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BANK PROTECTION TECHNIQUES USING SPUR DIKES

by

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A hydraulic model investigation was conducted to evaluate and demonstrate the effects of impermeable spur dikes as a bank protection technique in a concave bend. The tests were conducted to observe channel bed and bank response in a stream with noncohesive banks where suspended load is insignificant. Several parameters relative to spur dike design that were evaluated included: the length to spacing ratio, the orientation angle, and the effect of an apron or mattress of protection at the toe of the dike.

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Preface

The model demonstration reported herein was conducted as a part of the "Section 32 Program" authorized by Congress under the Streambank Erosion Control Evaluation and Demonstration Act of 1974, Section 32, Public Law 93-251 (as amended by Public Law 94-587, Sections 155 and 161, October 1976). The study was conducted during the period April 1980 to May 1981 in the Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES) under the direction of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory, and J. L. Grace, Jr., Chief of the Hydraulic Structures Division, and under the general supervision of N. R. Oswalt, Chief of the Spillways and Channels Branch. The project engineer for the study was Mr. R. R. Copeland assisted by Mr. E. L. Jefferson. This report was prepared by Mr. Copeland.

Commanders and Directors of WES during the conduct of this investigation and the preparation and publication of this report were COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

Contents

Conversion Factors, U. S. Customary to Metric (SI) Units of Measurement

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
cubic feet per second	0.02831685	cubic metres per second
feet	0.3048	metres
feet per second	0.3048	metres per second

BANK PROTECTION TECHNIQUES USING SPUR DIKES

Introduction

1. Spur dikes have been used extensively in all parts of the world as river training structures to enhance navigation, improve flood control, and protect erodible banks. A spur dike can be defined as an elongated obstruction having one end on the bank of a stream and the other end projecting into the current. It may be permeable, allowing water to pass through it at a reduced velocity; or it may be impermeable, completely blocking the current. Spur dikes may be constructed of permanent materials such as masonry, concrete, or earth and stone; semipermanent materials such as steel or timber sheet piling, gabions, or timber fencing; or temporary material such as weighted brushwood fascines. Spur dikes may be built at right angles to the bank or current, or angled upstream or downstream. The effect of the spur dike is to reduce the current along the streambank, thereby reducing the erosive capability of the stream and in some cases inducing sedimentation between dikes.

2. Although the use of spur dikes is extensive, no definitive hydraulic design criteria have been developed. Design continues to be based primarily on experience and judgment within specific geographical areas. This is primarily due to the wide range of variables affecting the performance of the spur dikes and the varying importance of these variables with specific applications. Parameters affecting spur dike design include: width, depth, velocity, and sinuosity of the channel; size and transportation rate of the bed material; cohesiveness of the bank; and length, width, crest profile, orientation angle, and spacing of the spur dikes.

3. This report is concerned with the use of impermeable spur dikes as a bank protection technique in a concave bend of a meandering stream. Design guidance drawn from several sources and reviewed herein

is generally based on experience and judgment on a variety of rivers throughout the world. A model study was conducted to evaluate several parameters relating to spur dike design. This study was not a scale model of any particular stream and was intended to demonstrate qualitatively the effect of various parameters on bank protection. These parameters include the spacing-to-length ratio and the orientation angle. The effect of an apron or mattress at the toe of the dike was also demonstrated.

Development of Spur Dike System Layout

Angle of dike to bank

4. The orientation of spur dikes (which is generally defined by the angle between the downstream streambank and the axis of the dike) has typically been determined by experience in specific geographical areas and by preference of engineers. There is considerable controversy as to whether spur dikes should be oriented with their axis in an upstream or downstream direction. Proponents of an upstream orientation claim that flow is repelled from dikes pointed upstream while flow is attracted to the bank by dikes slanted downstream. Sedimentation is more likely to occur behind spur dikes angled upstream so that less protection is required on the bank and on the upstream face of the dike. Advocates of a downstream orientation argue that turbulence and scour depths are less at the end of the spur dike when it is angled downstream. In addition, the more a spur dike is angled downstream the more the scour hole is angled away from the dike. Trash and ice are less likely to accumulate on dikes angled downstream. To date there has not been a sufficiently comprehensive series of tests either in the field or by model to settle this controversy. Therefore, it is often recommended that spur dikes be aligned perpendicular to the flow lines.

5. After reviewing spur dike applications in the rivers of Europe and America, Thomas and Watt (1913) concluded that the various alignments were probably of slight importance. Franzius (1927) reported that spur dikes directed upstream are superior to normal and downstream-oriented

spur dikes with respect to bank protection as well as sedimentation between the dikes. Water flowing over downstream-oriented spur dikes and normal to the axis is directed toward the bank, making submerged dikes with this alignment especially undesirable. A less adamant position was taken by Strom (1941), when he reported that the usual practice in New Zealand was to incline impermeable groins slightly upstream, but that downstream-oriented spur dikes had also been used successfully. Strom states that a spur dike angled downstream tends to swing the current below it toward midstream; this has a reflex action above the dike which may induce the current to attack the bank there. Thus, downstream-oriented dikes should only be used in series so that the downstream protection afforded by each dike extends to the one below it. The United Nations (1953) reported that the present practice was to construct spur dikes either perpendicular to the bank or to orient them upstream. This publication states that downstream-oriented dikes tend to bring the scour hole closer to the bank. An upstream dike angle varying between 100 and 120 deg was recommended for bank protection. The Indian Central Board of Irrigation and Power (1956), in their manual for river training, strongly discouraged the use of downstream-oriented dikes stating that a dike with such an orientation "invariably accentuates the existing conditions and may create undesirable results." Dikes with angles between 100 and 120 deg are recommended. Mamak (1964), reporting primarily on river training experiences in Poland, stated that dikes are usually set perpendicular to the flow or set upstream at angles between 100 and 110 deg. Lindner (1969), reporting on the state of knowledge for the U. S. Army Corps of Engineers, recommended perpendicular dikes except in concave bendways where they should be angled sharply downstream. Neill (1973) recommended using upstream-oriented dikes. After reviewing much of the literature on spur dikes Richardson and Simons (1973) recommended perpendicular spur dikes, suggesting that dikes with angles between 100 and 110 deg could be used to channelize or guide flow. Reporting on model tests and field experiences in Mexico, Alvarez recommended spur dikes with angles between 70 and 90 deg. In sharp or irregular curves the angle should be less, even as low as

30 deg. His studies indicated that upstream orientations called for smaller separations between spurs to achieve the same degree of bank protection. In the United States, the U. S. Army Corps of Engineers (1978) has generally oriented its spur dikes perpendicular or slightly downstream. On the Missouri River, dikes are generally oriented downstream with an angle of 75 deg. On the Red and Arkansas Rivers, dikes were placed normal to flow or at angles of 75 deg. The Memphis and Vicksburg Districts use perpendicular dikes. The St. Louis District uses both perpendicular and downstream-oriented dikes. The Los Angeles District (1980) uses dikes with an angle of 75 deg. As late as 1979, Jansen (1979) concluded that there is no definite answer as to whether spur dikes should be oriented upstream or downstream, and recommended using the cheapest solution--that being the shortest connection between the end of the dike and the bank. This corresponds with Lindner (1969) who stated that there has not been a sufficiently comprehensive series of tests either in the field or by model to conclude that any acute or obtuse angle for the alignment at dikes is superior or even as good as perpendicular to flow.

Spacing of spur dikes

6. The spacing between spur dikes has generally been related to the effective length (perpendicular projection) of the dike, although the bank curvature, flow velocity, and angle of attack are also important factors. The ratio of spur dike length to spacing required for bank protection is less than that required for navigation channels, as the primary purpose is to move the eroding current away from the bank and not necessarily to create a well-defined deep channel. Design guidance from several sources for spacing of spur dikes for bank protection is given in Table 1.

Local Scour at Spur Dikes

7. Intense vortex action is set up at the streamward end of a spur dike. Intermittent vortices of lesser strength occur along both the upstream and downstream faces of the dike. This turbulence causes

Table 1

Spur Dike Spacing for Bank Protection

Spacing	Type of Bank	Reference	Comment
1L	Concave	United Nations (1953)	General practice
2 to 2.5L	Convex	United Nations (1953)	General practice
4 to 6L	Concave	Richardson and Simons (1973)	Bank may need riprap
3L	Concave	Grant (1948)	
5.1 to 6.3L	Straight	Alvarez	
2.5 to 4L	Curves	Alvarez	
2 to 2.5L		CBIP (1956)	
1.5	Concave	Los Angeles District (1980)	Levee protection with riprap
2.0	Straight	Los Angeles District (1980)	
2.5	Convex	Los Angeles District (1980)	
2		Neill (1973)	
4		Neill (1973)	If two or more dikes
3 to 5L		Strom (1941)	

bed material to be suspended, where it becomes easier for the current to carry it downstream. The depth of the scour hole that develops around the spur dike and the angle of repose of the bed material are the primary factors which determine the extent of bank erosion in the vicinity of the dike (Figures 1 and 2). Thus, it is necessary to make an estimate of anticipated scour at the nose of the spur dike in order to provide for a spur dike depth that is greater than the depth of the scour hole.

8. Currently an established procedure for predicting scour depths at the nose of spur dikes is lacking. The most reliable design procedure would be to estimate scour depths based on experience with

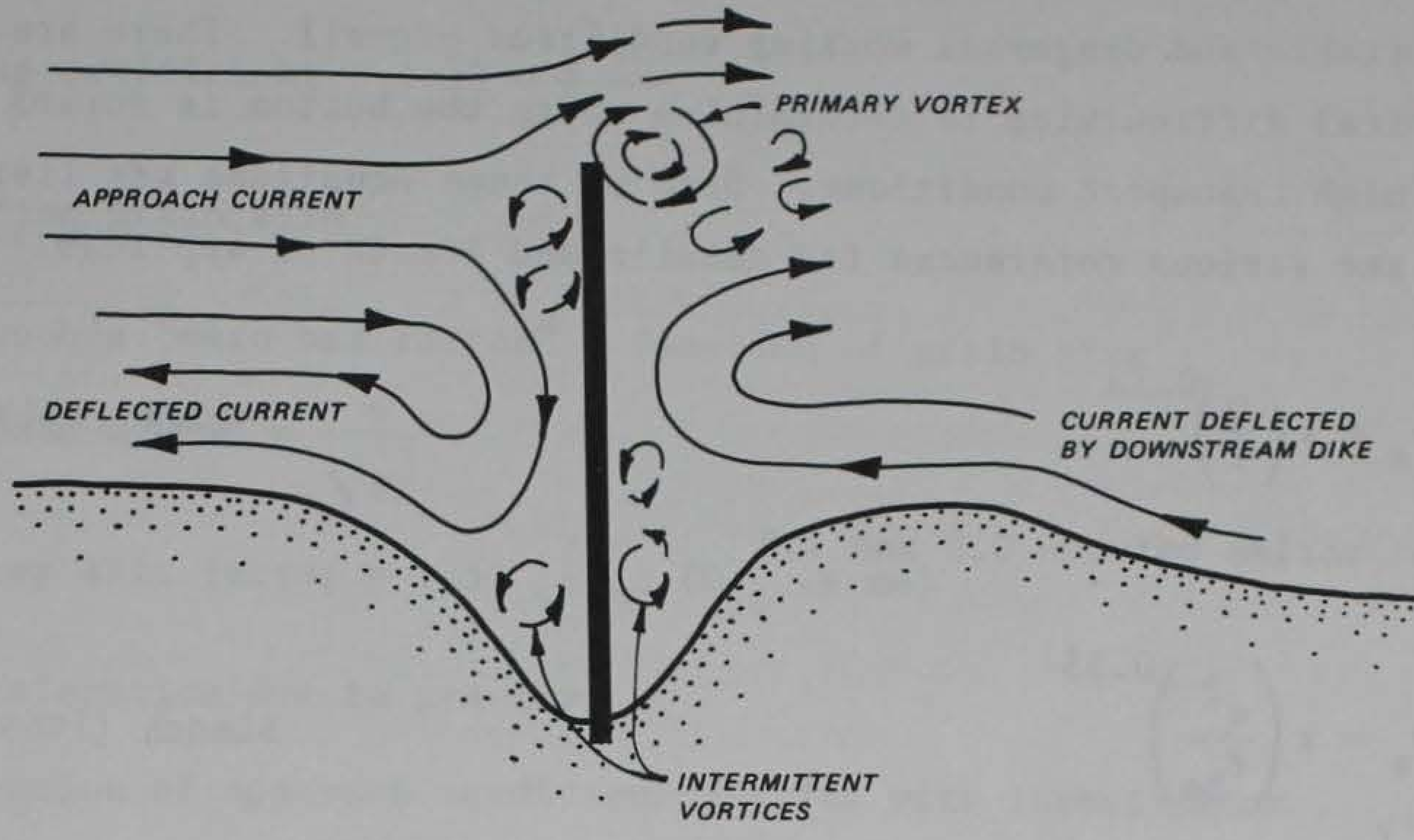


Figure 1. Flow patterns at spur dike

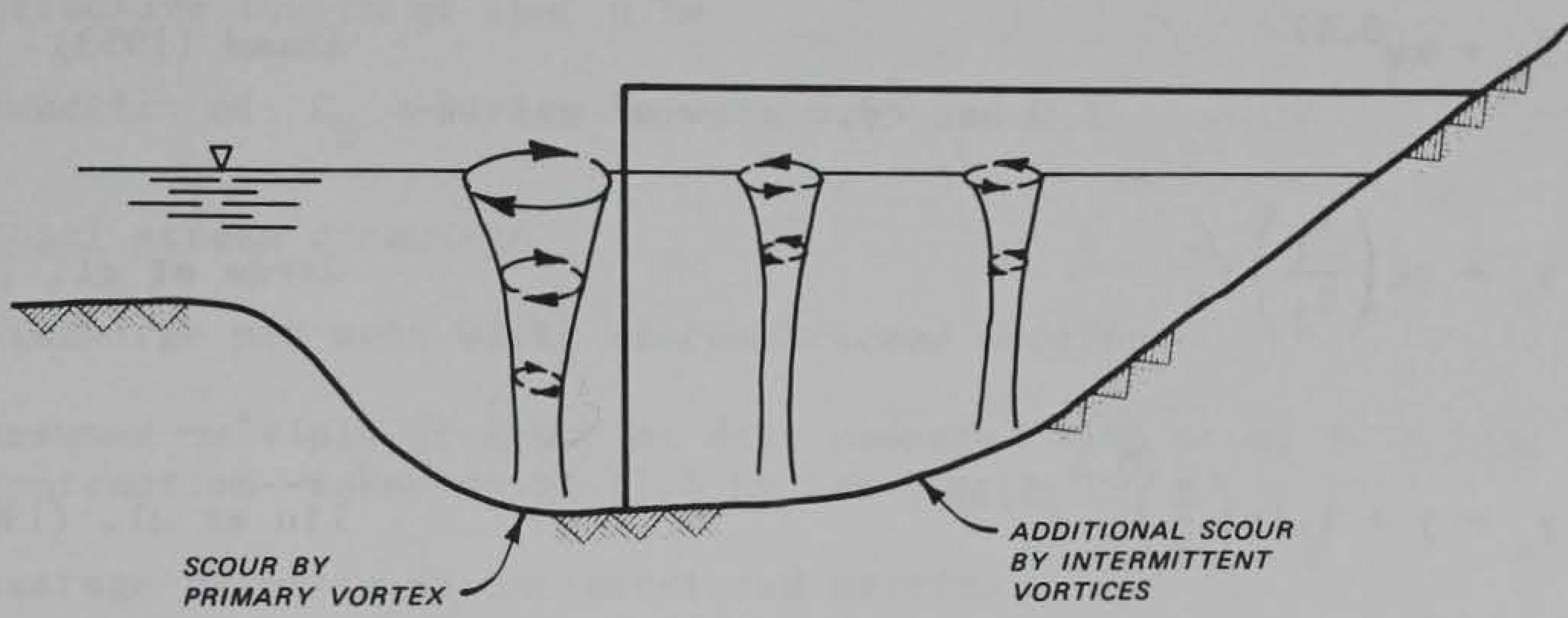


Figure 2. Scour hole profile along spur dike

similar situations in the stream in question. Movable-bed models may be used to give indications of relative scour depths. In the absence of any guidance from the field or models, one of several predictive equations may be used to obtain a rough estimate of scour depth.

9. Several investigators have proposed equations for predicting scour depths at the nose of spur dikes. These equations were derived from tests in laboratory flumes with limited verification by prototype testing. Prototype data are very difficult to obtain due to filling of the scour hole on the recession limb of flood hydrographs, and the

general unpopularity of obtaining data at high river stages when uncomfortable and dangerous working conditions prevail. There are also technical difficulties in determining where the bottom is during turbulent high transport conditions. Some of these equations are listed below; see various references for details and limits of applicability.

1. $$y_s = k\left(\frac{Q}{f}\right)^{0.33}$$ Inglis (1949)

k varies between 0.8 and 1.8

2. $$y_s = k\left(\frac{q^2}{F_{bo}}\right)^{0.33}$$ Blench (1969)

k varies between 2.0 and 2.75

3. $$y_s = kq^{0.67}$$ Ahmad (1953)

4. $$y_s = yK\left(\frac{B_1}{B_2}\right)F_n^n$$ Garde et al. (1961)

5. $$y_s = y + 1.1y\left(\frac{L}{y}\right)^{0.4}F_n^{0.33}$$ Liu et al. (1961)

6. $$y_s = 8.375y\left(\frac{D_{50}}{y}\right)^{0.25}\left(\frac{B_1}{B_2}\right)^{0.83}$$ Gill (1972)

7. $$\frac{L}{y} = 2.75\ \frac{y_s - y}{y}\left\{\left[\frac{1}{r}\ \frac{(y_s - y)}{y} + 1\right]^{1.70} - 1\right\}$$ Laursen (1962a)

B_1 = original channel width

B_2 = constricted channel width

C_D = drag coefficient = $1.33 \frac{\Delta\gamma_s D_{50}}{\omega^2 \rho}$

D_{50} = median grain size

F_{bo} = Blench's "zero bed factor" = function of grain size

F_n = Froude number = $\frac{v}{\sqrt{gy}}$

f = Lacey silt factor = $1.59 \sqrt{D_{50}}$ (D_{50} in mm)

g = acceleration due to gravity

k = function of approach conditions--varies with investigator

K = function of C_D --varies between 2.5 and 5.0

L = effective length of spur dike

n = function of C_D --varies between 0.65 and 0.9

Q = total stream discharge

q = discharge per unit width at constricted section

r = assumed multiple of scour at dike compared with scour in a long contraction--taken to be 11.5 by Laursen

v = average velocity in unconstricted section

y = average depth in unconstricted section

y_s = equilibrium scour depth measured from the water surface

$\Delta\gamma_s$ = difference in specific weight between sediment and water

ρ = mass density of water

ω = settling velocity of sediment

10. There is a general lack of agreement among investigators as to which parameters are most important in determining scour depths. Early investigators found that the contraction ratio and velocity were the most significant parameters. Laursen (1962b) maintains that when

there is sediment movement upstream of the spur dike (which would be true for most alluvial streams but not necessarily true for many laboratory flumes) the scour depth is independent of the contraction ratio and velocity and is primarily a function of the upstream depth and the length of the dike. Liu et al. (1961) and Cunha (1973) also determined that the contraction ratio was not important once sediment movement was established; however, Liu et al. considered velocity to be an important parameter with or without sediment movement. Confusing the issue, in recent studies by Garde et al. (1961) and Gill (1972) it was determined that the contraction ratio was an important parameter, with or without sediment movement. Gill concluded that velocity was not an important parameter; Garde concluded that it was. There is an equal division of opinion on the importance of bed material size. Inglis (1949), Blench (1969), Garde et al. (1961), and Gill (1972) found grain size to be important. Laursen (1962b), Liu et al. (1961), and Ahmad (1953) determined sediment size to be insignificant. These equations are based primarily on results from laboratory testing on a single spur dike in a straight flume. Thus, the effect of current attack angle is generally neglected. Inglis, Blench, and Ahmad provided for a variable coefficient to account for severity of attack, and Laursen and Garde provided for adjustments to account for the orientation angle of the spur dike axis. None of the predictive equations presented herein has attained any widespread acceptance, and it is likely that the contestable issues will remain unsettled until sufficient prototype data are obtained.

Demonstration Model Study

11. Model tests were conducted in a 130- by 50-ft sand bed flume. A meandering stream with three bends was molded in the flume as shown in Figure 3. The channel top width was 8 ft with an average depth of 0.24 ft. The stream sinuosity was 1.6 and the slope was 0.0012. A constant discharge of 2.7 cfs was recirculated through the model except for one test when a discharge of 4.6 cfs was used. There was bed-load movement in the model but no suspended load. The bed material was a

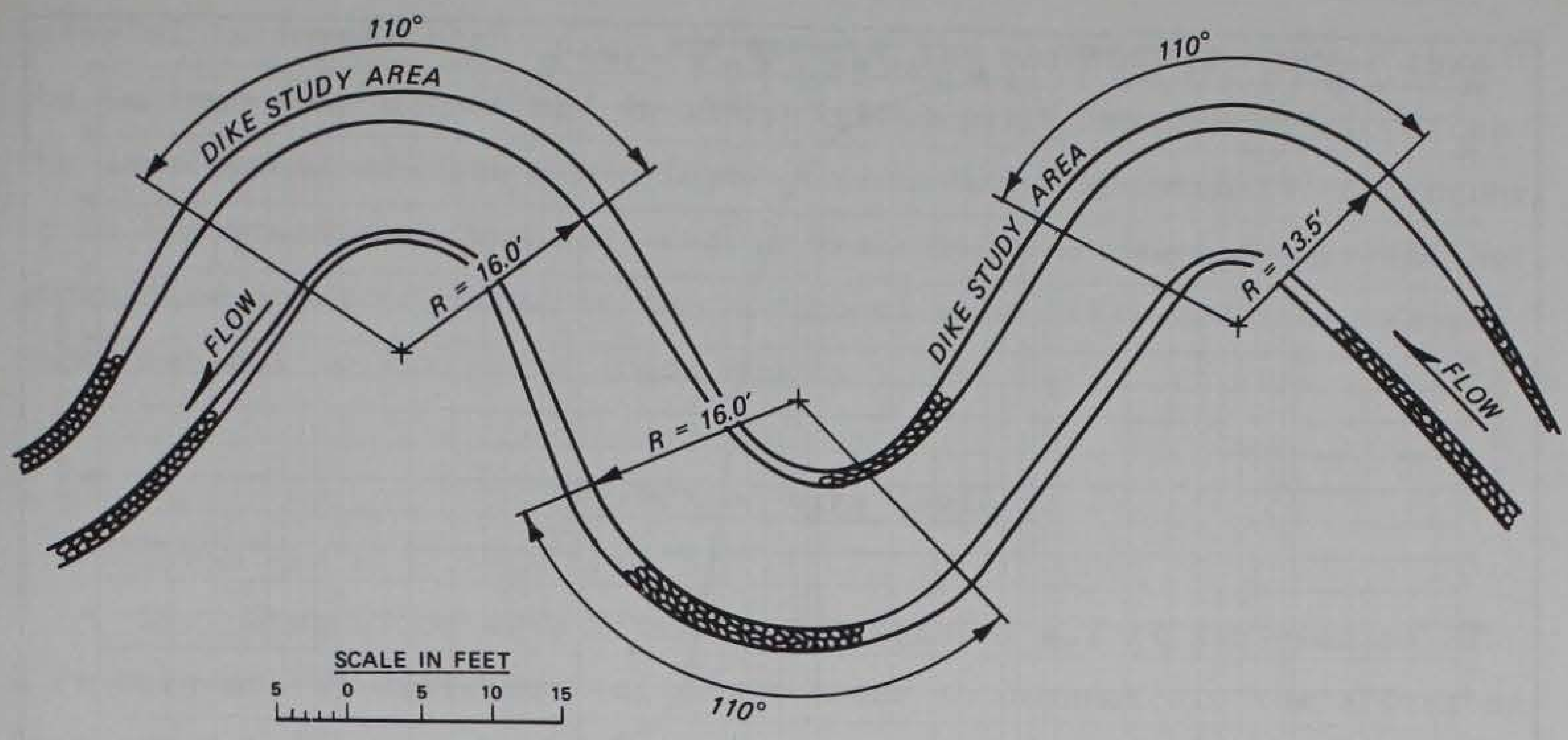


Figure 3. Streambank erosion test facility

medium sand and was recirculated. Velocities were measured at middepth with a paddle-wheel velocity meter. The spur dikes were made of sheet metal representing any relatively narrow impermeable structure. The stream was returned to approximately its original shape at the beginning of each test. Lines, 0.4 ft apart, were spray-painted along the bank for reference. A constant discharge was then run for 24 hr through the model. Most of the significant scour and bank erosion had occurred at the end of 8 hr, after which additional changes occurred slowly so that essentially equilibrium conditions had been achieved by the end of the test period. Effects of various spur dike spacings and orientation angles were then compared.

Effect of the Coarse Fraction of the Bed Material

12. The sand used in the model study was a uniform medium sand (D_{50} = 0.45 mm). Gradation curve of the sand was obtained by standard methods (Figure 4). The sand was not sieved prior to being placed in the model and thus may be assumed to represent a typical river sand deposit.

13. At the conclusion of each series of tests an armor layer of coarse material was observed in the scour holes formed at the spur dikes. The grain diameters of the material in these scour holes, as shown in Figure 5, varied between 3 and 30 mm. Thus, all of the armor

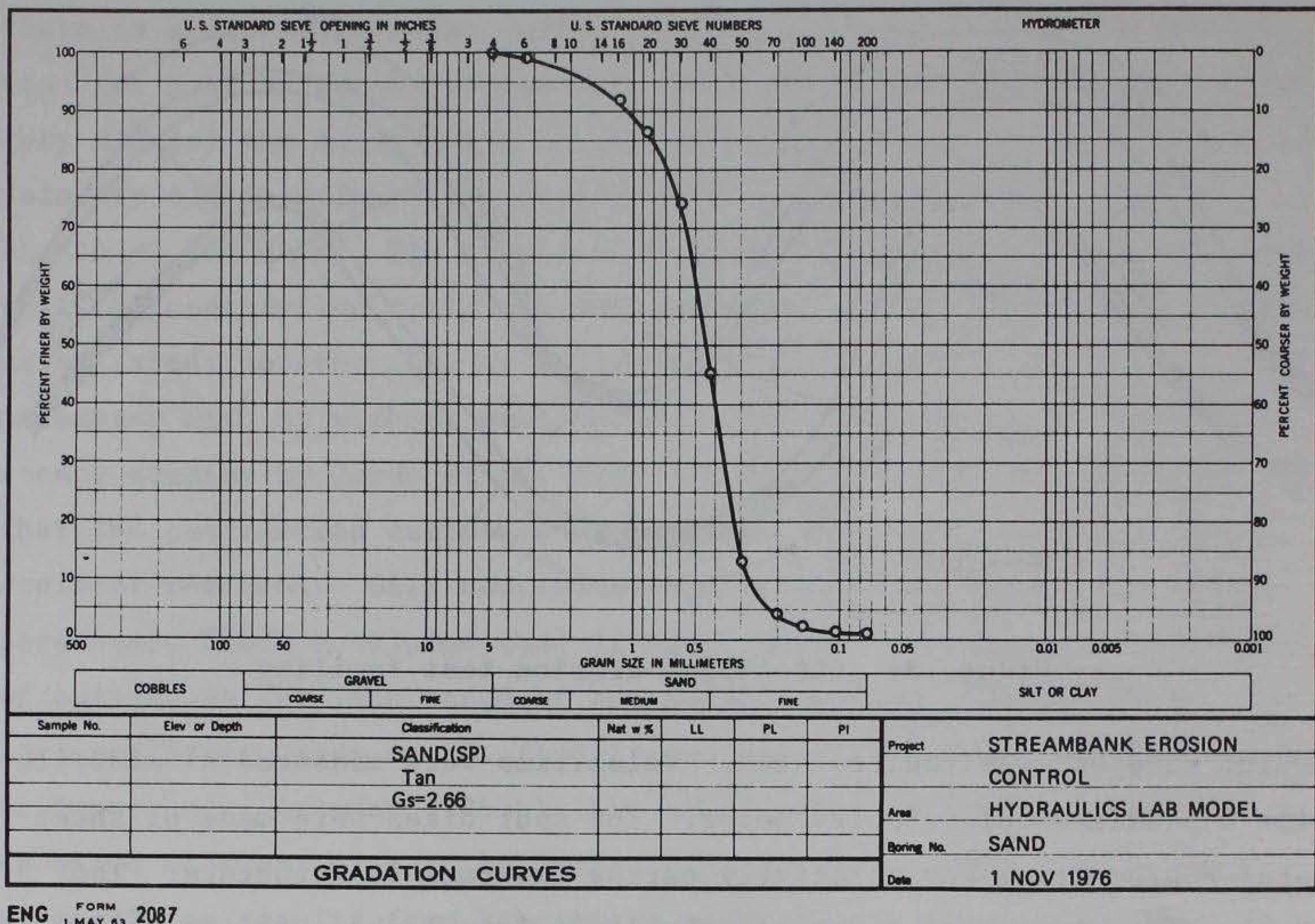


Figure 4. Gradation curve

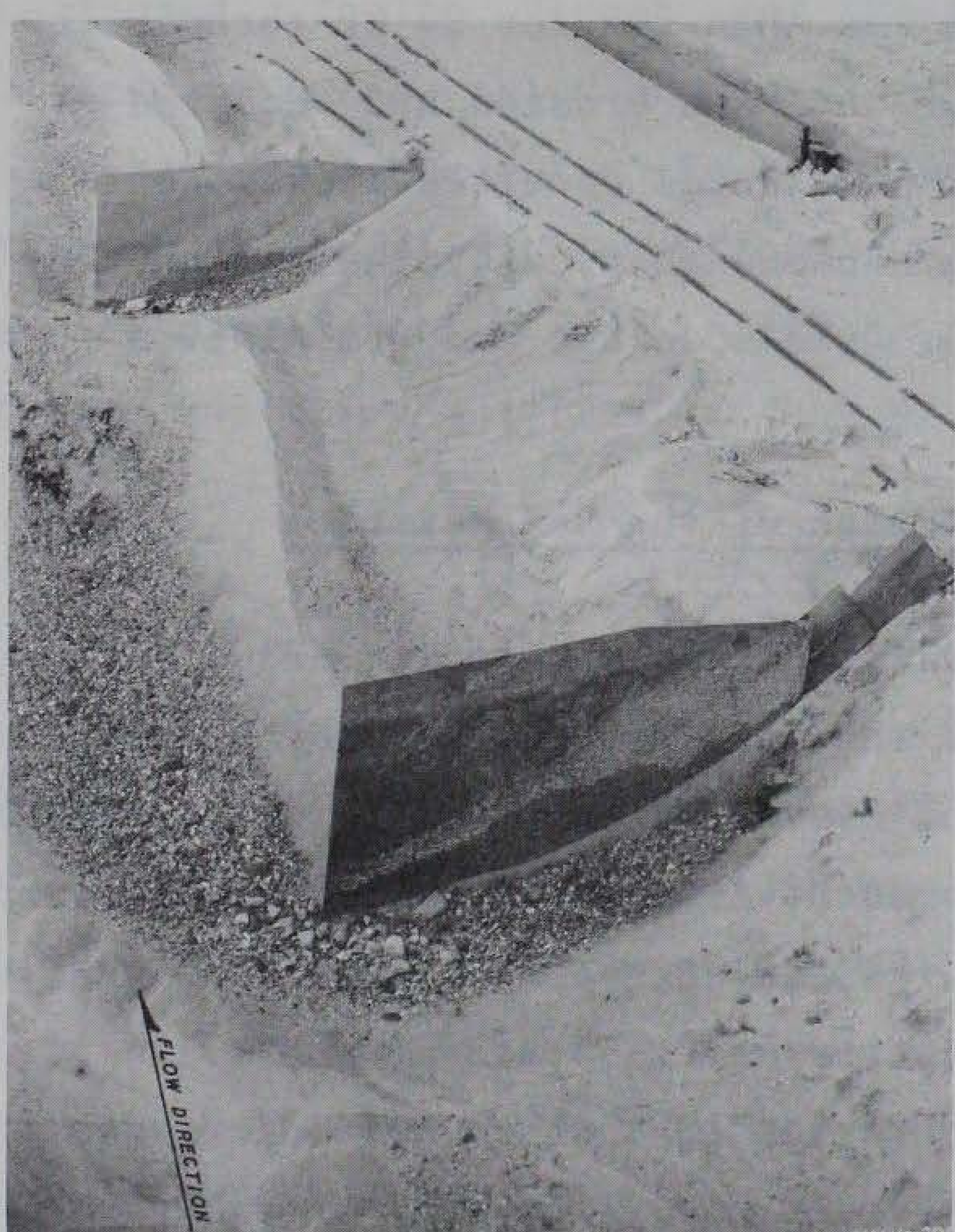


Figure 5. Armor layer in scour hole

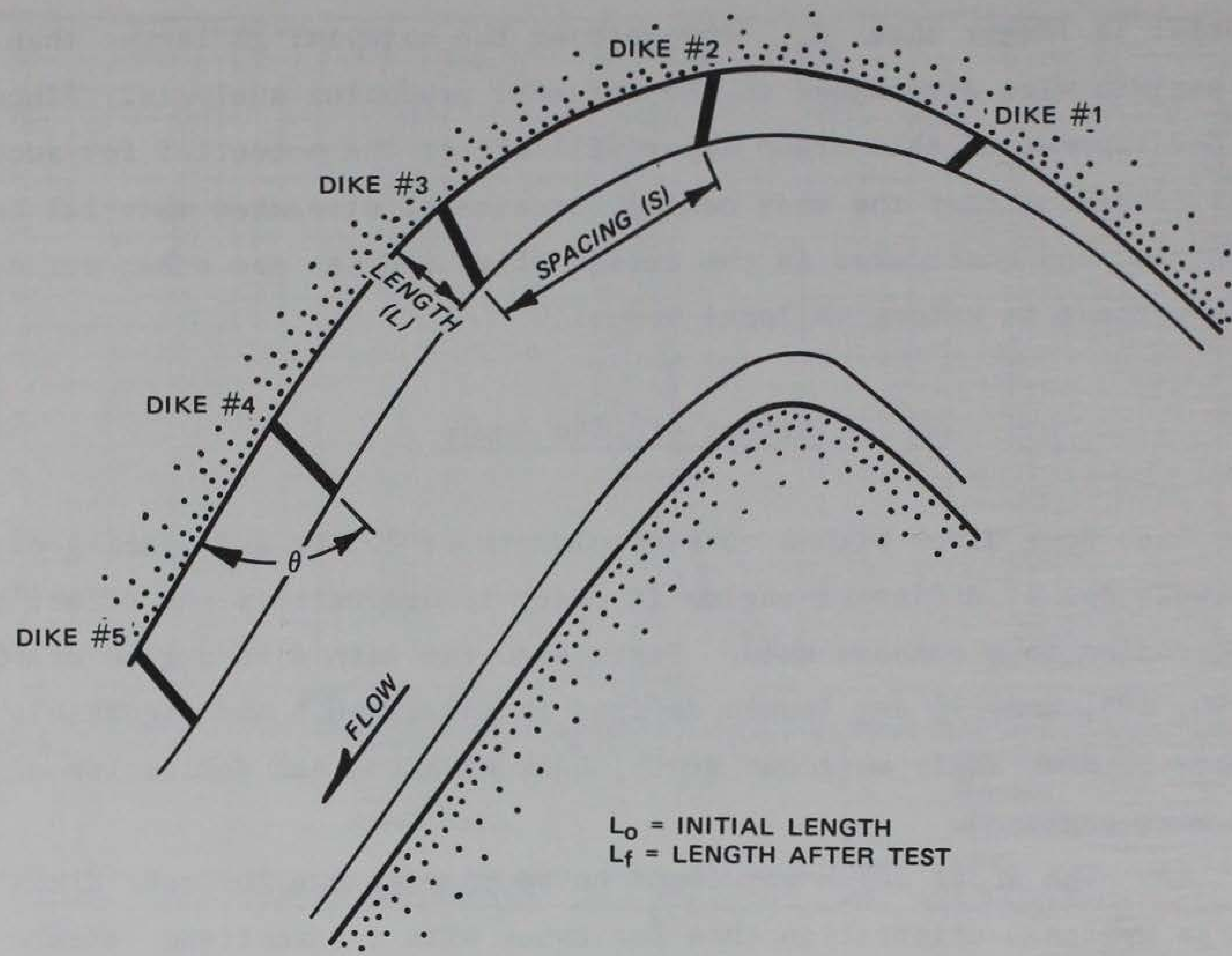
material is larger than d_{95} and much of the material is larger than the maximum size determined in the original gradation analysis. Since the development of this armor layer will affect the potential for scour, it is important that the very coarse fraction of streambed material be identified and considered in the design of spur dikes and other structures subject to extensive local scour.

Effect of Dike Angle

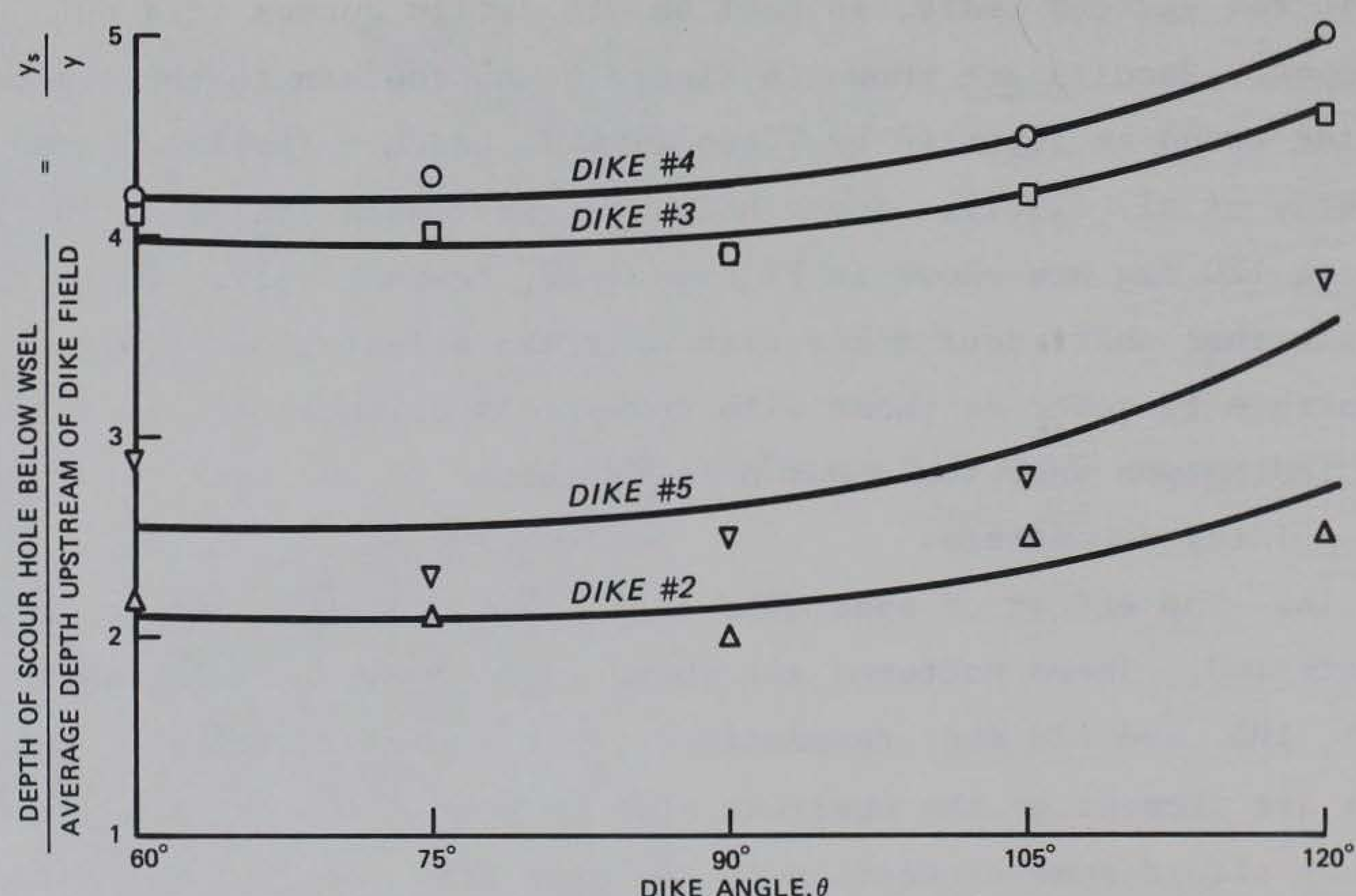
14. Spur dikes with a constant length of 2.2 ft and spacing of 9 ft were set at different angles in order to demonstrate the effect on bank erosion in a concave bend. Tests were run with dike angles of 60, 75, 90, 105, and 120 deg (angle defined in paragraph 5 and Figure 6). Effects of dike angle on scour depth, bank erosion, and deflection of flow were analyzed.

15. The scour depth was found to be more severe for spur dikes with an upstream orientation than for those with a downstream orientation. There was some variability in the extent of armor layer development in the various tests, so that smooth design curves were not developed. Results are shown in Figure 6 and conform to the generally accepted trend as reported by Tison (1962), Laursen (1962b), Ahmad (1953) and Garde et al. (1961). Scour holes for spur dike angles at 60, 75, 105, and 120 deg are shown in Figures 7-10, respectively. These figures indicate that short spur dikes with upstream orientations are just as susceptible to scour as those with downstream orientations. Also, there is no indication that the scour hole is closer to the bank for spur dikes pointed downstream.

16. The effect of spur dike angle on surface flow patterns was demonstrated. These patterns are shown in Figures 11-14 for angles of 60, 75, 105, and 120 deg, respectively. It is apparent that larger eddies are present on the upstream side of spur dikes oriented upstream. This may afford some protection to the spur dike root but can cause scour of the root if the eddies are sufficiently large enough. However, erosion at the spur dike root is also a function of the extent and depth



a. Dike location



b. Effect of dike angle on scour depths, $F_n = 0.4$, $S/L_o = 4.5$

Figure 6. Spur dike

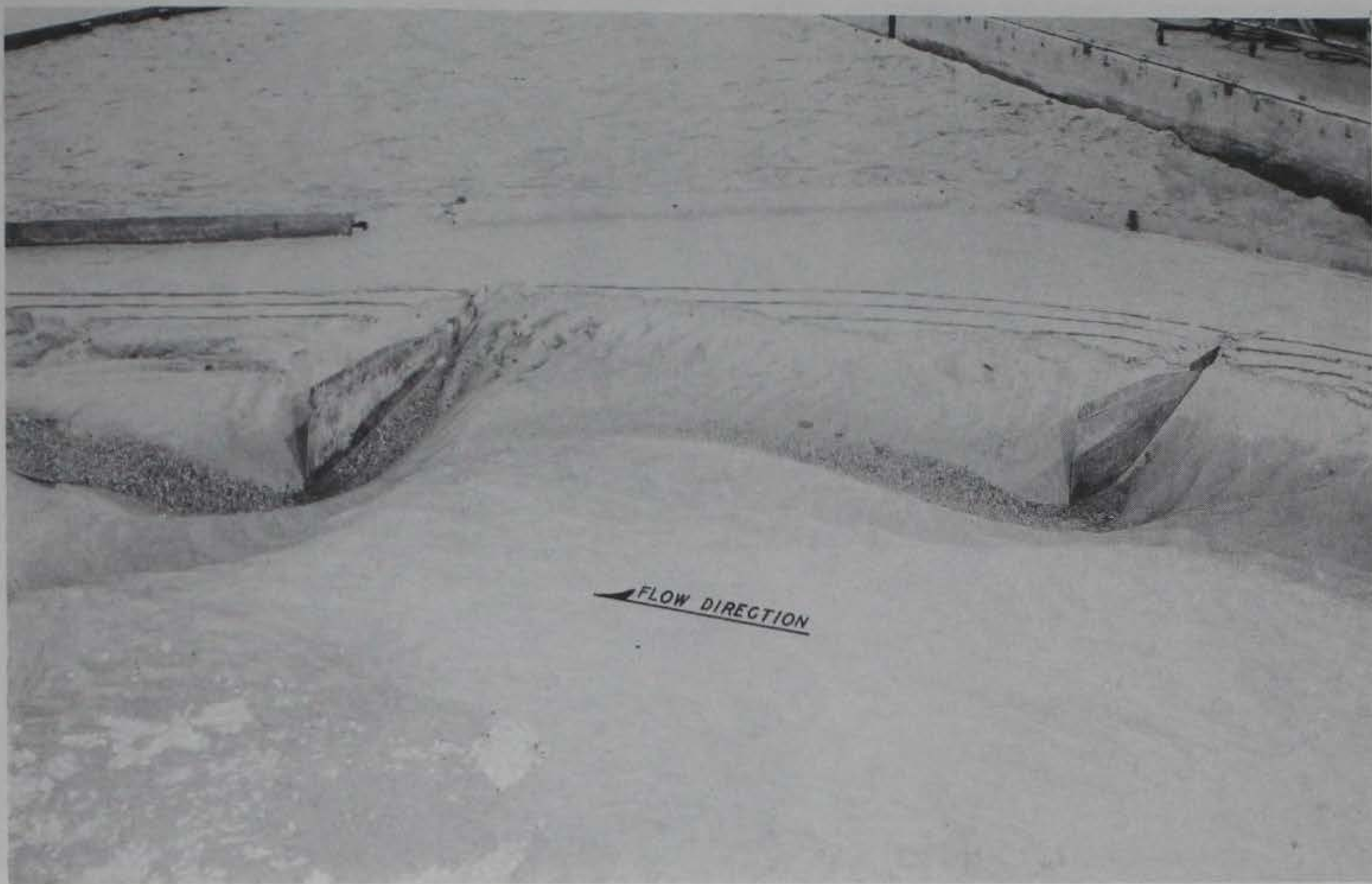


Figure 7. Scour hole patterns; spur dike angle 60 deg

Figure 8. Scour hole patterns; spur dike angle 75 deg

Figure 9. Scour hole patterns; spur dike angle 105 deg

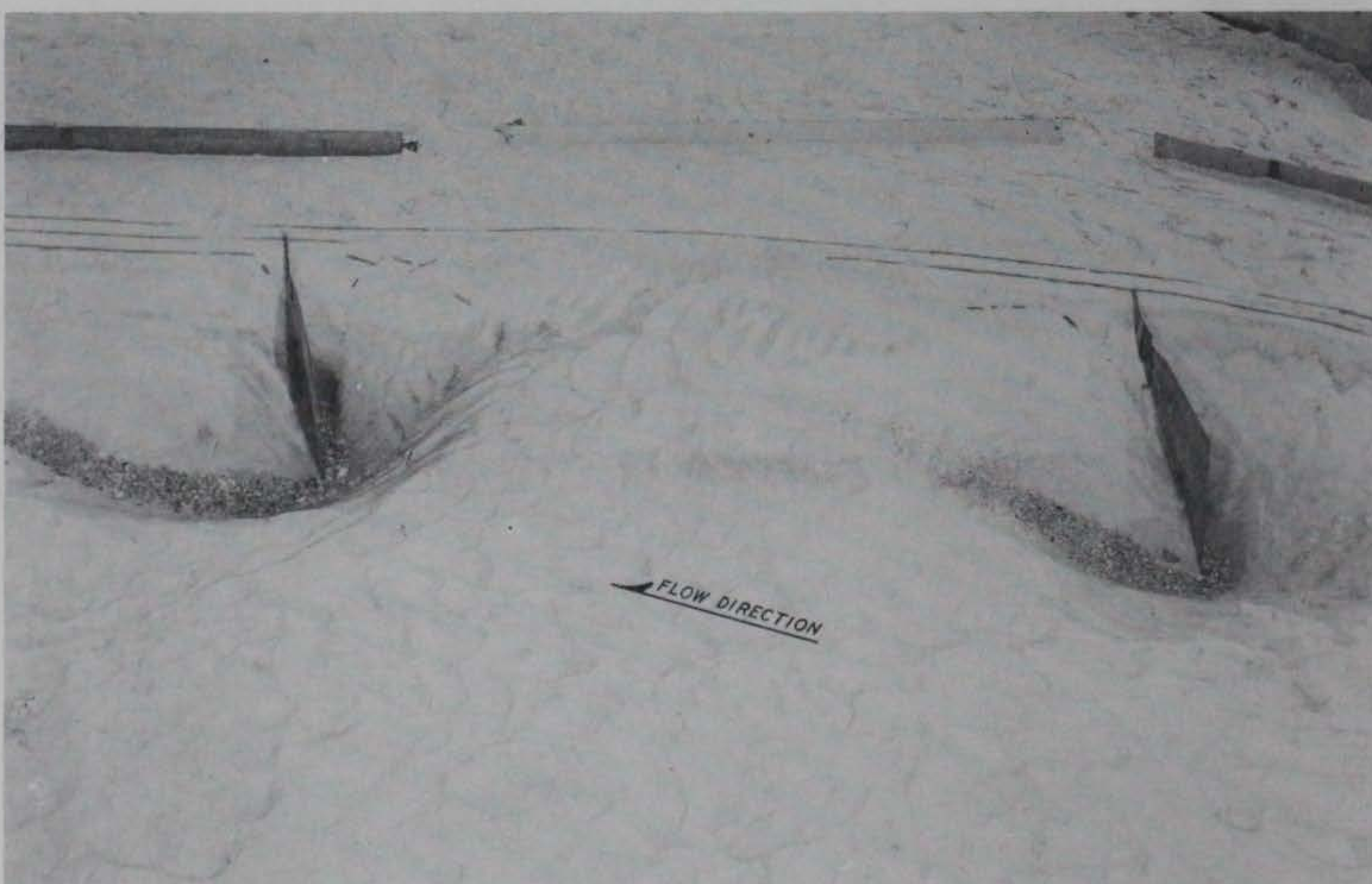


Figure 10. Scour hole patterns; spur dike angle 120 deg

Figure 11. Surface flow patterns; spur dike angle 60 deg

Figure 12. Surface flow patterns; spur dike angle 75 deg

Figure 13. Surface flow patterns; spur dike angle 105 deg

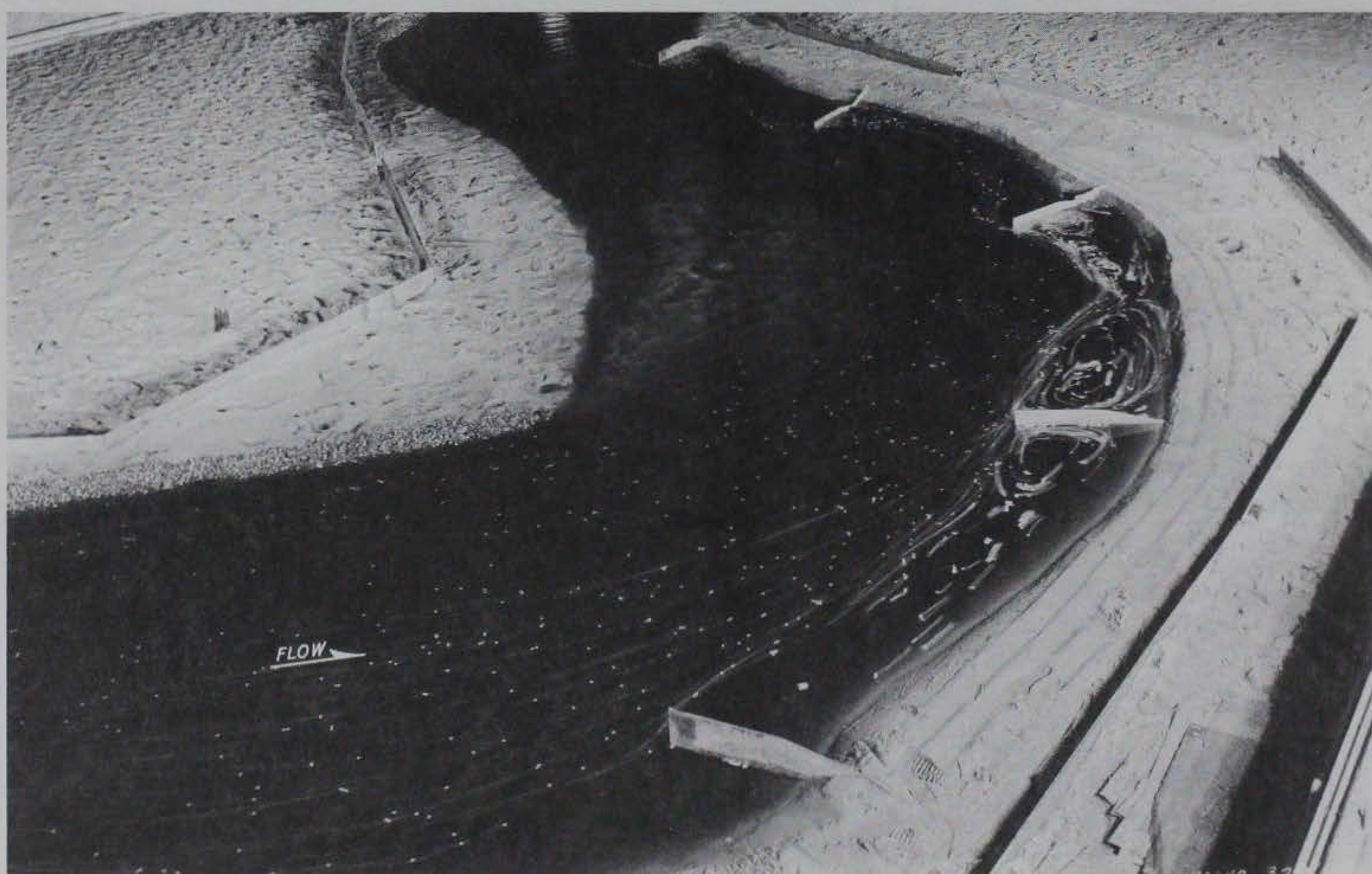


Figure 14. Surface flow patterns; spur dike angle 120 deg

of the scour hole if scour extends to the root. Since scour depths are greater for spur dikes with an upstream orientation, the potential benefit provided by the upstream eddy may be canceled out by the increased size of the scour hole. The spur dikes angled downstream were more successful in directing the flow toward the center of the channel, thus providing protection for a greater distance downstream.

17. The effective length (projection normal to the current) apparently is a more significant factor than the spur dike angle in providing bank protection. Figures 7-14 demonstrate that bank erosion is more severe with orientation angles at 60 and 120 deg than with angles of 75 and 105 deg. It may therefore be concluded that the spur dike should be oriented perpendicular to the bank to obtain the most effective bank protection.

Spacing-Length Ratio

18. In the demonstration model the riverward ends of the spur dikes were initially set a specific distance from the bank. As the testing proceeded, bank erosion occurred between the spur dikes. The rate of erosion was rapid at the beginning of the test but was fairly stable after 24 hr. At the conclusion of testing the distance from the riverward end of the spur dike to the eroded bank was measured and used to determine a relatively stable spacing-length ratio. The initial and maximum final spacing-length ratios for each test are plotted in Figure 15. Data indicated that for the conditions in the demonstration model ($Q = 2.7$ cfs, $F_n = 0.4$), the optimum spacing to length ratio was about 3 to 1.

19. The spacing-to-length ratio is a function of the approach velocity and discharge. This was demonstrated in the model by increasing the discharge from 2.7 to 4.6 cfs and allowing the model to run for 24 hr. With this higher flow the optimum ratio was reduced to about 2 to 1. These results serve to emphasize the need to study proposed bank protection with spur dikes on a site specific basis, using experiences in similar conditions or a model study.

20. The effectiveness of the spur dike in deflecting flow away

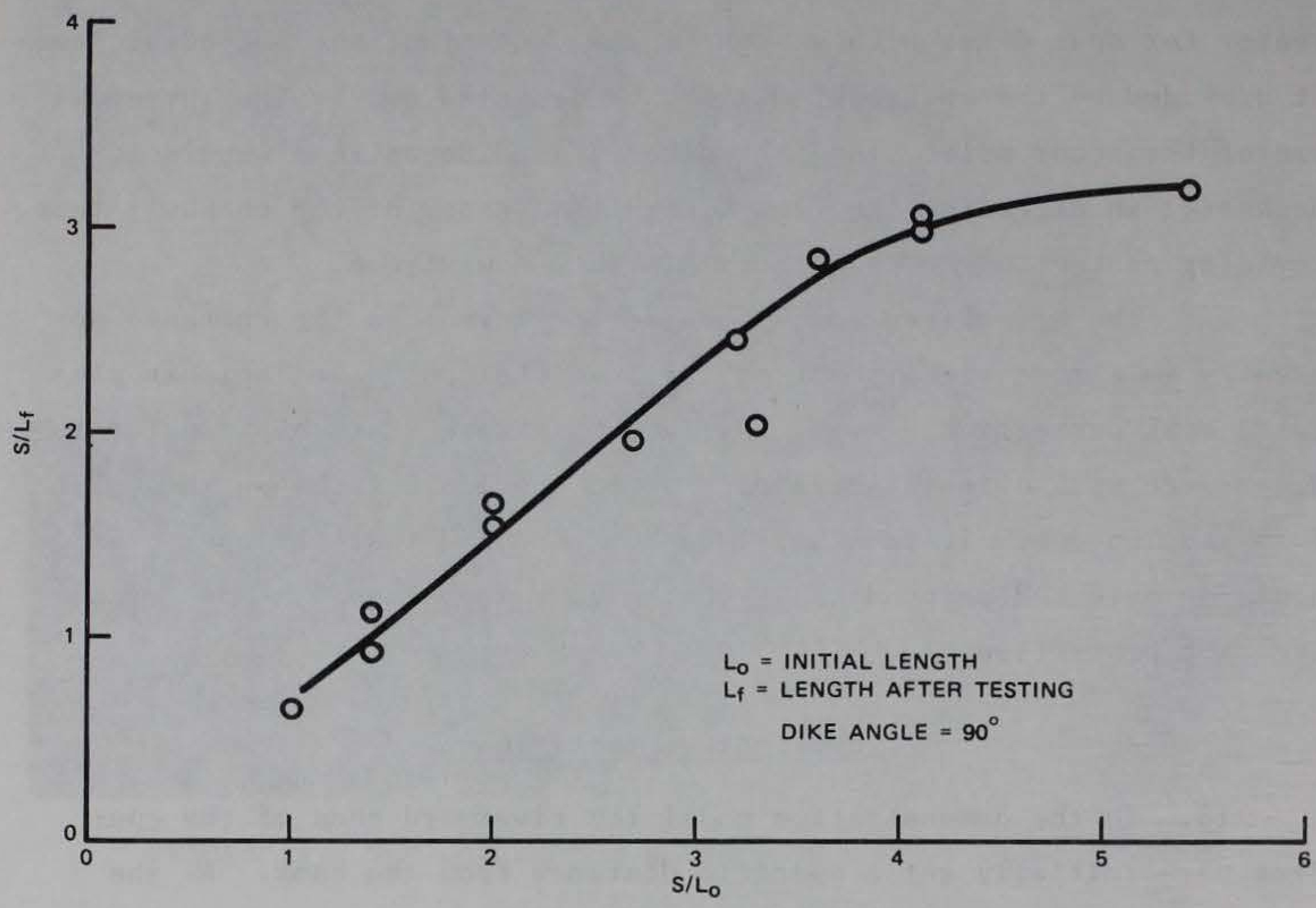


Figure 15. Spacing-length ratio; dike angle 90 deg

from the bank decreases as the length-spacing ratio increases. The eddy pattern set up between dikes is illustrated in Figure 16. With a type 1 circulation pattern the main current is deflected outside of the spur dike field, and a single eddy develops between the dikes. This pattern is optimum for navigation projects because a continuous deep channel is maintained along the face of the spur dike field. With a type 2 circulation pattern a second eddy appears, but the main current is deflected outside of the spur dike field. As the distance between the dikes increases, a type 3 pattern develops in which the main current is directed at the dike itself, creating a much stronger eddy behind the dike and greater turbulence along the upstream face and at the spur dike lower nose. When a type 4 pattern develops, the stability afforded to the upstream dike is washed out and a single strong reverse current develops. With a type 5 pattern the flow diverted by the upstream spur dike is directed at the bank between the dikes. Eddies form on both

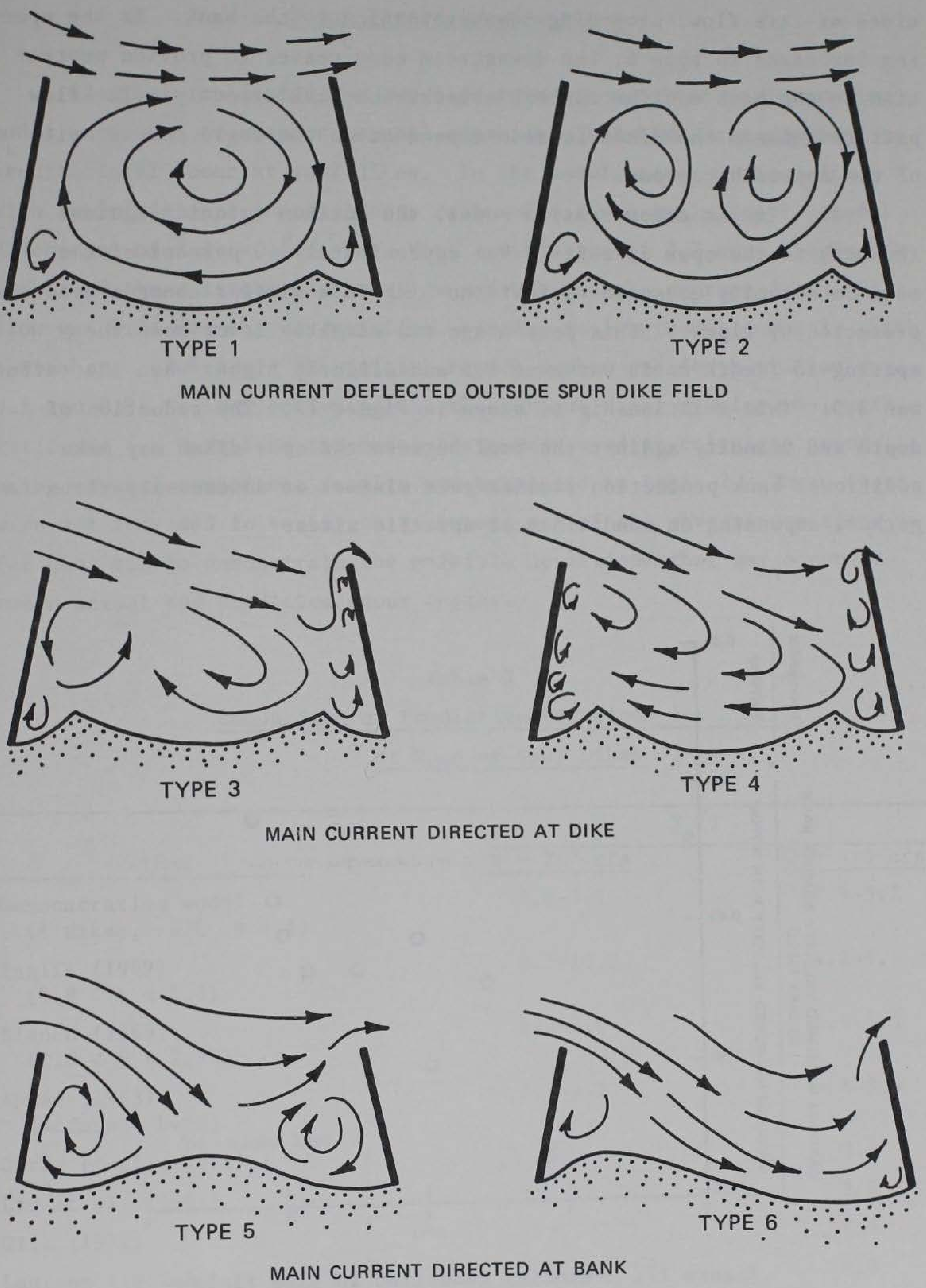


Figure 16. Flow patterns between dikes

sides of this flow, providing some protection to the bank. As the spacing increases to type 6, the downstream eddy ceases to provide protection to the bank and the current attacks the bank directly. The flow pattern between the dikes is also dependent on the angle and velocity of the approach current.

21. In the demonstration model, the maximum velocity against the bank in the spur dike field was approximately 40 percent of the maximum velocity measured against the bank in a similar concave bend protected by riprap. This percentage was slightly lower when the spacing-to-length ratio was near 1.5 and slightly higher when the ratio was 3.0. This relationship is shown in Figure 17. The reduction of depth and velocity against the bank between the spur dikes may make additional bank protection requirements minimal or unnecessary altogether, depending on conditions at specific sites.

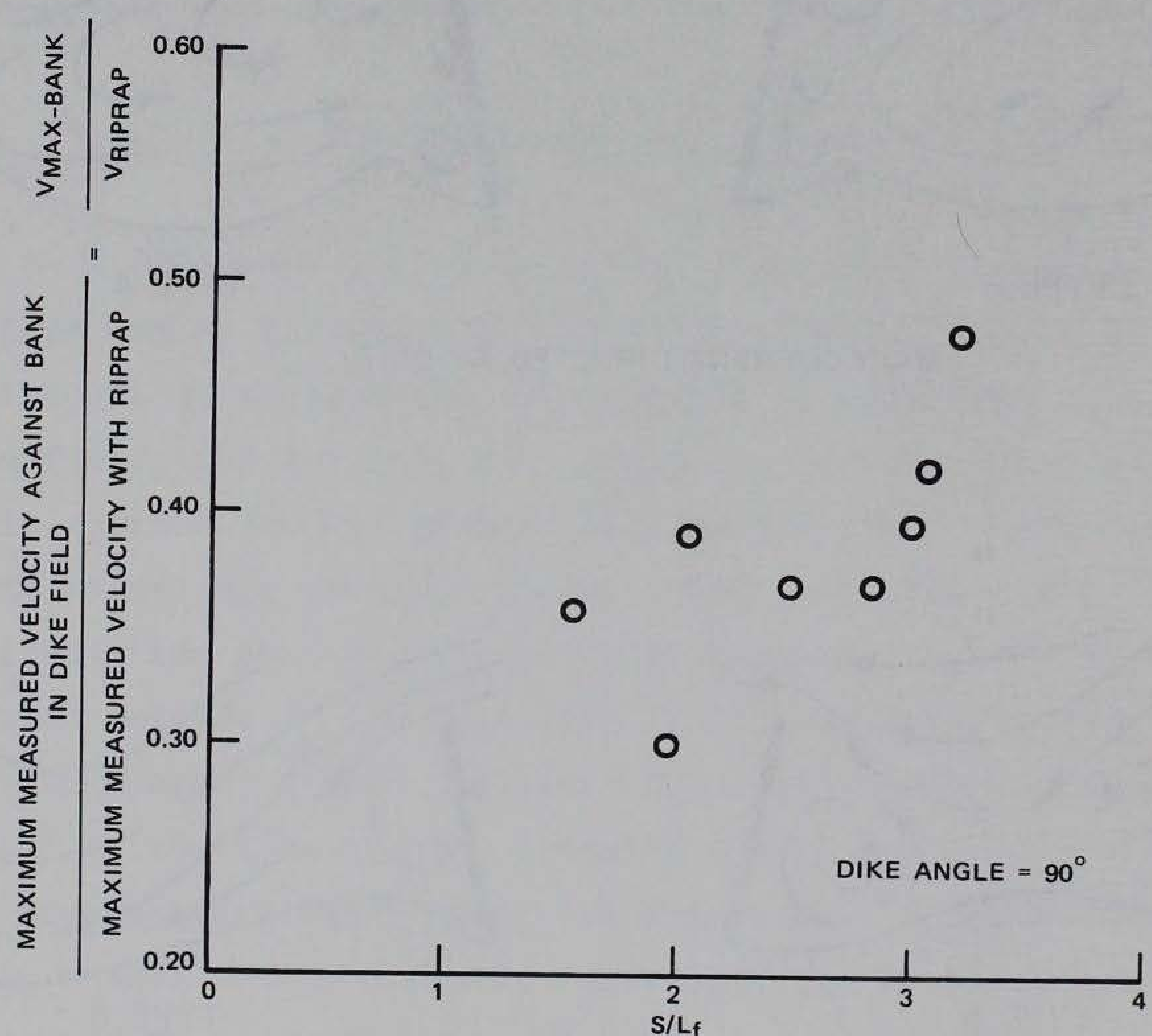


Figure 17. Velocity reduction in dike field; dike angle 90 deg

Scour Prediction Equations

22. Data collected for two flow conditions in the demonstration model were used to compare several equations that have been proposed to predict local scour at spur dikes. In the model, scour at four dikes with an initial spacing to length ratio of 4.1 was evaluated for model discharges of 2.7 and 4.6 cfs. With a discharge of 2.7 cfs, the Froude number of the upstream channel flow was 0.4 and the average depth of flow was 0.24 ft; the maximum final spacing-to-length ratio was 3. With a discharge of 4.6 cfs the initial Froude number and depth of flow were 0.5 and 0.31 ft, respectively, and the maximum final spacing-to-length ratio was 2. Data from the model tests were used to calculate scour using several equations; results are tabulated in Table 2. These tests were not intended to verify or recommend any of the several equations for use, but to demonstrate the possible deviations that may occur between actual and predicted scour depths.

Table 2

Comparison of Predictive Equations for Scour at Nose of Spur Dikes

Method	y_s/y	
	Q = 2.7 cfs	Q = 4.6 cfs
Demonstration model (4 dikes, $S/L_o = 4.1$)	2.0-3.9	2.9-5.2
Inglis (1949) ($0.8 < k < 1.8$)	4.5-10.2	4.2-9.4
Blench (1969) ($2.0 < k < 2.75$)	4.3-5.9	3.9-5.4
Ahmad (1953) (moderate bend)	3.7-4.3	3.8-3.9
Garde et al. (1961)	3.0	3.1
Liu et al. (1961)	2.9	2.8
Gill (1972)	3.2	2.7
Laursen (1962a)	5.3	4.8

Effect of Stone and Gabion Aprons

23. In order to minimize the severe scour that occurs at the toe of a spur dike, mattresses and aprons are often used. These may be constructed of willows, stone, or rock-filled wire baskets. The effect of a riprap apron was demonstrated in the model; the apron (of 5/8-in. rock) was placed around the toe of the dike at a radius of 0.5 ft (approximately twice the initial average depth) at a thickness of 0.08 ft. Initial placement and conditions after 24 hr of testing are shown in Figures 18 and 19, respectively. The apron did not significantly affect the amount of bank erosion or the maximum scour depth. However, the point of maximum scour was moved away from the toe of the spur dike and slightly downstream, substantially improving the structural integrity of the spur dike.

24. Gabion aprons were also demonstrated in the model. The gabions in the model, 0.5 ft long, 0.12 ft wide, and 0.04 ft thick, were made of standard aluminum screen and filled with crushed rock passing and retained on No. 4 and No. 8 sieves, respectively. In the model the gabions were not tied together as they would be in prototype installations, so the separation of gabions that occurred in the model may not be representative of larger scale applications. Initial placement and conditions after 24 hr of testing are shown in Figures 20 and 21, respectively. As with the stone aprons, bank erosion and maximum scour depths were not affected significantly by the gabion aprons. However, even with separation of the gabion baskets the point of maximum scour was moved away from the toe of the spur dike.

Comparison of Scour Depths

25. In the demonstration model, a comparison was made of scour depths in a concave bend protected by riprap to the depths created with a spur dike field. As shown in Figure 22, scour depths are considerably greater at the toe of spur dikes. However, model tests by Liu et al. (1961) indicated that the scour depths at vertical wall dikes, such as

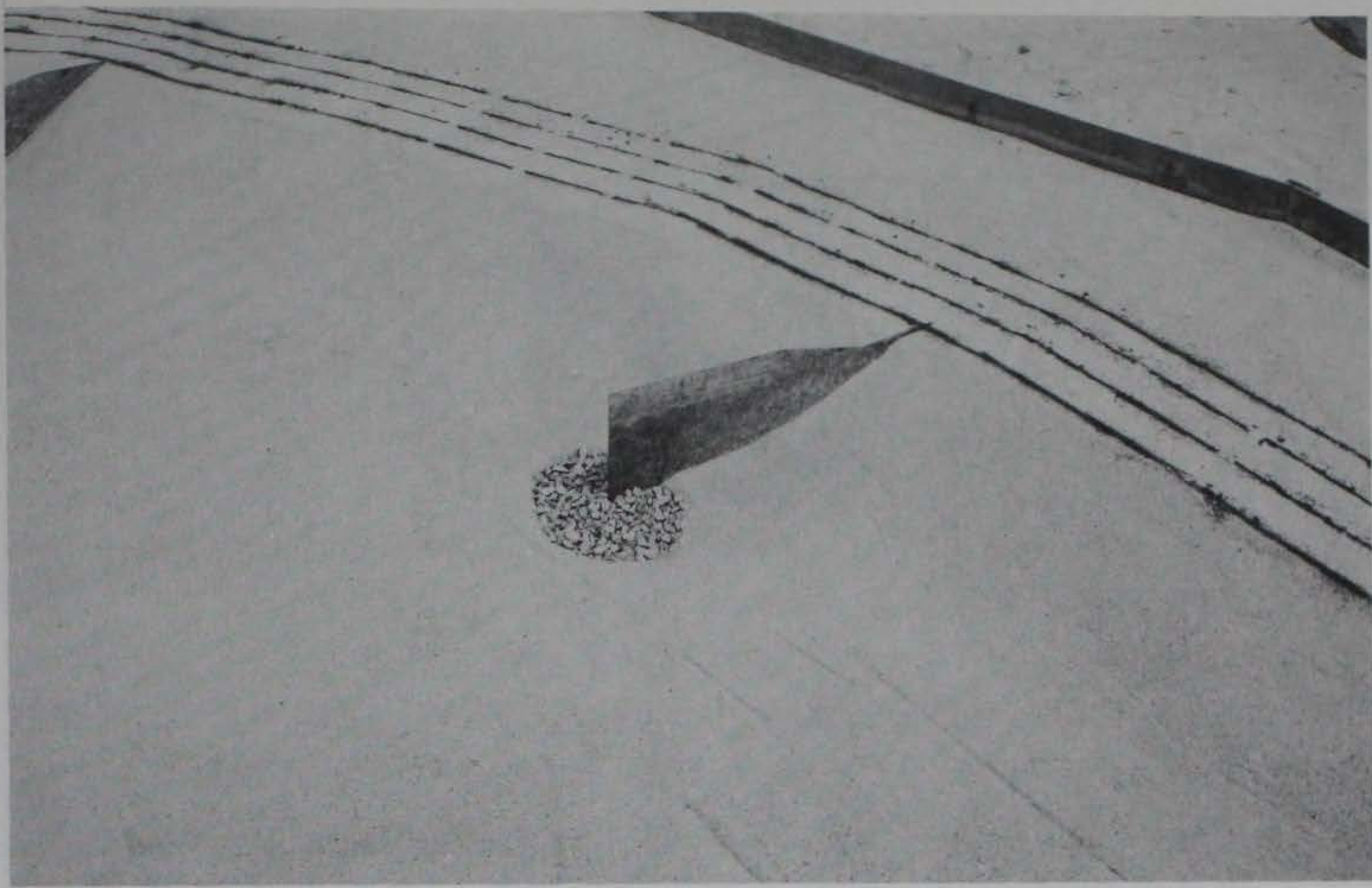


Figure 18. Initial placement of stone apron

Figure 19. Final conditions for stone apron after 24 hr

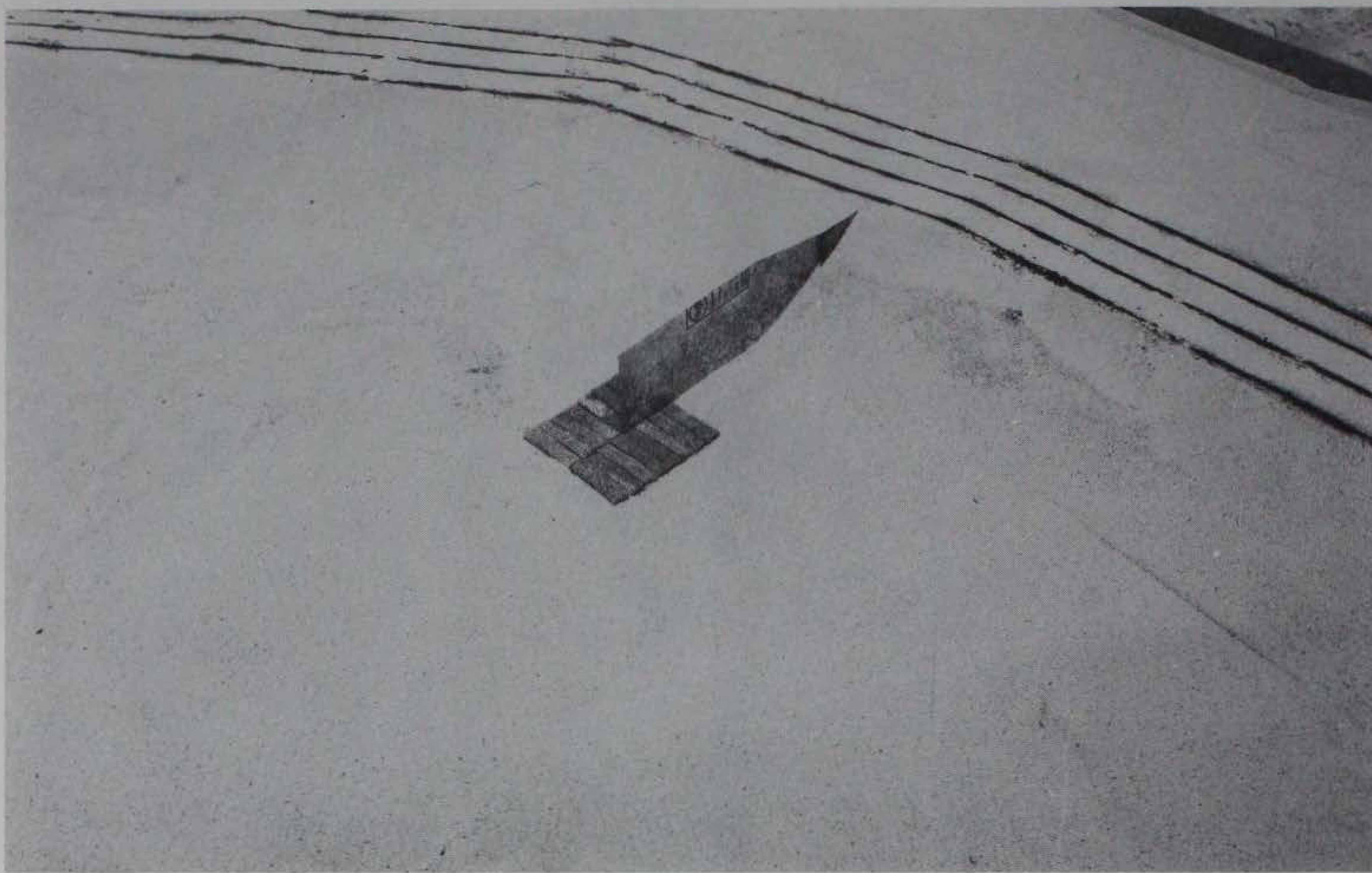


Figure 20. Initial placement of gabion apron

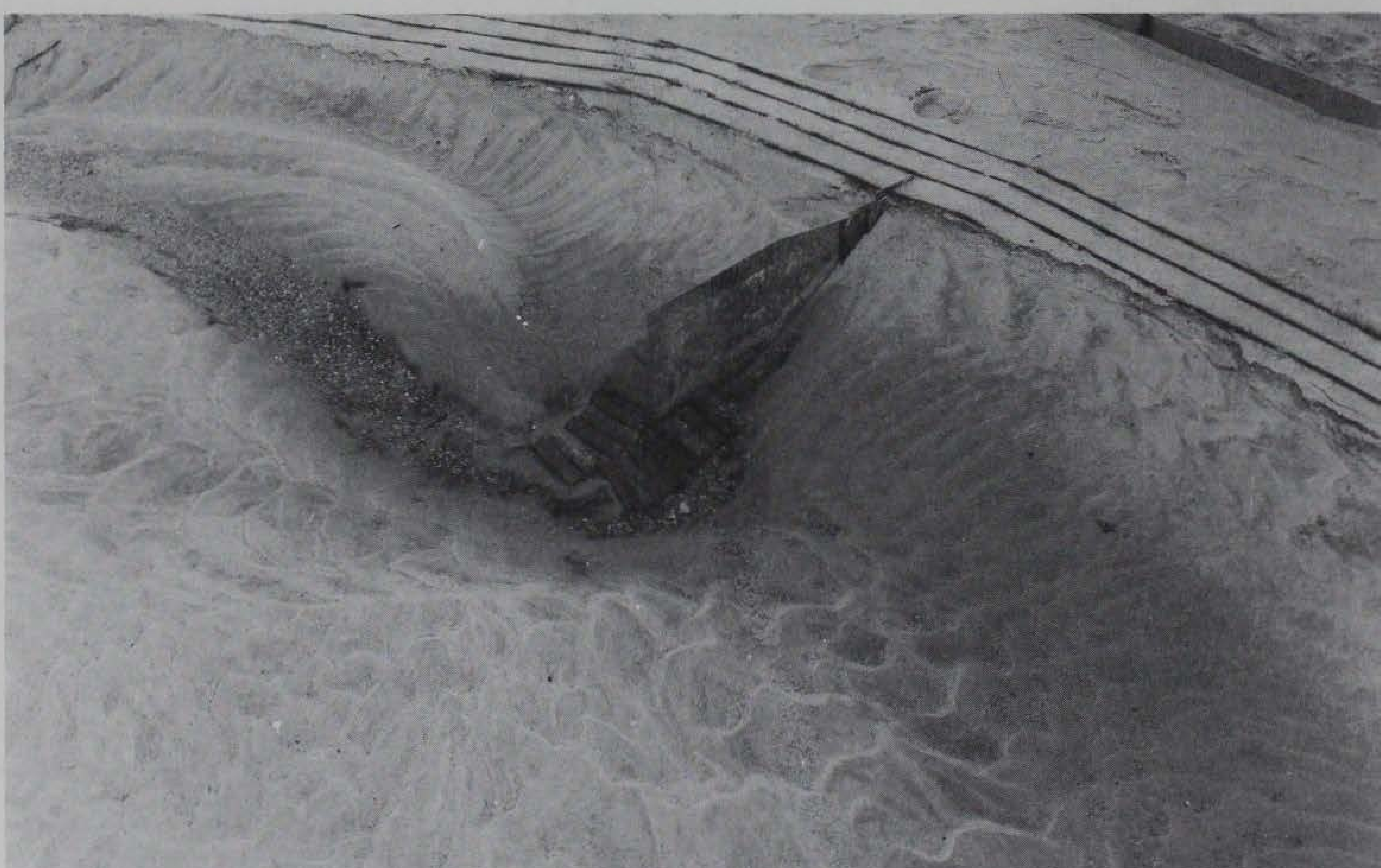


Figure 21. Final conditions for gabion apron after 24 hr

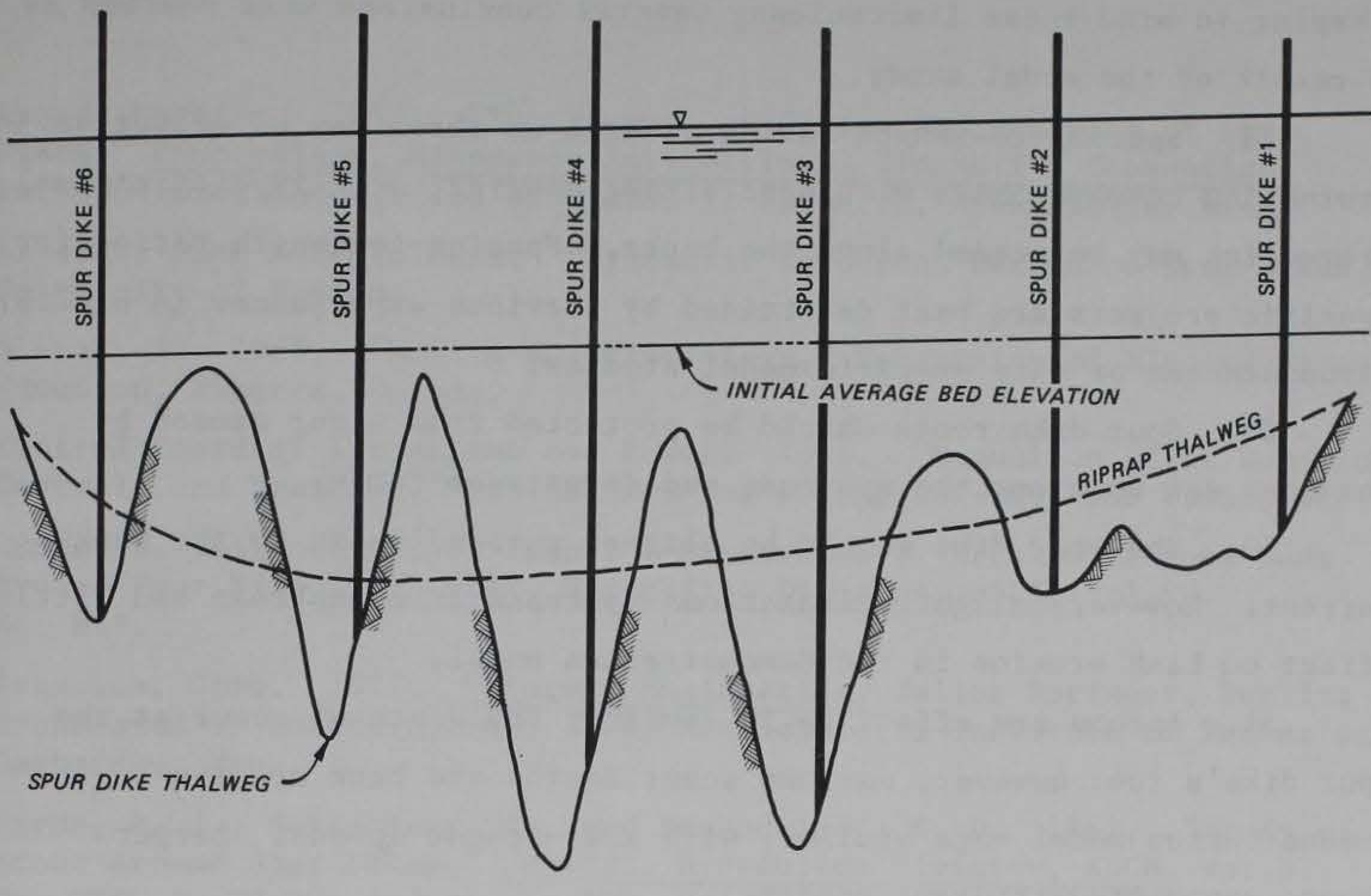


Figure 22. Comparison of thalwegs with riprap and spur dikes

those used in the demonstration model, are about twice the size of scour holes produced at spur dikes with sloping upstream and downstream sides and a rounded sloping nose. The sloping shape is typical of earth and rock-fill dikes with riprap protection.

26. Based on the investigations reported herein there was no apparent correlation between the spacing-to-length ratio and the maximum scour depth. Apparently the scour depth is primarily a function of the magnitude and direction of the approach current, discharge, depth of flow, and the orientation angle of the dike.

Conclusions

27. General design guidance cannot be developed from the demonstration model study. Limitations of the study included steady flow, with only two discharges, a single approach angle, and relatively uniform bed material, no suspended load, and no prototype data for model adjustment to use as a guide in judging reasonableness of predictions.

Keeping in mind these limitations, several conclusions were reached as a result of the model study.

28. Spacing-to-length ratios as high as three may be effective in protecting concave banks with spur dikes; however, some type of minimal protection may be needed along the banks. Spacing-to-length ratios for specific projects are best determined by previous experiences in similar circumstances or site specific model studies.

29. Spur dike roots should be protected from scour caused by vortices set up along the upstream and downstream faces.

30. The spur dike should be aligned perpendicular to the bank or current. However, slight orientations upstream or downstream had little effect on bank erosion in the demonstration model.

31. Aprons are effective in limiting the depth of scour at the spur dike's toe; however, maximum scour depths and bank erosion in the demonstration model were similar, with and without aprons. Larger aprons may yield different results.

32. The development of a scour hole at the toe of the spur dike may be retarded by the formation of an armor layer. This armor may develop from the very coarse size fractions of the bed material, a size fraction that should not be neglected when bed material samples are taken and analyzed.

33. Site specific model studies will provide useful information with respect to velocity reduction against the bank and relative scour tendencies.

34. Existing equations for scour prediction at spur dikes are questionable when applied to dikes in concave bends.

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