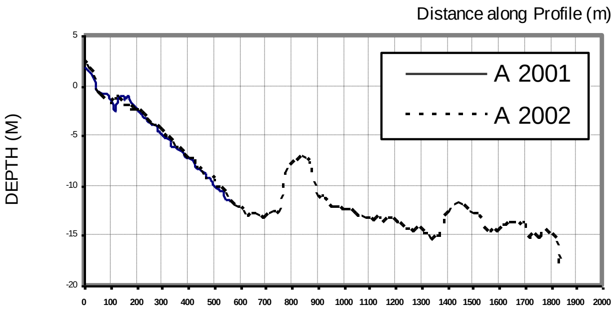

Fig. 8. Profile no.13.0 along the Alexandria coast.

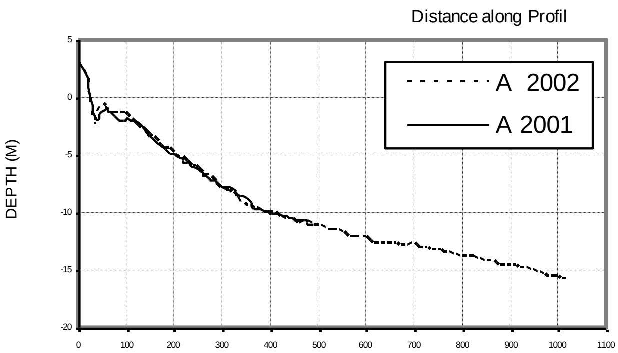

Fig. 9. Profile no.15.0 along the Alexandria coast.

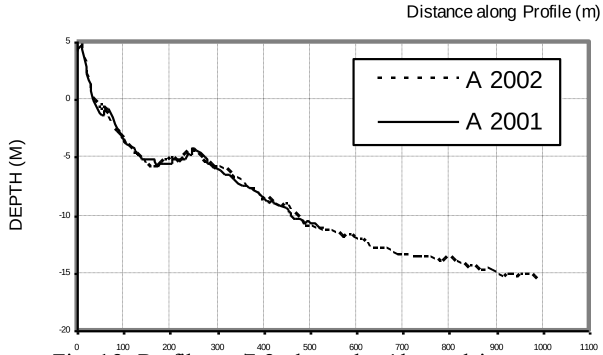

Fig. 10. Profile no.7.0 along the Alexandria coast.

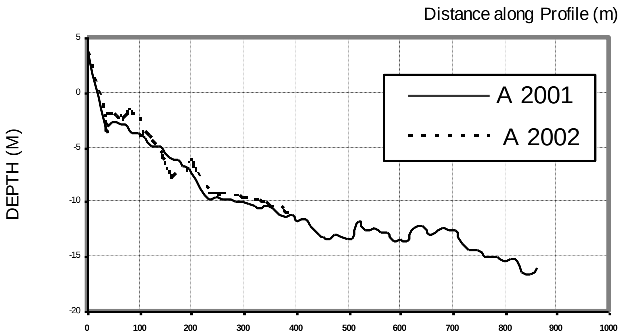

Fig. 11. Profile no.21.0 along the Alexandria.

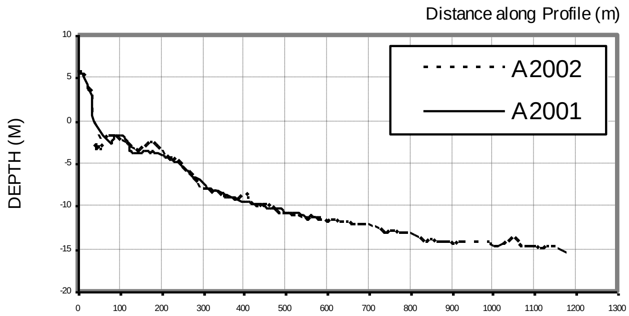

Fig. 12. Profile no.28.0 along the Alexandria coast.

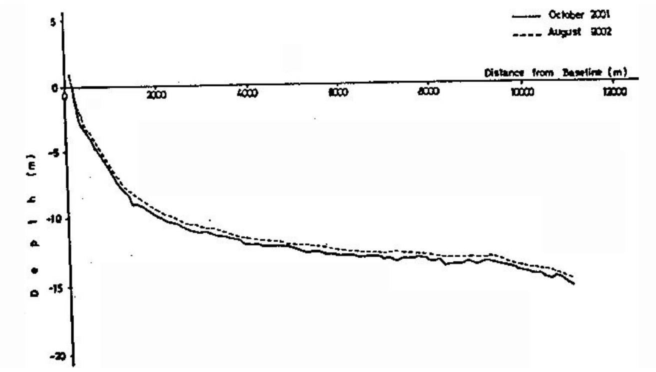

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Fig. 13. Profile No. (1) along Abu-Quir Bay.

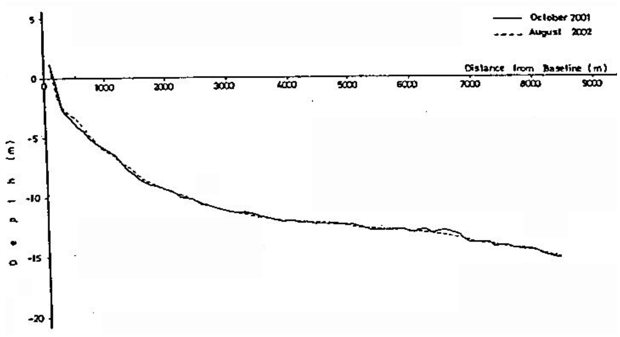

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Fig. 14. Profile No. (2) along Abu-Quir Bay.

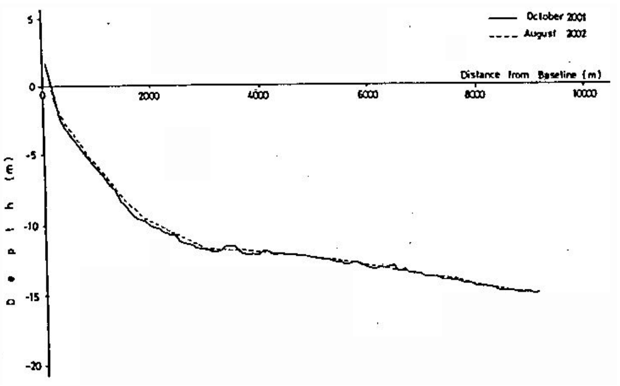

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Fig. 15. Profile No. (3) along Abu-Quir bay.

from Abu Quir bay to Baltim resort and the field data collected along Alexandria beaches and Abu Quir bay.

The obtained dimensional equations are:

$$d_c = 43.89 H_s - 20.9. \quad (7)$$

In this case depended on H_s only.

$$d_c = 47.92 H_s - 0.028 g T^2{}_s - 7.6. \quad (8)$$

In this case depended on H_s, g and T_s .

$$d_c = 27.37 H_s + 0.045 g T^2{}_s - 124.08 D_{50} - 11.5. \quad (9)$$

In this case depended on H_s , g , T_s and D_{50}. where d_c and H_s in meters , T_s in seconds and D_{50} in mm.

5. Evaluation of the developed expressions

Table 1 shows the evaluation of closure depth calculations using the obtained equations against the available field data along the Nile Delta Coast. Also standard deviation is calculated for each proposed equation and zone by numerical model.

A discrepancy ratio $D_r = C_c / C_m$ was used for comparison, where C_c is the calculated total load concentration and C_m is σ are $\bar{D}_{ri} = \sum D_{ri} / N$ and $\sigma = \left(\sum (D_{ri} - D_r)^2 / N\right)^{1/2}$. The results show a good agreement with the actual field measurements. The table shows a comparison between the present model results and the previous expressions obtained by other researchers. The presented model gives better agreement with field data than most of the other expressions. fig. 32 shows a comparison between developed equations and Hallermeier [12] equation in view of field data. From table 1 it is found the best developed equation to calculate the closure depth is eq. (9) but tacking into consideration that it needs to measure H_s, T_s , D_{50} .

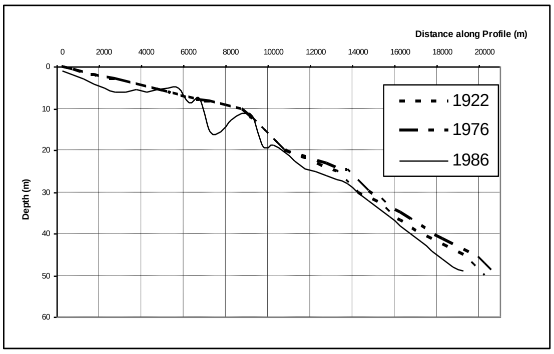

Fig. 16. Profile no.1 along the Western nile delt.

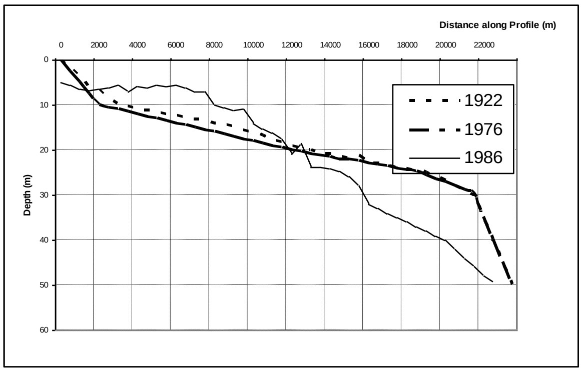

Fig. 17. Profile no.2 along the Western Nile delta coast.

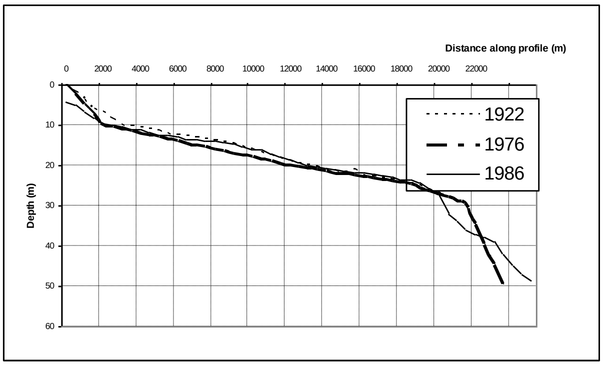

Fig. 18. profile no. 3 along the Western nile delta coast.

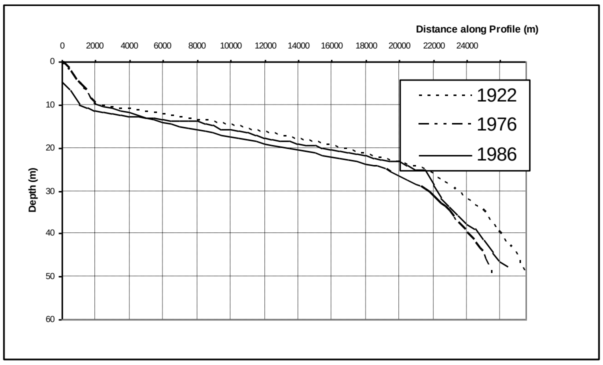

Fig. 19. Profile no. 4 along the Western nile delta coast.

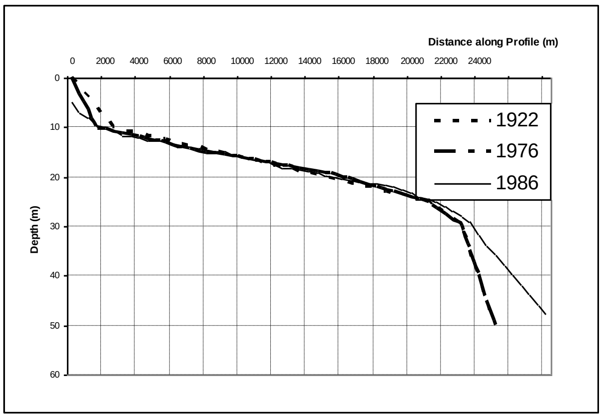

Fig. 20. Profile no. 5 along the Western nile delta coast.

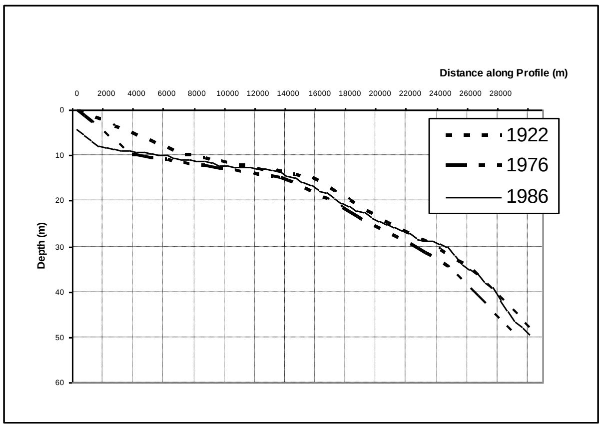

Fig. 21. Profile no. 6 along the Western nile delta coast

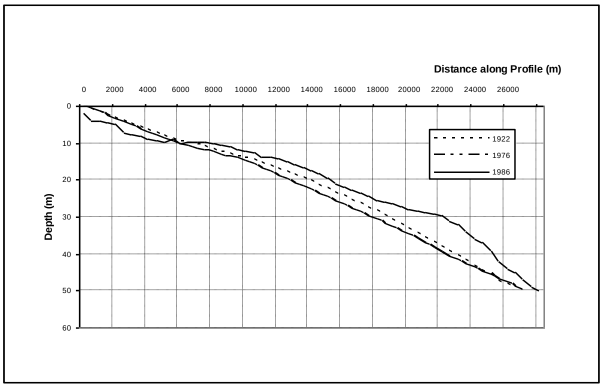

Fig. 22. Profile no.7 along the Western nile delta coast.

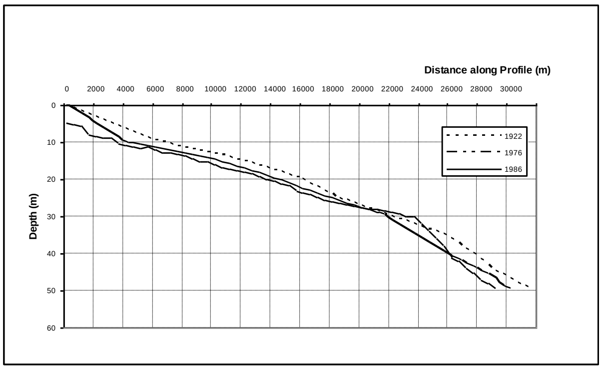

Fig. 23. Profile no. 8 along the Western nile delta coast.

6. Conclusions

The Nile Delta Coast from Alexandria to Baltim resort is divided into four stretches (Alexandria, Abu Quir bay, Rosetta Promontory, West El- Burullus to Baltim resort). The closure depth has been determined from 26 beach profiles taken from different surveys (1920/1922, 1976, 1984, 2001, and 2002). A statistical regression analysis is used to develop new expressions for the estimation of closure depth in front of The Nile Delta coast. The obtained expressions

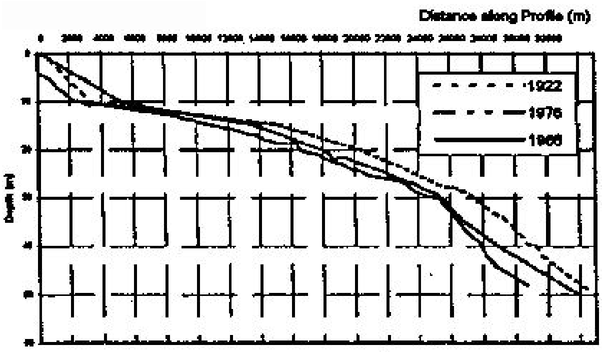

Fig. 24. Profile no. 9 along the Western nile delta coast.

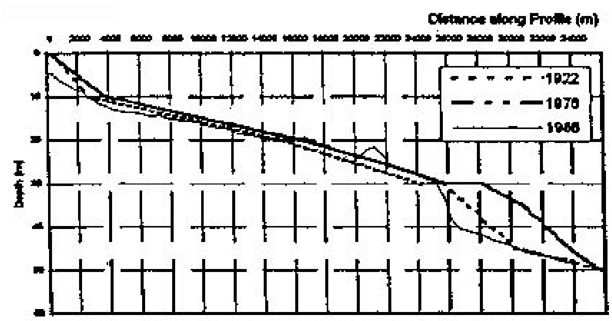

Fig. 25. Profile no. 10 along the Western nile delta coast.

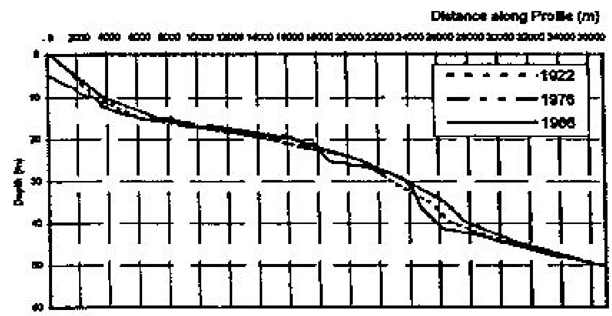

Fig. 26. Profile no. 11 along the Western nile delta coast.

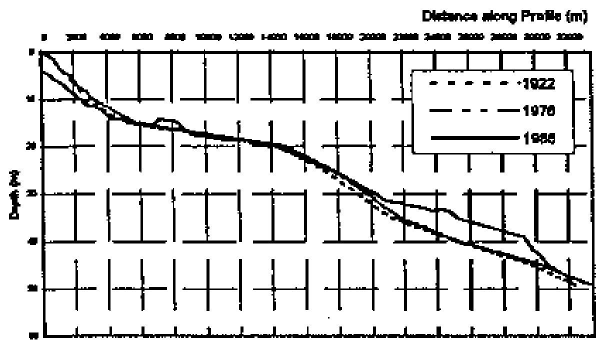

Fig. 27. Profile no. 12 along the Western nile delta coast.

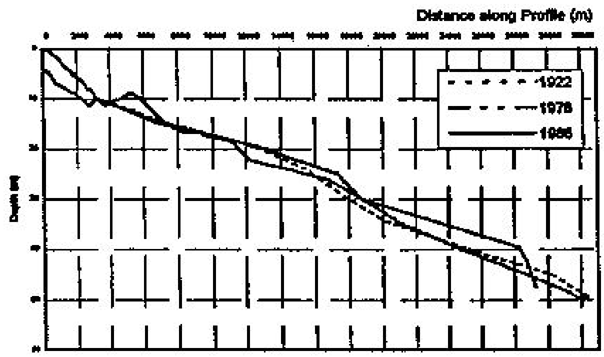

Fig. 28. Profile no. 13 along the Western nile delta coast.

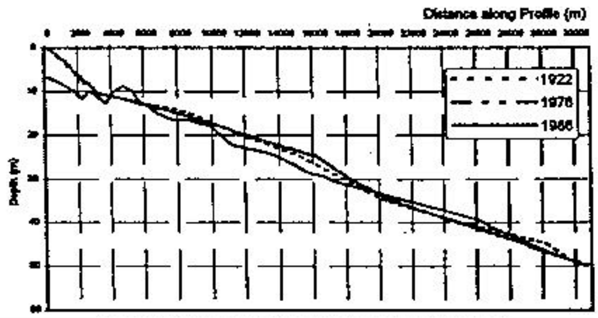

Fig. 29. Profile no. 14 along the Western nile delta coast.

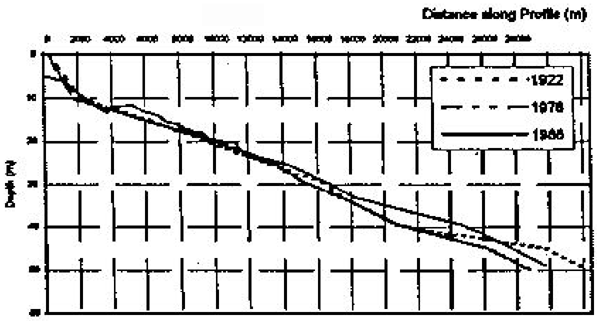

Fig. 30. Profile no. 15 along the Western nile delta coast.

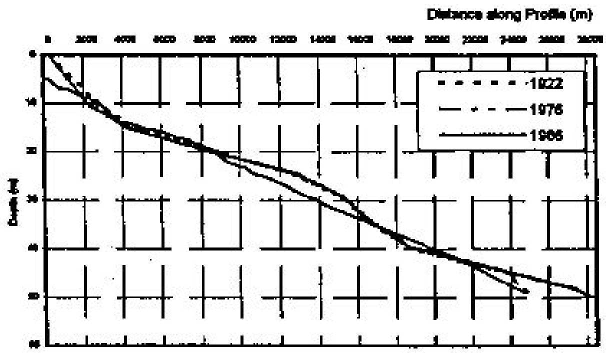

Fig. 31. Profile no. 16 along the Western nile delta coast.

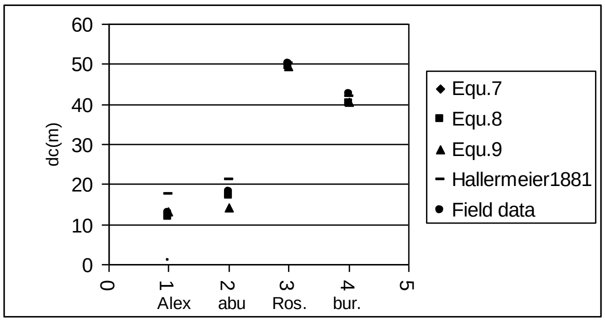

Fig. 32. Compaison between developed equations and Hallermeier [12] in view of field data.

show a much better agreement with the observed data compared with most of the previous studies.

Nomenclature

dc	is the closure depth,
T_s	is the significant wave period,
H_s	is the significant wave height,
H_{sm}	is THE mean of the annual distribution of significant wave height,
$H_{s\,(12h,t)}$	is the wave height which occurs only 0.137 % of the time,
D_{50}	is the grain size,
g	is the gravitational acceleration,
σ	is the standard deviation,
$\overline{D}_r$	is the mean statistical discrepancy ratio.

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