

EFFECT OF SIZE AND UNIT WEIGHT
OF MATERIALS IN BANK PROTECTION

A Thesis submitted by

AIN-UN-NISHAT

In partial fulfilment of the requirements
for the degree of M.Sc.Engineering in
Civil Engineering majoring in Water
Resources Engineering

BANGLADESH UNIVERSITY OF ENGINEERING & TECHNOLOGY
DACCA

JANUARY, 1975



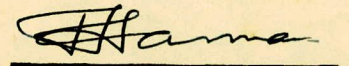
T.62

EFFECT OF SIZE AND UNIT WEIGHT OF MATERIALS
IN BANK PROTECTION

A Thesis by
Ain-un-Nishat

Approved as to style and content by:

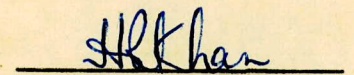
Chairman of the Committee


Dr. A. Hannan

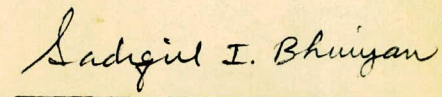
Head of the Department


Dr. A. Hannan

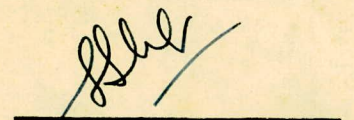
Member


Dr. H. R. Khan

Member


Dr. S. I. Bhuiyan

Member


Dr. S. Shahrul Huq

January, 1975



JANUARY 23, 1975

WE HEREBY RECOMMEND THAT THE THESIS PREPARED BY
AIN-UN-NISHAT UNDER THE SUPERVISION OF DR.A.HANNAN
ENTITLED EFFECT OF SIZE AND UNIT WEIGHT OF MATERIALS
IN BANK PROTECTION BE ACCEPTED AS FULFILLING THIS PART
OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE
IN CIVIL ENGINEERING MAJORING IN WATER RESOURCES
ENGINEERING.

COMMITTEE

CHAIRMAN OF THE COMMITTEE

Dr. A. Hannan

HEAD OF THE DEPARTMENT

Dr. A. Hannan

MEMBER

Dr. H. R. Khan

MEMBER

Dr. S. Shahrul Huq

MEMBER

Dr. S. I. Bhuiyan

ABSTRACT

EFFECT OF SIZE AND UNIT WEIGHT OF MATERIALS IN BANK PROTECTION

A study to determine the suitability of a lighter material, such as 'burnt clay lump' which is can be made available locally, to replace stone in bank protection work was taken up. The effect of size and unit weight of materials in bank protection was studied in laboratory in a straight channel using cubical blocks made of sand-cement mortar and brick. Saturated sand-cement block had a specific gravity of 2.68 resembling that of stone and brick blocks had a specific gravity of 2.18.

Critical velocity at failure of the blocks used as bank protective material was determined on four different side slopes. The volume of blocks was found to vary with the velocity at failure as the 6th and 7th power for sand-cement blocks and brick blocks respectively. The weight of blocks was found to vary with the velocity at failure as the 4.75th and 5.5th power for sand-cement blocks and brick blocks respectively.

It was observed that interlocking of the blocks and the waves in the channel are also major factors in the determination of proper size of bank protective materials. It was also concluded that on a flatter side slope blocks of much less weight are required.

ACKNOWLEDGEMENT

The author is indebted to many individuals for help given in various forms during the course of his study. The author gratefully acknowledges his indebtedness to Dr. Abdul Hannan, Professor and Head, Department of Water Resources Engineering, Bangladesh University of Engineering and Technology Dacca, under whose affectionate guidance and constant encouragement, it was possible on his part to present this study in the form as is seen.

The author extends his deep appreciation to Dr. Hamidur Rahman Khan, Dr. Sadiqul Islam Bhuiyan and Dr. Syed Shahrul Haque for their review of the manuscript and helpful comments and corrections.

The author wants to specially thanks to his colleague Shahjahan Kabir Chowdhury, who helped him with valuable suggestions.

The author is indebted to his wife Samina Sultana, for her patient bearing.

TABLE OF CONTENTS

Abstract	iv
Acknowledgement	v
Table of Contents	vi
Notation	viii

Chapter		Page
I	INTRODUCTION	
	General Introduction	1
	Objective of Study	4
II	LITERATURE REVIEW	
	General Remarks	5
	Causes of Bank Failure	5
	Hydraulic Actions Involved in Bank Failure	6
	Mechanics of Hydraulic Erosion	8
	Forces Exerted by Flowing Water	9
	Tractive Force	10
	Methods of Bank Protection	13
	Bank Protection with Revetment	13
	Design of Revetment	14
	Determination of Size and Weight of Stone	15
III	EXPERIMENTAL PROCEDURE	
	General Remarks	18
	Experimental Set-up	18
	Preparation of Slope Protecting Blocks	19
	Test Channel	20
	Experimental Procedure	22

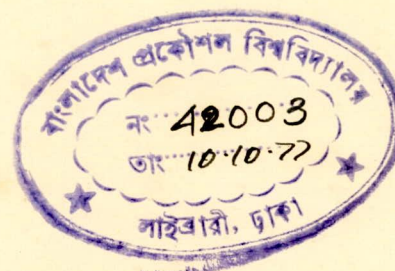
Chapter	Page
IV RESULTS AND DISCUSSION	
Introduction	24
Effect of Unit Weight	24
Effect of Size	25
Effect of Interlocking	25
Effect of Waves	26
Effect of Side Slope	26
V CONCLUSION	27
BIBLIOGRAPHY	41

NOTATIONS

A	Projected area of object normal to flow	sft
b	bottom width of channel	ft
C_D	Coefficient of Drag	
d	depth of channel	ft
D	Diameter of particles	inches
F_D	Total Drag force	
K	Tractive force ratio	
Q	Discharge	cfs
R	Hydraulic radius of channel	ft
S	Slope of energy grade line	ft/ft
S_s	Specific gravity of particles	
T	Thickness of revetment	ft
V	Velocity of flow	fps
γ	Unit weight of water	Lb/cft
τ	Tractive force	lb/sft
τ_c	Critical tractive force	lb/sft
τ_s	Critical tractive force on slope	lb/sft
τ_L	Critical tractive force on bed	lb/sft
ν	Kinematic viscosity	
ϕ	angle of inclination of side slope	
θ	angle of repose of the material	
ϕ'	constant	
ρ	mass density of the liquid	
ψ	constant, 70° for broken rock placed randomly	

T. 62

CHAPTER I INTRODUCTION



General Introduction

In a broad sense, a bank can be defined as a sloping surface of land coming in contact with a body of still or flowing water. Bank protection therefore includes any protective work that aims at maintaining the stability of land against the action of water. Under such a broad definition bank protection includes works of shoreline protection along the sea and lakes against waves and littoral drift, protective works along navigation channel against the waves created by passing vessels, and protective works along embankments and banks of rivers for the purpose of flood control, navigation or river training.

Since time immemorial people have flocked together to build townships and home-steads on the bank of rivers. But due to shifting characteristics of alluvial rivers the banks are subjected to erosion. The construction of embankments along river banks to protect the country side from flood is also being practised since early days. But embankments, designed usually from stability consideration fail when it has to bear high velocity of water. As such various protective systems are being developed and practised in bank protection works. The side slope of irrigation and drainage canals also need protective efforts.

Bangladesh is a land of rivers, interlaced by the numerous channels of the three mighty river systems of the world viz. the Ganges, the Brahmaputra and the Meghna. Severe flood during monsoon and shifting of rivers are recurring features in this country. As such bank protection works are one of the major engineering works in this country.

River bank failure has been observed by engineers and investigators and various solutions and suggestions are being put forward. Protective works of various types and systems are taken up, the design of which are mostly based on experience and empirical methods.

The proper method and type of protective work to be applied at a particular site needs careful investigation and planning as these projects involve huge expenditure. Bank protection can be achieved by indirect methods e.g., construction of spur, groyne, jetty etc., and by direct methods e.g., construction of revetments, armours, ripraps, etc. Though all these methods are being applied successfully under various conditions, the use of stone revetment is common and applied under critical conditions effectively. In this method a blanket of protective stone is laid down to the desired thickness and slope which is sufficient to prevent erosion.

Of the various methods of bank protection work being applied, the use of stone-revetment is common in Bangladesh. Dumping of stones do not give successful results because if

the stones are smaller than required they themselves will be carried away and cannot prevent erosion. But stone is costly and ~~scarce~~ in Bangladesh. Sand-cement block is being used in place of stone in Serajganj, in the District of Pabna.

Mass concrete can successfully replace stone because of its similarity in properties. But cement is a costly material in Bangladesh and its demand in construction works exceeds the supply. As such suitable replacement of stone is desired.

Lumps of clay burnt in a manner similar to the burning of bricks, in sizes having desired weight may be successfully used in revetment. But as the unit weight of burnt clay is less than that of stone, a much bigger size will be ~~required~~ for the same weight. The increase in size will invite difficulties in proper burning and handling. Again due to the increase in size and volume the magnitude of the forces acting on the blocks will be more, thus requiring blocks of more weight. Production of burnt clay lumps of required size and shape is possible with available local materials, because a high quality of burning is not essential. Only it is to be ensured that the lumps themselves do not disintegrate under the forces acting on them. With an additional advantage that burnt clay lumps can be manufactured in desired quality and quantity at the work site requiring no transportation cost, its use in bank protection work as a replacement of stone can be investigated. But before any recommendation is

made, the proper size and weight of 'burnt clay lump' required is to be determined and economy of its use established.

Of the various factors that control the size and weight of bank protective material velocity of flow, bank slope, unit weight of the material used, shape and interlocking of the material when placed on bank, waves and secondary current in the channel are the major ones. A logical approach for such a study is to conduct experiments in a smaller scale and to extrapolate the results for prototype conditions. With the above ideas in mind, the study of the effect of unit weight and size of bank protective material was taken up as a research project.

Objective of Study

The objective of this work were:

- i. To develop a suitable laboratory facility and experimental set-up.
- ii. To study the effect of unit weight of materials in bank protection.
- iii. To study the effect of size of materials in bank protection.
- iv. To study the effect of bank slope on weight and volume of materials used in bank protection.
- v. To determine relationship between velocity of flow and weight of materials to be used in bank protection.

CHAPTER II

LITERATURE REVIEW

General Remarks

As bed and banks of alluvial streams are erodible, it is this type of stream along which protective works are mostly required both for bank protection and river training purposes. Bank protection works also assist in deepening navigation channels in the bendways by resisting erosion of the bends and inducing scour of the bed.

There has been various methods of bank protection. But no one type of protection is suitable for all situations, nor will the best type of a particular situation withstand the greatest flood passing through the channel section. All the methods have relative merits and suitability under different conditions. As such causes of river bank failure, the hydraulic actions involved in failure, the mechanism of erosion, forces exerted by flowing water and causes of failure of bank protective works is to be understood first before a particular method can be chosen or the performance of a particular system can be analysed. The practised design considerations and methods of bank protection works with stone revetments are also discussed.

Causes of Bank Failure

A bank may fail owing to any one or a combination of the following causes (2):

- i. Washing away of soil particles of the bank by current or waves i.e., by erosion.
- ii. Sliding due to the increase of the slope of the bank as a result of erosion.
- iii. Undermining of the toe of the lower bank subsequently causing the collapse of over hanging material deprived of support i.e. by scour.
- iv. Sloughing or sliding of slope when saturated with water.
- v. Sliding due to seepage of water flowing back into the river after receding of a flood.
- vi. Piping of sublayer due to movement of ground water to river which carries away sufficient material with it.

The causes in short are i) erosion, ii) sliding, iii) Scour and iv) Seepage.

Hydraulic Actions Involved in Bank Failure

The different actions responsible for erosion in a particular location can be classified as follows(2):

- i. Frictional erosion by trangetial flow.
- ii. Impingement erosion by curvilinear flow.
- iii. Eddy erosion below restrictions and reef.
- iv. Erosion in varied flow.
- v. Erosion in unsteady flow.
- vi. Wave erosion.
- vii. Static erosion.

Frictional erosion by tangential flow is due to the drag or tractive force at the perimeter combined with the force of gravity which act on particles on the bank.

In curvilinear flow the high mid-stream flow moves towards bank and this together with transverse current dislodge and carry away the bank materials.

Eddies and turbulence is generated when flow passes a restriction or a reef. Eddies attack the particles on bed or bank causing failure.

Varied flow involves acceleration and deceleration of flow. ~~Accelerating~~ flow causes bed scour while decelerating stream causes deposition on bed.

Unsteady flow introduces several contingency which contribute to erosion. One is saturation of bank in rising stage which flows back into the river making the bank weak. On the falling stage free ground water springs from the bank which causes sliding forces. On the rising stage, the increasing transport power of the stream entrains loose bed material of progressively larger size and uses them to corrade the under lying harder materials in a pattern of general scour.

Waves are one of the major agents in erosion. The erosive power of waves are functions of the offshore profile, the direction, height and the period of oscillations. Attack is strongest if deep water is continuous along the bank. Waves need not be very high, even wake waves from passing vessels in still water or pier in moving water is quite powerful. Static

erosion is due to the solvent and chemical action of flowing water. Again the salts in bed or bank material may be leached. This phenomenon is unlikely in an old channel but may occur in an artificial new channel or on embankments exposed to standing water. Another static action is quickening of saturated soils by percolation of ground water towards a free surface and the bank or bed becomes unstable.

Mechanics of Hydraulic Erosion

The process of hydraulic erosion has two steps, (2):

(i) the dislodgement of one or more solid particles from adhesive, cohesive or interlocked contact with a mass of such particles and (ii) the transport of the particle or particles away from the location so that other particles may now be attacked.

The resistance along the contact of a moving body to a stationary body is friction. When one of the two bodies is fluid, the conflict along its boundary disturbs its motion for some distance away, the zone of disturbance being called boundary layer. The thickness and dynamic characteristics of this layer depends on the roughness of the solid boundary and velocity of the passing fluid.

Smooth banks can tolerate much higher velocity while the bond of the particles forming bed and bank add to it.

Factors influencing the rate of erosion are i) velocity of flow ii) properties of side and bed materials iii) types of loads carried by the river iv) slope of the stream v) discharge and cross-section vi) turbulence of flow.

Forces Exerted by Flowing Water

Erosion of river banks and scour of bed take place when the soil particles composing them are acted upon by forces sufficient to cause them move,

Water flowing in a stream produces various forces such as centrifugal force, centripetal force, tractive force or shear force and drag force. Centrifugal and centripetal forces are the consequences of flow in a bend or curved path. The secondary or spiral flow is related to centrifugal force acting on the flow, which produces transverse water surface slope or superelevation.

The centripetal force which acts in the opposite direction to the centrifugal force is the resistance of the bank. The resistance of the bank maintains the superelevation of the water surface, causing difference in hydrostatic pressure on the side of the water prism. This difference in hydrostatic pressure balance both centrifugal forces and the radial component of shear force on the bed caused by secondary currents. Secondary currents, if present contribute to the movement of particles from bed or bank.

The gravitational force motivating the flow in open channels is balanced by shear stress developed on the wetted perimeter. The force exerted by the flowing water on the perimeter acting in the direction of flow is known as 'tractive force'

This force for a straight channel of uniform flow is given by

$$\tau = \gamma RS \quad \text{where}$$

τ = tractive force, lb/sft.

γ = unit weight of water lb/cft.

R = hydraulic radius, ft.

S = slope of energy grade line, ft/ft.

The magnitude of drag forces on various objects can be approximated by using the basic relation (7)

$$F_D = C_D \frac{A \times \rho \times v_o^2}{2} \quad \text{where}$$

F_D = total drag force

C_D = coefficient of drag, which varies with size and shape of the object and Reynold's number.

ρ = mass density of the liquid

A = projected area of the object normal to the flow

v_o = mean ambient velocity of flow

Tractive Force

Tractive force concept is often applied to initiation of particle movement. When this force is just adequate to move a particle, the tractive force is referred to as the critical tractive force τ_c , which is the minimum value of τ to initiate motion for noncohesive materials. Shield(9) found critical tractive force on bed materials as follows:

$$\tau_c = \phi' \left[\frac{D \sqrt{g R S}}{D} \right] \gamma (S_s - 1) D$$

where ϕ' = constant

D = dia of particle

S_s = specific gravity of particles

τ_c = critical tractive force

Krey (7) proposed the relationship

$$\tau_c = 0.076 \gamma (S_s - 1) D$$

Other studies that have related a critical bed velocity to particle diameter and particle weight is presented in Fig.-1. (Simons and Anding, 1969).

Critical tractive force is smaller for sinuous channels and its values for different degrees of sinuosity of channels as compared to straight channels as suggested by Lane is given in Table 1.

TABLE - 1

Degree of sinuosity	% of critical tractive force required to initiate bed load movement as compared to straight channel	corrospond- ing per cent of mean velocity
Straight channel	100	100
Slightly sinous channel	90	95
Moderately sinous channel	75	81
Very sinous channel	60	78

The above statements refer to the erosion of the non-cohesive bed of channels. On a slope the resistance of a sediment particle to motion is reduced by the sliding force of the

particle itself on an inclined plane due to its own weight. The ratio of τ_s , the tractive force required to move a particle on the inclined plane to τ_L , tractive force required to move a particle on level bottom is called tractive-force ratio and is denoted as K.

$$K = \sqrt{1 - \frac{\sin^2 \phi}{\sin^2 \theta}} \quad \text{where}$$

θ = angle of repose of the material

ϕ = angle of inclination of side slope

Another important point to be considered is the distribution of tractive force on the side slope of a channel which has been worked by Olsen and Florey (Chow, 1959) and is presented in Table - 2.

TABLE - 2

Maximum Tractive Force on Side Slope of Trapezoidal Channels Expressed in terms of $\gamma \cdot D \cdot S$

Side Slope	Ratio of bottom width b to depth D		
	2	4	8
2:1	0.760	0.770	0.770
1:1.5	0.735	0.750	0.760

Methods of Bank Protection

There are four general ways of dealing the problems of bank protection. The most commonly used method is to face the slope with more resistant material. This direct method of bank protection includes works done directly on the bank itself such as revetment, concrete paving etc.

The second method is to reduce the force of attacking water. The third method is to move the direction of the attacking water away from the eroding bank. These two indirect methods of bank protection includes such works which are not constructed directly on the banks but in front of them e.g. piles, jetties, groyne, spurs, **retards**, baffles etc.

A fourth, the simplest and the surest of success is, of course, a retreat from the location of hazard. This is not always feasible from both economical and socio-political view points.

Bank Protection with Revetment

This kind of protection, also called riprap consists of stone layers placed directly over the banks. Where stones of required size and quality are available in sufficient quantities stone revetment is the most suitable and adopted method of bank protection. The advantages under these conditions are

1. It is flexible and is not imparied nor weakened by

slight movement of the slope due to settlement or other minor adjustment.

2. Local damage or loss is easily repairable by the addition of stones where required.

3. Constuction is not complicated.

4. Appearance is natural, hence acceptable in recreational areas.

5. Vegetation often grow through the stones adding structural values and also reduces roughness.

6. Desired slope and thickness to the revetment surface can be provided.

7. May be reinforced in critical zones.

8. It is salvagable, may be stockpiled and re-used if necessary.

Causes of failure of revetment works are i) insufficient depth of protection, ii) insufficient weight of protecting materials and iii) non-flexibility of the mattress.

Design of Stone Revetment

In designing the slope protection with stone revetment the following five requirements are to be determined:

- i. Size and weight of stone
- ii. Depth at which stones are founded
- iii. Elevation of the top of the protection.
- iv. Thickness of protection
- v. Face slope.

In the design principles adopted and available, reliance is placed on experience and judgement. Analytical investigations such as tractive force concept, critical tractive force, tractive force ratio, studies of scour under different conditions by various investigators have undoubtedly thrown some light on the subject, but there is still much scope for their perfection.

Determination of Size and Weight of Stone

The size and weight of stone required for a given revetment is a function of a flow velocity, usually taken as the velocity at a distance of 10 ft. from the bank. Available formulae and suggestions for computing the size of rock which will resist movement by the flow give results varying over a fairly wide range.

The formula proposed by La bash (1936) is found to be effective.

$$W = \frac{4.1 \times 10^{-5} \times S_s \times V^6}{(S_s - 1)^3 \cos^3 \phi}$$

The relationship used by California Highway Engineers (2):

$$W = \frac{.0002 \times V^6 \times S_s \times \operatorname{cosec}^3 (\psi - \phi)}{(S_s - 1)^3}$$

Where ψ = constant, 70° for broken rock placed randomly. In the United States general practices can be summerised as given in the Table 131

TABLE - III

Velocity fps.	Riprap thickness inch	Maximum size, lb	Riprap grading, average size, lb	20% size lb	Filter thickness inches
6 to 12	12	150	30-50	20	6
12 to 15	15	250	50-80	20	6
15 to 18	18	400	80-150	20	6

It is reported(5) that on the lower Mississippi graded stone ranging in sizes from 6 to 125 lb and 10 inches thick is used on a 4 inches gravel blanket. On the Missouri River in Iowa and Nebraska, the specifications provide that thickness of the quarry-run cast stone be 10 inches at the top of the slope increasing uniformly to 15 inches where it joins the trench fill and that the maximum size of stone be 250 lb.

In India(9) "one-man" stone pitching with a thickness given by $T = 0.6 Q^{1/3}$, where T is the thickness in ft and Q is the discharge in cfs, is used.

Protection of Other Dimensions

Retentment should be founded in a toe-trench dug to bed rock. But where bed rock is not within reach the toe should be carried below the depth of scour. Falling apron, which is a stone blanket extending from the bottom of the slope pitching into the river bed is successfully used in India.

Thickness of the protection must be sufficient to accommodate the largest stone. Jones (1966) states that the thickness

of the riprap should be at least $1\frac{1}{2}$ times the average stone size and that this should be increased below the water surface. As flatter slopes as possible should be adopted because it requires lighter stone.

Backing material prevent the loss of finer particle from slope and is essential where stones of nearly uniform size is used. Stones should be placed in well interlocked state. Hand placement achieves interlocking best.

CHAPTER III

EXPERIMENTAL PROCEDURE

General Remarks

The research work was aimed at studying the effect of unit weight, size and weight of materials in protection works on various bank slopes at laboratory scale. The laboratory investigations carried out was divided into three different phases. First phase was to design and construct a suitable recirculating channel system with available measurement facilities. The second phase was concerned with the preparation of protective blocks and determining their various physical properties. The third phase was carrying out of the experiment in the channel laid out earlier.

All the experiments were conducted in the Hydraulics Laboratory of the Department of Water Resources Engineering.

Experimental Set-up

Nature of the experiments suggested the use of a tilting type flume so that longitudinal slope could be adjusted to obtain gradual increase in velocity in the channel. As no such suitable flume or set up was available, a recirculating channel system was laid on ground (Fig. 2). It consisted of a sand plain measuring 30'-0" long, 5'-0" wide and 3'-0" deep. Bottom of the channel was lined with galvanised iron sheets to stop seepage of water. On both sides of channel

were two rails 7'-0" apart and their heights could be adjusted to give proper initial slope to the sand channel. Over the rails was a crosswise frame on which a point gauge was attached for measurement of depth in a channel. Two reservoirs of sufficient capacity, one at upstream end with adequate baffles to dampen the turbulence of incoming water and the other at downstream end with arrangements to recover sand carried by water, were built. The pump available in the laboratory had a capacity of 2.5 cfs which was very high as to the actual need. It was used in the experiment with a loss-line that could return any volume of water back to the downstream reservoir from which water was pumped, leaving the desired volume of water to flow through the experimental channel. This was attained through pipe network and valves. To measure discharge a v-notch was placed at entrance of the channel and it was duly calibrated. To measure velocity of flow, the use of dye was chosen.

Preparation of Slope Protecting Blocks

To study the effect of unit weight of protecting materials two types of blocks were prepared. The first type was prepared with brick while the material for the other one was sand-cement mortar. The specific gravity of sand cement ~~mortar~~ blocks were close to that of stone. As such the sand cement blocks were used in place of stone because proper size and shape of blocks could be obtained with it.

To study the effect of size and volume, four different sizes of blocks were prepared with each of the above mentioned materials. All the blocks were grinded very carefully to form cubes. The four different sizes of cubes were $\frac{1}{4}$ ", $\frac{3}{8}$ ", $\frac{1}{2}$ " and $\frac{3}{4}$ ". The number of cubes prepared were sufficient for covering the test zone in experimental set-up.

All the cubes were measured and then weighted both in dry and in saturated condition. The volume, and the dry and saturated unit weights of the blocks were computed. The saturated unit weight of brick was 136.25 lb/cft and that of sand cement block was 167.0 lb/cft. offered a suitable variation in unit weight for the experimental use. Physical properties of the blocks are presented in Table IV.

Test Channel

For determination of the effectiveness of different protective materials of various sizes in a straight channel, a trapizoidal section was tried. But it was found that a full trnpizoidal channel is not suitable in conducting experiments because the velocity on the bank remains low at all discharge within experimental limitation. This was due to the fact that water was allowed to enter the channel through a straight path and the velocity along the bank was low. So a channel section with one side vertical and the other side according to desired slope was tried and found workable. The channel section had an average depth of 10" with a bottom width of 3", side slope being varied during the experiment. (Fig.2).

TABEL IV

Physical Properties of the Bank Protecting Cubes

Material:- Brick

Size	Volume cft.	Weight of each cube Lb		Unit weight Lb/cft.	
		Dry	Saturated	Dry	Saturated
$\frac{1}{4}$ " cube	9.05×10^{-6}	.00102	.00130	112	143
$\frac{3}{8}$ " cube	3.05×10^{-5}	.00320	.00396	105	130
$\frac{1}{2}$ " cube	7.24×10^{-5}	.00795	.00980	109	135
$\frac{3}{4}$ " cube	2.44×10^{-4}	.02650	.03300	108	137

Average Unit Weight

109.5 136.25Material:-Sand-Cement block

Size	Volume cft.	Weight of each cube Lb		Unit weight Lb/cft.	
		Dry	Saturated	Dry	Saturated
$\frac{1}{4}$ " cube	9.05×10^{-6}	.00143	.00159	158	176
$\frac{3}{8}$ " cube	3.05×10^{-5}	.00463	.00508	152	166
$\frac{1}{2}$ " cube	7.24×10^{-5}	.01250	.0122	155	168
$\frac{3}{4}$ " cube	2.44×10^{-4}	.03640	.03860	149	158
Average Unit Weight				<u>153.5</u>	<u>167</u>

Sp. Gr. of saturated brick blocks = 2.18

Sp. Gr. of saturated sand cement blocks = 2.68

Side slope of the bank was considered as a variable. Considering the usual practice of side slope, four side slopes were selected, viz, 1:2, 1:2.5, 1:3 and 1:3.5. The sloping side was laid down carefully. The vertical side of the channel was lined with brick. The sloping face was also properly lined excepting a reach of 2'-0" where the tests were carried out. The bed of the channel had fine sand.

Experimental Procedure

Before actually starting a test the geometry and alignment of the channel laid out were checked. Water was allowed to run for for sometime to get a stable longitudinal slope. In the test zone mentioned earlier a filter blanket made up of coarse sand was placed over which saturated blocks of a particular size and material was placed in interlocked condition.

Water was allowed to flow at a very low velocity and its effect on the protective blocks was observed. If the blocks stayed in place, the velocity of flow was increased by gradual increase in discharge in the channel. In this manner the critical velocity of failure of the blocks was found out. At this condition the head of flow over the v-notch and the cross-sectional area over the test zone were recorded from which the average velocity in the channel was calculated. The actual velocity causing the failure of the bank protection work was also measured with dye, for this purpose, a reach of 10'-0" was marked along the channel and coloured particles were introduced into the flow at the depth at which the blocks

was first moved. Time time required to cover the reach was recorded and ~~three~~ readings were taken.

The whole process was repeated thrice for each size of blocks of a particular material and a mean of nine such recorded velocity was taken to be the velocity at failure for that set of blocks on that particular side slope.

The whole process was repeated for all other types of protective blocks on all the four selected side slopes.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

All data obtained were processed and is presented in Tables 5,6,7, and 8. The data were then plotted as shown in figs. 3,4,5,6,7,8,9, and 10 analysed. The values of coefficients and exponents of different parameters were calculated and is also presented in Table 9 and 10.

Some other important observations which are not expressed in the above Tables and Figures are also discussed separately.

Effect of Unit Weight

The logarithmic plotting of velocity (Figs. 3,4,5, and 6) at failure against weight of blocks showed definite trend for each type of blocks having different unit weight. The weight of the blocks made of brick varied exponentially with velocity and the values of the exponents were 5.62, 5.3, 5.28 and 5.35 on side slope of 1:2, 1:2.5, 1:3 and 1:3.5 respectively. The corresponding values of the exponents for the blocks made of sand cement mortar was 4.85, 4.5, 4.64 and 4.64. Approximately it can be said that weight varied as 5.5th power of velocity of flow for brick blocks and as 4.75th power of velocity of flow for sand cement blocks.

On examining the values of exponents it is found that for the same velocity a much heavier block is necessary in the case when lighter material is used. The size and volume of

the block of same weight made from materials having lower unit weight will be bigger than that made from materials of higher unit weight. Hence the block of lighter material having same weight has more wetted surface, will encounter a higher magnitude of tractive force at the same velocity of flow. Thus blocks made of materials of lower unit weight will be able to bear a lower velocity of flow. The above reasoning justifies the difference in the values of exponent of velocities.

Effect of Size

In order to determine the effect of size of protective material in bank protection work, the critical velocity in fps was plotted against volume in cft in log-log paper (Figs. 6,7,8, and 9). It was found that the volume of brick blocks varied exponentially with velocity and the values of exponent were 6.7, 6.9, 6.95 and 7.0 on side slope of 1:2, 1:2.5, 1:3, 1:3.5 respectively. The corresponding values of the exponent for the blocks made of sand cement mortar was 5.82, 6.08, 6.08 and 6.12. Approximately it can be said that volume of brick blocks varied as the 7th power of velocity of flow and that for the sand cement blocks as the 6th power of velocity of flow.

The reasoning put forward for analysis of the effect of unit weight is also valid for the effect of size and volume.

Effect of Interlocking

Interlocking is one of the major governing factors in failure of revetments. It was observed that isolated blocks

failed at much lower velocity. Even loosely placed blocks failed earlier.

It was also observed that when a block from the protective layer is carried away the whole section failed very quickly. Some times the whole protective system failed together at other times only a part of the protective layer failed and loosened particles have been carried along channel bottom while the rest part remained there withstanding that velocity.

It was further observed that interlocking can be better achieved through good gradation.

Effect of Waves

Though all the test results reported is free from effect of waves, it was observed that it has a considerable effect in dislodging the blocks. When the amplitude of the waves is considerable in comparison with the total depth of flow the effect is pronounced. When the velocity is low but the flow has high waves the selection of block size may totally depend on the wave only.

Effect of Side Slope

From tractive force concept it is found that critical tractive force increases with ~~flatenning~~ of slope. The present study conforms to this concept. Tables 5, 6, 7 and 8 shows that critical velocity increased with flatenning of slope.

CHAPTER V

CONCLUSION

The conclusions of this study are:

1. The volume of blocks was found to vary exponentially with the velocity of failure. The approximate value of the exponent for blocks prepared with brick was 7.0 and the that for blocks prepared with sand cement block was 6.0.
2. The effect of unit weight is also equally pronounced. The saturated weight of the blocks were found to vary exponentially as 5.5th and 4.75th power (approximately) of critical velocity for blocks made of brick and sand-cement respectively.
3. Interlocking of the revetment material is a great factor in determination of size of a particular material to be used in bank protection. Wave is also important in selection of size.
4. With flatter side slope lighter material can be effectively used in bank protection works.

Recommendations for Further Study

Following recommendations are made for future research work in this field.

1. Further tests with bigger blocks shall help in further improvement to determine the effect of unit weight and size.
2. Effect of waves is to be studied
3. Effect of secondary current and curvilinear flow should be investigated.

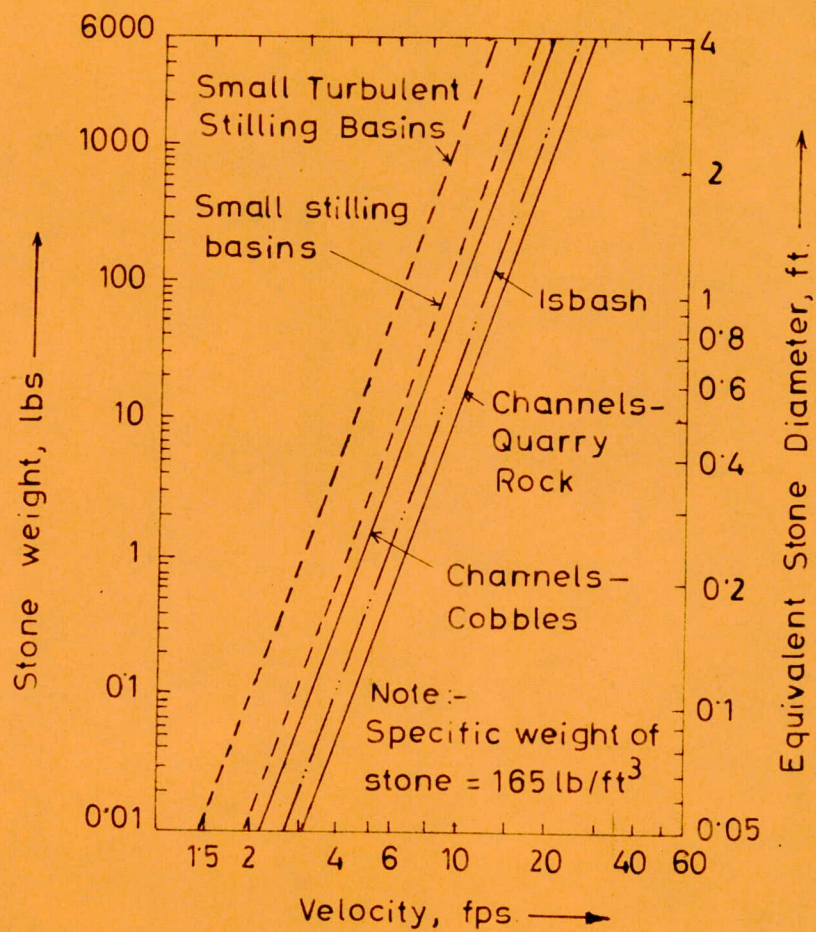


Fig. 1 Critical bed velocity versus stone size.

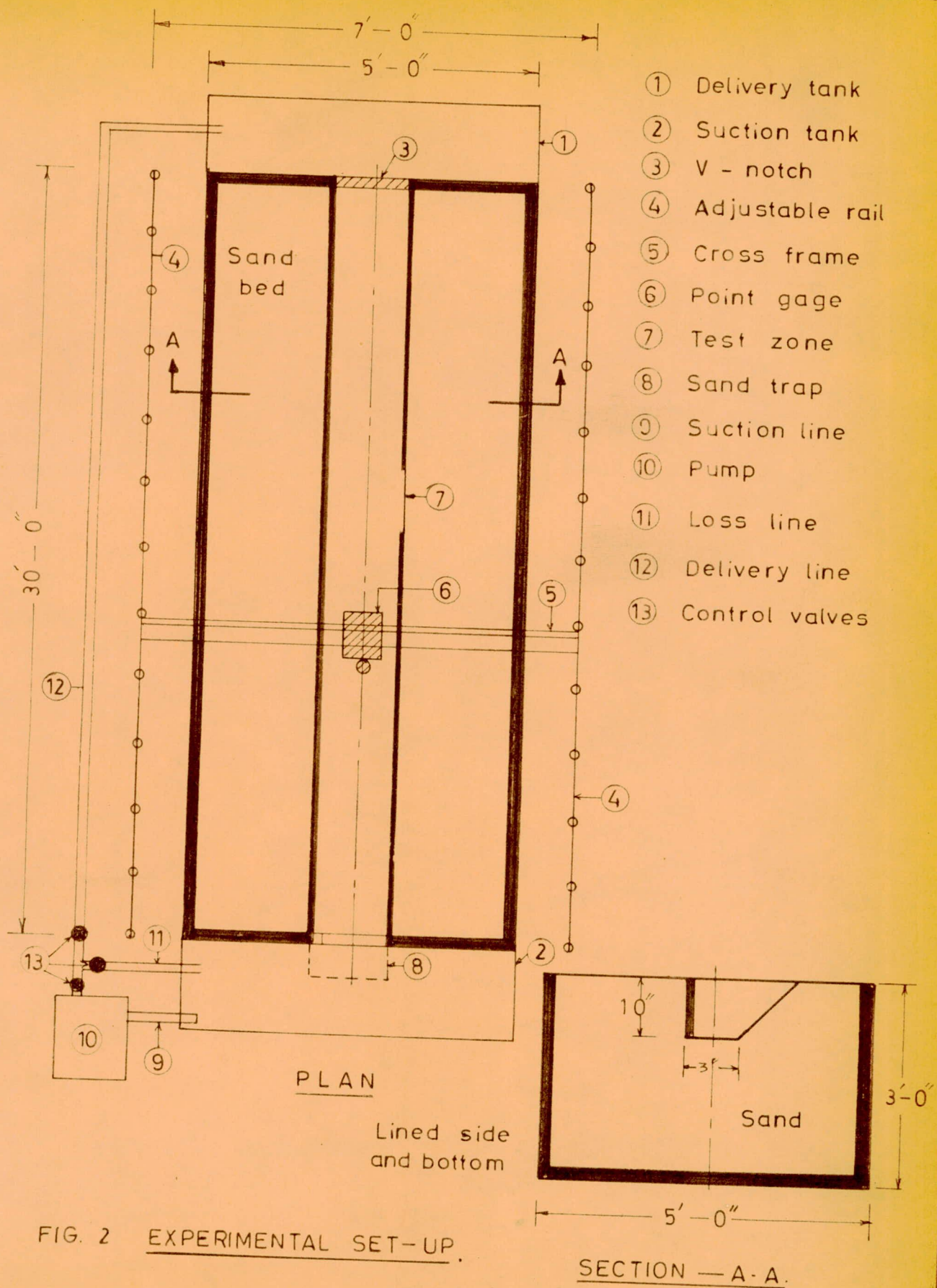


FIG. 2 EXPERIMENTAL SET-UP.

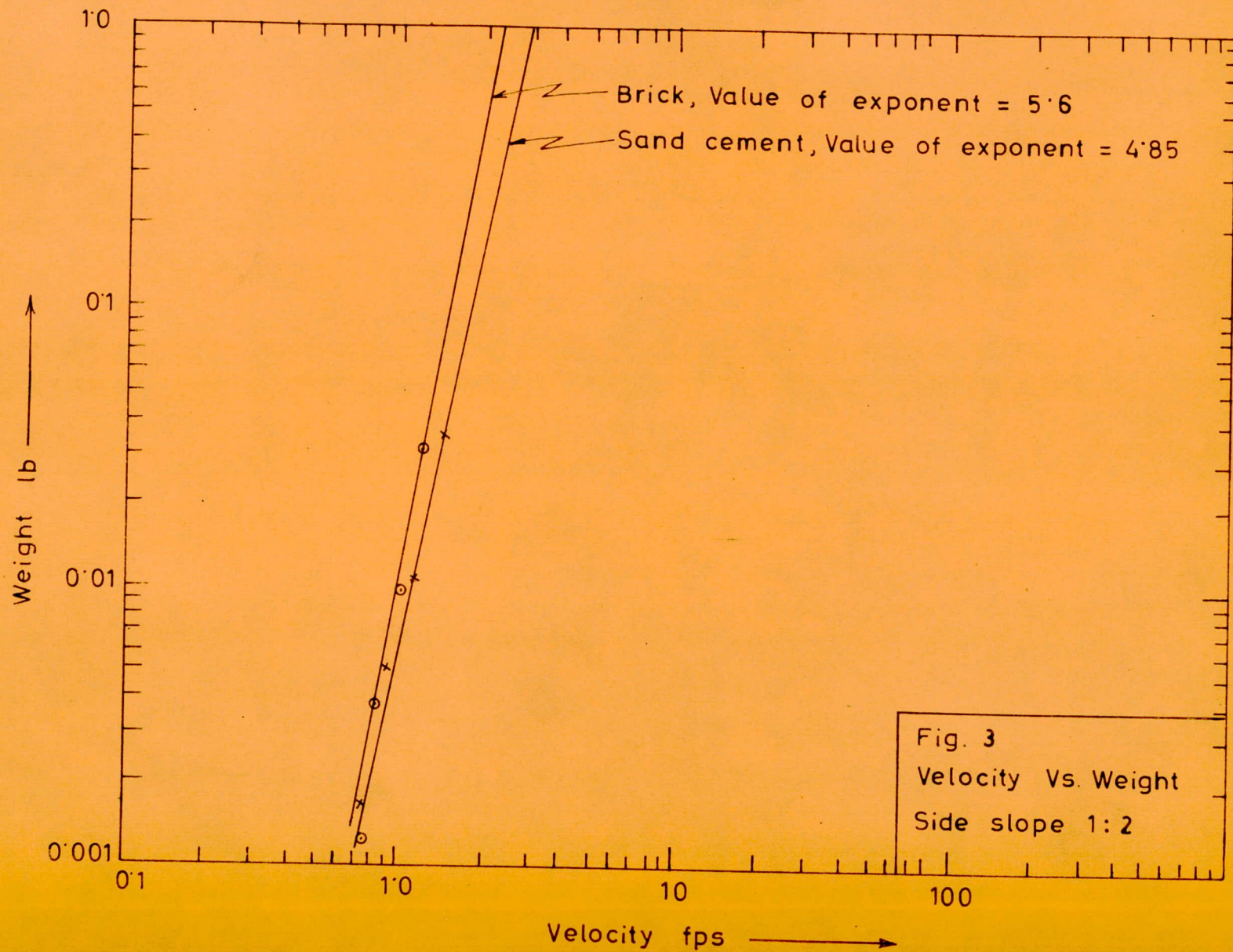
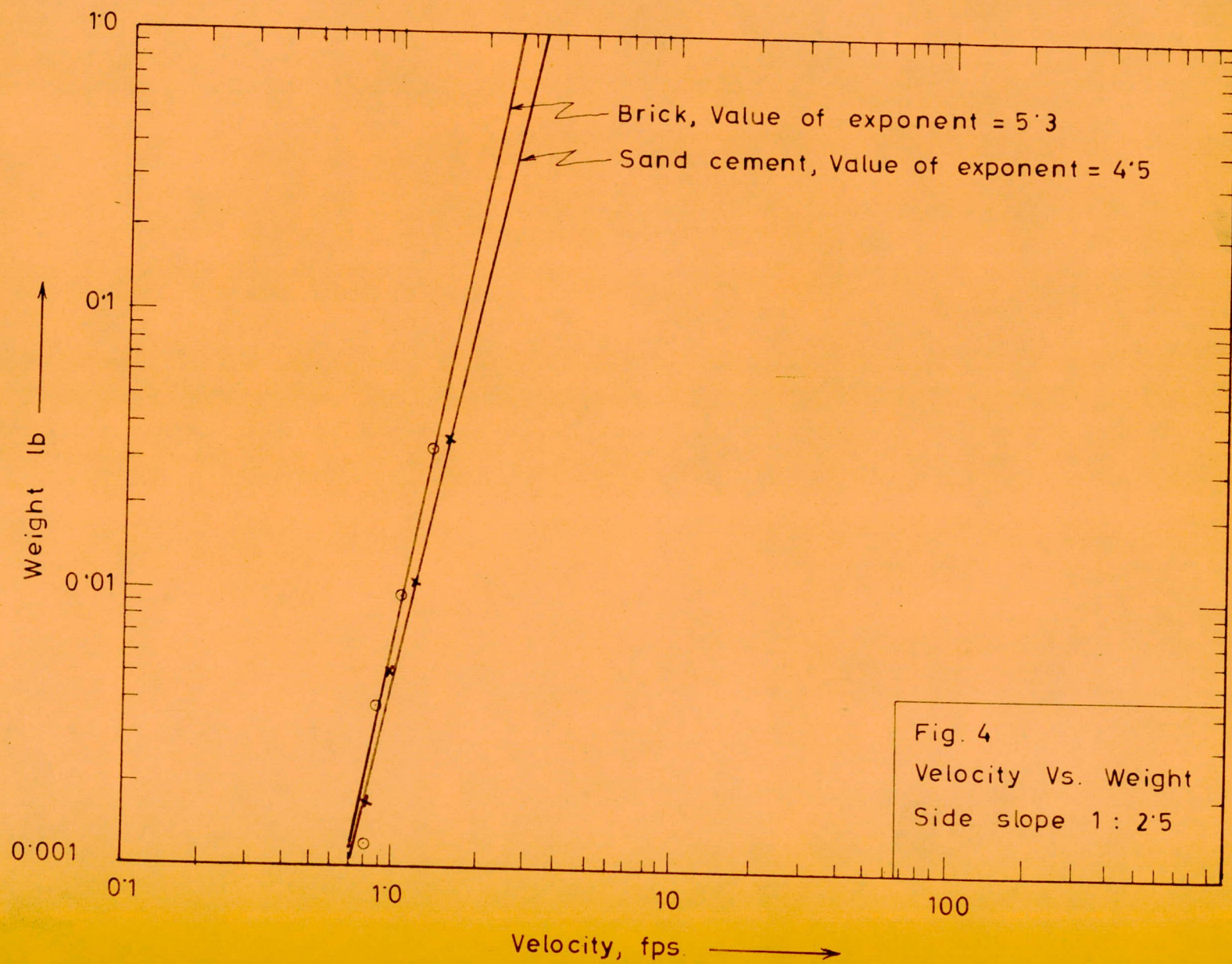
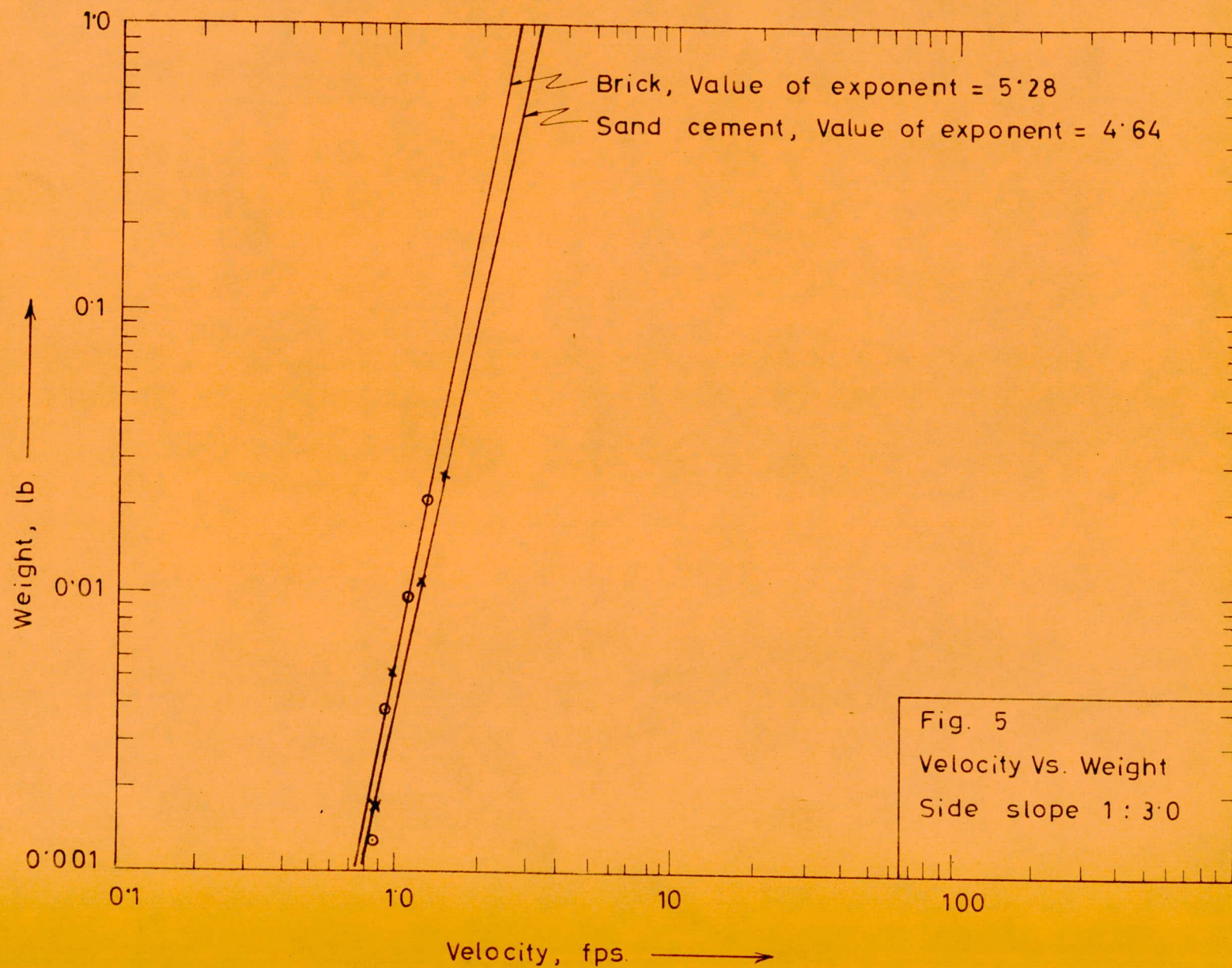
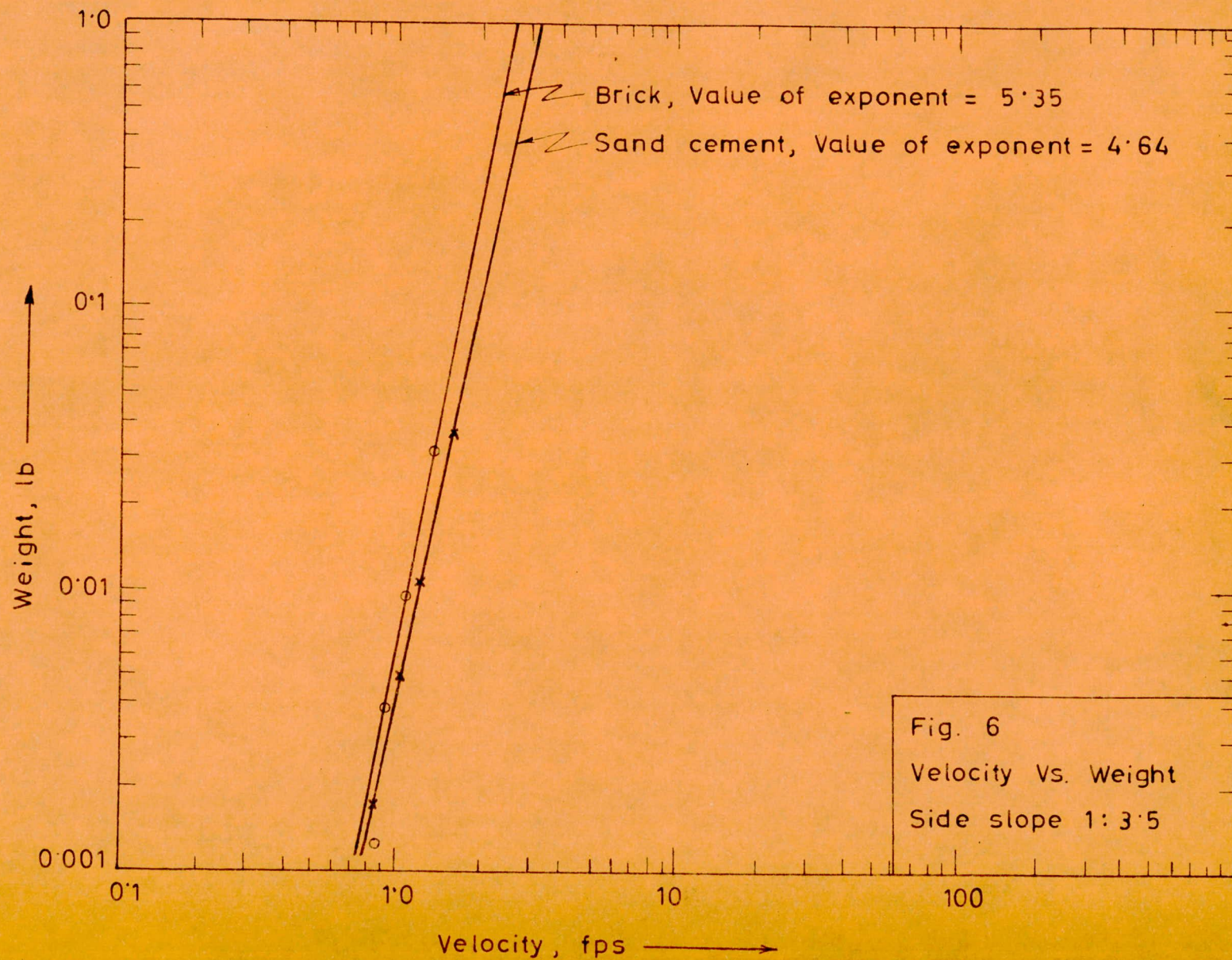


Fig. 3
Velocity Vs. Weight
Side slope 1:2







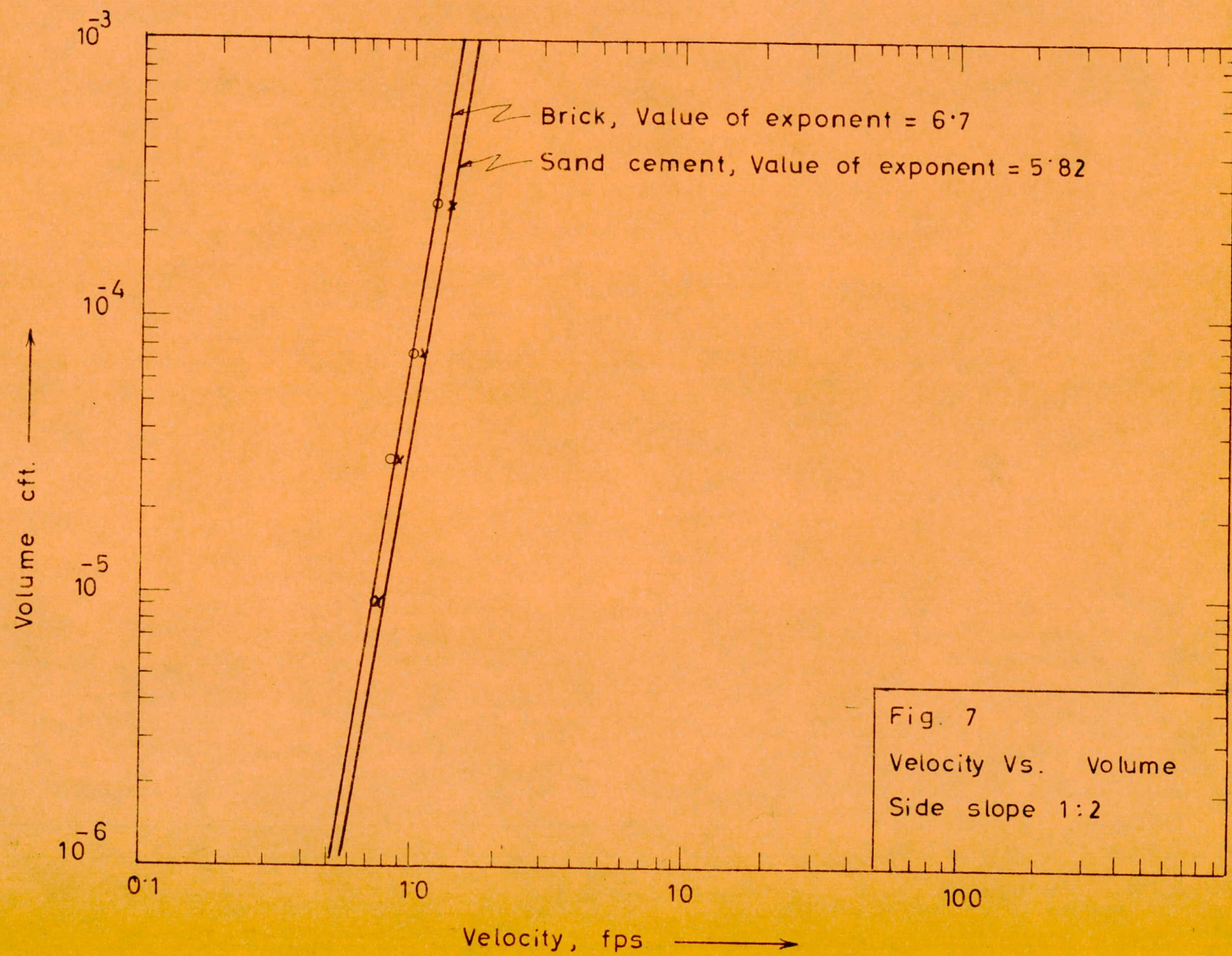
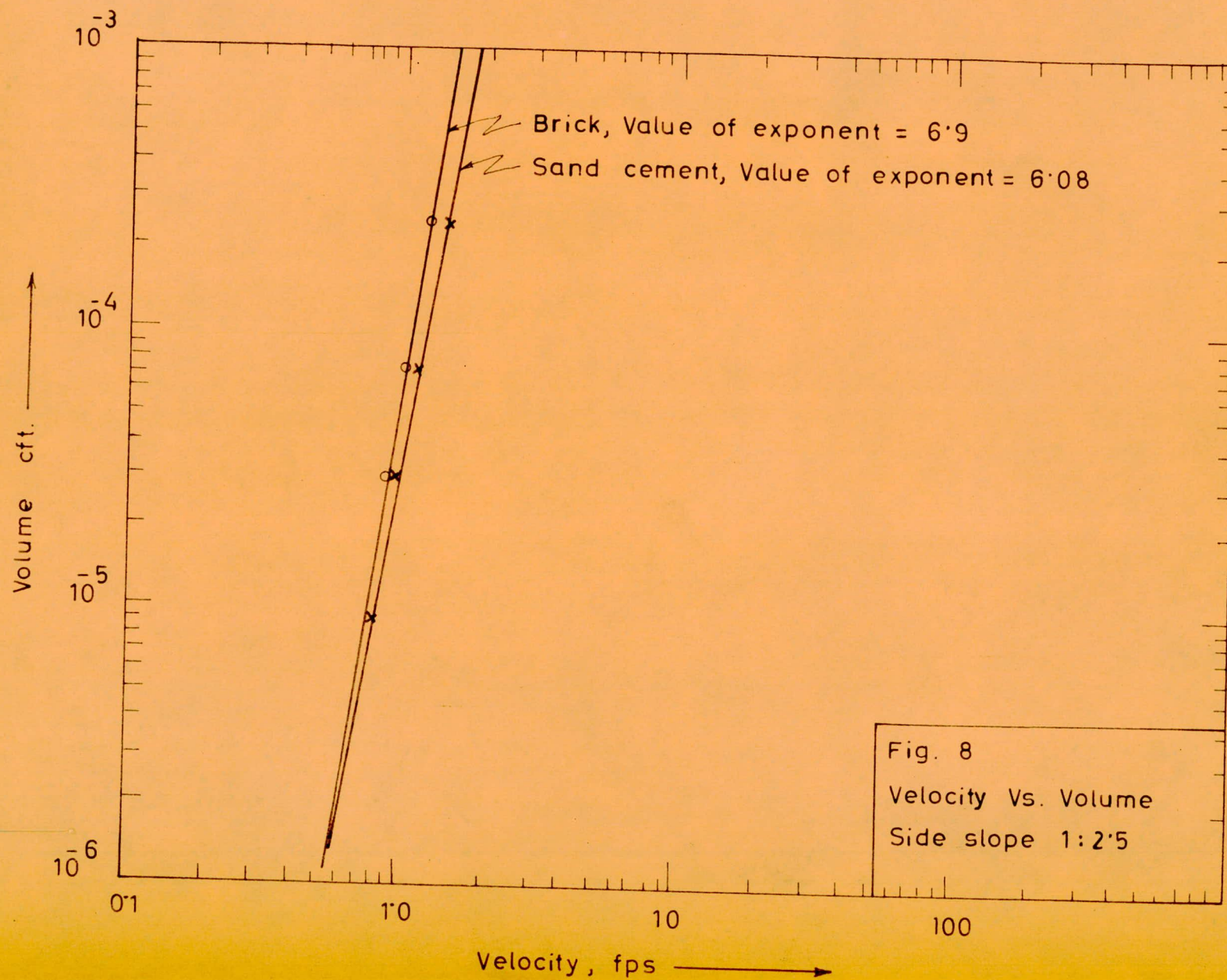


Fig. 7

Velocity Vs. Volume

Side slope 1:2



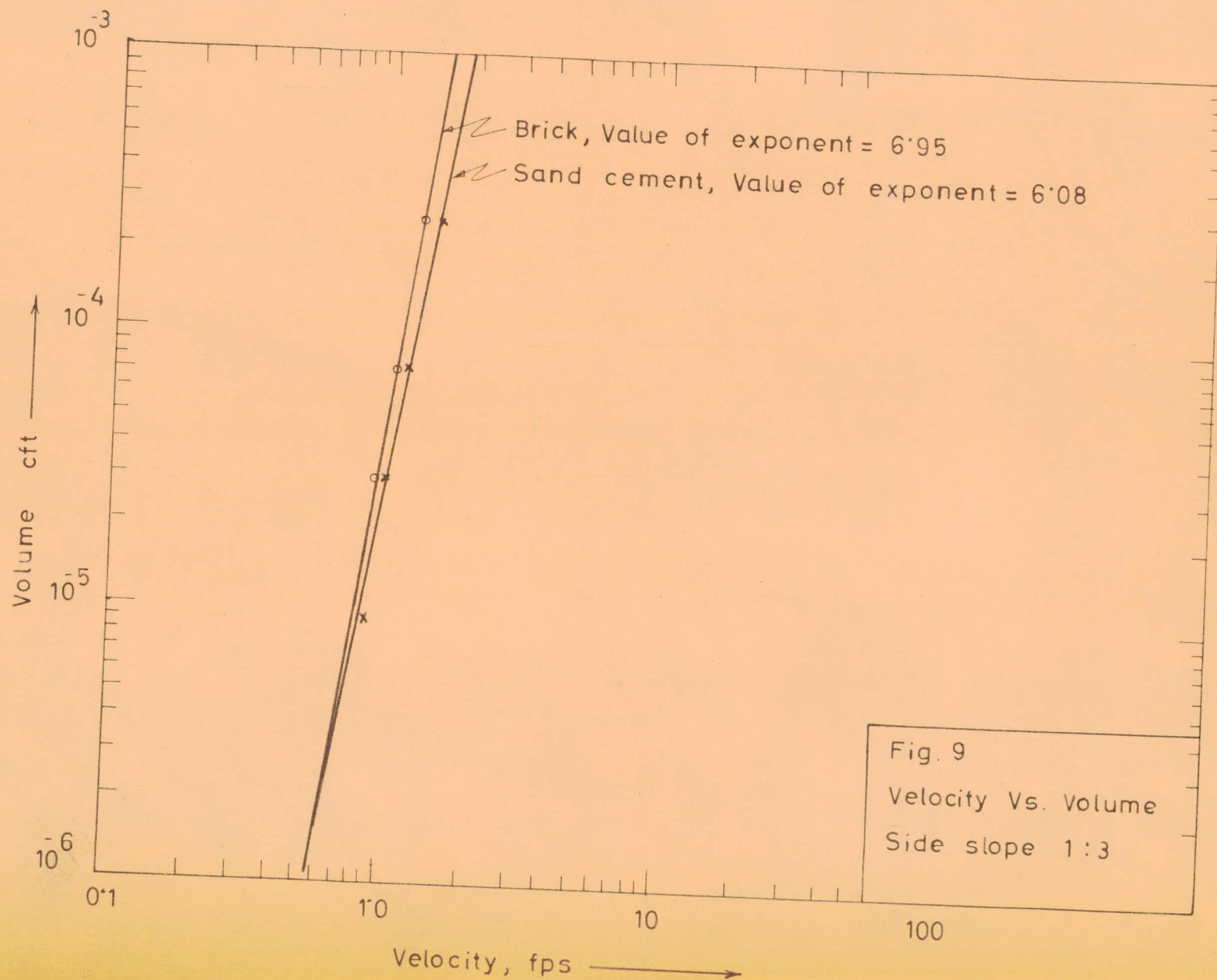


Fig. 9
Velocity Vs. Volume
Side slope 1:3

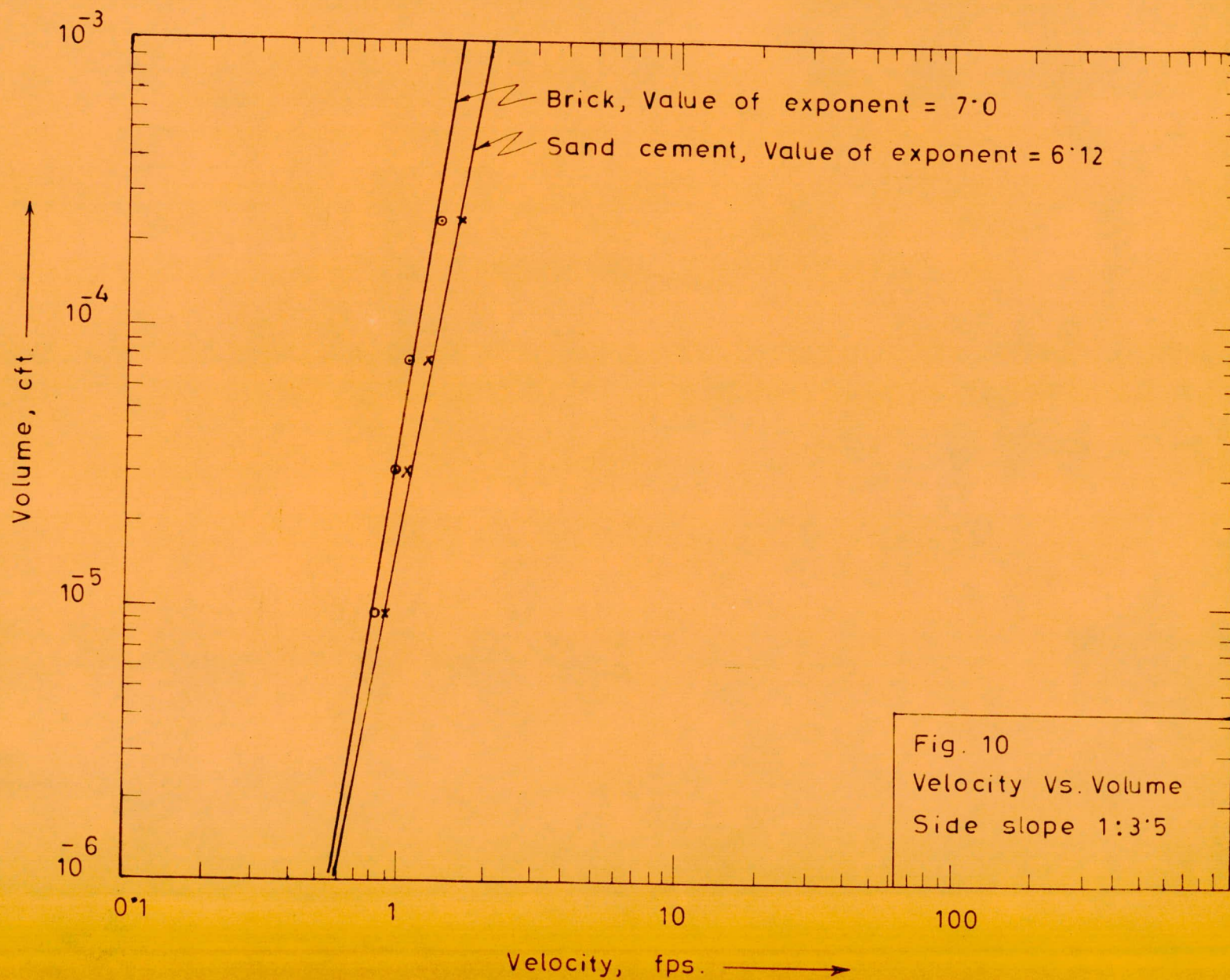


TABLE 5

Determination of Critical Velocity; Channels

Side Slope = 1:2.0

SIZE	MATERIAL	VOLUME, cft.	SATURATED WEIGHT, lb.	VELOCITY REQUIRED
$\frac{1}{4}$ "	Brick	9.05×10^{-6}	0.00130	0.750
	Sand cement	9.05×10^{-6}	0.00159	0.750
$\frac{3}{8}$ "	Brick	3.05×10^{-5}	0.00396	0.835
	Sand cement	3.05×10^{-5}	0.00508	0.870
$\frac{1}{2}$ "	Brick	7.24×10^{-5}	0.00980	1.010
	Sand cement	7.24×10^{-5}	0.0122	1.135
$\frac{3}{4}$ "	Brick	2.44×10^{-4}	0.0330	1.330
	Sand cement	2.44×10^{-4}	0.0386	1.430

TABLE 6

Side Slope = 1:2.5

SIZE	MATERIAL	VOLUME, cft.	SATURATED WEIGHT, lb	VELOCITY REQUIRED, cfs.
$\frac{1}{4}$ "	Brick	9.05×10^{-6}	0.00130	0.800
	Sand cement	9.05×10^{-6}	0.00159	0.800
$\frac{3}{8}$ "	Brick	3.05×10^{-5}	0.00396	0.870
	Sand cement	3.05×10^{-5}	0.00508	0.910
$\frac{1}{2}$ "	Brick	7.24×10^{-5}	0.00980	1.053
	Sand cement	7.24×10^{-5}	0.0122	1.175
$\frac{3}{4}$ "	Brick	2.44×10^{-4}	0.0330	1.430
	Sand cement	2.44×10^{-4}	0.0386	1.590

TABLE VII

Side Slope = 1:3.0

SIZE	MATERIAL	VOLUME, cft.	SATURATED WEIGHT, lb	VELOCITY REQUIRED
$\frac{1}{4}$ "	Brick	9.05×10^{-6}	0.00130	0.835
	Sand cement	9.05×10^{-6}	0.00159	0.835
$\frac{3}{8}$ "	Brick	3.05×10^{-5}	0.00396	0.910
	Sand cement	3.05×10^{-5}	0.00508	0.935
$\frac{1}{2}$ "	Brick	7.24×10^{-5}	0.00980	1.075
	Sand cement	7.24×10^{-5}	0.0122	1.250
$\frac{3}{4}$ "	Brick	2.44×10^{-4}	0.0330	1.540
	Sand cement	2.44×10^{-4}	0.0386	1.670

TABLE VIII

Side Slope = 1:3.5

SIZE	MATERIAL	VOLUME, cft.	SATURATED WEIGHT, lb.	VELOCITY REQUIRED
$\frac{1}{4}$ "	Brick	9.05×10^{-6}	0.00130	0.855
	Sand cement	9.05×10^{-6}	0.00159	0.870
$\frac{3}{8}$ "	Brick	3.05×10^{-5}	0.00396	0.945
	Sand cement	3.05×10^{-5}	0.00508	1.020
$\frac{1}{2}$ "	Brick	7.24×10^{-5}	0.00980	1.120
	Sand cement	7.24×10^{-5}	0.0122	1.330
$\frac{3}{4}$ "	Brick	2.44×10^{-4}	0.0330	1.610
	Sand cement	2.44×10^{-4}	0.0386	1.750

TABLE IX 9

Exponents With Which Velocity
Varied With Weight

Side Slope	Brick Blocks	Sand Cement Blocks
1:2.0	5.62	4.85
1:2.5	5.3	4.5
1:3.0	5.28	4.68
1:3.5	5.35	4.64
Approximately 5.5		Approximately 4.75

TABLE X 10

Exponents With Which Velocity
Varied With Volume

Side Slopes	Brick Blocks	Sand Cement Blocks
1:2.0	6.7	5.82
1:2.5	6.9	6.08
1:3.0	6.95	6.08
1:3.5	7.0	6.12
Approximately	7.0	Approximately 6.0

BIBLIOGRAPHY

BIBLIOGRAPHY

1. Chow, Ven Te., "Open Channel Hydraulics"
McGraw Hill Book Co. Inc., New York, 1959
2. Department of Works, Division of Highway, State of California, U.S.A., "Bank and Shore Protection in California Highway Practice" Bank Protection Committee, Division of Highways, Box-1499, Sacramento-7, California, U.S.A.
3. Henderson, F.M., "Open Channel Flow",
The Macmillan Company, New York, 1966
4. Jones, L.B., "Snake River Bank Stabilization",
Proceedings of ASCE, Waterways and Harbour Division, Vol-92, No. ~~WW~~-1, February, 1966
5. Linder, C.P., "Channel Improvement and Stabilization Measures" Chapter VIII of "State of Knowledge of Channel Stabilization in Major Alluvial Rivers",
edited by G.B. Fenwick, Corps of Engineers, U.S. Army, October, 1969
6. McEwan, J.S., "Bank and Levee Stabilization, Lower Colorado River", Proceedings of ASCE, Waterways and Harbour Division, Vol-87, No. ~~WW~~-4, November, 1961
7. Simons, D.B. and Anding, M.G., "Hydraulics" Chapter IV of "State of knowledge of Channel Stabilization in Major Alluvial Rivers", edited by G.B. Fenwick, Corps of Engineers., U.S. Army, October, 1969

8. Task Committee on Channel Stabilization Works;
"Channel Stabilization on Alluvial Rivers",
Proceedings of ASCE, Waterways and Harbour
Division, Vol-91, No. WW-1, February, 1965
9. United Nations, "River Training and Bank Protection"
United Nations Publications, Bangkok, 1953

T.62

