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ALIGNMENT OF DYKES FOR BANK PROTECTION AND MAINTAINING THALWEG FOR NAVIGATION IN ALLUVIAL RIVER WITH FINE SEDIMENT

Mohammed Alauddin[1] and Tetsuro Tsujimoto[2]

***Abstract**: An alluvial channel at low land as in Bangladesh is highly dynamic in nature; being exposed to severe bank erosion at high flood causes huge landloss as well as rapid sedimentation at low flow interrupts navigation. Dykes, revetments etc are typically used to overcome these problems, but the goals are not achieved as expected. This study investigates optimum orientation of dykes for effective functioning at high flow and low flow both. RIC-Nays, 2D model for flow and morphology, developed by the Foundation of Hokkaido River Disaster Prevention Research Center, Japan is used in the study upon confirmation through the detailed experimental data. The channel and flow parameters are selected in conformity with a typical river of Bangladesh. Three main parameters are considered here to evaluate the performance of dykes – erosion in channel bed (thalweg), deposition in dyke-field, and scour near dykes. Two types of dykes: non-permeable and permeable, and four alignments: 100^0, 90^0, 80^0 and 70^0 to the direction of flow are considered. Computations reveal that smaller angled dykes function better in respect of deepening the channel bed, except deposition near bank reduces.*

***Keywords**: alluvial channel; bank erosion; thalweg; dyke-field; dyke orientation.*

INTRODUCTION

Alluvial river channels are highly dynamic in nature as they pass through the alluvium, loose sedimentary materials formed through entrainment, transportation and deposition throughout the channels, involving diverse phenomena: turbulent flows, secondary flows, sediment transport, bank erosion processes and so on.

Alluvial River, Jamuna in Bangladesh

The country is a part of the Bengal delta, formed by the complex influence of three mighty rivers of the world: the Ganges, the Brahmaputra, and the Meghna. The combined basin area of which is about 1.72 million sq. km. and spread over China, India, Nepal, Bhutan, and Bangladesh. Bangladesh is the lowest riparian country, and thus it has been the natural outlet for enormous amount of water and sediment over the annual cycle. Planform changes are

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particularly dramatic in the river, Jamuna (downstream part of Old Brahmaputra distributary in Bangladesh), and this large, braided, sand-bed river has a total width of the order of 10 to 15 km and a number of islands are present inside the river. A widely varying discharge, easily eroded banks and highly mobile bed materials cause response to fluvial processes quickly adopting and abandoning numerous anabranches at all levels within its braided system. Water and sediment discharge in the Jamuna is dominated by the annual monsoon that usually begins in April, with a steeply rising hydrograph that peaks in late July/early August and drops to a low in February. A mean annual peak discharge of approximately 69,000 m^3/s (Delft Hydraulics & DHI, 1996b) with a maximum of approximately 100,000 m^3/s (recorded during severe flooding in 1988) is known from the daily discharge data recorded at Bahadurabad, and annual sediment transport is up to 2000×10^6 tons, the third highest alluvial sediment load in the world (Schumm & Winkley, 1994).

Definition of the Problem

Due to very drastic nature of the Jamuna River, apart from losing the homesteads of people along the rivers, the erosion and bank recession in monsoon have significantly limited agricultural and industrial development in the area. On the other hand, the navigational routes are often hampered and usually ships/boats are forced to travel longer distance on the way towards the destination in dry season, even sometimes they cannot move inside the river for several hours to several days because of the rapid unknown sedimentation in the channels. Dykes, revetments etc are typically used to overcome these problems, but in some cases the targeted goals are not achieved as expected, resulting failure of the structures due to scour, sudden and big responses from the dykes which make unstable the other regions away from the structures, such as the islands (*Chars*, local name, where a number of people are living) etc., attack to the bank where the dykes are installed by some oblique flow and so on, and stable water courses are not established rightly. However, in large rivers (in terms of width) like Jamuna, it is too expensive and impracticable to contract the total flow providing dykes on both sides. Thus, necessity arises to optimize the deflection of flow from the bank, guiding the flow smoothly, so as to minimize the impact to other regions and to concentrate the flow for deepening the channel for navigation in dry season. In the present study the optimum orientation of dykes is explored to have their effective functioning for high flow and low flow conditions both.

So far experimental work led to a better understanding of the dyke induced flow, but not to optimized design of new dykes. The possibilities of exploring alternative designs have come into sight with the availability of computer models. Depth-averaged two-dimensional models (Tingsanchali and Maheswaran 1990, Jia and Wang 1999, Zhang et al. 2006, and some others) have been used to simulate hydrodynamic flow fields near dykes considering corrections for stream line curvature in momentum equations. Using large eddy simulation, McCoy et al. (2008) studied the flow hydrodynamics in a straight channel containing a series of dykes with shallow embayments. Separation of flow occurred at the dyke-head causes the formation of return currents towards the dyke-field area and often attack the riverbank. Therefore, permeable dykes are, sometimes, preferred as a solution of the above problem (FAP 21, 2001); where a dyke acts as a roughness (resistance) to the flow, but does not block as the impervious dykes do. The loss of energy at the lee side of dykes due to form drags reduces the flow velocity in the dyke region and hence influences deposition.

Despite the history of dykes is for long and their widespread use, there is still lack of knowledge about their effects in river. Even though local scour phenomena near a single dyke has been discussed by many researchers (Tingsanchali & Maheswarn 1990, Chen & Ikeda 1997, Kuhnle 2002, Duan et al. 2009 and others), discussions about the overall bed degradation in the main channel, and aggradations in the dyke regions caused by a series of dykes are not sufficient yet. Usually dykes are placed in series so as to achieve better effect from both bank protection and navigation point of view. The embayment region between successive dykes acts as a dead water zone, where the mean velocities are much smaller compared to the main channel. Therefore this paper presents the morphological impact of dykes with various orientations for the most optimal one to be identified in natural rivers with shallower embayment regions compared to main channel.

Aim and Objectives

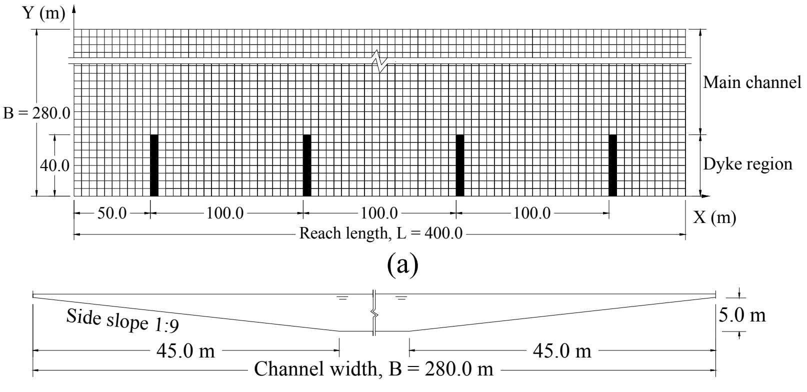
This study is mainly aimed at improving the understanding in stabilizing the main stream of an alluvial river through protection of bank erosion at high flood and establishment of navigation channel at low flow time as well. Keeping in view the above considerations, objectives of the present study can be summarized as follows:

(i) To investigate flow dynamics against various orientation of dykes in sand-bed alluvial river channels.
(ii) To investigate the sediment processes and the changes of bed topography in the far and near bank regions.
(iii) To compare the performance of the dykes of different orientations to suggest the best one for field uses.

MODEL SETUP AND PROCEDURE

Model Setup

The modeled area is a schematized straight river reach with four dykes of same orientation for each run, which is 400.0 m long (*L*) with a bed slope of 7.5 cm /km. Dykes are located at one side of the reach with projected length, $L_d = 40.0$ m and spacing, $S = 100.0$ m (i.e. aspect ratio, $S/L_d = 2.5$). Figs. 1(a and b) depict the model layout with a typical orientation of dykes and grids, and channel cross-section, respectively. The flow is in the *x*-direction with $x = 0$ at upstream end and *y*-axis is pointing to the left bank in the transverse direction. Since at high water stages, discharge is distributed over a much wider area, the bank regions are provided with a mild slope, 1:9 on either side to avoid the deviation from the natural situation, whereas it is much larger from the consideration of submerged repose angle; this is necessary to reflect the effect of low flow, as only a part of a dyke length (less than 50%) is effective to function that time. The channel width, *B* is taken as 280.0 m, fixed by considering one of the subchannels of the river near bank. Various orientations of dykes such as 100^0, 90^0, 80^0, and 70^0 to the direction of flow as designated by **100d** through **70d** (Fig. 2), respectively are considered to find optimum one including two types of dykes in terms of permeability: (i) non-permeable (**100d**, **90d**, **80d**, **70d**), and (ii) permeable (**90d**, **80d**, **70d**). For the former, the cells in computation domain are solid, while for the later; the area of dyke is occupied by group of non-submerged cylinders which have form drags against flow.



(a)

(b)

Fig. 1. (a) Planview of the reach of interest; (b) Channel cross-section.

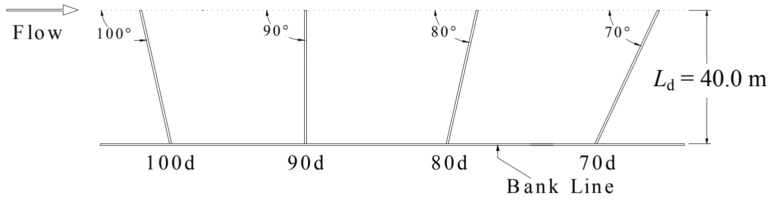


Fig. 2. Orientation of dykes.

Procedure

In this study three indices are thought as the design criteria of dykes through which their performance be confirmed; these are (i) erosion in main channel (thalweg), (ii) deposition in dyke-field, and (iii) scour near dykes. The first one specifies the availability of flow depth in the main channel for navigation at low flow time, the second one the protection of channel bank from recession at high flood, and the third one indicates the stability of dyke structures against scour near dyke-tip at high flood time.

Above key-parameters taken place due to the impact from the series of dykes of various orientations are planned to study with numerical model. RIC-Nays, a two-dimensional model for flow and morphology, developed by the Foundation of Hokkaido River Disaster Prevention Research Center, Hokkaido University, Japan is used in this study upon confirmation through the detailed experimental data. The shallow-water equation for two-dimensional (2D) unsteady flow expressed in a general coordinate system is calculated on the boundary-fitted structured grids using the finite-difference method. Ashida and Michiue (1972) equation is used to calculate bed load towards the streamline direction, and then the effect of cross-gradient (Hasegawa, 1983) and the influence of secondary flow (Engelund, 1974), are taken into account. For sediment concentration, the exponential distribution in the vertical direction is assumed and the 2D advection-diffusion equations are used for planar distribution of suspended sediment. Finally the bed deformation is calculated using the 2D sediment continuity equation.

Idealized flow and sediment parameters are considered in the computation; two different discharges are considered to replicate the responses of dykes in both high flow and low flow conditions: a constant discharge of 2600.0 m^3/s (Q_h) as high flow and 650.0 m^3/s (Q_l) as low flow considering the variation of flow in the river over the hydrological year, and the median size of sediment is chosen as 0.16 mm for the whole domain. Initial and downstream water surface is set by uniform flow condition. In this study we use a computational time step of 0.1 sec. and all of the runs are made for the duration of 7 days, when the temporal variations of variables are considerably reduced. Relatively smaller grid sizes are used near dyke, increasing gradually as distance increases away from the dyke. The computation is made for flow and bed topography both past an infinite series of emerged dykes (periodic conditions in the streamwise direction). The advective term is calculated by upwind difference scheme, and mixing length turbulence model is used in diffusion.

MODEL VERIFICATION

The model is first verified based on detailed experimental measurements performed by Rajaratnam and Nwachukwu (1983), where they studied the flow in a laboratory flume near dyke-like structures. An experimental dataset for a thin 0.15-m -long dyke (*b*) with a flow discharge of 0.045 m^3/s, flow depth of 0.189 m, and Froude number of 0.19, is considered for comparison. Velocity measurements made at sections with distances of x/b = 2, 4, 6, 8 downstream of the dyke (*x*, distance from dyke section) are compared with the simulated results shown in Fig. 3, in which the mixing-length turbulence model is adopted. The flow field of the physical model is well reproduced by the numerical model outside of the dyke-field, but some differences are observed downstream of the dyke where the flow is highly skewed.

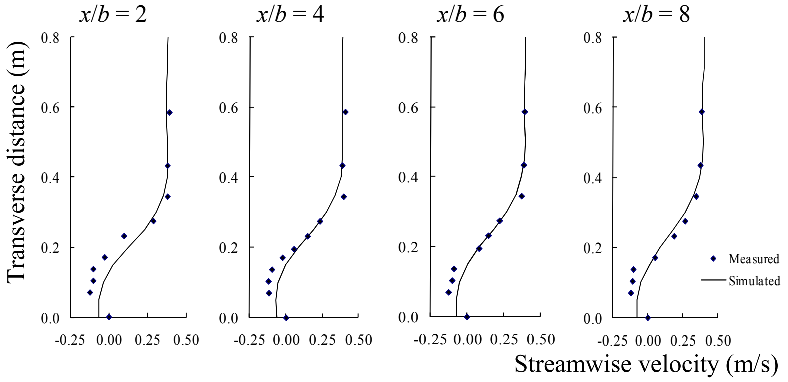


Fig. 3. Comparison of the simulated results with the experimental data.

Although, the flow phenomena near a single dyke, especially for a submerged one, are three-dimensional (3D), the physics of the present problem, the responses from the series of dykes to influence deposition at embayment regions and erosion in main channel, however, is almost two-dimensional (2D). Moreover, a depth-averaged, 2D model is advantageous for its cost-effective and easiness to calibrate and it requires less input data for practical engineering applications.

RESULTS AND DISCUSSION

Selected results of the flow fields and bed deformation processes are presented in this section to understand the channel morphodynamics resulted from interaction of dykes with various orientations to choose effective one. Three main parameters are considered here to evaluate the performance of dykes - erosion in channel bed (thalweg), deposition near bank, and scour depth near dykes. The first represents the maintenance of navigation, the second the anti-erosion of bank, and the third the stability of dyke structures. These parameters are explored here for different dykes from the results described below.

Flow Pattern

The computations show that flow contracted due to dyke intrusion and thus cause the flow to accelerate in the main channel. These can be observed from Figs. 4(a-d), where the existence of a skewness of stream wise components of velocities, *u* is depicted with higher intensity at high flow condition and vice versa.

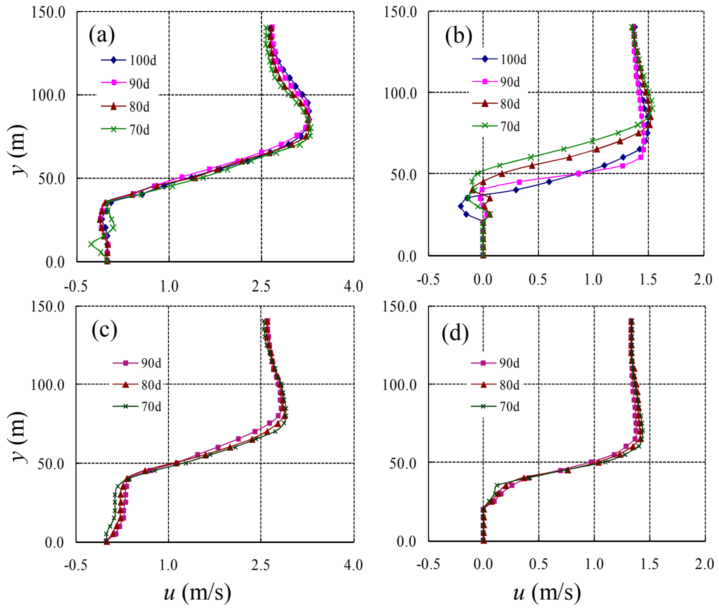


Fig. 4. Streamwise velocity profiles at 20.0 m downstream of second dyke for impermeable (a) high and (b) low flow, and permeable (c) high and (d) low flow.

Figs. 5(a-d) show depth-averaged velocity fields along with bed topography in dyke-fields as well as in main channel portion for various orientations and types of dykes. In high flow condition, mostly one gyre (large-scale secondary flow eddy inside the embayment) system occupies the whole area of the impermeable dykes [Fig. 5(a)]. Whereas, two-gyre velocity fields are observed in the dyke-fields at low flow condition with higher aspect ratio [Fig. 5(b)], except that it is not so clear for the case of **100d** at high flow and low flow both. The upstream part of a dyke-field contains the secondary gyre in the direction opposed to the primary gyre. The mean velocity of recirculating flow is much less than the approaching flow velocity (=2.15 m/s for high flow), so that sediment concentrations exceed the transportation capacity and they settle in the recirculation zone. But, recirculation of flow is observed stronger for the dyke, **70d** in the dyke-field and hence, near bank erosion occurred. In contrast with the impermeable dykes, the momentum transfer by the water flowing through the dykes prevents the formation of a recirculating flow, and mostly, results in a unidirectional flow in the dyke-fields [Figs. 5(c and d)]; however, some scour is still present

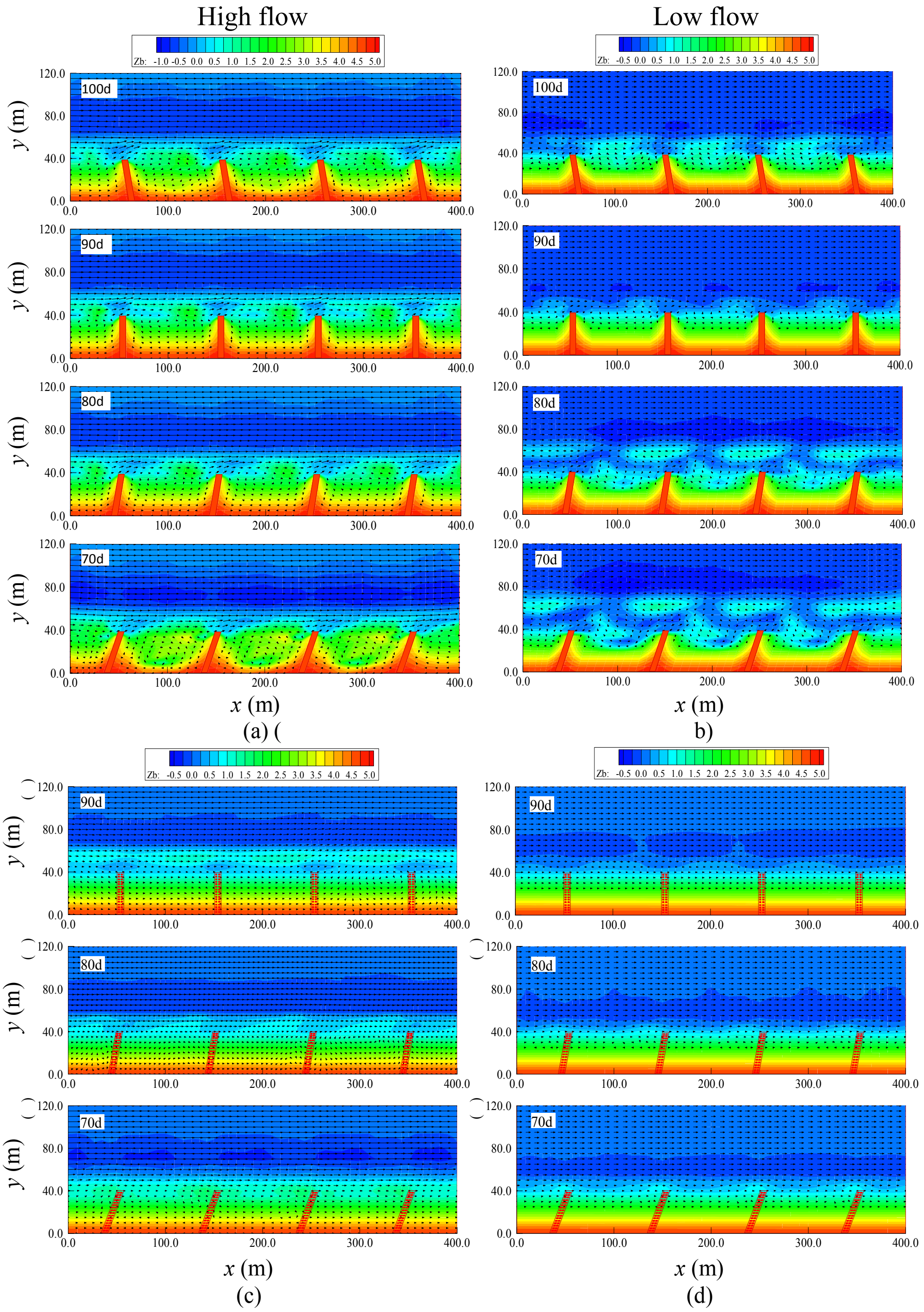


Fig. 5. Velocity vectors and bed contours with various orientations of impermeable (a) high flow and (b) low flow, and permeable (c) high flow and (d) low flow, dykes.

near dykes at high flow condition. The amount of flow diversion and flow reduction towards the main channel and the bank side, respectively, depend mainly on permeability of the structure. So, the permeability should be optimized considering these factors.

Morphological Changes

In case of impermeable dykes with high flow, bed-changes are almost identical [Fig. 5(a)], except that impact of larger-angled dykes is higher at larger distance and vice versa, corresponds to the velocity profiles [Fig. 4(a)]. At low flow condition, channel erosion is observed higher for smaller-angled dykes [Fig. 5(b)], though some irregular patterns of channel bed are formed near dyke-region; may be, this is the reason of getting thalweg at larger distance. This is also advantageous in sense of wave-effect from water-vehicles, which creates an additional outflow velocity and transports sediment out from the dyke-field. Similar results are also observed in case of permeable dykes, where smaller-angled dykes favor deeper channels [Figs. 5(c and d)].

All sets of the simulated and averaged data of the middle region of dykes (between second and third ones) for the parameters: erosion in channel bed (ΔZ_{ch}), distance of thalweg (Y_{ch}), deposition in the dyke-fields (ΔZ_{df}), and scour depth near dykes (ΔZ_{d}) are summarized in Table 1, to compare the performance of dykes for various alignments.

Table 1. Average values of the parameters

Dyke alignment	Parameters		High flow (Q_h = 2600 m^3/s)		Low flow (Q_l = 650 m^3/s)	
			Impermeable	Permeable	Impermeable	Permeable
100^0	Main channel	ΔZ_{ch}(m)	-0.66 -		0.21	
		Y_{ch}(m)	81.0 70		.0	
	Dyke-field	ΔZ_{df}(m)	0.37 0		.13	
	Scour near dyke	ΔZ_{d}(m)	-0.28 -			
		X_d, Y_d (m)	150.0, 50.0		-	
90^0	Main channel	ΔZ_{ch}(m)	-0.64	-0.30 -	0.20 -	0.05
		Y_{ch}(m)	80.0	78.0 6	3.0 67	.0
	Dyke-field	ΔZ_{df}(m)	0.34	0.15 0	.14 0.	07
	Scour near dyke	ΔZ_{d}(m)	-0.25 -		-	-
		X_d, Y_d (m)	153.0, 50.0	-	-	-
80^0	Main channel	ΔZ_{ch}(m)	-0.67	-0.34 -	0.30 -	0.08
		Y_{ch}(m)	78.0	74.0 8	0.0 62	.0
	Dyke-field	ΔZ_{df}(m)	0.28	0.16 0	.12 0.	07
	Scour near dyke	ΔZ_{d}(m)	-0.16 -		-	-
		X_d, Y_d (m)	165.0, 48.0	-	-	-
70^0	Main channel	ΔZ_{ch}(m)	-0.73	-0.39 -	0.32 -	0.12
		Y_{ch}(m)	76.0	72.0 8	5.0 62	.0
	Dyke-field	ΔZ_{df}(m)	0.15	0.13 0	.08 0.	05
	Scour near dyke	ΔZ_{d}(m)	-0.10 -		-	-
		X_d, Y_d (m)	180.0, 48.0	-	-	-

These data (Table 1) are also presented with Figs. 6(a-f), where the variation of the variables against various dykes is clearly visible. This is observed that depth of scour near dykes is not significantly high; this may be the influence of the neighboring dykes, and only noted for high flow and impermeable dykes. Erosion in channel bed is observed higher for impermeable dykes as that for permeable ones and also significant difference in erosion is observed for different dyke orientations, even at low flow time [Figs. 6(a and d)]. At high flow condition, deeper channel is formed at larger distance correspond to larger-angled dykes, but it is differing at low flow time due to formation of some bed-irregularities near dyke regions [Figs. 6(b and e)]. Aggradations in the embayment regions with impermeable dykes are observed higher for larger angles, but this trend is not apparent with permeable dykes [Figs. 6(c and f)]. Fig. 6(c) also shows the variation of scour depth near impermeable dykes at high flow condition, where lower values are evident for smaller angles.

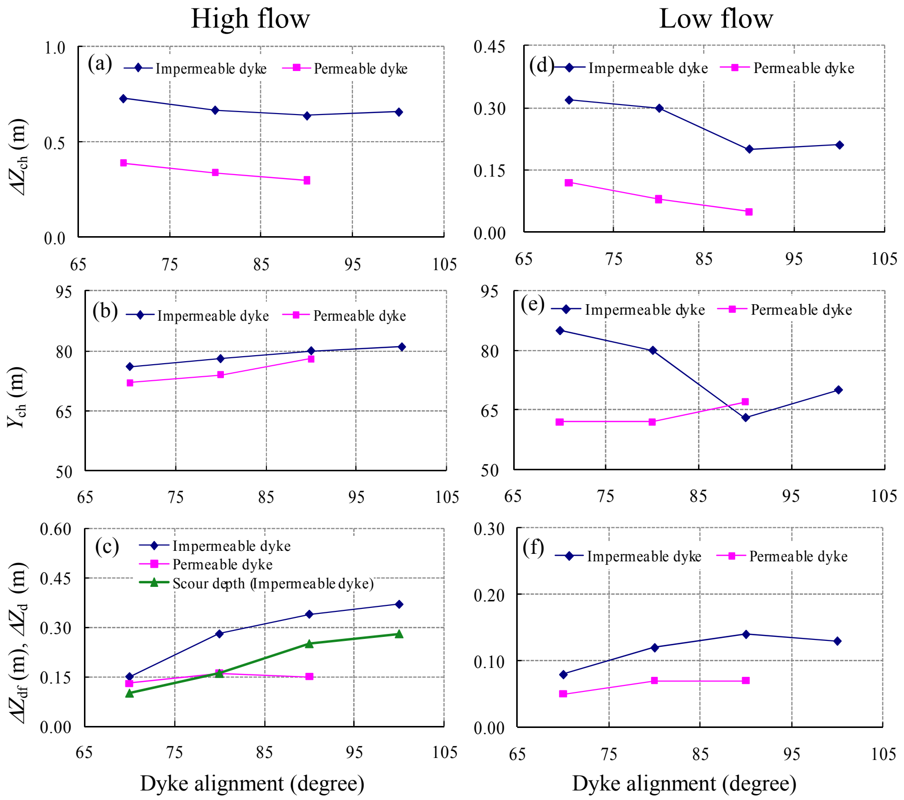


Fig. 6. Changes of variables: (a,d) erosion in channel bed (ΔZ_{ch}); (b,e) location of thalweg (Y_{ch}); (c,f) deposition in dyke-field (ΔZ_{df}) and scour near dykes (ΔZ_{d}) (high flow, impermeable) at high flow and low flow, with dyke alignments.

CONCLUSIONS

This study was conducted to test the performance of dykes installed in a series with different orientations to find one which will function effectively at high flow and low flow both. The conclusions drawn from simulated results are summarized in the following points.

1. Erosion in channel bed was observed higher with smaller-angled dykes for impermeable and permeable dykes both, even this was apparent at low flow condition.
2. The location of thalweg was closer to the dykes of smaller angles except low flow (impermeable) case, due to formation of some sand-bars near dykes.
3. For the dykes of larger angles, higher deposition was observed in the dyke-fields for impermeable dykes, but it was not obvious for permeable dykes.
4. Depth of scour near dykes was considerably reduced for smaller angled dykes.

Here smaller angled dykes are functioning better in respect of deepening the channel bed, except deposition near bank is reduced; even near bank erosion is observed at high flow for 70^0 impermeable dykes. Thus the 80^0 aligned dykes can be recommended to optimize the problem of navigation and bank erosion both in sand-bed alluvial rivers.

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