PAPER NO.439

DESIGN OF EARTHEN DIKES

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By

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1.0 INTRODUCTION

A proper design of spur dikes is of utmost importance when dealing with river training and channel stabilization problems. The purpose of this paper is to present a state of the art of the subject. In para 2 spur dikes in general have been dealt with whereas paras 3 and 4 cover only earthen spur dikes.

Literature published from 1960 to date has been carefully reviewed and a bibliography is given at the end. Earthen spur dikes are very commonly used in Indo-Pakistan sub-continent for river training purposes. Therefore special reference has been made at some places in the paper about the common practices in use in the region.

2.0 SPUR DIKES

2.1 Definition of Spur Dikes

In river mechanics, spur dikes are defined as dikes placed laterally from the river banks. Sometimes they are termed simply as dikes. Spur dikes to highway engineers, have acquired a special meaning because of their localized interest with rivers. In highway engineering, spur dikes are guide banks placed at or near the end of approach embankments to guide the stream through the bridge opening. In Pakistan and India they are simply referred to as spurs where they essentially mean, unless otherwise specified with a prefex, as an earthen embankment or dike projecting into river bed from a high marginal bank, provided with an impregnable armoured head for training a river stream. They are named as mole- heads, T-heads, hockey heads or inverted hockey according to the shape of impregnable heads.

2.2 Uses of Spur Dikes

The specific purposes for which spurs may be used are:-

i) To train river above diversion headworks in

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favourable position and approach and stablize the course.

- ii) To protect lands, property, town, flood protection embankments from river erosion.
- iii) To reclaim land.
- iv) To fix lower limits of confluence of a tributary system with the main river.
- v) To prevent the erosion of road embankments.
- vi) To direct the flow into a constricted bridge waterway opening.

2.3 Principal Types

Spur dikes can be broadly classified as permeable and impeseable.

2.3.1 Permeable Dikes

The permeable dike depends for its success upon its ability to slow the current over a portion of the channel area and thereby induce deposition of sediment. The accumulation of sediment and the retardation produced by the dike system causes the main channel section to carry a larger proportion of the water than it did in the absence of the dike system, thereby increasing the current and the sediment transport capacity. As a result, a more efficient section and greater depth are maintained in the main channel.

With the usual design a permeable dike on its own reduces the cross-sectional area very little. Thus for full contractional effect it must be accompanied by substantial deposition, most of which occurs downstream from the dike. As this is accomplished principally by slowing of the current in the dike field which causes the water to drop suspended sediment, it is evident that a permeable dike will be most efficacious on a stream where the velocity is sufficient to carry coarse sediment fractions that can be induced in deposit by a moderate reduction in velocity and in which a substantial load of such sediment is present.

Following are some of the permeable dikes in common use:

2.3.2 Timber Pile

Timber pile dikes of various designs have been used from single pile in line, single pile staggered, to single row clumps and multiple row clumps. The design selected depends on the depth of the stream and the voilence of the attack to which the dike will be subjected, and the spacing of the piles or clumps may be varied from one project to another in accordance with the quantity and the character of the sediment transported.

2.3.3 Steel Jetties

The purpose of the steel jetty is solely to add roughness to a channel or overbank area, and thereby either deflect eroding current away from the bank, levee, or structure or cause base formation within the jetty field and thereby contract the channel to the desired width . Development of vegetation on these bars enhances the action of the system by protecting the deposits from erosion and increasing the rate of further deposition.

Steel jetties have been constructed in various configurations. The most common units of which steel jetties are composed are the steel jacks and steel tetrahedrons.

2.3.4 'Killa'-Bushing Spurs:

This type of permeable spurs are very commonly used in the Indo-Pakistan sub-continent. This spur essentially consists of two or more rows of wooden logs,mostly bamboos, driven into the channel bed oriented at right angles to the banks. They are tied together with steel wires or thin ropes. The spacing in between is filled with brushwood obtained from nearby plantation. This brushwood may be loaded with stone, stone filled crates, sand filled gunny bags etc. River training with this type of spurs has been tried in the above mentioned region with more or less success. They are built across the current and scour takes place along them into which brushwood settles. The brushwood is replenished regularly. The flow downstream is reduced and the sand picked up from the scour is dropped resulting in gradual silting up and progressive reduction of flow across the works. Illustration is given in Fig.1.

Permeable spurs consisting of trees tied to anchors on bank with ropes and weighed down with stone crates are often used for bank protection against erosion with good results.

2.3.5 Impermeable Dikes

Impermeable dikes of many types have been used. Their principal characteristic is that they are constructed relatively tight, so little or no water passes through them. Where used for channel contraction or bank protection purposes they do not depend on the deposit of sand in the dike field to as great extent as do the permeable dikes. Nevertheless sand between the dikes is necessary to make the contraction or protection continuous along the dike field and to reduce the scouring of the banks between the dikes that may be caused by eddies and overtopping flow, unless other measures, such as the installation of L-heads, are taken to accomplish the same results.Impermeable dikes are especially useful where the suspended sand movement is low.

Some of the commonly used impermeable dikes are as follows:

2.3.6 Stone-Fill Dikes

Dikes composed entirely of quarried stone are termed stone-fill dikes.

Fig.9 gives some details of this type of spur.

2.3.7 Stone-Filled Timber Pile Dikes

In many instances existing permeable timber dikes have been converted into impermeable dikes by filling them with stone to increase their effectiveness, either when the timber deteriorated or when the stone transport was found too low for the permeable dike to be effective.

2.3.8 Asphalt Concrete Dike

This type of dike is constructed by placing hot asphalt in water to form underwater portion of a dike. An asphalt dike cannot adjust itself to erosion as can a rock dike, but if it is exposed during low stages it can be repaired at low cost.

2.3.9 Sills

Sills in the bottom of the channel were employed on the Atchafalaya River to forestall further deepening of the river and the accompanying increase of diversion from the Mississippi River. The low-level dikes on the Middle Mississippi are examples of sills placed in an overly deep section to encourage widening of the navigation channel. Sills or submerged spur dikes may have a beneficial effect in regulating and stabilizing the navigation channel when built outward from the convex side of a long bendway.

2.3.10 Earthen Spur Dikes

They consist of an earthen embankment which is invariably protected at the nose with stone-pitching. If the material is mostly sandy it is covered with a protective surface to take the direct attack and prevent erosion and leaching of the sand. This type of dike can only be used where construction is placed above water. It is justified to build earthen dikes only where it would be less costly than a stone or stone-filled pile dike, or, than a permeable pile dike. They are commonly used in Indo-Pakistan sub-continent due to their effectiveness and low cost.

3.0 DESIGN OF EARTHEN SPUR DIKES

3.1 Number of Spurs

A single spur projecting into a river coming under action induces erosion of bank immediately upstream of the spur head and the flow is in a curve. The curvature of flow increases the velocity along the spur nose and erosion is progressive.

A single spur tends to cause severe flow disturbance and deep scour at its outer end. Spur should normally be used in groups and a single spur should normally be avoided where the main current would impinge against it.

3.2 Orientation

When constructed in the form of earth embankments, spurs should generally be pointed upstream so as to create a dead water pond which provides a 'cushion' to prevent erosion of the upstream face. It is then necessary to place protection on the spur nose only.Spurs pointing upstream are termed as repelling spurs or repelling groynes because of the fact that they throw water away from the affected bank.

If pointed downstream to act as flow deflectors, the upstream faces may require protection against erosion along their full length. The angle which spur dikes make with the axis of the current requires careful study. For deflecting strong currents, short spur dikes set at right angles to the axis of the current are generally considered best. The angle of deflection upstream varies from 80° to 60° with the bank or 10° to 30° with a line perpendicular to the thalweg.

3.3 Spacing between Spurs

The location i.e. whether at a concave or a convex bank, or at a crossing affects the spacing of spurs. A larger spacing can be adopted for convex banks and a smaller one for concave banks, with intermediate spacing at the crossings. A spacing of 2 to 2½ times the length of groynes is found suitable where only a few spurs are required. This is due to the reason that the length of bank protected by each spur appears to be at least twice its projected length perpendicular to the current. For a group of four or more, the spacing may be upto four times their projected length.

Figure 3 may be referred.

3.4 Length of Spur

Whether to choose fewer long spurs or a greater number of short ones depends upon their distributing effects upon the opposite bank and upon the channel upstream and downstream. In the case of earthen spurs, the longest spur which will not produce excessive erosion and disturbance should be used, since the major cost of this type is in the slope revetment and the apron on its outer end.

In view of a series of short spurs, consideration should be given to placing slope revetment directly along the bank or dike under attack. This is usually a cheaper and a neater solution.

Based on dimensional analysis, an empirical relation can be used for determining the minimum spur length l, required to control a river loop.

$$\frac{l}{B} = 0.11 \quad (A/F)^{3/2}$$

Where B = Width of river
F = Frouds Number
A = Arc/chord ratio

In a system of training works it is only one or two spurs which will be in action at any one time but all spurs are designed to come under action at one time or another depending upon changes in the river course.

3.5 Scour at the Spur Nose

Scour is caused due to a lack of balance between the transport capacity of the flow and the sediment in motion. An increase in the velocity increases the transporting capacity. If the sediment load is less than this capacity, the bed gets scoured. This is what happens at the nose of a spur dike. As the water flows around it, the flow pattern is changed due to reduction in the width of channel and sheer distribution around the spur dike is modified. This results in the scour action. The obstruction caused by the spur generates a vortex trail that moves in front of the spur and throws up the eroded material which is transported downstream by the main flow. The phenomena is illustrated in Fig. 4.

3.5.1 Methods of prediction of Scour

Due to the complex nature of the vortex flow phenomena, the prediction of the maximum depth of local scour is largely dependent upon the empirical approaches adopted by various investigators. Some of the empirical relationships are as follows. The definition sketch is given in Fig. 6.

i) Liu Equation

$$\frac{ds}{di} = 1.1 \left(\frac{a}{d_1}\right)^{0.40} (F_1)^{0.33}$$

Where ds = Equilibrium depth of scour measured from the mean bed level to the bottom of the scour hole.

a = Length of spur dike measured normal to the embankment.

d_1 = Upstream depth of flow

F_1 = Upstream Froude Number

$$= \frac{V_1}{\sqrt{gd_1}}$$

This equation is recommended to be used for spurs with

$$0 < \frac{a}{dl} < 25$$

ii) C.S.U.Training and Design Manual

It has been suggested that if $\frac{a}{d_1} > 25$, following relationship be used:

$$\frac{ds}{d_1} = 4 \quad F^{0.33}$$

iii) Izzard and Bradley's Equation

They suggest the following equation for bridge abutments and river spurs:

$$(d+ds) = 1.40 \quad q^{2/3}$$

iv) Regime Approach

The regime philosophy solves, to a useful degree of accuracy, most of the engineering problems of river evolution, including that of scour around hydraulic structures. Following are some of the commonly used methods which use the regime concept:

a) Blench Method

The scoured depth can be calculated by the following procedure.

Estimate q_f, the flood discharge intensity immediately upstream of the pier.

q_f = Velocity x depth.

The corresponding regime depth d_{fo}, is given by

$$d_{fo} = \sqrt[3]{\frac{qf^2}{F_{bo}}}$$

Where F_{bo} = Blench's zero bed factor (Fig. 5)

Estimate the maximum scoured depth, as zxdfo where value of z varies from 2.0 to 2.75

b) Lacey's Formula

The maximum scoured depth relative to water surface is given as follows:

$$R_s = 0.47 \quad \left(\frac{Q}{f_1}\right)^{1/3}$$

where Q is discharge and f_1 is Lacey's silt factor (Values of f_1 given in the following table).

Mean grain size of Cohesionless bed material (mm)	Value of f_1
0.08	0.5
0.16	0.7.
0.23	0.85
0.32	1.0
0.50	1.25
0.72	1.5
1.00	1.75
1.30	2.0

Lacey recommends the following increase in scour depth

Straight reach	1.27(R)
Moderate bend	1.50(R)
Severe bend	1.75(R)
Right angle bend.	2.00(R)

c) Khosla's Approach

He relates Lacey's formula for scoured depth to the discharge intensity by the following relationship:

$$(R) = 0.9 \left(\frac{q^{2/3}}{f_1^{1/3}}\right) \quad \text{where}$$

q = discharge per unit width.

The water surface level corresponding to Q must be known to find the scour level. The value of f_1 is normally taken as 1.0 for sandy materials. The equation gives mean value of the scoured depth.

d) Garde's Equation

He suggests the following empirical relationship for finding out the depth of scour.

$$\frac{d+ds}{d} = K . \frac{1}{\alpha} . F^n \quad \text{where}$$

$$F = \frac{V}{19\ D}$$

d = Average depth of flow
ds = Maximum scoured depth.
α = Opening ratio = $\frac{B-b}{B}$
B = Width of the spur dike.
b = Unconstructed water way.

K and n are functions of the drag coefficient of sediment C_D and can be read from the graph. The value of C_D can also be calculated from the following.

$$C_D = \frac{4}{3} \cdot \frac{g.\ \gamma s.\ dm}{w^2} \quad \text{Where}$$

γs = Difference of specific weight between sediment and water.

dm = Medium size of the sediment.
w = Settling velocity of the sediment.
γ = Specific weight of water.

4.0 PROTECTION OF SPUR NOSE

Lack of protection against undermining is a frequent cause of failure of the spur head. Following methods may be used.

4.1 Where-ever deep scour is not expected, the slope revetment may be continued down to an inerodible material or to below the expected scour level. It becomes impractical and uneconomical if deep scour is expected.

4.2 A cut-off wall of sheet-piling from the toe of the revetment down to an inerodible material or to below the expected scour level can be driven.

4.3 A flexible apron is laid horizontally on the bed at the foot of the revetment. Only flexible protection such as stone, concrete blocks, etc. is likely to have any permanence on a yielding base. When scour occurs the material will settle covering the size of the scour hole on a natural slope. The stone will settle normally to a slope of about 1 upon 2, when it is undercut by scour. This method is recommended for noncohesive channel beds. If the ground is cohesive the apron will remain on a cliff as scour occurs. When the cliff fails by sliding, it will carry away the end of apron and nose head will be lost.

Above methods are illustrated in Fig. 7.

4.4 Punjab Practice

Fig. 8 shows a typical section of the nose of the spur dike protected by stone apron used as a standard design procedure for hydraulic structures in India and Pakistan.

The quantity of stone in the aprons should be sufficient to afford approximately 3 ft. cover over a slope of 2 upon 1 below the level at which the apron is originally laid to the bottom of the deepest likely scour.

The thickness of stone pitching for protection of the various grades of sands and slopes of rivers can be estimated from the following table.

Fall per mile in inches	3	9	12	18	24
	Thickness of stone pitching in inches.				
Sand classification					
Very coarse.	16	19	22	25	28
Coarse	22	25	28	31	34
Medium	28	31	34	37	40
Fine	34	37	40	43	46
Very fine	40	43	46	49	52

5.0 DETERMINATION OF STONE-SIZE

An empirical rule given by Blench (1969) is stated as follows "A rough guide is that a large sand bed river will normally need stone about 150 lbs. if it does not have a very large bed; a small one might have stone as small as 50 lbs. A gravel river with small bed load charge should use stone at least twice the diameter of the largest material that rolls on the bed, if moderate attack is expected; for very violent attack, as at a major spur nose, three times size is safer".

There is considerable variation in the practical formulas and charts published by different agencies for the prediction of size of stone for stability which depends on local flow velocity adjacent to the slope, stone density, depth of flow, degree of turbulence, curvature of flow and slope angle.

Searchy compares graphs of stone size vs local flow velocity against the slope, based on the recommendations of four agencies in the United States. Neill(1973) has suggested a compromise curve for these graphs,assuming a specific gravity of 2.65.

The local velocity against the slope of an embankment more or less parallel to the flow may be taken as approximately two thirds of the cross-sectional mean,where the channel is straight. For the flow around a severe bend, he suggests to assume velocity upto four-thirds of the cross-sectional mean. A considerable higher value of local velocity is to be used for the nose of the spur.

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Figure—1
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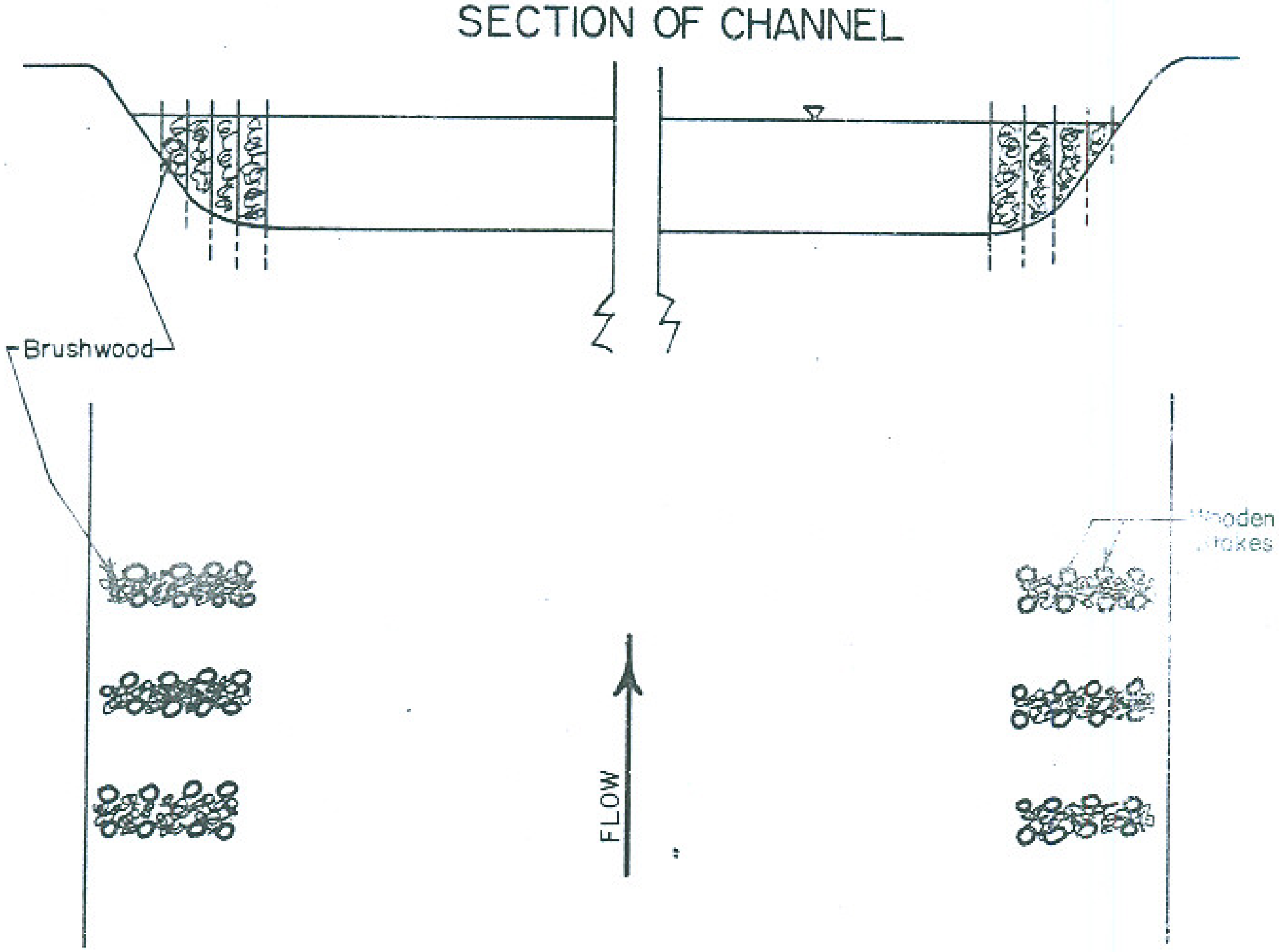
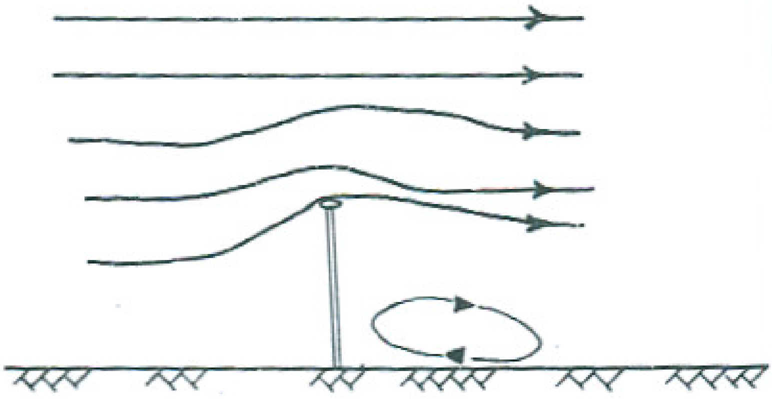

SECTION OF CHANNEL

KILLA SPURS

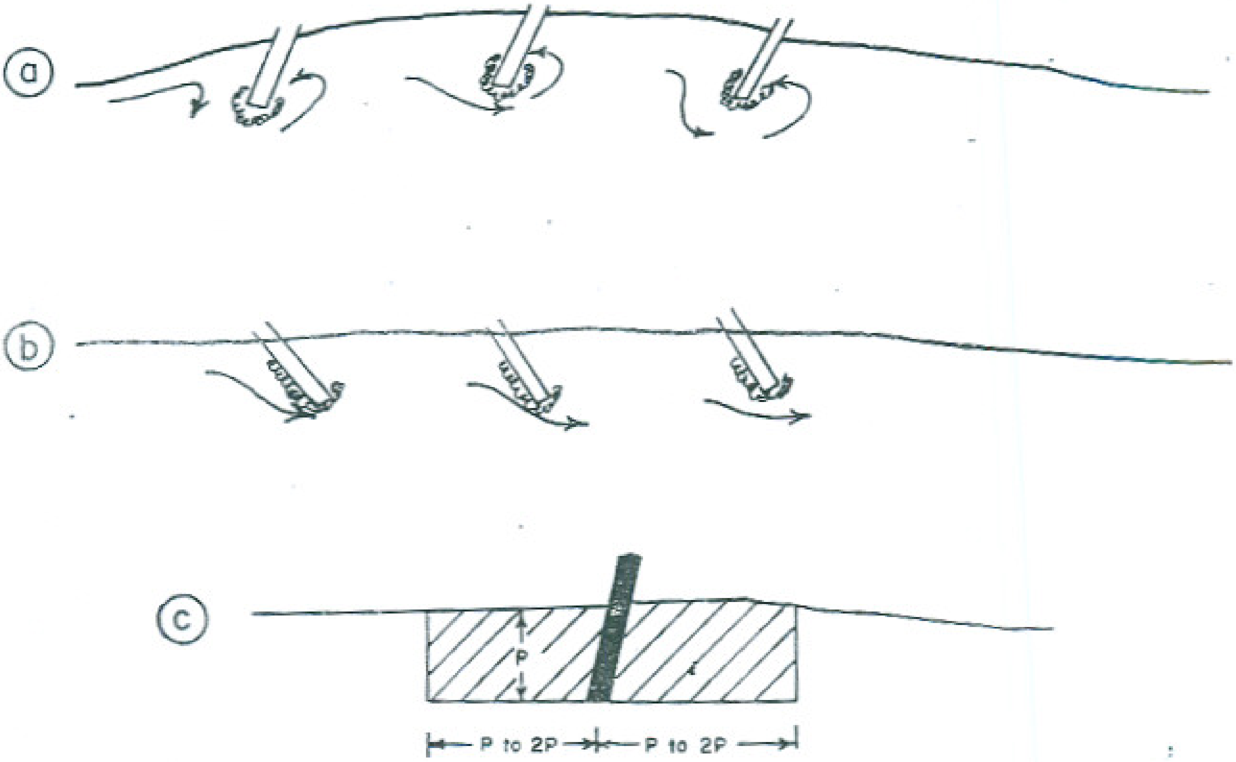
PLAN OF EARTHEN CHANNEL

Figure —2



FLOW AROUND A SINGLE SPUR

Figure — 3



ORIENTATION AND SPACING OF SPUR

a. Spurs pointed upstream

b. Spurs pointed downstream

c. Approximate area protected by a spur

Figure — 4

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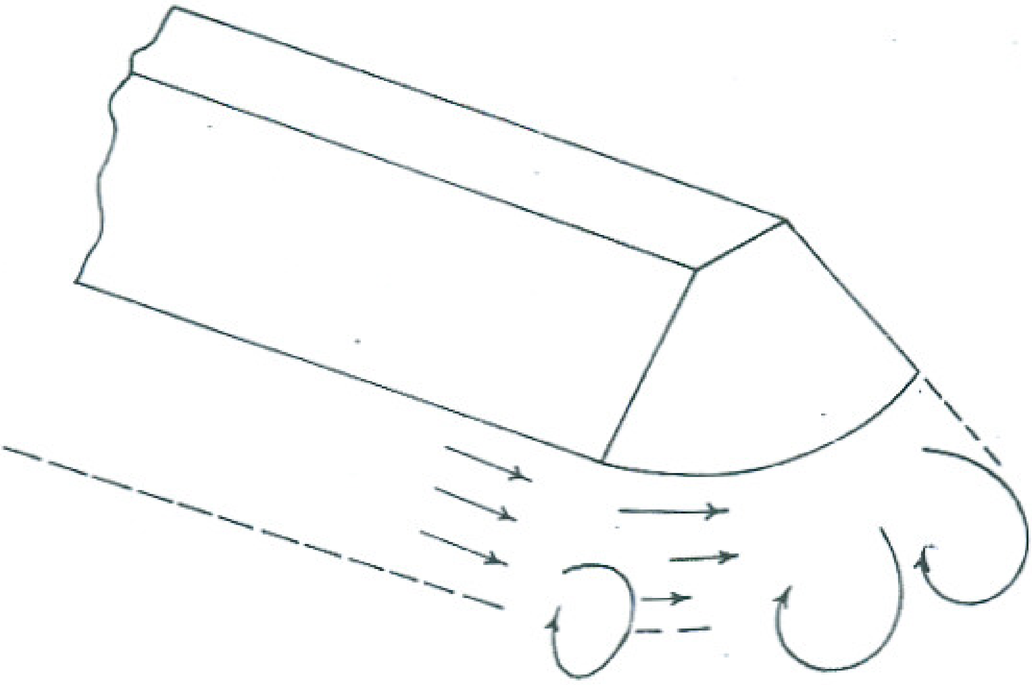
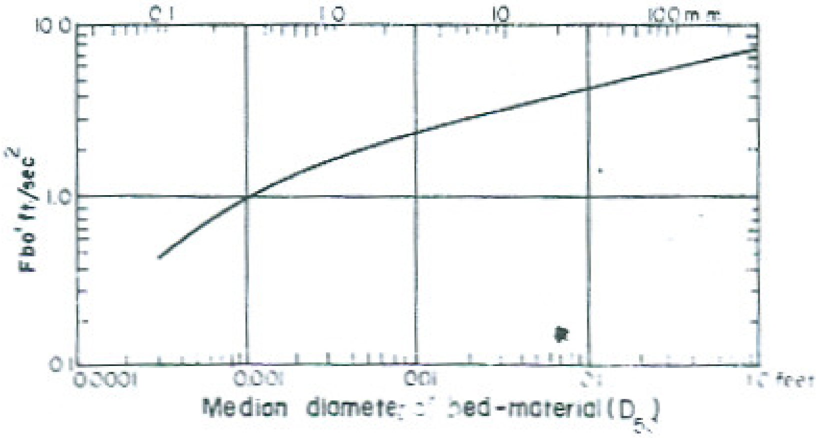


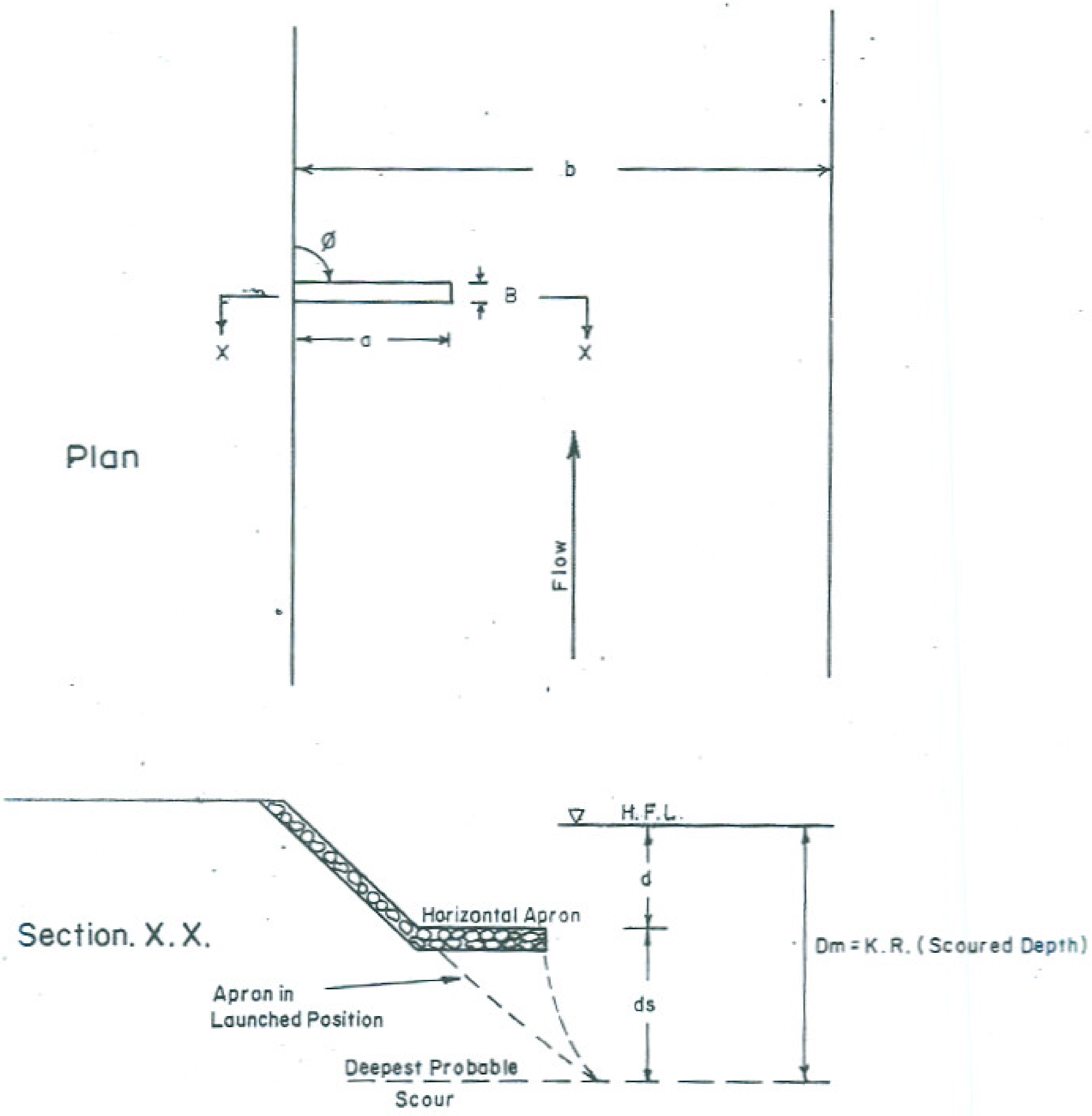
SCHEMATIC REPRESENTATION OF SCOUR AT NOSE OF SPUR DIKE

Figure — 5



FROM BLENCH (1969)

Figure – 6



DEFINITION SKETCH FOR SCOUR AROUND SPUR-DIKE

Figure - 7
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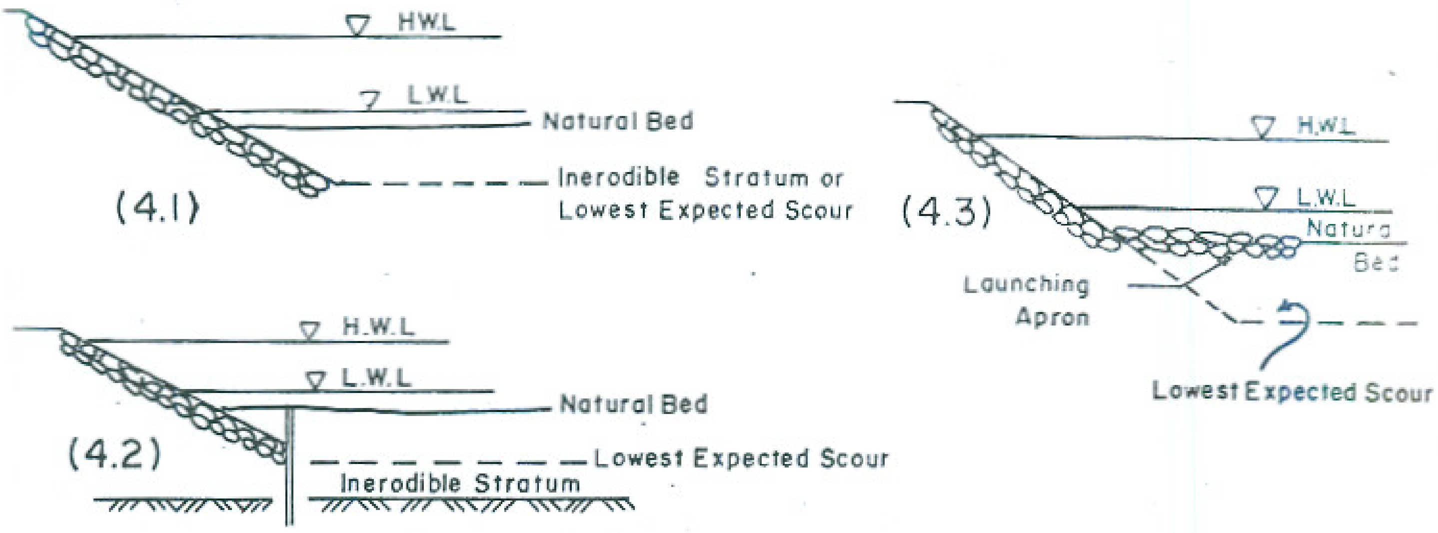
THE METHODS OF PROTECTION OF SPUR NOSE



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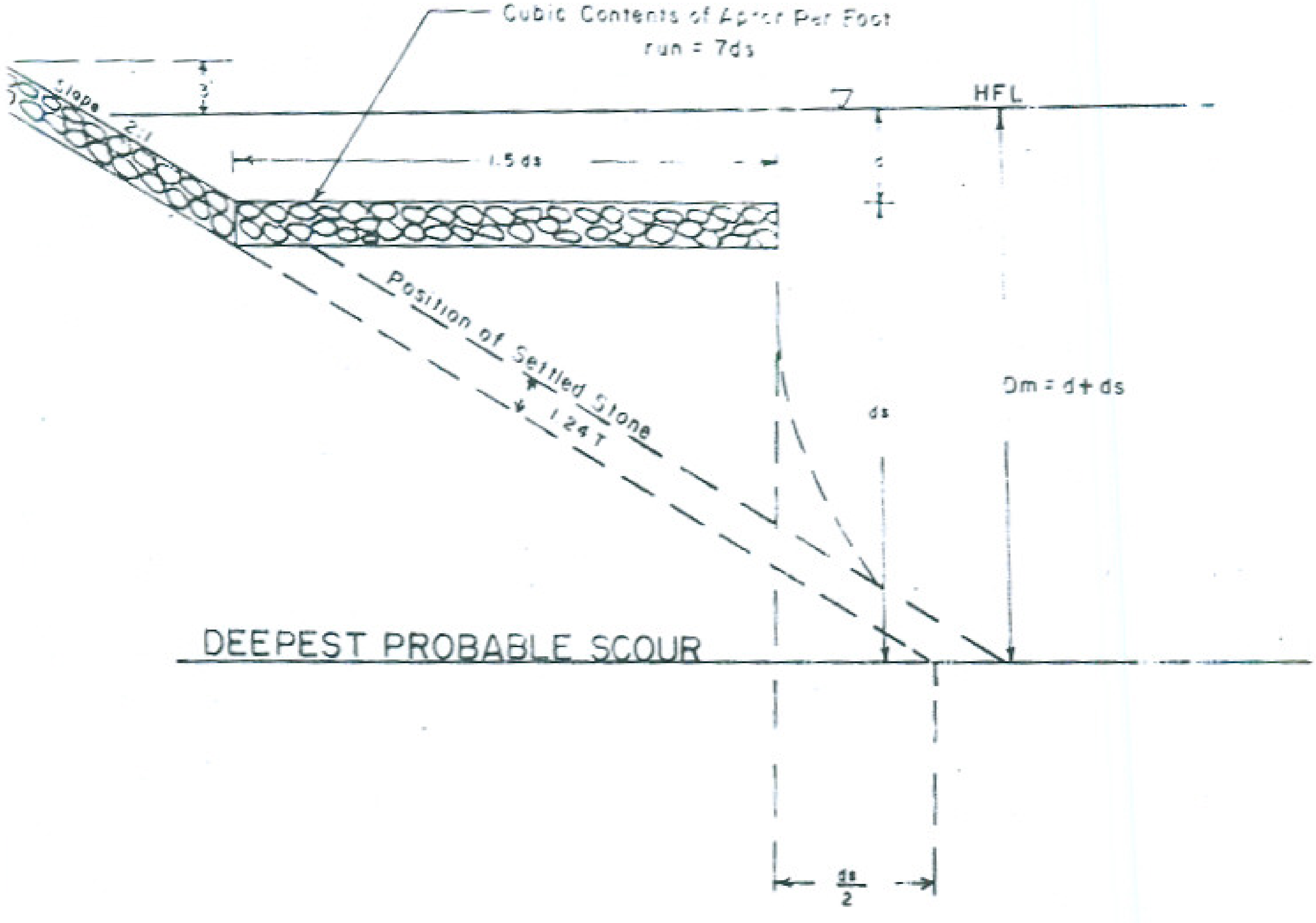

PROTECTION OF SPUR NOSE
WITH STONE APRON

Figure – 9
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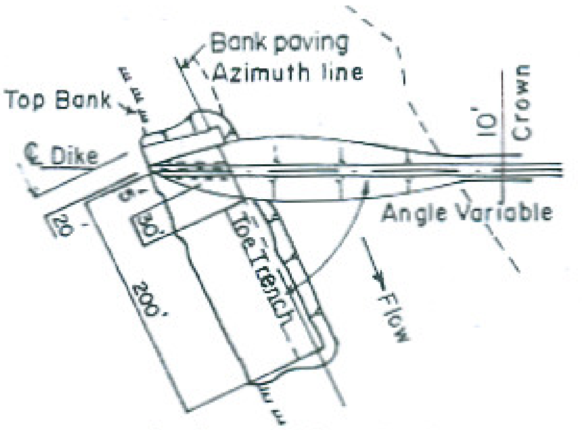
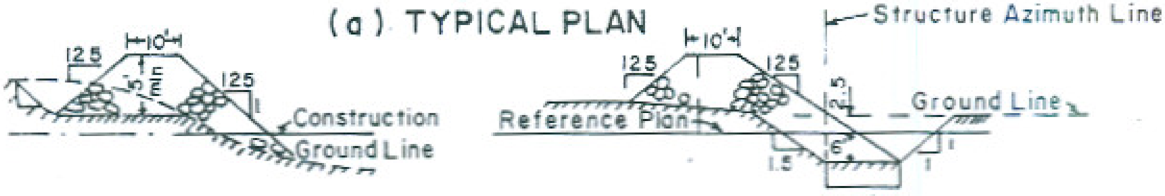
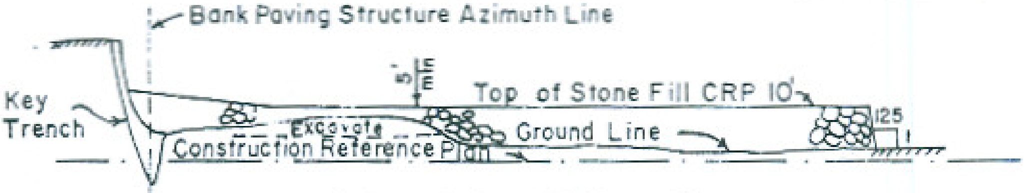


(a) TYPICAL PLAN



(b) TYPICAL SECTION

(c) TYPICAL SECTION WITH TOE TRENCH



(d) TYPICAL PROFILE

STONE – FILL DIKES