# A Review on the Effect of Spurs on Flow and Morphology of Channels

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**Abstract**

Spurs are structures made with engineering materials starting at the riverbank with a root and ending at the regulation line in the flow channel in order to deflect the flowing water away from critical zones. They are also used to develop aquatic habitats by causing stable pools in unstable, disturbed streams. When a spur crosses a waterway the natural balance of the river is disturbed, results in a major disturbance of the flow pattern around the structure base. This disturbance leads to the initiation of scour process, and is considered to be the major cause of structural instability. Investigations on the effects of spurs have a long history and still receive much attention to the researchers. An optimal design of a spur is the first requirement to make it sustainable and function properly. In view of that, a thorough understanding to the effect of spurs on the hydrodynamics and morphology is essential. This paper presents a review on various spurs and their effects on flow patterns and channel morphology.

***Keywords:*** *Spur, Riverbank, Flow Pattern, Scour, Hydrodynamics, Morphology.*

## 1 Introduction

Most of the rivers in Bangladesh are geologically young and morphologically very active. They carry sediment loads from the large catchments. Shifting of river course is a very common problem. Spurs are structures that project into the flow channel in order to alter flow direction away from the critical zones reducing flow velocity near bank and inducing deposition. They change the flow pattern, and bed elevation configuration accordingly. Spurs may be permeable allowing the water to flow through at reduced velocities or impermeable blocking and deflecting the current largely. Permeable spurs are fabricated from piles, bamboo or timbers, whereas impermeable spurs also called solid spurs, are constructed using soil with revetment works, RCC, rock, gravel, or gabions. Also, they may be built with different planview shapes. Aesthetic and environmental aspects of spurs have much consideration as a promising measure to enhance diversities of channel morphologies and riveting eco-system. Estimation of the length, width and depth of the scour in the vicinity of spur is the main concern of engineers for years, as this is the significant criterion for proper design of spur foundation.

Many researchers received much attention to investigate the effects of spurs on the channels to explore the optimal design of a spur to make them sustainable and function properly. Therefore, detailed up-to-date information on the effect of spurs on the hydrodynamics and channel morphology are explored in this study and are summarized in this paper.

## 2 Changes in Flow Pattern

Many researchers investigated the flow pattern in the vicinity of a single spur and spurs in a series as well. The flow past a spur may be divided into three zones: a main flow zone from the head of the spur to the opposite side of the channel, a wake zone behind the spur and a mixing zone in-between them (Zhang and Nakagawa, 2008) (Figure 1). The spur confines a certain part of the river cross section and affects appreciably the kinematic structure of the flow. Mean velocity and specific discharge increase due to construction of spurs. Ishii et al (1983), Chen & Ikeda (1997), and Ouillon & Dartus (1997) conducted such a study which described the geometry of separation region downstream of a spur in a straight channel. From the laboratory experiments

Molinas et al. (1998) reported that the velocity at the spur head might be increased up to 1.5 times the approaching flow velocity, depending on the flow conditions and spur protrusion ratios. Also Ho et al. (2007) presented similar results.

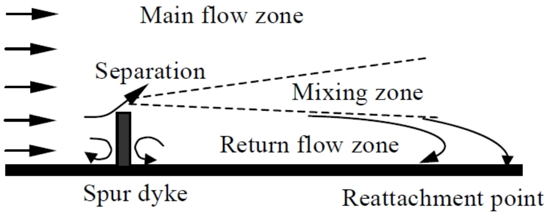


Figure 1: Flow zones due to a spur; source: Zhang and Nakagawa (2008)

The spur field is not really of the flow conveying cross section of a river. Accordingly, the flow pattern in spur field does not directly contribute to the discharge in the main channel. Reducing the stream velocity has little effect on the flow pattern, whereas lowering the spur head does affect the pattern (Uijttewaal et al, 2001). Moreover, flow pattern in the side of spur field may change with change of its geometry, location along the river or spur orientation (Przedwojski et al., 1995).

Kurzke et al. (2002) executed a laboratory test to calculate the exchange of water quantities between the main flow zone and the impermeable spur field. Through the close review to the flow field exhibits the fact that the flow pattern for un-submerged spurs is predominantly two-dimensional. The small-scale three-dimensional turbulence plays a minor role in the mass and momentum exchange process between the spur-field and the main channel (Uijttewaal,1999). Further, Uijttewaal (1999) concluded his observation on the effect of geometry on the flow field that the spur-field length to width ratio determines the number and shape of eddies that emerge in the stagnant flow region. An aspect ratio close to unity gives rise to a single eddy. A larger aspect ratio gives room for two stationary eddies, a large one called primary eddy, in the downstream part of the spur-field, and a smaller secondary eddy, emerges near the upstream spur. In a long spur field with length to width ratio of around six, the flow penetrates into the spur field (Figure 2). In order to save the channel bank from erosion by the return current an aspect ratio less than three is recommended by Zhang based on both numerical and experimental results.

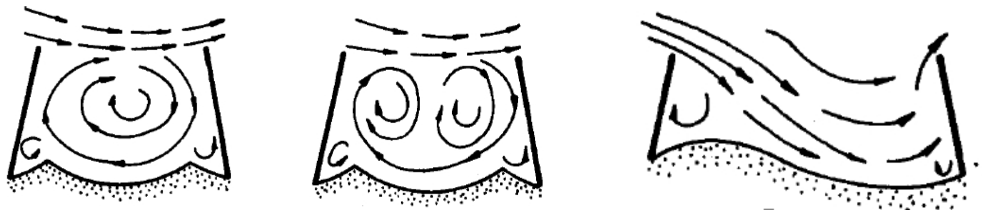

Figure 2: Flow pattern in a spur-field; source: Przedwojski et al. (1995)

Horizontal large eddies are formed near a spur that shed from the tip of a spur. Through measuring the water level fluctuations along the centreline of the migrating vortices, Chen & Ikeda (1997) found that there is a clear periodic water level fluctuation. The flow field is unsteady, and there is significant difference between the time averaged and instantaneous flow fields.

Complexity of the flow past a spur further increases with the development of scour hole. The flow near the tip of the spur is strongly three dimensional (Krebs et al, 1999). If the spur is submerged, the flow structure becomes more complex. The over-topping flow has a significant impact on the nature of the vortices around the spur. The primary vortex gains an upward component in the lee of the spur dyke (Kuhnle et al., 1999, 2002). And a strong downward flow is introduced to the wake area behind the spur dyke (Ishigaki and Baba, 2004). Furthermore, the over-topping ratio (water depth to spur height) has an important control on the geometry of the resulting scour hole. The flow in local scour generally shows three-dimensional (3D) characteristics. This 3D flow may be divided into several components. In front of the spur, there exists a bow wave near the water surface and a downflow towards the channel bed due to the stagnation of approaching flow. As a result of the flow separation, a horseshoe vortex develops in the lower part at upstream side of the spur (Figure 3). Investigating the flow structure and the bed deformation around various impermeable and permeable spurs, Zhang and Nakagawa (2009), and Alauddin and Tsujimoto (2010) argued that there might be a way to achieve a balance in modifying the flow conditions by suitably combining impermeable spur and permeable spur.

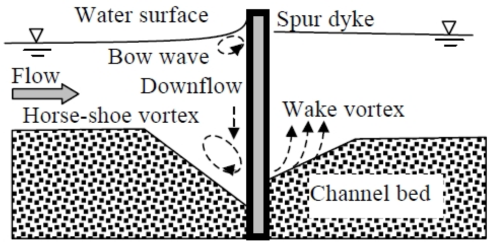


Figure 3: Typical flow in a scour hole; source: Zhang and Nakagawa (2008)

## 3 Changes in Bed Topography

Bank materials of the major rivers in Bangladesh consist of loose non-cohesive sediments such as sand, silt and small amount of clay, which is highly susceptible to erosion. The flow velocity and scour depths in all the major rivers are very high. This is of much interest to understand the morphological changes in the channels after construction of spurs for various purposes. It is expected that people might take full use of rivers, aesthetic and ecological values if spurs are effectively arranged.

The scouring occurs in the channels are divided into three classes: general scour, local scour and constriction scour. General scour takes place on channel bed due to sediment transport by the flow condition irrespective of whether or not spur there. Local scour occurs directly from the impact of spur on the local flow pattern. Channel bed is lowered due to the imbalance of sediment transport in the channels. Constriction scour arises from the narrowing of water course by the presence of spurs.

Due to spur installation, the flow width decreases which in turn changes the velocity profile in the region around the contracted width. Hence, the flow velocity and Froude number are considered very important measures of the flow condition which play a main role in analyzing the scour hole characteristics around a spur. According to Zhang and Nakagawa (2009), the half horse-shoe vortex generally results in a local scour which has a conical shape in the upstream and becomes elongated in the downstream with a relatively mild slope. On the other hand, the compressed horse-shoe vortices around the pile group usually leads a valley-shaped scour hole with a steep slope in the upstream and a mild one in the downstream.

Zhang et al (2005) studied the morphological consequences of series impermeable spurs through laboratory experiments. The representative formula for determining equilibrium scour depth is that proposed by Melville based on a series of experiments conducted in the University of Auckland, New Zealand (Melville, 1992; Melville, 1995; Melville, 1997). Johnson made a comparison of seven commonly used and cited formulae (including Melville's formula) with a large set of field data for both live-bed and clear water scour (Johnson, 1995). An extension of this kind of researches is to take into account the temporal variation of the local scour holes. Most of them are achieved by determining a function relating the time-dependent scour depth to the equilibrium scour depth, e.g. Chiew and Melville, 1999; Kothyari, U.C. and Ranga Raju, 2001; Coleman, et al., 2003; Dey and Barbhuiya, 2005.

Garde *et al.* (1961) suggested that the maximum scour depth greatest for a spur with an inclination angle of 90 degree and smaller for all other inclinations upstream and downstream. Khasaf (1991) carried out laboratory experiments for scour pattern around diverse cases of impermeable spur changing geometry and the angle of inclination of spur with respect to the flow direction. It is found that scour depth increases with increasing the degrees of opening ratio, Froude number, and the degrees of angle of inclination of spur with respect to the flow direction. The greatest width of scour hole was found corresponding to the 135 degree spur, but they provided improved aquatic habitats and minimize the possible erosion of the channel bank. Alauddin (2001) conducted studies to comprehend the flow and morpho-dynamics against various orientation and configuration, non-submerged spur in straight sand-bed channels. He found that the spur of smaller angles promoted the flow pattern for developing deeper channel at low flow and minimize scour near spur at high flow.

Ezzeldin et al. (2007) studied the local scour around single straight impermeable submerged spur installed in a channel with different angles with respect to the flow direction. They showed the main reason for the drift is vortex, which takes the form of a horseshoe around spur, but its impact disappears when it reaches Froude number that lessens the intensity of the flow around the spur. Hence, the vortex causing erosion becomes weaker and slower. So the ability of flow to carry sediment decreases.

Karami and Ardeshir (2008) performed experiments on spurs placed in a series and introduced a spur to reduce the scouring of the downstream spurs which was called a protective spur. The effect of each spur had on other spurs of the series was investigated experimentally, with an emphasis on the influence of the protective spur in reducing the scour around other spurs. The incorporated protective spur was shown to effectively decrease the scour around the spurs placed sequentially. Nevertheless, it was left susceptible to scour potential which diminished its functionality. To decrease the scour potential around a protective spur as the main focus, and the sequential spurs, incorporation of another spur called sacrificial spur is proposed by Jourabi *et al.* (2015).

Uddin and Hossain (2011) made an estimate for maximum local scour depth around the bell mouth spur constructed along the bank of straight channel to locally change of river conditions. They observed that scour depth varied proportionally with the variation of flow velocity and Froude number. According to the study made by Ezzeldin et al (2007), the maximum scour depth, $d_S$, is the dependent variable and can be expressed as a function of other independent variables as follows.

$$d_S = f(g, \rho, \nu, H, V, V_c, B, b, \phi, S, L_{up}, L_{down}) \qquad (1)$$

Where, g = gravitational acceleration, ρ = fluid density, ν = kinematic viscosity, H = depth of approach flow upstream of the piles, V = mean flow velocity, $V_c$ = critical flow velocity, B = channel width, b = length of obstruction, ϕ = angle of attack, S = shape factor, $L_{up}$ = length of scour upstream the spur, $L_{down}$ = length of scour downstream the spur dike.

Through laboratory experiments, several researchers independently reached at similar expression for the equilibrium scour depth near spurs. The expression takes the form, $d(\infty) = K\,q^{2/3}$ (e.g. Gill, 1972; Klingeman et al.,1984, and Hoffmans & Verheij, 1997). The expression of Ahmed as given by Hoffmans & Verheij (1997) reads:

$$y_{s,e} + h_0 = K_A K'_A \left(\frac{q}{1-m}\right)^{2/3} \qquad (2)$$

Where:
$y_{s,e}$ = equilibrium scour depth below initial depth
$h_0$ = initial water depth
m = b/B, b and B are the width of the dike and channel respectively.
$K'_A = 2.14 g^{-1/3}$ ($\cong 1.0\ m^{-1/3}s^{2/3}$)
$K_A = 2K_p K_s K_\alpha K_\mu$
$K_p$ = correction factor for the influence of channel bend, (inner = 0.85, outer = 1.1~1.4)
$K_s$ = for the shape of structure, (vertical wall = 1.0, 1:1 sloped =0.85)
$K_\alpha$ = for the angle of attack, (30o to 150o = 0.80 ~ 1.10)
$K_\mu$ = for the influence of porosity (0.2 porosity =1.0, 0.5 porosity =0.9~0.6)

Suzuki et al. (1987), showed through laboratory experiments, that the local scour depth around a spur located far downstream in a series of spurs is a function of the spacing (*S*) to length (*L*) ratio, and it could be expressed roughly in the following form:

$$\frac{Z_{s,DS}}{Z_{s,1}} = 0.07.\frac{S}{L} + 0.14 \qquad \text{for } 2 < \frac{S}{L} < 10 \qquad (3)$$

Where:
$Z_{s,DS}$ = scour depth around any spur far downstream.
$Z_{s,1}$ = scour depth around the first spur which is similar to the scour depth near a single spur and could be estimated using any of the above mentioned formulae.

When (*S/L*)>12, i.e. the spurs are very far apart, the group action vanishes and the scour depth near any spur is nearly the same as that of a single spur.

Based on analysis of field data for unidirectional flow in rivers, the following scour depth expression has been proposed (Hoffmans and Verheij, 1997):

$$d_{s,max} = \alpha[q_o/(1-m)]^{2/3} - h_1 \quad (4)$$

with:
$d_{s,max}$ = maximum scour depth near head of structure,
$h_1$ = mean water depth of contracted section before scour,
$q_o$ = discharge per unit width upstream of contracted section (in $m^2/s$),
m = L/B= blocking coefficient,
B = channel width,
α = coefficient depending on geometry (≈1 to 2 for straight channel and spur normal to bank).

Lacey (1930) proposed a formula for the prediction of the maximum scour depth around abutment-type structures, as follows (see Rahman and Haque, 2003):

$$d_{s,max} = 0.47 h_1 K\, [Q/(f\, h_1^3)]^{1/3} - h_1 \quad (5)$$

with:
$d_{s,max}$ = maximum scour depth near head of structure,
$h_1$ = mean water depth of contracted section before scour,
Q = regime discharge (in m3/s),
$f = 56(d_{50})^{0.5}$ = sediment factor,
$d_{50}$ = sediment diameter (in m),
K = coefficient depending on geometry (≈2 for rounded head to 4 for steep sloping head).

Rahman and Haque (2003), taking the structure length into account, modified the above equation into:

$$d_{s,max} = 0.47 h_1\, M^{1/3}[1+1.5L/h_1]^{1/3} - h_1 \quad (6)$$

with:
$d_{s,max}$ = maximum scour depth near head of structure,
$h_1$ = mean water depth of contracted section before scour,
$M = Q/(fh_1^3)$= discharge coefficient,
$f = 56(d_{50})^{0.5}$= sediment factor,
$d_{50}$ = sediment diameter (in m).

Rahman and Haque (2003) also presented field data of scour depths near abutment-type structures along the Jamuna river in Bangladesh. The relative scour depth values ($d_{s,max}/h_1$) are in the range of 0.5 to 2 for a length scale of about $L/h_1$=7 to 12 and about 1 for $L/h_1$=40. This latter value is significantly over predicted by Equations (5 and 6).

Klaassen and Vemeer ( 1988) developed a formula for calculating scour depth in the Jamuna River. Their study was specially based on the feasibility study of the Jamuna Bridge. The equation is as follows,

$$\frac{h_{cr}}{H} = 1.292 + 0.037\theta \quad (7)$$

$h_{\mathrm{cr}}$ (m) average scour depth within the channel related to DWL.

Dawood (2013) conducted laboratory experiments using three different numbers of impermeable non-submerged spurs (single, double and triple) with different shapes (straight, T-head and L-head) in a straight channel. It was found indirect relationship relating the effect of spur numbers and shape on maximum depth of scour. 1, 1.5, and 2 times the length of spurs were used in the experiments, noted that increasing the spacing by 0.5 times spur length caused increasing the scour depth by around 20%.

## 4 Ecology due to Spurs

Other than land reclamation, aquatic habitats in alluvial rivers can be restored installing in-stream structures such as spur dykes to enhance channel diversities in terms of flow patterns, bed topographies and substrate compositions. Variety in flow pattern developed by the structures play essential roles in the life cycles of many aquatic species such as fishes and macroinvertebrates, and are recognized as the important habitat suitability in the riverine area (Shields et al, 1992; Biron et al, 2004; Kemp et al, 2011; Kadota et al, 2010).

As found from field survey by Uddin and Rahman (2011), some char lands are formed along the bank after installation of spurs. Due to low water and backward water flow simultaneously, different types of fish populations dwell there. However, it is very difficult to maintain in-stream flow requirement that is very important for maintaining the river ecology and aquatic habitat necessary for the healthy life cycle.

## 5 Conclusions

The present study was targeted to explore the effect of spurs on flow and morphology of channels. Due to spur, specific discharge and velocity of flow increase in the main channel. Change in spur geometry, lowering of spur head, orientation of spur, location of spurs in a river, etc. affect the flow pattern. The flow pattern for emerged spurs is predominantly two-dimensional. The small-scale three-dimensional turbulence plays a minor role in the mass and momentum exchange process between the spur-field and the main channel. In submerged spurs, the over-topping flow has a significant impact on the nature of the vortices around the spur. A balance in modifying the flow conditions can be achieved by suitably combining impermeable and permeable spurs.

Due to the impact of spurs on the local flow pattern, local scour occurs. Scour depth varies based on orientation and configuration of spurs. The spurs of smaller angles promote the flow pattern for developing deeper channel at low flow and minimize scour near spur at high flow. A series of spurs are useful for protecting bank from erosion, and stability of the targeted spurs can be made providing additional protective spur in the upstream side. Variety in flow pattern developed by the spurs make the important habitat in the riverine area which play essential roles in the life cycles of many aquatic species. This paper also summarizes the estimation methods of scour depth due to spurs by various researchers.

## References

Alauddin, M., Tashiro, T. and Tsujimoto, T. (2011). Experimental investigation of channel responses against different configurations of spurs. Advances in River Engineering. JSCE. 17, 335-340.

Alauddin, M. (2011). Morphological stabilization of lowland rivers by using a series of Groins. PhD Thesis, Department of Civil Engineering, Nagoya University, Japan.

Biron, P.M. Robson, C., Lapointe, M.F. and Gaskin, S.G. (2004). Deflector designs for fish habitat restoration, Environmental Management. 33(1), 25-35.

Chen, F.Y. and Ikeda, S. (1997). Horizontal separation in shallow open channels dykes. Journal of Hydro-science and Hydraulic Engineering.15(2),15-30.

Chiew, Y. and Melville, B.W. (1999). Temporal development of local scour at bridge piers. Proc. of the North American Water and Environment Congress (CDs). Anaheim, CA, ASCE.

Coleman, S.E., Lauchlan, C.S. and Melville, B.W. (2003). Clear-water scour development at bridge abutments. Journal of Hydraulic Research. IAHR, 41(5), 521-531.

Dawood. A.M. (2013). A study of scour and deposition around spurs. MSc Thesis. Department of Civil Engineering, University of Kufa, Iraq.

Dey, S. and Barbhuiya, A.D. (2005). Time variation of scour at abutments, Journal of Hydraulic Engineering. ASCE.131 (1), 11-23.

Ezzeldin, M.M., Saafan, T.A., Rageh, O.S. and Nejm, L.M. 2007. Local scour around spur dikes. Eleventh International Water Technology Conference, IWTC11 2007, Sharm El-Sheikh, Egypt.

Garde, R. J., Subramanian, K. and Nambudripad, K. D. 1961. Study of scour around spur-dikes. J. Hydraul. Div.,Am.Soc. Civil.Eng., 87(HY6), 23-37.

Gill, M. A. 1972. Erosion of sand beds around spur dikes. Journal of Hydraulic Engineering, ASCE, 98(HY9), 1587-1602.

Khasaf, (1991). Experimental investigation of scour and deposition around spur-dikes",Msc thesis, college of engineering, university of Baghdad, Iraq.

Ho, J., Yeo, H.K., Coonrod, J. and Ahn, W.S. (2007). Numerical modeling study for flow pattern changes induced by single spur. 32nd Congress of IAHR, Italy, CD-ROM.

Hoffmans, G. J. C. M., and Verheij, H. J. (1997). Scour manual, A.A. Balkema, Rotterdam.

Ishigaki, T. and Baba, Y. (2004). Local scour induced by 3D flow around attracting and deflecting groins. Proc. of 2nd International Conference on Scour and Erosion, Meritus Mandarin, Singapore, Nov, 14-17, 301-308.

Ishii, C. (1983). Shape of separation region formed behind a groin of non-overflow type rivers. XXIAHR congress, Moscow, USSR 405-412.
Johnson, P.A. (1995). Comparison of pier-scour equations using field data. Journal of Hydraulic Engineering, ASCE, vol.121 (8), 626-629.
Jourabi, Y.J., Ardeshir, A. and Karami, H. (2015). Experimental research on sacrificial spur dikes to reduce scouring. Proc. of the 36th IAHR World Congress, The Hague, the Netherlands.
Kadota, A., Kojima, E. and Suzuki, K. (2010). Mean and coherent structures caused by several types of groin. Annual Journal of Hydraulic Engineering, JSCE. 54, 937-942.
Karami, H., Ardeshir, A., Saneie, M., Behzadian, K., and Jalilsani, F. (2008). Reduction of local scouring with protective spur dike. Proc. of the World Environmental and Water Resources congress. ASCE, Hawaii, USA.
Kemp, P., Sear, D., Collins, A., Naden, P. and Jones, I. (2011). The impacts of fine sediment on riverine fish. Hydrological Processes. 25, 1800-1821.
Klaassen, G.J. and Vermeer, K. (1988). Channel characterics- tics of the braiding Jamuna River, Bangladesh.
Proc. of International Conference on River Regime, Wallingford, England.
Klingeman, P.C., Kehe, S.M., and Owusu, Y.A. (1984). Streambank erosion protection and channel scour manipulation using rockfill dikes and gabions. Rep. No. WRRI- 98, Water Resources Research Institute, Oregon State Univ., Corvallis, Oregon.
Kothyari, U.C. and Ranga Raju, K.G. (2001). Scour around spur dikes and bridge abutments. Journal of Hydraulic Research, IAHR. 39 (4), 367-374.
Krebs, M., Zanke, U. and Mewis, P. (1999). Hydro-morphodynamic modelling of groin fields. 28th IAHR congress, Graz, Austria.
Kuhnle, R.A., Alonso, C.V. and Shields, F.D.Jr. (1999). Geometry of scour holes associated with 90o spur dykes. Journal of Hydraulic Engineering, ASCE. 125 (9), 972-978.
Kuhnle, R.A., Alonso, C.V. and Shields, F.D.Jr. (2002). Local scour associated with angled spur dikes. Journal of Hydraulic Engineering, ASCE. 128 (12), 1087-1093.
Kurzke, M., V. Weitbrecht and Jirka G.H. (2002). Laboratory concentration measurements for determination of mass ex-change between groin field and main stream. River Flow 2002, Bousmar & Zech (eds.): 1, 369-376.
Melville, B.W. (1992). Local scour at bridge pier. Journal of Hydraulic Engineering, ASCE. 118 (4), 615-631.
Melville, B.W. (1995). Bridge abutment scour in compound channels. Journal of Hydraulic Engineering, ASCE. 121 (12), 863-868.
Melville, B.W. (1997). Pier and abutment scour: a integrated approach. Journal of Hydraulic Engineering, ASCE, 123 (2), 125-136.
Molinas, A., Kheireldin, K. and Wu, B. (1998). Shear stress around vertical wall abutments. J. Hydraul. Eng., ASCE. 128, 811-820.
Uddin, M.N. and Rahman, M.M. (2011). Socio-Economic Impact of Erosion along the Right Bank of the Jamuna River in Bangladesh. DUET Journal,1(2), 35-42.
Ouillon, S. and Datus, D. (1997). Three dimensional computation flow groin. Journal of Hydraulic Engineering, ASCE. 123(II), 962-970.
Przedwojski, B., Blazejewski, R., and Pilarczyk, K. W. (1995). River training techniquesfundamentals, design and application. A.A. Balkema, Rotterdam.
Rahman, M.M. and Haque, M.A., 2003. Local scour estimation at bridge pier site: modification and application of Lacey formula. International Journal of Sediment Research. 18(4), 333-339.
Shields, Jr. F.D. and Milhous, R.T. (1992). Sediment and aquatic habitat in river systems. ASCE Task Committee on Sediment Transport and Aquatic Habitats, Sedimentation Committee. Journal of Hydraulic Engineering, ASCE. 118(5), 669-687.
Suzuki, K., Michiue, M., and Hinokidani, O. (1987). Local bed form around a series of spur dikes in alluvial channels. XXII IAHR Congress, Lausanne, Belgium, 316-321.
Uddin, M.J. and Hossain, M.M. (2011). Local scour around non-submerged bell mouth groin. Int. Journal of Engineering & Applied Sciences. IJEAS, 3(2), 37-51.
Uijttewaal, W. S. J. (1999). Spur field velocity patterns determined with particle tracking velocimetry. 28th IAHR congress, Graz, Austria.
Uijttewaal, W. S. J., Lehmann, D., and van Mazijk, A. (2001). Exchange process between a river and its spur fields - model experiments. Journal of Hydraulic Engineering, ASCE. 127(11), 928-936.
Zhang, H. and Nakagawa, H. (2008). Investigation on morphological consequences of spur dyke with experimental and numerical methods. Advances in Hydro-science and Engineering (Wang, Kawahara, Holtz, Tsujimoto & Toda eds), 8, September 8-12, Nagoya, Japan, CD-ROM.
Zhang, H. and Nakagawa, H. (2009). Characteristics of local flow and bed deformation at impermeable and permeable spur dykes. Annual Journal of Hydraulic Engineering, JSCE. 53, 145-150.