PMO-Flood Control and Sabo Engineering Center
Department of Public Works and Highways (DPWH)

FCSEC
TECHNICAL REPORT

Experiment on the Effective Arrangement of Spur Dikes as Countermeasure Against Bank Erosion Using Simplified River Model

Jesse C. Felizardo, Engineer IV
Harold N Uyap, Engineer III
Wataru Sakurai, JICA Expert

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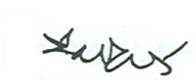
MESSAGE

The DPWH hydraulic laboratory, which was completed in 2003 through the JICA grant aid, opens its door to research initiatives in the field of flood control and sabo engineering. Initial trainings in the hydraulic principles, familiarization and operation of the facilities and equipment have been going on for more than a year now.

The staff of FCSEC with the support of the JICA experts was able to assimilate the techniques of river modeling in the initial attempt to simulate Badoc River in line with the planning and design of appropriate countermeasures. This paper serves as preliminary report of the studies accomplished in the laboratory.

It is our hope that this effort will further the understanding and the skills of the engineers in planning and design of flood and erosion mitigation countermeasures.



RESITO V. DAVID, MNSA
Project Director

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Abstract:

In the Philippines, planning and design of spurdikes are based from the technical drawings and plans of previous projects and lately from the duly formulated Technical Standards and Guidelines for Flood Control Projects. To simulate the effect of spurdike before applying in the actual field conditions and partly to verify the content of said manuscript, experiment was conducted using a scaled down model of Badoc River in the Northern Philippines. To supplement the insufficient data required in making river model, satellite images were downloaded and processed using GIS software. The alignment and width of the target river segment were laid out on the flume and overlaid with sediment samples which will have the same hydraulic effect with the actual river. The bedform of the actual river was reproduced on the flume as a result of the water discharge. The provision for length of the formulated technical standards in the experiment did not give ideal result. Arranging the spur dikes according to the flow lines of the river, thus necessitating variations in the length of spur dikes and orientation, has controlled the scouring, deposition of the sediments and deflected the flow towards the center of the channel.

Key Words : Spurdikes, length, alignment, flow line, scour, simplified river model

Introduction

Spur dikes are one of the most popular countermeasures against river bank erosion, especially in Northern Luzon, where the planning and design are derived from the technical drawings and past experiences. Design criteria were formulated from the documented foreign experiences for flood control in the Project for the Enhancement of Capability of DPWH Engineers in the Field of Flood Control and Sabo Engineering (ENCA), However, limited pages were only devoted for spur dikes, which may not be sufficient to have intensive planning.

Spur dike has no absolute standards. The characteristics such as position, length with respect to river width, orientation, height and width are determined empirically. Observation of the actual river hydraulic conditions is required for effective planning and design of the spur dikes, where inadequate river and hydrological information becomes constraining factor. It is because the engineers could not perform cross-sectional survey due to limitations in the instruments and other resources.

As alternative, hydraulic laboratory experiment is necessary to simulate river phenomena. Modern means to acquire river information are available with the aid of various software and satellite images. Out of these, the physical characteristics of prototype rivers can be replicated in the laboratory and scrutinized and verified through hydraulic experiment and later in the actual site conditions.

Background Information

One of the rivers visited by the team for the preparation of the On the Job Training Curriculum under Project ENCA was Badoc River in Ilocos Norte, approximately 30 km south of Laoag City. Preliminary site investigations focused on selected river segment prone to frequent bank erosion.

Badoc River has drainage area of approximately 200 km^2. The river course meanders due to sedimentation at the target site and bank erosions affect the adjacent

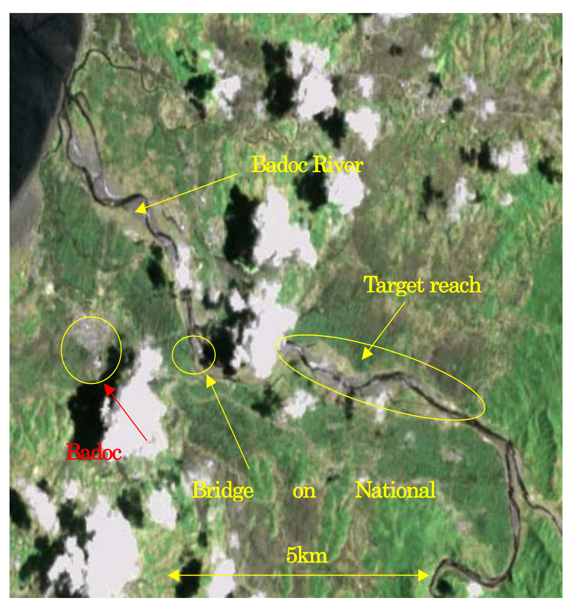

Figure 1 The target area in satellite image

barangay road and agricultural fields (Fig.1,2). To protect from further damages, gabion spur dikes were constructed along the river but ineffective due to insufficient

Figure 2 River condition of Badoc River

Figure 3 Damaged spur dike

length and required number (Fig.3). To reduce the damage wrought by the uncontrolled hydraulic river conditions, proper countermeasures are required. As an initial step, experiment was conceived to verify and understand hydraulic conditions in the scaled down model in preparation for planning of spur dikes in the actual river

However, the only available information were NAMRIA 1:50,000 map, site photos, river channel gradient equivalent to 1/600, sediment size ranging from 1mm to 15mm composing of sand and gravel and the flood level. The depth of the water reckoned from the past maximum flood was determined from site interview. The bed material was assumed to have a mean diameter of 15 mm. The value of manning's n was deemed equivalent to 0.035, the river width has an average of 200 m and the past largest flood depth of the river was approximated to be 3 m, where the estimated velocity was 2.4 m/s and the discharge was 1,500m^3/s.

Objectives of the experiment

1) To determine the effective arrangement of spur dikes on preventing bank erosion by controlling flow pattern in a meandering river channel using movable bed experiment

2) To prepare an easy-implementing method on movable bed experiment despite limitations on the river information.

3) To verify the provisions and limitation of the sections in technical standards and guidelines developed by the Project ENCA which deals with the spur dike

Methodology

<u>Estimation of planned shape of the river</u>

Landsat satellite images dated year 2000 from website http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp, and from SRTM 90 m grid DEM, where the picture of the alignment and extent of the river system were taken, compensated the deficiency of detailed information of the river. Kashmir 3D, free software from http://www.kashmir3d.com, converted the image to higher resolution color and then the resulting distorted image was modified by Manifold GIS software (http://www.manifold.net.).

From the image, the river bank lines assumed the boundary of the dense vegetation and the non-vegetation zones as referred to in the site photo (Fig.4). From the GIS, the x-y coordinates of the bank lines were calculated and exported to Excel and laid out on the wide flume according to the planned scale (Fig.5).

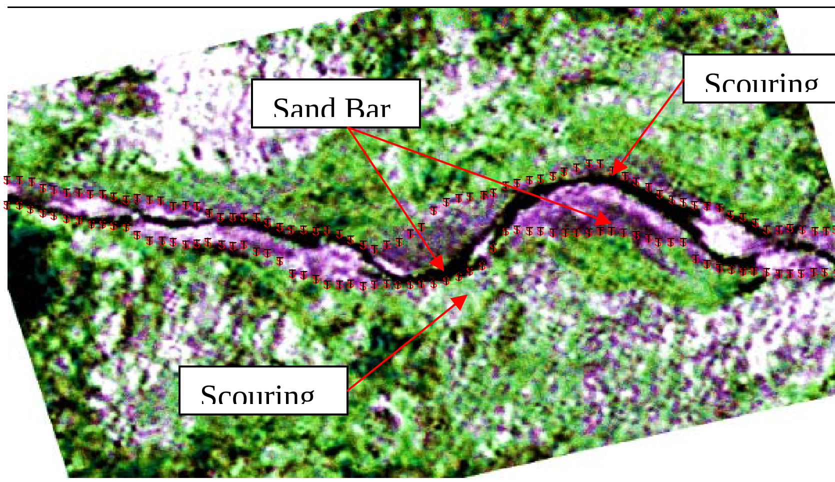

Figure 4 Badoc River Satellite Image

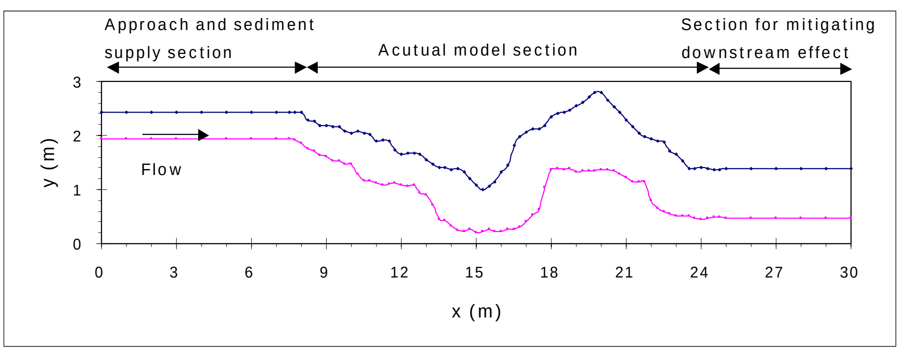

Figure 5 Laid out with coordinates

The Experiment Condition

The river model was laid out on the wide flume (L30m x W3m) in the laboratory at horizontal scale of 1/100 according to the capacity of the flume and the vertical scale at 1/200 enough to reproduce similarity of sediment transport parameter with the prototype, represented by τ^*, (u_{*c}/ u_*), (u_*/w_0) and Re^*, The ratio of the model to the prototype was between 0.8 -1.2. Table 1 shows parameters of the condition. Figure 6 depicts the regimes related to sediment transport for the proto type river and some selected models of past experiences as confirmatory tool between the proto type and the model.

The past maximum flood was $1500m^3/s$. Since the hydrograph could not be reproduced due to lack of field data, discharge was set at steady flow of past maximum flood.

Due to the limitation of the available suitable material commonly used for experiment, lahar material from Mt. Pinatubo was applied (Fig.7). It has mean diameter of 0.45mm with specific gravity of 2.5.

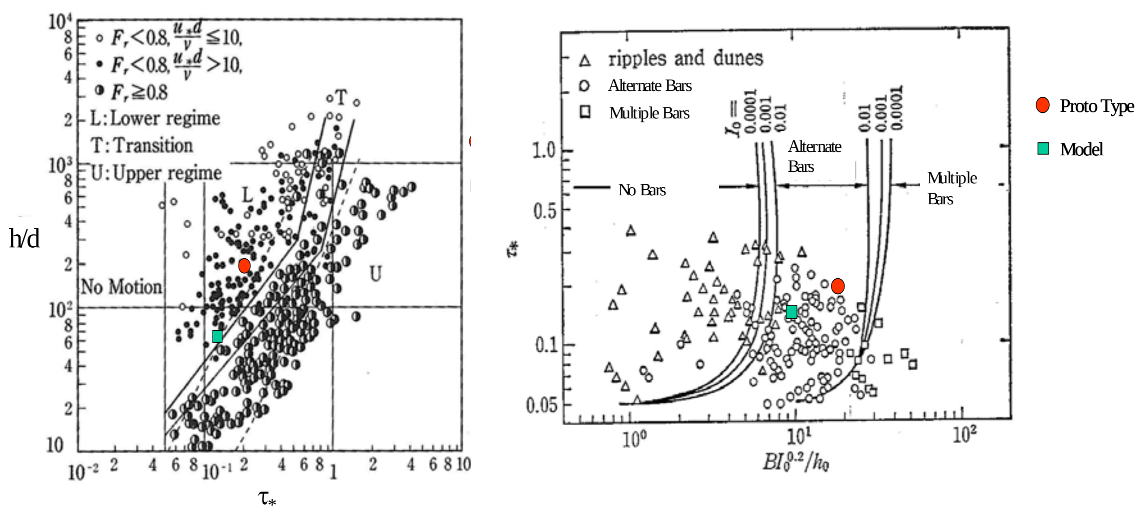

Figure 6 Regimes

Table 1 Experiment Hydraulic Condition

Item	Condition	Proto Type	Model Scale	Remarks
			H 200	
			V 100	
Length of Channel	L(m)	5,000	25	
Width of Channel	B(m)	200	1.0	
Diameter of Bed Material	d (m)	0.015	0.00045	
Water Depth	h (m)	3.00	0.030	>0.03
Manning Coefficient	n	0.035	0.023	
1/(Energy Gradient)	1/I	600	300	
Energy Gradient	I	0.00167	0.00333	
Velocity	V(m/s)	2.426	0.243	
Discharge	$Q(m^3/s)$	1,456	0.0073	
Froude Number	Fr	0.45	0.45	
Specific Gravity of Bed Material	σ	2.64	2.5	
Submerged Specific Gravity of Bed Material	σ-1	1.64	1.5	>0.4
Shear Velocity	u_*(m/s)	0.221	0.031	
Shields Parameter	τ^*	0.203	0.148	
Shields Parameter Ratio	τ^*r	―	1.37	0.8 - 1.2
Critical Shear Velocity	u_{*c}(m/s)	0.110	0.016	
(Critical Shear Velocity) / (Shear Velocity)	u_{*c}/u_*	0.50	0.51	
(Critical Shear Velocity) / (Shear Velocity) Ratio	$(u^*c/u^*)_r$	―	0.97	0.8 - 1.2
Falling Velocity of Bed Material	w_0(m/s)	0.40	0.056	
(Shear Velocity) / (Falling Velocity)	u^*/w_0	0.55	0.56	
(Shear Velocity) / (Falling Velocity) Ratio	$(u^*/w_0)_r$	―	0.99	0.8 -1.5
Grain Reynolds Number	Re*	3698	15.7	>20
(Water depth) / (Diameter)	h/d	200	67	
Non-dimensional Parameter related to Bar	$BI^{0.2}/h$	18.5	10.7	

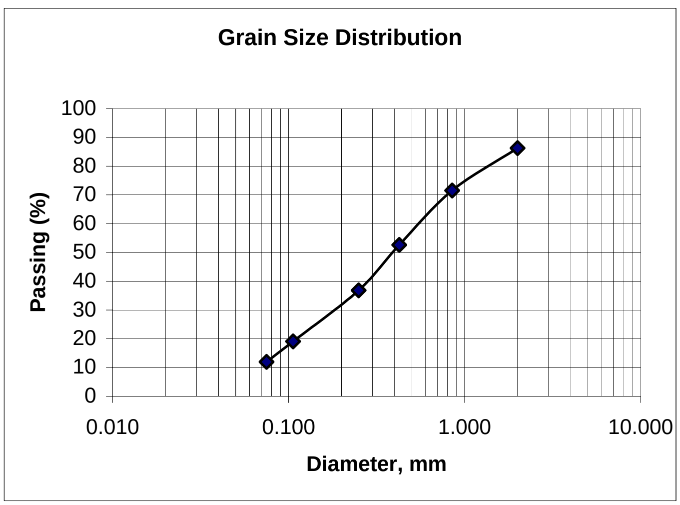

Figure 7 Grain Size Distribution

<u>Type of Spur Dike Used</u>

The Spur Dikes are designed as follows

1) Type: Boulder type "Type II"
2) Alignment: Perpendicular to the bank line
3) Dimensions: Length =20m (10% of average width of the river)
   Crest=2m
   Height=1m (33%of flood level)
4) Spacing: Spacing=30m (1.5 x Length)

Spur dike conditions are derived from the Technical Standards and Guidelines for Flood Control, under Project ENCA.

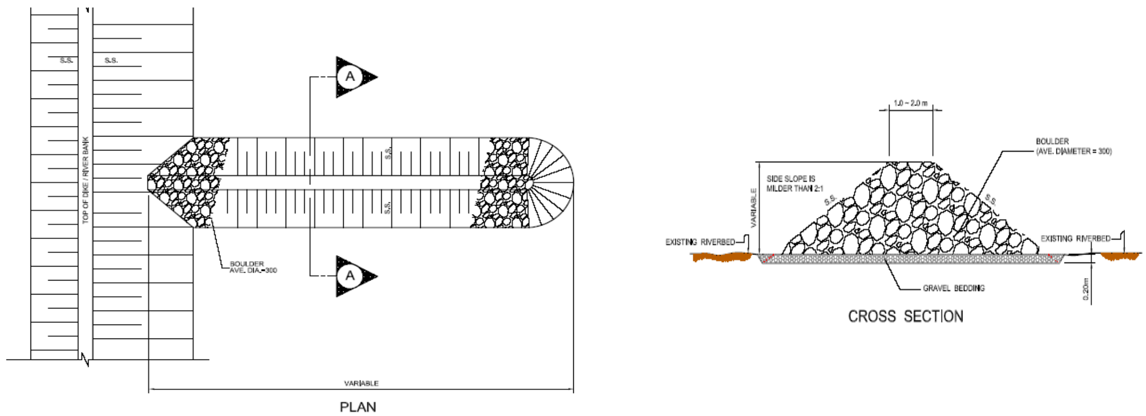

Figure 8, Boulder type "Type II"
Source : Typical Standard Drawing, Project ENCA

30 pieces of spur dike wooden model fixed underneath by steel plates to withstand the discharge (Figure 9) were prepared.

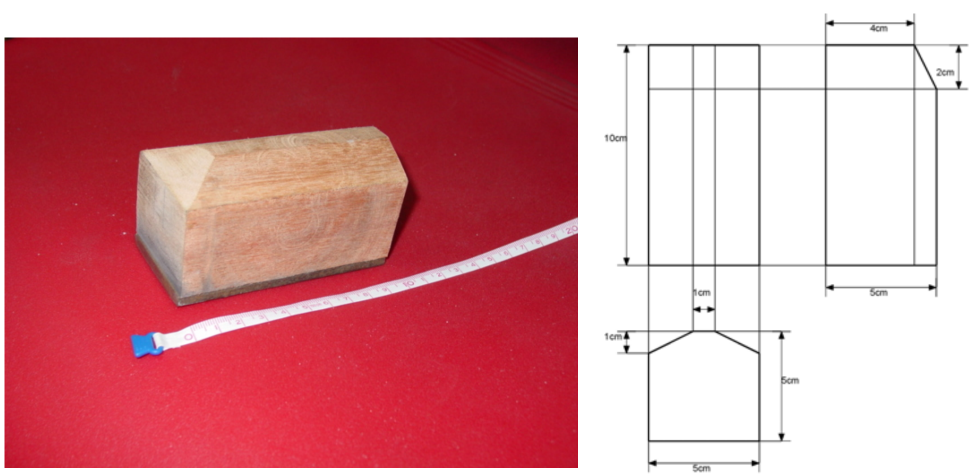

Figure 9 Spur Dike Model

<u>River Model</u>

The river model was constructed using pieces of 1m×0.2m galvanized sheet plates sides fastened to 0.05 m x 0.05 m wooden posts (Figure 10). The plates were aligned on the riverbank lines per coordinates derived and staked out on the flume as shown in Figure 10. This technique made possible the horizontal outlining of the river model on the flume without the benefit of the detailed cross-sectional data.

River shape, sand bar and scoured portions caused by meandering and other factors can be replicated, however, not all the detailed shape of the river.

The river model was then filled with 10 cm lahar from the upstream to the downstream as bed materials.

Figure 10 The River Model (Parts and Panorama)

Measurement

The target area for measurement was within the station limit from stations 2 +000 to 3+000 (Fig 11). Water velocity and riverbed elevation were measured every 20-30 cm cross section with 10 cm interval.

Experiment cases

All cases were tested as described below on November 2004 at the DPWH Hydraulic Laboratory with the participation of staff from Planning Service, PMO-Major Flood Control, Bureau of Design, Bureau of Construction and Bureau of Research and Standards.

Preliminary Experiment

The preliminary experiment was designed to verify if the model can reproduce the scouring and erosion pattern which occurred in a proto type river and to observe the flow condition which would serve as basis for the necessary countermeasures to be introduced in the flume.

Case 1

The spur dikes were arranged according to the perceived best location in the attacked zones, usually the bends of the river and the immediate downstream opposite bank. The fabricated sample blocks had only one length limiting only one spur dike length throughout the target channel stretch. Please refer to Figure 12, Arrangement of Spur Dikes Case 1.

Case 2

At the right bank, the spur dikes were placed not on the severely scoured area but on the farther upstream with assumption that the flow would be diverted from the attacked zone to the center. At the left bank, arrangement comprised three spur dikes at the attacked zone and on the severely scoured portion, arrangement was increasing length and oriented a little upstream with assumption that the flow would be diverted towards the center of the flume. Set conditions ignored the Technical Standards and Guidelines and limited the number of spur dikes. Please refer to Figure 13, Arrangement of Spur Dikes Case 2.

Case 3

Basing from the results of Cases 1 and 2, the final arrangement of spur dikes were on the attacked zone with gradual changes in the alignment and the increase in the length of spur dike following a smooth flow line. Similar assumption was applied to the right and downstream left bank.

Experimental Results and Analysis

Preliminary Experiment

Figures 4 and 11 show the similarity of the outline of river course with the prototype river after allowing water discharge to flow in the flume after two hours. The concentration of water, in green color, flowed directly to the attacked zone after station 2+800 and veered to the opposite bank at station 2+400. Sand bars deposited on the inner bends and scouring occurred on the outer bends as seen on the figure below. The position of scouring and sand bar were almost similar to the Badoc River, which proves that the riverbed form, like sand bar and scoured portion due to river shape, can be reproduced in a simple river model.

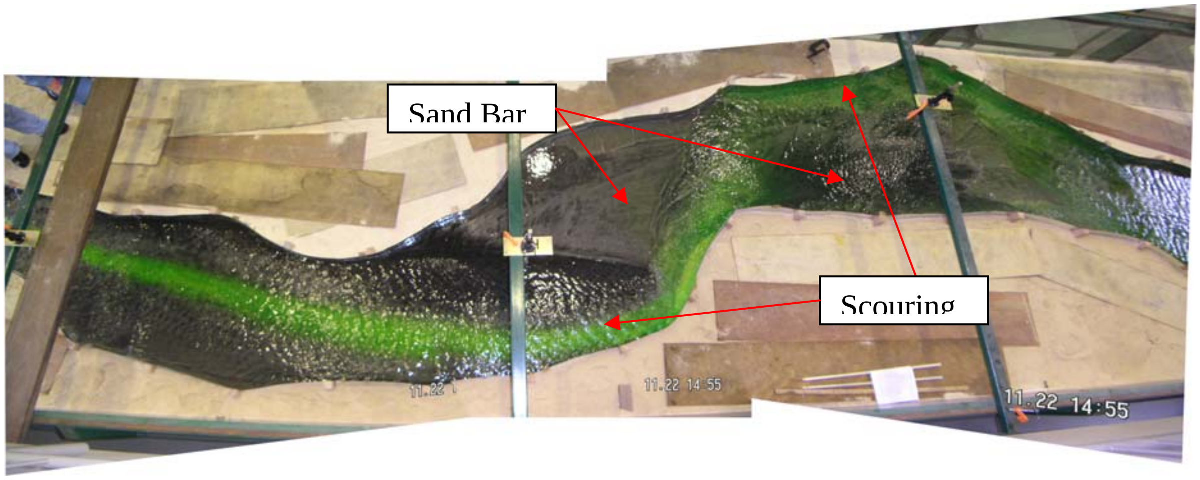

Figure 11, Preliminary Experiment

<u>Case 1</u>

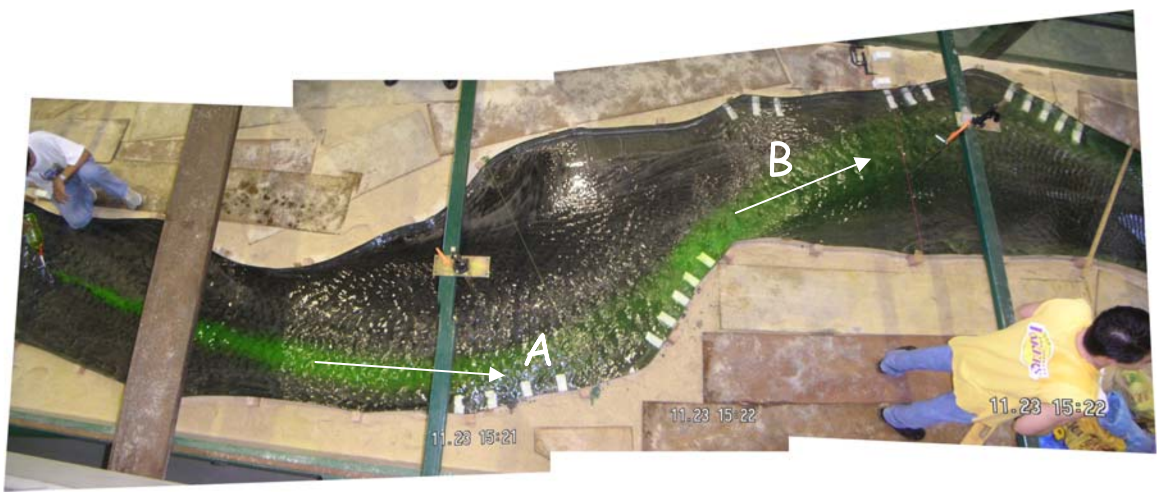

Figure 12, Arrangement of Spur Dikes Case 1

Referring to Figures 11 and 12, comparing with the no spur dike case, the flow pattern indicated by green color, shows the direction moved toward the bank (arrow A), which indicates that the direction was not diverted. However, there was a change in the downstream flow (arrow B), which was prone towards the center and somewhat away from the bank, especially at the attacked zones but not sufficient to counter the scouring.

After analyzing case 1, the longer spur dikes, which exceeded the limit of 10 % of the channel width as provided for in the technical standards, were applied in the attacked zone. For experiment purpose this provision was set aside to find out the better arrangement.

Also, the location, alignment and arrangement of spur dikes were modified in the succeeding case in view of the flow line and the bank line.

Case 2

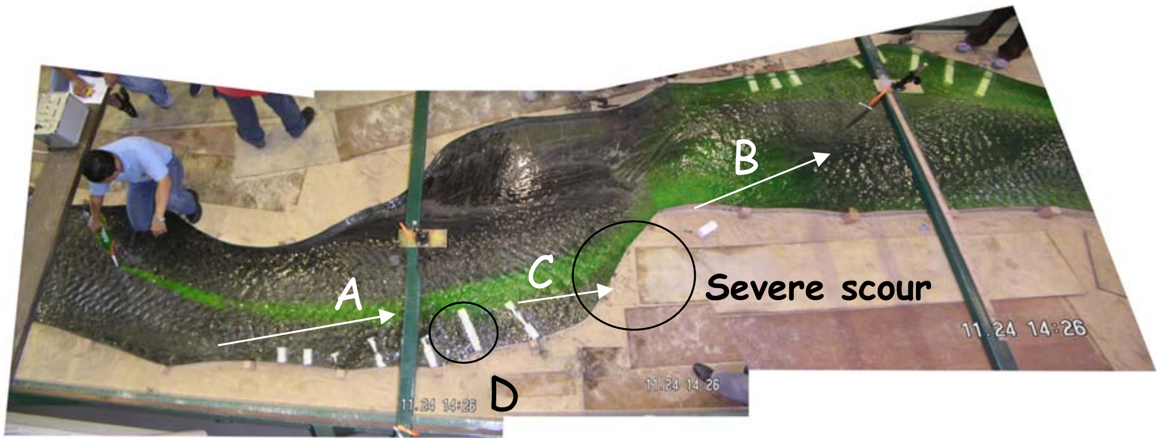

Figure 13, Arrangement of Spur Dikes Case 2

As the spur dikes were placed further upstream from the attacked zone on the right bank and gradually elongated downstream, the flow had significant change. Flow was diverted away from the bank (arrow A). However, in the segment where there was no spur dike, the flow was directed toward the area before the constricted portion, see the encircled area at the tip of arrow C, where there was severe scour.

After the constricted section, there was no significant change in flow direction at arrow B as compared to case 1.

At point D, local scouring at the tip end of the spur dike was great due to higher velocity caused by abrupt change of spur dike length. Changes in the length after the first three spur dikes were abrupt where the flow line was ignored. The alignment and length should be smoothly adjusted according to the flow line which required placing of spur dikes in the directly attacked area rather than merely diverting the flow away from the bank.

Case 3

Among all the cases after adjusting the alignment and length of the spur dikes in consideration of the smooth flow line, Case 3 has achieved the desired result. Further improvement was necessary at the most constricted section by providing additional protective works. Please refer to Figure 14, Arrangement of Spur Dike Case 3, at arrow A direction, the flow line was almost similar to case 2, considered as effective. At arrow B direction, water flow was smoother and straighter and less meandering than that of case 2. The spur dike at arrow C could divert water flow away from the right bank, and there was minimal scour at point D.

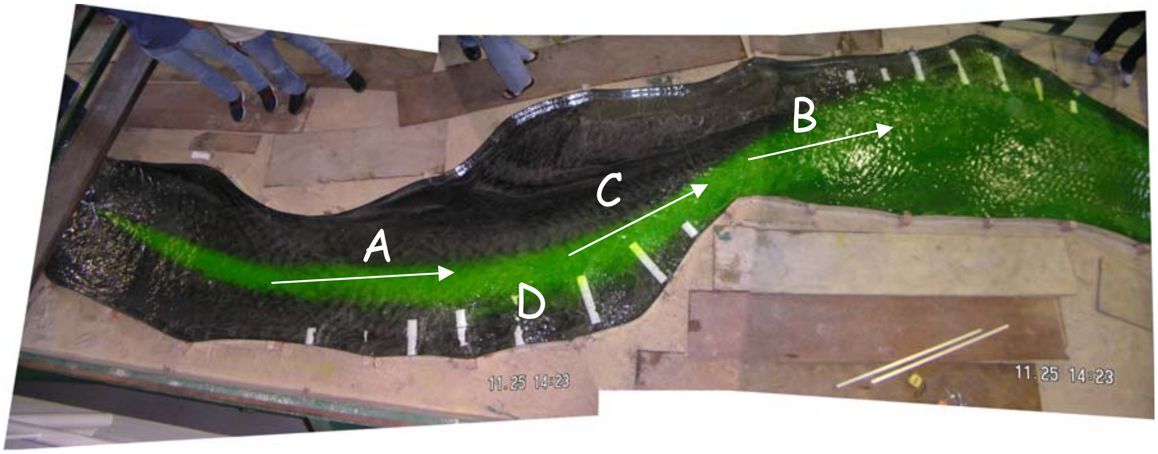

Figure 14, Arrangement of Spur Dikes Case 3

<u>Water Velocity and Bed Elevation at Stations 2 + 700 and 2+200</u>

Water Velocity and bed elevation were measured at different sections of the flume especially in the target area. Water Velocities were measured during the high stage of water discharge and the bed elevations were measured.

Stations 2 +700 and 2 + 200 were the locations of expected severe scouring since they were in the attacked zone. Comparatively shown below are the results of all the cases.

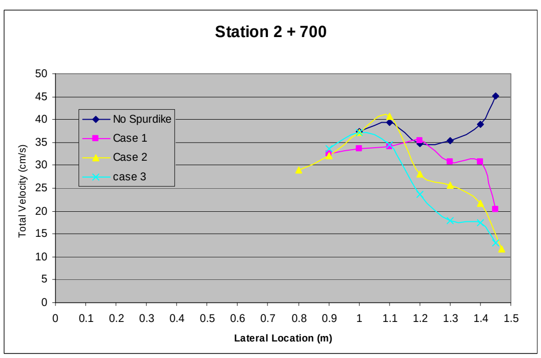

Figure 15, Velocity at 2 +700

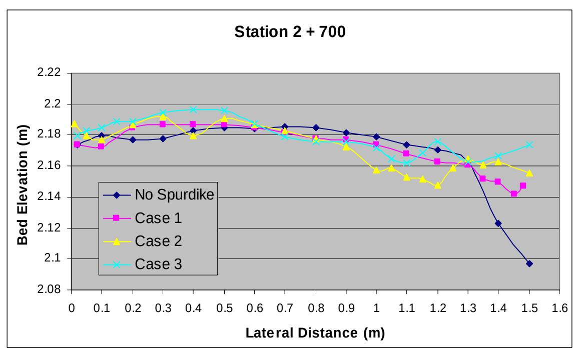

Figure 16, Bed Elevation at 2 +700

Regarding station 2+700, the velocity of case 1 along the right bank was half of the no-spur dike case. Peak velocity was diverted 1.2 m away from the right bank. The scoured depth in between 1.4 - 1.6 m was greatly reduced compared to no-spur dike case. In the incident where the riverbed was lowered to 3 cm, spur dikes were difficult to maintain.

In case2, as the spur dikes were elongated, the velocity along the right bank were reduced equivalent to one fourth of the no-spur dike case. Effect of spur dikes shows the velocity peaked at 1.1 m obviously farther right than case1 and was almost the same with the no-spur dike case. Because the spur dike was elongated, section where velocity was lower than that of the no-spur dike case was longer than that of case1. The scoured depth along the right bank was smaller than that of the no-spur dike case, however, the bed from points 1.1 m to 1.2 m where the velocity was fastest has heavy scouring. Its elevation was 2 cm lower than that of the no spur dike case, 4 cm lower than that of left bank where there was no scouring.

In case3, the peak velocity appeared at 1.1 m, the closest to the center of the river course among all the cases. Furthermore, the velocity distribution formed gentler curve than that of other cases, the rapid change of velocity did not appear. The riverbed elevation at 1.1 m where the velocity was fastest was 2 cm lower than that of the left bank, but the riverbed elevation at the end of the right bank was almost the same to that of the left bank. This means that the result of case3 was the most effective.

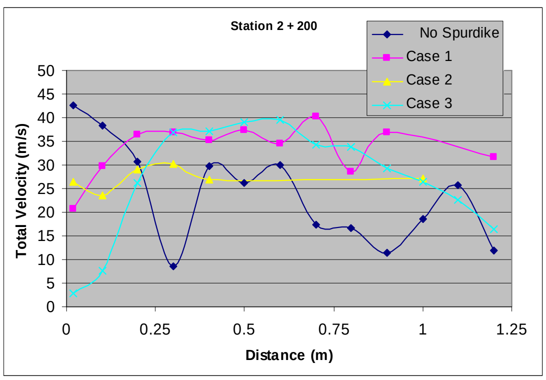

Figure 12, Velocity at 2 + 200

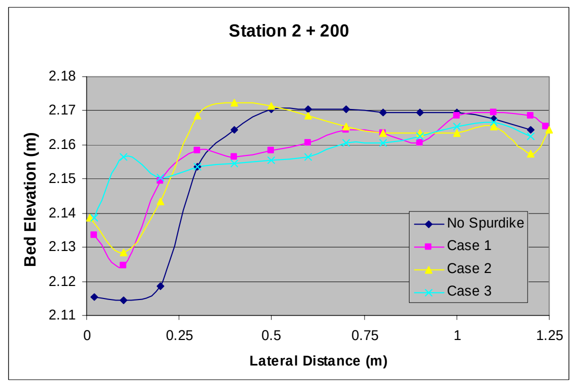

Figure 13, Bed Elevation at 2 + 200

Just right after the bend, the flow moved directly to the opposite bank at station 2+200, now the attacked zone. The graph shows the tendency was almost the same to that of station 2+ 700.

It can be noted that the longer spur dikes and gradual changes of spur dikes length following smooth flow line is very effective.

The flow analysis using the digital videocam, Figure 14, shows the velocity distribution in the channel in a grid sections using velocity vector field or Particle Image Velocimetry. The color intensity corresponds to the velocity rate of the water as it passes the video camera. The intensity of color changes according to the velocity of the flow; the darker the color the faster is the velocity, the lighter the color the slower is the velocity. Near the boundaries and in between spur dikes, velocity dissipated greatly as compared to the flow near the center. High velocity is concentrated away from the tip of spur dike towards the center of the channel. In effect, the reduced velocity has lower tractive force to transport sediment downstream which in turn kept the bank protected.

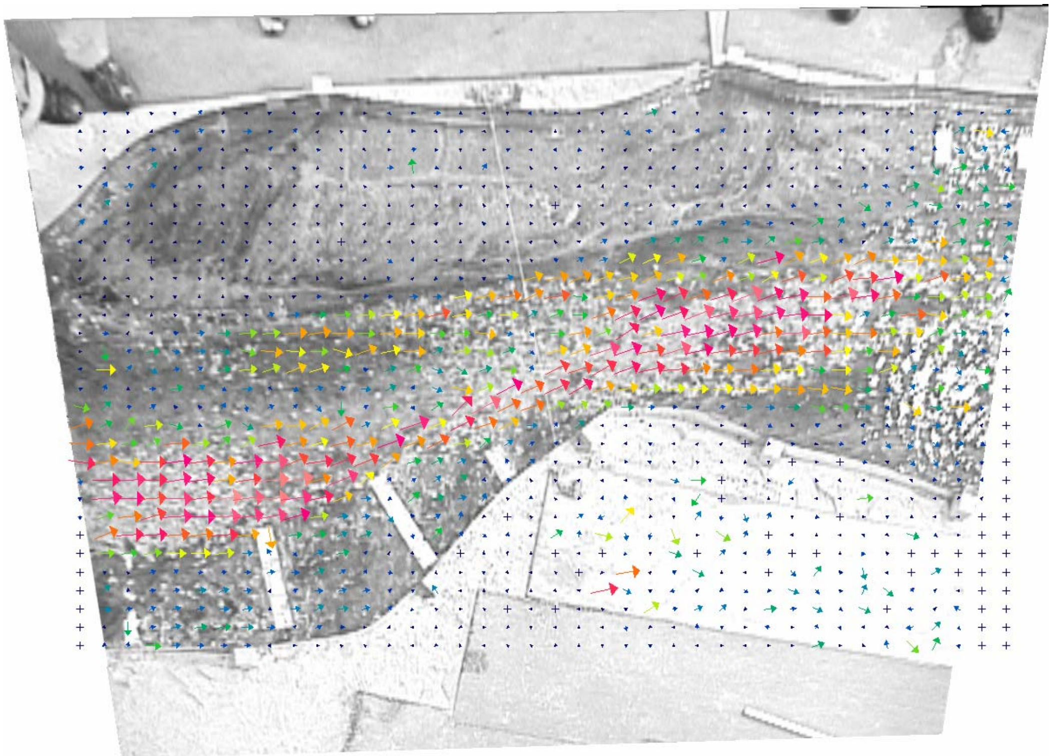

Figure 14, Velocity Distribution

Conclusion

The results of the experiment can draw some important conclusions in the planning and design of spur dikes.

- The river hydraulics, sand bar formation scour and the flow patterns should be considered in without and with countermeasures cases.
- The variations in the length and alignment of spur dikes should follow the smooth flow line.
- The "Simplified River Channel Model Test" reproduces overall bar development scenario, associated scour and deposition pattern similar to the actual river. This modeling is effective alternative to examine the change of flow and bed pattern caused by spur dike. It is a powerful tool and yet cost-effective.

On the provisions on the Technical Standards and Guidelines TSG, the following are established.

- Flexibility in the length and alignment of spur dike should be observed instead of the specific provisions for the length and the orientation of spur dikes according to river condition (see pages 118 - 123, Volume I, Flood Control, Technical Standards and Guidelines).

- Gradual alteration of spur dike setting in length and alignment effectively controls the flow pattern efficiently and minimizes the local scour. Flow pattern and sand bar associated with spur dikes should be always considered.

Recommendation

The Philippines experiences economic difficulties affecting its infrastructure development. Funds for the flood control projects come in trickles, thus, greatly affecting its implementation resulting to ineffective countermeasures leading to frequent damages to structures per se. With this predicament, spur dikes are recommended to be constructed phase by phase according to plan in a river segment in a yearly basis governed by the following.

- Construction of spur dikes can be started from the upstream in the section where scouring is not severest. This will ensure that during heavy floods, the spur dike will sustain and not be washed away by the high velocity. Then, gradually the spur dike construction progresses from the low to high severe scoured zones.

- In the high priority area prone to heavy scouring and erosion, the spur dikes may be constructed initially shorter than planned and then gradually lengthen according to plan in the succeeding budget years to provide emergency or immediate protection.

Acknowledgement

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- Marites Quimpo — Engineer III

Bureau of Design

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PMO-Major Flood Control Projects Cluster I

- Celerino V. Cruz   Engineer III

PMO-Major Flood Control Projects Cluster II

- Rose Abegail G. Calma   Engineer I

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