Technical Journal, University of Engineering and Technology (UET) Taxila, Pakistan Vol. 23 No. 1-2018
ISSN:1813-1786 (Print) 2313-7770 (Online)

Experimental Investigation of Channel Bank Vegetation on Scouring Characteristics Around A Wing Wall Abutment

M. U. A. R. Amir[1], H. N. Hashmi[2], M. Baloch[3], M. A. Ehsan[4], U. Muhammad[5], Z. Ali[6]

[1,2,3,4,5,6]*Civil Engineering Department, U.E.T. Taxila, Pakistan*
[1]umarjam6100@gmail.com

Abstract-Abutments in bridges transmit major part of the weight of the structure to the foundations. Local scouring in the vicinity of the bridge abutments leads to the excessive damages particularly on the downstream of the structures and in extreme cases causes failure. In this study, experiments were performed in order to estimate the effect of channel bank vegetation on different scouring characteristics i.e. scour depth in the vicinity of the abutment, time to attain the equilibrium by the sediment particles and the depth of water required to displace the sediment particles from bed of the channel under two different scenarios(with and without channel bank vegetation). Channel bank vegetation proved an effective tool for minimizing and limiting different scouring characteristics around a wing wall abutment. The scour depth was reduced 39% as compared to that of banks without any vegetation at maximum flow rate of $0.04 m^3/s$. Furthermore, sediment particles attained equilibrium 15 hours earlier in case of vegetated banks as compared to that of non-vegetated banks showing a significant drop of 42% for achieving equilibrium. Water depth required for the incipient motion of the sediments increased by 23% by the incorporation of vegetation on banks of the channel. It was found that vegetation on banks of the channel enhances the service life of the hydraulic structures by minimizing scouring in the vicinity of the structures.

Keywords-Channel Banks Vegetation, Non-vegetated Banks, 60^o Wing Wall Abutment, Local Scouring, and Equilibrium Time

I. INTRODUCTION

Local scour is caused by local obstructions such as bridge piers and bridge abutments while general scour arises by disproportion in sediment transport at bridge constrictions and curvature effects [i]. Local scour around bridge piers and other cross drainage structures has been investigated by several researchers [ii-iii].

Wooden debris and logs in the vicinity of bridges offer larger circumvention to the flow as compared to that of deserted bridge piers. This supplementary hindrance results in increased scour and sediment removal as compared to the absence of drift intensification which results into the piping under the bridges and hence lead towards the unexpected stability failures [iv].

Woody vegetation on flood plains strongly influences the deposition and erosion of sediments in case of over bank flows and results into decreased shear stress magnitude on the sediment surface [v]. Numerical simulation for the influence of woody vegetation on sediment transport and flow characteristics is a complicated process because of complex relationship between drag force on vegetation, flow, variation in bulk density of the fluid and settling velocity of the suspended sediments [vi]. Riparian vegetation on a sediment laden bed results in decreased sediment erosion at the interface between the flood plain and open channel [vii].

Fluvial process leads towards the removal of vegetation or sediments from channel banks and beds is termed as scour. Riparian vegetation acts as first line of defense for flood controls such as embankment breach, up to some extent [viii]. Lateral migration of vegetated banks is more passive as compared to the non-vegetated banks [ix]. Provision of abutments on the bends can affect the pattern of bed and bank erosion [x].

Local abutments scour is a major issue with destructive consequences and is detrimental to the abutments hence ultimately leading to the bridge failure. Based on the abutment location in case of highway cross drainage structures, channel bank vegetation mainly governs scouring process in the territory of such structures. River flood plains and banks are most liable places for vegetation. Vegetation type and density of vegetation also effects the scouring around cross drainage structures. Sediment transport phenomenon is dependent largely on channel bed and banks vegetation. Hence effect of vegetation should be considered while designing highway cross drainage structures such as bridges and culverts [xi].

Flow process in the vicinity of the abutments deep seated in the sand bed is a complex process [xii]. Similarly using hydrogen bubble technique to estimate 3-D flow filed in a scour hole around a wing wall abutment, it was found that primary horse shoe vortex is a major cause for scouring around the abutments [xiii]. Channel bed shear stress near the edges of the abutments is almost 30% greater than the approaching bed shear stress [xiv].

Vegetation is excessively used for the mitigation of land sliding at country sides. Vegetation is helpful for ameliorating stability of the slopes for the period ranging from 5-12 months per year. Moreover, the slopes densefied with vegetation proved to be more stable than those of non-vegetated slopes [xv]. Generally in meandering rivers, the banks are made up of cohesive soils. The collective use of genetic and spatial analysis algorithms, in individual for the assessment of geotechnical stability originally of the hydrodynamic mesh, badges the deliberation of biophysical conditions for a protracted river reach with complex bank geometries, with only a minor enhance in run time [xvi]. Impact of vegetation and other weeds/shrubs on roughness, flow hydraulics and sediment trapping in channels are assessed by the field measurements and modelling and their resilience to high flow evaluated from observed flood impacts [xvii]. Vegetation furbishes a harmonious positive effect on landslides generated as a result of excessive rainfalls. Similarly the vegetation on banks of the channels reduces the banks erosion in case of cohesive soils. During high floods, the resistant provided by the vegetation on banks of the channel become significant and acts as first defense against the breaches [xviii]. Use of agricultural land for commercial residential purposes is extending day by day. In most of the countries of the world, this extensions has prevailed in highland areas and confounds deforestation of natural riparian vegetation. Due to deforestation of such natural riparian vegetation, land sliding rate has increased up to frightful extent [xix].

Many researchers have investigated the local abutment scour however, none of them considered the effect of vegetation on local scour around the abutment as well as equilibrium time for the sediments in a river is yet to be explored. The present investigation is to observe the effect of vegetation on channel banks on local scour around the abutments because the vegetation on channel banks not only imparts the strength to the channel banks but also streamlines the complex phenomenon of sediment transport. Hence in this experimental study, the effect of vegetation on channel banks is evaluated on local scouring around a 60° wing wall abutments.

Many researchers tried to estimate the scouring characteristics in the vicinity of the abutments using shear stress and flow velocity approaches. However, the effect of channel bank vegetation on scouring characteristics around the wing wall abutments is needs further investigation.

II. Objectives

The objectives of the research work were:-

- To determine an optimum depth of water required for incipient motion of sediments in an open channel in case of vegetated and bare banks.
- To analyze the effect of channel bank vegetation on scour depth in the vicinity of a 60° wing wall abutment.
- To assess the effect of vegetation on time required by the sediment particles to attain equilibrium.

III. Methodology

Experimental work was carried in the manual laboratory flume 20m long, 1m wide and 0.75m high available in the Hydraulics Engineering Laboratory, University of Engineering and Technology, Taxila. Discharge was measured by a rectangular notch constructed conforming to ASTM standard D5242-92 (2013) located at the downstream end of the flume as shown in Fig.1.

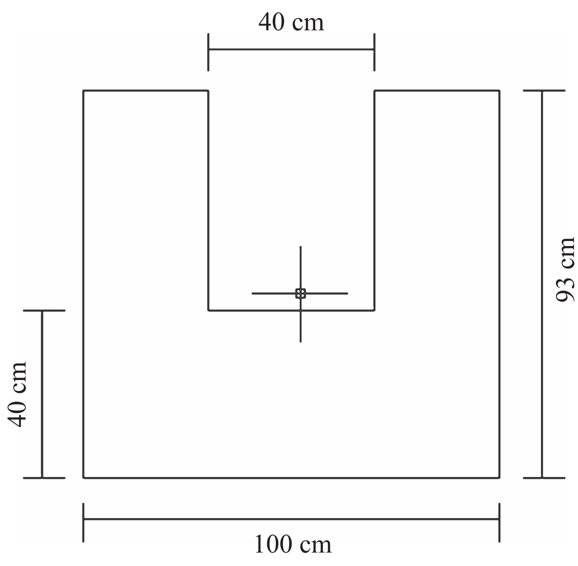


Fig. 1. Rectangular notch conforming to ASTM D5242-92

The discharge was measured by using equation 1;

$$Q=\frac{2}{3}(2g)^{\frac{1}{2}}C_d L_e [H_e]^{\frac{3}{2}} \quad (1)$$

Where C_d is coefficient of discharge for the notch. Its value was taken as 0.59, g is acceleration due to gravity i.e. 9.81 m/s^2, L_e is effective crest length which is 40 cm (Fig. 1), H_e is head above the crest of the notch measured with the help of point gauge having an accuracy up to 0.001m. A simplified equation for the measurement of discharge is given below by equation 2,

$$Q = 0.7\,[H_e]^{\frac{3}{2}} \qquad (2)$$

Depth of the flow was measured by another point gauge with a least count of 0.001m.Average flow velocity was measured by velocity sensor supplied by EDIBON. Similarly in order to evaluate the scour depth analytically, Lacey's equation mentioned in equation 3 was used.

$$d=\left[\frac{q^2}{f}\right]^{\frac{1}{3}} \qquad (3)$$

Where "d" is scour depth, "q" is defined as flow intensity i.e. flow per unit width and "f" is Lacey's silt factor dependent on mean sediment size d_{50} [xx].

Abutment was made of wood with a 60° wing wall as shown in Fig. 2. Total width of the abutment was kept as 90mm with the front width facing the sediments as 40mm.

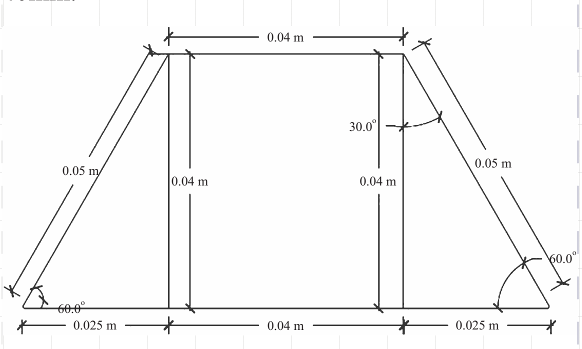


Fig. 2. Dimensions of 60° wing wall abutment

Sand was obtained from the basin of River Indus at 1000m downstream of Taunsa Barrage to simulate actual field sediments. A sand bed of 300 mm in height was laid uniformly throughout the channel. A Sand mixture passing through 4.75mm sieve and retaining on 0.150mm sieve with a fineness modulus of 2.62, complying with ASTM136-06 was used as channel bed material. The gradation curve for the sandy soil is shown in Fig. 3.

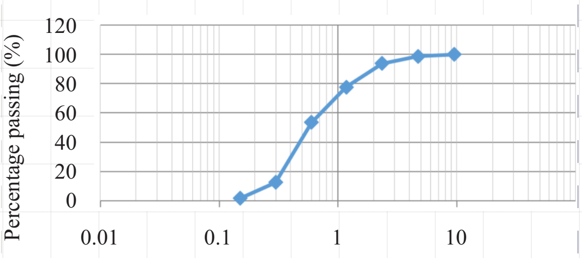


Fig. 3. Gradation curve for sand material used as channel bed

Wheat residual stems with an average diameter of 3.5mm were used as channel bank vegetation. Wheat stem was locally available at low cost. The diameter of the wheat stem was almost similar to those of the shrubs (with diameter of 3.3mm) located at the abutment of Taunsa Barrage. The density of wheat stem was kept as 300 stems per metric length of the flume. Roughness coefficient was taken 0.025 as suggested by Ven Te Chow for the channel with sediment bed and sides covered with grass/weeds [xxi]. Channel with sediments, abutment and vegetated banks is shown in Fig. 4.

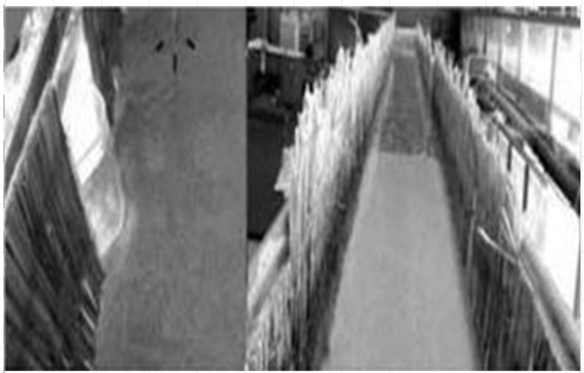


Fig. 4. Channel with vegetated banks, abutment and sediments

Channel was operated with the help of a centrifugal pump having a maximum capacity of 0.05 cumecs. Water was extracted from the underground water tank and then again discharged into the same water tank for further use. Channel was operated until the undisturbed sediments due to drag force of the water attained the equilibrium state. The time to achieve the equilibrium was recorded with the help of a stop watch having an accuracy up to 0.01 seconds. Scour depth on the upstream and downstream of the 60° wing wall abutment was measured with the point gauge after one hour interval.

IV. Results and Discussion

Experimental program comprised of ten consecutive runs corresponding to single discharge. Discharge variation was made after successful completion of required trials for a set discharge. Three different discharges were used in order to have a well-defined simulation of local scour characteristics round the abutments. Discharges for the experimental setup are shown in the Table I.

TABLE I
DISCHARGES USED IN THE EXPERIMENTAL SETUP

Sr. #	Discharge (m^3/s)	Bank Conditions	No. of runs
1	0.02	Vegetated	5
		Non-Vegetated	5
2	0.03	Vegetated	5
		Non-Vegetated	5
3	0.04	Vegetated	5
		Non-Vegetated	5

Local scour around the bridge piers increases with the increase in discharge and is inversely related to water depth to invoke scouring [xxii]. As soon as the channel attained the depths satisfying the incipient motion criteria, phenomenon of sediment transport was pronounced. Results for the average flow depth after which scouring of the sediment started are shown in Fig. 5.

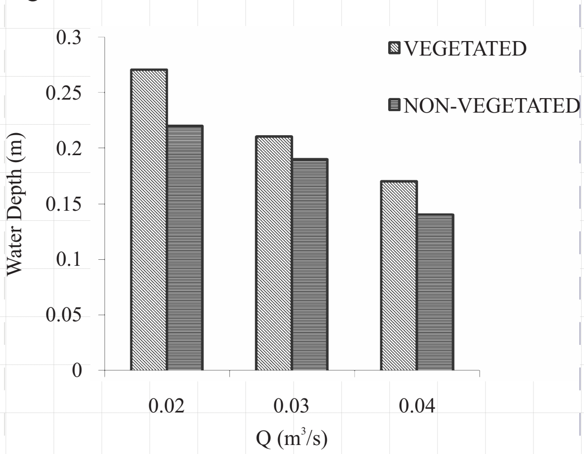


Fig. 5. Water depth required for initiation of sediment transport

It can be observed from the Fig. 5 that with the increase in discharge, depth required to fulfill the incipient motion criteria was decreased almost 30% as the discharge approaches from 0.02cumecs to 0.04 cumecs in case of non-vegetated banks. However almost 10% decrease in depth was observed when vegetation was introduced on the banks.

It was found that with the increase in discharge, scour hole in the vicinity of the abutment became more pronounced. Fig. 6, Fig. 7 and Fig. 8 represents the scour profile on 400 mm upstream and downstream of the abutment for a discharge of $0.02m^3/s$, $0.03m^3/s$ and $0.04\ m^3/s$respectively.

It can be observed from Fig. 6, Fig. 7 and Fig. 8 that scour profile attained its normal position at a distance of 400mm on upstream and downstream of the abutment

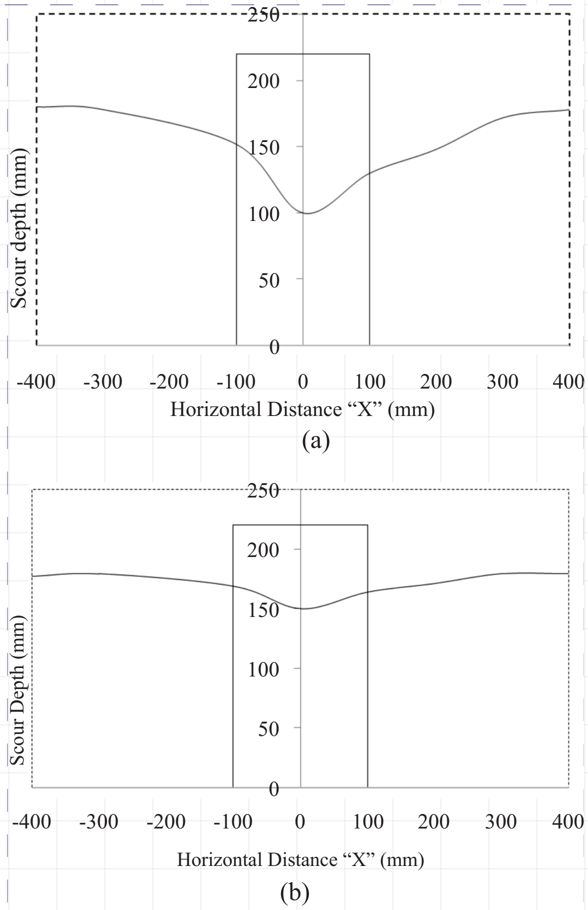
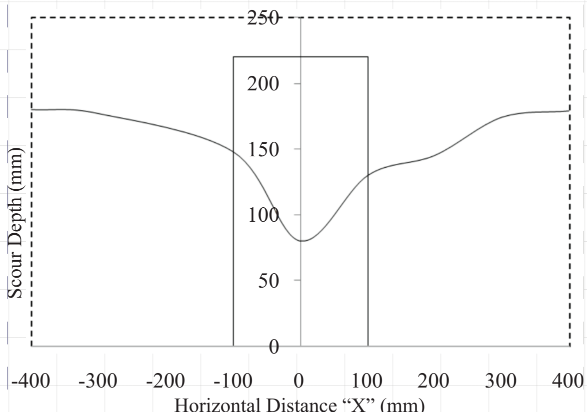
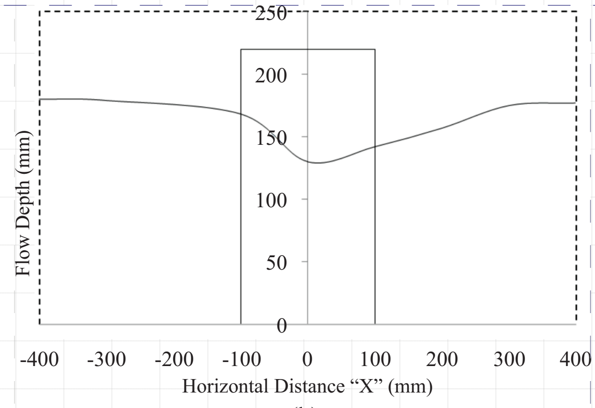


Fig. 6. Local scour profile for flow rate of $0.02m^3/s$ (a) Non-vegetated banks (b) Vegetated banks

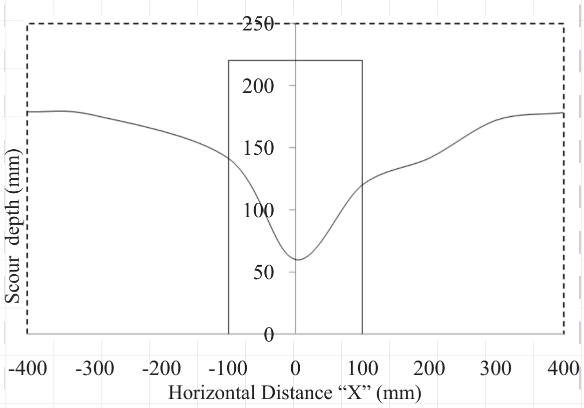


(a)

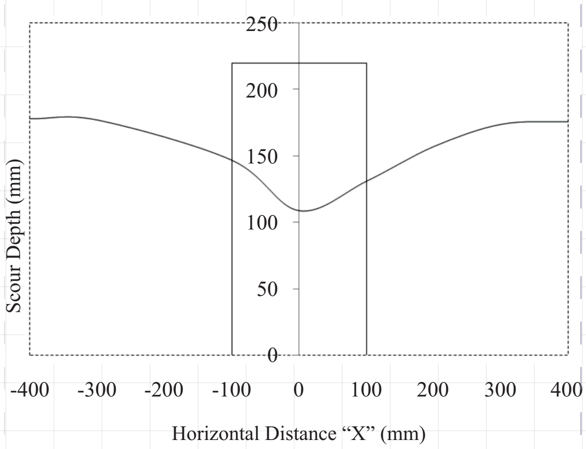


(b)

Fig. 7. Local scour profile for flow rate of 0.03m^3/s (a) Non-vegetated banks (b) Vegetated banks



(a)



(b)

Fig. 8. Local scour profile for flow rate of 0.04m^3/s (a) Non-vegetated banks (b) Vegetated banks.

A comparison for scour depth is made in Fig. 9. It can be recognized from Fig. 9, that maximum scour depth for non-vegetated banks was observed as 120mm at a flow rate of 0.04m^3/s and for vegetated banks run, it was at 74mm. With the increase in flow rate from 0.02 m^3/s to 0.04 m^3/s, scour depth marked up to 33% for non-vegetated banks however, relatively higher increase of 52% was observed for the same increase in flow rate for vegetated banks.

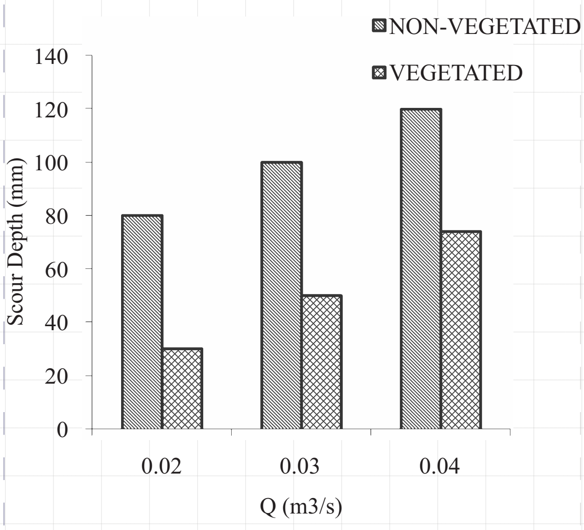


Fig. 9. Variation in scour depth with the increase in flow rate

It can be observed that erosive potential of the water is directly related to the velocity of flow. Similarly, the time required to attain the equilibrium after scouring of sediments from sandy channel bed was also influenced by the vegetation as well as flow rate. Fig. 10 represents the variation in equilibrium time after scouring for vegetated and non-vegetated banks.

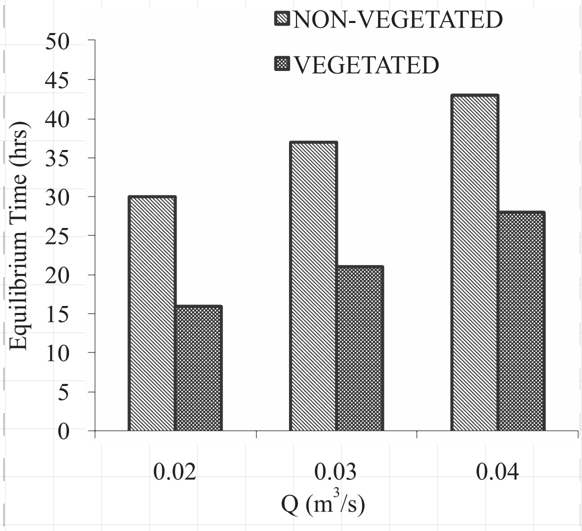


Fig. 10. Variation in equilibrium time with the increase in discharge.

It can be observed from Fig. 10 that vegetation on the channel banks strongly influenced the equilibrium time after scouring of channel bed. Average delay in the equilibrium time after scouring in case of non-vegetated banks was 42% as compared to vegetated channel banks. Hence vegetation affects the equilibrium time positively for a bridge pier.

V. CONCLUSIONS AND RECOMMENDATIONS

Following conclusions have been drawn from the study;

- The depth of water in an open channel required to initiate the sediment transport (scouring) process at minimum flow rate of 0.02m^3/s was 0.22m and 0.27m for non-vegetated and vegetated banks respectively. Similarly at high flow rate of 0.04 m^3/s, water depth necessary for initiation of scouring process is 0.14m and 0.17m for bare and vegetated banks respectively. Hence the vegetated banks resulted in delayed scouring and on an average 23% more water depth is required to start scouring process.
- Vegetation on banks of the channel reduces the scour depth around the abutment. At high flow rate of 0.04 m^3/s, the observed scour depth was 120mm and 74mm for bare and vegetated banks respectively. Maximum scouring occurred on downstream of the abutments while it extended 400mm upstream and downstream from the center line of the abutment. Beyond 400mm, no scouring was observed. Hence vegetation serves as first line of defense during high flows.
- Channel bank vegetation has significant influence on the time required to attain equilibrium by the sediment particles after they get displaced by drag force of water. At low flow (0.02 m^3/s), a drop of 46% in equilibrium time was observed by the introduction of vegetation on channel banks. Similarly, at high flow (0.04 m^3/s), a drop of 42% was observed.

Based on the outcomes of the present study, it is recommended that channel bank vegetation significantly controls scouring characteristics around a wing wall abutment and channel bank vegetation must be practiced particularly on downstream of the hydraulic structures up to the influence zone of the scouring.

REFERENCES

[i] H. H. Chang. (1988). Fluvial Process in River Engineering, A Wiley-Inter-science Publication John Wiley & Sons.

[ii] G. Murtza, H. Nisar and U. Naeem. (2017). Experimental Investigation of bridge pier scouring. Mehran University Journal of Engineering and Technology. Vol. 20. No.1 (PP. 117-124).

[iii] A. Wahib, H. Nisar and R. Farooq. (2015). Measurement of momentum transfer coefficient for a sand bed channel. Journal of Hydraulic Engineering. Vol.128. No. 7. (PP. 664- 673).

[iv] V. Diehl and A. Hensen. (2014). Study of scour around bridge piers and abutments. International Journal of water resources and environmental engineering. vol. 78. No. 10.(PP. 206–212).

[v] R. Smith and Anctil F. (2007). Effect of woody vegetation on erosion of floodplains. Journal of Canadian Civil Engineering. vol. 26. No. 4 (PP. 468-475).

[vi] J. Oster, Fazel Najfabadi E. and Singh V. P. (2008). Numerical simulation of woody vegetation on banks on distributions of velocity and Reynolds stress under accelerating flow. Arabian Journal of Science and Engineering. vol. 15. No. 3(PP. 708-713).

[vii] Ranson. (2000). Influence of riparian vegetation on sediment erosion in an open channel. Journal of Hydraulic Engineering. vol. 109. No. 3 (PP. 339-350).

[viii] Carnell and D. C. Froehlich (2003). Effect of riparian vegetation on flood control. Journal of Hydraulic Engineering. vol.111. No. 6 (PP. 380-388).

[ix] R. Pizzuto, Sui J. and KabiriSamani A. 92003). Effect of vegetated banks on lateral migration of banks. Journal of International Sediment Research. vol. 15. No. 4 (PP. 222-231).

[x] Sukhdovel, A. Gribzadeh and M. Moradian (2000). Investigation of flow structure around the elliptical abutments. Iranian Journal of Science and Technology. vol. 34. No. 2 (PP. 31-38).

[xi] Z. Bryan. (2006). Reduction of local scour around bridge piers using slots and collars. Journal of Hydraulic Engineering. vol. 125. No. 5 (PP. 302-30).

[xii] Junn (2004). Turbulent flow field in a scour hole at a semicircular abutment. Arab Gulf Journal of scientific research. vol. 32. No. 1(PP. 112-122).

[xiii] Kwan, A. Kohli and W. H. Hager (2003). Use of hydrogen bubble technique to estimate 3-D flow filed in a scour hole around a wing wall abutment. Iranian Journal of Science and Technology. vol. 48. No. 2 (PP. 61-80).

[xiv] A. Fared, Smith and Vincent J.(2002). Numerical modeling of effects of bank friction and woody bank vegetation on channel flow and boundary shear stress in the Rio Puerco. Journal of Hydrological Processes. vol. 25. No. 4 (PP. 241-254).

[xv] J. H. Kim, T. Fourcard, C. Jourdan, J. Maeghat, Z. Mao, J. Matyer, L. Meylan and Stokes A. (2017). Vegetation as a driver of temporal variations in slope stability: The impact of hydrological processes. Geophysical Research Letters An AGU Journal. vol. 44. No. 10 (PP. 4897-4907).

[xvi] Y. Rousseau, M. J. Vanand P. M. Biron. (2017). Simulating bank erosion over an extended natural sinuous river reach using a universal slope stability algorithm coupled with a

morphodynamic model. Geomorphology. Vol. 295. (PP: 690-704).

[xvii] J. Hooke, S. Baets, J. Poesen, A. Meerkerk, B. V. Wesemael and L. H. Cammeraat (2017). Effectiveness of Plants and Vegetation in Erosion Control and Restoration. Combating Desertification and Land Degradation. Springer Briefs in Environmental Science. Springer, Cham. vol. 3 (PP: 79-104).

[xviii] G. Ollauri and S. B.Mickovski. (2017). Hydrological effect of vegetation against rainfall-induced landslides. Journal of Hydrology. Vol. 549. (PP: 374-387).

[xix] T. Alemu, S. Bahrndorff, K. Hundera, E. Alemayehu and A. Ambelu. (2017). Effect of riparian land use on environmental conditions and riparian vegetation in the east African highland streams. Limnologica - Ecology and Management of Inland Waters. Vol. 66. (PP: 1-11).

[xx] A. R. Kazi. River Training and Control. Manual of Irrigation Practice. Vol. 1. (PP: 6).

[xxi] V. T. Chow. Uniform Flow. Value of roughness coefficient n. Open Channel Hydraulics. Vol.2. (PP: 152).

[xxii] V. Cihat and Carancina I. (2011). Effect of flow rate on scour around bridge piers: Effect of wood debris roughness and porosity. Alexandra Engineering Journal. vol. 28. No. 1 (pp. 23–32).