# Influence of Spur Dikes Shapes on Scour Characteristics

Mohsen M. Ezzeldin, Tharwat A. Sarhan, Sally F. El-Rashedy

**Abstract--** A series of laboratory experiments were conducted for estimating the maximum depth of scour and other related characteristics for the available shapes of spur dikes. This research focuses on a comparison of various configurations of spur dikes as straight, hockey, mole head, L-shape and T-shape. The effect of flow properties such as Froude number and flow discharges under the clear water condition on the maximum scour depth was investigated, the results indicated that hockey shape shows better performance in reducing scour depth, however, straight shape has a desirable impact on habitat as large hole of scour is formed. For all layout of spur dikes when Froude number increases the depth of scour or relative scour depth increases for all discharges. At the same time, when discharge increases, depth of scour increases for all flow depths. An empirical relationships for prediction of maximum scour depth for each shape were determined, also a general equation for any shape of spur dikes as a function of both Froude number and shape factor was determined by either percentile or coding methods is presented.

**Keywords--** Scour depth, Spur dike, straight, Hockey shape, Mole head, L-shape, T-shape.

## 1 INTRODUCTION

River banks are usually exposed to migration of soil particles from its place that causes scour then forming deposition of eroded sediments traveling downstream which made another damage for rivers. The erosive action is formed due to flowing of water over stream bank or may be changed in the stream flow or formed after a new structure like dams. This failure of river banks can threaten the balance of natural rivers, lands and structures like bridges [1]. Therefore, bank protection is a major concern in hydraulic river engineering for environment reclamation and secure important structures and properties.

One of the best solutions to this challenging problem is spur dikes. It is considered a common river training structure that provides flow diversion away from the bank and constructs a new flow alignment causing reduction in velocity near the bank. Complicated intensive system vortices are formed along upstream and downstream faces of spur dike [2]due to constriction of river channel and the increase of velocity there, this turbulence can easily move soil materials, then causing a scour hole around the structure which indicates the extent of bank erosion in natural situations.

In response to contribute in river bank stabilization a better understanding of scour mechanism is essential, estimation of the maximum depth of scour and the developed scour hole is in need for its foundation design which should be able to sustain maximum local depth of scour around spur dikes without needing to excessive maintenance

A lot of researches mentioned the different choices of installing spur dikes in plan individually and discussed various aspects during implementation of this structure as spur dike alignment, contraction ratio or length of spur dike, permeability, appearances as a single spur dike or in group using one or two available shapes of spur dike, etc.

The effect of spur dike length was investigated by [3]around T- shape spur dikes in 90 degree flume, using four contraction ratios and wing lengths of spur dike and also change in flow discharges was considered . An experiments around L-shape spur dike in a 180 degree bend flume were conducted by [4], the effect of four lengths was evaluated at different contraction ratios with constant wing length, various Froude numbers and locations on bend were considered, an empirical equation for prediction of scour depth around L-shape was developed. An experimental study was carried out by [5]on T-shaped non-submerged spur dike located in a 90° bend for different lengths and wing lengths of spur dike.

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The effect of spur dike alignment was studied by [6]and compared with the effect of spur dike length on scour process. Different orientation angles were tested and results showed that maximum depth of scour occurs at repelling groin. A laboratory experiments were conducted by [7] around non- submerged spur dike to study the effect of orientation angles of 25, 40 and 90 with constant angle nose and with various Froude numbers then the effect of nose angle was considered to measure hole scour characteristics.

The behavior of scour around single spur dike and multiple spur dikes was presented experimentally by [8], results showed that multiple spur dikes were able to decrease maximum scour depth than single spur dikes. Another study conducted by [9] studied the effect of protective spur dike experimentally with three main series of spur dikes to get the proper design of these structures. The length of protective spur dikes is recommended to be 60% of the length of the main spur dikes. The protective spur dike with an angle of 45 or 90 degrees was considered as optimum design.

A research was studied by [10]proved that the minor spur dike has a key role on protection group of dikes as it reduced the scour rate at the head of spur dike by (10-33%) compared with a protective one, therefore, first spur dike has maximum scour then the fourth one and spur dikes in between have a small effect. The good performance of minor spur dike appeared at location where the distance between spur dikes is twice spur dike length. Another study by [11] was shown that increasing distances between two spur dikes resulted in an increase in length of the reattachment zone at downstream of spur dikes to distance equal to 8.1 the length of spur dikes.

The influence of permeability around various combinations of permeable and impermeable spur dikes was investigated by [12]. The permeability effect was studied experimentally by [13] on rectangular dikes comparing impermeable and permeable dikes with different permeability percentage 20%, 40%, 60% and 80%.

The importance of geometric standard deviation and grain size parameter was shown by[14]. Also the effect of cohesive sediment mixture on the variation of scour around spur dikes was studied by [15] .

The influence of spur dike configuration in plan was investigated by [16] for three cases, straight shape, L-shape oriented in the upstream direction and L-shape oriented in the downstream direction for different values of Froude numbers to control erosion in the channel. Maximum scour depth occurs when Froude number increases regardless of the shape of spur dike. Spur dike was angled at different degrees, the optimum angle is found at 60 degrees in the upward flow of L-shape and 110 degrees in the downstream direction. Also [17]investigated numerically the effect of various directions of L-shape, T-shape and straight spur dike to determine their influence on instantaneous-coherent flow and mean flow structures. An experimental comparison was conducted by [18] between three shapes of L-shape spur dike in180 degree flume bend oblong wing shape, rectangular wing shape and rectangular chamfered wing shape of spur dike with various Froude numbers and flow intensities, it was deduced that oblong wing shape is the proper shape for reducing scour depth.

The effect of different wing shapes of T-shape spur dike was investigated by[19]. The minimum scour was observed by oblong wing of the T- shape. This reduction is about 20 % of rectangular wing shape, scour depth around rectangular chamfered is less than simple rectangular spur dike. The time development of the scour hole was installed around all shapes. An empirical relation was developed using shape factor equal 1, 0.92, 0.94 for rectangular wing, rectangular chamfered wing and oblong wing sequentially. A numerical model was conducted by [20] around three hockey dikes with software FLUENT. The results showed that the best location for a consecutive hockey shape is to be at a distance equal to two time length of spur dike to avoid flow pattern from returning to the beach.

As it can be evidenced from a review of literature that intensive studies examined scour pattern around specific layout of spur dike, but no studies have given an attention to perform a comparison of those types and with an emphasis on the crucial role of spur dikes configuration on river protection. Therefore, in this research an attempt to study the impact of various shapes of spur dikes with some changes in physical properties of flow as Froude number and discharges in order to help as a primary guide in selecting a proper shape of spur dike in rivers in early stages .

## 2 DIMENSIONAL ANALYSIS

Dimensional analysis is used to obtain different non dimensional terms to develop a homogeneous relation that describes the relation between scour hole parameters and other variables related to scour phenomenon, scour characteristics around various designs of spur dikes depend on the following parameters in (1)

$$ds = f\,(y, v, \upsilon, \rho, g, d_{50}, L, L'', B, S_F or K) \quad (1)$$

In which ds = the maximum scour hole depth, L = spur dike length, L" = wing wall length, B = channel width, y is water depth, V is mean flow velocity, $\rho$ = fluid density, $\upsilon$ = fluid kinematic viscosity, $g$ = the gravitational acceleration, $d_{50}$ is the median diameter of sediment, $S_F$ or $K$ is shape factor or code factor for spur dikes. Using dimensional analysis the relative scour depth can be written as (2):

$$ds / y = f\,(Fr, \mathrm{Re}, d_{50} / y, L / y, L'' / y, S_F or K) \quad (2)$$

After the elimination of constant parameters. The final relationship can be written as (3):

$$ds / y = (Fr, S_F or K) \quad (3)$$



## 3 EXPERIMENTAL APPARATUS

Experiments were carried out in a straight flume at the hydraulics laboratory of Mansoura University Fig (2). The flume is 10 m long with rectangular section and its width is equal to 74 cm and depth 38.5 cm. The sides and the bed of flume were made up of epoxy material. The spur dike of 15 cm long and 2.2cm thickness was fixed to the flume perpendicular to the flow direction. Spur dike length is adjusted to be 20% of the channel width which provides the same contraction ratio recommended by [21] and [22] .

A 15 cm thickness of bed sediment having a median size $d_{50}$ of 0.75 mm was placed in the flume. For measuring process a digital point gauge was fixed on the carriage which can be moved along the flume length and width. Pumps recirculated water from the underground tank to the flume and feed to two head tanks. Water discharge was measured by a rectangular weir which was fixed at the outlet of the second head tank. A screen was located at the upstream end of the flume to reduce flow turbulence. There were an-inclined wood side to decrease the effect of disturbance.

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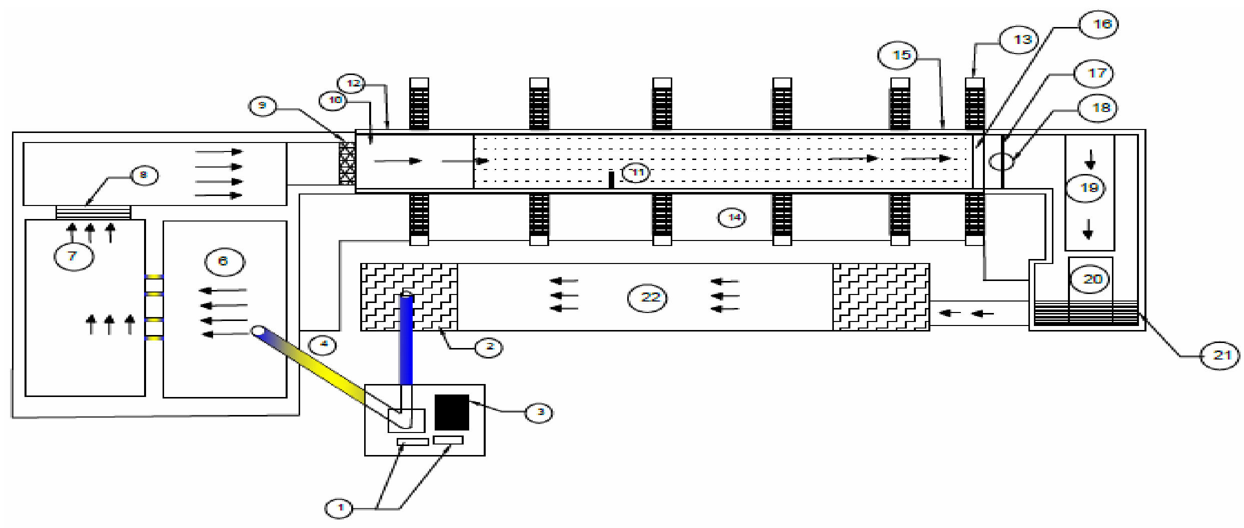



1- Centrifugal pump
2- Intake from sump
3- Motor
4- Delivery pipe
5- Suction pipe
6- First tank
7- second tank
8- Rectangular wire
9- Gravel screen box
10- Upstream inclined wood
11- Spur dike Model
12- Metal flume
13- Bracing wood
14- Side walk
15- Rails for moving gauge point
16- sand trap
17- Tail gate
18- Screw wheel
19- Collecting tank
20- calibration rectangular tank
21- outlet to underground sump

*Fig. 1 plan view of the flume layout*


*Fig. 2 Schematic illustration of a spur dikes models*

## 4 EXPERIMENTAL PROCEDURES

The model was installed in the flume, channel bed has been carefully leveled by using the hand trowel to ensure surface regularities and smoothing along the channel bed surface. For keeping standard bed level constant which used in measuring the results of scour, a gauge point and spirit level were used for checkup the levelling before each experiment in random places and initial elevation of sand level was taken. For starting the run, the water flow filled the flume slowly until the sand bed material was saturated, then the sluice gate was lifted up gradually to adjust the required flow depth. For each experiment after accomplishing 3 hours, the pump valve was closed, flow depth was allowed to drain from flume to sump at a slow rate for preventing disturbance, the same period of equilibrium scour depth was used by (Zhang et al., 2013), (Takaran et al., 2015), (Masjedi et al., 2010a) and (Zhang, Nakagawa, & Mizutani, 2012). Gauge point with an accuracy of +1% mm is used to record scour levels and the bed profile.

Seventy five experiments were carried out in this paper and five shapes of spur dikes were considered straight shape, mole shape, hockey shape, L shape and T shape. Three different flow discharges of 23.8, 20.3 and 13.95 Lit/sec were used, each one has five different flow depths with Froude numbers ranged from 0.16 to 0.4.

## 5 RESULTS AND ANALYSIS

### 5.1 The Impact of Discharge on Scour Depth

The impact of discharge and Froude number on scour process around straight, hockey, mole, L and T shapes was tested. Different Froude numbers of (0.15, 0.17, 0.18, 0.19, 0.22, 0.23, 0.25, 0.26, 0.27, 0.30, 0.33, 0.35, 0.39 and 0.40) were used. Three discharges were applied to all shapes of 13.95, 20.04 and 23.95 (Lit/Sec). Variation of relative scour depth with Froude number for different values of discharges are shown in Fig 3. The results indicated that for various designs of spur dikes, an increase in relative scour depth was observed when Froude number increases. Furthermore, Fig 4 shows the longitudinal profile of scour hole and sediment deposit for various designs. The location of maximum scour depth usually appears at the nose of spur dike, even though in the case of hockey shape the smooth deflection of flow helps in moving the apex of the hole or maximum depth of scour away in the downstream direction, it was moved about 0.3 to 0.45 of spur dike length toward the downstream, maximum scour depth appears at a distance ranged from 0.1 to 0.15 of length of spur dikes from the nose. The location of maximum depth of scour around T-shape is found at a distance about 13% to 20% of spur dike length. Contour maps of scour around available dikes were plotted to give more evidence to the previous results as shown in Fig 5.

### 5.2. The Impact of Spur Dike Configuration on Scour Depth

In the interest of raising the degree of protection in river banks the typical dimensionless graph for relative scour depth ds/y along all configurations of spur dikes are illustrated in Fig 6. Results showed when the discharge raises the relative scour depth increases. The lowest value of relative scour depth is noticed at hockey shape and the largest value is shown at straight shape. In other words the straight shape causes the largest changes in bed level as indicated by largest scour hole. The behavior of scour around straight shape is much close to this around L-shape, but L-shape causes less scour depth than straight one. Most of observed data indicated that mole spur dike gives scour depth slightly more T-shape and few points are out of this. An approximate trend of scour shows that straight shape appears as the largest one for forming maximum scour depth, then L-shape, Mole, T-shape finally the hockey shape

Fig (7) shows the three dimensional view of a scour hole at the equilibrium stage around straight and hockey shapes spur dikes.

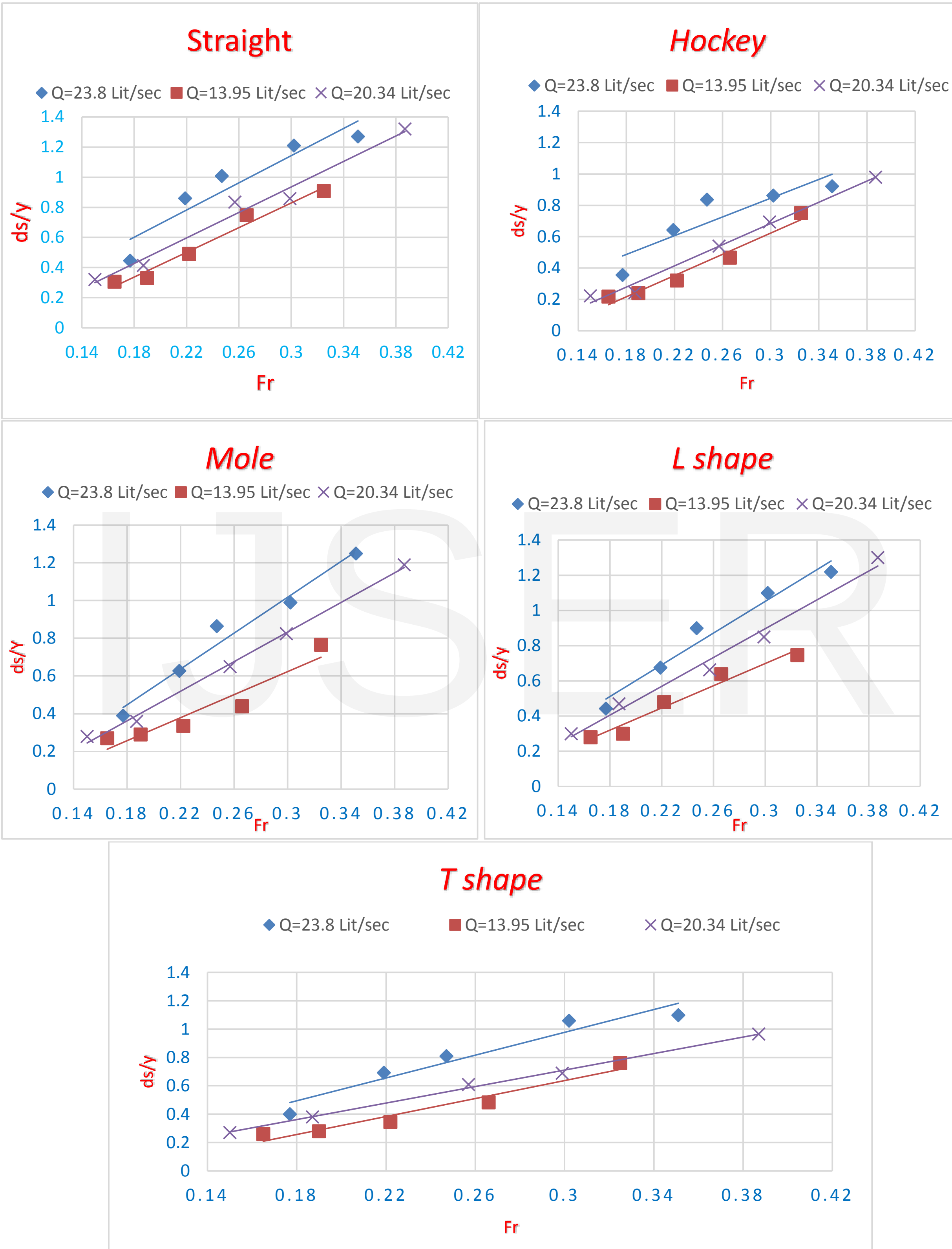



*Fig. 3 Variation of relative scour depths with Froude number for different discharges*

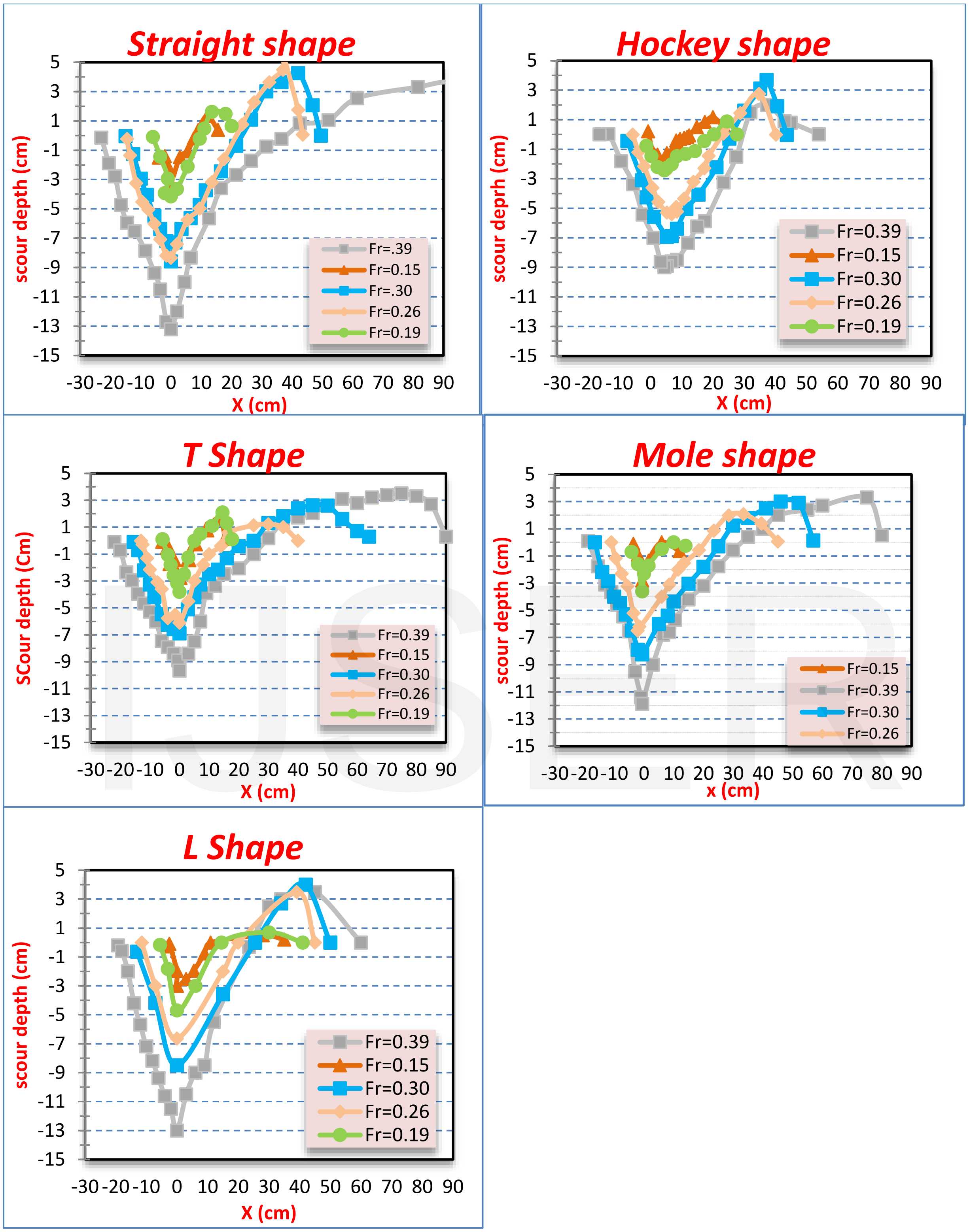



*Fig. 4 longitudinal profile of scour hole for various shapes for Q=20.34 Lit/sec*

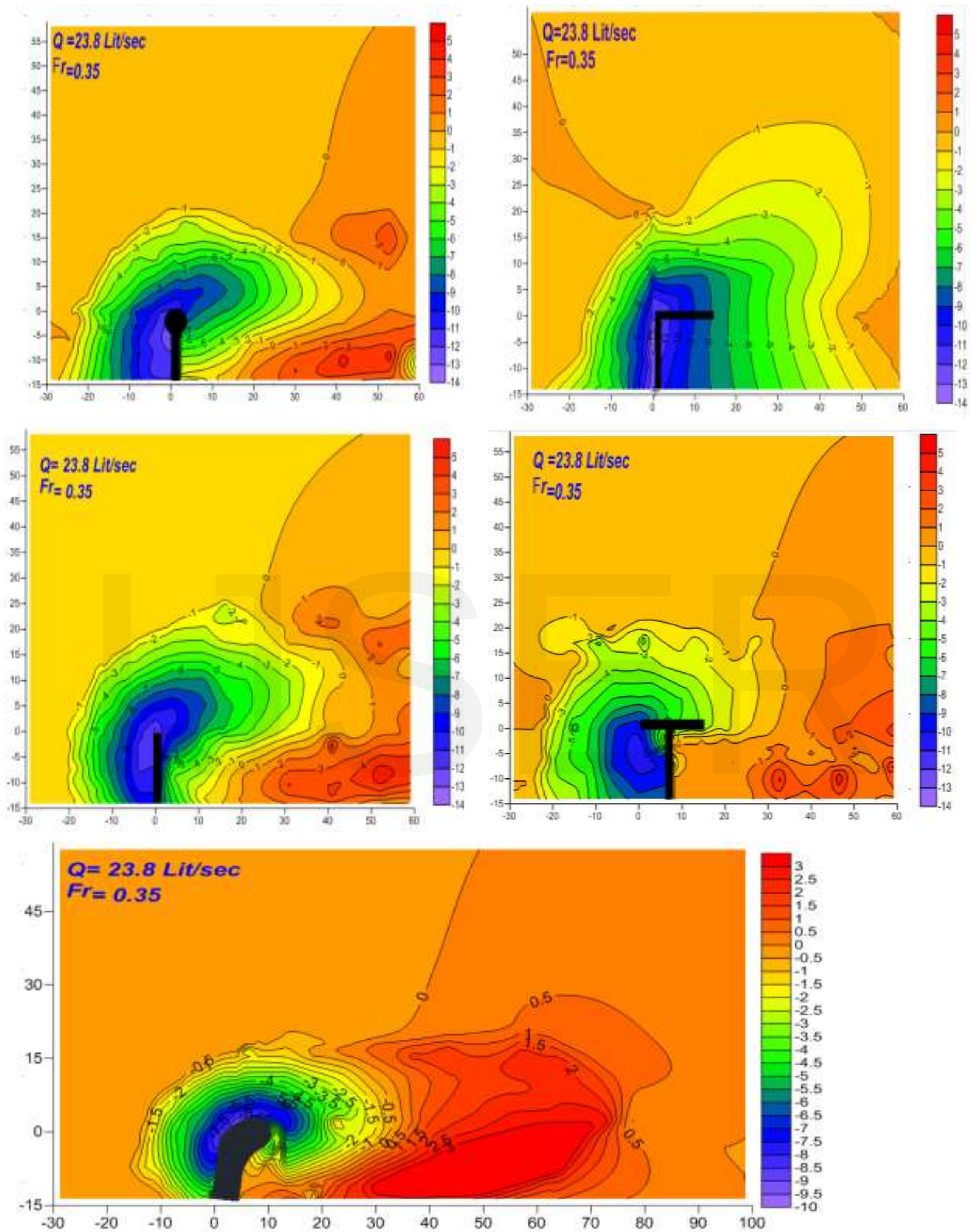



*Fig. 5 Scour contour map at equilibrium stage around various shapes of spur dikes*

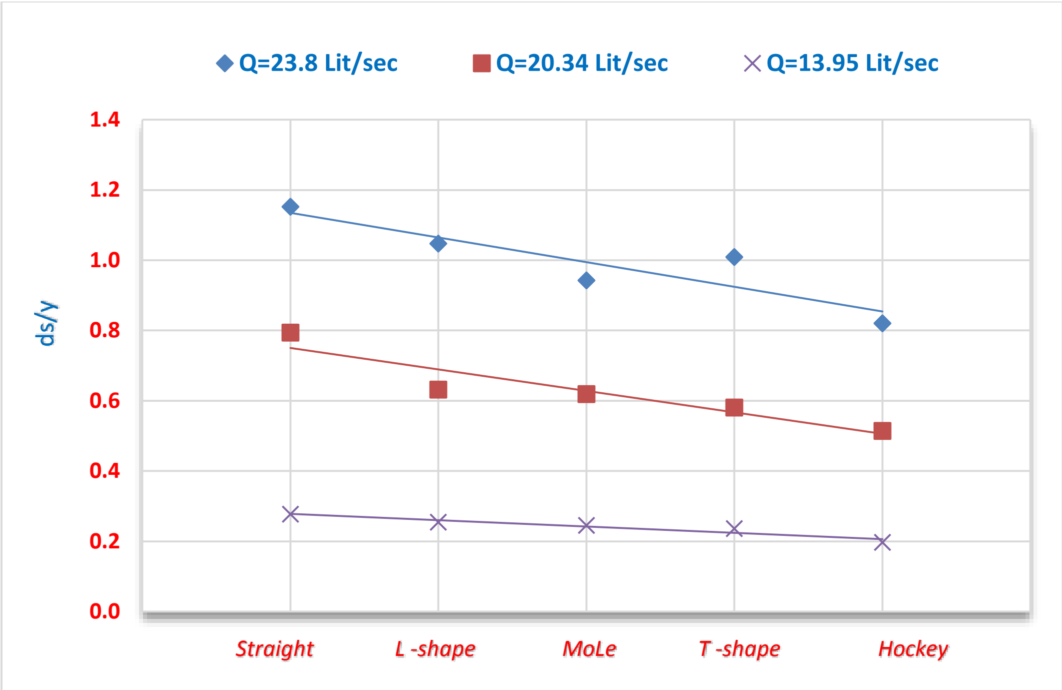



*Fig. 6 Typical dimensionless graph for relative scour depth ds/y for different configuration of spur dikes*

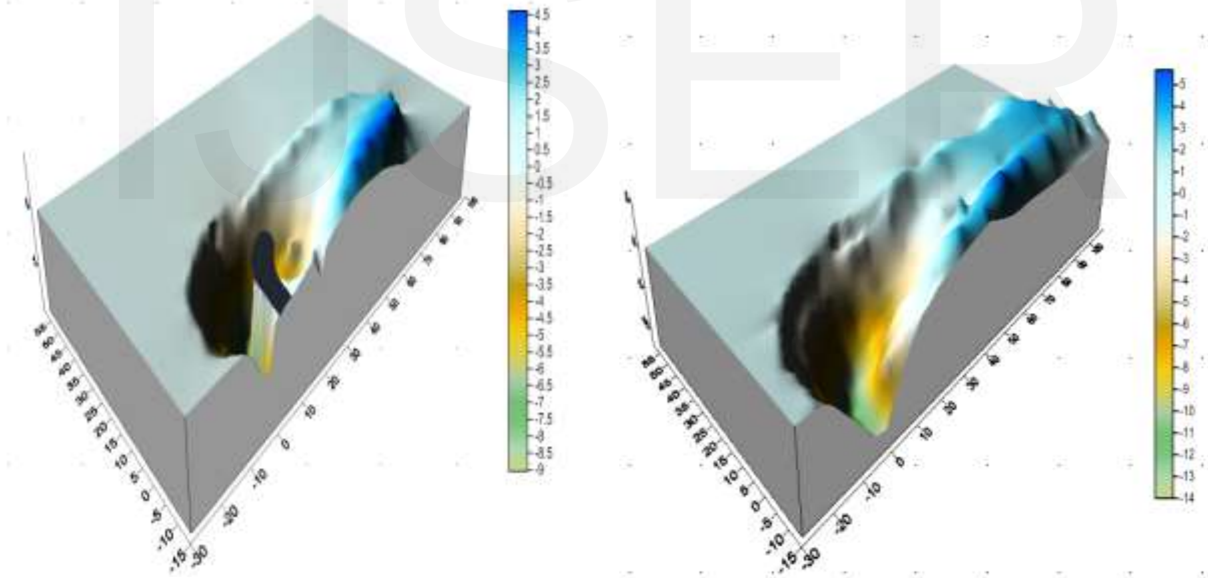


*Fig. 7 Three dimensional view of scour hole at equilibrium stage around straight and hockey shape*

# 6 EQUATIONS FOR RELATIVE SCOUR DEPTH

## 6.1 Equation for each model of spur dike

Numerous researchers studied the scour phenomena around spur dikes to develop an equation for predicting relative scour depth. Five empirical equations are proposed using nonlinear regression program SPSS for estimating maximum relative scour depth around various models of spur dikes, these equations are summarized in table (1). The accuracy of these equations is tested using the statistical performance indices root mean square error (RMSE), mean absolute error (MAE), mean absolute percent errors(MAPE), correlation coefficient (R) and coefficient of determination ($R^2$) .these parameters were defined by [23] and [24] as mentioned in (4) and found to be in the acceptable range as mentioned in many engineering applications. Where Y is the observed values, Y' is the corresponding predicted values and N is the total number of observed values.

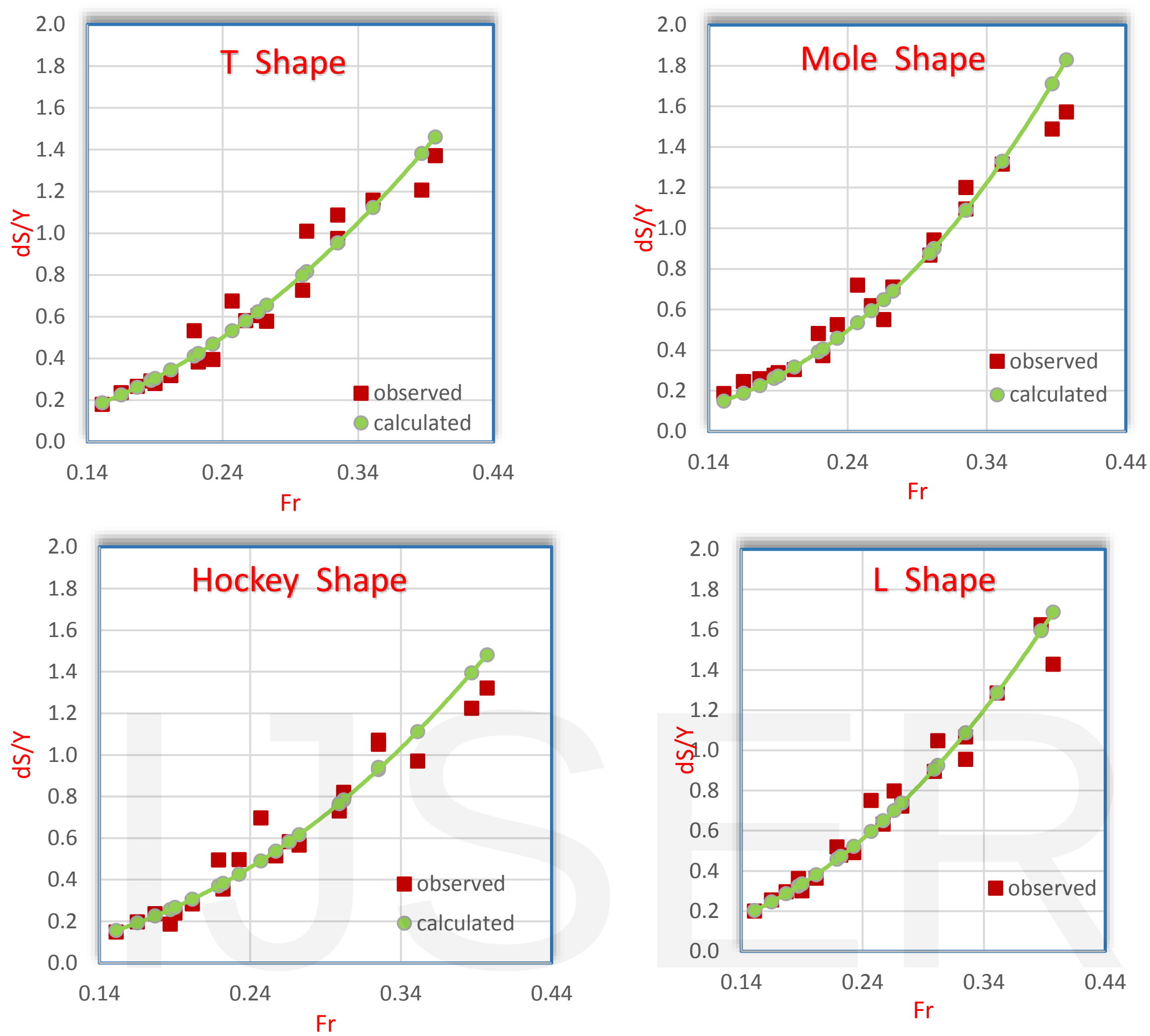
$$MAE = \frac{1}{N}\sum_{i=1}^{N}\left|Y_i - Y_i'\right| \qquad MAPE = \frac{100}{N}\sum_{i=1}^{N}\frac{\left|Y_i - Y_i'\right|}{\left|Y_i\right|} \qquad RMSE = \sqrt{\frac{\sum_{i=1}^{i=N}(Y_i - Y_i`)}{N}} \quad (4)$$

**General equation for each shape:**



| Spur dike shapes | Relative scour depth | R | MAE | RMSE | MAPE |
|---|---|---|---|---|---|
| Straight | $ds/y = 16.108Fr^{2.313}$ (5) | 0.98 | 0.085 | 0.108 | 9.899 |
| Hockey | $ds/y = 12.672Fr^{2.325}$ (6) | 0.97 | 0.072 | 0.095 | 11.640 |
| Mole | $ds/y = 19.945Fr^{2.587}$ (7) | 0.98 | 0.068 | 0.099 | 10.527 |
| L | $ds/y = 12.795Fr^{2.194}$ (8) | 0.98 | 0.054 | 0.084 | 7.043 |
| T | $ds/y = 10.397Fr^{2.125}$ (9) | 0.98 | 0.064 | 0.087 | 9.310 |

*Table (1) Summary of scour depth relations around spur dikes and its performance indices*



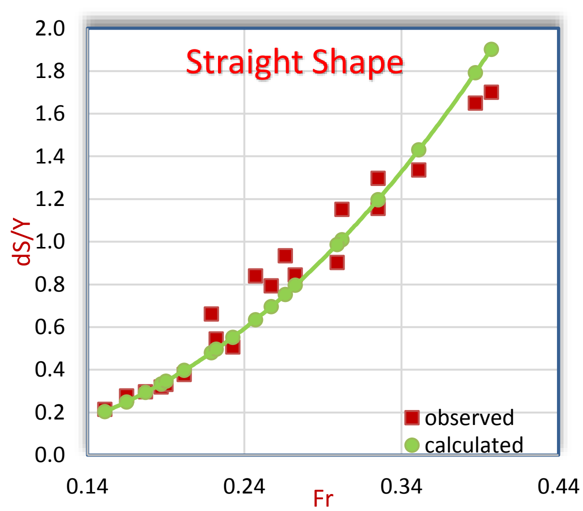




*Fig. 8 Comparison between experimental and predicted results*

### 6.2. General equation for different spur dike shapes

Many researchers have proposed equations to predict the scour depth depending on different parameters that can be applied only for one shape of spur dikes. [25], [6], [7], [26] and [27] give an equation for straight spur dike, [4] gives an equation around L-shape spur dike, [19] and [28] give an equation around T-shape spur dike, however, equations around hockey and mole were not found yet. Therefore, in this research a general equation for any shape of spur dikes was developed to give a good performance in prediction scour, Therefore, the developed equations can be deduced using two methods namely; percentile and coding methods, the coding method gives a coding number ( $K$ ) for each shape of spur dike from 1 to 5 and the percentile methods uses the shape factor values ( $S_F$ ) which approximately has achieved the observed data. the behavior of scour around abutment and pier is the same around spur dikes as [29] Proved, therefore, the percentile method has been used for prediction of the scour depth such as equations around abutment proposed by [30], [31] and [32] also scour equations around piers proposed by [33] and scour equation around bridges and pier proposed by [34].

#### 6.2.1 Coding method

The functional relation can be written as
$ds/y = a (k)^b (Fr)^c$, where a , b and c are constants, an equation has been developed using SPSS in (10) where the constants are a =11.75 b = -0.09 c = 2.09 , k is assumed coding factor as tabulated shown in table(2)as [35] used.

Equation (10) gives the best determination coefficient ($R^2$=0.94). Table (3) shows parameters for measuring the accuracy of this number coding equation. Table (4) shows statistical parameters of scour equations for appling k number code equation around each shape of spur dikes separately.

$$ds / y = 11.75 k^{-0.092} Fr^{2.097} \qquad (10)$$

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| shape | Straight | Hockey | Mole | L | T |
|---|---|---|---|---|---|
| K | 1 | 2 | 3 | 4 | 5 |

*Table(2) Number code factor for each shape*

| Spur dike equation(4) | R | MAE | RMSE | MAPE |
|---|---|---|---|---|
| | 0.972 | 0.013 | 0.039 | 2.007 |

*Table(3) Statistical parameters of k number code equation around spur dikes*

| SHAPE | R | MAE | RMSE | MAPE |
|---|---|---|---|---|
| Straight | 0.97 | 0.072 | 0.099 | 9.531 |
| Hockey | 0.94 | 0.114 | 0.142 | 24.457 |
| Mole | 0.98 | 0.058 | 0.075 | 9.984 |
| L | 0.97 | 0.075 | 0.099 | 9.382 |
| T | 0.97 | 0.067 | 0.088 | 10.036 |

*Table(4)Statistical parameters of scour equations for applied k number code equation around each shape of spur dikes*

### 6.2.2 Percentile method

From the previous relationships and the observed data the shape factor ($S_F$) was predicted for all shapes as seen in table (5)

| shape | Straight | Hockey | Mole | L | T |
|---|---|---|---|---|---|
| $S_F$ | 1 | 0.71 | 0.87 | 0.92 | 0.82 |

*Table(5) shape factor oaround various shapes of spur dikes*

Then by using this shape factor general equation for scour prediction are developed as seen

$$ds / y = 12.176 S_F^{0.092} Fr^{2.094} \quad (11)$$

Equation(11) gives the best determination coefficient ($R^2$=0.95), table(6) shows statistical parameters for general equation using shape factor in (11), table (7) indicates parameters for measuring the accuracy of shape factor equation if it applied for each shape separately

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| | R | MAE | RMSE | MAPE |
|---|---|---|---|---|
| $S_F$ Spur dike equation(5) | 0.970 | 0.015 | 0.042 | 2.307 |

*Table(6) Statistical parameters for for general equation using shape factor*

| SHAPE | R | MAE | RMSE | MAPE |
|---|---|---|---|---|
| **Straight** | 0.98 | 0.072 | 0.088 | 10.273 |
| **Hockey** | 0.97 | 0.063 | 0.082 | 12.869 |
| **Mole** | 0.98 | 0.055 | 0.070 | 10.396 |
| **L** | 0.98 | 0.060 | 0.083 | 8.330 |
| **T** | 0.97 | 0.073 | 0.093 | 11.534 |

*Table(7) Statistical parameters of scour equations for applied shape factor equation on each shape*

Based on equation (11) the final percentage of maximum depth of scour is tabulted in table(8) which identifies in trend to Fig (6) that indicates the general trend for spur dike. An approximate trend of scour shows that straight shape appears as the largest one for forming maximum depth of scour then L-shape ,Mole, T- shape finally the hockey shape .

| straight | L | Mole | T | Hockey |
|---|---|---|---|---|
| 1 | 0.93 | 0.89 | 0.85 | 0.75 |

*Table(8) percentage of maximum depth of scour around spur dikes*

## 7 VERIFICATIONS

To show the accuracy of developing equations and its performance in predicting the maximum scour depth near spur dikes, equations proposed by [4], [36] and [7]were used. Minimum percentage of error 25% was used for checking the accuracy of equations, this range of measuring error is acceptable in many hydraulic researches as [37], [38], [23] and [39]. For individual spur dike equations a comparison between predicted and observed relative scour depths using present straight spur dike equation with Nagy.2004 and Elsaiad et al.2016 is illustrated in Fig (9), Comparison between predicted and observed dimensionless scour depths using present L spur dike equation with Takaran et al. 2015 as seen in Fig (10). For measuring the ability of shape factor equation Eq (10) a comparison between predicted and observed dimensionless scour depths using present shape factor equation of spur dike in (11) with Takaran et al.2015 , Nagy.2004 and Elsaiad et al.2016 is shown in Fig(11). The comparison resulted that all these equations are under the agreement range.

(Takaran *et al.*, 2015)[4] developed Eqn.(12) for L shape

$$\frac{ds}{y} = 6.15(Fr)^{1.12}\left(\frac{L}{B}\right)^{0.28}\left(\frac{\theta}{180}\right)^{0.5} Ln\left(\frac{t+t_e}{t_e}\right)^{0.22} \qquad (12)$$

**Range of validation**: L /b(0.1 to 0.25) , Fr (0.23 to 0.35) where L is length of spur dike, B is channel width , θ is angle of spur dike with bank, location of spur dike, y is approach flow depth, t is time of scour, $t_e$ is maximum of time development of scour.

(Elsaiad *et al.*, 2016)[7] predicted Eqn.(13) for straight shape

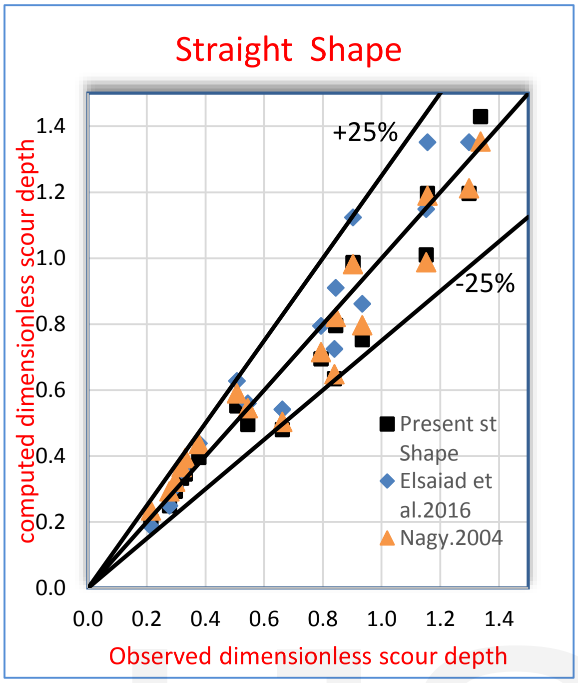
$$\frac{hs}{y} = 14.405\lambda + 0.714k_\theta - 0.8456 \qquad (13)$$

Where hs/y (0.15-1.3), λ (0.03- 0.166), $k_\theta$ (0.5-1.0), where hs is maximum depth of scour, λ is the kinetic factor $\lambda = Fr^2$ , Fr= Froude number, $k_\theta$ alignment coefficient = θ/90 , θ is the angle of spur dike junction with channel side.

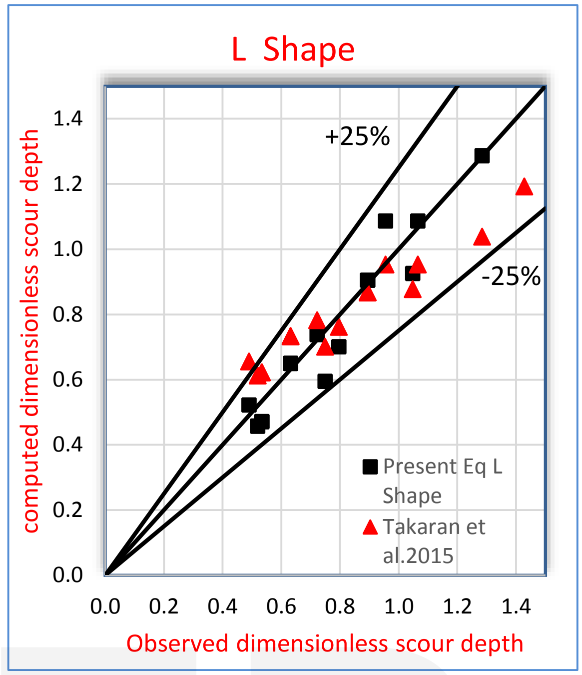
(Nagy, 2004) [36] predicted Eqn.(14) for straight shape

$$\frac{ds}{y} = 3.\frac{(l/y)^{0.42}(\sin\theta)^{0.717}}{(d_{50}/y)^{0.277}}.Fr^2 \qquad (14)$$

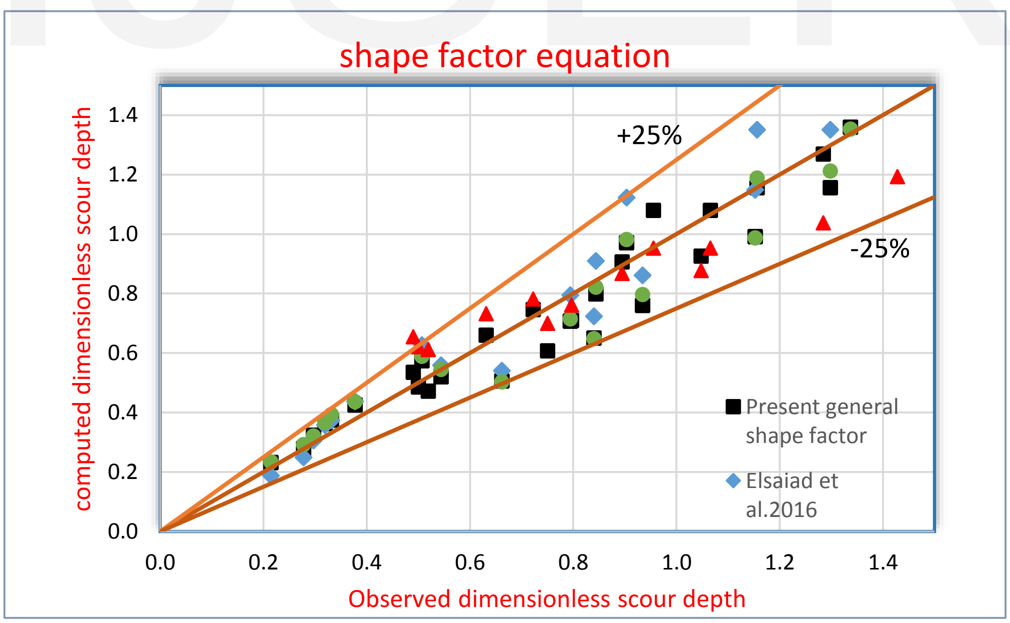
Where (*l/y*) is spur dike length ratio, y is approach flow depth.




*Fig(9)Comparison between predicted and observed relative scour depths using present straight spur dike equation with Nagy.2004 and Elsaiad et al.2016*




*Fig(10)Comparison between predicted and observed relative scour depths using present L spur dike with Takaran et al.2015*




*Fig(11)Comparison between predicted and observed relative scour depths using present Shape factor equation of spur dike (5) with Takaran et al.2015 , Nagy.2004 and Elsaiad et al 2016*

## 8 Conclusions

The main conclusions of this study can be summarized as follows:

- With the increase of Froude number, the maximum depth of scour increases
- The increase of relative scour depth is observed clearly as the effect of discharge increases, the same considerable pattern is found for all spur dike shapes
- Using hockey spur dike causes shifting of scour hole profile to move further in the downstream direction, it provided additional smooth deflection of flow, maximum depth of scour is located at a distance about 10% to 15% of spur dike length from the upstream face of spur dike
- For T-shape maximum depth of scour occasionally occurs in the upstream wing nose of spur dikes sometimes places at a distance about 13% to 20% convergence from this nose of spur dikes; however it was found that at the nose of spur dikes for different layout of spur dike
- Longitudinal profile of scour indicates that the formation of scour hole is mainly influenced by Froude number as the scour longitudinal limit is extended further in case of the greatest value of Froude number
- Hockey spur dike has the ability to minimize maximum depth of scour around spur dike by 75% from the scour developed around straight spur dikes
- Hockey spur dike is the most effective shape in reducing scour in spur region as compared to other configurations of spur dikes
- Amount of scour around straight spur dike is much more as compared to that at L, T, Mole and hockey shape, therefore straight shape of spur dike is more suitable in the case of navigation enhancement
- Mole and T-shape of spur dike produce maximum depth of scour are smaller than the similar depth around straight shape approximately about 89% & 85% respectively
- L-shape spur dike is more approach to straight shape as it is almost 92% of maximum depth of scour developed around straight shape and sometimes the same value or ranged slightly about the depth of straight spur dike

## 9 References


[1] SEPA, "Bank Protection Rivers and Lochs," *Good Pract. Guid.*, no. April, p. 47, 2008.

[2] S. M. Keh, "Streambank Erosion Protectio n and Channel Scour Manipulatio n Using Rockf ill Dikes and Gabions," *by Water Resour. Res. Inst. e Oregon State Univ.*, no. September, 1984.

[3] M. GHODSIAN and M. VAGHEFI, "Experimental study on scour and flow field in a scour hole around a T-shape spur dike in aa 90° benda 90° bend," *Int. J. Sediment Res.*, vol. 24, no. 2, pp. 145–158, 2009.

[4] P. Takaran, S. P. Terhadap, K. Karotena, B. Cosmos, and D. Rendah, "valuating Scour at L-Shape Spur Dike in a 180 Degree Bend," *Rep. Opin.*, vol. 4, no. 1, pp. 1–14, 2015.

[5] A. Masjedi, V. Dehkordi, M. Alinejadi, and A. Taeedi, "Experimental Study on Scour Depth in Around a T-shape Spur Dike in a 90 Degree Bend," *J. Hydraul. Eng.*, vol. 10, no. 10, pp. 1146–1152, 2010.

[6] M. M. Ibrahim, "Local bed morphological changes due to oriented groins in straight channels," *Ain Shams Eng. J.*, vol. 5, no. 2, pp. 333–341, 2014.

[7] A. A. Elsaiad and E. A. Elnikhely, "EXPLORATION OF SCOUR CHARACTERISTICS AROUND SPUR DIKE IN A STRAIGHT WIDE CHANNEL," *Int. water Technol. Journal, IWTJ*, vol. 6, no. 2, pp. 130–143, 2016.

[8] A. S. L. Manish Pandey, Z. Ahmad and P. K. Sharma, "SCOUR AND FLOW PATTERN AROUND SINGLE," *Int. Civ. Eng. Symp.*, no. March, 2014.

[9] H. Karami, A. Ardeshir, K. Behzadian, and M. Ghodsian, "Protective spur dike for scour mitigation of existing spur dikes," *J. Hydraul. Res.*, vol. 49, no. 6, pp. 809–813, 2011.

[10] A. Shafaie, A. Ardeshir, S. M. Sadat-Helbar, and M. Saneie, "The Effect of Minor Spur Dike on Scouring At the First Spur Dike in the Gravel Bed," *Fourth Int. Conf. Scour Eros. 2008*, pp. 196–200, 2008.

[11] Y. Safarpoor, S. S. Hashemi, À. R. Z. Grzqvwuhdp, R. I. D. Vsxu, G. Lv, and G. Lqwr, "( IIHFW RI 7 VKDSHG VSXU GLNH RQ ÀRZ VHSDUDWLRQ LQ D ƒ EHQG XVLQJ SSIIM model," *June 2017 J.*

*Natl. Sci. Found. Sri Lanka*, vol. 45, no. 2, pp. 159–168, 2017.
[12] H. Zhang, H. Nakagawa, M. Ogura, and H. Mizutani, "Experiment Study on Channel Bed Characteristics around Spur Dykes of Different Shapes," vol. 69, no. 2, pp. 489–499, 2013.
[13] J. Kang, H. Yeo, S. Kim, and U. Ji, "Permeability effects of single groin on flow characteristics," *J. Hydraul. Res.*, vol. 49, no. 6, pp. 728–735, 2011.
[14] H. Zhang, H. Nakagawa, and H. Mizutani, "Bed morphology and grain size characteristics around a spur dyke," *Int. J. Sediment Res.*, vol. 27, no. 2, pp. 141–157, 2012.
[15] A. S. Lodhi, R. K. Jain, and N. Karna, "TEMPORAL VARIATION OF SCOUR AT WAKE OF THE SPUR DIKES IN COHESIVE SEDIMENT DIKES IN COHESIVE SEDIMENT MIXTURES," no. December 2017, 2018.
[16] A. A. Dehghani, H. M. Azamathulla, S. A. Hashemi Najafi, and S. A. Ayyoubzadeh, "Local scouring around L-head groynes," *J. Hydrol.*, vol. 504, pp. 125–131, 2013.
[17] A. Kadota and K. Suzuki, "Flow Visualization of Mean and Coherent Flow Structures around T-type and L-type Groynes," *River Flow 2010 - Dittrich, Koll, Aberle Geisenhainer - © 2010 Bundesanstalt für Wasserbau ISBN 978-3-939230-00-7*, 2010.
[18] A. Masjedi, M. S. Bejestan, and P. Rahnavard, "Control of local scour at single L-shape spur dike with wing shape in flume bend," *J. Am. Sci.*, vol. 8, no. 9, pp. 1122–1128, 2010.
[19] A. Masjedi, M. S. Bejestan, and P. Rahnavard, "Reduction of Local Scour at Single T-Shape Spur Dike with Wing Shape in a 180 Degree Flume Bend," *world Appl. Sci. J.*, vol. 8, no. 9, pp. 1122–1128, 2010.
[20] A. H. Aini, "Numerical Method for Estimating Flow Pattern around Consecutive Hockey-Shaped Spur Dike with using Computational Fluid Dynamic," *Int. J. Sci. Eng. ISSN 2454 - 2016*, vol. 2, no. 2, pp. 2–7, 2016.
[21] R. Manual, F. Flood, R. Management, and S. Measures, "Chapter 6 : Physical Methods for River Training," pp. 60–77, 2002.
[22] A. Masjedi, M. S. Bejestan, and P. Rahnavard, "Reduction of Local Scour at Single T-Shape Spur Dike with Wing Shape in a 180 Degree Flume Bend," vol. 8, no. 9, pp. 1122–1128, 2010.
[23] Z. A. and P. K. S. Manish Pandey, "Estimation of Maximum Scour Depth near a Spur Dike Manish," *Can. J. Civ. Eng.*, 2015.
[24] M. Najafzadeh and G. A. Barani, "Comparison of group method of data handling based genetic programming and back propagation systems to predict scour depth around bridge piers," *Sci. Iran.*, vol. 18, no. 6, pp. 1207–1213, 2011.
[25] D. C. Froehlich, "Local scour at bridge abutments," *Proc. 1989 Natl. Conf. Hydraul. Eng.*, pp. 13–18, 1989.
[26] M. Fazli, M. Ghodsian, and S. Neyshabouri, "Scour and flow field around a spur dike in a 90 bend," *Int. J. …*, vol. 23, no. 1, pp. 56–68, 2008.
[27] Manish Pandey and K. P. Sharma, "Estimation of Maximum Scour Depth near a Spur Dike Journal:," *Estim. Maximum Scour Depth near a Spur Dike J.*, 2015.
[28] M. Vaghefi, M. Ghodsian, and S. A. A. S. Neyshaboori, "EXPERIMENTAL STUDY ON THE EFFECT OF A T- SHAPED SPUR DIKE LENGTH ON SCOUR IN A 90 °," vol. 34, no. 2, pp. 337–348, 2009.
[29] M. Pandey, Z. Ahmad, P. K. Sharma, and V. Kumar, "Experimental Study of Temporal Scour around Spur Dikes," *Civ. Eng. Syst. Sustain. Innov. ISBN*, pp. 164–171.
[30] B. Bruce and W. Melville, "PIER AND ABUTMENT SCOUR : INTEGRATED APPROACH," *J. Hydraul. Eng.*, vol. 123, no. 2, pp. 125–136, 1997.
[31] C. B. Tey, "Local scour at bridge abutments.," *Dep. Civ. Eng. Univ. Auckland.*, 1984.
[32] W. H. Wong, "Scour at bridge abutments," 1982.
[33] B. B. W. and a. j. sutherlan. Melville, "design method for local scour at b ridge pier," vol. 114, no. 10, pp. 1210–1226, 1989.
[34] E. M. Laursen and A. Toch, "Scour Around Bridge Piers And Abutments by," no. 4, 1956.
[35] A. Eghbalzadeh, M. Javan, M. Hayati, and A. Amini, "Discharge prediction of circular and rectangular side orifices using artificial neural networks," *KSCE J. Civ. Eng.*, vol. 20, no. 2, pp. 990–996, 2016.
[36] H. M. Nagy, "Maximum depth of local scour near emerged vertical-wall spur dike," *AEJ - Alexandria Eng. J.*, vol. 43, no. 6, 2004.
[37] C. Y. Wang, H. P. Shih, J. H. Hong, and R. V. Raikar, "Prediction of bridge pier scour using genetic programming," *J. Mar. Sci. Technol.*, vol. 21, no. 4, pp. 483–492, 2013.
[38] Z. A. and P. K. S. Manish Pandey, "Scour around impermeable spur dikes : a review Scour around impermeable spur dikes : a review," *ISH J. Hydraul. Eng.*, no. June, pp. 1–20, 2017.
[39] H. Basser, H. Karami, S. Shamshirband, A. Jahangirzadeh, S. Akib, and H. Saboohi, "Predicting optimum parameters of a protective spur dike using soft computing methodologies A comparative study," *Comput. Fluids*, vol. 97, pp. 168–176, 2014.