THESIS

STUDY OF RIVER BANK STABILISATION IN A BEND BY GROIN

MD. MONOWAR HOSSAIN

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN ENGINEERING
(WATER RESOURCES)

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MD. MONOWAR HOSSAIN

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Chairman of the Comittee	(Hamidur Rahman Khan)
Member	(Abdul Hannan)
Member	(Ainun Nishat)
Member	(M.Khorshed Alam)
Member	(Syed Mohib Uddin Ahmed)
Member	(A.M.M.G. Kibria)
Head of the Department	(Abdul Hannan)

A B S T R A C T

(29)

The present study was aimed at estimating the maximum scour depth at the toe of the both single and double groins, scour size formed at their toes and the downstream length protected by them. The research facilities of Hydraulics and River Engineering Laboratory of Water Resources Engineering Department of Bangladesh University of Engineering and Technology, Dacca was used. Eight test runs were made, five with single groin and rest three with double groins. The projection of the groins were varied from 5 percent to 25 percent of the channel width. These groins were placed at the concave bank of the laboratory channel when it achieved a quasi-stable nature.

It was observed that scour depth formed at the toe of the groins increased with the increase of groin projection. The scour depth at a given groin projection was found to be higher for the case of single groin than that of double groins. Strong statistical correlations were obtained for the case of double groins. For single groin, the data was scattered and correlation was very poor.

The scour area was also found to increase with the increase of groin projection and it was larger in case of double groins than single groin. The downstream length protected

by both the single and double groins were found to increase with the increase of groin projection. In case of single groin, inadequacy of data caused poor correlations. The trend obtained for variation of scour depth conforms with the equations of Inglis (1949) and Mushtaq (1953).

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TABLE OF CONTENTS

LIST OF FIGURES

FIGURES Page

FIGURES | | Page

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

SYMBOLS	DEFINITION	UNITS
A	Area of cross-section	ft^2
A_s	Maximum scour area	ft^2
b	Projection length of groin	ft
B	bar width between groin	ft
D	Mean depth of flow	ft
D_o	Maximum depth of flow at bends	ft
d_s	Maximum scour depth	ft
d_{se}	Equilibrium scour depth	ft
D_L	$0.473(Q/1.76\ d_m^{\frac{1}{2}})^{\frac{1}{3}}$	ft
d_{50}	Median bed material size	ft
F_r	Froude number	-
f	Friction factor Lacey's silt factor	-
g	Acceleration due to gravity	ft/sec^2
L	Length of the channel bend	ft
L_d	Downstream length protected by groin	ft
L_u	Upstream length protected by groin	ft
M_L	Meander wave length	ft
P	Wetted Perimeter	ft
Q	Flow rate	ft^3/sec
Q_s	Sediment load concentration	ppm
q	Discharge per unit width	$ft^3/sec/ft$
R_e	Reynold's number	-

SYMBOLS	DEFINITION	UNITS
R	Hydraulic Radius	ft
r	Coefficient of correlation	-
	Reciprocal of the bar slope	-
r_c	Radius of the curvature	ft
S	Slope	-
u/s	Upstream	-
d/s	Downstream	-
V	Mean velocity	ft/sec
W	Width of the channel	ft
ρ	Density of water sediment mixture	slug/ft^2
μ	Apparent dynamic viscosity of water sediment mixture	Ib-sec/ft^2
σ	Measure of the size distribution of the bed materials	-
ρ_s	Density of the sediment	slug/ft^3
γ	Specific Weight of water	lbs/ft^3
n	Manning's roughness coefficient	sec/ft$^{\frac{1}{3}}$
τ	Local shear stress	lbs/ft^2
HW	High Water	-
LW	Low Water	-
MHHW	Mean highest high water	-
MLLW	Mean lowest low water	-
BUET	Bangladesh University of Engineering and Technology.	-

CHAPTER - I

INTRODUCTION

1.1 General

Bangladesh is a part of the delta formed by the three mighty rivers of the world viz the Ganges, the Brahmaputra, and the Meghna. These rivers along with their numerous tributeries and distributeries form her network of waterways. They also carry huge discharges and sediment loads during the flood period, inundating areas on their banks. These rivers are constantly changing the physiographic and hydrographic nature of the lands by scouring bed and eroding banks during high discharge and flood.

The banks and beds of the rivers of Bangladesh are composed of mainly alluvial materials carried and deposited by itself. Bank caving in this type of river, specially at the bends is a continuous process. This can be visualised by the recent studies on the erosion of river Padma by Rahman (1978). He concluded that the Ganges-Brahmaputra confluence at Goalundo is migrating at the rate of 6880 feet per year. He stated that the bank line was shifting in an erratic manner and the maximum rate of erosion was approximately 1100 feet per year. Similar characteristics may be found in other rivers if studied in detail.

Land erosion by bank caving through the action of the moving water at the bends of the alluvial channels in Bangladesh is a great concern for two reasons. First, the unchecked erosion represent a loss of natural resources upon which we depend for our food and fibre; and second, its end product-sediment can represent a damage to flood plains, urban areas, navigation facilities, downstream reservoirs and other improvements.

To save lands, cities and costly engineering structures from river erosion, crores of takas are being expended each year. Various methods are in use to stabilise the river bends of which groin is very common in Bangladesh. Its popularity for protecting the bank erosion can be visualised by its frequent use at different places of the country like protection of Kurigram town against erosion of Dharla river, protection of Kushtia town from erosion of Gorai river,protection of Chandpur town from erosion of Meghna river, protection of Sirajgonj town from Jamuna river, protection of Sowapur bridge on Feni river, protection of erosion at Balla in Sylhet district by the Khowai river and protection of right bank embankment at downstream of Kazirhat regulator on the little Feni river.

The study of erosion problem is very complex and are guided by a number of factors and variables that influence river characteristics. It is difficult to isolate the variable and study them separately. The physical characteristics of the channel includes the shape of the channel cross-section , the configuration of the bed including the form of bed roughness, riffles and bars, longitudinal bed profiles and channel pattern In such a situation, small scales laboratory study may lead to prediction of the prototype behaviour of the alluvial rivers.

1.2 Importance of laboratory study

Owing to a number of complex factors in the design of hydraulic structure, adequate answers to various problems cannot yet be obtained by analytical methods. Small scale laboratory study have, therefore become very effective and handy tool for the engineer in the solution of his problem, specially where extreme complex variables are involved, for example, the behaviour of three dimensional vortices in the vicinity of a local scour.

Construction of any structure on a channel, specially rivers in alluvium is very expensive in many cases for its size and in most cases for the great difficulties involved during construction. It is this very high cost of the structure within the domain of a river that does not permit an error in the design. Laboratory study helps in visualizing the prototype behaviour in most cases at a fraction of the actual project cost and thus the possibility of error in design can be greatly reduced or even eliminated.

Small scale study in the laboratory is thus, always helpful for the following reasons:

i. They make it easier to visualize the whole problem

ii. They help in guessing the qualitative nature of the important details exposed in the bed.

iii. Various alternatives can be tested to achieve the best solution.

Results from small scale study in the laboratory do not always provide informations prevailing in the actual situation. As for example, the movement of sediment in a natural river is a combination of suspension, rolling and saltation, and most of its load is usually carried in suspension. In the laboratory channel, bed load movement is due to particle which move on or near the bed and very little material goes into suspension. Silting, as a result of movement of bed load can be reproduced fairly accurately in the laboratory channel, but siltation resulting from deposition of materials in suspension does not occur naturally in laboratory channel (Gole 1971).

It has also been observed that in the laboratory channels two-third of the scour takes place during 5 percent of the operation time, whereas silting is slower than in natural river. If the time during which laboratory channel is run is increased to permit more silt deposition, scour which occurs more quickly would be excessive. As the angle of repose of bed material remain the same both in natural river and laboratory channel, the later gives too large an extent of the scour hole. This exaggerated hole vitiate the flow pattern in the laboratory channel.

1.3 Objective of the Study

The study of bank stabilisation by groin in the bends of alluvial river is often necessary. But the present day knowledge regarding the behaviour of groins is far from being adequate. As such a study have been taken up with the following objectives:

i. to investigate the area and depth of scour at the toe of the groin for different projections for both single and double groins.

ii. to investigate the area protected in the bend both upstream and downstream of the single and double groins.

iii. to observe the effect on scour and area protected by the groins depending on its position of placement.

iv. to investigate the morphological changes at upstream and downstream of a bend due to placement of single and double groins.

CHAPTER - II

REVIEW OF LITERATURE

2.1 Introduction

The geometry and shape of an alluvial channel is the result of the interaction between water discharge, the quantity and characteristics of sediment discharge, and the composition of bed and bank materials. Prolonged interactions tend to achieve an equilibrium or " in regime " status. A channel in regime exists in a state of dynamic equilibrium, self adjusting its channel pattern, cross-sectional geometry, slope and bedform. These adjustments occur as the channels ability to transport sediment, balances the available sediment load.

Channel patterns probably represent an additional mechanism of channel adjustment which is tied to the channel gradient and cross-section. The pattern itself affect the resistance to flow. The existence of one or another pattern is closely related to the amount and character of the available sediment, the valley slope and the quantity and variability of discharge. An understanding of the nature of these channel patterns and the factors that are related to their occurence is important for both river regulation and channel stabilization works. In the following, a brief review is made on stable alluvial channel, bank stabilization works with special emphasis on groin and scour.

2.2 Stable Alluvial Channel

2.2.1 Definition

Lane(1955) presented an excellent definition of stable or regime channel as follows: A stable channel is an unlined earth channel for carrying water, the banks and bed of which are not scoured objectionably by moving water and in which objectionable deposits of sediment do not occur. Kennedy (1895 after Nishat 1981) suggested that a stable channel is non-scouring and non-silting type . Blench (1957) considered a channel "in equilibrium" to be one in which average value of various channel parameters do not show any definite trend of variation over a period of time.

Thus , in a stable channel, minor deposition or scour can take place but over a period of time the bank and bed must be stable.

2.2.2 Characteristics of stable alluvial channel

This type of river is characterised by the stability of the alignment of channel and slopes, as well as of its regime, which may change within a year, but shows little variations from year to year except, perhaps the river may migrate within its permanent bankline. Changes such as scouring and silting of bed, advancement of the deltas into the sea and changes in bed and water slopes over a long period of time do take place, but these are insignificantly small. Such rivers mould their characteristics in such a manner that most of the sediment load brought down by them is carried to the sea. The same river may have either aggrading, degrading, stable and other characteristics from its down to mouth. Its nature depend upon the amount and size of sediment entering the river, its load carrying capacity and other factors. Even the same reach in a river may pass through various types, depending on the variation of sediment load and discharge with time. But when this equalizes over a period of time, so that on the average, the energy of the stream is just sufficient to transport the material supplied to it, the stream is stable (Shen 1971).

2.2.3 Factors influencing channel stability

The factors that govern the stability of alluvial channels are many and varied and has been extensively studied by many scientist at various time. The distribution of shear stress at the beds and banks of the alluvial river influences its stability. Bankful discharge is an important factor in the determination of stable channel geometry(Lacey 1958). Leopold and Maddock(1953) found that the width, depth and velocity in rivers varied with the mean annual discharge. Lane (1957) found that the longitudinal slope of a stream has major effect on stream channel form. Leopold and Wolman (1957) obtained that meandering occurs more at a lower channel slope than at braided or straight channels for the same bankful discharge. It is known that sediment properties and its gradation materially affects the hydraulic behaviour of the alluvial channels (Shen 1971). Seepage from the ground water to the channel or from the channel to the ground affects its stability. Another important factor in channel stability is the composition of bed material which influences the critical tractive force. Vegetation along channel banks also is found to be helpful in bank stability.

Secondary currents or transverse flow is one of the major factors that control the geometry of the alluvial channels. Shen (1971) reports that the phenomenon of secondary currents has been extensively studied by various researchers e.g.Einstein and Li (1958), Einstein and Shen (1964), Shen and Komura(1968) and Goldstein (1965).

2.2.4 Secondary current or Transverse flow

Most channels provide flow in a main flow direction at each point along the channels. It is also observed, even in a straight channel that bed sediment is not evenly distributed over the width; it forms asymmetric patterns of bars and moves in paths that contain significant cross-components. Flow components in the direction of the cross-section is known as secondary currents. In a steady flow these secondary currents must be circulations for reasons of continuity and are possible only if the vorticity of the flow has component in the direction of main flow. The secondary current is intimately connected with that of vorticity.

In laboratory flumes, the secondary velocities in the transverse direction has been found to vary from 0.6% to 2.5% of the main mean flow velocity. Secondary circulation concentrated near the outer corner of the boundary has significant effect on the stability of the channel. Shen and Kamura(1968) fo nd in a laboratory flume that a strong circulation developed at the junction between smooth bed and rough wall can actually enhance meandering tendencies in straight alluvial channels.

Figure 2.1a shows the cross-section in a bend of open channel flow. Let us separate a fluid element with length dx and depth h and let us consider the forces acting on it in the radial direction. Two forces will act on the element under consideration ; the centrifugal force, whose variation over the vertical will correspond to the variation of the square of tangential velocities, and an opposing force, due to the existence of a transverse slope, this force is obviously constant throughout the depth and can be expressed by γdz. A graphical summation of these two curves Figure 2.1(b) indicate the absence of equilibrium in the fluid in the plane of the stream cross-section. The curve obtained from the summation of the transverse velocity components indicates the presence of a flow directed toward the concave bank in the upper part of the vertical, and of a reverse flow in its lower part. Since there should be no residual flow discharge in the transverse direction, the areas of these curves of opposite direction must be equal. Transverse currents superimposed on the longitudinal flow , form a screw like type of circulation which can be observed in river bends. This explain the existence of the transverse currents.

2.3 Bank Stabilisation Methods

2.3.1 Introduction

The stabilisation of a river in its broad aspects, cover all engineering works constructed on a river to guide and confine the flow of river channel and to control and regulate the river bed configuration for effective and safe movement of floods and river sediments. River stabilisation may be done by different types of protective devices which may be classified as to the materials of which they are constructed, the general shape of the devices, or as in the following according to their function or application.

i. Armor
ii. Ratard
iii. Jetty
iv. Groin
v. Bulkhead
vi. Baffle

The river stabilisation devices have long histroy world over and is one of the earliest engineering achievement of controlling the river flow by man. However, the suitability of the method used for stabilisation is dependent not only on the purpose but also on the fund available, convenience in use for short-run effect and ease of maintenance.

The use of groin as a popular means in the stabilization of river banks is due to one or more of the following reasons:

i. Stabilises the river along a desired course by attracting, deflecting or repelling the flow in channel.

ii. Protects the river bank line from eroding and caving by keeping the flow away from it.

iii. Creates a slack of flow with the result of silting up of the area in its vicinity ;.

iv. Contracts a wide river channel usually for improvements of depth for creating facility of goods and smooth navigation.

2.3.2 Groin

A groin is a bank or shore protection structure constructed in the form of a barrier placed transverse to the primary motion of water and extends from bank into the river, designed to control the movement of bed load. This structure is known by several names, the most familiar being spurs, spurdikes, and transverse dike and constitute probably the most widely used stabilization works.

These devices are usually solid; however, upon occassions to control the elevation of sediments they may be constructed with openings. They may be classified according to the method and materials of construction, functions served and height.

2.3.2.1 Classification according to method and materials of Construction

i. Impermeable groins

a) Single line of steel or concrete sheet piling

b) Double line of steel or concrete sheet piling, filled

b) Rock dike-plain cement concrete; grouted or asphalt surfaced.

ii. Permeable groin

a) Precast plain cement concrete blocks

b) Precast plain cement concrete cells

c) Metal rectangular cell

d) Pile groin

e) Tree groin

(i) Impermeable Groin

Impermeable or solid groins consist of rock fill or earth core armoured with resistant materials like stone grouted, pre-cast plain cement concrete blocks, fascine mattress. They do not allow appreciable flow through them. They are designed to attract, repel or deflect the flow away from the bank along a desired course.

An apron is usually provided to prevent slipping of stone of the groin nose and shank into the scour hole in the vicinity. For this reason the apron stone should be sufficient after lanching to shield the sloping facies of the land bank from below the bottom of the slope faces down to the deepest bed level. The stone weight should not be less than 100-120 pounds each.

Generally, it is expensive to make a very flat slope for the nose of the groin. Groins are therefore given normally a slope 1:2 to 1:3 . Scour gradually diminishes from head to the bank and apron protection can be reduced accordingly.

(ii) Permeable groin:

Permeability of a structure indicates a damping action on the velocity of flow as distinguished from the deflecting or repelling action of impermeable structure. Permeable groin therefore, fall into the class of sedimenting groin. They obstruct the flow and slacken it to cause deposition of sediment carried by the river. They are, therefore, best suited for sediment carrying streams. In comparatively clear rivers, their action results in damping the erosive strength of the current and thus prevent local bank erosion. As sediment accumulates between the groin, the foreshore becomes more or less permanent, so that, need to use durable material does not arise. Permeable groin require only temporary or a semi-permanent construction.

Permeable groin have the important advantage of being comparatively cheap. They are therefor, specially adaptable for river works where stone is difficult to obtain. Experience have shown, that permeable groins are more effective than solid ones in the control of river course or in the protection of banks erosion, specially in a silt-laden river. Flow through the groin does not change abruptly like that passing in impermeable groin, thus resulting in no serious addies and scour holes. This is perhaps the reason why silt deposit is evenly and quickly affected.

Permeable groins are not however strong enough to resist shocks and pressure from debris, floating ice and logs. They are therefore, unsuitable for upper reaches of rivers. During floods submerged type of groins are danger to navigation.

The most common type of permeable groins used in our country are tree groin and pile groin because of their availability, ease of construction and economy and functions served.

2.3.2.2 Classification according to functions served

These are of the following types :

i. Attracting type
ii. Repelling type
iii. Deflecting type

(i) Attracting type of groin

Groins pointing downstream in the direction of flow attracts the river at its nose. Such a groin causes scour holes to form closer to the bank than the groin inclined at right angles. In otherwords, they tend to maintain the deep currents close to the bank. The main attack of the river is on the upstream face of the spur and therefore needs better protection compared to that on the downstream (Fig. 2.2)

Its use has been limited by the experience of rivers in many countries. These groins endanger the adjacent banks and are not usually recommended in the Indian sub-continent due to failure of protecting certain structures from bank erosion. However, some engineers suggest that they may be constructed at 0.4 of the mender length upstream of the object to be served.

(ii) Repelling type of groin

Groins pointing upstream against the flow deflect the river away to the other bank. Repelling groins are usually successful in achieving the desired result if they are properly located with due regard to their position in relation to the meander length. The angle of deflection upstream varies 60° to 80° with the banks or in other words, the goin facing upstream make an angle of 10° to 30° with a line perpendicular to the bank or thalweg (Fig. 2.2). Generally the head of the repelling groin causes disturbance in the flow at its nose and heavy scour occurs downstream due to eddy formation. These groins therefore should have a strong head to resist the direct attack of swirling current. The scour diminishes from the head towards the bank and protection of the slope and apron can be reduced accordingly. A still water pocket is formed upstream of this type of groin and suspended load brought down by the rivers get deposited in this pocket.

(iii) Deflecting type of groin

A deflecting groin is much shorter in length than a repelling groin and is generally constructed in river perpendicular to the bank and it only deflects the flow(Fig.2.2)

2.3.2.3 Classification according to the hegith of groin below high water

These are mainly submerged and non-submerged type. Generally non-submerged type of groins are prefered.

2.3.2.4 Special types of groin

Special types of groins include Denehy's T-headed groin, hockey groin and so many others named after local use or of persons contributed for it (Fig. 2.2).

Denehy's groin was first used for bank protection in 1880 by Denehy at the Okhla barrage, Delhi on the Yamuna river. Later, this type of groins were used at Narora(Uttar Prodesh) on the Ganges and also for the protection of Kushtia town from the erosion of Gorai river. The head of the groin has T-shape of which the front perpendicular arm is parallel to the current. A longer portion of the head is usually on the downstream side. These groins are usually economical since a shorter length can protect more areas from erosion compared to the other types.

Amongst the various design for groin heads, a groin with a curved head is termed as a hockey groin. It increases the attracting tendencies of the groin and is not likely to be helpful for bank protection.

2.3.3 Design criteria of groin

Factors pertinent to design are : materials, alignment grade, permeability, length and spacing.

Common materials inorder of permanance are stone, concrete , steel and timber. Stone groins are built in a massive trapezoidal section that depend on weight for stability. Concrete is precast either in heavy solid blocks, fillable cells, or skelatal interlocking forms like tetrapods. Steel may be as simple as a line of sheet piling, or compounded of H-piling, walling and sheathing. Timber is adaptable to a multitude of forms : sheet piling, pile fence, pile bent, ballasted crib or boom.

Alignment of groin has been the subject of comprehensive study by many engineers, both in theory and in observation of performance, but without deriving a conclusive or compelling reason for departing from the conventional alignment normal to the bank line.

Grade of groin should conform to the ultimate profile of the land protected by groin for overall security. Since, sand may be entrained over a low barrier, the grade may be established higher than the land but this is very rare.

Permeability is permitted as a desirable characteristics instead of being designed as a necessary element. Ordinary placement of stone will leave 30 percent voids, which is usually advantageous. Grouting seals most of the passage, but may be necessary to adapt small stone to serve exposure.

Regarding the spacing between adjacent groins, the general practice has been to adopt a certain proportion of their length, varying with the width of the river. Groins are usually spaced further apart with respect to their length in a wide river than in a narrow one, if their discharges are nearly equal. The location of the groins i.e. whether at a concave or a convex bank, or at a crossing, affects their spacing. A larger spacing is usually adopted for convex banks and a smaller one for concave banks with intermediate spacings at the crossings. A spacing of 2.0 to 2.5 times the length of groins is a general practice.

No general rules has yet been formulated for fixing the length of groins. It depends entirely on the exigencies arising in a specific case. However, a relationship between length and spacing of groin may be established as suggested by California Highway Practice (Fig. 2.3)

$$b = \alpha B + rh \qquad \text{-----} \; (2.1)$$

where,

b = length of groin in ft.

α = obliquity of entrapped bar in radian

B = bar width between groin

r = reciprocal of bar slope

h = range in stage.

A typical section of a trapezoidal groin defined by a top width and side slope is shown in the Fig. 2.4.

Varshney and Mathur (1977) analysed a large number of river training measures incorporating repelling groins constructed in India and suggested the following relationship for evaluating the length of groin, if arch chord ratio of the acute loop is available.

One groin ($Q \leq 28000$ cumecs)

$$\frac{b}{W} = 0.755 \left(\frac{\sqrt{A}}{Fr^{1.5}} \right)^{-0.65} \qquad \text{---- (2.2)}$$

One groin ($Q > 2800$ cumecs)

$$\frac{b}{W} = 0.469 \left(\frac{A}{Fr} \right)^{-0.45} \qquad \text{--- (2.3)}$$

Two or more than two groin ($Q > 2800$ cumecs)

$$\frac{b}{W} = 0.369 \frac{A^{0.55}}{Fr^{0.33}} \qquad \text{--- (2.4)}$$

and a general equation for the relations as follows:

$$\frac{b}{W} = 0.374 \left(A^{-0.29} / Fr^{-0.145} \right) \qquad \text{--- (2.5)}$$

where,

b = length of groin

W = width of active river

Fr = flow froude number

A = arc-chord ratio of worst loop

2.4 Scour

2.4.1 Introduction

Scour holes are created by the flowing water around the toe of the groin, bridge piers, abutments and other hydraulic structures. These holes may cause for its failure. If the scour depth is great enough to uncover the supporting soil of these structures, it may subside there and ultimately washed out by the current.

The following interrelated factors may cause change in elevation of bed at the toe of the groin or around piers or abutments.

(i) Local scour : Scour caused directly by the flow disturbance of the structure. It occurs adjacent to the structure, and its magnitude varies according to the flow, sediment and shape of the structure.

(ii) Scour due to contractions : The reduction of flow areas by the presence of structure will increase the flow velocity there, augment the capability of flow to carry more sediment than the upstream reach and thus decrease the river bed at the contracting section.

2.4.2 Local Scour

Local scour is defined as the abruptdecrease in bed elevation near a hydraulic structure due to erosion of bed material by the local flow induced by the structure. The type of the local scour may be classified by the amount of sediment transport into and out of the scour hole.

Let q'_s be the capacity of the flow to transport sediment out of the scour hole and let q''_s be the rate at which sediment is supplied to the scour hole by the undisturbed flow.

The following cases arise:

(i) No scour, i.e., $qs' = qs'' = 0$; (2) Clear water scour i.e., $qs' > 0$ and $qs'' \sim 0$ and (3) scour with continuous sediment motion is., $qs'' \geq qs' > 0$. Only case 2 and 3 cause abrupt changes in bed elevation. Since sediment movement on the bed begins and increases gradually, the distinction between case 2 and case 3 is not a sharp one. It has been found that the depth of scour varies almost linearly with tractive force for clear water until an equilibrium depth is reached(Shen 1971). The distinction between case 2 and case 3 and definition of equilibrium scour depth, dse , are shown in Fig. 2.5.

2.4.3 Origin of local scour

The growth of scour hole is preceeded by the apperance of large-scale vortex structure in the flow. The sudden appe-rance of the vortex structure are the basic mechanism of local scour and this fact has been recognised by many investigators e.g. Tison (1940), Posey (1949), Laursen and Toch (1956), Shen, Schnieder and Karaki (1969), Roper and others (1967).

Laursen (1960) found experimentally that with continuous sediment motion, the depth of scour is a function of the depth of flow and geometry of the structure. Carstens(1966) related the scour with the general sediment motion.

2.4.4 Scour due to contraction

The increased velocity due to contraction of the flow area is probably the major cause of failure of hydraulic structure. Laursen(1960, 1963), and Komura (1966) are major contributors in this area of research. Contrary to local scour, where all analyses are based on experimental results, the investigations on scour due to reduction of flow area are more analytical in nature.

2.4.5 Scour at the toe of groin

Scour depth at the toe of groin has been studied in small scale laboratory channels and in a model studies by different researchers. Inglis (1949) concluded from the model test of groins at the Ganges near Hardings Bridge that groin projecting from the bank into the channel give widely varying values of maximum scour depth, ranging from 1.7 to 3.8 D_L,

where,

$$D_L = 0.473 \left[Q/1.76 \ d_m^{0.5} \right]^{\frac{2}{3}} \qquad \text{--- (2.6)}$$

depending upon the severity of the river curvature which inturn depend on the length, angle of projection and position of the groin in relation to the attack.

Mushtaq (1953) suggested an equation after studies in a laboratory channel to calculate the probable scour depth for various discharge intensities at the toe of the groin in the following form :

$$d_s = kq^{\frac{2}{3}} \qquad \text{---(2.7)}$$

where, k is a factor whose value is dependent on the position of groin and q is the discharge per unit width at the groin constriction. He analysed the problem of scour by plotting different non-dimensional terms that affect it. He defined a term, $d_s/q^{\frac{2}{3}}$ as scour constant which is widely accepted in the study of scour at groin toe.

Khosla by using Kennedy's (Mushtaq 1953) regime flow formula and after applying correction for velocity, connected the depth of scour with discharge intensity by the relation,

$$d_s = 0.90\ (q^2/f^{\frac{1}{3}}) \qquad \text{--- (2.8)}$$

where, f is a Lacey's silt factor, which is a function of silt size. This formula holds for regime channels, He also recommended multiplications factor in calculation of d_s for different types of bends.

Laboratory studies at Irrigation Research Institute, Lahore(1969) have found that groin projection have a definite influence on the downstream length protected. This council suggested an optimum projection beyond which groin projection have an adverse effect in its performance.

CHAPTER - III

LABORATORY SET UP AND MEASUREMENTS

3.1 Introduction

The study was carried out in the Hydraulics and River Engineering Laboratory of the Department of Water Resources Engineering of Bangladesh University of Engineering and Technology, Dacca. The existing facilities of the alluvial sand bed flume with all other necessary arrangements were used in this respect. A brief description of the facilities and the experimental procedure is given below:

3.1.1 The Flume

The flume was 50 feet long, 15 feet wide and about 3 feet 6 inches deep having double walls along its length (Fig. 3.1). The inner wall was provided with $\frac{1}{2}$ inch diameter hole with a spacing of one foot both in horizontal and vertical direction to facilitate movement of water from the sand bed to the annular space between the two adjacent walls and vice versa. The water table was controlled and maintained to the desirable level in the sand bed by regulating the water level in the annular space. The outer wall and bed of the flume was water tight to avoid losses due to seepage.

3.1.2 Water supply system and measuring device

Water was supplied to the test channel by two centrifugal pumps. These pumps were installed near the tail water tank. Water was introduced at the inlet of the channel.

with the help of two delivery pipe lines, which after flowing through the channel entered into the tailwater box. It was re-circulated by means of the pumps. This process was followed to have a continuous supply through the test channel.

Two-one inch automatic flow meters were connected (one in each pipe line) to the pipe lines to measure the volume of water flowing through each line with an accuracy of one-hundreth of a gallon. The time for 10 gallons flow was recorded by a stop watch and the discharge rate was calibrated.

The desired discharge was achieved with the help of the loss line attached to each delivery pipe line. Required amount of flow was allowed into the test channel and excess was diverted into the tailwater box through the loss line.

3.1.3 Tailwater box :

The tailwater level was maintained constant by supplying water from the main supply line of the laboratoty. Approximately one foot length of the test channel at the downstream end, measured from tailwater box, was kept submerged throughout the tests to permit the stream to change its longitudinal water surface slope naturally. This also eliminated backwater effects in the lower part of the test channel and also helped the pumps to operate under a constant head, thereby maintaining a more or less constant discharge.

3.1.4 The sand bed

The bed and bank material consisted of a mixture of fine and course sand for which the gradation curve is shown in Fig. 3.2. The median size, which is defined as d_{50} i.e. 50 percent of the material is finer than the given size was found to be about 0.1473 mm. Size distribution of the bank and bed materials is also expressed by the gradation co-efficient 6. This parameter is defined as:

$$\sigma = \frac{1}{2} \left(\frac{d_{84}}{d_{50}} + \frac{d_{50}}{d_{16}} \right) \qquad \text{--- (3.1)}$$

in which d_{84} and d_{16} are the size of the bed or bank material for which 84 percent and 16 percent materials respectively are finer. Hence, σ is the average slope of the two segments of the size distribution curve. Its value was found to be 2.65.

3.1.5 Flow entrance

In all set of tests an initial bend of about 30° with the longitudinal axis of the initial channel was provided to develop uniform meander pattern. This entrance section was made of thin steel plates about four feet long. This allowed a slow transition in velocity from the entrance to the channel.

3.1.6 Initial channel

A channel was moulded in the bed by means of trowel and template, as shown in Fig. 3.1. In all tests, the size of the initial channel was 9 inch wide and 2 inch deep.

3.1.7 Sediment feeding

For sediment feeding, same materials composing the bed and bank was used. Sediment was introduced at the entrance of the test channel with the help of an automatic dry sand feeder. The feeder was driven by a motor which was attached to a gear box, having control devices to regulate the rate of sediment feed into the channel. A calibration curve for the sediment feeder was prepared Fig. 3.3. This operation was required to maintain the desired sediment load in the channel. The desired rate of sediment feed was that one which caused the change of longitudinal slope of the channel bed minimum. This rate was determined by few trial runs before the actual test run and was found to be 885 ppm.

3.1.8 Discharge and slope

Discharge and slope was kept constant throughout the study . A constant discharge of 0.0267 cfs and slope of 0.0052 was provided in all tests.

3.1.9 Measurements

A movable bridge was designed on which a point gage was mounted to take readings. The bridge was operated manually along the length of the channel,. Its position was read by noting the marks on the rail over which the bridge was moving The bridge was marked in feet and inches with zero at the center that coincides with the center line of the initial channel. All readings were taken with the help of level with a fixed bench markk to avoid any error arising due to sag of the movable bridge.

3.2. Experimental Procedure

Before each tests, the sand in the flume was levelled and compacted. A channel was excavated along the center line of the flume. In each test the bed of the channel was given a slope with the help of a tightly held string along the center line of the channel and measuring the elevation at an interval of five feet. Before water was introduced into the test channel, the ground water table was raised by pumping water into the annular channels and filling the tailwater tank.

The recirculating pump was set to maintain the desired discharge with the help of the loss line. The dry sediment was fed at the entrance of the channel with the previously calibrated sand feeder at the predetermined rate to maintain the slope change within allowable limits.

A total ot eight test run were made in the laboratory. In five of them effect of single groin were studied and in the other three double groins, a spacing of two times the projection lengths were used. In all the runs groins were placed in two different locations, spacing between them were such that the flow characteristics at the downstream groin were not affected by the upstream groin. Thus ten sets of results were obtained in the study of single groin while six sets were obtained under double groin condition.

In the study of both single and double groins projection lengths were varied from 5 percent to 25 percent. In the study of single groin location of the groins were also varied. The groins were placed at a channel bend after the test run achieved a quasi-equlibrium status.

At the beginning of the test run, the rate of change in bank formation was very high. After several hours of running the channel appeared to have obtained a stable shape which was evident from more or less stable shape of the meander. Groins were placed at that stage. The time required to achieve the quasi- stable form varied from 40 hours to 72 hours depending on the method of run i.e. continuous or intermittent. At the end of this stage the following data were collected:

i. Location of the left and right banks along its profile.

ii. Location and slope along the thalweg

iii. Location of pools and crossings

iv. Cross-section of the channel at bends where the groins were placed and at crossing downstream of the said bends.

After the completion of the collection of the above data, groins, impermeable, made of solid metal plates, were placed at the desired locations. The channel was then run. The effect of groin placement was observed. Test run continued until stability was restored. The following measurements were made at the end of this stage:

i. Location of left and right bank along its profile

ii. Location and slope of the thalweg

iii. Cross-section of the channel at bends where groins were placed and at crossing where earlier measurements were taken.

iv. measurements of the area and depth of scour hole formed at the toe of the groin.

v. Length of the area protected along the bankline of the channel, both at upstream and downstream from the groins for the said bend.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Introduction

The scour depth and scour area formed at the toe of the groin and downstream length protected due to placement of groin, the parameters that form a relationship amongst them have been considered for analysis. These parameters are length of groin projection b, average width of the channel W, scour depth d_s, scour area A_s and downstream length protected L_d . Mushtaq(1953), suggested that b/W is a more useful independent variable than b for the analysis of scour at a groin toe. He also considered q, the discharge per unit width of the channel at groin constriction as an important variable. Considering μ and ρ as relevant fluid properties and g, the acceleration due to gravity, he obtained an equation (equation 2.7) from a parameter $d_s/q^{\frac{2}{3}}$ was established. He termed it as scour constant K, which is widely used for the analysis of scour at a groin toe. The scour depth calculated by using Mushtaq's equation, Inglis's equation and Khosla's equation were compared to the scour depth obtained in the present study.

The relationship presented in this study were established by statistical analysis using IBM 370/115, located at the BUET Computer Centre. The form of the correlation which produced the best value of coefficient of correlation (r) was taken as the final correlation.

4.2 Effect of groin on bank erosion and deposition

It has been mentioned in article 3.2 that groins were placed at two different bends for each set of test such that the downstream groins were not affected by the presence of upstream one. Figures 4.1 to 4.10 show the position of single groin and figures 4.11 to 4.16 show the positions of double groins. These figures indicate the projection of groins and identify the position of placement with reppect to average width of the channel bend for the case of single groin. Bank-line and thalweg has been shown before and after placing of groins by firm and broken lines respectively. Locations of sediment deposited areaand erosion have also been shown in these figures. Depositions were found to be formed at the downstream side of the groin whereas erosion at the upstream. Areas protected from further erosion by silt deposition were measured as the length at downstream of the groin along the bank and erosion was measured by the length eroded by bank-caving at the upstream face of groin.

Study of the figures from 4.1 to 4.16 show that when groins were placed with any projection at a bend of the concave bank, there were some siltation downstream of it. It was also observed that as the projection of the groins were increased, the length of the silted up area also increased. Figure 4.1 to 4.10 show the zones of silt deposition and erosion for the case of single groin and figures 4.11 to 4.16 show the same for the case of double groins. The major cause for siltation at the downstream of the groins was the obstruction created by the groin projection to the main flow with a change of velocity and direction. As the projections were increased the deep water channel may have shifted away from the bank towards middle of the channel and creating a slack of flow near the downstream bank of the channel resulting in siltation there.

To determine the effect of groin projection in the downstream length protected, two parameters b/W and L_d/W were used. Best fit correlation were determined for linear, semi-logerithmic and logerithmic forms of equation. Fig. 4.17 shows the best fit condition obtained in logerithmic plotting.

The equations for single groin and double groins conditions are:

Single groin, $L_d/W = 2.84(b/W)^{0.74}$ --- (4.1)

Double groin, $L_d/W = 1.49(b/W)^{0.47}$ --- (4.2)

Figure 4.17 indicate that with the increase of groin projection ratio, single groin may have better performance over double groins. This is contrary to the established concepts in bank protection techniques. At this stage of study, no definite conclusion may be derived in this respect, mainly due to insufficiency of the data volume. In the study of double groin condition, all groins were placed at the same location, the variable being the groin projection. In case of single groin, while changing the groin projection, inadvertently the groin position were moved away from the correct locations. Probably, this is the reason of anomaly in the performance of single groin over double groins. Though equation 4.1 and 4.2 are not recommended to be conclusive , they show the probable trend of groin projection in protecting the downstream length.

It has been observed that with the increase in radius of carvature, there was decrease in maximum depth . This phenomena was also valid with-groin condition. A plot (Fig. 4.18) has been obtained for single groin condition. This is in agreement with Rzhanitsyn (1960, after Simon 1971).

Erosion was observed at the upstream position of the groin locations. This may be due to the flow in transverse direction caused by the placement of groin.

4.3 Effect of groin on the cross-sectional area and velocity

Figures 4.19 to 4.26 show the variation of cross-section at the bends where groins were placed and variation of cross-section at crossings downstream of it for the case of single groin. The continuous firm line indicates the cross-section before placing of groin and broken line indicates the cross-section after placing of groin. The variation of cross-sectional area for the case of double groins both at bends where groins were placed and at downstream crossings are shown in Figs. 4.27 to 4.32 . Due to placement of groin at the concave bends, the channel width were reduced and effective cross-sectional area of the flow was decreased. Since the discharge was constant, the average velocity of flow was increased. The increased velocity resulted in scour of the bed vertically downward at the groin side and the deep water channel was shifted away fr the groin.

Erosion was observed at the bank opposite of the groin side. This may be the effect of secondary currents generated by the projection of groin. Little variation of cross-section were observed at crossings for both single and double groins. The changes of average velocity at the crossings were also insignificant. These are shown in appendix-B. Small change in width-depth ratio at the crossings for different tests can also be seen from the tables. The deflected current at the bends may have lost its energy in scouring around groin toe by forming vortex and eddies and that may be the probable reason for more or less stable nature of crossings.

4.4 Effect of groin on the size of the scour hole

Scour holes were formed at the toe of the groin for all tests. The plan areas of the scour holes are shown in figures 4.1 to 4.10 for the case of single groin and in figures 4.11 to 4.16 for the case of double groins. The size of the scour holes were found to increase with the increase of groin projection for both single and double groins. To ascertain the trend of increase of scour area with the increase of groin projection, the parameters A_s and b/W were plotted in normal, semi-logerithmic and logerithmic papers for both single and double groins. Best fit correlations were obtained for the plottings on these papers. Figure 4.33 shows the best fit correlations with equations in logerithmic form for both single and double groin conditions and are expressed as follows:

Single groin : $A_s = 0.887\ (b/W)^{0.245}$ ---(4.3)

Double groin : $A_s = 2.679\ (b/W)^{0.596}$ ---(4.4)

The best fit line for the case of double groins have a good correlation of 0.892 . However, in the study of single groin, the correlation was very poor. The coefficient of correlation in this case was only 0.39 . Thus, statistically results obtained for single groins may not be acceptable. Collection of more data for single groin condition is obviously essential. However, figure 4.33 does reflect on the nature of scour hole size with the increase in groin projection; scour area varies as some power of groin projection for both single and double groin condition.

It may be observed in figures 4.1 to 4.16 that the shape of the scour holes for single and double groin conditions differ. The shape of the scour hole for double groins were found to be elliptical and for single groin a balloon shape with a bulge at one corner pointing toward the downstream direction. The shape of the single groin scour hole is in agreement with Mushtaq (1953).

The strong vortex structure formed at the toe of single groin having a vertical axis of rotation widened the scour area with the increase of groin projection. For the case of double groin probably, a weaker vortex structure was formed at the toe of the second groin along with the vortex at first groin toe enlarging the scour area at the downstream direction producing a shape like ellipse having its major axis along the flow direction.

4.5 Effect of groin on depth of scour hole

Efforts were made in this study to form some idea about the maximum scour depth formed due to the groins. As mentioned before, the shapes of the scour hole differed. Similarly, the locations of the maximum scour depth also differed between the single groin and double groin condition . In figures 4.1 to 4.10 approximate contour lines with the location of the deepest point for single groin condition are shown. Figures 4.11 to 4.16 show similar observations for double groin conditions. It may be seen that the location of the deepest point for double groin conditions are close to the second groin and located approximately at the same distance from the bank as the groin length. For single groins, the deepest point was slightly away from the groin nose and in the downstream direction.

To determine the effect of groin projection, the relationship between b/W and maximum scour depth d_s was obtained as shown in figure 4.34. The form of equations for which the best values of r was accepted. For double groin condition, a very high degree of coherence was obtained ($r = 0.972$).

In case of single groin, the data was scattered as evident from the poor correlation of 0.38 only. In the study of single groin conditions weak correlation was obtained in previous section and the probable reason has already been explained. However, the trend of scour depth variation with groin projection may be assumed from figure 4.34 . The equations for the two conditions are:

Single groin : $d_s = 0.205\ (b/W) + 0.196$ --- (4.5)

Double groins : $d_s = 0.583\ (b/W) + 0.046$ --- (4.6)

It may be observed here that the scour depth for the case of double groins are less than that for single groin at the same projection. This variation may be explained by vortex structure formed at the groin toe. As mentioned in section 4.4, the vortex having its vertical axis of rotation is the cause for increase of scour area. The increase in scour depth with the increase of groin projection is due to the vortex induced by the groin at its toe which has a horizontal axis of rotation. The strength of the vortex may be a function of the shape and geometry and number of inducing structure. Two parallel groins may have a dampening effect on the strength of vortex structure and thus result in smaller scour depth in case of double groin. The point of maximum depth were found to occur a little downstream from the toe of the groin due to combined action of vortex structure and flow velocity towards the downstream direction.

4.6 Effect of groin projection on scour constant

The variation of scour constant, $K = d_s/q^{\frac{2}{3}}$ with the groin projection was also studied. As was done before, the best form of correlation was obtained for both single and double groin condition (Fig. 4.35). Once again very good correlation was obtained for double groins condition ($r \doteq 0.87$) , while for the single groin condition scatter in data produced in poor correlation ($r = 0.20$). The equations for single and double groins may be expressed as:

Single groin : $K = 2.510(b/W) + 5.125$ ---(4.7)

Double groins : $K = 11.811(b/W) + 0.995$ ---(4.8)

Scour constant is a measure of scour depth. Though equation 4.7 and 4.8 do not produce definite relationship between K and b/W , they may be used in preliminary evaluation of scour dimensions.

4.7 Comparison of predicted scour depth

Inglis(1949) from the observation of model studies of groins at the Ganges near Hardinge bridge concluded that maximum scour depth varies widely; ranging from 1.7 D_L to 3.8 D_L depending on the severity of river curvatures, length and angle of projection and position of the groin, where D_L, have been defined by equation 2.6, and with d_m as median grain size of the bed materials. The maximum scour depth calculated by the equations obtained in this study(equations 4.5 and 4.6) lies within the range given by Inglis's equation for the case of single groin. The maximum scour depth calculated by equation 4.6 is in agreement with Mushtaq's equation (equation 2.7) for the prediction of probable scour depth for double groins only. The scour depth obtained in this study are very high compared with the prediction by Khosla's equation (equation 2.8).

CHAPTER - V

CONCLUSION AND RECOMMENDATION

5.1 Conclusion and Recommendation

The present study deals with the problem of bank erosion of alluvial rivers. To stabilize the eroding banks by groins,a laboratory study was carried out and a series of tests were made as described in the preceeding chapters, based on which following conclusion may be drawn.

(a) The scour depth formed at the toe of groin increases with the increase of groin projection. The maximum depth of scour at the toe of single groin was found to be greater than the maximum scour depth formed at the toe of double groin for the same projection (Fig. 4.34). The variation of the scour depth with groin projection was also studied and a definite correlation could be obtained for double groin condition (equation 4.6). In case of single groin no statistical correlation could be obtained but the trend is similar to that of double groin. Results obtained in this study are in agreement with Mushtaq(1953) and Inglis (1949).

(b) The size of the scour hole increases with the increase of groin projection and that the area of scoure hole for double groin is larger than the area of scour hole for single groin at same projection. Much scatter in data was obtained for single groin condition. A good fit of data for double groin condition is given by equation 4.4. The shape of the scour hole for single groin was balloon shaped with a bulge pointing towards downstream direction. For double groins, the scour hole was elliptical in shape.

(c) The downstream length protected by groins also increased with increase of groin projection, the variation being logerithmic. However, at this stage of study no definite equation can be suggested due to inadequacy of data volume.

(d) An increase of relative radius of curvature was observed with the decrease of maximum depth at pool. This observation is in agreement with that of Rzhanitsyn, 1960(Simons 1971).

5.2 Suggestions for future studies

As a next step in the laboratory investigation, the study of the effect of groin projection on scour and area protected may be extended by incorporating the following:

i. By using different size of bed and bank materials

ii. By varying the discharge over a wide range

iii. By changing the spacing of groin

iv. By providing inclination as well as changing projection of the groin.

v. By using groins of various shapes and types

vi. By changing the location as well as projection of the groin.

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APPENDICES

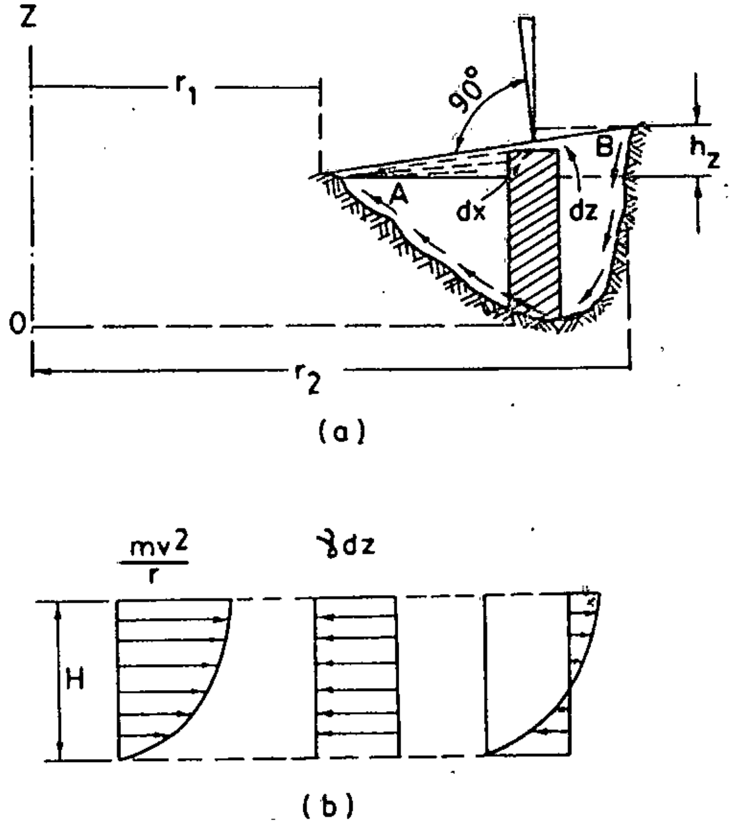


Figure.2·1 Secondary currents at bends of open channels (after Simons, 1970)

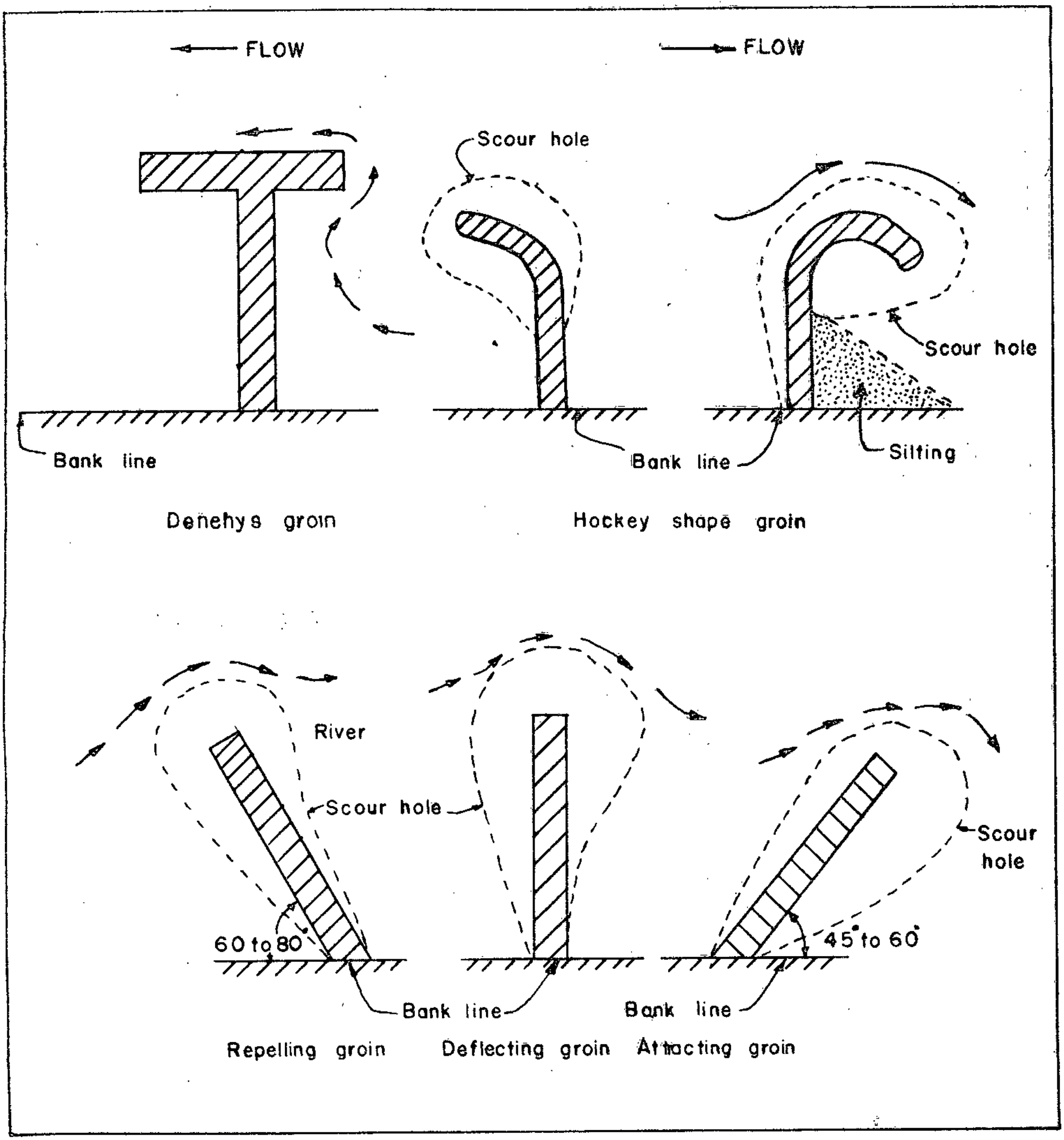


Fig. 2.2 different types of groin (after Punmia and Lal 1977)

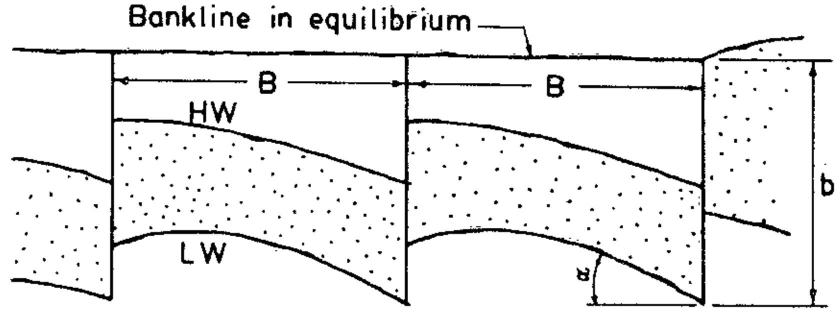


Figure 2·3 Groin design (after California Highway Practice)

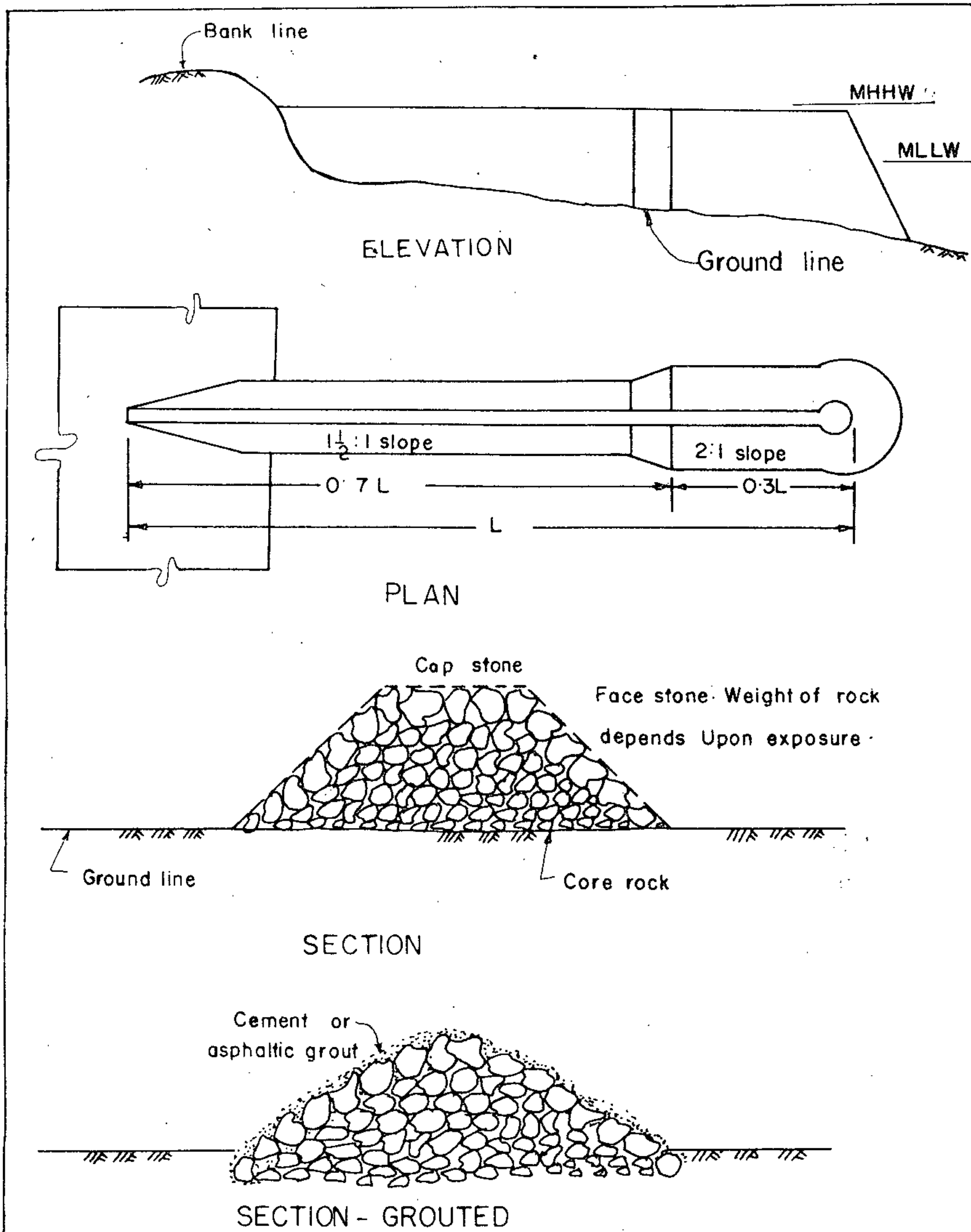


Fig. 2·4 Typical stone dike groin details. (after California Highway Practice)

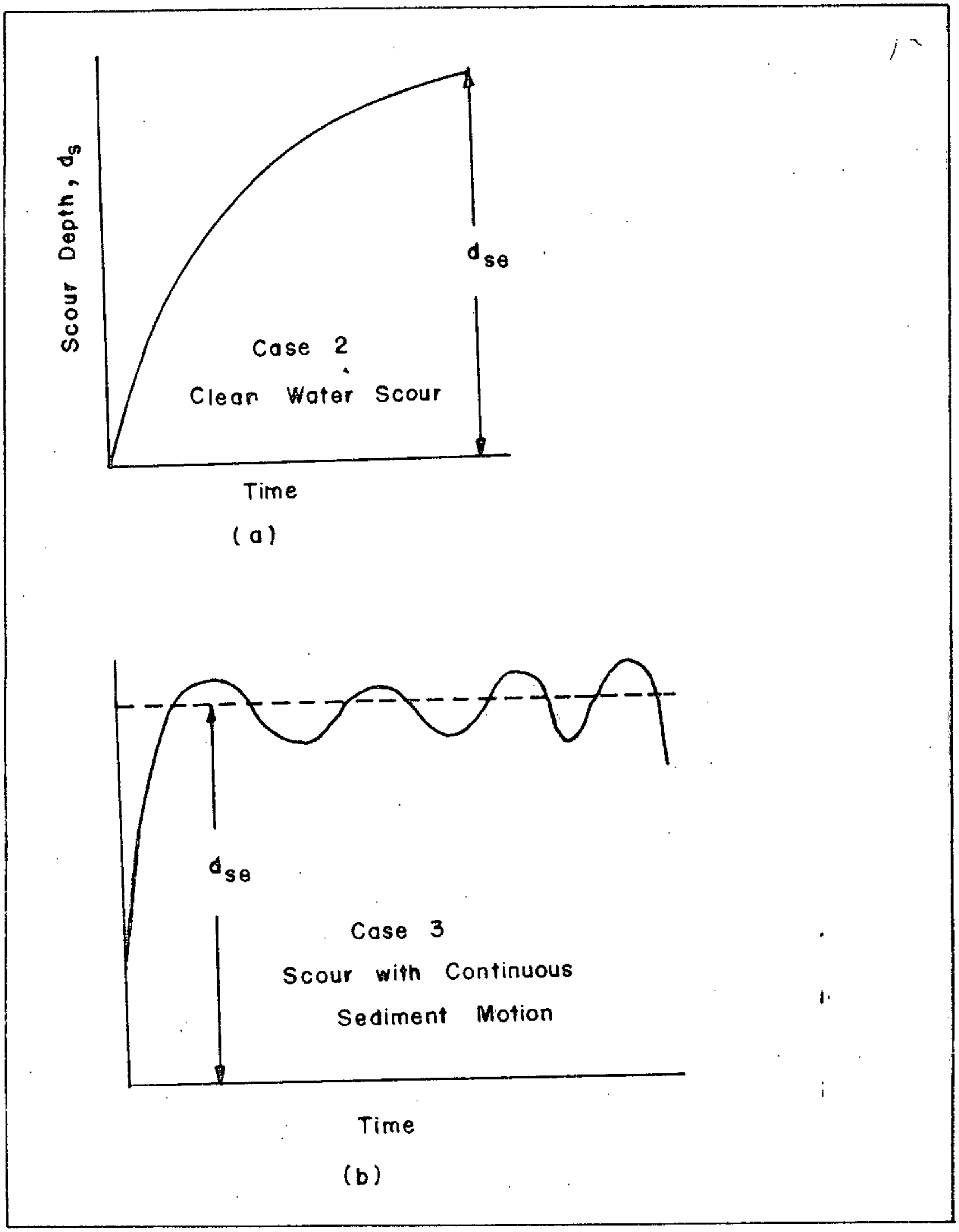
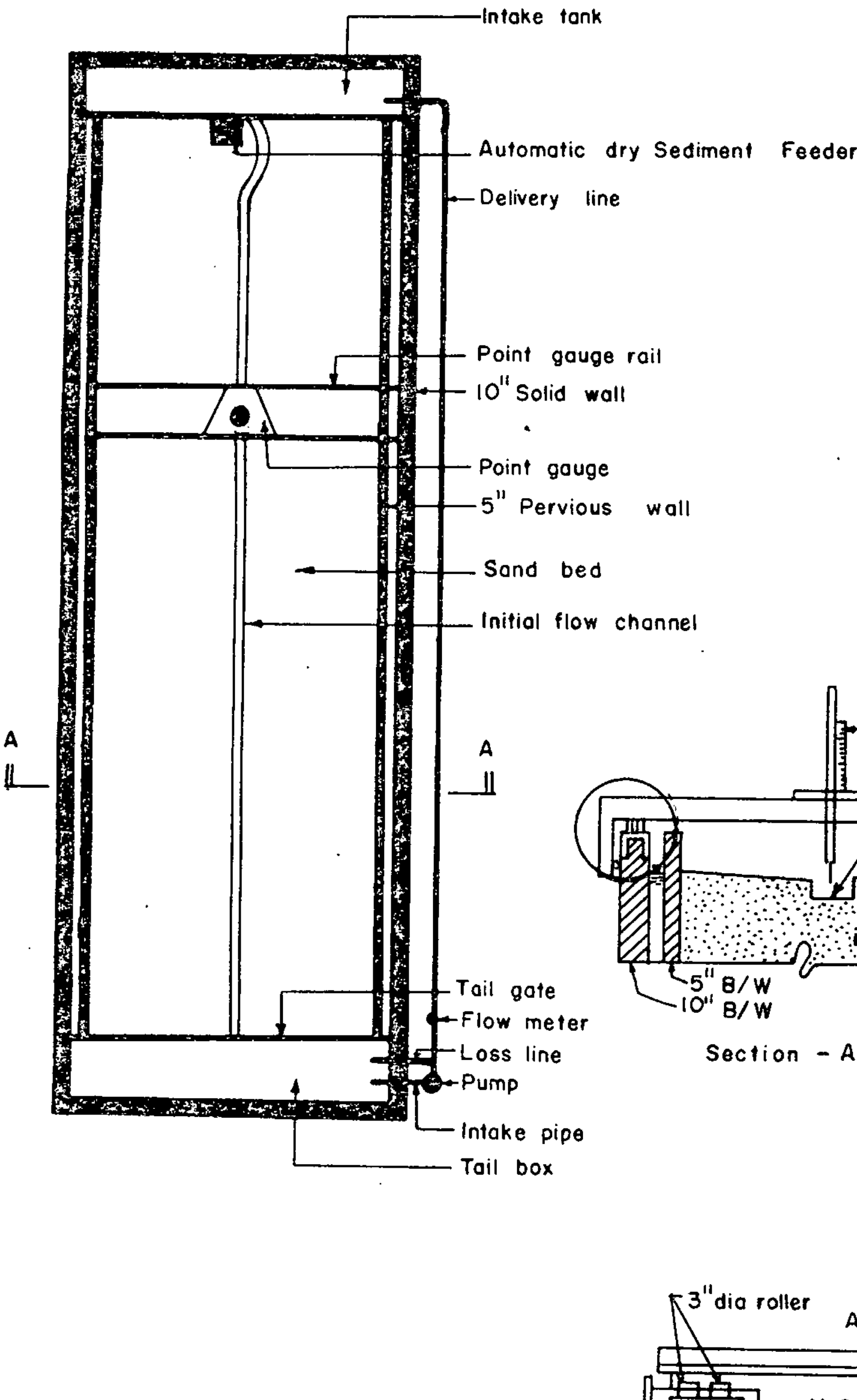
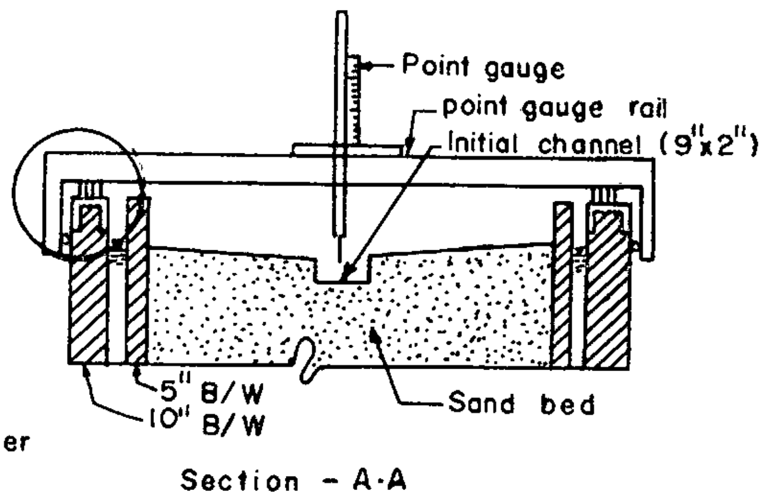


FIG. 2·5 Time variation of scour depth.
(after Shen 1971)





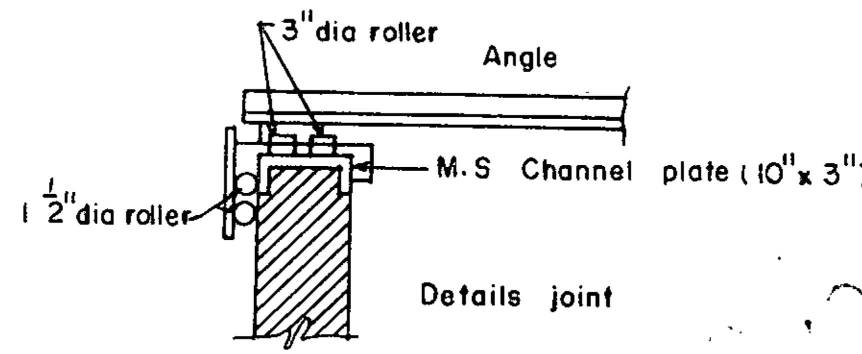


Fig. 3.1 Experimental set-up

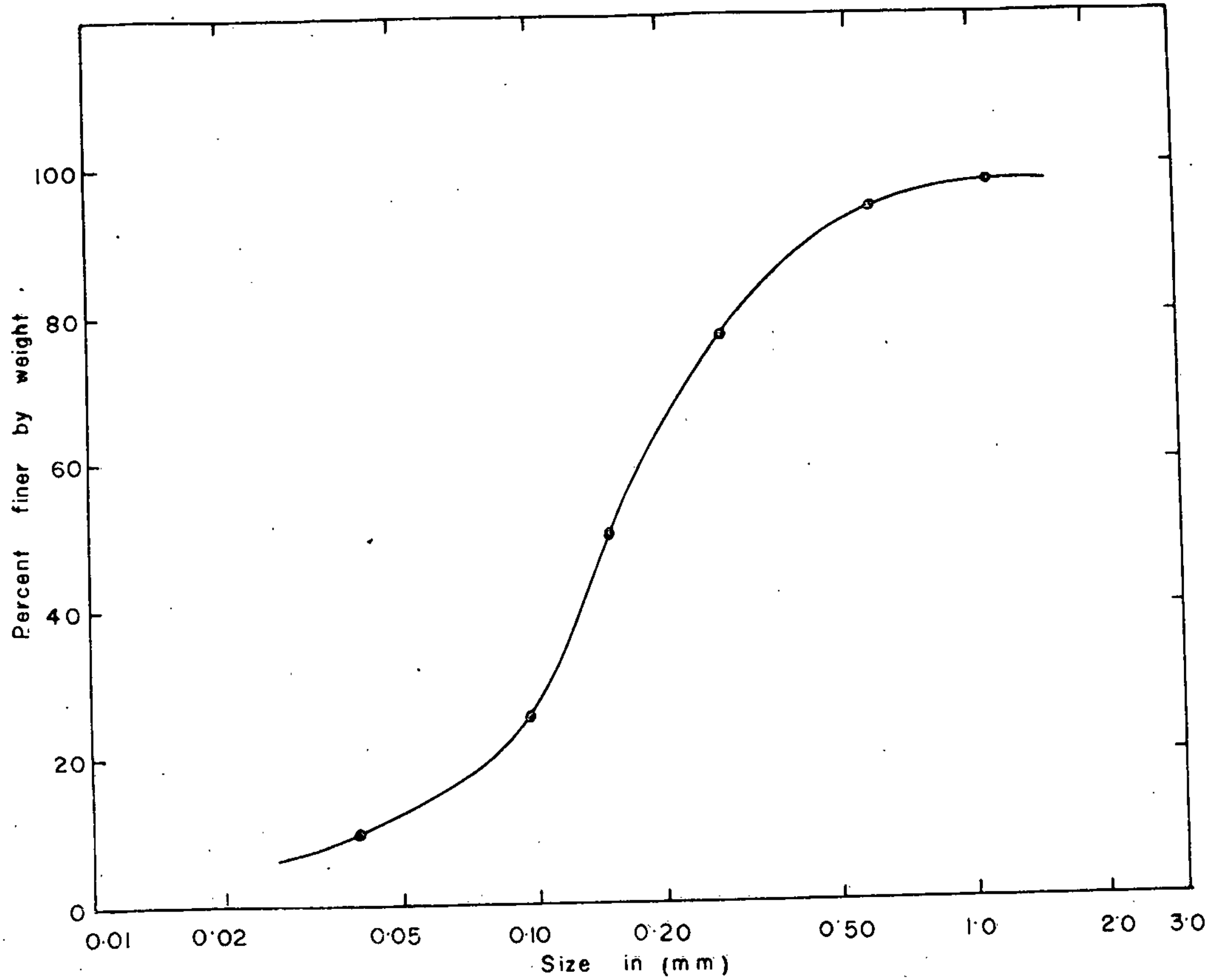


FIG. 3·2 Size distribution of bed material

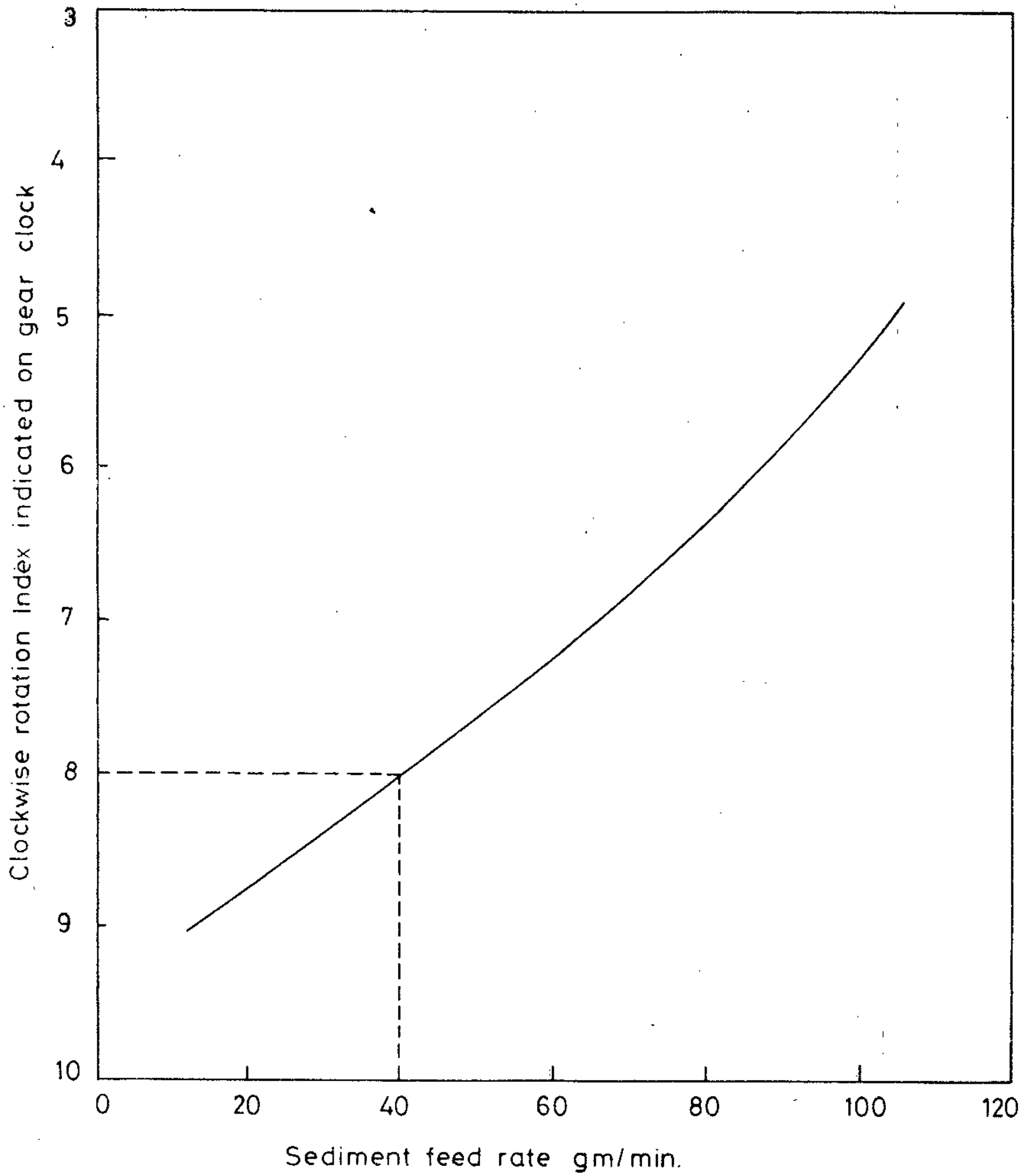


Fig. 3.3 Calibration curve for dry sediment feeder (d_{50} = 0.1473 mm, σ = 2.67)

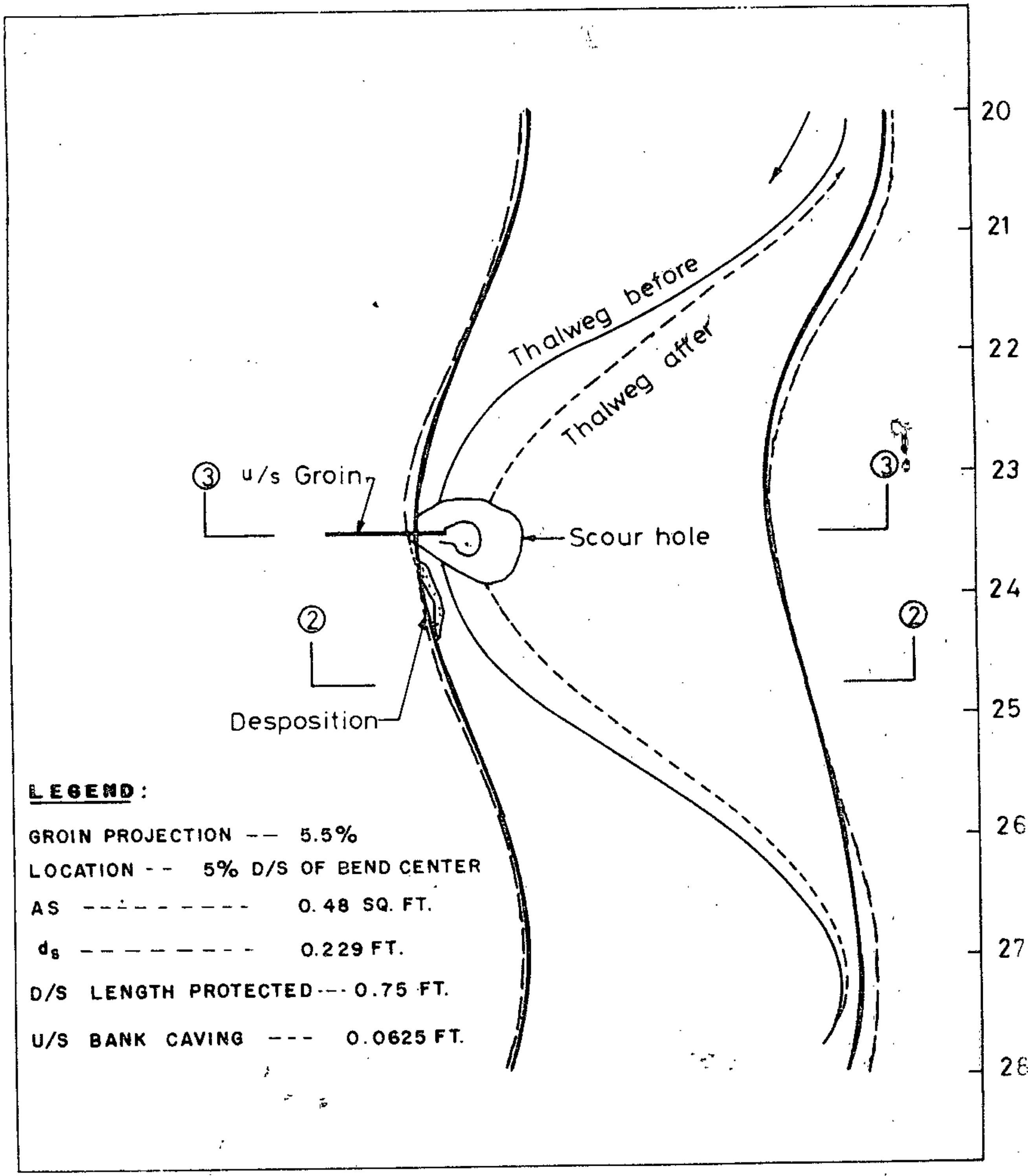


Fig. 4·1 Scour pattern and silt deposition for Set up 1.

Scale : 1 : 15 Q = 0.0267 cfs

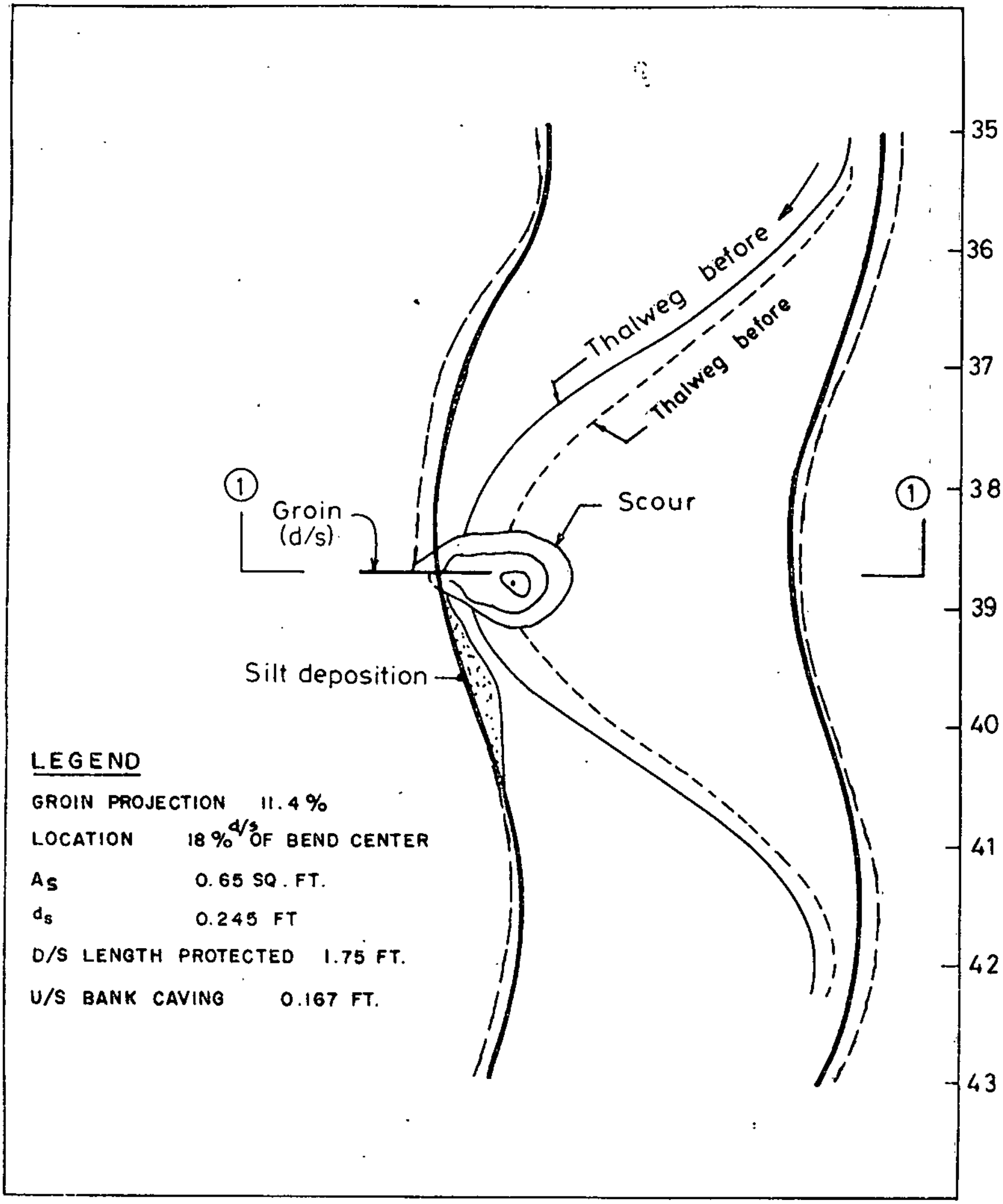


Fig. 4·2 Scour pattern and silt deposition for set up 1

Scale: 1 : 15 Q = 0.0267 cfs

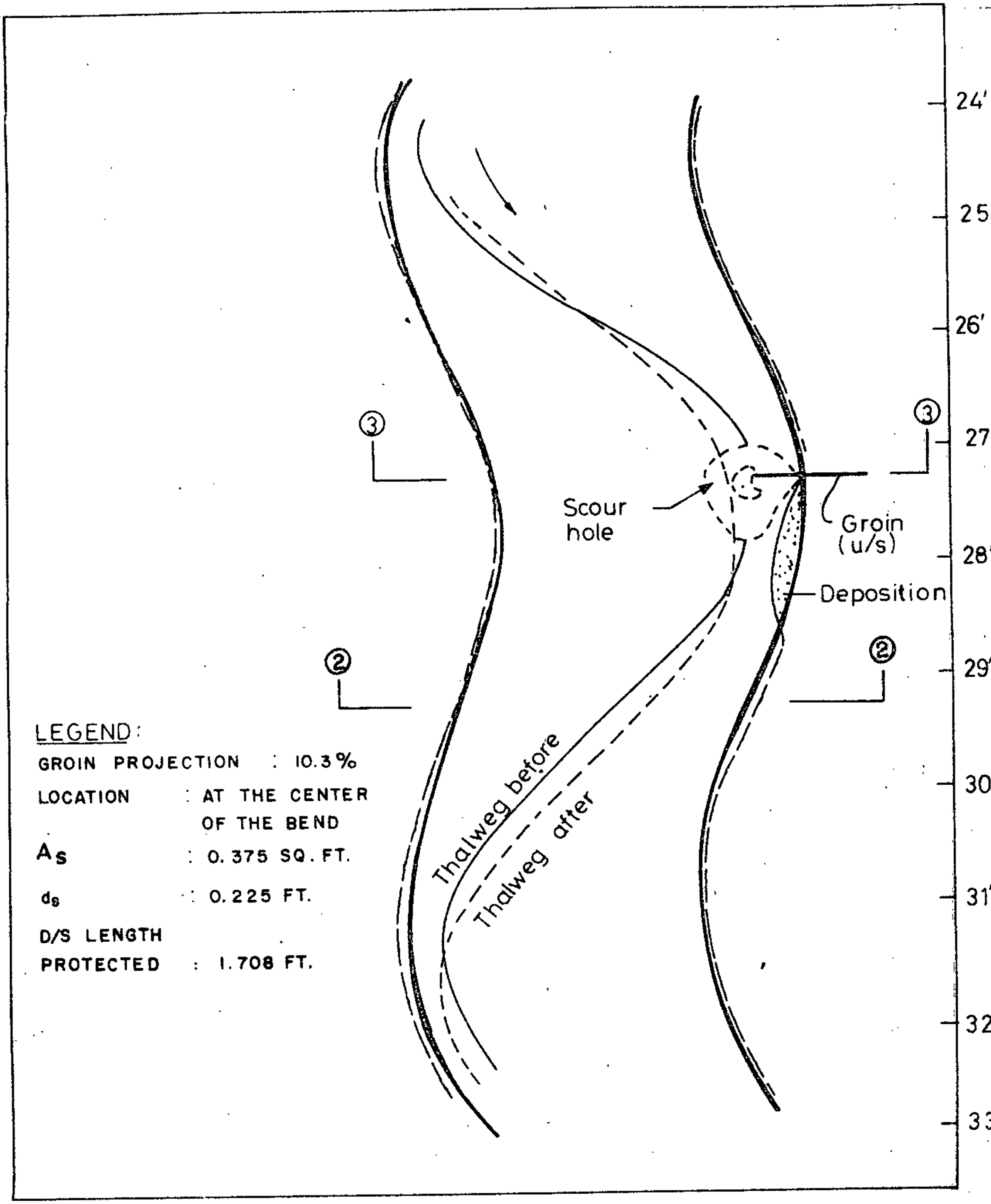


Fig. 4.3 Scour pattern and silt deposition for set up 2.

Scale: 1:15 Q = 0.0267 cfs

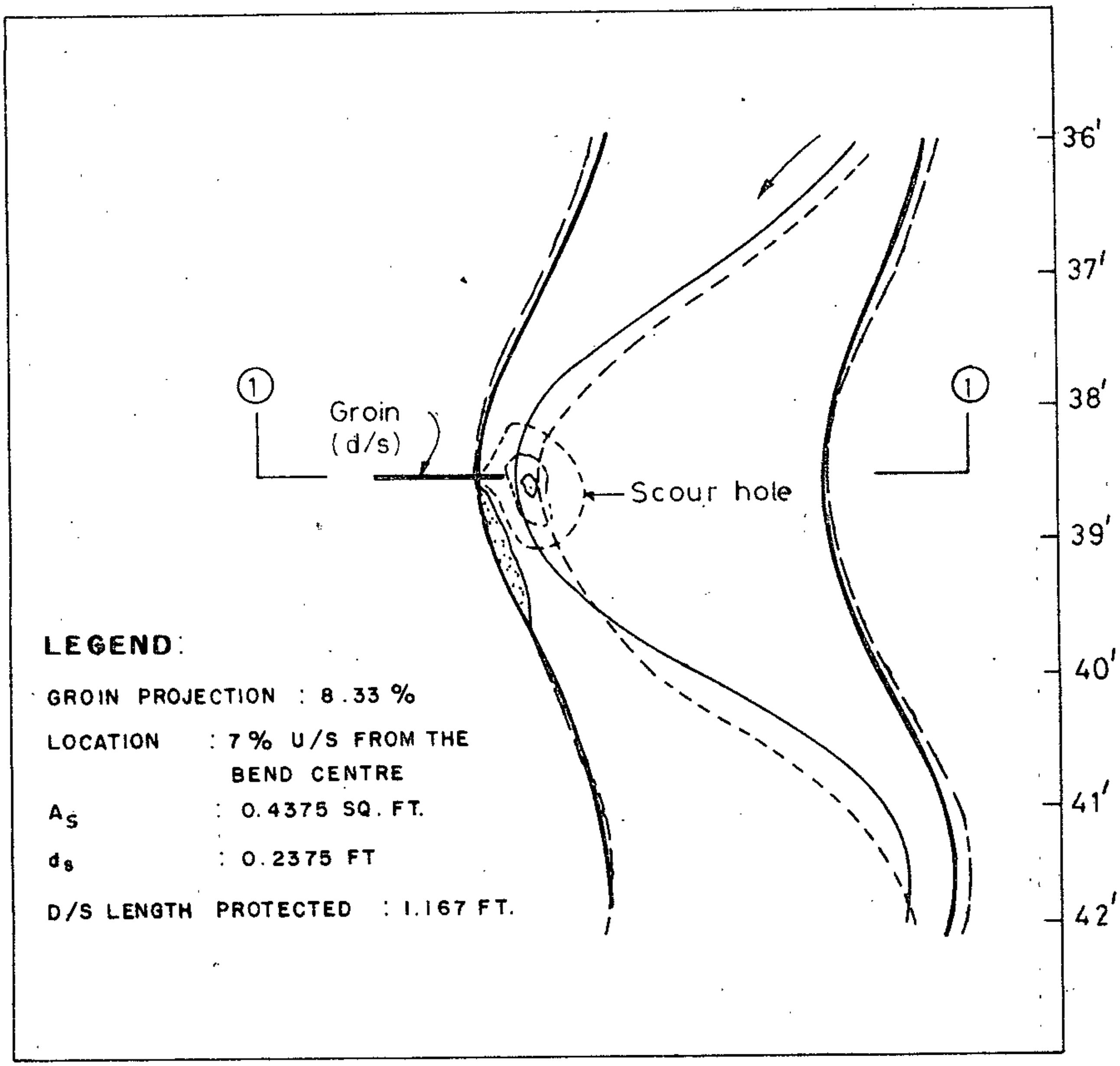


Fig. 4·4 Scour pattern and silt deposition for set up 2 (Scale: 1 : 15). Q = 0.0267 cfs

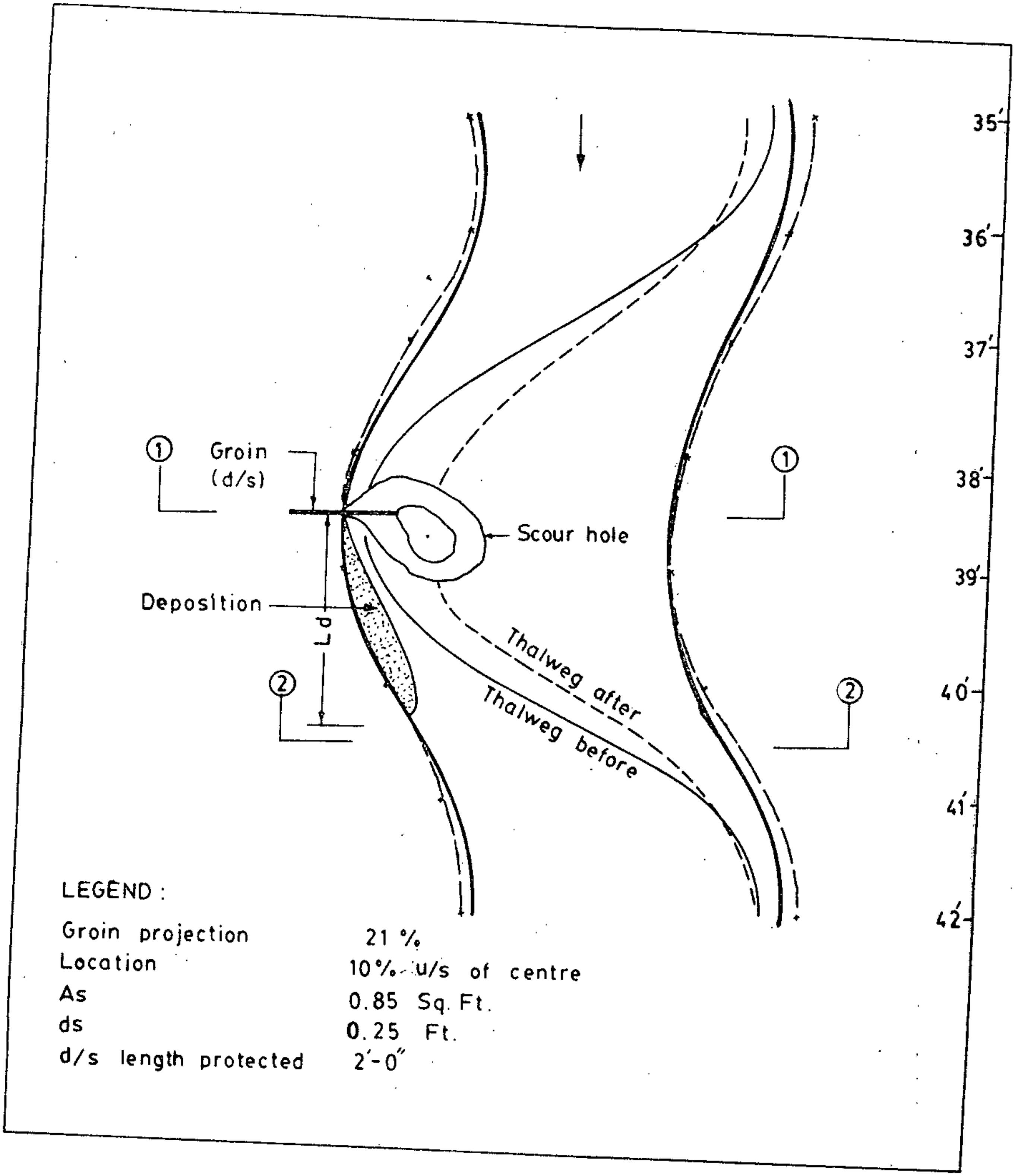


Fig. 4.5 Scour pattern and silt deposition for set up 3. (Q = 0.0267 cfs)

Scale 1 : 15

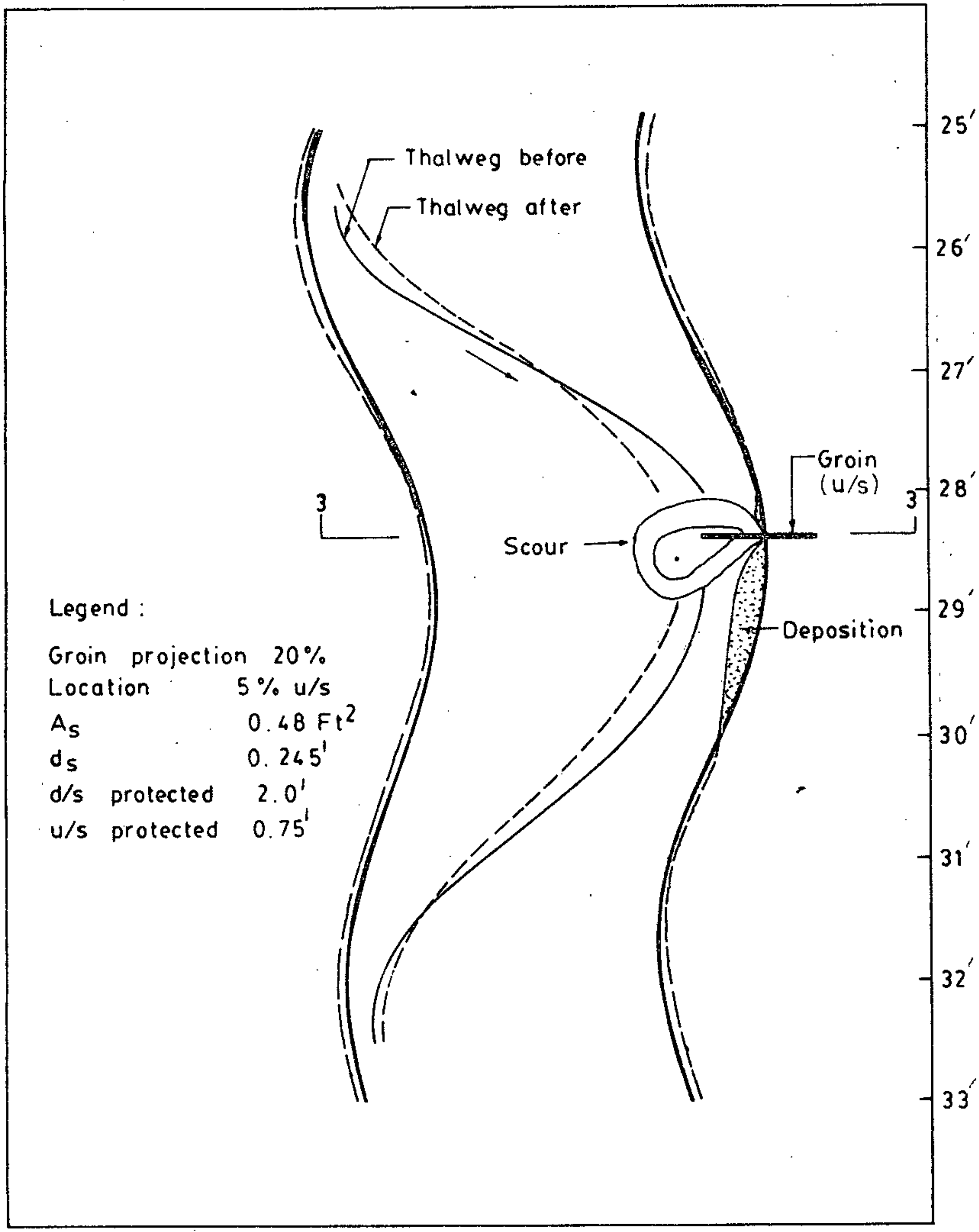
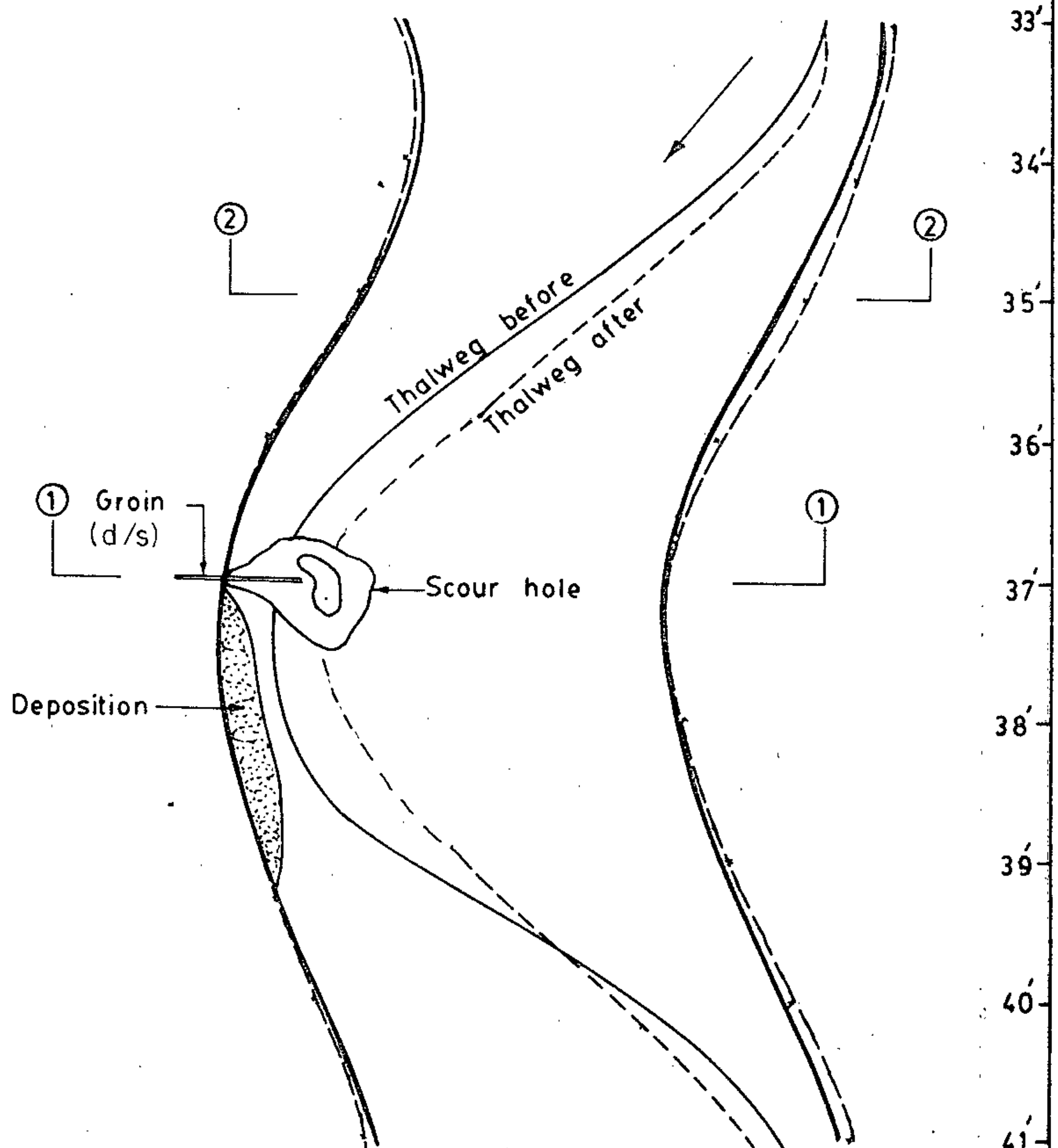


Fig. 4·6 Scour pattern and silt deposition for set 3
Q = 0.0267 cfs
Scale 1:15



LEGEND :

Groin projection		19.7 %
Location	:	18 % U/s from center of bend
As		0.56 Sq. ft.
ds		0.2458 Ft.
D/s length protected		2.25 Ft.
U/s length protected		0.75 Ft.

Fig. 4.7 Scour pattern and silt deposition for set up 4 . Q = 0.0267 cfs

Scale : 1 : 15

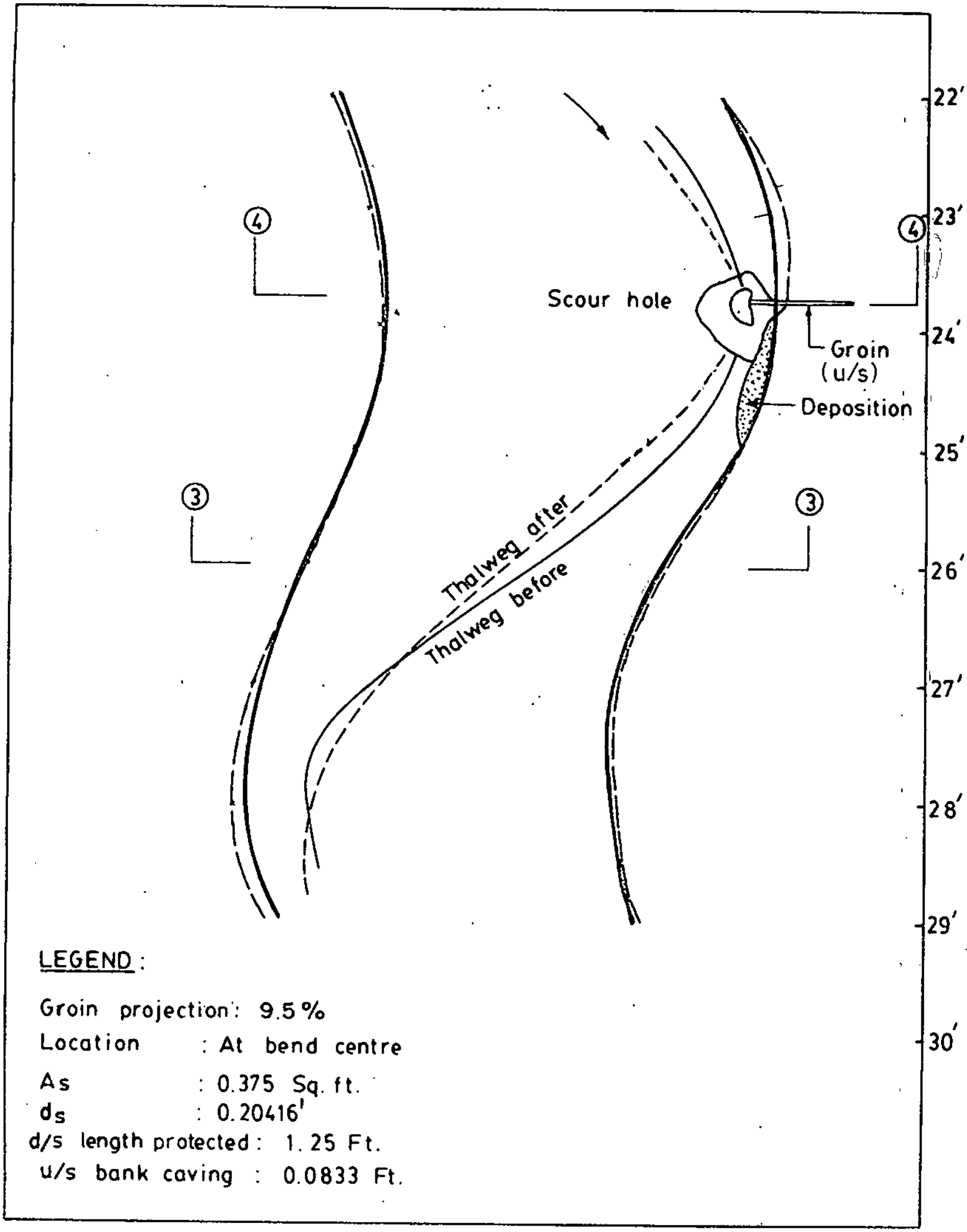


Fig. 4.8 Scour pattern and silt deposition for set up 4. (Q = 0.0267 cfs)

Scale : 1:15

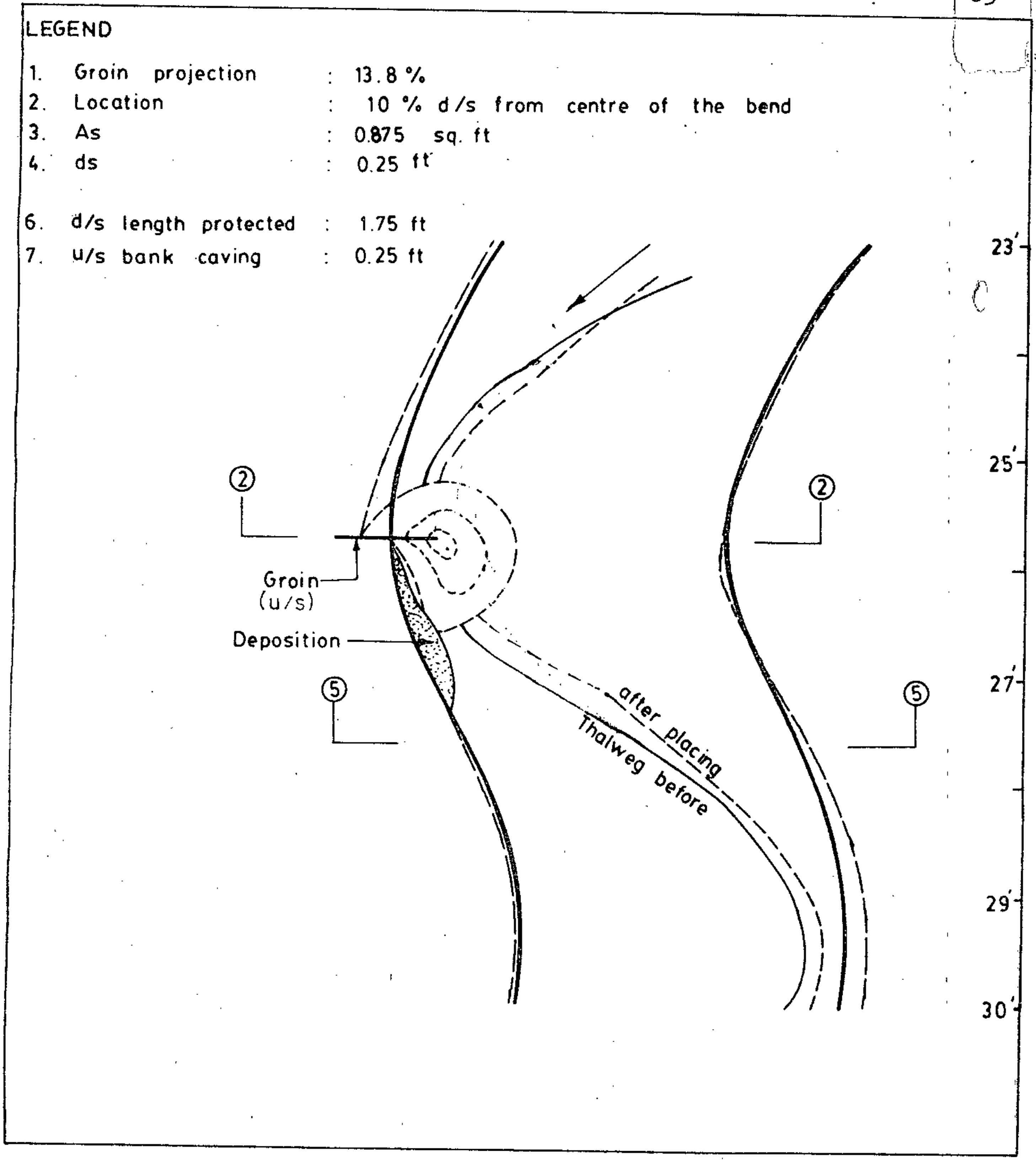


Fig. 4·9 Scour pattern and silt deposition for set up 5 . (Q = 0.0267 cfs)

Scale : 1:15

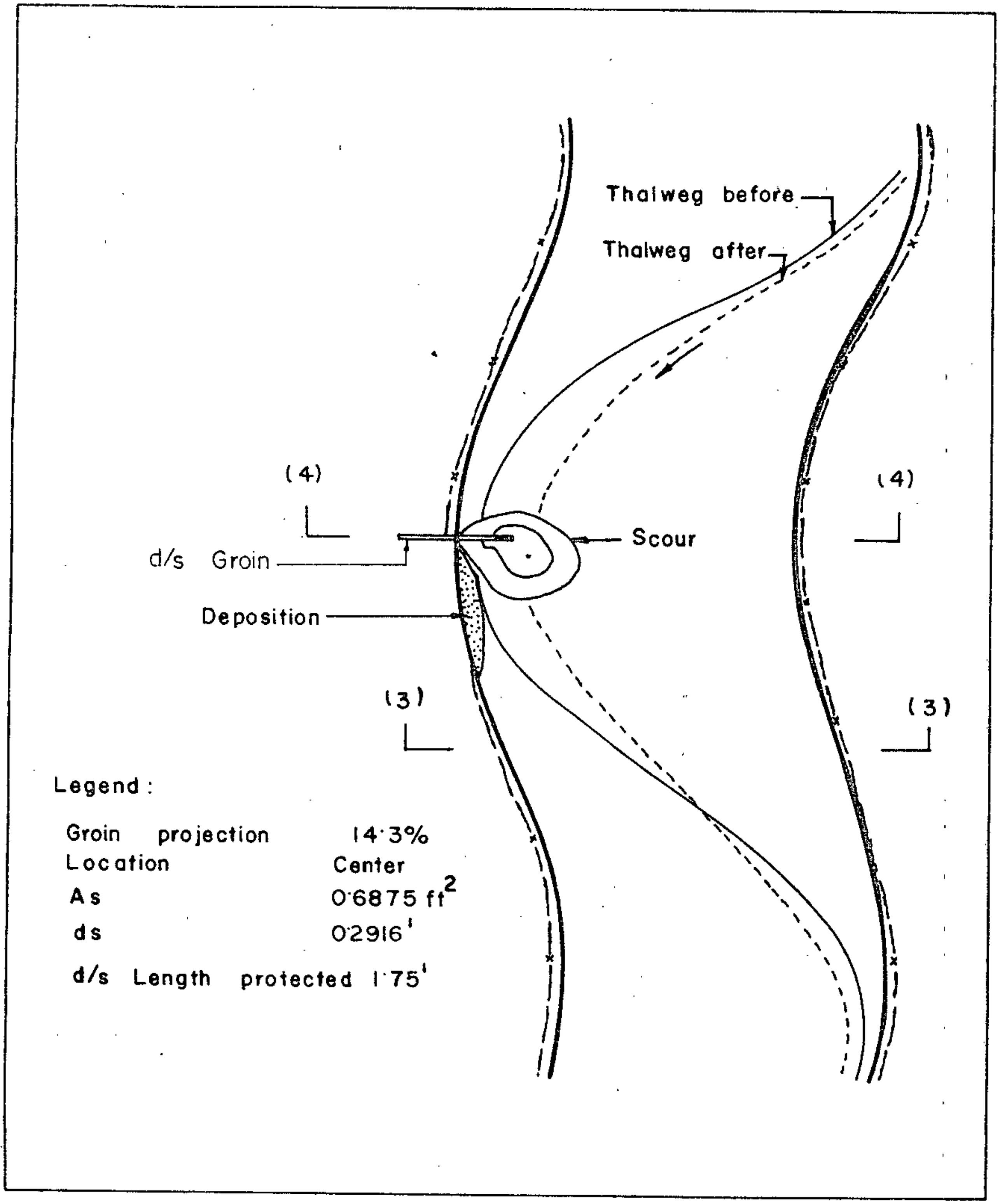


Fig. 4.10 Scour pattern and Silt deposition for set up 5. Q = 0·0267 cfs.
Scale : 1:15

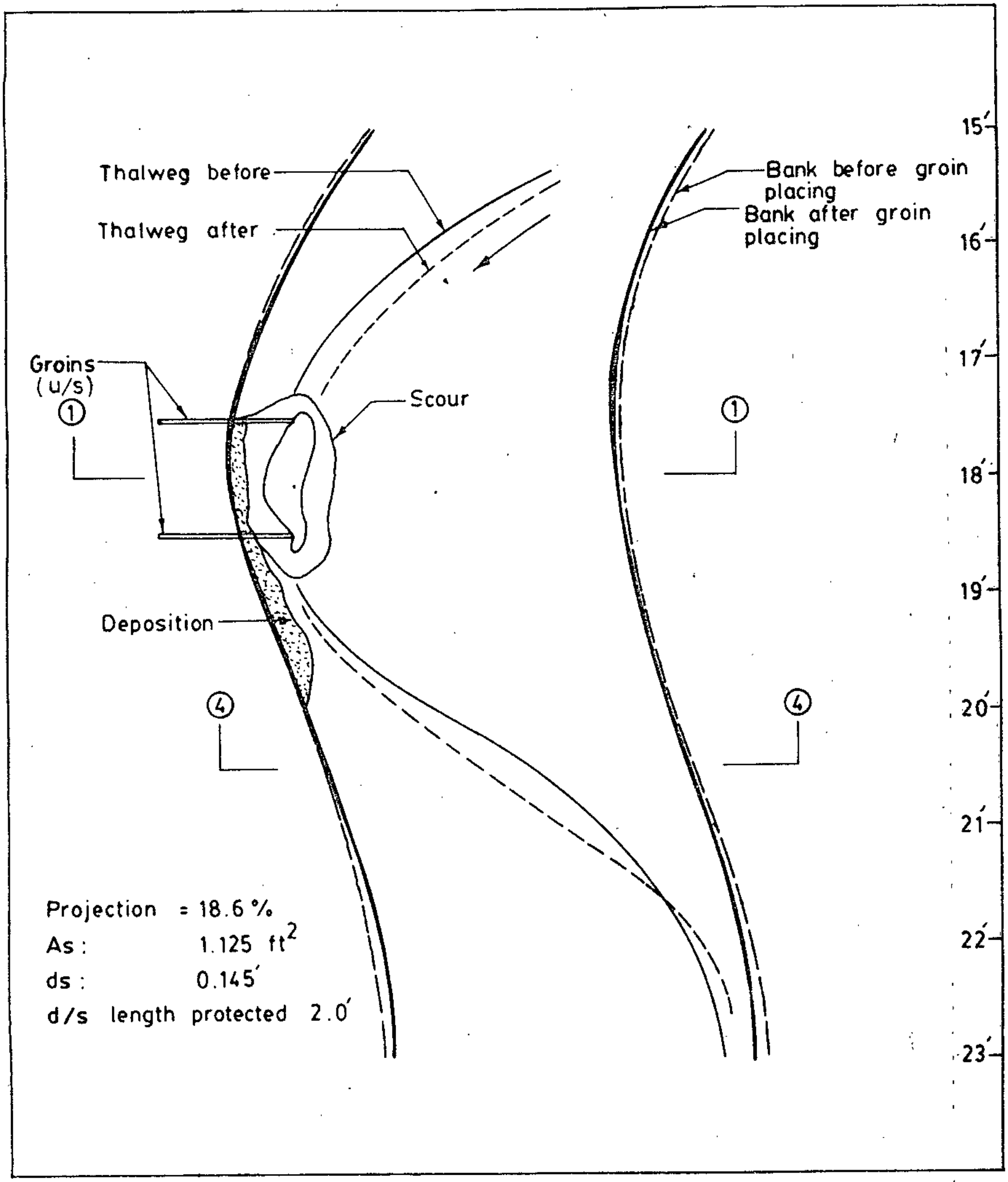


Fig. 4.11 Scour pattern and siltation for set 6 . (Q = 0.0267 cfs)

Scale : 1 : 15

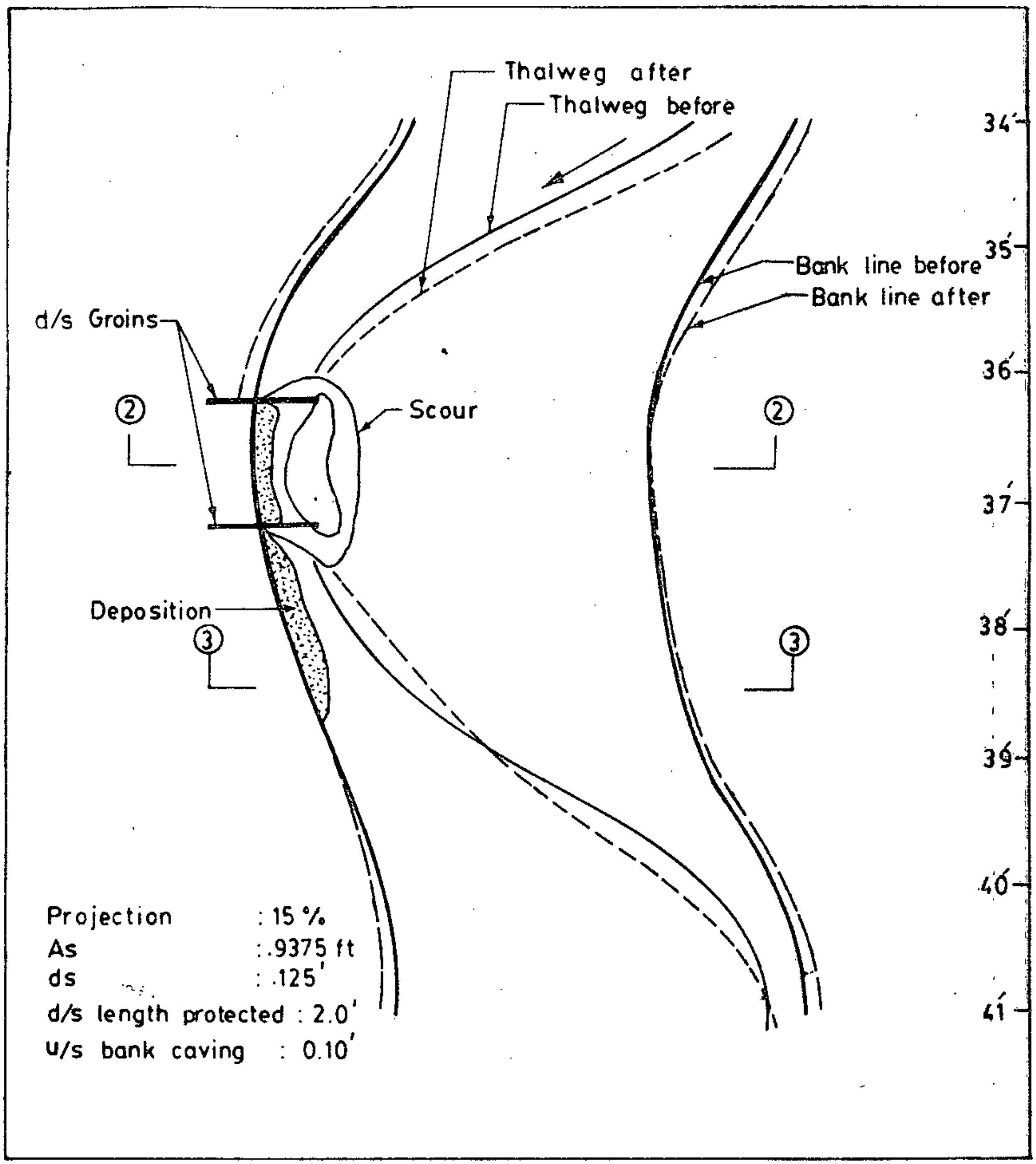


Fig 4.12 Scour pattern and siltation for set 6 . (Q = 0.0267 cfs)

Scale : 1 : 15

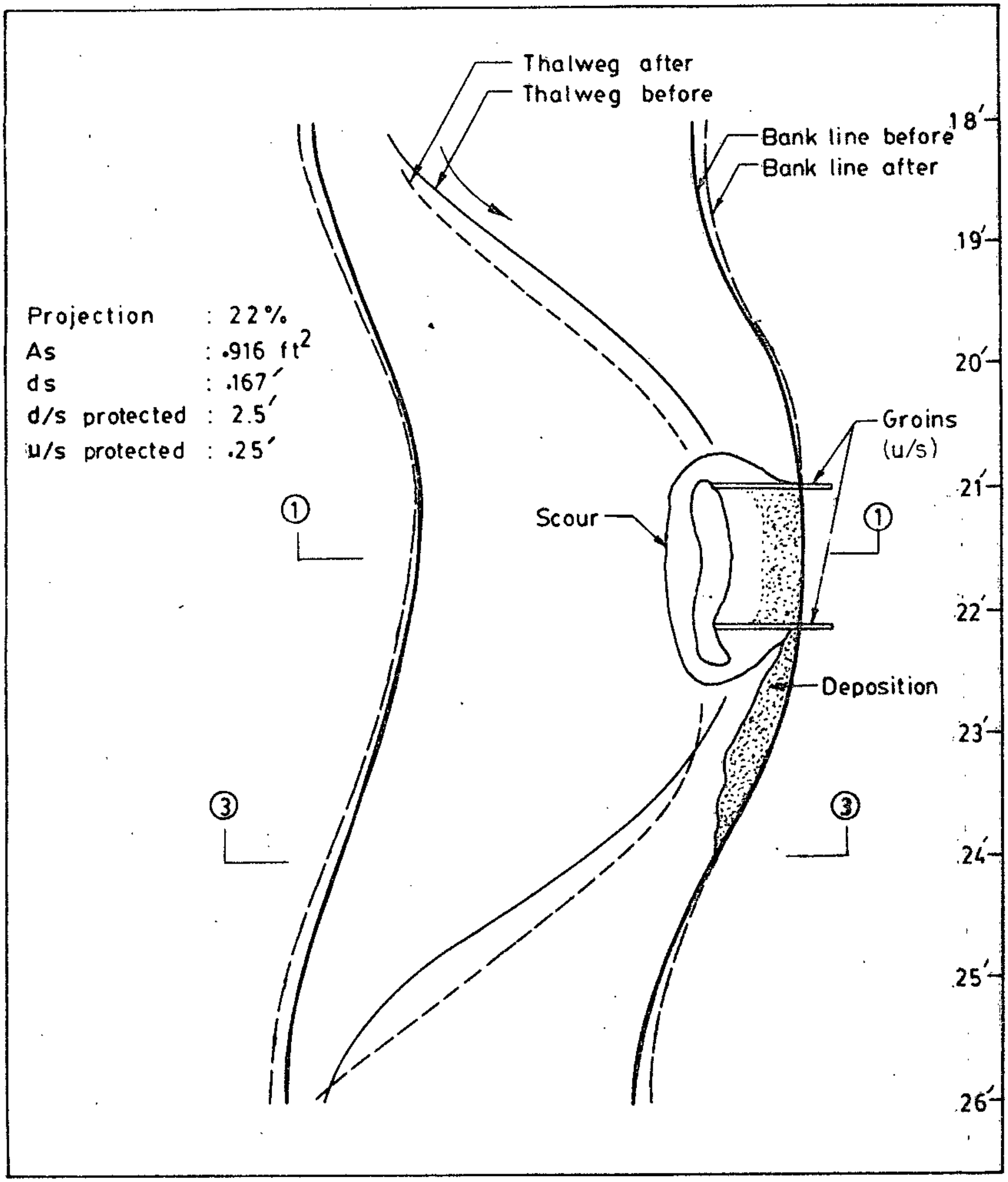


Fig. 4.13 Scour pattern and deposition for set 7. (Q = 0.0267 cfs)

Scale : 1:15

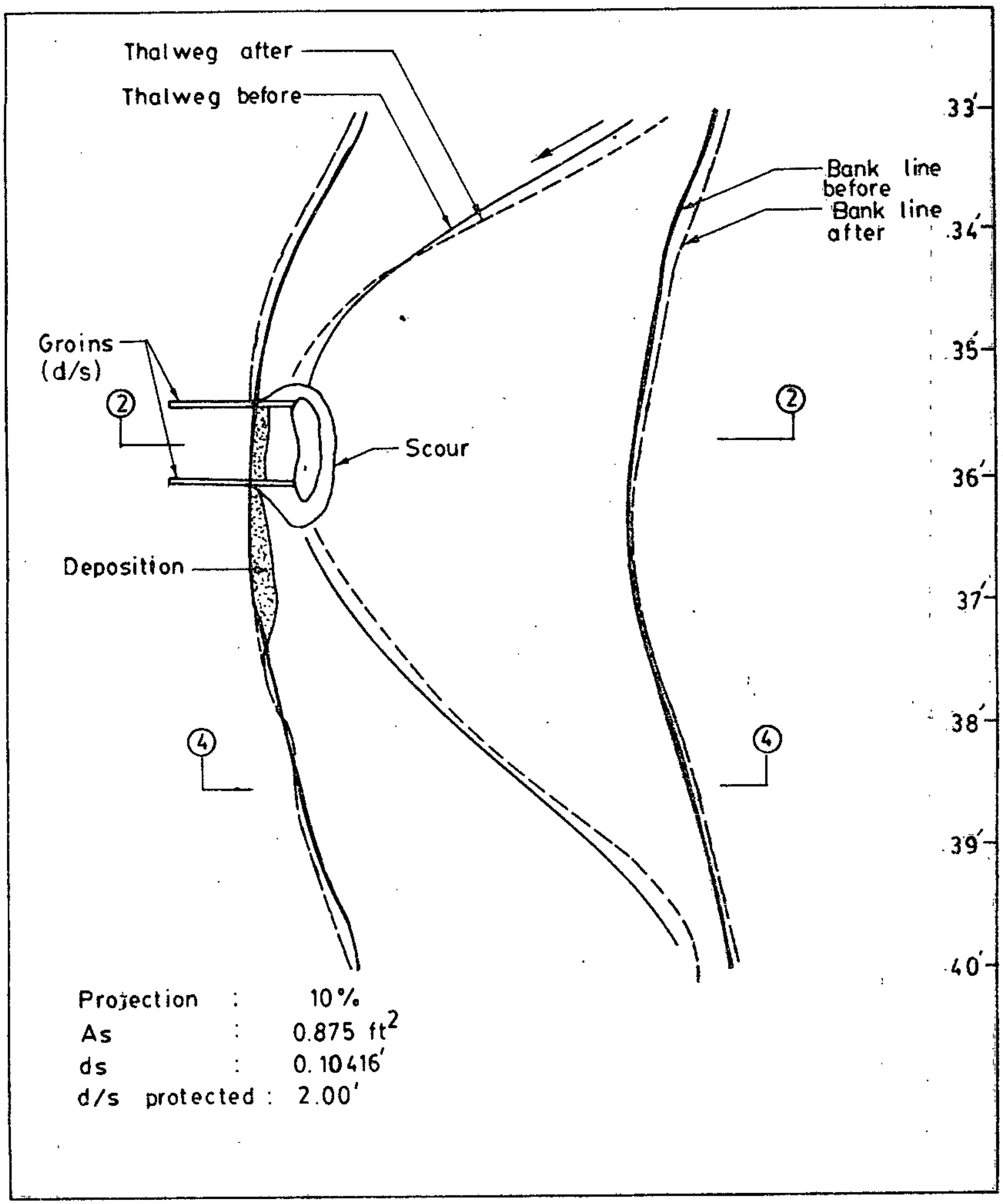


Fig. 4.14 Scour pattern and deposition for set 7 . (Q = 0.0267 cfs)

Scale 1 : 15

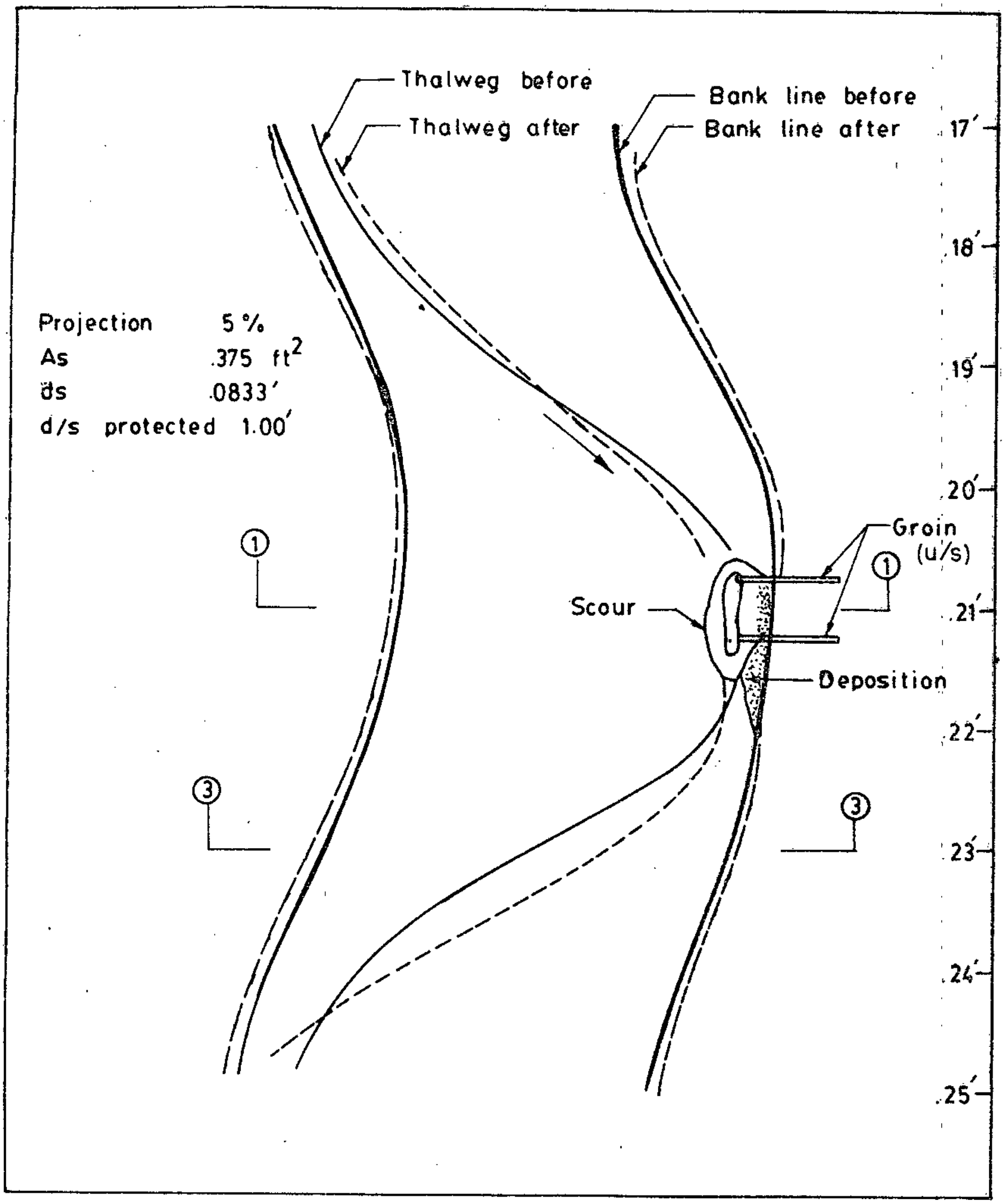


Fig. 4.15 Scour pattern and deposition for set 8. (Q = 0.0267 cfs)

Scale : 1:15

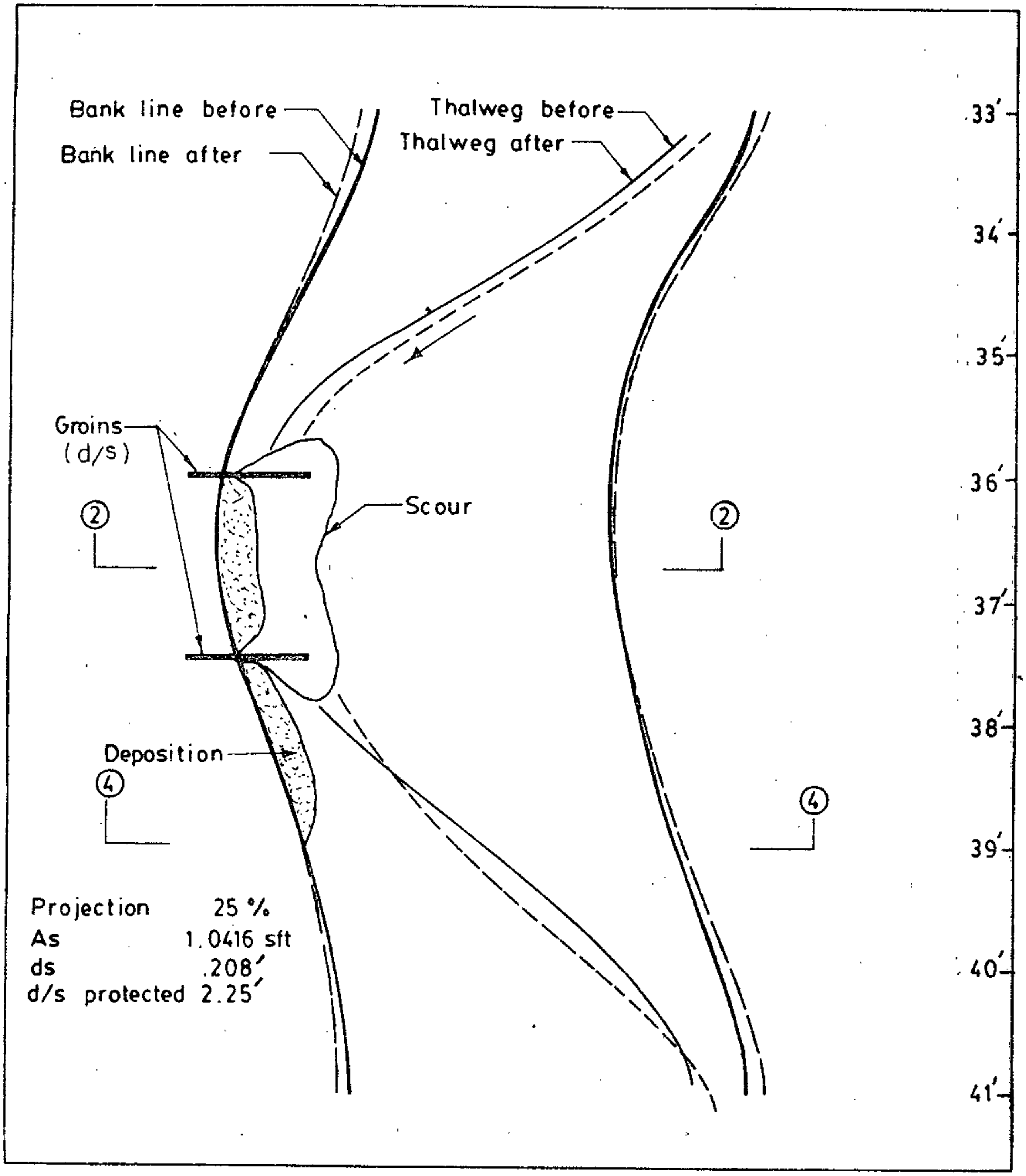


Fig. 4.16 Scour pattern and deposition for set 8. (Q = 0.0267 cfs)

Scale : 1 : 15

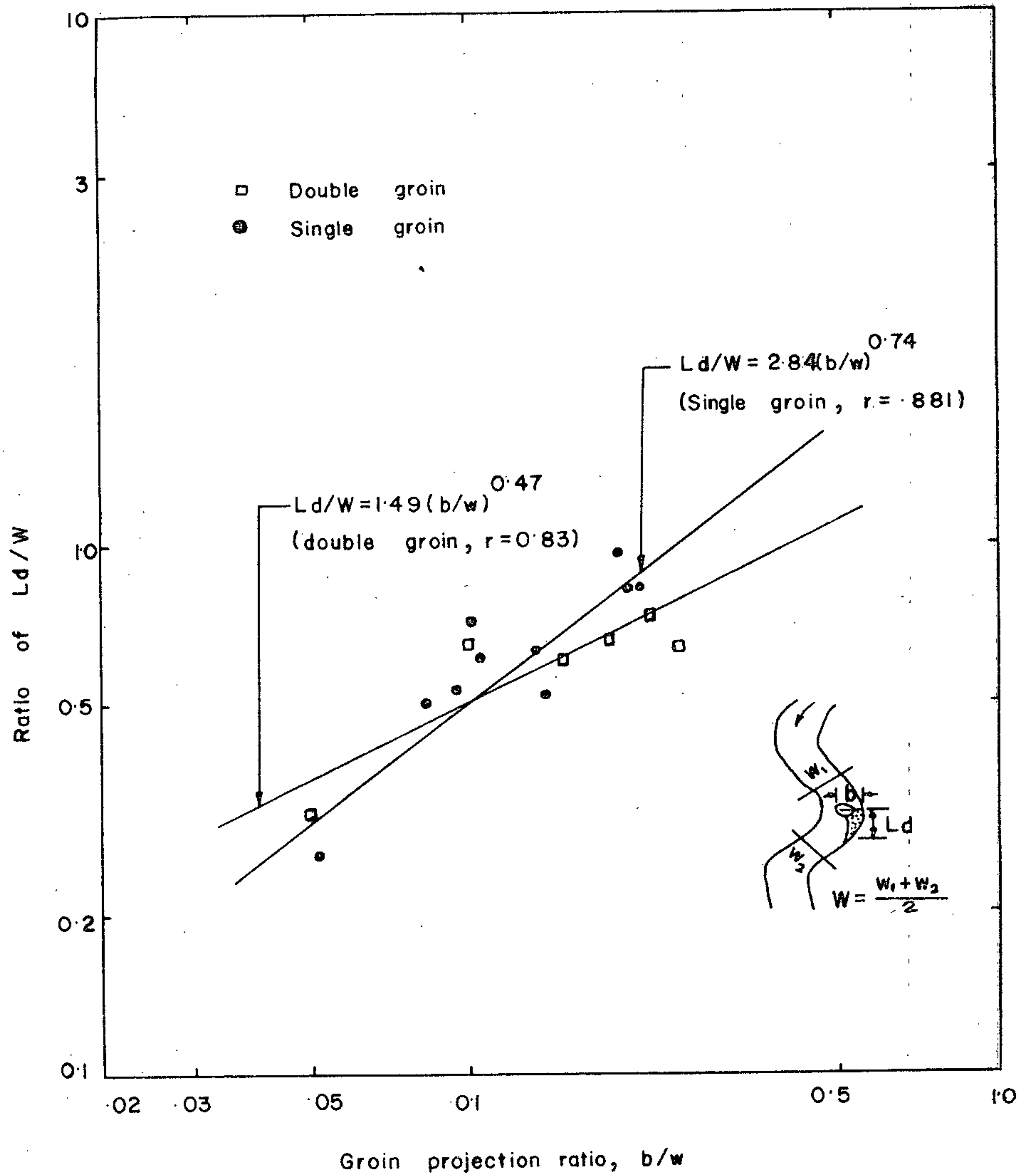


Fig. 4·17 Relationship between groin projection and downstream length protected Q = 0·0267 cfs

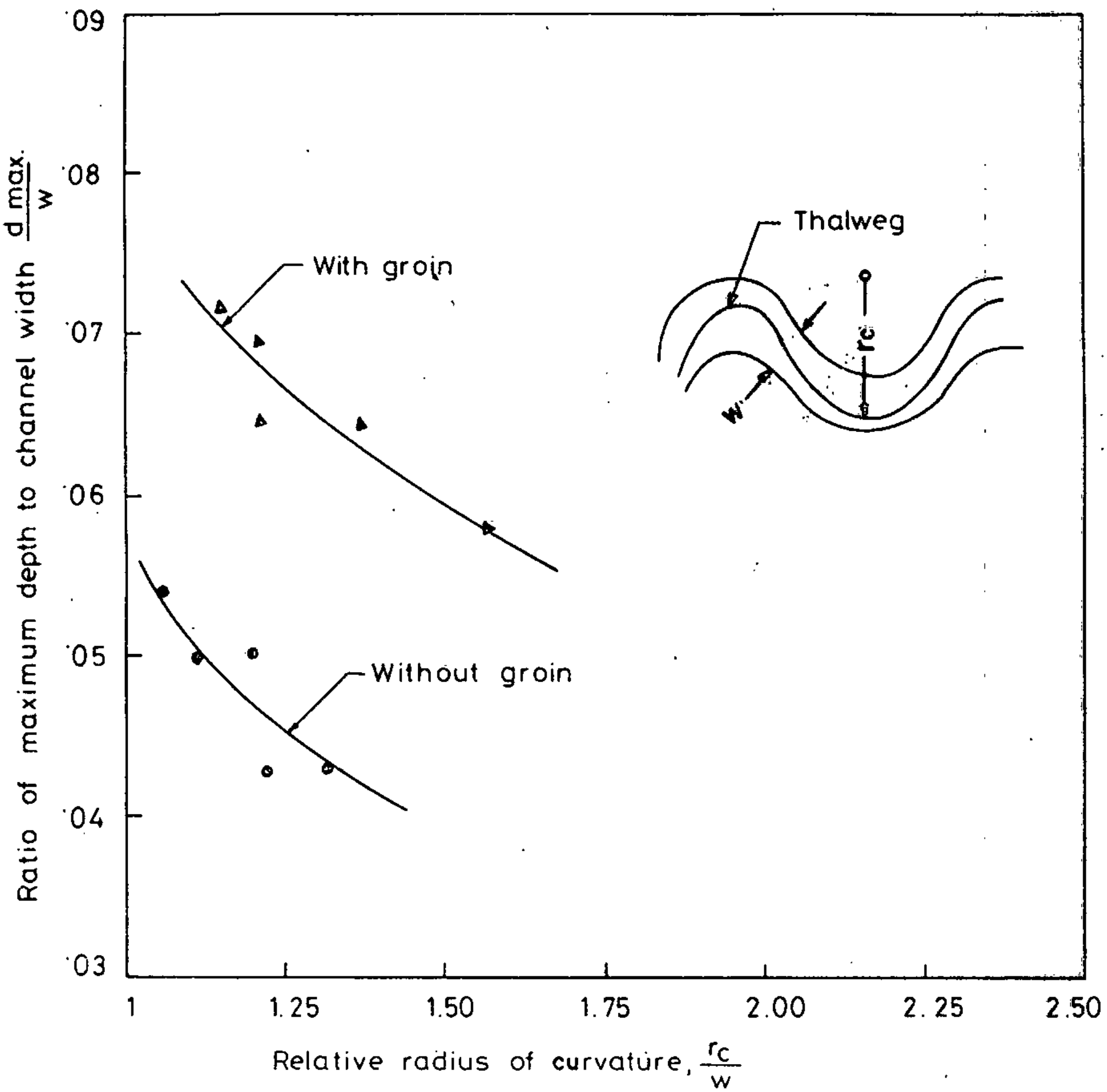


Fig.4·18 Relationship showing maximum depth at the bends with radius of curvature. (Q = 0.0267 cfs), single groins.

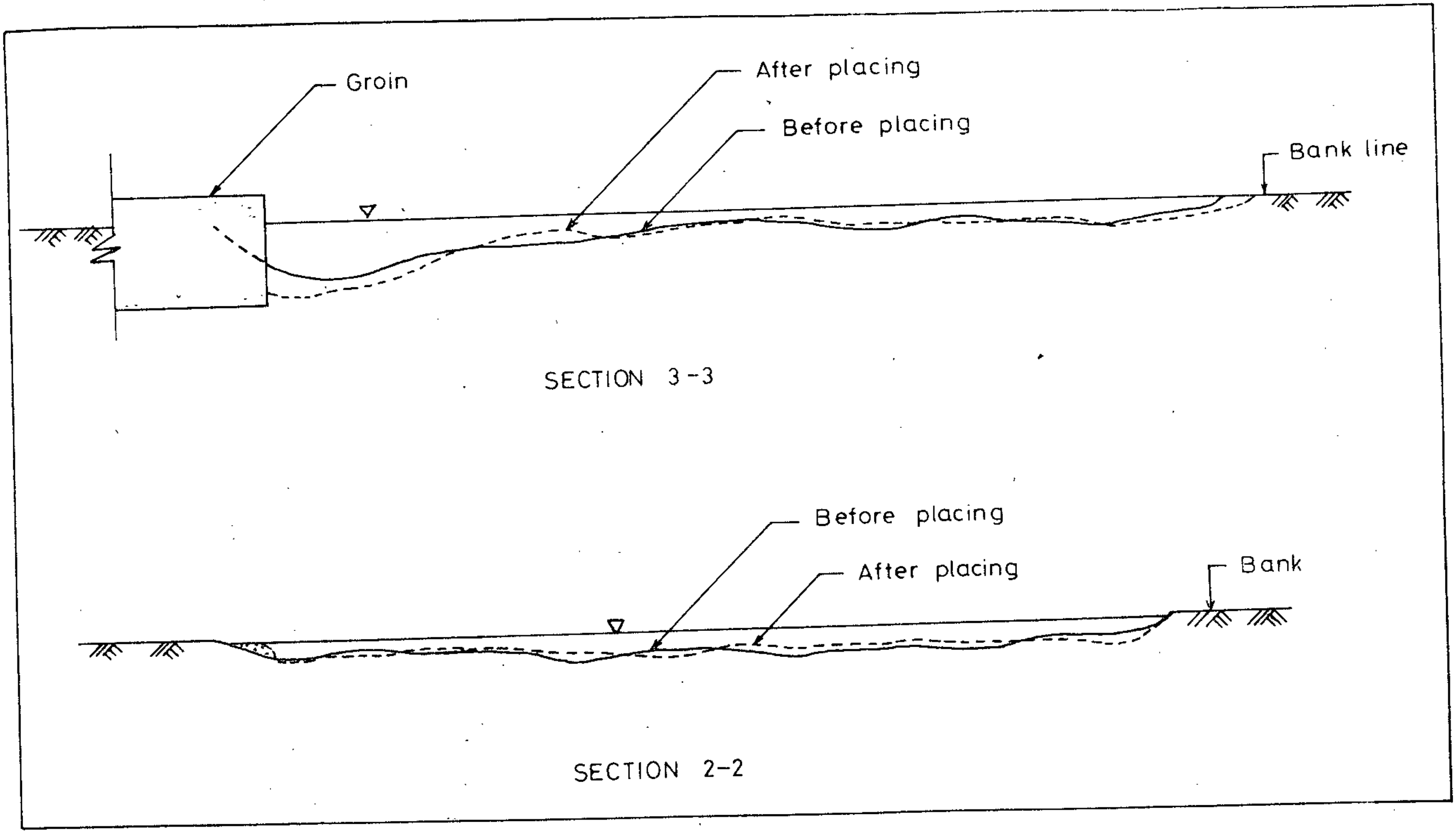


Fig. 4·19 Variation of Cross - Section before and after placement of groin set up 1. (Scale: 1 : 5) (Q = 0.0267 cfs)

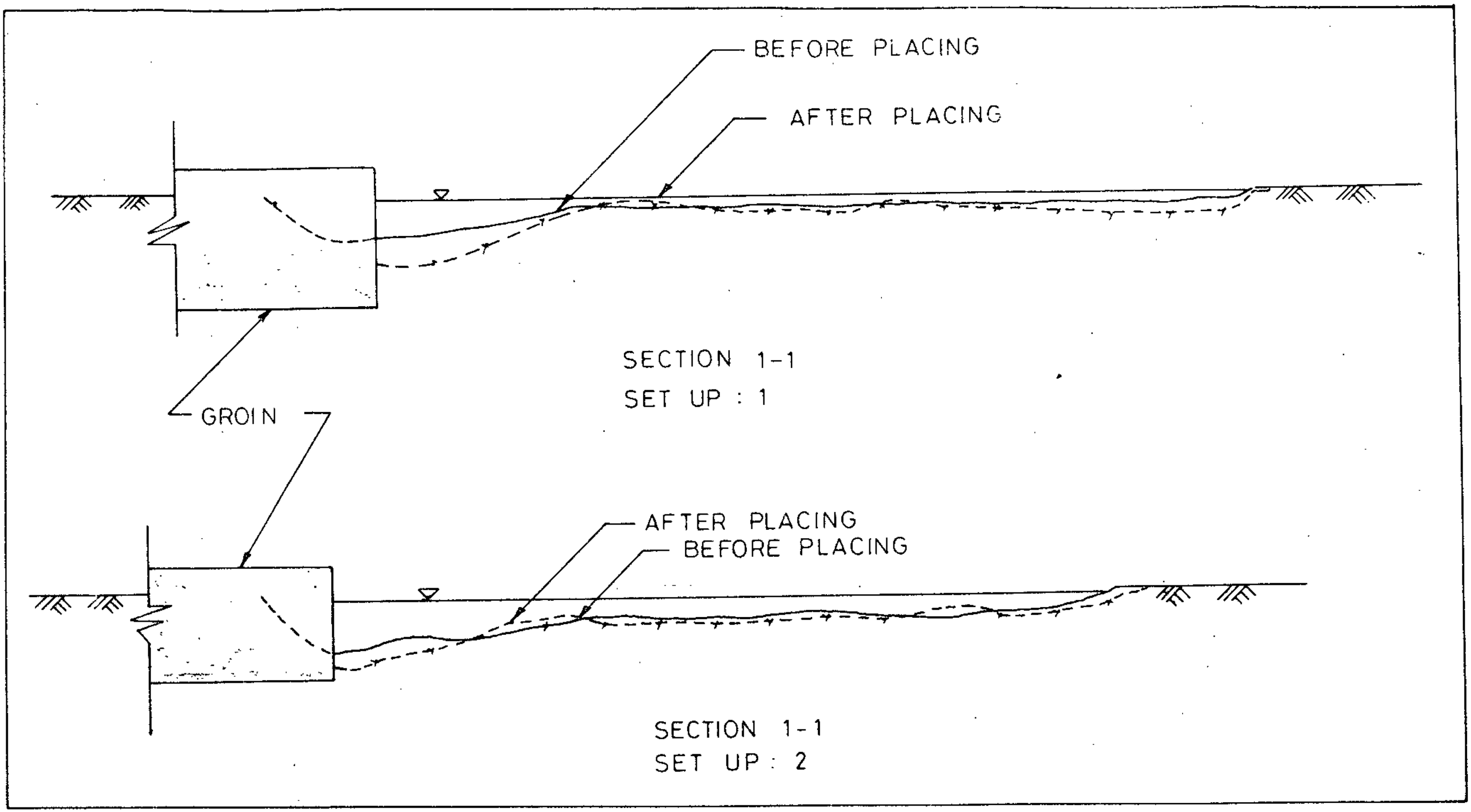


Fig. 4-20 Variation of Cross Sections before and after groin placing
Scale: 1 : 5 (Q = 0.0267 cfs)

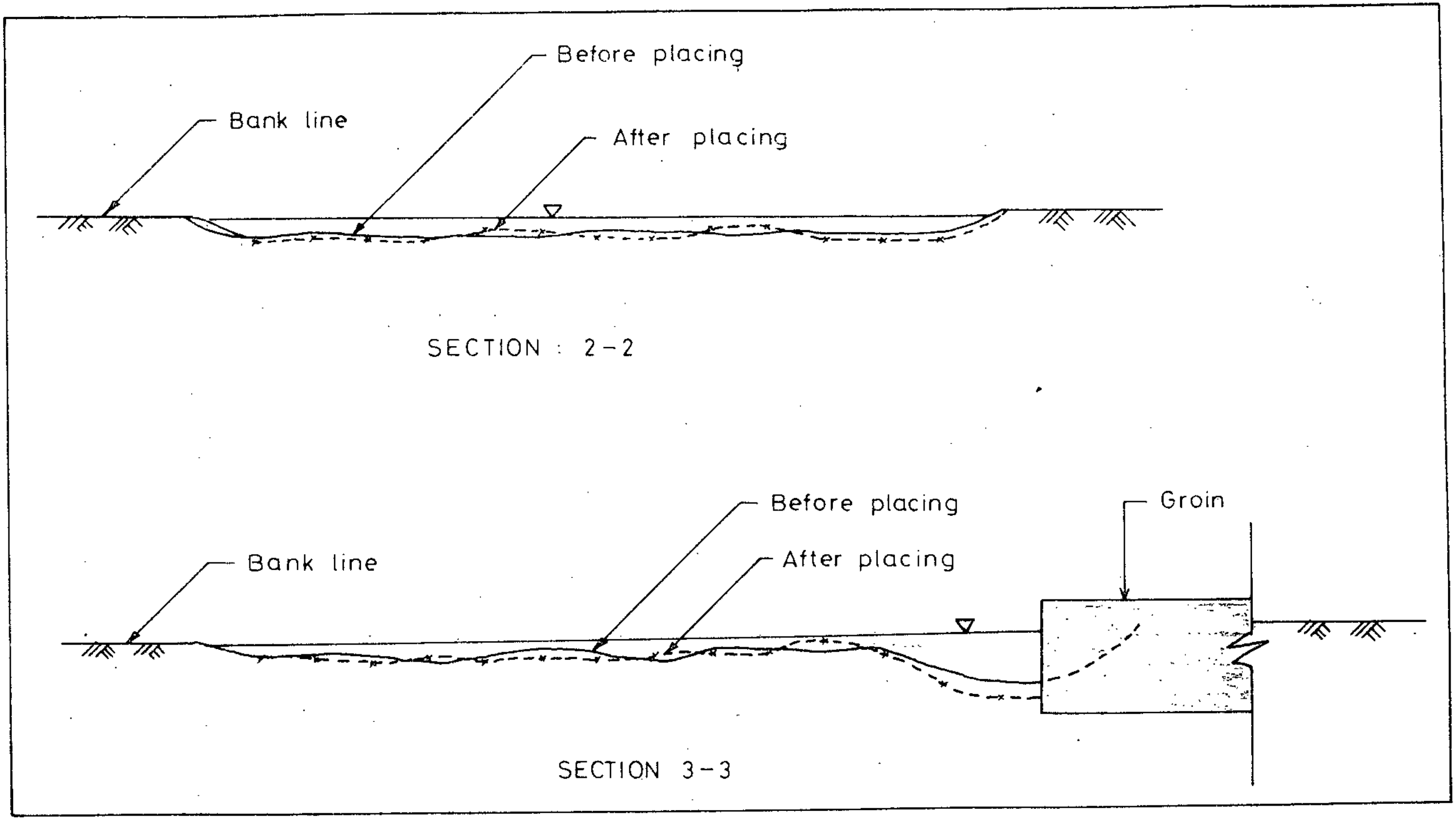


Fig. 4·21 Variation of Cross Section before and after placement of groin set up 2. (Scale 1:5)

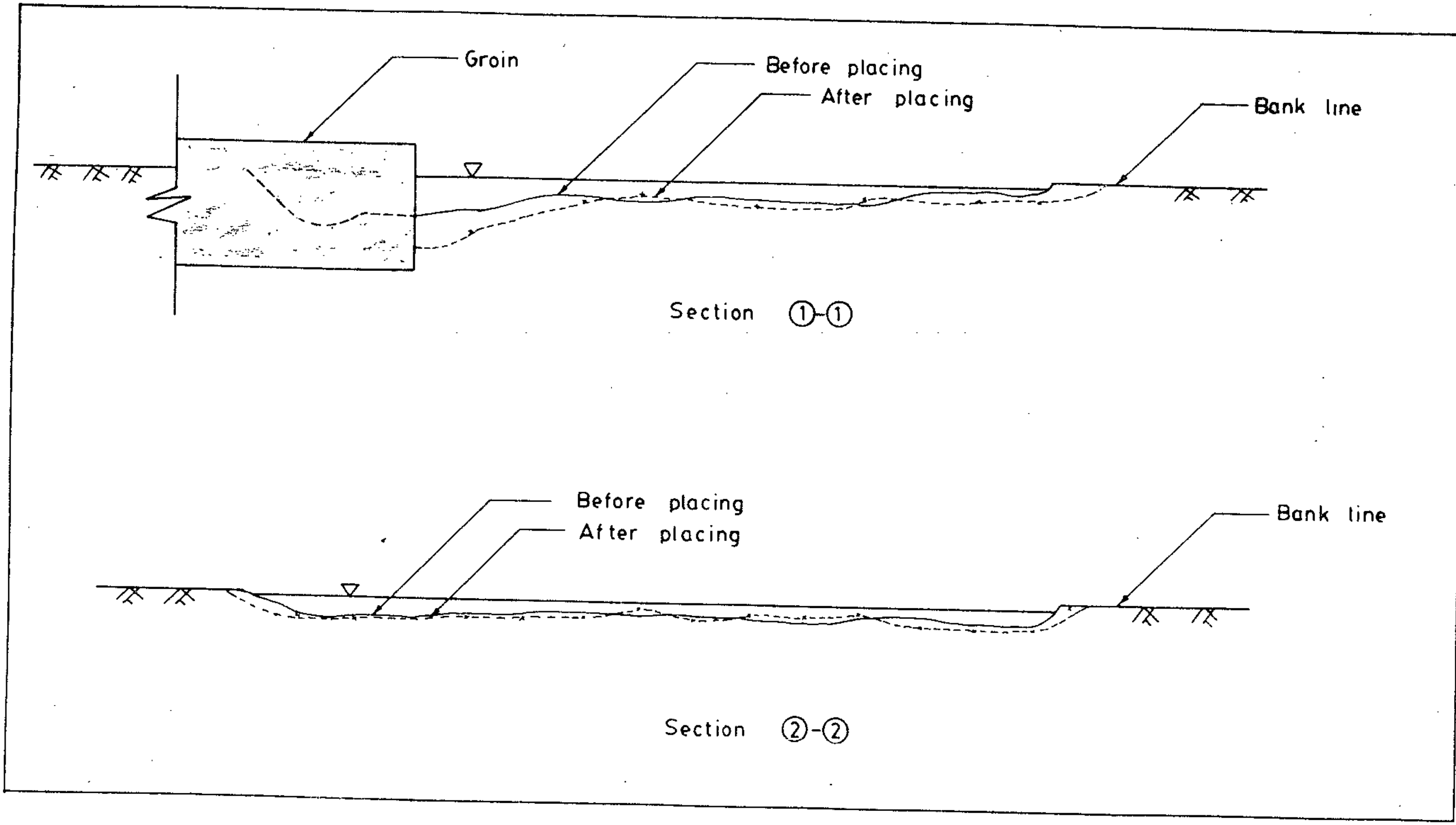


Fig. 4.22 Variation of cross-section before and after placement of groin set up 3. (Q = 0.0267 cfs)

Scale : 1 : 5

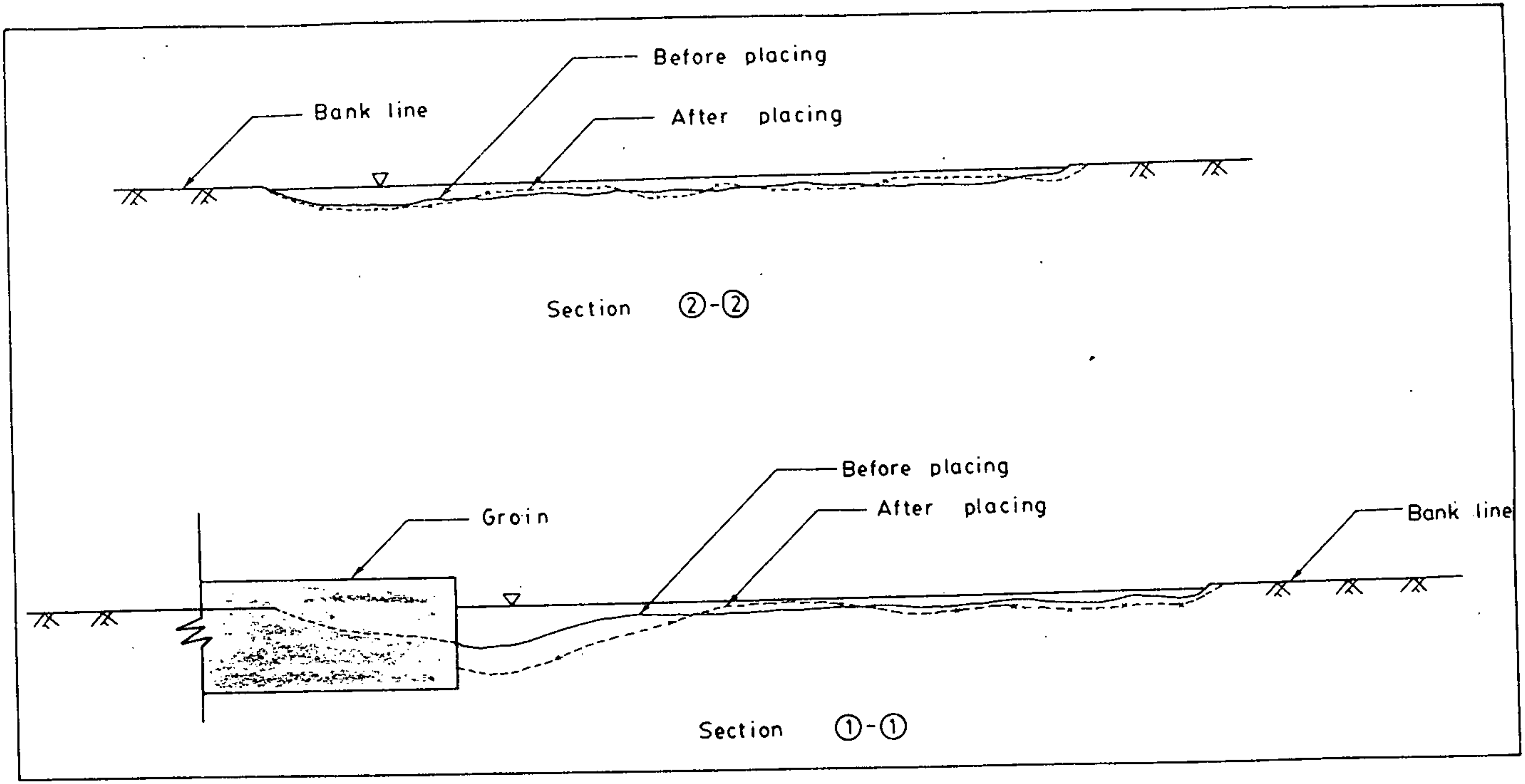


Fig. 4.23 Variation of cross-section before and after groin placement set up 4 . (Q = 0.0267 cfs)

Scale : 1 : 5

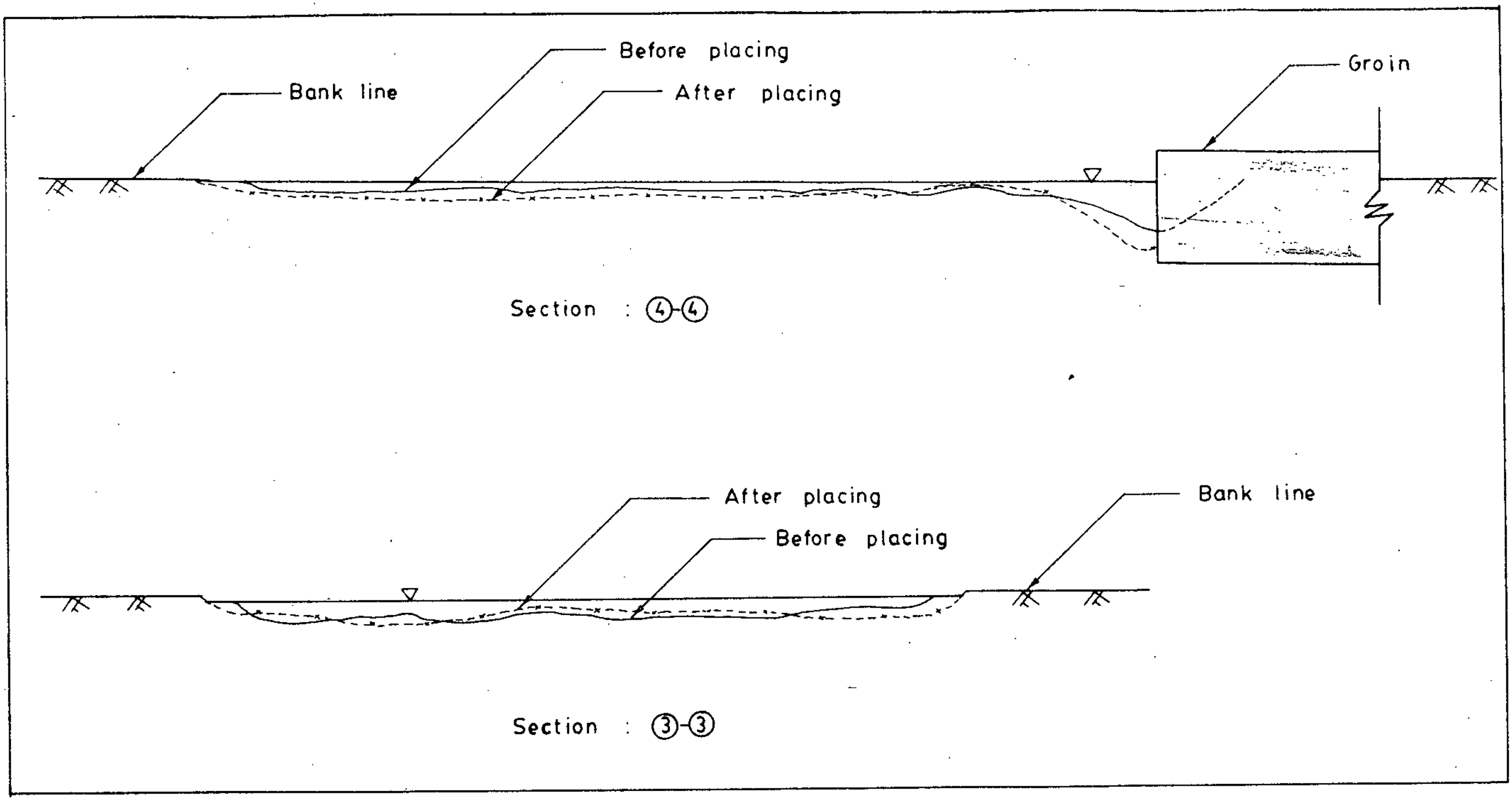


Fig 4.24 Variation of cross-section before and after groin placing set up 4 . (Q = 0.0267 cfs)

Scale : 1:5

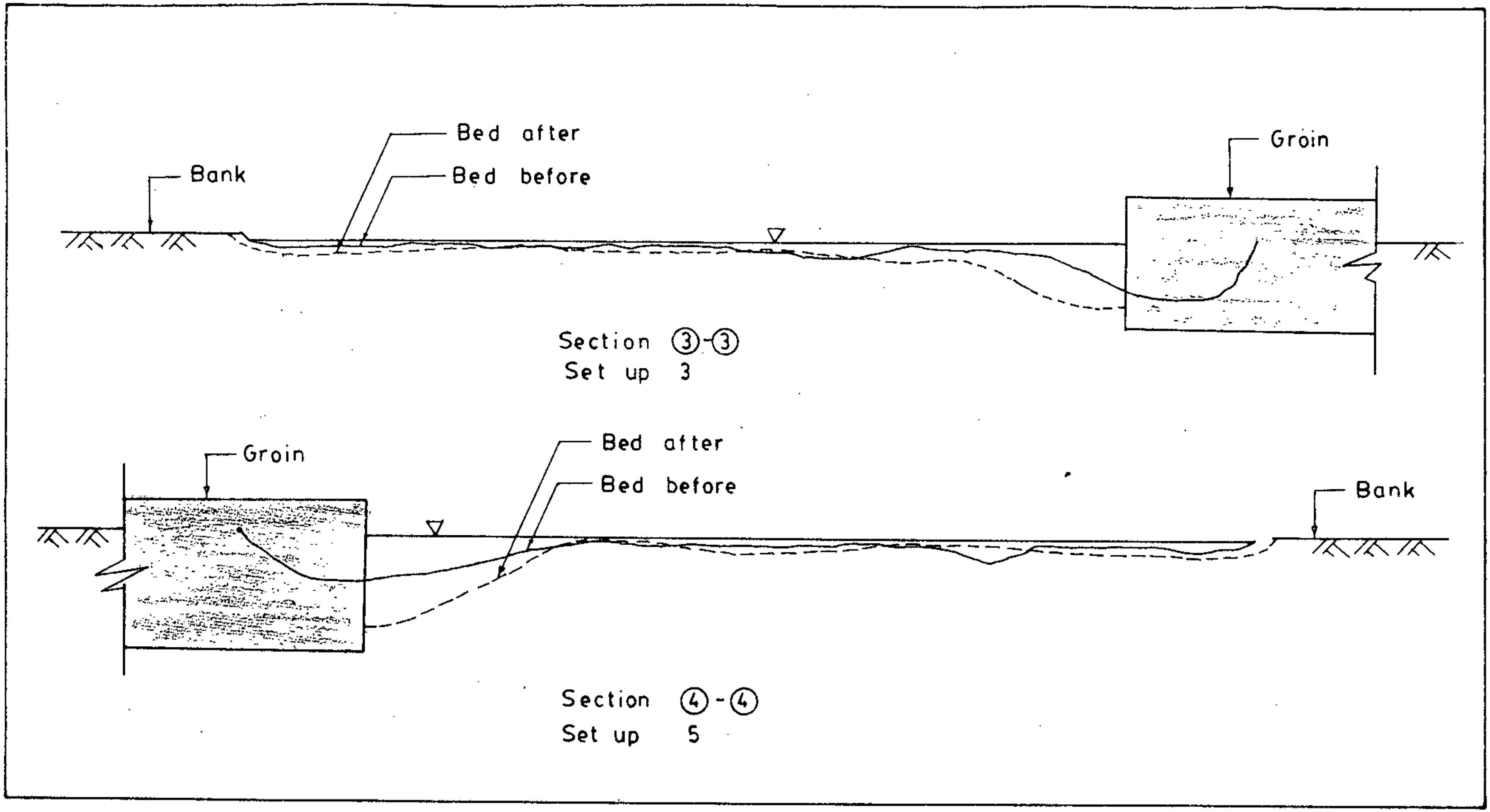


Fig. 4.25 Variation of cross-section before and after groin placing.
(Q = 0.0267 cfs) Scale 1:5

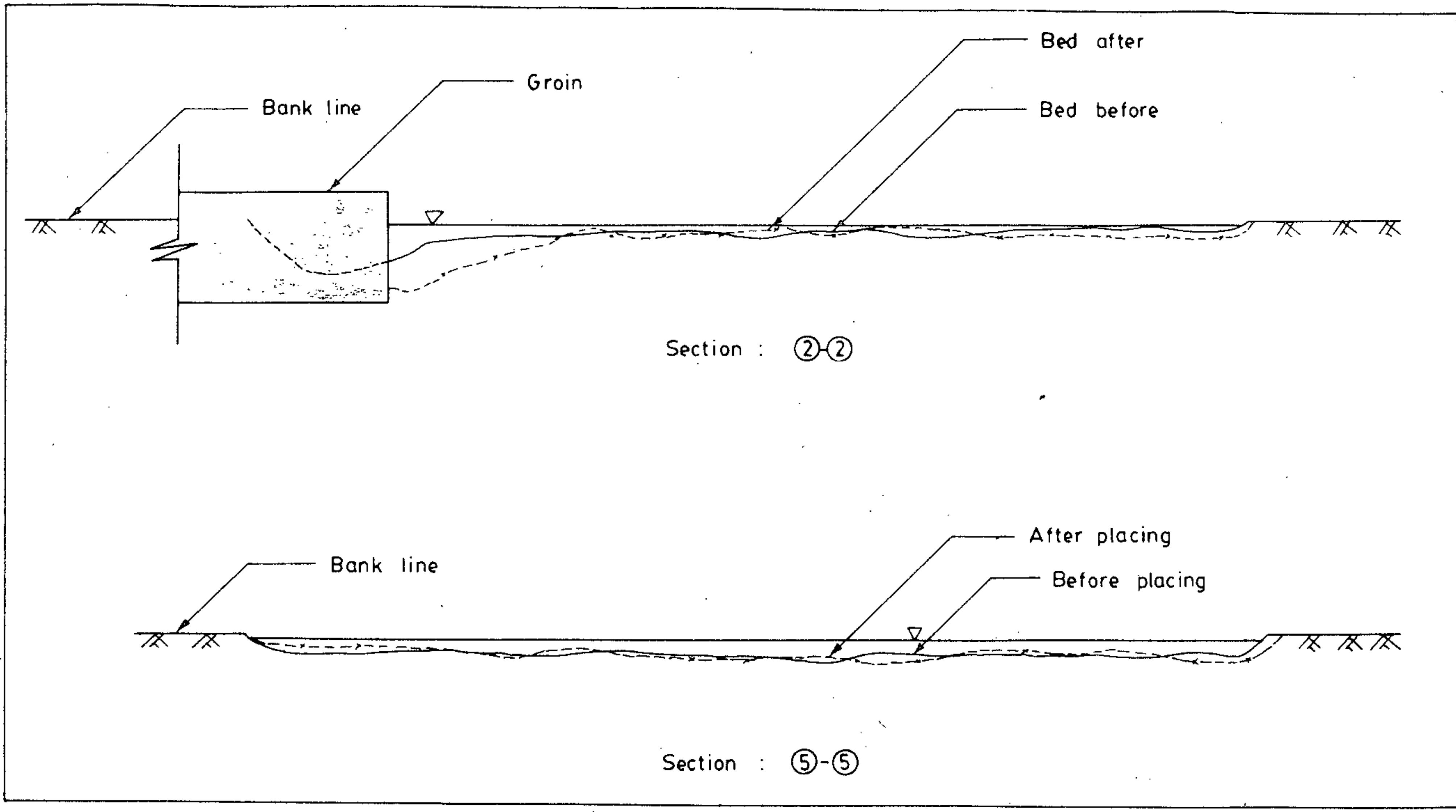


Fig. 4·26 Variation of cross section before and after groin placing set up 5. (Q = 0.0267 cfs)

Scale : 1:5

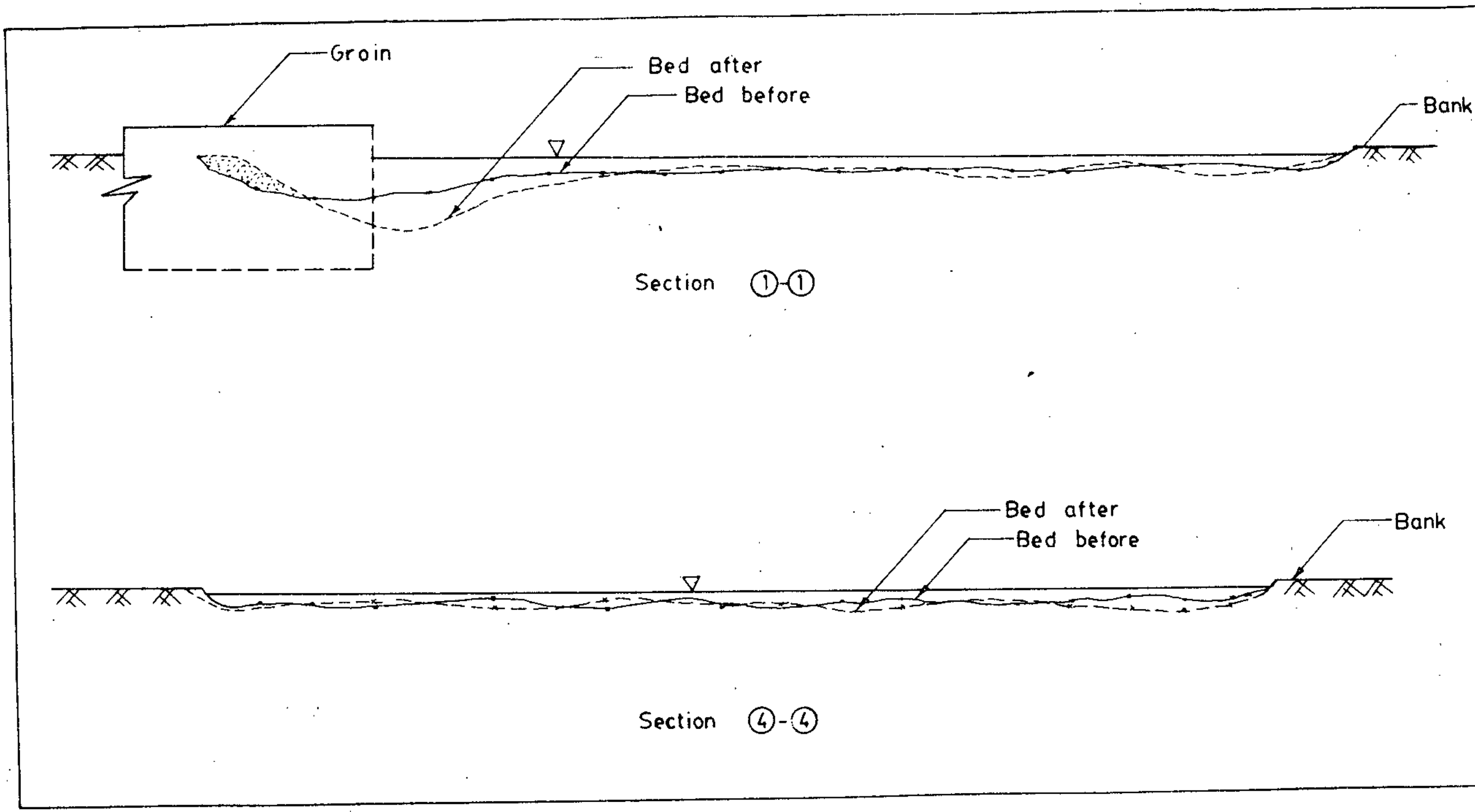


Fig. 4.27 Variation of cross-section before and after placement of groin for set up 6. (Q = 0.0267 cfs)

Scale : 1:5

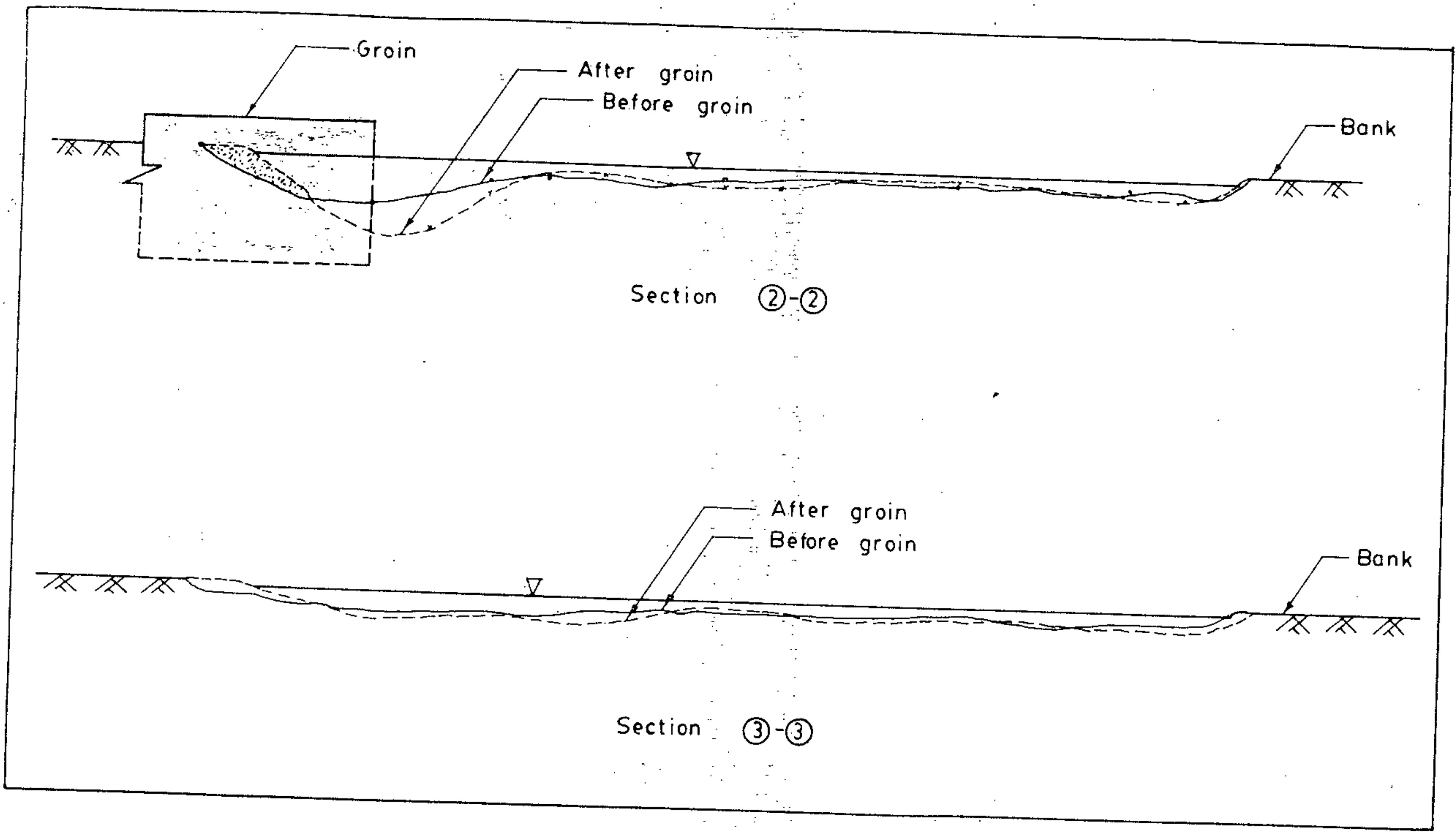


Fig. 4·28 Variation of cross-section before and after groin placing set up 6. (Q = 0.0267 cfs)

Scale : 1:5

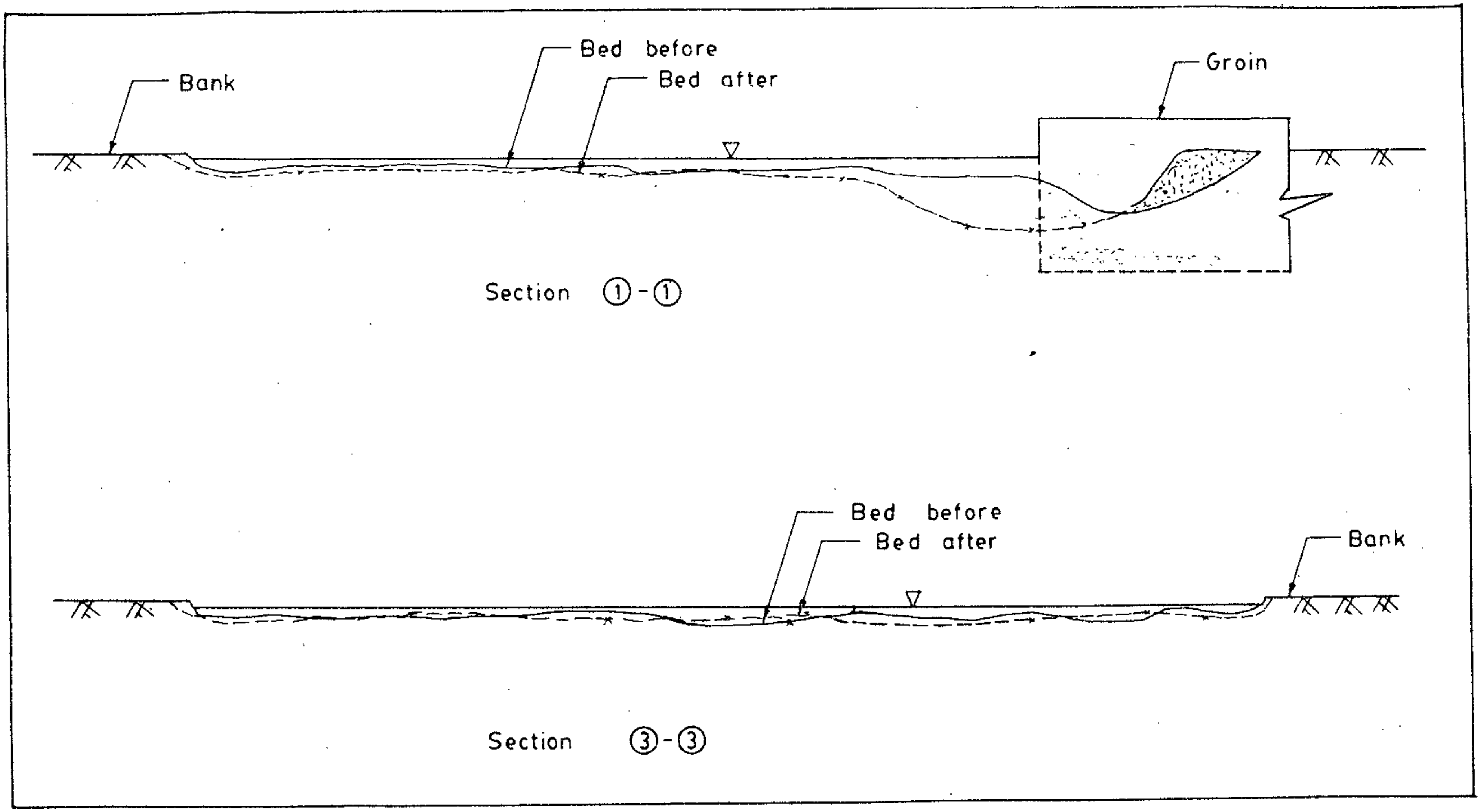


Fig. 4.29 variation of cross-section before and after groin placing set up 7. (Q = 0.0267 cfs)

Scale 1 : 5

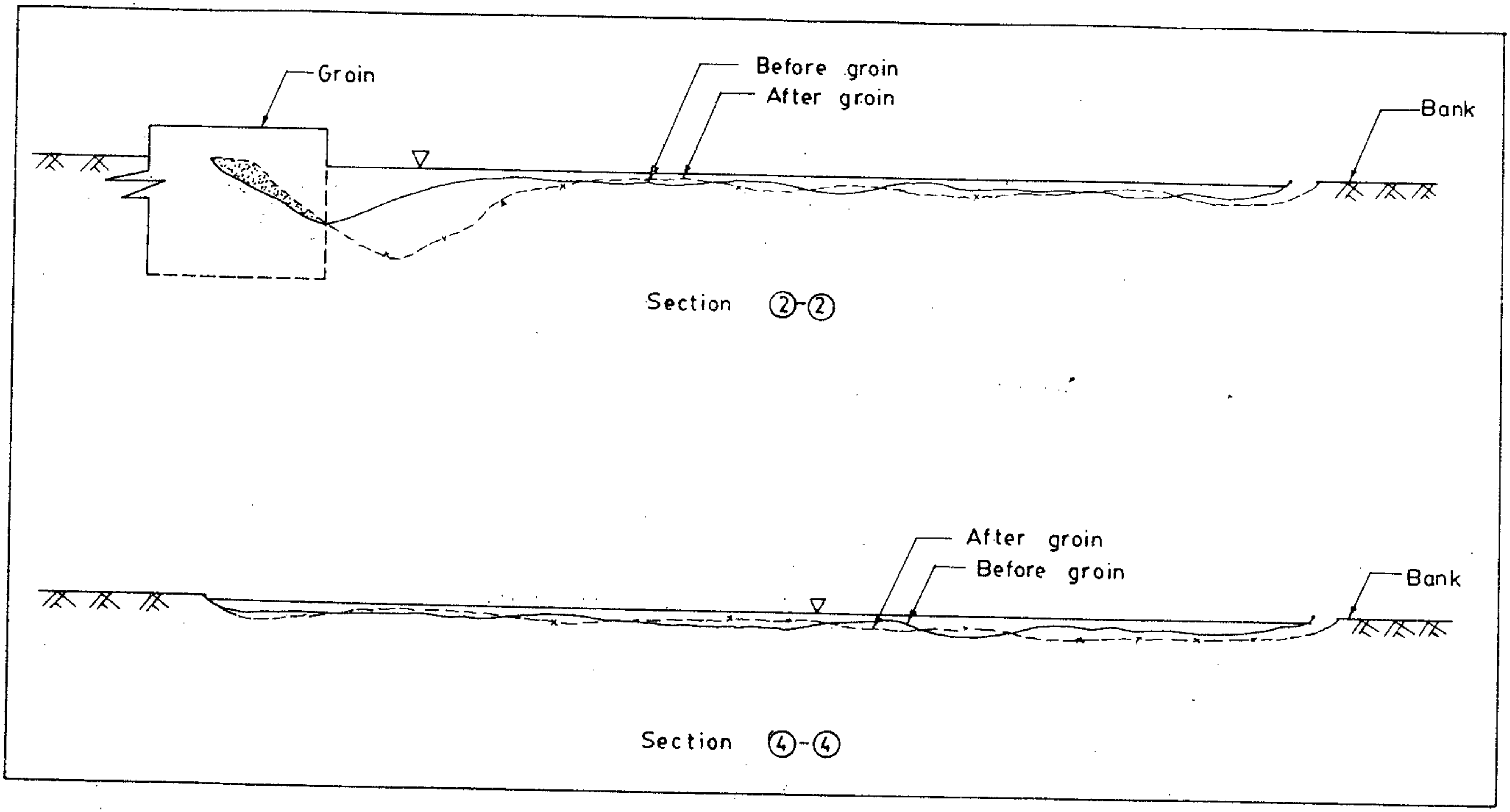


Fig. 4·30 Variation of cross-section before and after groin placing set up 7. (Q = 0.0267 cfs)

Scale 1 : 5 .

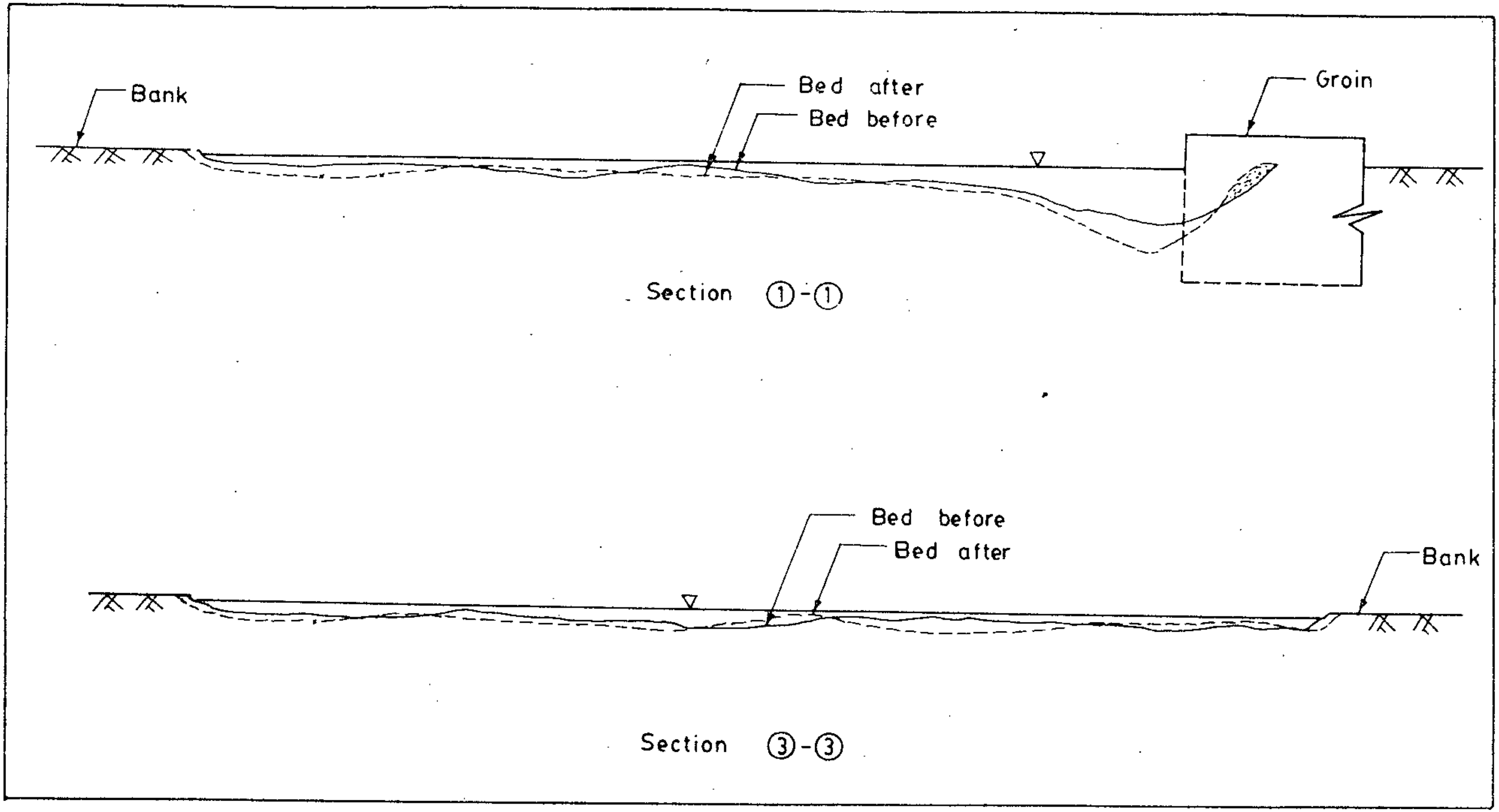


Fig. 4·31 Variation of cross section before and after groin placing set up 8. (Q = 0.0267 cfs)

Scale : 1 : 5

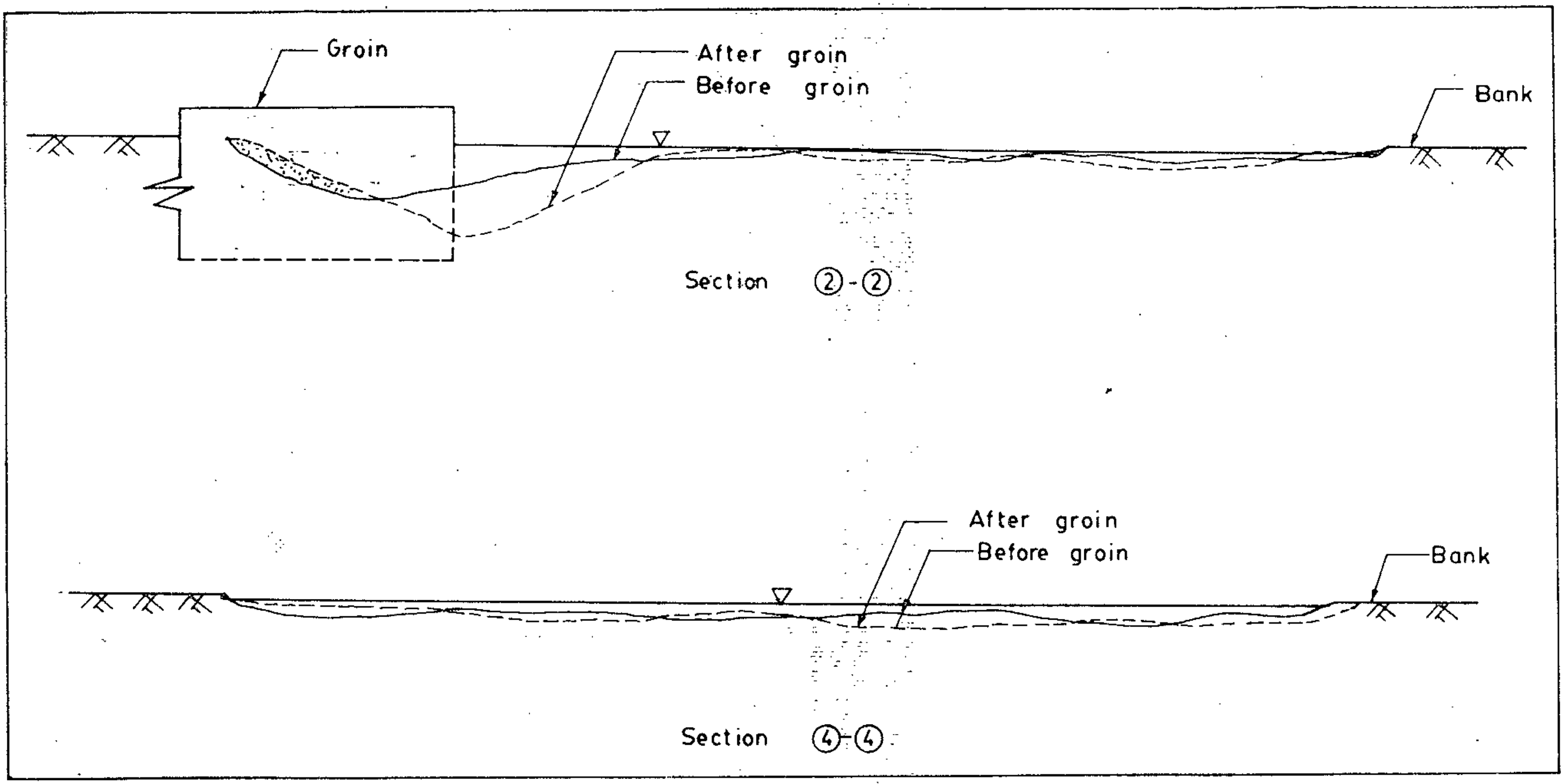


Fig. 4·32 Variation of cross section before and after groin placing set up 8 . (Q = 0.0267 cfs)

Scale : 1 : 5

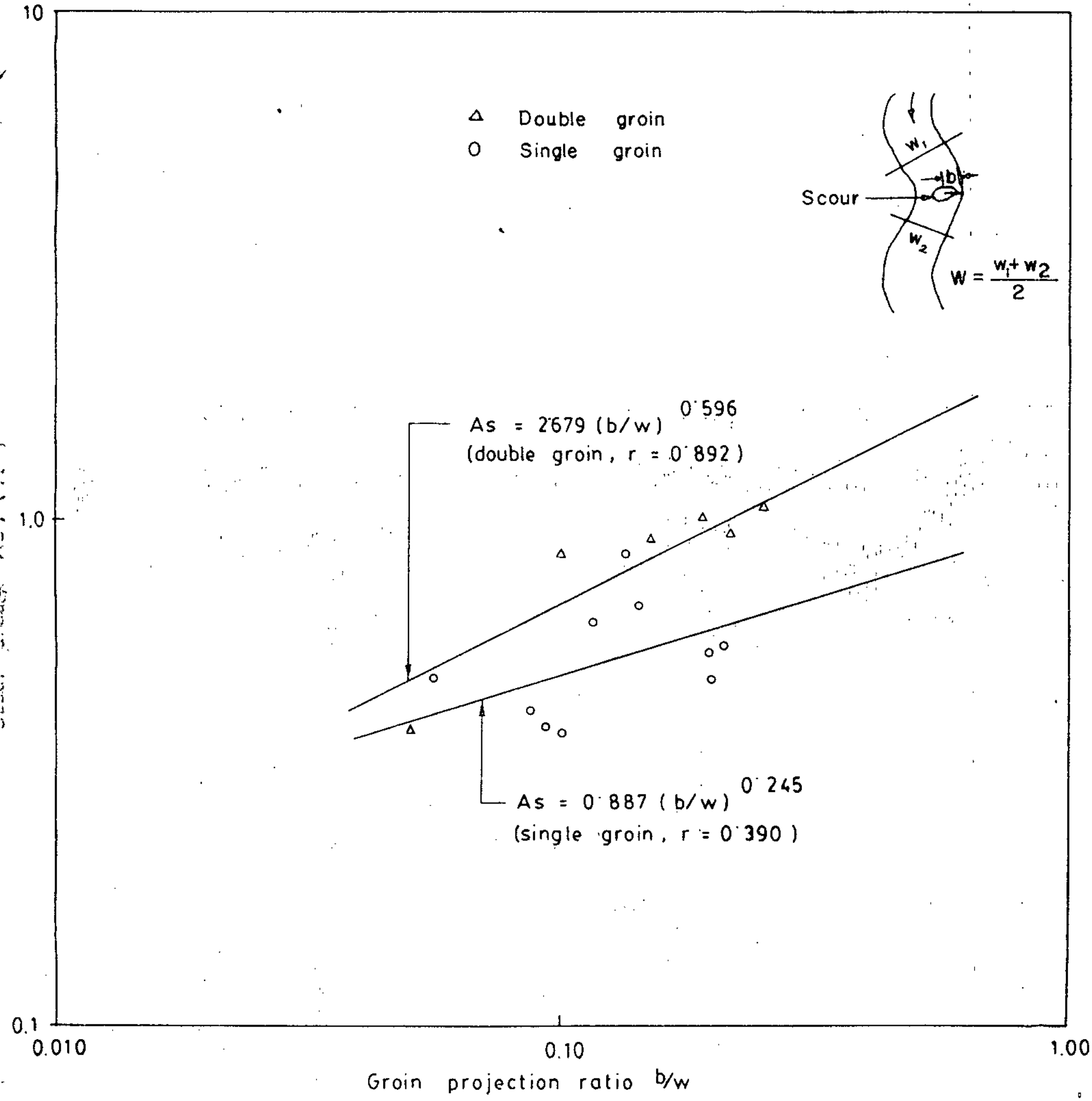


Fig.4.33 Relationship between scour area and groin projection. (Q = 0.0267 cfs)

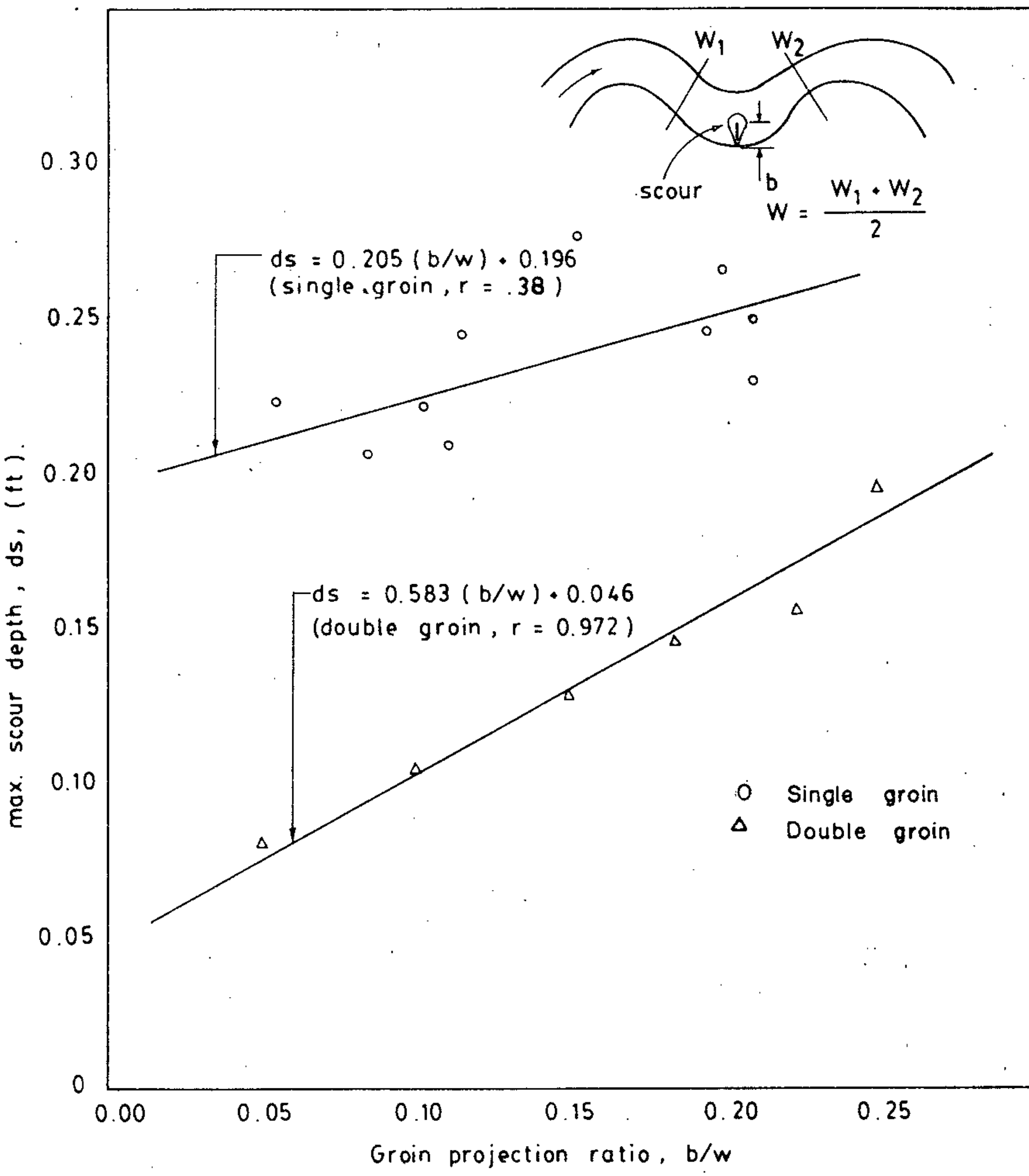


Fig. 4·34 Relationship between groin projection and maximum scour depth. (Q = 0.0267 cfs)

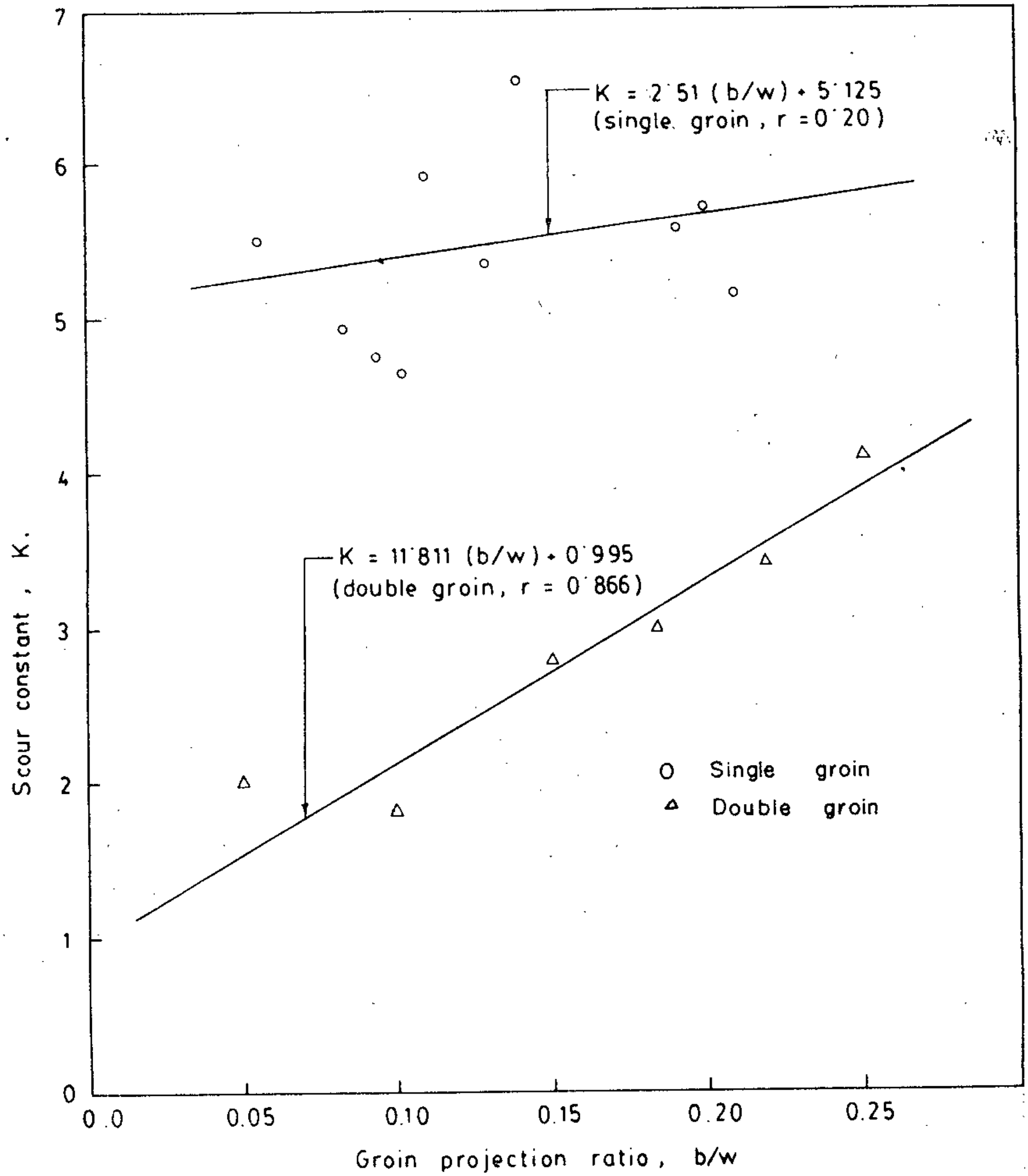


Fig. 4.35 Relationship between scour constant, K, and groin projection. (Q = 0.0267 cfs)

T A B L E S

TABLE 1

Set up 1 — Initial Channel Slope : 0.0052

Section 1-1 (d/s bend) — Discharge : 0.0267 cfs

Groin : Single Projection: 11.4%	Before groin placing	After groin placing
Slope	0.00735	0.00778
Projection, ft.	0.33300	-
Channel width, ft.	2.91600	3.16600
Area of cross-section, sft	0.10400	0.19400
Maximum depth of flow, ft.	0.14580	0.24500
Average depth of flow, ft.	0.03370	0.06250
Average velocity of flow, fps	0.25600	0.13800
Wetted perimeter, ft.	3.00000	3.23000
Hydraulic radius, ft.	0.03100	0.05800
Meander length, ft.	8.85800	8.54000
Meander thalweg length, ft.	10.82600	10.97000
Channel length, ft.	8.00000	8.00000
Channel sinuosity	1.10000	1.06700
Thalweg siuosity	1.35300	1.37000
Shear stress, pounds/sft	0.01500	0.03900
Stream power, ft-pounds/sec-ft	0.01224	0.01280
Maximum depth to width ratio	0.05000	0.06500
Froude number	0.24500	0.09800
Relative radius of curvature	0.1100	1.21000
Manning's n	0.04700	0.06600

TABLE - 1(Continued)

Set up : 1	Initial channel slope: 0.0052
Section: 1-1(d/s bend)	Discharge : 0.0267 cfs.
Groin: Single	Projection 11.4%

Maximum scour depth, ft.	0.20800
Plan area of scour, sft.	0.65000
Downstream length protected, ft.	1.75000
Upstream length protected, ft.	-
Scour constant, K	5.92000
Upstream length protected/ projection	-
Downstream length protected/ Projection	5.25000

TABLE 1

Set up : 1 Initial Channel Slope : 0.0052

Section : 3-3 (u/s bend) Descharge : 0.0267 cfs.

Groin : Single Projection : 5.5%	Before groin placing	After groin placing
Slope	0.00735	0.00778
Projection, ft.	0. 1667	-
Channel width, ft.	3.08300	3.08300
Area of cross-section, sft.	0.13800	0.18000
Maximum depth of flow, ft.	0.16670	0.22000
Average depth of flow, ft.	0.04400	0.05800
Average velocity of flow, fps.	0.19300	0.14800
Wetted Perimeter, ft.	3.28000	3.33000
Hydraulic radius, ft.	0.04200	0.05400
Meander length, ft.	8.85800	8.54000
Meander thalweg length, ft.	10.82600	10.97000
Channel length	8.00000	8.00000
Channel sinuosity	1.10000	1.06500
Thalweg sinuosity	1.35300	1.37000
Shear stress, pounds/sft.	0.01920	0.03600
Stream power, ft-pounds/sec-ft	0.01200	0.01600
Maximum depth to width ratio	0.05400	0.07200
Froude number	0.16200	0.11000
Relative radius of curvature	1.05000	1.24000
Manning's n	0.04500	0.06800

TABLE - 1(Continued)

Set up : 1	Initial channel slope : 0.0052
Section: 3-3 (u/s bend)	Discharge : 0.0267 cfs
Groin : Single	Projection : 55%

Maximum scour depth, ft.	0.220
Plan area of scour, sft.	0.480
Downstream length protected,ft	0.750
Upstream length protected,ft.	-
Scour constant, K	5.522
Upstream length protected/ projection	-
Downstream length protected/ projection	4.490

TABLE 1

Set up : 1 — Initial channel slope : 0.0052

Section: 2-2 (d/s bend) — Discharge : 0.0267 cft.

Groin Projection:	Before groin placing	After groin placing
Slope	0.00735	0.00778
Projection, ft.	-	-
Channel width, ft.	2.83000	2.830
Area of cross-section, sft.	0.11800	0.121
Maximum depth of flow, ft.	0.054	0.0625
Average depth of flow, ft.	0.0416	0.0427
Average velocity of flow, fps	0.22600	0.2200
Wetted Perimeter, ft.	2.85000	2.8660
Hydraulic radius, ft.	0.04140	0.0422
Meander length, ft.	8.85800	8.5400
Meander thalweg length, ft.	10.82600	10.9700
Channel length, ft.	8.00000	8.0000
Channel sinuosity	1.10000	1.0670
Thalweg sinuosity	1.35300	1.3700
Shear stress, pounds/sft.	0.01900	0.0260
Stream power, ft-pounds/sec-ft	0.01200	0.0160
Maximum depth to width ratio	0.01910	0.0221
Froude number	0.19000	0.19000
Relative radius of curvature	1.11000	1.2100
Manning's n	0.0490	0.0520

TABLE 2

Set up : 2
Section: 1-1 (d/s bend)

Initial Channel slope: 0.0052
Discharge:0.0267 cfs.

Groin : Single Projection: 8.33%	Before groin placing	After groin placing
Slope	0.00760	0.00840
Projection, ft.	0.20830	-
Channel width,ft.	2.50000	2.50000
Area of cross-section, sft.	0.11800	0.13190
Maximum depth of flow, ft.	0.1667	0.20830
Average depth of flow, ft.	0.0460	0.05250
Average velocity of flow, fps	0.2200	0.20000
Wetted perimeter, ft.	2.6250	2.77100
Hydraulic radius ft.	0.0450	0.04700
Meander length, ft.	8.0200	9.10000
Meander thalweg length, ft.	10.2500	11.32000
Channel length, ft.	7.5000	7.75000
Channel sinuosity	1.0700	1.17000
Thalweg sinuosity	1.3600	1.46000
Shear stress, pounds/sft.	0.0220	0.02700
Stream power, ft-pounds/sec-ft.	0.0130	0.11400
Maximum depth of width ratio	0.0668	0.08330
Froude number	0.1800	0.15000
Relative radius of curvature	1.3700	1.50000
Manning's n	0.0740	0.05100

TABLE - 2

Set up : 2 Initial channel slope : 0.0052

Section: 1-1 (d/s bend) Discharge : 0.0267 cfs.

Groin : Single Projection : 8.33%

Maximum scour depth, ft.	0.2083
Plan area of scour, sft	0.4375
Downstream length protected, ft.	1.1670
Upstream length protected, ft.	-
Scour constant, K	4.9700
Upstream length protected/ projection	-
Downstream length protected/ projection	5.6000

TABLE 2

Set up : 2

Section: 3-3 (u/s bend)

Initial Channel slope: 0.0052

Discharge : 0.0267 cfs.

Groin : Single Projection: 10.3%	Before groin placing	After groin placing
Slope	0.00760	0.00840
Projection, ft.	0.29160	-
Channel width, ft.	2.83300	2.54160
Area of cross-section, ft.	0.11800	0.12500
Maximum depth of flow, ft.	0.16250	0.22080
Average depth of flow, ft.	0.04167	0.04900
Average velocity of flow, fps	0.22000	0.21360
Wetted p rimeter, ft.	2.95000	2.86600
Hydraulic radius, ft.	0.04000	0.04300
Meander length, ft.	8.02000	9.10000
Meander thalweg length, ft.	10.25000	11.32000
Channel length, ft.	7.50000	7.75000
Channel sinuosity	1.07000	1.17000
Thalweg sinuosity	1.36000	1.46000
Shear stress, pounds/sft.	0.01900	0.02560
Streampower, ft-pounds/sec-ft.	0.01260	0.01390
Maximum depth to width ratio	0.05700	0.08700
Froude number	0.18900	0.15900
Relative radius of curvature	1.20000	1.47500
Manning's n	0.04900	0.05230

TABLE 2 (Continued)

Set up : 2	Initial Channel slope: 0.0052
Section: 3-3 (u/s bend)	Discharge : 0.0267 cfs.
Groin : Single	Porjection : 10.3%

Maximum scour depth, ft.	0.220
Plan area of scour, sft.	0.375
Downstream length protected, ft.	1.700
Upstream length protected, ft.	0.750
Scour constant, K	4.760
Upstream length protected/ projection	3.420
Downstream length protected/ projection	5.820

TABLE 2

Set up : 2 — Initial channel slope : 0.0052

Section: 2-2 (u/s bend) — Discharge : 0.0267 cfs.

Groin Projection:	Before groin placing	After groin placing
Slope	0.00760	0.00840
Projection, ft.	-	-
Channel width, ft.	2.3300	2.4600
Area of cross-section, sft.	0.0668	0.0833
Maximum depth of flow, ft.	0.0580	0.0710
Average depth of flow, ft.	0.0280	0.0340
Average velocity of flow, fps	0.4000	0.3200
Wetted perimeter, ft.	2.3600	2.5400
Hydraulic radius, ft.	0.0280	0.0327
Meander length, ft.	8.0200	9.1000
Meander thalweg length, ft.	10.2500	11.3200
Channel length, ft.	7.5000	7.7500
Channel sinuosity	1.0700	1.1700
Thalweg sinuosity	1.3600	1.4600
Shear stress, pounds/sft.	0.1300	0.0178
Stream power, ft-pounds/sec-ft.	0.0126	0.0139
Maximum depth to width ratio	0.0248	0.0288
Froude number	0.4200	0.3000
Relative radius of curvature	1.2000	1.4750
Manning's n	0.0290	0.0400

TABLE - 3

Set up : 3 — Initial Channel Slope: 0.0052

Section: 1-1 (d/s bend) — Discharge : 0.0267 cfs.

Groin : Single	Before groin placing	After groin placing
Slope	0.0076	0.0084
Projection, ft.	0.5000	-
Channel width, ft.	2.3750	2.3330
Area of cross-section, sft.	0.10416	0.1590
Maximum depth of flow, ft.	0.1667	0.2250
Average depth of flow, ft.	0.0430	0.0680
Average velocity of flow, fps	0.2560	0.1670
Wetted Perimeter, ft.	2.2650	2.4600
Hydraulic radius, ft.	0.0400	0.0650
Meander length, ft.	8.1200	7.8700
Meander thalweg length, ft.	9.8400	9.8400
Channel length, ft.	7.7500	7.7500
Channel sinuosity	1.0470	1.0200
Thalweg sinuosity	1.2700	1.2700
Shear stress, pounds/sft.	0.0200	0.0356
Stream power, ft-founds/sec-ft.	0.0126	0.0139
Maximum depth to width ratio	0.0700	0.0960
Froude number	0.2100	0.1100
Relative radius of curvature	1.5800	1.8200
Meanning's n	0.0480	0.0587

TABLE - 3 (Continued)

Set up : 3 | Initial Channel Slope: 0.0052

Section: 1-1 (d/s bend) | Discharge : 0.0267 cfs.

Groin : Single	Projection : 21%
Maximum scour depth ft.	0.2290
Plan area of scour, sft.	0.5800
Downstream length protected, ft	2.0000
Upstream length protected, ft.	-
Scour constant, K	5,0500
Upstream length protected/ projection	-
Downstream length protected/ projection	4.000

TABLE - 3

Set up : 3 — Initial Channel Slope: 0.0052

Section: 3-3 (u/s bend) — Discharge : 0.0267 cfs.

Groin : Single Projection: 20%	Before groin placing	After groin placing
Slope	0.0076	0.0084
Projection, ft.	0.5416	-
Channel width, ft.	2.6670	2.2085
Area of cross-section, sft.	0.1110	0.1215
Maximum depth of flow, ft.	0.1667	0.2458
Average depth of flow, ft.	0.0420	0.0550
Average velocity of flow, fps	0.2400	0.2200
Wetted Perimeter, ft.	2.9520	2.7060
Hydraulic radius, ft.	0.0380	0.0450
Meander length, ft.	8.1200	7.8700
Meander thalweg length, ft.	9.8400	9.8400
Channel length, ft.	7.7500	7.7500
Channel sinuosity	1.0470	1.0200
Thalweg sinuosity	1.2700	1.2700
Shear stress, pounds/sft.	0.01990	0.0288
Stream power, ft-pounds/sec-ft.	0.01260	0.0133
Maximum depth to width ratio	0.06250	0.1110
Froude number	0.2100	0.16700
Relative radius of curvature	1.4100	1.92000
Manning's n	0.0600	0.06200

TABLE - 3 (Continued)

Set up : 3

Section: 3-3 (u/s bend)

Initial Channel Slope : 0.0052

Discharge : 0.0267 cfs.

Groin : Single	Projection : 20%
Maximum scour depth, ft.	0.2458
Plan area of scour, sft.	0.4800
Downstream length protected, ft.	2.0000
Upstream length protected, ft.	0.7500
Scour constant, K	5.7300
Upstream length protected/ projection	1.3800
Downstream length protected/ projection	3.6900

TABLE - 3

Set up : 3

Section: 2-2 (u/s bend)

Initial Channel Slope: 0.0052

Discharge : 0.0267 cfs.

Groin Projection:	Before groin placing	After groin placing
Slope	0.0076	0.0084
Projection, ft.	-	-
Channel width, ft.	2.4160	2.5800
Area of cross-section, sft.	0.0690	0.0900
Maximum depth of flow, ft.	0.0625	0.0833
Average depth of flow, ft.	0.0280	0.0349
Average velocity of flow, fps	0.3870	0.2960
Wetted perimeter, ft.	2.4600	2.6200
Hydraulic radius, ft.	0.2800	0.0340
Meander length, ft.	8.1200	7.8700
Meander thalweg length, ft.	9.8400	9.8400
Channel length, ft.	7.7500	7.7500
Thalweg sinuosity	1.0470	1.2700
Shear stress, pounds/sft.	0.01320	0.0180
Stream power, ft-pounds/sec-ft.	0.01260	0.0139
Maximum depth to width ratio.	0.0248	0.0322
Froude number	0.41000	0.2800
Relative radius of curvature	1.4100	1.9200
Manning's n	0.0300	0.0420

TABLE - 4

Set up : 4 Initial Channel Slope : 0.0052

Section: 1-1 (d/s bend) Discharge : 0.0267 cfs.

Groin : Single Projection: 19.7%	Before groin placing	After groin placing
Slope	0.0064	0.0071
Projection, ft.	0.5400	-
Channel width, ft.	2.7500	2.1670
Area of cross-section sft.	0.0760	0.0900
Maximum depth of flow, ft.	0.1208	0.2250
Average depth of flow, ft.	0.0270	0.0420
Average velocity of flow, fps	0.3500	0.3000
Wetted perimeter, ft.	2.7800	2.6240
Hydraulic radius, ft.	0.0270	0.0340
Meander length, ft.	9.3500	9.3500
Meander thalweg length, ft.	10.3300	10.3300
Channel length, ft.	7.6700	7.6700
Channel sinuosity	1.2100	1.2100
Thalweg sinuosity	1.3400	1.3400
Shear stress, pounds/sft.	0.0110	0.0186
Streampower, ft-pounds/sec-ft	0.0111	0.0120
Maximum depth to width ratio	0.0440	0.1040
Froude number	0.2750	0.2570
Relative radius of curvature	1.2700	1.7300
Manning's n	0.030	0.042

TABLE - 4 (Continued)

Set up : 4	Initial Channel Slope : 0.0052
Section: 1-1 (d/s bend)	Discharge : 0.0267 cfs.
Groin : Single	Projection : 19.70

Maximum scour depth, ft.	0.2250
Plan area of scour, sft.	0.5600
Downstream length protected, ft	2.2500
Upstream length protected, ft.	0.7500
Scour constant, K	5.4800
Upstream length protected/ projection	1.8500
Downstream length protected/ projection	4.1500

TABLE - 4

Set up : 4

Section: 4-4 (u/s bend)

Initial Channel Slope : 0.0052

Discharge : 0.0267 cfs.

Groin : Single Projection: 9.5%	Before groin placing	After groin placing
Slope	0.0064	0.0051
Projection, ft.	0.2500	-
Channel width, ft.	2.9160	2.7500
Area of cross-section, sft.	0.07986	0.0900
Maximum depth of flow, ft.	0.12080	0.1720
Average depth of flow, ft.	0.0270	0.0320
Average velocity of flow, fps	0.3300	0.2966
Wetted perimeter, ft.	2.9540	2.9540
Hydraulic radius, ft.	0.0270	0.0310
Meander length, ft.	9.3500	9.3500
Meander thalweg length, ft.	10.3300	10.3300
Channel length, ft.	7.6700	7.6700
Channel sinuosity	1.2100	1.2100
Thalweg sinuosity	1.3400	1.3400
Shear stress, pounds/sft.	0.0110	0.0142
Stream power, ft-pounds/sec-ft.	0.0112	0.0120
Maximum depth to width ratio	0.0410	0.0650
Froude number	0.3500	0.2900
Relative radius of curvature	1.2000	1.3600
Manning's n	0.3320	0.0400

TABLE - 4 (Continued)

Set up : 4	Initial Channal Slope : 0.0052
Section: 4-4 (u/s bend)	Discharge : 0.0267 cfs.
Groin : Single	Projection : 9.5%

Maximum scour depth, ft.	0.1875
Plan area of scour, sft.	0.3750
Downstream length protected, ft.	1.2500
Upstream length protected, ft.	-
Scour constant, K	4.740
Upstream length protected/ projection	-
Downstream length protected/ projection	5.000

TABLE - 4

Set up : 4

Section: 2-2 (d/s bend)

Initial Channel Slope: 0.0052

Discharge : 0.0267 cfs.

Groin Projection :	Before groin placing	After groin placing
Slope	0.0064	0.0071
Projection, ft.	-	-
Channel width, ft.	2.3750	2.5400
Area of cross-section, sft	0.0690	0.0760
Maximum depth of flow, ft.	0.0540	0.0540
Average depth of flow, ft.	0.0290	0.0300
Average velocity of flow, fps	0.3860	0.3500
Wetted perimeter, ft.	2.4600	2.6200
Hydraulic radius, ft.	0.0280	0.0290
Meander length, ft.	9.3500	9.3500
Meander thalweg length, ft.	10.3300	10.3300
Channel length, ft.	7.6700	7.6700
Channel sinuosity	1.2100	1.2100
Thalweg sinuosity	1.3400	1.3400
Shear stress, pounds/sft.	0.0120	0.0130
Streampower, ft-pounds/sec-ft.	0.0110	0.0118
Maximum depth of width ratio	0.0227	0.0222
Froude number	0.4000	0.3560
Relative radius of curvature	1.2000	1.3600
Manning's n	0.0280	0.0330

TABLE - 4

Set up : 4 — Initial Channel Slope: 0.0052

Section: 3-3 (u/s bend) — Discharge : 0.0267 cfs.

Groin Projection:	Before groin placing	After groin placing
Slope	0.0064	0.0071
Projection, ft.	-	-
Channel width, ft.	2.0000	2.3750
Area of cross-section, sft.	0.0729	0.0833
Maximum depth of flow, ft.	0.625	0.0625
Average depth of flow, ft.	0.0360	0.0350
Average velocity of flow, fps	0.3600	0.0320
Wetted perimeter, ft.	2.1300	2.4600
Hydraulic radius, ft.	0.0340	0.0330
Meander length, ft.	9.3500	9.3500
Meander thalweg length, ft.	10.3300	10.3300
Channel length, ft.	7.6700	7.6700
Channel sinuosity	1.2100	1.2100
Thalweg sinuosity	1.3400	1.3400
Shear stress, pounds/sft.	0.0140	0.0140
Stream power, ft-pounds/sec-ft.	0.0110	0.0120
Maximum depth to width ratio	0.0310	0.0263
Froude number	0.3300	0.3000
Relative radius of curvature	1.2000	1.3600
Manning's n	0.0320	0.0360

TABLE - 5

Set up : 5

Section: 2-2 (u/s bend)

Initial Channel Slope: 0.0052

Discharge : 0.0267 cfs.

Groin : Single Projection: 13.8%	Before groin placing	After groin placing
Slope	0.00625	0.00521
Projection, ft.	0.4160	-
Channel width,ft.	3.0000	2.5800
Area of cross-section, sft.	0.1215	0.1110
Maximum depth of flow, ft.	0.1416	0.1958
Average depth of flow, ft.	0.0505	0.0426
Average velocity of flow, fps	0.0220	0.2400
Wetted perimeter, ft.	3.1200	2.7800
Hydraulic radius, ft.	0.0380	0.0390
Meander length, ft.	7.8700	8.3600
Meander thalweg length, ft.	10.8300	10.8300
Channel length, ft.	7.5000	7.5000
Channel sinuosity	1.0500	1.1100
Thalweg sinuosity	1.4400	1.4400
Shear stress, pounds/sft.	0.0148	0.0122
Streampower, ft-poundd/sec-ft.	0.0100	0.0068
Maximum depth to width ratio	0.0500	0.0736
Froude number	0.1700	0.1750
Relative radius of curvature	1.0830	1.2800
Manning's n	0.0590	0.0500

TABLE- 5 (Continued)

Set up : 5 Initial Channel Slope : 0.0052

Section: 2-2 (u/s bend) Discharge : 0.0267 cfs.

Groin : Single	Projection : 13.8%
Maximum scour depth, ft.	0.2000
Plan area of scour, sft.	0.8750
Downstream length protected, ft.	1.7500
Upstream length protect, ft.	-
Scour constant, K	5.3400
Upstream length protected/ projection	-
Downstream length protected/ projection	4.2000

TABLE - 5

Set up : 5

Section: 4-4 (d/s bend)

Initial Channel Slope : 0.0052

Discharge : 0.0267 cfs

Groin : Single Projection: 14.3%	Before groin placing	After groin placing
Slope	0.00625	0.00521
Projection, ft.	0.4580	-
Channel width, ft.	3.2000	2.83000
Area of cross-section, sft.	0.1230	0.1300
Maximum depth of flow, ft.	0.1450	0.2250
Average depth of flow, ft.	0.0380	0.0460
Average velocity of flow, fps	0.2160	0.2100
Wetted perimeter, ft.	2.3800	2.9500
Hydraulic radius, ft.	0.0370	0.0440
Meander length, ft.	9.8400	10.5000
Meander thalweg length, ft.	11.8000	12.3000
Channel length, ft.	8.5000	8.5000
Channel sinuosity	1.1500	1.2300
Thalweg sinuosity	1.3800	1.4400
Shear stress, pounds/sft.	0.0146	0.0143
Stream power, ft-pounds/sec-ft.	0.0100	0.0087
Maximum depth to width ratio	0.0450	0.0810
Froude number	0.1760	0.1700
Relative radius of curvature	0.7800	0.8800
Manning's n	0.0580	0.0600

TABLE - 5 (Continued)

Set up : 5	Initial Channel Slope : 0.0052
Section: 4-4 (d/s bend)	Discharge : 0.0267 cfs.
Groin : Single	Projection : 14.3%
Maximum scour depth, ft.	0.2916
Plan area of scour, sft.	0.6875
Downstream length protected, ft.	1.5000
Upstream length pretected, ft.	-
Scour constant, K	6.5900
Upstream length protected/ projection	-
Downstream length protected/ projection	3.2700

TABLE - 5

Set up : 5 Initial Channel Slope: 0.0052

Section: 5-5 (u/s bend) Discharge : 0.0267 cfs.

Groin : Projection:	Before groin placing	After groin placing
Slope	0.00625	0.00521
Projection, ft.	-	-
Area of cross-section, sft.	2.8750	3.0800
Maximum depth of flow, ft.	0.12840	0.1388
Average depth of flow, ft.	0.0446	0.0450
Average velocity of flow, fps	0.2079	0.1840
Wetted perimeter, ft.	2.9500	3.1100
Hydraulic radius, ft.	0.0439	0.0456
Meander length, ft.	9.000	9.000
Meander thalweg length,ft.	10.9700	11.2100
Channel length, ft.	8.2500	8.2500
Channel sinuosity	1.0900	1.0900
Thalweg sinuosity	1.3300	1.3600
Shear stress, pounds/sft.	0.0170	0.0150
Stream power, ft-pounds/sec-ft.	0.0100	0.0087
Maximum depth to width ratio	0.0520	0.0520
Froude number	0.1700	0.1500
Relative radius of curvature	0.9400	1.0230
Manning's n	0.0640	0.0680

TABLE - 5

Set up : 5 Initial Channel Slope: 0.0052

Section: 3-3 (d/s bend) Discharge : 0.0267 cfs.

Groin Projection:	Before groin placing	After groin placing
Slope	0.00625	0.00521
Projection, ft.	-	-
Channel width, ft.	3.3330	3.5000
Area of cross-section, sft.	0.1380	0.1450
Maximum depth of flow, ft.	0.1250	0.13750
Average depth of flow, ft.	0.0417	0.0410
Average velocity of flow, fps	0.1930	0.1830
Wetted perimeter, ft.	3.4400	3.6000
Hydraulic radius, ft.	0.0401	0.0402
Meander length, ft.	9.000	9.000
Meander thalweg length, ft.	11.7100	11.7100
Channel length, ft.	8.2500	8.2500
Channel sinuosity	1.0900	1.0900
Thalweg sinuosity	1.4200	1.4200
Shear stress, pounds/sft.	0.1560	0.0130
Stream power, ft-pounds/sec-ft.	0.0100	0.00868
Maximum depth to width ratio	0.0380	0.0390
Froude number	0.1670	0.1600
Relative radius of curvature	1.048	1.0350
Manning's n	0.0520	0.0540

TABLE- 6

Set up : 6

Section: 1-1 (u/s bend)

Initial Channel Slope; 0.0052

Discharge : 0.0267 cfs.

Groin : Double Projection: 18.6%	Before groin placing	After groin placing
Slope	0.00555	0.00602
Projection, ft.	0.6667	–
Channel width, ft.	3.3330	2.6667
Area of cross-section, sft.	0.1493	0.13368
Maximum depth of flow, ft.	0.1250	0.15420
Average depth of flow, ft.	0.04479	0.05013
Average velocity of flow, fps	0.1788	0.1997
Wetted perimeter, ft.	3.3628	2.9528
Hydraulic radius, ft.	0.04439	0.04527
Meander length, ft.	10.97000	11.07200
Meander thalweg length, ft.	13.04130	14.27200
Channel length, ft.	10.0000	10.0000
Channel sinuosity	1.0970	1.1070
Thalweg sinuosity	1.3040	1.4270
Shear stress, pounds/sft.	0.01537	0.0170
Stream power, ft-pounds/sec-ft.	0.00924	0.010029
Maximum depth to width ratio	0.03750	0.057800
Froude number	0.14880	0;157200
Relative radius of curvature	1.10020	1.40620
Manning's n	0.07780	0.07340

TABLE- 6 (Continued)

Set up : 6

Section: 1-1 (u/s groin)

Initial Channel Slope: 0.0052

Discharge : 0.0267 cfs.

Groin : Double	Projection : 18.6%
Maximum scour depth, ft.	0.1453
Plan area of scour, sft.	1.1250
Downstream length protected, ft.	2.0000
Upstream length protected, ft.	-
Scour constant, K	2.6348
Upstream length protected/ projection	-
Downstream length protected/ projection	2.9900

TABLE - 6

Set up : 6

Section : 2-2 (d/s groin)

Initial Channel Slope: 0.0052

Discharge : 0.0267 cfs.

Groin : Double Projection: 15%	Before groin placing	After groin placing
Slope	0.00555	0.00602
Projection, ft.	0.45833	-
Channel width, ft.	3.2916	2.8333
Area of cross-section sft.	0.14062	0.1319
Maximum depth of flow, ft.	0.14583	0.2292
Average depth of flow, ft.	0.04272	0.046568
Average velocity of flow, fps	0.18900	0.20200
Wetted perimeter, ft.	3.35400	3.23900
Hydraulic radius, ft.	0.04190	0.0407
Meander length, ft.	8.8580	9.10400
Meander thalweg length, ft.	11.7120	11.81100
Channel length, ft.	7.7500	8.0000
Channel sinuosity	1.1430	1.1380
Thalweg sinuosity	1.5110	1.4760
Shear stress, pounds/sft.	0.0145	0.11529
Stream power, ft-pounds/sec-ft.	0.00924	0.01003
Maximum depth to width ratio	0.04270	0.08080
Froude number	0.16180	0.16520
Relative radius of curvature	0.91100	1.14700
Manning's n	0.06710	0.06760

TABLE-6 (Continued)

Set up : 6	Initial Channel Slope: 0.0052
Section : 2-2 (d/s groin)	Discharge : 0.0267 cfs.
Groin : Double	Projection : 15%

Maximum scour depth, ft.	0.1250
Plan area of scour, sft.	0.9375
Downstream length protected, ft.	2.0000
Upstream length protected , ft.	-
Scour constant, K	2.806
Upstream length protected/ projection	-
Downstream length protected/ projection	4.3636

TABLE - 7

Set up : 7 Initial Channel Slope: 0.0052

Section : 1-1 (u/s groin) Discharge : 0.0267 cfs.

Groin : Double Projection: 22%	Before groin placing	After groin placing
Slope	0.00638	0.00643
Projection, ft.	0.6670	-
Channel width,ft.	3.0000	2.33300
Area of cross-section, sft.	0.1649	0.14062
Maximum depth of flow, ft.	0.21667	0.30000
Average depth of flow, ft.	0.05496	0.06027
Average velocity of flow, fps	0.16190	0.18980
Wetted perimeter, ft.	3.19800	2.46000
Hydraulic radius, ft.	0.05150	0.05710
Meander length, ft.	10.82600	10.82600
Meander thalweg length, ft.	11.81100	12.30000
Channel length, ft.	9.25000	9.25000
Channel sinuosity	1.17000	1.17000
Thalweg sinuosity	1.27800	1.33000
Shear stress, pounds/sft.	0.02015	0.02290
Stream power, ft-pounds/sec-ft.	0.01064	0.01072
Maximum depth to width ratio	0.07220	0.12850
Froude number	0.12170	0.13620
Relative radius of curvature	1.16670	1.60700
Manning's n	0.09800	0.93000

TABLE - 7 (Continued)

Set up : 7
Section : 1-1 (u/s groin)

Initial Channel Slope : 0.0052
Discharge : 0.0267 cfs.

Groin : Double	Projection : 22%
Maximum scour depth, ft.	0.1667
Plan area of scour, sft.	0.9166
Downstream length protected, ft.	2.5000
Upstream length protected, ft.	-
Scour constamt, K	3.2800
Upstream length protected/ projection	-
Downstream length protected/ projection	3.75

TABLE - 7

Set up : 7

Initial Channel Slope: 0.0052

Section : 2-2 (d/s groin)

Discharge : 0.0267 cfs.

Groin : Double Projection: 10%	Before groin placing	After groin placing
Slope	0.00638	0.00643
Projection, ft.	0.33300	-
Channel width, ft.	3.25000	2.5833
Area of cross-section, sft.	0.15625	0.1736
Maximum depth of flow, ft.	0.1458	0.2500
Average depth of flow, ft.	0.0481	0.06721
Average velocity of flow, fps	0.1708	0.15380
Wetted perimeter, ft.	3.2810	3.28100
Hydraulic radius, ft.	0.0476	0.05290
Meander length, ft.	11.0728	11.31890
Meander thalweg length, ft.	12.0728	12.30300
Channel length, ft.	9.7500	9.75000
Channel sinuosity	1.1356	1.22300
Thalweg sinuosity	1.2366	1.26000
Shear stress, pounds/sft.	0.01895	0.02124
Stream power, ft-pounds/sec-ft.	0.0106	0.01070
Maximum depth to width ratio	0.0448	0.09670
Fraude number	0.13730	0.10450
Relative radius of curvature	1.0769	1.45200
Manning's n	0.9130	0.10950

TABLE-7 (Continued)

Set up : 7

Section : 2-2 (d/s groin)

Initial Channel Slope: 0.0052

Discharge : 0.0267 cfs.

Groin : Double

Projection : 10%

Maximum scour depth, ft.	0.10416
Plan area of scour, sft.	0.87500
Downstream length protected, ft.	2.00000
Upstream length protected, ft.	-
Scour constant, K	1.79600
Upstream length protected/ projection	-
Downstream length protected/ projection	6.000

TABLE- 8

Set up : 8

Section : 1-1 (u/s bend)

Initial Channel Slope: 0.0052

Discharge : 0.0267 cfs.

Groin Projection: Double 5%	Before groin placing	After groin placing
Slope	0.00527	0.00518
Projection, ft.	0.16670	-
Channel width, ft.	3.25000	3.08333
Area of cross section, sft.	0.13880	0.12847
Maximum depth of flow, ft.	0.14580	0.20830
Average depth of flow, ft.	0.04270	0.04167
Average velocity of flow, fps	0.19236	0.20780
Wetted perimater, ft.	3.37500	3.12500
Hydraulic radius, ft.	0.04112	0.04110
Meader length, ft.	9.84200	10.33400
Meander thalweg length ft.	11.81110	12.30310
Channel length ft.	9.33300	9.25000
Channel sinuosity	1.05450	1.11700
Thalweg sinuosity	1.126500	1.33000
Shear stress, pounds/sft.	0.013500	0.01313
Stream power, ft-pounds/sec-ft	0.008780	0.00863
Maximum depth to width ratio	0.04480	0.06750
Froude number	0.16400	0.17940
Relative radius of curvature	1.15400	1.24300
Manning's n	0.06600	0.061400

TABLE-8 (Continued)

Set up : 8

Initial Channel Slope: 0.0052

Section: 1-1 (u/s bend)

Discharge : 0.0267 cfs.

Groin : Double	Projection : 5%
Maximum scour depth, ft.	0.0833
Plan area of scour, sft.	0.3750
Downstream length protected, ft.	1.0000
Upstream length protected, ft.	-
Scour constant, K	2.0750
Upstream length protected/ projection	-
Downstream length protected/ projection	5.9800

TABLE - 8

Set up : 8 — Initial Channel Slope: 0.0052

Section : 2-2 (d/s bend) — Discharge : 0.0267 cfs.

Groin : Double Profection : 25%	Before groin placing	After groin placing
Slope	0.00527	0.00518
Projection, ft.	0.83300	-
Channel width, ft.	3,66700	2.8750
Area of cross-section, sft.	0.19090	0.1736
Maximum depth of flow, ft.	0.1875	0.2700
Average depth of flow, ft.	0.0250	0.0603
Average velocity of flow, fps.	0.1398	0.1538
Wetted perimeter, ft.	3.7720	2.9520
Hydraulic radius, ft.	0.5059	0.5879
Meander length, ft.	9.94200	10.82600
Meander thalweg length, ft.	13.77000	13.94700
Channel length, ft.	9.75000	9.75000
Channel sinuosity	1.0092	1.11030
Thalweg sinuosity	1.4100	1.43030
Shar stress, pounds/sft.	0.0166	0.01880
Stream power, ft-pounds/sec-ft	0.00878	0.00664
Maximum depth to width ratio	0.05113	0.09390
Froude number	1.10800	0.11040
Relative radius of curvature	1.09000	1.44900
Manning's n	0.10600	0.10500

TABLE-8 (Continued)

Set up : 8	Initial Channel Slope: 0.0052
Section: 2-2 (d/s bend)	Discharge : 0.0267 cfs.
Groin : Double	Projection : 25%
Maximum scour depth, ft.	0.020833
Plan area of scour, sft.	1.041660
Downstream length protected, ft.	2.250000
Upstream length protected, ft.	-
Scour constant, K	4.66700
Upstream length protected/ projection	-
Downstream length protected/ projection	2.70000