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Bed Shear Stress Evaluation at the Nile River Bends on Rosetta Branch

[1] Gamal Elsaeed, [2] Mohammad Ibrahim, [3] Hossam Elsersawy
[1] Professor of Water Resources and Hydraulics, Faculty of Engineering, Shobra, Banha University, Cairo, Egypt
[2] Lecturer, Faculty of Engineering, Shobra, Banha University, Cairo, Egypt
[3] Assistant Professor, Nile Research Institute, National Water Research Center, Cairo, Egypt
gelsaeed@feng.bu.edu.eg (Corresponding author)

ABSTRACT

In this paper the effect of releasing (emergency and maximum) flow discharges on bed shear stress at 3.5 km length meandering river reach at Kafr El-Zayat City from km 145.00 to km 148.50 D.S of El-Roda Gauge at Kafr El-Zayat City. 2-D numerical model "SMS" in addition to hydrographic measurements were combined for this purpose. The available data related to hydrographic and hydraulics of the reach under study was collected. Water levels and discharges at several years were studied to determine the different flows passing in the Rosetta branch. The bed levels data at several years were compared to study the development of the morphology on the bend. The studied reach was simulated four times by the 2-D numerical model using the available survey reach at years 1982, 1998, 2003 and 2006. The flow discharges were used as upstream boundary condition and the water level was used as downstream boundary condition. The model was calibrated and verified using the field measured velocities. Two proposed alternatives were suggested as possible solutions of the problems of scour and deposition for the tested reach. The first alternative, the outer bends were filled with layers of filter and riprap up to level -5.00 m MSL. In additional to the first alternative, the inner sides of the bends were dredged to level -3.00 m MSL as second alternative. The two alternatives were numerically tested for the maximum and emergency flows and bed shear stress was estimate. The results showed that in the case of alternative 2 the bed shear stress was reduced in the vicinity of the banks compared to the basic case and the first alternative. Consequently, alternative 2 was presented as a proper solution for the meandering problems in this reach in addition to its high protection against the bank failure.

1. INTRODUCTION

The Nile River is relatively straight with some sinuous reaches over short distances that are related to steeper slopes. The increase in sinuosity in turn increases the bed slope more than 10cm/km. Steeper portions become more active and bank erosive. During high floods, greater discharges than the annual maximum were released. These peak discharges cause local scour in the vicinity bridges, harbors and other structures and inundation to former flood plains that are currently in use. So at high discharges the scouring action was expected to continue in these areas, also the bed shear stress would be highly affected. The meander wavelengths of the River Nile varied from 2500m to 4500m. The meander pattern was subsequent to the construction of the High Aswan Dam (H.A.D.) as a result of a reduction in discharge and sediment load. After constructing H.A.D, the Nile was considered as a very low energy river with low water surface gradients. Also the suspended bed material loads for the Nile downstream Aswan has changed substantially as a result of the creation of Lake Nasser HRI, [1]. But High discharges released from HAD should be properly dealt with. As, these peak discharges cause damages to the water control structures along the Nile and its branches. Relatively high discharges cause local scour near bridges, harbors and other structures. Relatively high discharges increase shear stresses applied at river beds. Also, relatively high discharges cause inundation to former flood plains currently in use. Such inundation in turn ruins agricultural properties, urban areas, and roads and may expose human lives to danger. So it was found that bed shear stresses area fundamental factor in the study of discharges in river bends. Many researchers made the study of bed shear stresses is the basic aim of their researches. C. I. Thornton et al. [2] made a model study in a rigid bed channel with natural plan form, thalweg, and cross sections derived from field surveys. Then Kb values (Kb is the ratio of shear stress in a channel bend way to the straight channel approach shear stress) were derived from shear stresses measured in rigid, trapezoidal-shaped channels (Kb ranges from 1.05 to 2.5).Donatella Termini [3] published a paper, its aim was to gain some insight into how the momentum transport by cross-stream circulation contributes to the bed shear stress redistribution.

Experimental analysis, based on a detailed dataset collected in a large-amplitude meandering laboratory flume was presented in the paper. From these data an evaluation was made of the terms in the depth-averaged momentum equations. Guang HUO et al. [4] published an article, in which a shear plate was mounted on the bottom in a wave flume and direct measurements of the smooth and rough bed shear stress under regular and irregular waves were conducted with the horizontal force exerted on the shear plates by the bottom shear stress in the wave boundary layer. The distribution of the bottom mean shear stress varying with time was measured by examining the interaction between the shear plate and shear transducers. Raphael W. Crowley et al. [5] used the sediment erosion rate flume (SERF) to evaluate various methods to estimate shear stresses in a flume-style erosion rate testing device. Also, Raphael W. Crowley et al. [6] used sediment erosion rate flume (SERF) device to get shear stresses. It was computationally modeled using CD-adapco's Star-CCM+ at varying flow rates and sample roughness's so that wall shear stresses could be evaluated during a piston-style erosion test. Richard A. Jepsen et al. [7] used a laboratory and field device called the sediment erosion actuated by wave oscillations and linear flow (SEAWOLF) flume. It was developed by Sandia National

Laboratories in which high-resolution, particle-image velocimetry (PIV) has been applied to investigate turbulent flow shear stresses for a variety of flow conditions. Wenyu Yang et al. [8] presented the findings from a study of the rheological properties of both sandy and cohesive (kaolin and mud) bed sediments under shear and mechanical vibration loads. As a result it was found that the rheological properties of the sediments depended not only on the magnitude of the shear load but also on its duration. B. VERMEULEN et al. [9] explored the possibility of using a horizontally deployed acoustic Doppler current profiler (ADCP) to monitor bed shear stress, applying a prescribed boundary layer model, previously used for discharge estimation. B.N.

Bockelmann-Evans et al. [10] introduced details of an experimental and theoretical study to determine the bed boundary shear stress along vegetated river beds introducing a novel field measuring method, namely the Fliess Wasser Stammtisch (FST)-hemispheres. The results of this study provide a basis for enabling the FST-hemispheres to be used to evaluate the boundary shear stress for a wider range of applications in the future, including vegetated river beds. Chao Liu et al. [11] presented an approach to modeling the depth-averaged velocity and bed shear stress in compound channels with emergent and submerged vegetation. Tiago Abreu et al. [12] presented a new formulation to predict the bed shear stress under skewed/asymmetric oscillatory flows (with or without a co-linear mean current). It was found by testing that the results of the new formulation and the momentum-integral method agree well, but differ from those with the log-fit method. Alvaro Galan et al. [13] built a new instrument to directly measure the bottom shear stress under different conditions of periodic waves.

Both monochromatic and sawtooth-shaped waves have been tested, and the experimental shear stress time histories were compared with the results obtained from a numerical model. Jaya Kumar Seelam et al. [14] presented direct measurements of bed shear stresses (using a shear cell apparatus) generated by non-breaking solitary waves. The measurements were carried out over a smooth bed in laminar and transitional flow regimes.

Analytical modeling was carried out to predict total and skin shear stresses. Yunwei WANG et al. [15] carried out annular flume experiments, using the sediment samples collected from the lower part of the inter-tidal zone at Xiaoyangkou, Jiangsu coast, China. A derived relation between the bed shear stress and suspended sediment concentration was presented. Also results of experiments indicated that, from a critical level onward, suspended sediment concentration has a strong influence on the bed shear stress. Laurel G. Larsen et al. [16] predicted shear stresses and sediment redistribution potential in different vegetation communities. Using a field-validated numerical model, state-space diagrams was developed that provide these predictions over a range of water-surface slopes, depths, and associated velocities in

Everglades ridge and slough vegetation communities. Jerome Peng-Yea Maa et al. [17] presented results of two laboratory experiments on the cohesive sediment deposition behavior. Direct observations on when and where the bed is formed suggest that deposition only occurs when the local bed-shear stress (τ_b) is less than a critical value. Gonzalo Simarro et al. [18] presented an approach for calculating turbulent flows in a wave-current boundary layer over a slowly varying bed. As a part of the results, bottom shear stress and the spatial variation of the boundary layer thickness are also obtained. Present results compare well with experimental data and can explain the asymmetries in the bottom shear stress under sawtooth shaped waves. M. Sterling et al. [19] examined the use of data obtained from large eddy simulations in exploring the instantaneous characteristics of boundary shear stress. Conditional sampling is used in order to provide an insight into the average behavior of an extreme shear stress event. Finally, proper orthogonal decomposition showed that the behavior of the shear stress is complex and cannot necessarily be attributed to a single major flow event.

2. METHODOLOGY

The “SMS” 2-D mathematical model would be employed, at first, to simulate the morphological and hydrological characteristics in the reach of Rosetta branch. The present study would be carried out applying the following:

a. Collecting the available data of the reach under the study related to hydrographic and hydraulics.
b. Reviewing the available scour hole information in the available literature.
c. Reviewing the previous available studies related to this subject, also determine the different flows at several years passing in the Rosetta Branch from the HAD.
d. To study the development of the morphology on the bend, the reach available bed level data at several years were compared.
e. The reach was numerically simulated for four times using the surveyed data at different years aiming to model calibration and verification.

3. MODEL CONSTRUCTION

The simulated length was about 3.5km, including 13 piers under 3 bridges. The mesh was generated for the studied area, and the bed elevations were determined using the bathymetric survey of the river. The mesh was designed by dividing the studied reach into different regions. Each region was divided into elements called quadrilateral elements and triangular elements. It should be mentioned that the designed mesh was condensed at the locations of the bridge piers to simulate the dimensions of piers with high accuracy (Fig.1).The depth file was created based on the hydrographic survey data collected in 2006. The discharge and the water level were used as upstream and downstream boundary conditions respectively. The hydraulic roughness coefficient was defined at each grid point and ranged from 0.02 to 0.05.

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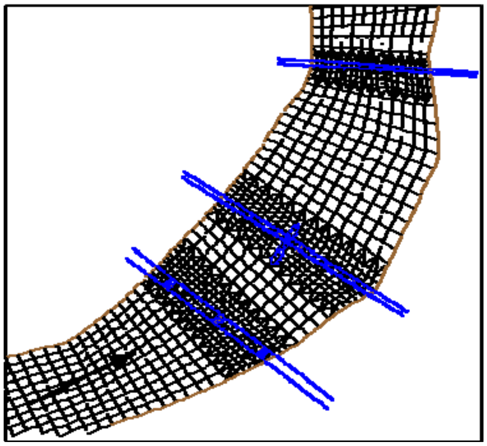

Fig 1: Mesh Generation

3.1 Model Calibration

The model was run using the field hydraulic measurements in 2006. The discharge of 222.8m^3/sec and the corresponding water level of 2m MSL were used as upstream and downstream boundary conditions respectively. In calibration process, the velocity distributions were located at 3 different cross sections, (Fig.2). The water surface slope was adjusted in the model by changing the roughness coefficient up to a good agreement between the prototype, and model water surface slope was obtained after which the roughness coefficient was fixed. Figs. 3-5 showed good agreement between the velocities obtained from the used model and field measurements at different cross sections.

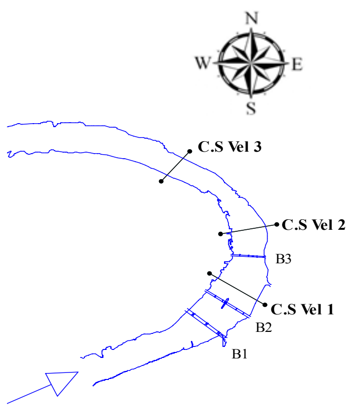

Fig 2: Location of the Calibration Cross Sections

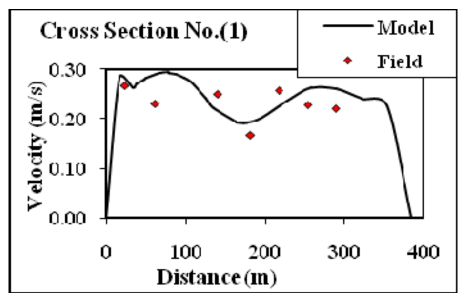

Fig 3: Flow Velocity Calibration at Cross Section (1)

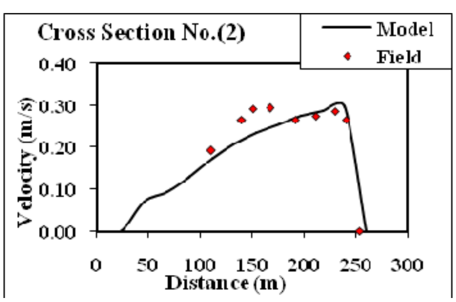

Fig 4: Flow Velocity Calibration at Cross Section (2)

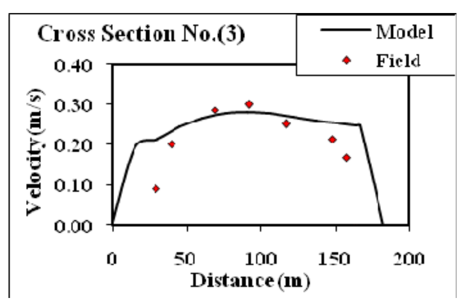

Fig 5: Flow Velocity Calibration at Cross Section (3)

4. SIMULATION OF THE PROPOSED SOLUTIONS AND RESULTS

Two proposed alternatives to improve the morphology of the bend were suggested and simulated separately by the SMS model. In the first alternative, the scour hole of the outer bend was filled by layers of filter and riprap up to level -5.00 m MSL. In additional to alternative 1, dredging the inner sides to level -3.00 m MSL was proposed as second alternative. The model was run for the two alternatives at maximum and emergence flow with its corresponding water levels which were 809.03 m^3/s, 2546.30 m^3/sec, +2.60 m MSL and +5.90 m MSL respectively. The flow discharge was used as upstream boundary condition and the water level was used as downstream boundary condition.

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4.1 Comparisons of Bed Shear Stress between the Two Alternatives

4.1.1 Maximum Flow

In case of maximum flow the bed shear stress was estimated at the whole reach for the basic case, the first alternative and the second one. Figure (6) shows the location of bed shear stress more than 2 N/m^2 and ranges between 2 and 15 N/m^2 for the basic case. It was found to be concentrated in the outer curves of the bend. Figure (7) shows the locations of bed shear stress more than 2 N/m^{2}and ranges between 2 and 6 N/m^2 for the first alternative. Figure (8) shows the locations of bed shear stress more than 2 N/m^2 and ranges between 2 and 4 N/m^2 for the second alternative.

It was noticed that the results of bed shear stress in case of the second alternative was reduced compared with the first alternative and the basic case, also the bed shear stress disappeared in some areas in the outer curve in case of the second alternative compared with the first one and the basic case.

Figure (9) shows comparison of the bed shear stress along ten cross sections in the cases of original, alternative 1 and 2.

After reviewing the shear stress distribution along the ten cross section the following can be concluded:

a. The bed shear stress in case of alternative 2 became regular in cross sections 1, 3, 4, 5, 6, 7, 8 and 10 comparing with alternative 1 and basic case.
b. The shear stress beside the banks reduced at section 2 comparing with the basic case and alternative 1.
c. The shear stress of cross section no 9 in case of alternative 2 increased than the basic because this section have big filling, consequently the velocity was increased.

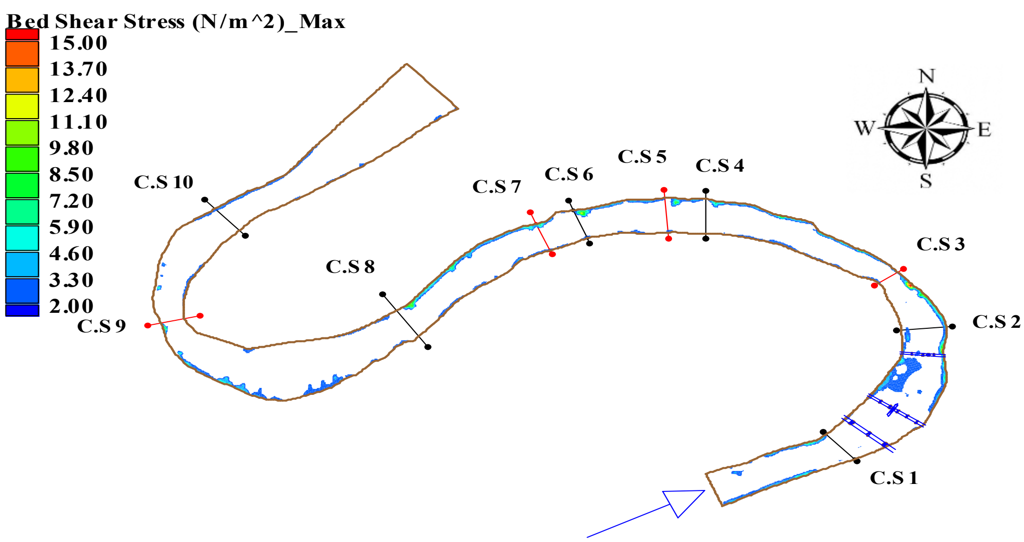

Fig 6: Bed Shear Stress for Max Flow conditions in the case of the Basic case

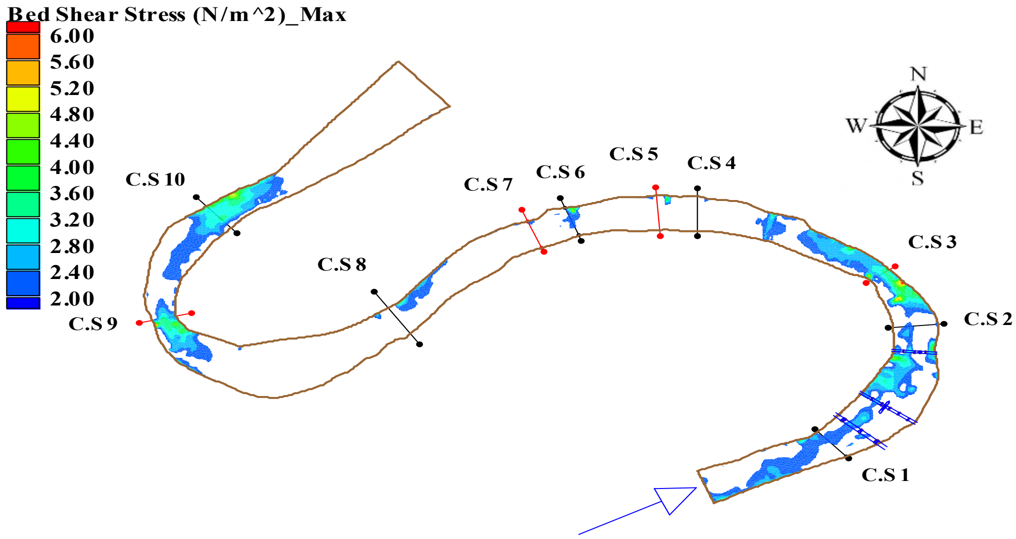

Fig 7: Bed Shear Stress for Max Flow conditions in the case of Alternative 1

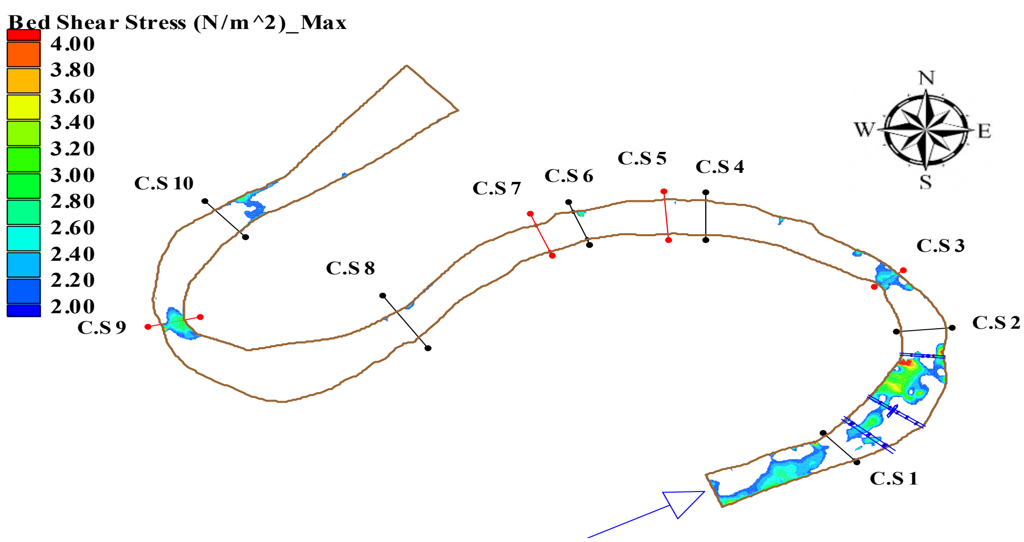

Fig 8: Bed Shear Stress for Max Flow conditions in the case of Alternative 2

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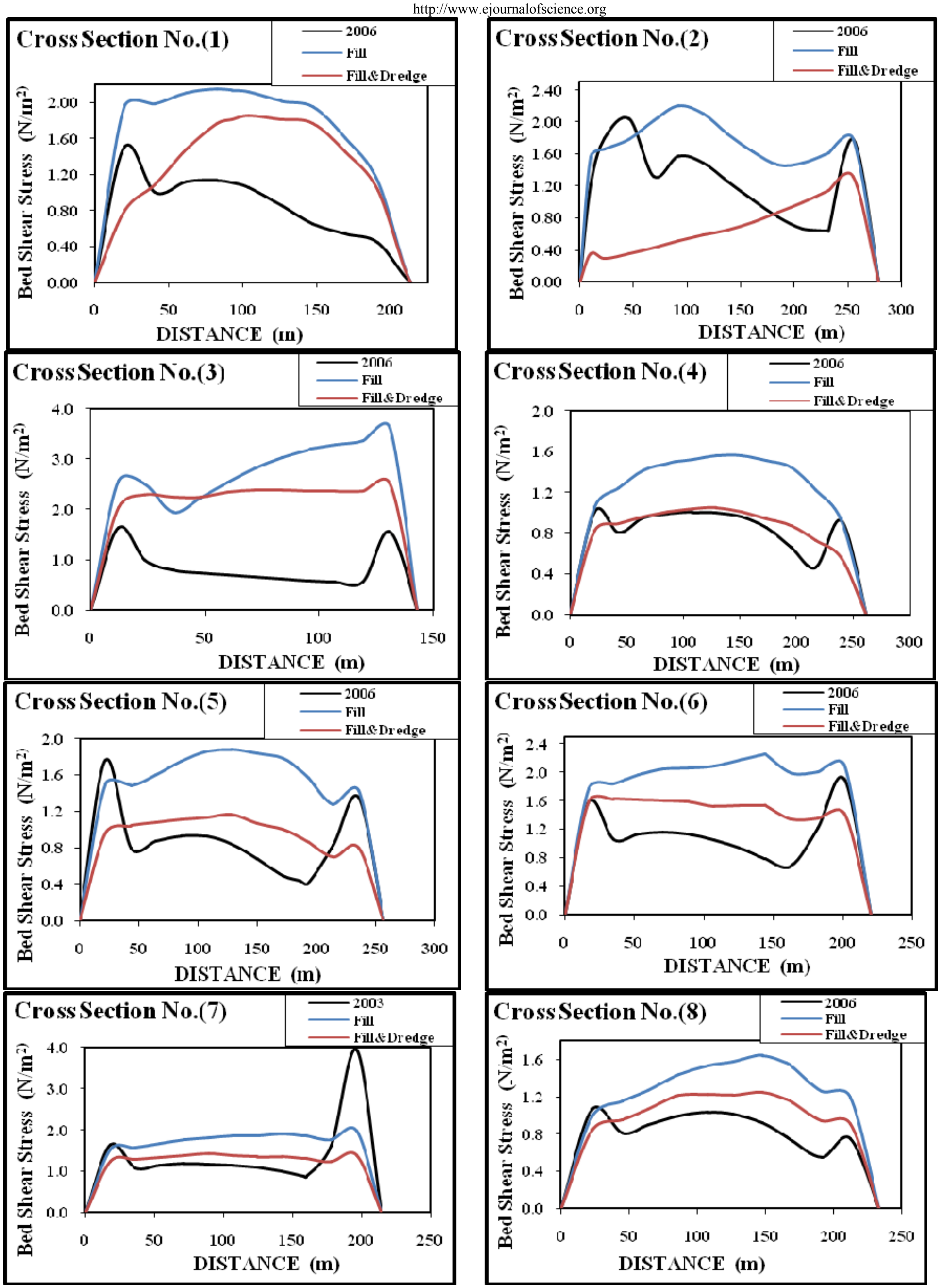

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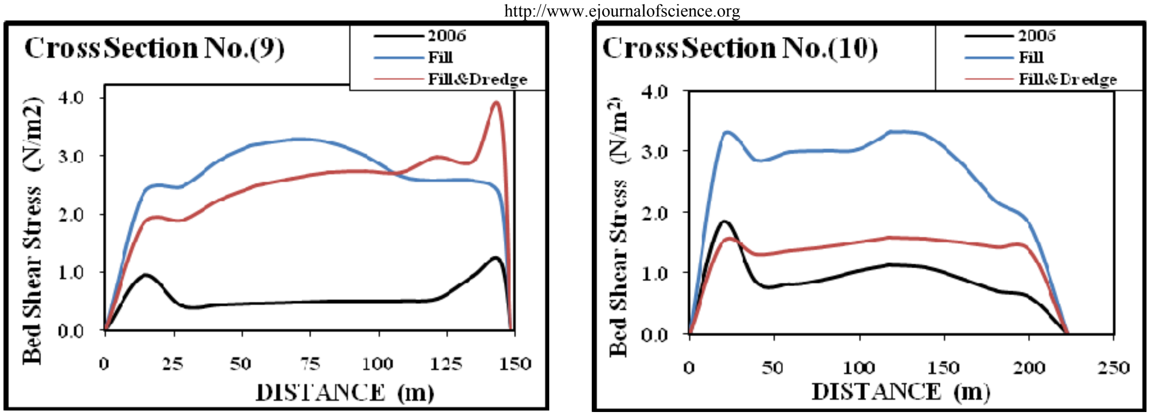

Fig 9: Shear Stress comparison of the basic, Alternatives 1 and 2 at Maximum Flow

4.1.2 Emergency Flow

In case of emergency flow the bed shear stress was estimated at the whole reach for the basic case, the first alternative and the second alternative. Figure (10) shows the location of bed shear stress more than 2 N/m^2 and ranges between 2 and 30 N/m^2 for the basic case. It was found to be concentrated in the outer curves of the bend. Figure (11) shows the locations of bed shear stress more than 2 N/m^2 and ranges between 2 and 18 N/m^2 for the first alternative. Figure (12) shows the locations of bed shear stress more than 2 N/m^2 and ranges between 2 and 15 N/m^2 for the second alternative.

It was noticed that the results of bed shear stress in case of the second alternative was reduced compared with the first alternative and the basic case, also the bed shear stress disappeared in some areas in the outer curve in case of the second alternative compared with the first one and the basic case. Figure (13) shows comparison of the bed shear stress along ten cross sections in the cases of original, alternative 1 and 2.

After reviewing the shear stress distribution along the ten cross section the following can be concluded:

- The bed shear stress in case of alternative 2 became regular in cross sections 1, 2, 3, 5, 6 and 7 comparing with alternative 1 and basic case.
- The shear stress beside the banks reduced at sections 1, 2, 5, 6 and 7 comparing with the basic case.

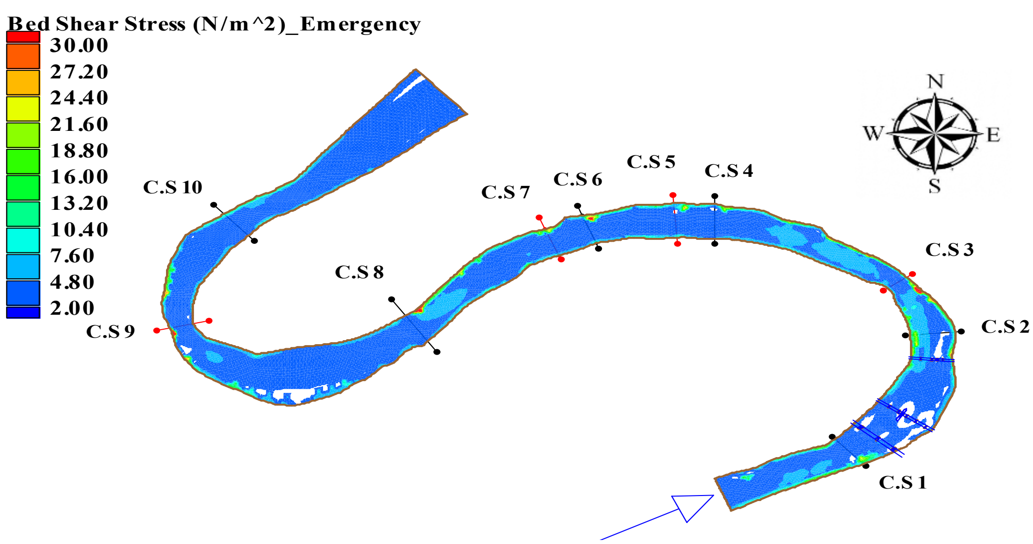

Fig 10: Bed Shear Stress for Basic case at Emergency Flow

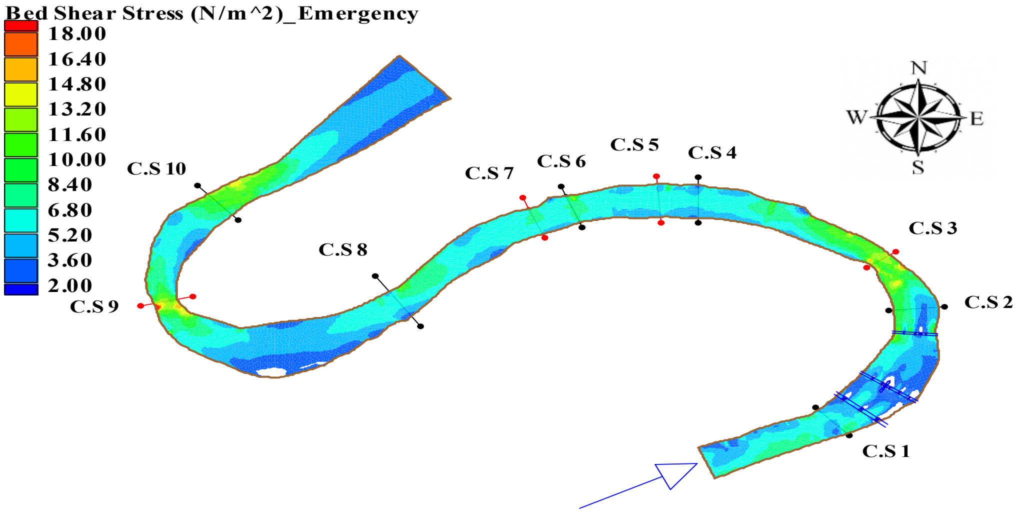

Fig 11: Shear Stress for Alternative 1 at Emergency Flow

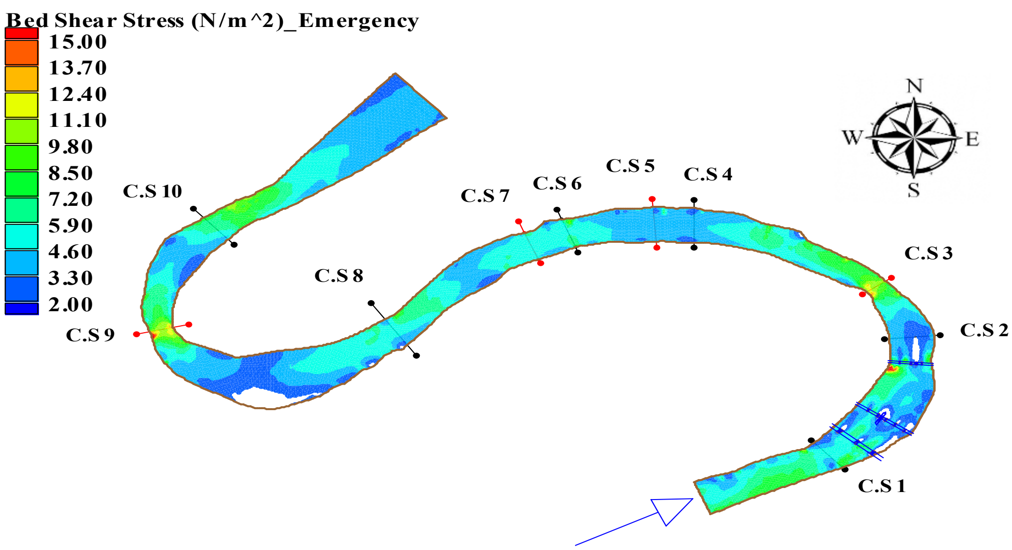

Fig 12: Shear Stress for Alternative 2 at Emergency Flow

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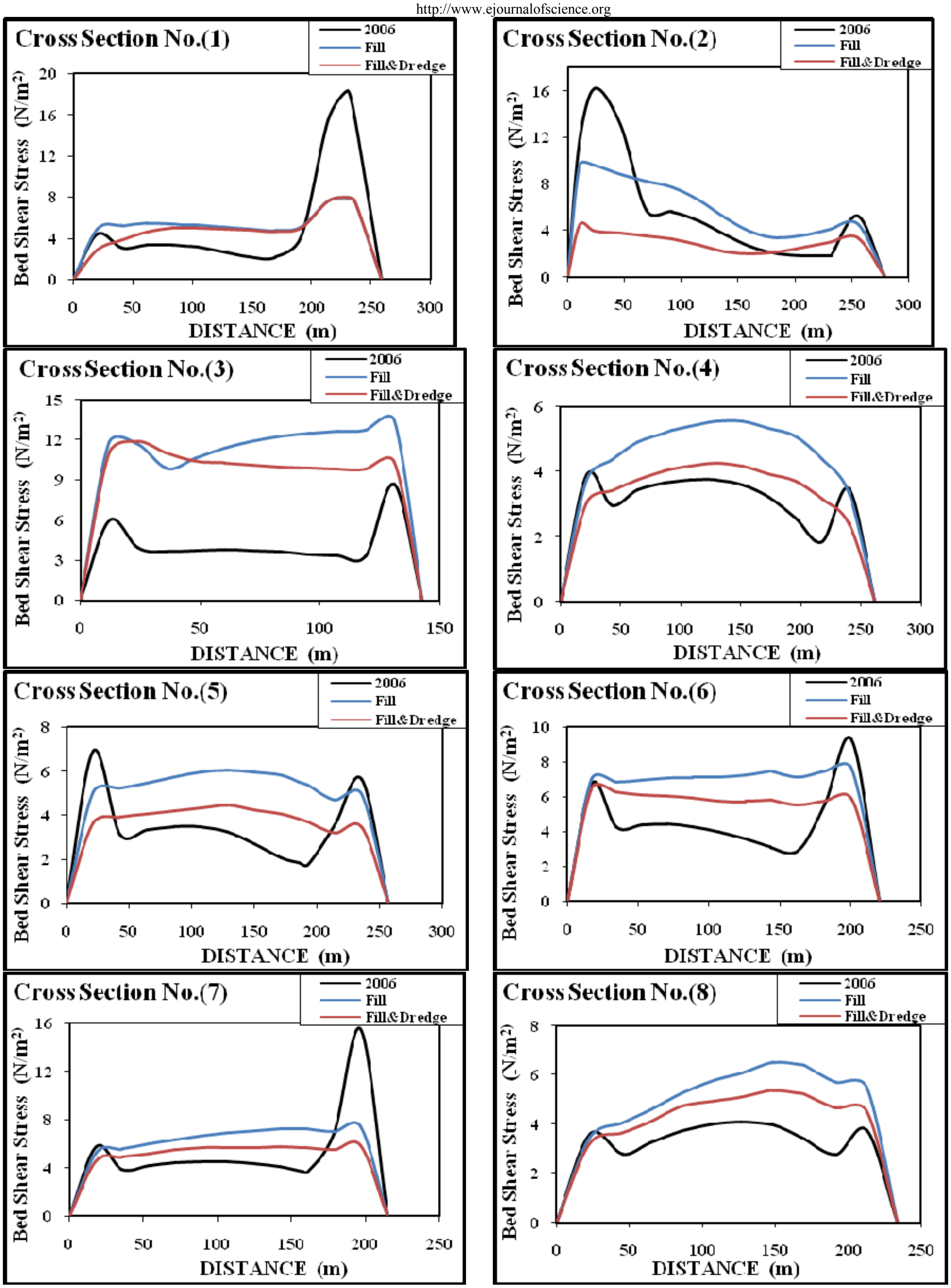

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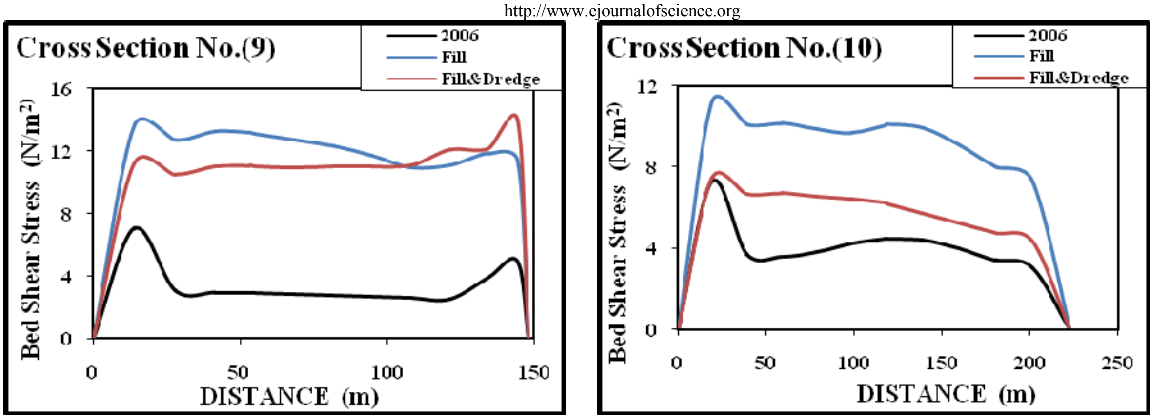

Fig 13: Shear Stress comparison of the basic, Alternatives 1 and 2 at Emergency Flow

5. CONCLUSION

Based on the results of comparing the two purposed solutions by surveying of year 2006, the following was concluded:

a. In the case of emergency and maximum flow the values of shear stresses were reduced in the case of the second alternative compared to the first one and the basic case.
b. In the case of emergency and maximum flow the bed shear stress was unnoticed in some locations at the outer bend for the second alternative compared to the first one and the basic case.
c. For all tested runs of the of basic and two alternatives in the case of emergency flow conditions, the values of shear stresses were maximized and highlighted at the all tested length of the reach. Consequently, the bed scour and bank instability expected to be found along the tested reach, which intern expose the bridges of Kafr El-Zayat city to foundation failure as a result of the scouring action to their peers.

6. COMPETING INTERESTS

Authors have declared that no competing interests exist.

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