1. INTRODUCTION

Curved open canal are subjected to complicated erosion and deposition processes. Many researches made an effort to solve erosion problem in open canals [1-5]. A study presented CFD model to predict erosion process in three different S-bends [6]. The tests were conducted for S-bends of the curvature’s radius ratio (Ø/L=1.5). The results showed areas of the maximum erosion along the S-bend. Based on a recent study specified that narrow rivers were subjected to stabilized meanders [7]. A research pointed to that the 135° bend can be treated as a typical regular meander [8]. Studied the lateral movement of alluvial in the Rio Grande [9]. Previous study recommended an empirical formula for the prediction of scouring in bends, see Eq. (1) [10].

$$S_{max}/W = 2.077 - 0.19 \ln (\frac{\Omega}{L})$$  \hspace{1cm} (1)

Studied the consequence of flow discharge on the capacity of the sediment transport [11]. A study examined the different constraints affect the computations of GCHE2D model [12]. The roughness coefficient of the beds is the main factor affecting the flow in open canals. Others provided results of investigations of the bends’ scour in Warta River [13]. The scour at bends was calculated by a numerical model. A maximum scour equation along the bend was introduced. Recent research built a 2-D numerical model to detect the transportation of the sediment through open canals [14]. Then other study used two numerical models to detect the scouring problems at Nile River upstream of the new intake of Esmaielia canal [15]. Two-dimensional horizontal numerical model to detect the morphological changes in rivers of bends [16]. Two experiments were conducted to calibrate the model. Previous study applied one of the available solvers in iRIC software to simulate velocity field around piers under contraction effect [17]. Results showed, pile of 4.812 a comparative extension yielded minimal velocity. In fact, no available researches studied erosion processes around the supports along curved reaches. This paper presents experiments for the erosion and deposition processes along 180° bend through open canal. Experiments are conducted with the curvature’s radius ratio (Ø/L) varies between 3.0 to 8.5. The optimum location of bridge supports along the bend are defined. Nays2DH Model is applied to simulate the flow and erosion processes. The numerical results are compared with the tests for open canal.
erosion processes. The support's diameter = 3.2 cm was fixed in the centerline of the open canal (i.e. \( \omega = 90^\circ \)). The tests are conducted for centerline's radius of = 50 cm, 66 cm, 100 cm, and 160 cm. 

3. DESCRIPTIONS OF RESULTS

3.1 Optimum location of the Support

The results of the deposition and erosion phenomenon through open canal with beds at different \( \omega \) and \( \Omega/L\) are analyzed in the following section.

Figure (3a and 3b) presents the examined erosion and deposition at the support itself. It was looked out that, \( SP_{\text{max}}/W_{\text{down}} \) (i.e., the relative erosion depth at support) is the minimum for the status of \( \omega = 41^\circ \). In contrast, \( DEP_{\text{max}}/W_{\text{down}} \) (i.e., the relative deposition depth at support) is the maximum for the status of \( \omega = 41^\circ \).

Figure (4a and 4b) presents the examined erosion and deposition at the outer bend. It was looked out that, the rate of the depth of erosion \( S_{\text{max}}/W_{\text{down}} \) is the minimum for the statuses of \( \omega = 90^\circ \) and \( 180^\circ \). The rate of the maximum deposition \( DE_{\text{max}}/W_{\text{down}} \) is the minimum for the statuses of \( \omega = 90^\circ \) and \( 180^\circ \).

Figure (4c and 4d) presents the examined phenomenon at the inner bend. It was looked out that, \( S_{\text{max}}/W_{\text{down}} \) is the minimum for the status of \( \omega = 90^\circ \) and \( 180^\circ \). Moreover, \( DE_{\text{max}}/W_{\text{down}} \) is the minimum for the statuses of \( \omega = 70^\circ \) and \( 180^\circ \).

3.2 The Optimum Curvature

The results of the deposition and scour phenomenon in bends of different curvatures are analyzed in the following section. The status of \( \Omega/L = 8.5 \) gives minimum values of \( S_{\text{max}}/W_{\text{down}} \) and \( E_{\text{max}}/W_{\text{down}} \) at the outer boundary, see figure (5a, and 5b), respectively. Moreover, \( \Omega/L = 8.5 \) gives the minimum values of \( DE_{\text{max}}/W_{\text{down}} \) at the inner boundary, see figure (5d). It was looked out that, \( S_{\text{max}}/W_{\text{down}} \) is the minimum for the status of \( \omega = 8.5 \).

Figure (5c) presents the maximum deposition at the studied reach. It was looked out that, there is an acceptance between the measurements and Nays2DH for \( F_{\text{max}} < 0.5 \). On the other hand, the gap is noticeable between measurements and the calculations for the range of \( F_{\text{max}} > 0.5 \). General speaking, Nays2DH model gives more scoured depths than the detected in the lab. RSQ for the modeled cases are 98.329% and the correlation factor between the numerical modeling and the gauged = 93.98%.

4. OVERVIEW OF NAYS2DH MODEL

The numerical two dimensional in plan Nays2DH model was built by Dr. Yasuyuki Shimizu [18]. It is a powerful model used to detect the flow and sediments behavior through open canals. Nays2DH model is a solver imbedded in iRIC software [19]. A research also presented basic equations of the sediment transport and flow used in Nays2DH model [18]. The main formulas of the flow include the continuity and the momentum equations.

Few papers were presented for applications of Nays2DH model. Based on a study discussed 6- solvers embedded in iRIC software [20]. Environmentally assessed water conditions and the sediment action in the reservoir of Ogaki Dam for different operation statuses using Nays2D model [21]. A recent study applied Nays2D model for open canal subjected to water surface fluctuations [22]. The model was compared with observatories of gauged water surface levels.

5. DESCRIPTION OF THE GENERATED NUMERICAL MODELS

The generation of the Nays2DH Model passes through few steps. At the first, the mesh is generated as illustrated in figure (7a). The mesh is schematized into 10- cells in lateral direction and 70- cells in longitudinal direction. The dimensions of a single cell are \( 0.02 \times 0.02 \) m. The total number of cells is 700. The topographic bed of the model is given as figure (7b).

5.1 The open canal bends without supports

Nays2DH Model was built for the statuses of proposed open canal without any supports existed in the canal. The model characteristics include \( \omega = 50^\circ \) and \( F_{\text{max}} = 0.2 \times 0.7 \). The flow conditions include different water surface slopes (the slope \( 2.4 \times 0.01 \), \( 0.002 \), \( 0.003 \), \( 0.004 \), \( 0.005 \) and \( 0.006 \)), the same flow discharge \( (Q = 0.24 \text{ m}^3/\text{sec}) \) and the same time for the test \( (T = 600 \text{ second}) \). The bed material was defined \( (F_B = 1900 \text{ micron}) \).

5.2 The case of locating a support

Nays2DH Model was built for the statuses of proposed open canal with a support existed in different locations. The flow properties include followings: the discharge \( Q = 0.0024 \text{ m}^3/\text{sec} \), the flow surfaces is uniform slope of 0.0045. The supports' locations include 4- positions (i.e. \( \omega = 41^\circ \), \( \omega = 53^\circ \), \( \omega = 70^\circ \) and \( \omega = 90^\circ \)).

6. CALIBRATION OF THE NUMERICAL MODEL

The results of Nays2DH Model are compared with tests. Figure (8) presents the maximum \( P_{\text{max}}/W_{\text{down}} \) through the examined reach and for both the measurements and the calculated ones by Nays2DH model against \( F_{\text{max}} \). It was looked out that, there is an acceptance between the measurements and Nays2DH for \( F_{\text{max}} < 0.5 \). On the other hand, the gap is noticeable between measurements and the calculations for the range \( F_{\text{max}} > 0.5 \). General speaking, Nays2DH model gives more scoured depths than the detected in the lab. RSQ for the modeled cases are 88.329% and the correlation factor between the numerical modeling and the gauged = 93.98%.

7. NUMERICAL RESULTS

The results of the Nays2D HD Model are presented for the statuses of proposed open canal with supports, see figure (9). Figures (9a, 9b, 9c, 9d) display the numerical outcomes of the scour and deposition processes along the studied reach for the several flow conditions. It is obvious that, the scour depth increases as \( F_{\text{max}} \) increases.

The results of Nays2D HD Model are presented for the statuses of proposed open canal without supports, see figure (9). Figures (10a, 11b, 11c and 11d) display the numerical generation maps for the streamline's distribution for different positions of the support. It is easily seen that, the flow lines become in an equal distribution across the section in the cases \( \omega = 70^\circ \) and \( 90^\circ \).

Figures (12a, 12b, 12c and 12d) display the numerical generation maps for the velocity vectors distribution for different positions of the support. The figure illustrates that, the velocity vectors become in an equal distribution across the section in the cases \( \omega = 70^\circ \) and \( 90^\circ \).

Figure (13) displays the scoured bed profile at the support for cases of different positions of the support. It can be realized that, the scour is minimum for the status of \( \omega = 41^\circ \). Moreover, the deepness of scouring is the maximum for the case 26 of \( \omega = 90^\circ \).

8. CONCLUSIONS

This paper presents experiments and numerical modelling for the erosion and deposition processes along a bend through open canal for the several cases of localizing bridge support at the center line of the canal. The main conclusions include the following:

(1) The experimental results show that:

- The status of \( \omega = 41^\circ \) gives the minimum relative erosion depth at support, \( SP_{\text{max}}/W_{\text{down}} \) in contrast it gives the maximum relative deposition depth at support \( DEP_{\text{max}}/W_{\text{down}} \).
- For the outer bend, the status of \( \omega = 90^\circ \) and \( 180^\circ \) give the minimum rate of the erosion \( S_{\text{max}}/W_{\text{down}} \) and the maximum deposition \( E_{\text{max}}/W_{\text{down}} \).
- For the inner bend, the status of \( \omega = 90^\circ \) and \( 180^\circ \) give the minimum rate of the erosion \( S_{\text{max}}/W_{\text{down}} \). Statuses of \( \omega = 70^\circ \) and \( 180^\circ \) give the maximum deposition \( E_{\text{max}}/W_{\text{down}} \).
- The status of \( \Omega/L = 8.5 \) gives minimum values of \( S_{\text{max}}/W_{\text{down}} \) and \( E_{\text{max}}/W_{\text{down}} \) at both outer and inner boundaries.
- The status of \( \Omega/L = 8.5 \) gives minimum values of \( SP_{\text{max}}/W_{\text{down}} \) and \( DEP_{\text{max}}/W_{\text{down}} \) at the support itself.

(2) Results of Nays2DH Model are comparing with measurements for the status of open canal without any supports. RSQ for the modeled cases are 88.329% and the correlation factor between the numerical modeling and the gauged = 93.98%.

(3) The numerical outcomes of Nays2DH Model show that scouring areas around the support is minimized for the status of \( \omega = 41^\circ \). The status of \( \omega = 70^\circ \) gives minimum scouring processes in the studied reach.
Figure 1: [a] the scour and deposition locations along the bend [b] the support [c] the model parameters [d] Isometric along the bend [e] Section x-x

Figure 2: The rates of maximum scour versus time

Figure 3: The deposition and scour at the support for \( \phi/L = 3.0 \) and different \( \omega \) (a) \( DEP_{\text{ maxi}}/W_{\text{ down}} \) versus \( F_{\text{roude}} \) at the outer bend (b) \( SP_{\text{ maxi}}/W_{\text{ down}} \) versus \( F_{\text{roude}} \)

Figure 4: The deposition and scour for \( \phi/L = 3.0 \) and different \( \omega \) (a) \( S_{\text{ maxi}}/W_{\text{ down}} \) versus \( F_{\text{roude}} \) at the outer bend (b) \( DE_{\text{ maxi}}/W_{\text{ down}} \) versus \( F_{\text{roude}} \) at the outer bend (c) \( S_{\text{ maxi}}/W_{\text{ down}} \) versus \( F_{\text{roude}} \) at the inner bend (d) \( DE_{\text{ maxi}}/W_{\text{ down}} \) versus \( F_{\text{roude}} \) at the inner bend

Figure 5: The deposition and scour conditions for different \( \phi/L \) and \( \omega = 90^\circ \) (a) \( S_{\text{ maxi}}/W_{\text{ down}} \) versus \( F_{\text{roude}} \) at the outer bend (b) \( DE_{\text{ maxi}}/W_{\text{ down}} \) versus \( F_{\text{roude}} \) at the outer bend (c) \( S_{\text{ maxi}}/W_{\text{ down}} \) versus \( F_{\text{roude}} \) at the inner bend (d) \( DE_{\text{ maxi}}/W_{\text{ down}} \) versus \( F_{\text{roude}} \) at the inner bend

Figure 6: The deposition and scour conditions of different \( \phi/L \) and \( \omega = 90^\circ \) at the support (a) \( S_{\text{ maxi}}/W_{\text{ down}} \) versus \( F_{\text{roude}} \) (b) \( DE_{\text{ maxi}}/W_{\text{ down}} \) versus \( F_{\text{roude}} \)

Figure 7: (a) the generated mesh of the Nays2DH model (b) the bed topography of the generated mesh

Figure 8: \( S_{\text{ maxi}}/W_{\text{ down}} \) versus \( F_{\text{roude}} \) for measurements and Nays2DH

Figure 9: the scoured bed for different flow conditions (a) $F_{roude} = 0.232$ & slope=0.001 (b) $F_{roude} = 0.349$ & slope=0.002 (c) $F_{roude} = 0.421$ & slope=0.003 (d) $F_{roude} = 0.538$ & slope=0.004 (e) $F_{roude} = 0.587$ & slope=0.0045 (f) $F_{roude} = 0.73$ & slope=0.005

Figure 10: the scoured bed for different locations of the support (a) $\omega = 41^\circ$ (b) $\omega = 53^\circ$ (c) $\omega = 70^\circ$ (d) $\omega = 90^\circ$

Figure 11: streamlines for different support's locations (a) $\omega = 41^\circ$ (b) $\omega = 53^\circ$ (c) $\omega = 70^\circ$ (d) $\omega = 90^\circ$

Figure 12: velocity vectors for different locations of the support (a) $\omega = 41^\circ$ (b) $\omega = 53^\circ$ (c) $\omega = 70^\circ$ (d) $\omega = 90^\circ$

Figure 13: the bed profile before the support

REFERENCES


Engineering Heritage Journal (GWK) 3(2) (2019) 01-05


