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Improving Flow Conditions along Inner Curve of Damietta Branch Bends (Case Study)

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ملخص البحث :

أثبتت الدراسات والبحوث التي أجريت علي مجاري الأنهار الطبيعية المنحنية تولد تيارات حلزونية ثانوية ناتجة عن قوي الطرد المركزيه مما يسبب العديد من المشاكل. هذه القوي تعمل علي تولد تيارات مائية سطحية ذات سرعة عالية نسبيا في اتجاه القوس الخارجي لمنحني النهر واخري أقل سرعة بالقرب من القاع في اتجاه القوس الدخلي. تؤدي التيارات الخارجية السطحية المتعاظمة القيمة الي حدوث نحر وإنهيار الجسر الخارجي للمجري بينما تعمل التيارات الداخليه علي حمل المواد الناتجة عن النحر والتي تترسب بالقرب من الجانب الداخلي للنهر. يؤدي توالي حدوث ظاهرتي النحر بالجسر الخارجي والترسيب بالقرب من الجانب الداخلي الي حدوث ازاحة تدريجية لمجري النهر في اتجاه القوس الخارجي للانحناء مما يقلل أعماق المياه باجزاء القطاع المائي الداخلية و بالتالي يحد من كفاءه المجري الملاحيه. بناءا عليه فإنه يمكن المحافظة علي مورفولوجية النهر بمواقع المنحنيات وذلك بالعمل علي تحسين خواص التيار المائي بهذه المواقع وذلك بإستخدام مثبطات لسرعة التيار المائي المتعاظم بالمنحني الخارجي للنهر والتي تعمل في نفس الوقت علي تحسين خواص سرعة التيار بالمنحني الداخلي للنهر. هذه المثبطات تعرف هندسيا بالحمايات الدائمة التأثير لجوانب النهر والتي قد تكون رؤوس حجرية أو هدارات غاطسة أو موجهات لتيارات الأعماق أو حمايات حجرية لجوانب النهر. لذا فإن إختيار النوع الأمثل والتصميم الأفضل هندسيا لهذه الحمايات يتوقف علي التغيرات المورفولوجية للنهر والخواص الهيدروليكية وبيانات التصرفات والمناسيب علاوة علي درجة إنحناء هذا الجزء من المجري وهو الهدف من هذه الدراسة

لتحقيق الهدف من البحث تم إستخدام جزء منحني من مجري نهر النيل بمجري فرع دمياط يبلغ طوله حوالي ٦,٨٦ كيلومتر والذي يتميز بوجود منحنيان منعكسان الأمامي منهما في إتجاه الغرب بينما الخلفي في إتجاه الشرق. اوضح الرفع المساحي الهيدروجرافي الحديث للمنطقة المذكورة ومقارنتها بالنتائج السابقة لنفس الحبس علاوة علي البيانات الهيدرولوجية والقياسات الهيدروليكية المختلفة أنه يمكن اعتبار هذا الحبس مثالي لإجراء هذه الدراسه لوضوح تأثير ظاهرتي النحر والترسيب علي كل من المنحني الخارجي والداخلي علي الترتيب. هذه القياسات أوضحت حدوث نحر موضعي وإنتقال لمواد القاع بالقوس الخارجي لكل من منحنيي النهر مما يهدد استقرار الميول الجانبيه بينما يحدث ترسيب ملحوظ في الجانبين المقابلين للنهر مما ادي الي عدم إنتظام سرعة التيار المائي وإزاحة المجري في إتجاه المنحني الخارجي لتحسين هذا الوضع وحماية المنحنيان الخارجيان للحبس

موضوع الدراسة فإنه يمكن إجراء أعمال تطهير بمناطق الإطماء والذي يعرف بالحلول السريعة المؤقته التأثير أو إستخدام عوارض حجريه علي مسافات مناسبه في مناطق النحر العميقه. بناءا عليه عرض البحث مراجعة تاريخية موجزة للبحوث والدراسات السابقة الخاصة بمنشآت الحمايات الدائمة التأثير شاملا المواصفات وخطوات التصميم ومواد الإنشاء علاوة علي إستعراض كافة القياسات الهيدروليكية والهيدروجرافية التي تم إجرائها حديثا للحبس موضوع الدراسة والبيانات الهيدرولوجية الخاصة بالتصرفات المارة والمناسيب المقابلة. تم في المقابل عرض خصائص ومميزات النموذج الرياضي ثنائي الابعاد الذي تم معايرته ةتحقيقه بإستخدام البيانات التي تعكس الوضع المورفولوجي للحبس موضوع الدراسة. تم بعد ذلك إستخدام البيانات الخاصة بالحبس موضوع البحث علاوة علي طرق تصميم منشآت الحمايات الدائمة في حالة إستخدام رؤوس حجرية من خلال بدائل مختلفة تلي ذلك إستخدام النموذج الرياضي ثنائي الأبعاد في إختبار بدائل التصميمات المختلفة لكل من الرؤوس الحجرية التي يمكن إستخدامها لحماية مواقع مختلفة من المنحنيات الخارجية للحبس موضوع الدراسة والتي إشتملت علي 15 إختبار لكل من الرؤوس الحجرية. تم مقارنة نتائج جميع هذه الإختبارات بنظير كل منها خلال الوضع الحالي للمجري لمختلف التصرفات المارة والتي أوضحت أن إستخدام الرؤوس الحجرية في حماية المنحني الخارجي للنهر بالحبس موضوع الدراسة تعطي نتائج أفضل من تلك التي تم الحصول عليها في حالة إستخدام الهدارات الغاطسة بناءا عليه تم تحديد أفضل تصميم ومواقع إنشاء الرؤوس الحجرية التي تعطي أفضل توزيع لسرعة التيار المائي.

الكلمات المفتاحيه :
المنحنيات الداخليه –السدود المحفزه-الظروف الهيدرولوجيه-التعريه و الترسيب.

Abstract:

The main aim of this study is to evaluate the influence of river meandering on the water flow, which is one of the key factors affecting bank erosion and bed scour at the outer curves as well as deposition and sedimentation at the inner curves due to the secondary induced spiral currents formed from the generated centrifugal force at river bends. Spiral currents that prevent these negative effects can be created by using multiple rows of submerged vanes. Application of permanent regulation works, such as bendway weirs or spur dikes, will also help to improve flow conditions through the curved reach along the vulnerable zones of the outer curved reaches - could prevent bank erosion at the outer curve and sedimentation at the inner curve. Given that the River Nile can be thought of as a natural stream with a number of sharply curved stretches, the 6.860 km Damietta branch with two consecutive bends from km 95.219 to km 102.088 downstream of the El-Rodah Gauge Station was selected for the current investigation as a Case study. The study plan was designed to demonstrate the actual boundary condition across the meandering zones and to assess the applicability of implementing the permanent river regulation works already in place to enhance the morphological and hydrological conditions in the chosen river reach. As a result, both earlier and more recent hydrographic studies pertaining to the study reach were carried out. This showed that the inner curves of the river bends are experiencing major deposition while the outside curves of the river bends are experiencing severe bed erosion, which causes the flow currents to be delayed.

To carry out the present study, a two dimensional mathematical model “SMS” was used to simulate the study reach for the purpose of representing the water body in order to test the suitability of applying river regulation works to improve the morphological and hydrological conditions. Experimental results indicated that the use of spur dikes after selecting the appropriate places, increase the water velocity in places subject to sedimentation by 250% and reduces the water velocity in places subject to erosion by 90%, which works to improve the morphological characteristics of the region and reaching the optimum velocity.

Keywords: Inner curves, Spur dikes, SMS, Hydrological conditions, Erosion and Sedimentation.

1. Introduction

1.1 Literature Review

Due to internal geometry changes, different discharge scenarios, and the properties of channel materials, such streams have a propensity to migrate towards the outer curve side. Channel depth, width, and alignment can be impacted by bed scouring, bank erosion, and deposited material. The movement of silt may also interfere with the use and operation of navigational infrastructure and buildings, including locks, harbors, stations, and water intakes. Therefore, the suitable river training works required to solve river meandering issues would have their design based on knowledge of river character in alluvial hydraulics (Wail Fahmy, 2006)[1]. In addition to ensuring enough water transportation throughout the river system, regulation works are necessary to fulfill other significant advantages to humanity, such as agriculture and navigation. In light of this, a number of engineering projects, such as dams, barrages, weirs, spur dikes, bendway weirs, and submerged vanes, could be installed permanently, while in some circumstances, dredging is required. However, Temporary River works need to be periodically repeated by artificially removing sediment from place where sufficient flow depth is required (Klaassen and Ahmed, 2003) [2]. The drawing of water from rivers is one of the most ancient human activities; there are many different purposes such as water purification for Domestic use, irrigation, and cooling. It is designed of an intakes on the riverbeds of the tasks that occupy engineers where sediment transport is the main problem facing the water treatment plants. Therefore, the problem is reflected of how to take water out of the river while leaving the sediment behind (Helmut Scheuerlein, Felix Mtalo, 2009) [3].Spur dikes are stone spurs that extend into the stream from the bank to minimize erosion by forcing flow away from the bank. Spurs can also be constructed from natural materials, such as Large Woody Debris (LWD), and are designed to provide biological benefits and habitat restoration. Spurs are used in river engineering to minimize bank erosion and lateral stream migration, thereby protecting infrastructure such as roads, bridges, and dwellings. It is clear that the physical characteristics of spurs and the resulting flow modifications result in desirable habitat benefits (CA Fish and Game, 1998) [4]. (Vaghefi, 2012) [5] did research on a T-shaped spur dike in a river bend and discovered that as the length of the spur dike increases, the maximum depth of scour also increases, and as the Froude number of flow decreases, the dimensions of the scour hole also rises. (Azma Shahraki, 2017) [6] Showed how a slope in the body of a spur dike could reduce the size of the scour hole around it.

Moreover, maximum scour was recorded with an angle of 90^o, while maximum scour was observed with an angle of 60^o along the spur dike. Elongation and progress of deposition to downstream increased with increase in spur dike wall angle, so that at wall angles of 60^o and 90^o, respectively, the lowest elongation and progress of deposition and the highest elongation and progress was to downstream, could be observed. The maximum scour depth of each spur dike is at the spur dike head. The scour depth of the first dam is the largest, and the scour depth increases with the increase of intensity of water flow. When the river width narrowing rate is 0.25, the spur dike layout should be considered from the perspective of the cover effect of the first spur dike, and the spacing of the spur dikes is between 2l and 3l. The experiment results can effectively reflect the influence of different spur dikes spacing on the scouring patterns and the scour depth of the dam head (Jian NING, 2018) [7]. The maximum scour depth occurs at upstream side, near nose of spur dike and erosive sediment was deposited at downstream side for both the spur dikes. For the same opening ratio and flow conditions, the scour depth has been found to be minimum when the angle of inclination is 60° (Dharmendra Nath & Utpal Kumar Misra, 2017) [8]. (M. Shafai Bejestanb, 2016) [9] presented the best shape of spur dikes in paper which control the lateral movement of river bends. In a 90-degree river bend, trapezoidal spurs (TS) were installed at four different locations (4L, 5L, 6L, and 8L). The same experiments were carried out again with the addition of conventional spurs (rectangular in shape) for comparison. With a 30° angle from the bank to the upstream, TS were fastened to the flume bank. One fifth of the flume's width was the effective length (L) of the spurs, which measured the distance perpendicularly from the bank to the spur's tip. Results indicate that, on average, the scour depth at the tip of the TS is much lower than it is at the RS Maximum scour depth in spaces of 4L and 8L was found to be 0.6 and 1.034 times the effective length of the structure, respectively. The best location for trapezoidal vanes in the outer bank bend appears to be 4L. In testing on a straight flume for various flow conditions, this was done by placing a sequence of triangular vanes at intervals of 4Le (Le is the effective length of the structure) (five Froude numbers of 0.18, 0.20, 0.22, 0.24, and 0.26). The results showed that the geometric size of the scour hole in the triangular vanes was less than that in the rectangular spur dikes. The rectangular spur dikes' scour holes were, on average, 1.3 and 1.5 times longer and deeper than those of the triangular vanes. Additionally, the triangular vanes had an advantage over the rectangular spur dikes in that the maximum scour depth was around 40% farther from the bank when taking those triangular vanes into account (Mohammad Bahrami, 2016) [10].Iglesias in 2002 simulate physical and mathematical modeling to treat several relevant hydraulic engineering problems by using SMS. Application of numerical models was preferred in the present study to create conception of physical reality that result in quantitative predictions. Applying such multi-dimensional hydrodynamic modeling techniques require extensive display and analysis of spatial data. For this reason, the graphical, statistical, and database capabilities of the Surface-water Modeling System (SMS) would be applied during the present study to provide powerful tools for the analysis of model data and results.

1.2 Site Description

A certain reach of the Damietta branch was chosen to illustrate and study the consequence of all aforementioned irrigation and navigation problems. This reach is approximately 6.869 km long which located - as shown in Fig. (1) - downstream of Benha City from km 69.219 to km 76.088 downstream of Delta Barrages Damietta Branch and from km 95.219 to km 102.088 downstream of El-Roda Gauge Station. The reach was selected in such a way as to consist of two successive meandering curves where point bars and pools are the dominant bed forms and composed of a relatively homogeneous combination of fine sand and silt. The river free surface width is approximately 200 m at median flow. While some limited sandstone outcrops exist as well as one very limited area of coarse sand, gravel, and cobbles are emerged. Land use in the vicinity is predominated by crop production.

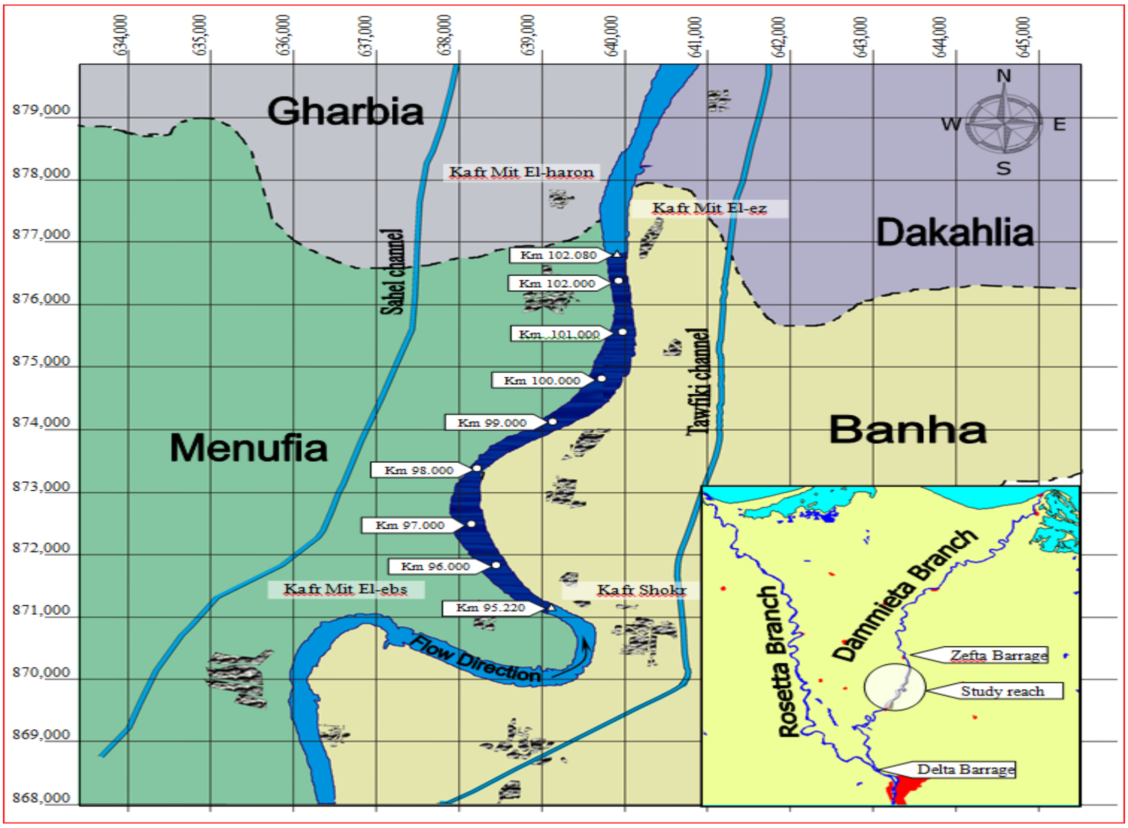

FIG (1): Location of the Study Reach

1.3 Problem Definition

Due to spiral currents created by the centrifugal force of the bend itself, river bends produce localized scour and bed erosion at the outer curves as well as deposition and sedimentation at the inner curves as shown in figure (2). At the flow surface of this spiral flow motion, relatively high velocities act in an outward direction while near-bed low velocities act in an inward direction. While the inward near-bed currents carry the eroded materials in an inward direction that deposits close to the inner bank, the enlarged outward surface currents produce bank erosion and bed scouring. These apparent facts cause the river bend to move toward the outer curve and worsen navigational conditions because there is not enough water depth close to the inner curve. As a result of monthly variations in water levels and flows, the morphology of some meandering sections of the Nile River, particularly along the Damietta branch, is constantly changing. Examples include bank failure, bed erosion and deposition, and island formation. Therefore, training structures such spur dikes, bend way weirs, submerged vanes, and bank revetment should be examined to assign the suitable solution that would redistribute the induced spiral currents to prevent inner curve sedimentation in order to improve morphological and hydrological conditions.

2020

1990

FIG (2): Changes that have occurred in different years in the case study.

1.4 Study Objectives

This study's primary goal is to improve the flow characteristics along the inner bank of a meandering river reach at the Damietta branch of the River Nile. Thus, modeling techniques would be used to simulate the morphological and hydrological conditions in a specific real meandering reach of the Damietta branch in order to achieve this goal. This would allow the suitable methodology of training structures to be assigned in order to improve and normalize flow condition and bank stability under various flow conditions. The optimum training structure is the one that takes into account heading up, shear stress, and velocity distribution while requiring the least amount of building money. To calibrate and verify the employed mathematical model, daily records of water surface levels and flow discharges for several previous years, as well as the most recent velocity measurements and several samples of bed materials along the study reach, would be analyzed. Various training schemes could then be tested, and the best solution could be determined as the one that improves the flow condition at the inner curve by the greatest margin relative to the current conditions.

2. Materials and Methods

2.1 Data collection

In order to simulate the study reach which is about 1.1 km by the SMS mathematical model, several pieces of data must be collected in order to calibrate and verify the model as following:

- Maps of the study reach and its surroundings were collected to understand the WTP location, intakes location, shore lines, and other affecting features along the river site.
- Hydrographic survey maps were collected in order to obtain bed levels and river morphology of the study reach, these maps were carried out by the Hydraulics Research Institute “HRI” of the National Water Research Center in 2011, furthermore In order to obtain visual understanding of the morphological characteristics of the study reach a total number of 8 cross section profiles were deduced from the prepared contour map.
- In order to calibrate the selected SMS mathematical model, vertical velocity distributions for four cross sections were measured.
- Manning coefficient (n) of bed roughness considered an important parameter for calibrating the mathematical models as well as for their verification process which was attained by the bed grain size distribution collected by Grab Sediment Sampler used by the HRI to collect 12 bed material samples from four cross sections revealed that the geometric mean diameter D50 of the collected samples ranges between a maximum values of 0.17 mm recorded at middle of the river, While the minimum value of 0.13 mm was recorded at east.
- Hydrological data was obtained in order to understand the maximum, minimum, and average annual discharges passing through the study reach of 926 m3/sec as well as the corresponding water levels (12m).

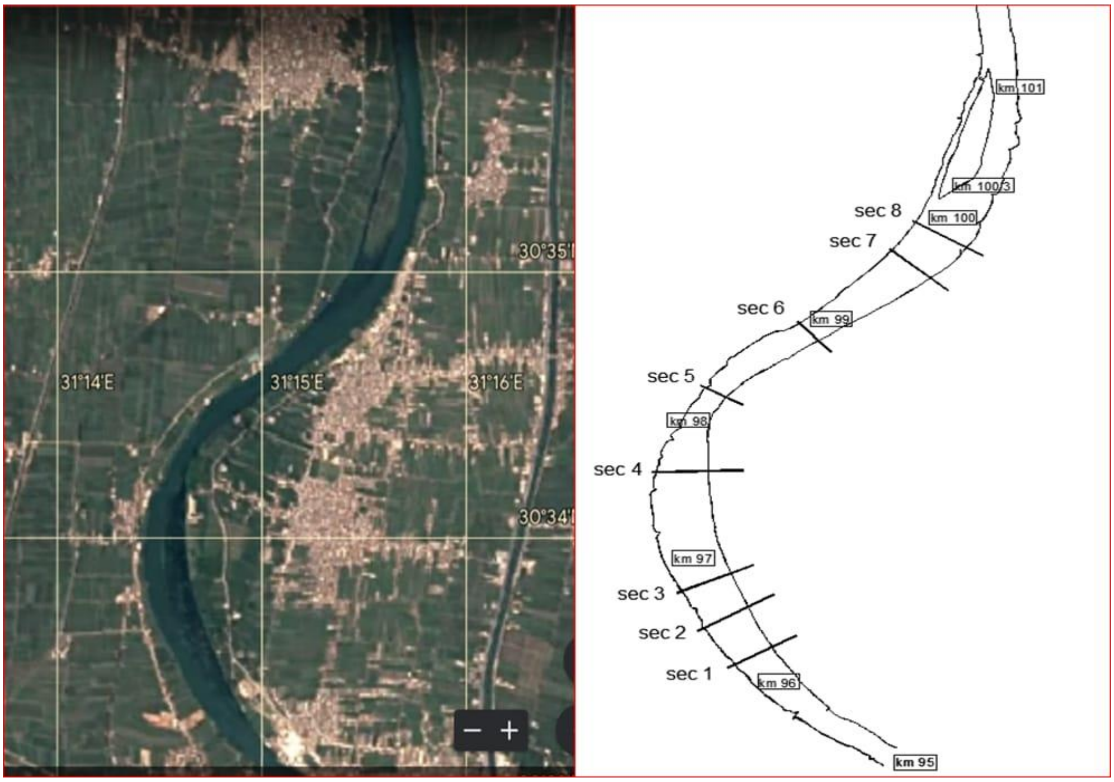

FIG (3): study area location map.

2.2 Methodology and Scope of Work

The "SMS" 2-D mathematical model would be employed, at first, to simulate the morphological and hydrological characteristics in the meandering reach of Damietta branch at the present conditions, after that, the reach modeling would be used to simulate different alternatives of river training works. This simulation would be used to assign the appropriate solution for improving and stabilizing flow condition, bank stability and secure safe and permanent navigation throughout different flow releases. The consequences and side effects of various treatment works such as spur dikes, bendway weirs, bank revetment and submerged vanes would be investigated. Therefore, long-term solutions for the improper bed configurations would enable a practical plan for desired river processes. With this in mind the present study would be carried out applying the following methodology:

- Identifying the main characteristics of the study area of Damietta branch to outline the study area basic case. Detailed information concerning river morphology, recent hydrographic and hydraulic measurements as well as the hydrological records is collected.
- Reviewing literature material for the relevant previous investigations concerning river morphology, meandering effect, temporary and permanent regulation works as well as the navigation concepts.
- Providing the necessary information about the applied 2-D "SMS" mathematical model as well as other models that may assist during the course of the study.

- Selection and design of various types of permanent regulation works needed to improve bend properties by assigning the appropriate alternative solutions of training structures. As well as testing each alternative solution and comparing the results to reach the proper solution for the study reach.

The critical velocity showed that just dredging at the intake location will reduce velocities, increasing the rate of deposition; however, using spur dikes will improve flow velocities, decreasing rates of deposition and reducing the necessary duration between dredging. The resulting turbidity needs to be explored even if all ranges of velocities corresponding to all alternatives fell below the shear velocity limit, showing that the area is still a deposition area.

2.3 Surface Water Modeling System (SMS-2D) and Model Calibration

The "SMS" 2-D mathematical model was developed by the Brigham Young University in cooperation with the U.S. Army Corps of Engineers, Engineer Research and Development Center (ERDC), and the U.S. Federal Highway Administration (FHWA). The family of SMS-2D model is an integrated package for simulation and analysis of free surface flows, sediment transport and morphological processes. In addition to the numerical model, this family includes two more members: a mesh generator (SMS-2D Mesh Generator). The Finite Element Surface Water Modeling System "FESWMS" is a comprehensive environment for two dimensional flows in horizontal plane model running under the SMS Interface. This model simulates either steady or unsteady 2-D surface-water flows, including sub- and super-critical conditions Lee and Froehlich (1986). FESWMS solves the vertically integrated equations of motion and continuity with a finite element scheme. Several model runs are made to achieve the best agreement between measured and resulted values from the model. The model calibration includes four cross sections (3, 4, 6 and 7) with the corresponding values for the velocity sections which obtained the average discharge equal to 926 m3/sec. and surface water level 12 m. The results of (SMS-2D) model were compared by the actual data. As shown in figure (4) the results of the observed data are close with the results of (SMS-2D) Model and that of the actual data with an average difference 8.5%.

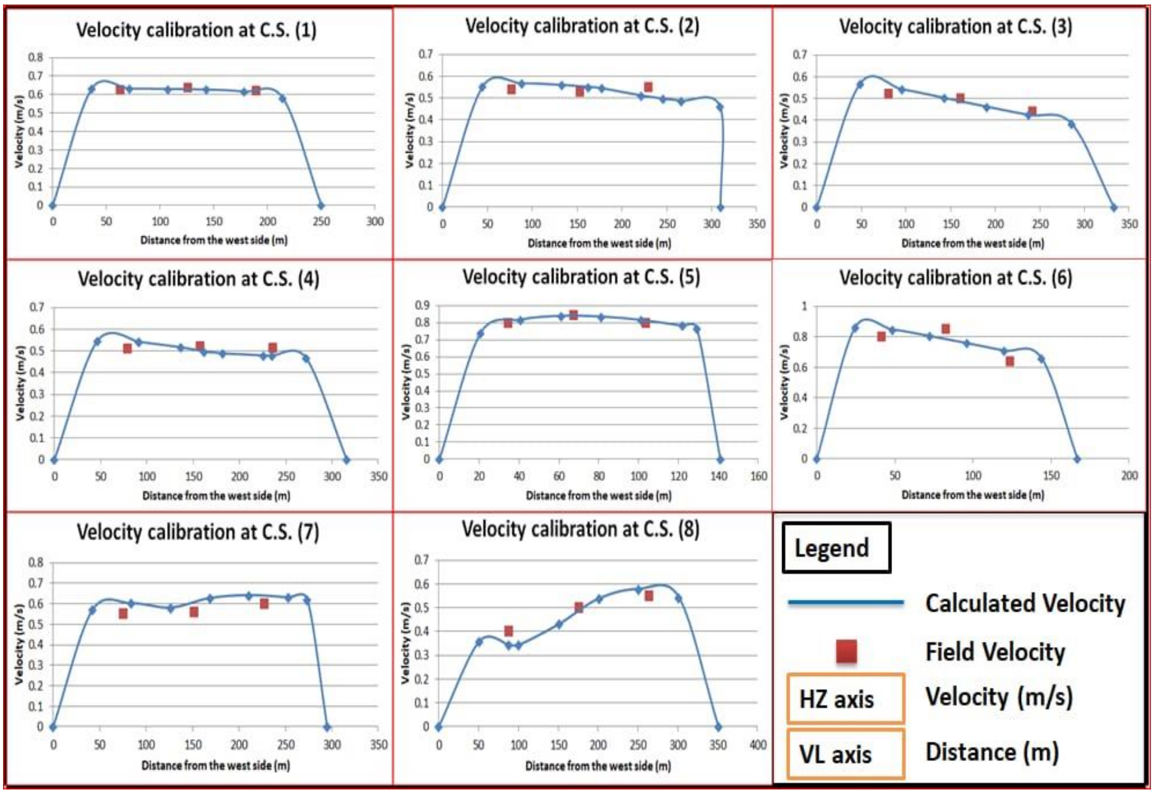

FIG (4): depth average velocities calibration and the cross section location

2.4 Optimum velocity

In order to investigate the different alternatives effect on sedimentation control at the location**,** the bed shear velocity was studied, but the bed sampling at the eastern side of the river revealed fine sediment which was out of range of the shields diagram so the critical velocity in the waterway was calculated by Niell's equation:

$$V_C = K_U \sqrt{y_2}$$

Where;

y_2 = equilibrium flow depth, m or ft.

K_U = 0.55217 for SI units or 1.0 for U.S. customary units

The critical velocity proved that only dredging at the intake location will decrease velocities thus increasing the rate of deposition. On the other hand using spur dikes will increase the flow velocities thus decreasing rates of deposition and extending the required period between dredging. Even though all ranges of velocities corresponding to all alternatives fell under the shear velocity limit which means that the region is still a deposition area, the consequent turbidity has to be investigated.

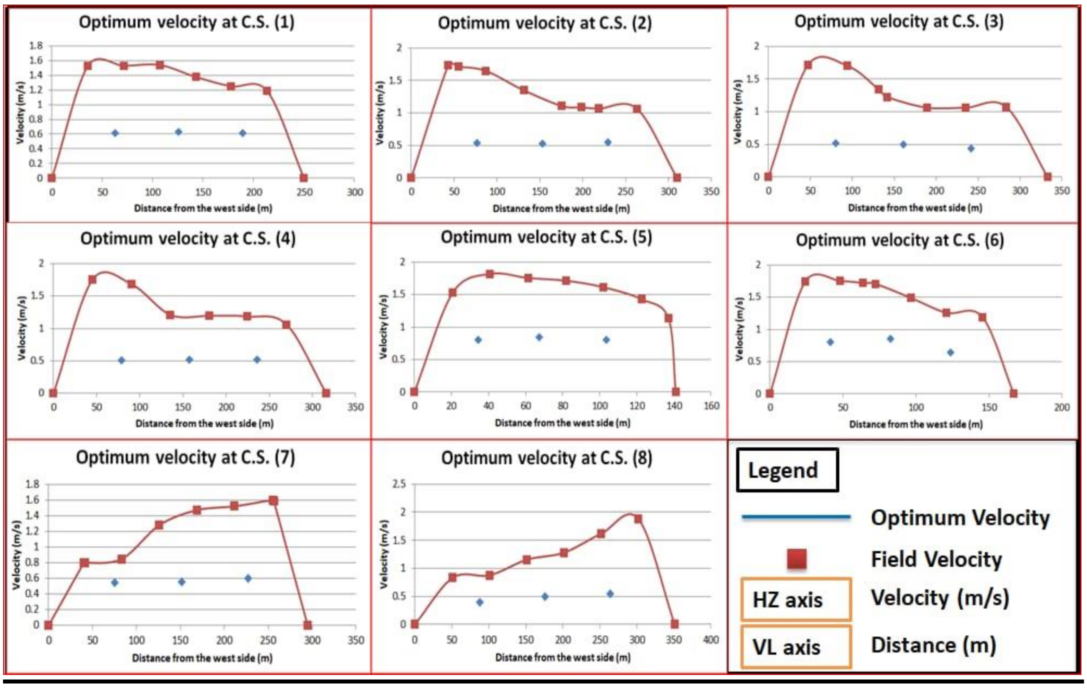

FIG (5): depth average velocities calibration and the cross section location

2.5 Different Alternatives

The flow-field features described above were considered by means of several sediment-control modifications used to modify the local flow field and to adjust the local riverbed bathymetry. The mentioned alternatives were individually tested then co-tested to reach the optimum sediment control option as shown in table (1). Simulating of different alternatives and knowledge the economical alternative was utilized through three stages: 2D SMS mathematical model to simulate the different alternatives and find the resulted velocities.

Table (1): All different alternatives

Test No.	Spur dike No.	Rotate angle	Length	Distance
1	1,2,3,4,5	90	55 m	3L=165 m
2	1,2,3,4,5	90	73 m	3L=219 m
3	1,2,3,4,5	90	55 m	4L=220 m
4	1,2,3,4,5	90	73 m	4L=292 m
5	1,2,3,4,5	90	55 m	5L=275 m
6	1,2,3,4,5	90	73 m	5L=365 m
7	1,2,3,4,5	90	110 m	3L=330 m
8	1,2,3,4,5,6,7,8	90	110 m	3L=330 m
9	1,2,3,4,5,6,7,8	60	110 m	3L=330 m
10	1,2,3,4,5,6,7,8	60	73 m	5L=365 m
11	1,2,3,4,5,6,7,8	60	92 m	5L=460 m
12	1,2,3,4,5,6,7,8,9	60	92 m	4L=368 m
13	1,2,3,4,5,6,7,8,9,10	60	110M	3L=330M
14	1,2,3,4,5,7,8,9	90	147 m	2L=294 m
15	1,2,3,4,5,6,7,8,9,10,11	90	147 m	2L=294 m

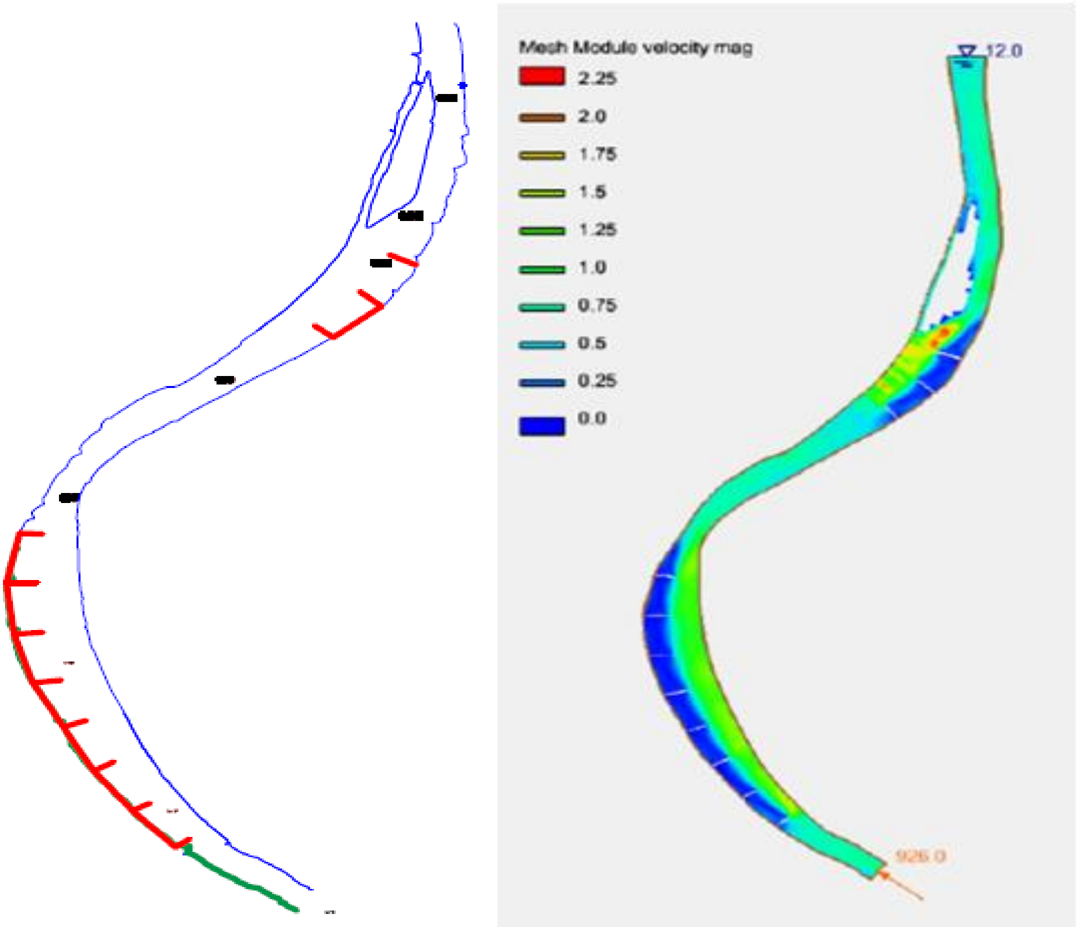

Figure (6): Different alternatives of spur dikes

3. Results and discussion

This test was conducted with a maximum flow discharge 926 m3/s (80 Mm^3/day). Figures (from 7 & 8) show the calculated flow velocity profiles for various spur dike designs at "UCS" in contrast to the original existing flow condition. The results are typically demonstrated by the significant velocity improvement through the main river channel and the velocity reduction close to the outer curve compared to the original condition. These results typically show that the velocity across the main river channel significantly increased when it was directed from the outer curve to the inner curve. Although the original condition's main river channel recorded a maximum velocity of 0.6 m/s, the applied design's corresponding value of .07 m/s and related to zone protection were achieved. The final result shows a percentage decrease of 88.33% over the original flow velocity when the optimum velocity was 1.8 m/sec. On the other hand, velocity improvement was obtained along the east inner curve which increased from .38 m/s at the original condition to 1.29 m/s as shown in Figures (8). This reveals a percent increase of 50% corresponding to the existing original condition. When the optimum velocity was1.07 m/s.

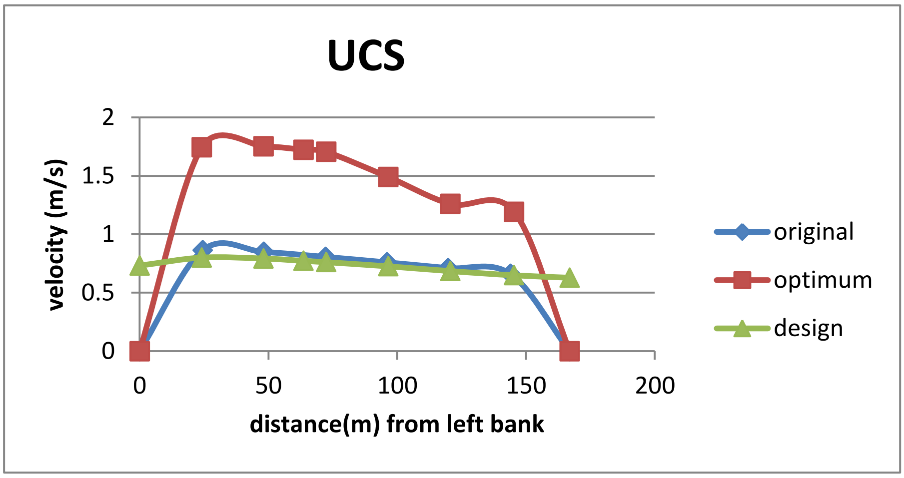

FIG (7) Comparison of velocity profiles in the case of protecting zone.

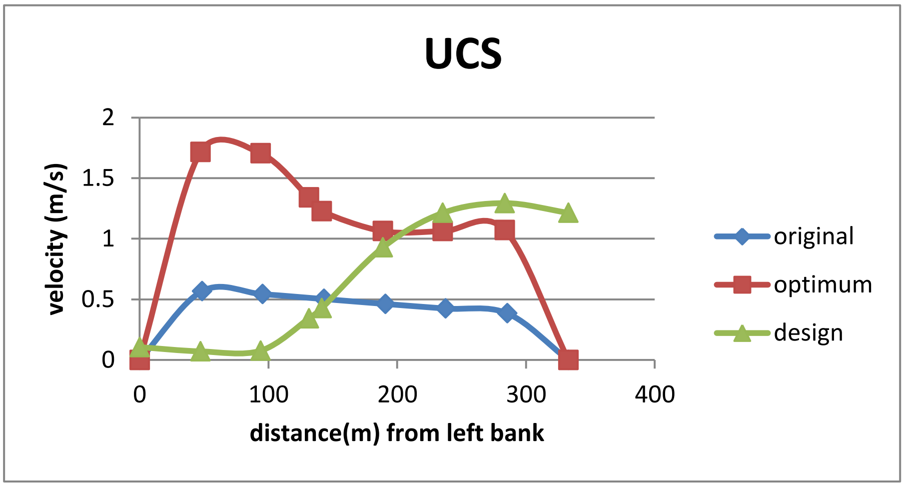

FIG (8) Comparison of velocity profiles in the case of protecting zone

Comparison of flow velocity profiles for different spur dike designs at the downstream cross section “DCS” versus that for the case of the original existing flow conditions are depicted as shown in Figs.(from 9 to 10). the minimum velocity of .34m/s was recorded at the west secondary river channel for the case of the original condition, the value of 1.26m/s for the applied design and related to protection of the zones were achieved. The achieved results reveal percentage increase of 16% relative to the original flow velocity when the optimum velocity was 1.28 m/s. Also the worked out results illustrates a significant velocity reduction near the east outer curved zone where bank erosion is usually taken place. In this case the velocity decreased from .64 m/s for the original flow condition to about 0.067 for the applied design in the case of protecting zone. The achieved results reveal percentage increase of 89.5% relative to the original flow velocity for the case of protecting zone. When the optimum velocity was 1.52 m/s. Consequently one may conclude that apply the proposed spur dike systems along the “DCS” cross section will provide sufficient protection for the outer curved bank as well as to inherent sediment deposition near the inner curved zones during the case of the max flow discharge protected zone.

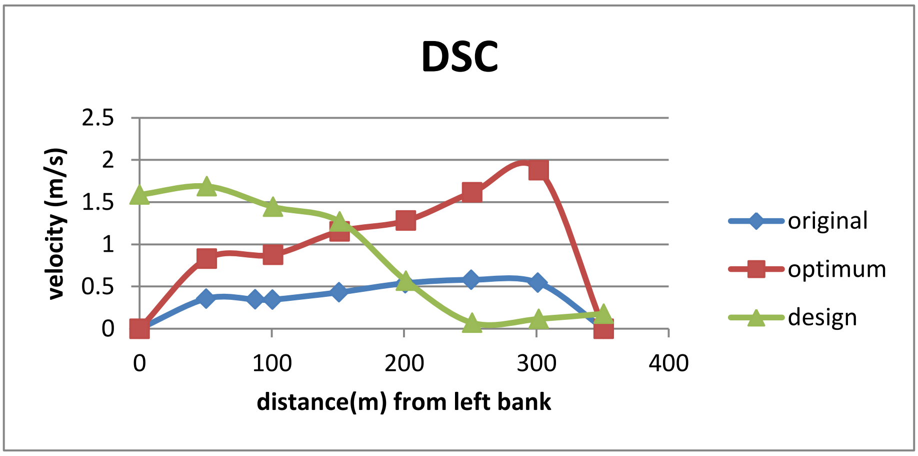

FIG (9) Comparison of velocity profiles in the case of protecting zone.

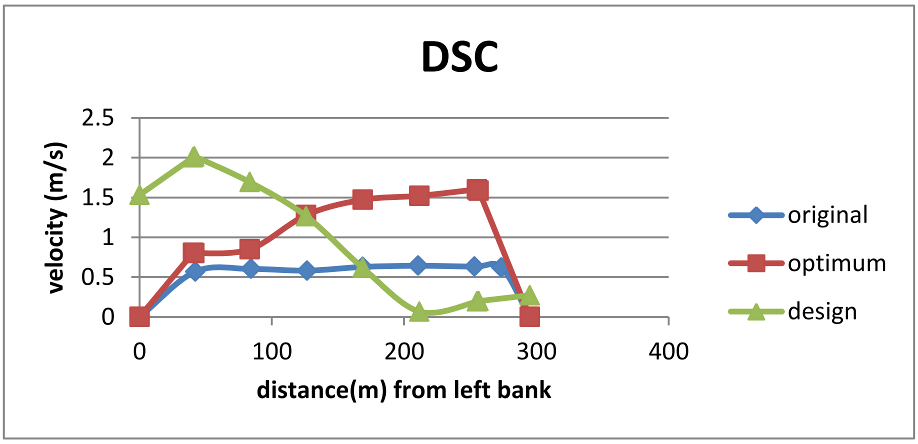

FIG (10) Comparison of velocity profiles in the case of protecting zone.

4. Conclusion

The “SMS” 2-D mathematical model was applied to simulate the flow pattern for 7 Km meandering located at Kafr Shokr City, Egypt. One suggested solution was used to handle the developed scour and deposition problems in the studied reach under different flow conditions. To assure the ability of the used model in simulating the studied reach; the model was calibrated and verified using prototype measurements at 8 different cross sections. Based on the results and focusing on the comparative study for the solution by the surveying of year 2013, by using the alternative number 15 the following was obtained:

1. At the "UCS" section, the west outer curve velocity decreased by 88.33%.
2. At the "UCS" section, the east inner curve velocity increased by 50%.
3. At the "DCS" section, the east outer curve velocity decreased by 89.5%.
4. At the "DCS" section, the west inner curve velocity increased by 16%.

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