DEVELOPMENT OF RATIONAL FORMULAE TO PREDICT THE ADVANCE AND RECESSION FLOW IN BORDER IRRIGATION METHOD

By

MARY REGINA F.

THESIS

Submitted in partial fulfilment of the requirement for the degree

Master of Technology in Agricultural Engineering

Faculty of Agricultural Engineering
Kerala Agricultural University

Department of Irrigation and Drainage Engineering
Kelappaji College of Agricultural Engineering and Technology
Tavanur 679 573
Malappuram

1992

DECLARATION

I hereby declare that this thesis entitled Development of Rational Formulae to Predict the Advance and Recession Flow in Border Irrigation Method is a bonafide record of research and that the thesis has not previously formed the basis for the award to me of any degree diploma associateship fellowship or similar title of any other University or Society

Tavanur

MARY REGINA, F

CERTIFICATE

Certified that this thesis entitled Development of Rational Formulae to Predict the Advance and Recession flow n Border Irrigation Method is a record of research work done independently by Smt Mary Regina F under my guidance and supervision and that it has not pre iously formed the basis for the award of any degree fellowship or associateship to her

Dr A N Remadevi

Chairman
Advisory Committee

and

Professor and Head
Department of Agrl Engg
College of Agriculture
Vellayani
Thiruvananthapuram

CERTIFICATE

We the undersigned members of the Advisory Committee of Smt Mary Regina F a candidate for the degree of Master of Technology in Agricultural Engineering with major in Soil and Water Engineering agree that the thesis entitled Development of Rational Formulae to Predict the Advance and Recession Flow in Border Irrigation Method may be submitted by Smt Mary Regina F in partial fulfilment of the requirement for the degree

Dr A N Remadevi
Professor and Head
Department of Agrl Engg
College of Agriculture
Vellayani
Thiruvananthapuram

CHAIRMAN

Prof K John Thomas,
Head
Department of Irrign &
Drainage Engineering
K C A E T Tavanur

MEMBER

Dr K I Koshy,
Professor & Head
Department of S A C
K C A E T Tavanur

MEMBER

Shri Jippu Jacob
Associate Professor
Dept of F P M E
K C A E T Tavanur

MEMBER

Dr P C Antoney
Associate Professor
Department of S A C
K C A E T Tavanur

MEMBER

External Examiner

ACKNOWLEDGEMENTS

With deep sense of gratitude and due respect I express my heartfelt thanks to Dr (Mrs) A N Remadevi, Chairman Advisory Committee It was her able guidance which helped me to carry out this research work promptly

I wish to express my profound thanks to Prof T P George Dean i/c Faculty of Agricultural Engineering and Technology for his guidance at all stages of this work

I am indebted to Prof K John Thomas Dr K I Koshy Shri Jippu Jacob and Dr P C Antoney members of the advisory committee, for their advice and suggestions during the investigation

I wish to express my heartfelt thanks to the staff and labourers, Instructional farm K C A E T

Thanks are due to all staff members especially Dr Joby V Paul Shri George Mathew, Shri Ajith Kumar and Shri V Ramachandran

My friends at K C A E T were of great support to me and I am short of words to express my humble thanks to them

Thanks are also due to the Kerala Agricultural University for awarding me the Research Fellowship for the post graduate programme

I am forever indebted to my dear ones for their encouragement and support during the course of study

Above all I bow my head before God Almighty for His blessings

MARY REGINA, F

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

SYMBOLS AND ABBREVIATIONS USED

Agri		Agriculture
Agric		Agricultural
ASAE		American Society of Agricultural Engineers
ASCE	-	American Society of Civil Engineers
cc		cubic centimetre, cubic centimetres
cm		centimetre centimetres
Div		Division
Engng		Engineering
FAO		Food and Agricultural Organisation (UN)
gm		gram grams
ha		hectare
hr		hour
IIT	-	Indian Institute of Technology
Inc		Incorporated
Irrgn	-	Irrigation
ISAE		Indian Society of Agricultural Engineers
J		Journal of
KAU		Kerala Agricultural University
KCAET		Kelappaji College of Agricultural Engineering and Technology
l		litre
lps		litres per second
Ltd		Limited

m		metre
min		minute
mm		milli metre, milli metres
No		Number
Obsd		Observed
PP		pages
Proc		proceedings
Pvt		Private
sec		second seconds
sl		serial
UNDP		United Nations Development Project
U P A U		Uttar Pradesh Agricultural University
USDA		United States Department of Agriculture
Vol	-	Volume
/	-	per
%		percent
Γ	-	symbol for gamma function

Introduction

INTRODUCTION

During the past several years man has gone through a period of reconsideration of the role of agriculture in human development Rural enterprise has emerged in developing countries into greater prominence as the basic area of activity for provision of welfare livelihood and new capital resources that will stimulate economic growth There is now widespread recognition that an increase in agricultural productivity is of vital importance to improve national income and personal welfare Given an ear to the world around cries for want of food and increased production can be heard Researchers show that land and labour productivity are generally much below the potential levels Even rational and intelligent farmers are operating on a production plan considerably below their potential In short the technology shelf is largely untapped by the majority of farmers Further, when isolated elements such as irrigation are taken down from the shelf the performance is generally disappointing

Irrigation is an attempt by man to locally alter the hydrological cycle inorder to make water available to farmer with respect to time location and quality as per the crop requirements The increased farm production and productivity created by irrigation not only enable us to feed the evergrowing population, but also help us to meet the mounting demands of raw materials from the fast growing industrial sector

Beginning with a gross irrigated area of 22 million ha during 1951 India has created an irrigation potential of 79 4 mha upto the end of seventh plan (1990) An annual growth rate of 3 million ha has been planned for the eighth plan It has been estimated that the geographical area of India is 328 8 million ha out of which 113 5 million ha can be brought under irrigation 58 5 million ha by major and medium irrigation projects and 55 million ha by minor irrigation projects

In the course of development of irrigated agriculture the major concern has been water which brings life to land Much progress has been made in harnessing rivers and construction of vast canal systems for distributing water to the land But very little care has been taken to the land itself Infact proper care has not been taken to ensure judicious and efficient use of water and land in irrigated farming

Irrigation is not mere application of water to the land but to supply water to the root zone of the plant according to the requirement The scientific knowledge of soil, plant and its environment with regard to water intake and retention is essential to determine the water application technique in the particular field Infact the type and availability of water and socio economic aspects also affect the selection of application technique

The border method of irrigation is adapted to most soils where depth and topography permit the required land levelling at a reasonable cost and without permanent reduction in soil productivity It is suitable to irrigate all close growing crops like wheat barley fodder crops and legumes The border method is advantageous as construction and operation of the system is simple and easy Labour requirement in irrigation is greatly reduced as compared to other conventional methods of surface irrigation

The proper design of border irrigation system is essential for uniform distribution and high water application efficiencies Border irrigation aims at supplying moisture to the root zone uniformly which can be fulfilled by maintaining the same opportunity time throughout the length of the border The irigation system designed for providing nearly equal opportunity time for all points on the border must be based on advance and recession functions This investigation was undertaken to develop the predictive relationship for water front advance and recession in field borders with cow pea as the crop

The specific objectives of the study are

1 To study the advance and recession of water in border strip irrigation as affected by different conditions of stream size and slope of land

2 To develop predictive relationships for advance time and horizontal recession time in border irrigation

Review of Literature

REVIEW OF LITERATURE

A brief review of border specifications intake rate analys@s water front advance and recession and influence of hydraulic resistance on surface irrigation flow are presented in this chapter

Irrigation water may be applied either by flooding it on the field surface by applying it beneath the soil surface by spraying under pressure or by applying it in drops Border irrigation is a common surface method of irrigation The land is divided into a number of long parallel strips called borders that are separated by low ridges The border strip has little or no cross slope but has a uniform gentle slope in the direction of irrigation Each strip is irrigated independently by turning in a stream of water at the upper end The water spreads and flows down the strip in a sheet confined by the border ridges

2 1 Border specifications

Michael (1978) has made the following recommendations on the various border strip parameters namely width length, and slope of border strips and size of irrigation streams

2 1 1 Width of border strip

The width of a border usually varies from 3 to 15 metres depending on the size of irrigation stream available and the degree of land levelling practicable It is uneconomical to keep the width less than about three metres ,as otherwise too many ridges will have to be formed per unit area of the field surface

The United States Department of Agriculture (1970) recommended the following widths for different grades

Table 1 Border strip widths for different grades

Land grade (percent)	Maximum strip width (feet)
0 0 0 1	120
0 1 0 5	60
0 5 1 0	50
1 0 - 2 0	40
2 0 4 0	30
4 0 6 0	20

2 1 2 Border length

The length of the border strip depends upon how quickly it can be wetted uniformly over its entire length This in turn depends on the infiltration rate of the soil the slope of the land and the size of the irrigation stream available For moderate slopes and small to moderate size irrigation streams the following border lengths are suggested (Michael , 1978)

Sandy and sandy loam soils	60 to 120 m
Medium loam soils	100 to 180 m
Clay loam and clay soils	150 to 300 m

Senapathy , Nayak and Sharma (1986) have formulated a general equation for selecting the length of border They have taken into consideration the advance of water front of the form $I \quad at^{b}$, intake rate of the soil of Kostiakov Lewis type of equation of the form $I \quad K t^{n}$ stream size and other soil parameters This method can be used for selecting the border length if a decision is already made regarding the width of the border It is expected that the length of border so selected will result in better water application and minimise the water losses

2 1 3 Border slope

The borders should have a uniform longitudinal gradient Excessive slopes will make the water run to the lower end quickly causing insufficient irrigation at the upstream end and deep percolation losses and breach of the bund at the down stream They also cause soil erosion in borders On the other hand too flat slopes will result in the very slow movement of the border stream causing deep percolation losses at the upper reaches and inadequate wetting down stream

Recommended safe limits of slopes in borders according to Michael (1978) are given below

Sandy loam to sandy soils	0 25	0 6 percent
Medium loam soils	0 2	0 4 percent
Clay to clay loam soils	0 05	0 2 percent

2 1 4 Size of irrigation stream

The size of irrigation stream needed depends on the infiltration rate of the soil and the width of the border strip It should be determined as accurately as possible as a part of the design of the system The requirement of the irrigation stream is expressed in terms of the rate of water flow per unit width of the border such as in l/sec/m this value multiplied by the width of the border is the size of the irrigation stream that should be delivered into each border

Table 2 presents some typical values of stream size for different soil types and slopes

Table 2 Typical values of stream sizes for different soil types and slopes

Soil type with rate of infiltration	Border slope percent	Flow per m width l / sec
Sandy soil	0 2 0 4	10 15
2 5 cm / hr	0 4 - 0 6	7 10
Loamy sand	0 2 - 0 4	7 - 10
1 8 2 5 cm/hr	0 4 - 0 6	5 - 8
Sandy loam	0 2 0 4	5 7
1 2 1 8 cm/hr	0 4 0 6	4 - 6
Clay loam	0 15 0 3	3 4
0 6 0 8 cm/hr	0 3 - 0 4	2 3
Clay		
0 2 - 0 6 cm/hr	0 1 0 2	2 4

(Source Michael (1978))

Petrasovits (1969) carried out border irrigation experiments in the fields of the experimental farm at Billauch Euphrates He conducted the tests in borders of 50 m 75 m and 100 m lengths The widths tried were 2 5 m 5 0 m , 7 5 m , and 10 0 m with discharges of 1 l/sec/m , 1 5 l/sec/m , 2 l/sec/m , 3 l/sec/m and 4 l/sec/m The slope of the experimental field was 1 0 to 1 2 per cent and 0 1 to 0 2 percent

The results revealed that the 2 5 m wide border is not satisfactory because of the difficulties in making ridges at closer spacings with mechanical means , although it was easy to get uniform distribution of water through out the strip

In the borders with 1 2 percent slope the velocity of the water front ranged between 8 m/min and 15 m/min This too led to erosion

He concluded that it was possible to efficiently irrigate borders of 100 m length and 5 m width with a water flow of 1 5 l/sec/m to 2 l/sec/m The time of irrigation would then be 8 5 minutes to 12 minutes The excess water at the border end was not more than 5 to 10 percent

Visalakshi (1983) has recommended the following specifications of border strips for nearly level fields based on her study on the hydraulics of border irrigation

Length of border		Upto 45 m
Width of border		4 6 m
Rate of flow	-	2 l/sec/m

Slope — should be laid in the direction of the natural slope

Height of bunds separating the strips — 20 cm

Base width of bunds — 30 cm

2 2 Intake rate analysis

The uniformity at which water can be distributed over a field can have a direct impact on the irrigation efficiency when irrigations are intended to fully meet consumptive use Thus it is of interest to know the uniformity of distribution of the irrigation water for any irrigation system For surface irrigation systems there are a number of factors which influence this uniformity Of this the most dominant one is the soil infiltration characteristics

The movement of water from the surface into the soil is called infiltration Infiltration rate or the intake rate is the soil characteristic determining the maximum rate at which water can enter the soil under specific conditions It depends upon soil texture and structure soil cracks depth of surface flow effect of velocity of surface flow and other soil characteristics

Accumulated infiltration or cumulative infiltration is the total quantity of water that enters the soil in a given time

Three methods of estimating infiltration characteristics of soil for the design of irrigation systems have been recognised They are (a) the use of cylinder infiltrometers

(b) measurement of subsidence of free water in a large basin , and (c) estimation of accumulated infiltration from the water front advance data Of these the use of cylinder infiltrometers is the most common method

Criddle et al (1956) presented an equation for calculating the contact time necessary , using the intake rate equation

$$dy/dt \quad At^{n}$$

Integration with respect to time gives the cumulative intake

$$y \quad \frac{At^{n+1}}{n+1}$$

The required contact time (t_{cr}) necessary to apply the desired depth of irrigation , y becomes

$$t_{cr} \quad \left\{ \frac{y\ (n+1)}{A} \right\}^{\frac{1}{n+1}}$$

where,

t_{cr} required contact time

y total depth of water to be applied

n constant

Philips and Farrel (1964) obtained solution for infiltration functions of the form $y \quad Kt^{\alpha}$ and $y \quad St^{1/2} + At$

Gray and Ahmed (1965) described a procedure to estimate intake rate in a border by a mass balance evaluation considering inflow to the border , surface storage and subsurface storage They assumed that both water intake and advance could be represented by empirical power function of time

Christiansen et al (1966) assuming constant normal depth at the upper end and using empirical power functions of water advance and intake rate related the intake rate to the advance of water in surface irrigation

Singh and Chauhan (1973) determined water intake rate from rate of advance and reported that this method would provide a good estimate of intake in surface irrigation

Field tests conducted under pre-sowing and post-emergence irrigation conditions showed that an equation of the following form would express best the accumulated infiltration time relationship (Michael 1978)

$$y \quad at^{\alpha} + b \qquad 0 < \alpha < 1 \quad t \neq 0$$

in which a, b are characteristc constants

y accumulated infiltration cm and

t elapsed time , minutes

Clemmens (1981) evaluated a number of methods for obtaining a reasonable estimate of the infiltration function for irrigation borders Data from using infiltrometers are fit to power functions for infiltration rate and cumulative infiltration rate versus time A volume balance within the border is used to adjust the data to give a better indication of the average infiltration conditions over the border The results of Bouwer's method which uses a series of borders as infiltrometers were compared to the results of ring data for actual field data

2 3 Water front advance in borders

The fluid flow phenomenon of surface irrigation is a case of unsteady nonuniform spacially varied open channel flow over porous bed with a free surface It represents a complex problem in theoretical analysis When water is turned on to a soil surface it flows in two directions Because of the pull of gravity a part of the stream is taken in by the soil while the remainder flows along the plane of soil surface Water advancing and receding in an irrigation bay is both nonuniform and unsteady because of infiltration in the soil This problem is of great practical importance in the design and operation of systems of surface irrigation

A mathematical expression containing all these factors would be very complex and has not been developed Amongst these factors the rate of advance of water front and the recession of water tail over the land surface represents most important characteristics of surface irrigation In the past considerable progress has been made in estimating the rate of advance by using the equation of continuity but very little investigation has been devoted to the study of rate of recession

The problem was first approached by Parker (1912) and Israelson (1913) to develop a logarithmic expression to give time of advance over the border strip having constant infiltration The equation is apparently not applicable when infiltration rate is a function of time , as is always the case

The next important continuity equation was proposed by Lewis and Milne (1938) in the form of an integral equation

$$qt \quad dx + \int_0^t y\ (t \ \ ts)\ x \ \ (ts)\ dts \quad \text{in which}$$

q constant rate of flow per unit width introduced at the upstream end of the border cm^2 / min

t total time for which irrigation water has been appl ed minutes

x distance the irrigation stream has advanced cm

d average depth of water over the ground surface , cm

ts value of t at which x(t) s , minutes

y(t ts) accumulated infiltration at the point x s at time ts cm

s value of x at t ts , cm and

x'(ts) the value of dx/dt at t ts

Philips and Farrel (1964) using Laplace transforms obtained solutions for the Lewis and Milne rate of advance equation This solution for the particular case in which the accumulated infiltration is given by the equation $y \quad Kt^a$ is

$$cy/qt = \sum_{0}^{\infty} \frac{\{ [(-Kt^{a})/c][T(1+a)] \}^{n}}{T(2+na)}$$

where

C	average depth of suface storage
q	inflow
y	accumulated infiltration
x	distance the wetting front has advanced
t	time
T	Symbol for the gamma function
K & a	Empirical constants
n	an integer

The above equation is cumbersome to solve because the convergence is not rapid for large values of t or a Wilke and Smerdon (1965) used IBM 709 digital computer for solving this equation and presented dimensionless curves which provided for a direct solution of the irrigation advance problem for border irrigation for the case where infiltration satisfies the equation $y = Kt^{a}$

At the Indian Institute of Technology Kharagpur under the scheme on Minor Irrigation and Water Use (Lal 1968) data on water advances have been collected on borders laid out at different grades These data have been compared with the dimensionless curves given by Wilke and Smerdon

Kumar and Tyagi (1971) conducted studies on advance and recession at U P A U Pantnagar They presents the advance phenomena as a function of several factors

X f (q T y V C g s) where

X advance distance

q inflow rate per unit width

T time from the beginning of the test

y cumulative intake from the beginning of the test

V Kinematic viscosity

C Chezy's roughness coefficient

g acceleration due to gravity

s slope

For complete analysis the relationship among all these parameters should be established since this is very complex it has not been attempted by them

The time for advances was noted at every 5 metres along the border length Analysis of data indicated that advance is a power function of time It fits to a power equation $X = At^B$, where

X Advance length

t time of advance

A & B constants

Sachan and Somalingam (1972) studied the effect of stage of crop on advance time in border irrigation Experiments were conducted in an out door flume with upland paddy crop At each stage of crop growth , the resistance for the flow varies thereby causing variation in the opportunity time The value of Chezy's roughness coefficient for four inflow rates was determined at five different stages of the crop

Experiments were done by Jobling and Turner (1973) in a rectangular flume 18 3 m long 0 6 m wide and 0 2 m deep They examined the effects of inflow infiltration slope bed resistance and time of cut off on the advance From the series of tests it was found that advance could be described by

$x_1 - a\,(1-e^{b\,ta}) + c\,(1\ e^{d\,ta})$ where

x_1 distance advanced by flow profile in time ta

a , b c & d constants

Michael (1978) reported that the water front advance in vegetated and non-vegitated borders can be predicted with reasonable accuracy by the following equations

$$x \quad \frac{qt}{b+d}\left[\frac{1}{\Gamma(2)} - \frac{\beta t^{\alpha}}{\Gamma(2+\alpha)} + \frac{\beta^2 t^{2\alpha}}{\Gamma(2+2\alpha)} - \frac{\beta^3 t^{3\alpha}}{\Gamma(2+3\alpha)} + \right.$$

for small values of t and

$$x \quad \frac{qt}{b+d}\left[\frac{1}{\beta t^{\alpha}\ (2\ \alpha)} - \frac{1}{(\beta t^{\alpha})^2\ \ (2\ 2\alpha)} + \frac{1}{(\beta t^{\alpha})^3\ \ (2-3\alpha)}\right.$$

for large values of t where $k/\ (b+d)$

in which k $a\,\Gamma(\alpha + 1)$

He has illustrated the infiltration advance problem as in Fig 1

Visalakshi (1983) in her study of the hydraulics of border

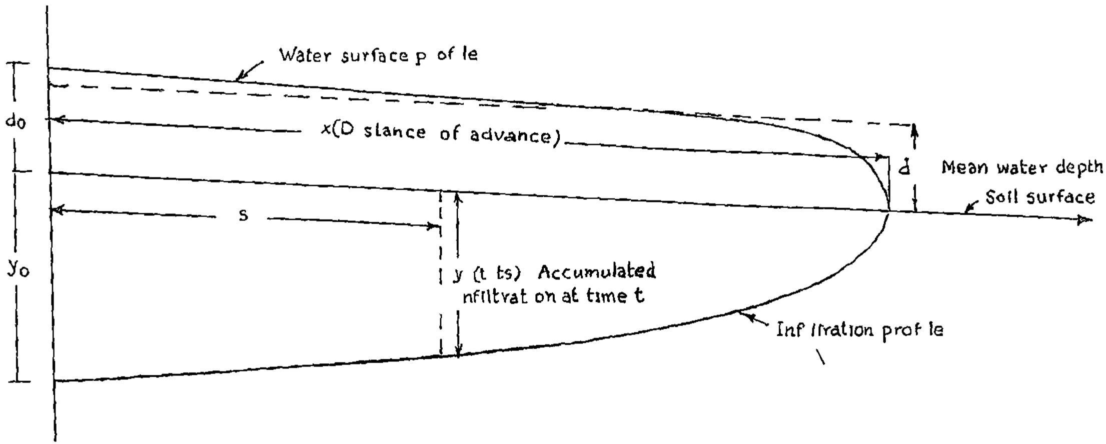


Fig 1 Diagram illustrating the infiltration—advance problem in border irrigation

irrigation found that the rate of advance was faster with increasing discharge rates and vice versa She tried three cut off ratios during the experiment and found that for 77 percent cut off ratio almost uniform distribution of water was attained

2 4 Recession flow in border irrigation

After the irrigation stream is cut off the tail water recedes down stream Recession flow is considered as the depletion of surface storage

The recession of a sheet of water has two distinct parts namely vertical recession and horizontal recession The vertical recession is the time elapsed since the stoppage of inflow till all the water recedes at the upstream end of the border The horizontal recession time is the time taken by the receding water tail to disappear from the surface of the border

Much literature is not available on this phase of border irrigation But this study is very essential for complete and efficient design of border irrigation

Kumar and Tyagi (1971) studied the recession phenomena in a 55 metre long border The time for recession was noted at every 5 metre along this length Analysis of the data gave an exponential relationship

$$T_R \quad A e^{Bx}$$, where

T_R Time of recession

x recession length

A & B Constants which vary with discharge and soil condition

They reported that, Shockley et al proposed an equation for vertical recession time tv ' , considering the infiltration rate to be nearly constant during the recession phase

$$tv = \frac{yn^2}{2sq} \quad \text{, where}$$

yn maximum depth of flow at upstream end

q inflow rate per unit width

s slope of border

The following relationship was obtained for the horizontal recession time th

$$th \sqrt{g/yc} = f\{ x/yc , S , c^2/g , I/ \ gyc \}$$

where

yc discharge per unit width represented by the critical depth

x advance distance

S slope

I infiltration rate

C Chezy's roughness coefficient

g acceleration due to gravity

The Chezy's roughness coefficient C is assumed to be constant during recession phase Hence the above equation was reduced to the form,

$$th \sqrt{g/yc} = f \{ x/yc , S , I/ \sqrt{g \ yc} \}$$

Jobling and Turner (1973) in their study of border strip irrigation point out that recession is mainly affected by the steady infiltration and the slope of the border

Singh and Mishra (1975) conducted experiments in a laboratory flume on bare soil and the times of vertical and horizontal recession were recorded with different inflow rates and slopes Empirical relationships for predicting vertical and horizontal recession times were proposed

$$tv \quad 2\ 138\ (yn^2 /2sq)^{0\ 8154}$$ where

tv vert cal recession time in seconds

yn maximum depth at the upstream end in cm

q inflow rate in lps / m width and

s slope

$$th \sqrt{g/yc} \quad a1\ [\ 1- \exp \{\ b1 \quad x/yc\ \}]$$ where

th horizontal recession time in seconds

g acceleration due to gravity

yc depth of flow

a1 & b1 constants

They also found that while slope had a large influence on recess ion time the inflow rate did not have any significant effect

Verma (1981) derived a mathematical relation to determine the recession flow in a border irrigation system for known advance and infiltration characteristics The derivation was based upon balancing the volume of water at different stages of the recession phase Subsurface storage was found from the known infiltration equation and surface storage was approximated by assuming a level surface profile for the ponded water

Ram et al (1986) illustrated the domains for flow on a freely draining border as in Figure 2

Resistance to flow in irrigation borders during post emergence irrigations is caused by the roughness of the ground surface and the retardance offered by plant stems and leaves In the pre sowing irrigation the hydraulic resistance offered to the flow of water is due only to the roughness of the ground surface The relative importance of the two factors causing resistance in post-emergence irrigations varies from one irrigation to the other

A review of past work indicated that the Manning's n calculated for uniform flow at a given depth and velocity , applies for all practical purposes , to non-uniform , unsteady flow in a border strip and will adequately represent the composite value of the hydraulic resistance in a vegitated border strip Manning s n' is obtained by the following formula expressed in matric units

$$n \quad (d^{5/3} s^{1/2}) / q$$ in which

d normal depth at the upstream end of the border , metres

s hydraulic gradient which is the ratio of the difference in the elevations between two sections of a channel and the

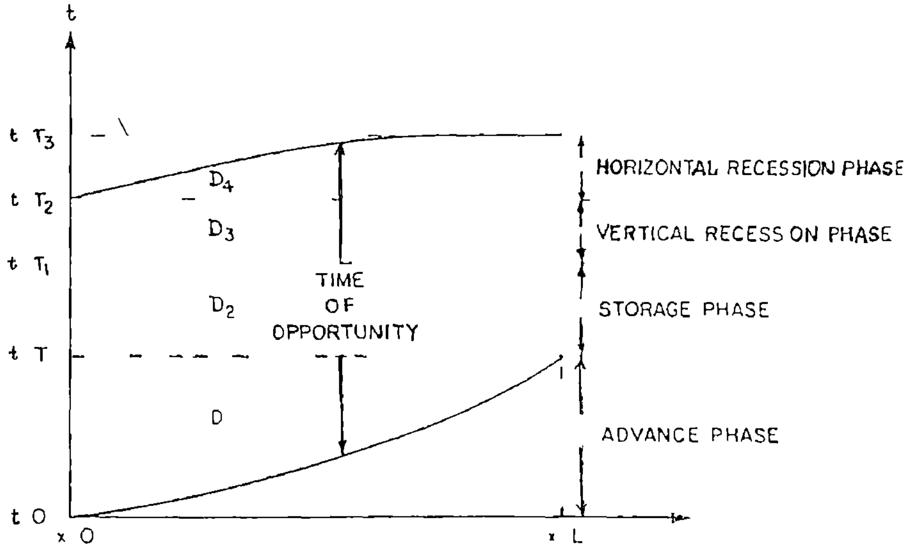


Fig 2 Solution domains for flow on a freely draining border

distance between them   dimensionless   and

q   entrance stream size   cubic metres per second

The resistance coefficient in non vegetated borders may be described by the Darcey Weisbach roughness coefficient

$f \quad 0\ 313/(Rn^{1/4})$ in which

f   Darcey   Weisbach resistance coefficient

Rn   Reynolds number

Materials and Methods

MATERIALS AND METHODS

Details and methodology of experimentation data collection and analysis are presented in this chapter

3 1 Location and Climate

The experiment was conducted in the paddy fields of KCAET , Tavanur It is situated at 10 52' 30" latitude and 76 east longitude KCAET has a total area of 40 99 ha out of which the total cropped area is 29 65 ha

Agroclimatically the area falls within the border line of northern zone and central zone of Kerala The area recieves rain fall mainly from the south west monsoon and to a certain extent from the north east monsoon The annual rainfall is in between 2500 mm and 2900 mm The investigation was carried out during the months of February , March and April of 1992 The meteorological observations for the period of investigation are presented in Appendix I

3 2 Soil characteristics of the experimental site

As the knowledge of the basic soil characteristics would be useful in interpreting the experimental results , a series of field and laboratory experiments were conducted to evaluate these characteristics

3 2 1 Soil texture

The relative proportions of sand , silt and clay in a soil mass determines the texture of a soil The determination of the soil texture is very important for any research in soil and water engineering and the mechanical composition of soil was determined by sieve analysis

3 2 2 Field capacity

Field capacity is defined as the moisture content of a soil after the drainage of gravitational water has nearly seized and the soil moisture content has become relatively stable

Materials used for the determination were soil augers sample boxes thermostatically controlled electric oven and balance The soil was wetted to near saturation in situ and left to drain for two days The surface was covered to prevent evaporation Soil samples were collected from different locations at different time intervals in sample boxes The moisture content was then determined by gravimetric method The procedure was repeated for different soil depths A graph was plotted with time in hours on X axis and percentage moisture content on Y axis The constant value of moisture content reached is the field capacity of the particular soil

3 2 3 Bulk Density

The weight of soil mass for unit volume (pore spaces and soil solids) gives the bulk density of the soil This equals the numerical value of its apparent specific gravity The core sample method of determination of bulk density of soils was adopted in the present study

3 2 4 Infiltration

The infiltration rate of the experimental field was determined by using double ring infiltrometer The cylinders were 25 cm deep and were formed of 2 mm rolled steel The inner cylinder from which the infiltration measurements were taken was 30 cm in diameter The outer cylinder , which was used to form the buffer pond to minimise the lateral spreading of water was 60 cm in diameter The cylinders were driven 10 cm deep into the soil This was done by hammering on a wooden plank placed on the top of the cylinder so as to prevent damages to the edge of the cylinders

The water level in the inner cylinder was read with a hook gauge Hook gauge measurements were made at frequent intervals at the beginning to determine the initial infiltration rate The readings were taken till a constant value was obtained Three different tests were conducted and the mean value was used for analysis

3 3 Experimental Details

To evolve the empirical relations of water front advance and recession of border irrigation , border strips at three different slopes were irrigated with three different stream sizes The strips were irrigated at approximately constant soil moisture levels Altogether five irrigations were given Time of advance and recession were noted at five metre intervals along the border strip Plate 1 shows the advance of water front along the border strip After the first irrigation cow pea seeds were dibbled in all the strips at a spacing of 15 cm X 25 cm Manures

Plate 1 Advance of water front in a border strip

Plate 2 Irrigated border strip - view from upstream end

and fertilizers were applied to the crop as recommended in the package of practices recommendations of the KAU Biometrical observations were noted and is shown in Appendix II

3 3 1 Land preparation

The three slopes selected were 0 2 percent 0 3 percent and 0 4 percent The magnitude and direction of the existing slope of the experimental plot was first determined using a levelling instrument Then the plot was divided into three and separate levelling was done with a tractor drawn leveller to attain these slopes The field was then ploughed with a tractor drawn cultivator and levelled by manual spade work

3 3 2 Layout of field

The total area of the experimental plot was 2800 square metres Border strips of length 40 m and width 2 m were chosen for the experiment After every strip a 30 cm buffer strip was provided to eliminate the lateral seepage on the adjoining plots The boundary ridges were 20 cm wide and 15 cm high

The experiment was laid out with 2 replications and 9 treatments The following were the treatments

T 1 0 2 percent slope 2 lps/m width stream size

T 2 0 2 percent slope 3 lps/m width stream size

T 3 0 2 percent slope 4 lps/m width stream size

T 4 0 3 percent slope 2 lps/m width stream size

T 5 0 3 percent slope 3 lps/m width stream size

T 6 0 3 percent slope 4 lps/m width stream size

T 7 0 4 percent slope , 2 lps/m width stream size

T 8 0 4 percent slope 3 lps/m width stream size

T 9 0 4 percent slope 4 lps/m width stream size

The complete layout of the experimental field is shown in Figure 3

3 3 3 Measurement of irrigation water

The irrigation water needs of the experiment was met from the open well of the KCAET farm The stream size was measured using a 90 degree V notch

The V - notch was made up of mild steel sheet 2 mm thick 115 cm wide and 50 cm high It was installed at the exit of a masonry tank sufficiently wide and deep to minimise turbulence Care was taken to install the V notch exactly vertical The scale for measuring the head was located at a distance of about four times the approximate head , from the V notch The channel section immediately down stream from the notch was protected from erosion

The head of water required for different stream sizes were as shown in Table 3 The relationship between the discharge and head is given by the following equation

$Q \quad 0\ 0138\ H^{5/2}$ in which

Q discharge in lps , and

H head in cm

The water was turned into the strips only after the flow in the supply channel was stabilised

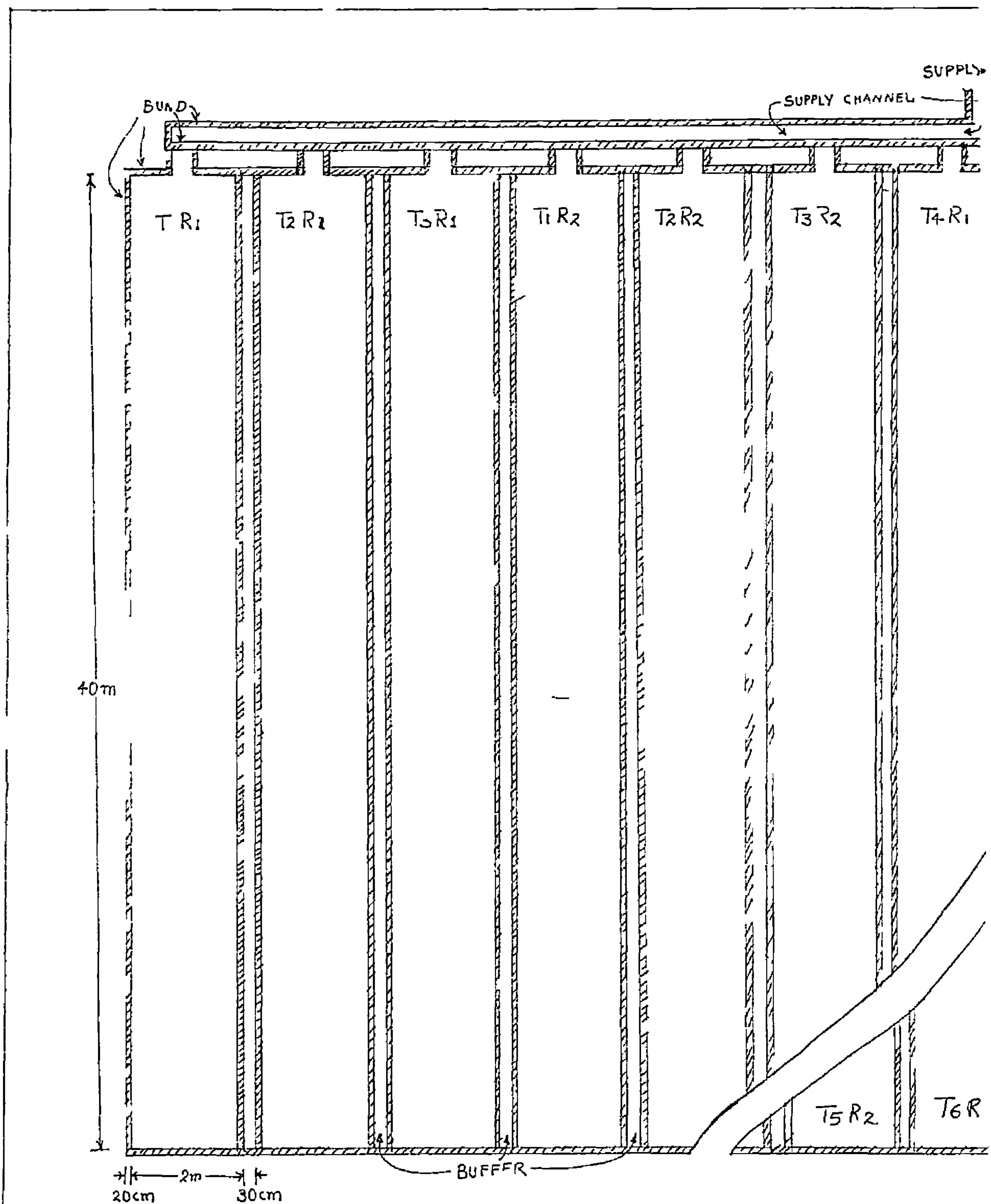


FIG 3 LAYOUT OF EXPERIMENTAL FIELD

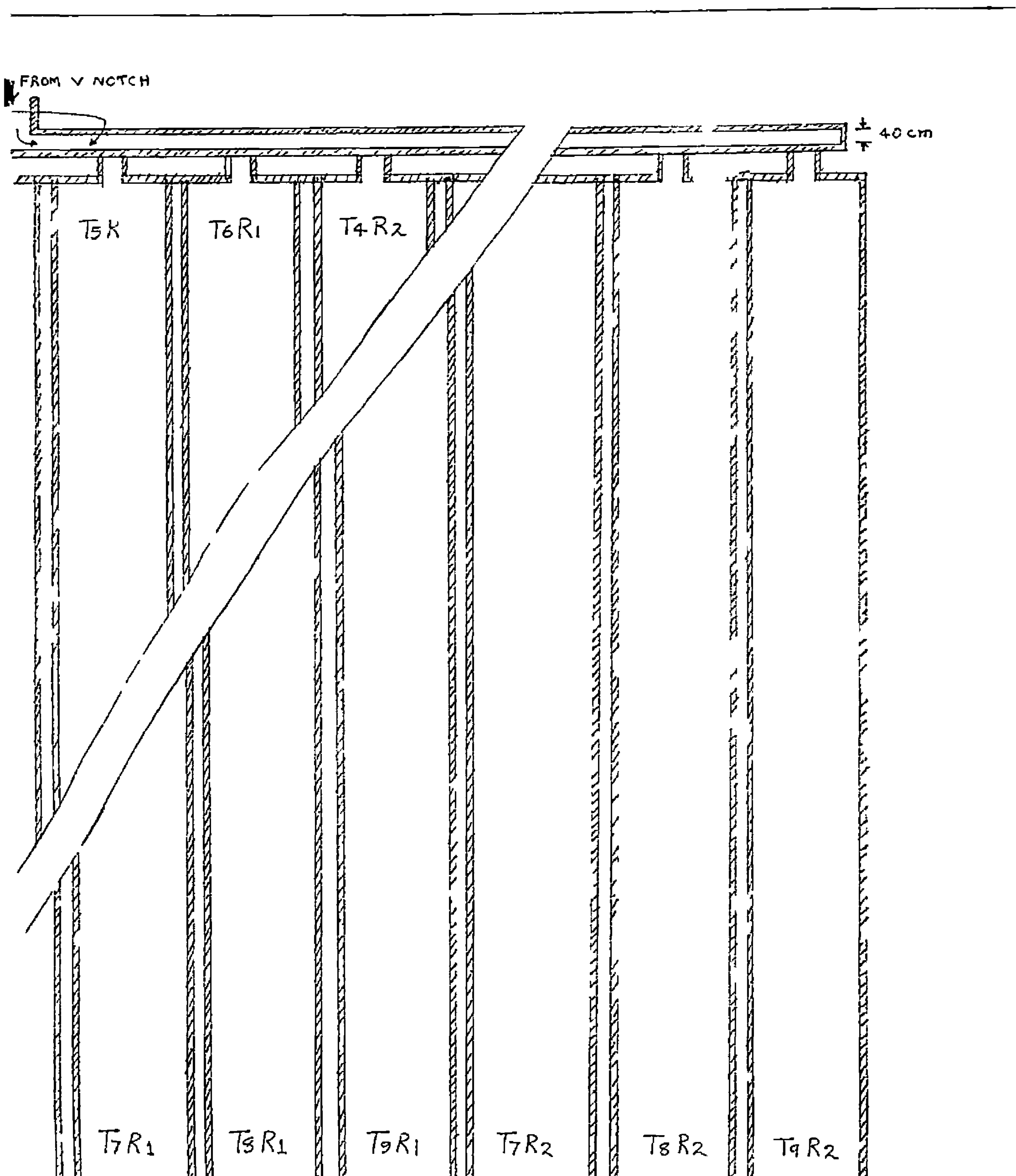

FROM V NOTCH
40 cm
T5K
T6R1
T4R2
T7R1
T8R1
T9R1
T7R2
T8R2
T9R2

Table 3 Head of water for different discharges measured on the V - notch

Flow rate (lps)	Height of water over V - notch
4	9 65
6	11 35
8	12 74

3 3 4 Cutoff length

Trial runs were conducted to find out the best cutoff length at which the irrigation stream is to be stopped It was observed that distribution of water upto the extreme tail end of the border strip can be achieved at 75 percent for stream size of 4 lps/m , 80 percent for 3 lps/m and 85 percent for 2 lps/m That is 30 m , 32 m , and 34 m respectively from the upstream end for a border strip of 40 m length Stakes were driven at these points and the supply stream was cutoff when the advancing front reached the point of cutoff

3 4 Advance time

The time of advance was noted for every 5 m distance from the upstream end of the border after diverting the inflow into the border Stakes were driven at 5 m intervals along the border length and the time taken by the water front to reach each of them was noted using a stopwatch

3 5 Recession time

The horizontal recession time at every 5 m interval was observed by the same method as described in section 3 4 and the observations recorded

3 6 Analysis of data

The data collected as described in sections 3 4 and 3 5 were analysed using standard procedures The data obtained from the first two irrigations was not considered for subsequent analysis since it was found to be inconsistent with the other sets of observations These are presented in Appendix IV & V

3 6 1 Advance curves

Curves were plotted with distance from the upstream end along the X axis and time of advance on the Y axis Mean value of the advance times at each distance for the last three irrigations with the respective replications were taken to plot the curves

3 6 2 Recession curves

Plots were made between distance from the upstream end on X axis and recession time on Y axis The mean values of observations of the last three irrigations were considered for plotting the curves

3 6 3 Uniformity of irrigation

Irrigation uniformity was assessed by comparing the advance and recession graphs plotted together The parellelism of the advance and recession curves was considered as a measure of uniformity of water distribution along the border That is the infiltration opportunity time or the time of ponding which is the vertical distance in time scale, between the advance and recession curves at different points should be the same for uniform distribution Comparative graphs of advance and recession for all the nine treatments were plotted and uniformity of application was assessed for each

3 6 4 Development of Rational formula for advance

The advance time was taken as a function of three variables namely stream size, slope and advance distance

t_a f (Q S X) ie

t_a $K (Q^a S^b X^c)$ where

t_a time of advance in seconds

Q stream size in lps/m width of border strip

S slope in percentage

X advance distance from upstream end in metres and

K, a, b, & c are constants

Multiple linear regression technique was used to find out the values of the above constants The logarithmic form of the above equation was considered for the purpose

$$\ln t_a \quad \ln (K) + a \ln (Q) + b \ln (S) + c \ln (X)$$

The values of ln (K) , a, b, and c were obtained from the multiple regression analysis done with a computer programme written in BASIC which is presented in Appendix VI

3 6 5 Development of rational formula for recession

Recession time was taken as a function of stream size slope and distance from the upstream end of the border

$t_r = f(Q, S, X)$ ie

$t_r = K Q^{a'} S^{b'} X^{c}$ where

Q stream size in lps/m

S slope in percentage

X distance from the upstream end in metres and

K', a' b' and c' are constants

Multiple linear regression technique was used here also to determine K', a', b' and c' in the same way as described in section 3 6 4

Results and Discussion

RESULTS AND DISCUSSION

The results of field studies conducted and the evolved rational formulae for advance and recession are presented in this chapter

4 1 Soil charecteristics of the experimental site

4 1 1 Texture

Results of the sieve analysis of the soil shows that the surface soil (60 cm) is sandy loam in texture comprising of 10 percent of gravel 65 percent sand, 12 5 percent clay

4 1 2 Field capacity

Observations of the moisture contents are presented in Table 4 and the plot of moisture content against time is given in Figure 4 It is seen that as time goes on moisture content gradually decreases and reaches a constant value This constant value is found to be 19 percent and it is taken as the field capacity of the particular soil

4 1 3 Bulk density

The weights of the core cutter and soil samples are given in Table 5 The mean bulk density is found to be 1 78 gm/cc

4 1 4 Infiltration

Field observations and the calculated values of infiltration rate and accumulated infiltration are presented in Table 6 Plots of infiltration rate and accumulated infiltration against elapsed time are given in Figure 6

The functional relationship between accumulated

Table 4 Moisture content percentage on dry basis (Field capacity)

Elapsed time (hours)	Weight of container (grams)	Weight of container + wet sample (grams)	Weight of container + dry sample (grams)	Weight of wet soil (grams)	Weight of dry soil (grams)	Moisture content on dry basis (percent)
24	9 95	79 04	58 70	67 28	48 75	38
30	11 41	104 10	84 00	91 48	72 60	26
32	11 02	106 31	81 43	86 73	70 40	23 2
34	12 30	92 31	78 60	80 21	66 29	21
36	4 92	51 04	43 60	46 03	38 68	19
38	11 41	99 00	85 50	88 18	74 10	19

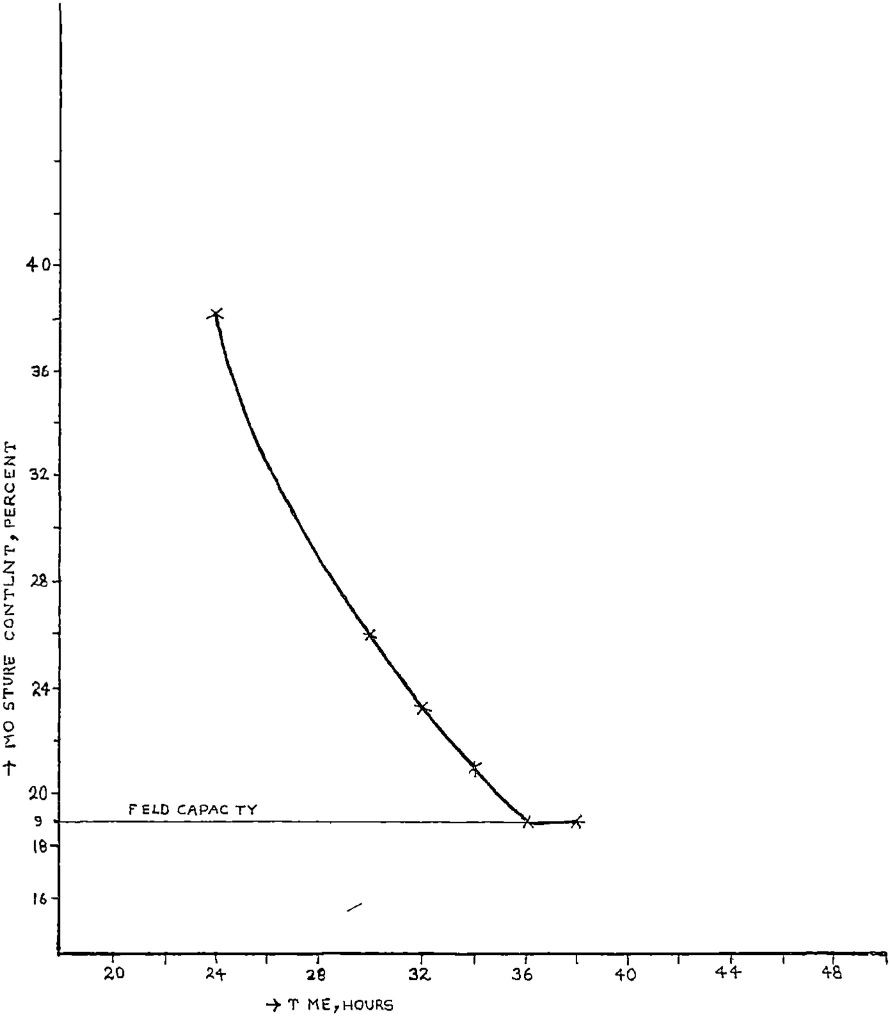


FIG 4 **FIELD CAPACITY** TIME Vs MOISTURE CONTENT

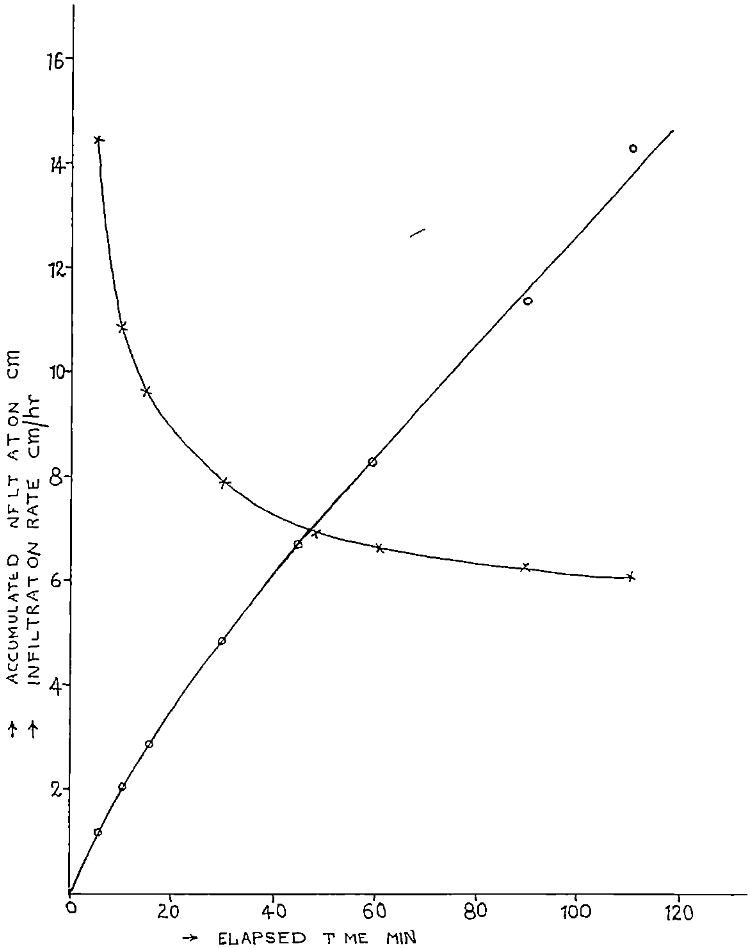


FIG 5 ACCUMULATED INFILTRATION AND INFILTRATION RATE

Table 5 Dry bulk density

Weight of core cutter gm	Weight of core cutter +dry sample gm	Weight of dry soil gm	Volume of dry soil cc	Bulk density gm/cc
1750	4405	2655	1500	1 77
1750	4420	2670	1500	1 78
1750	4435	2685	1500	1 79
			Mean	1 78

Table 6 Infiltration and accumulated infiltration of soil in situ

Serial Number	Elapsed time (min)	Depth of water level from mark (cm)	Infiltration rate (cm/hr)	Accumulated infiltration (cm)
1	5	1 2	14 4	1 2
2	10	0 9	10 8	2 1
3	15	0 8	9 6	2 9
4	30	1 95	7 8	4 85
5	45	1 75	7 0	6 6
6	60	1 65	6 6	8 25
7	90	3 15	6 3	11 4
8	120	0 3	6 0	14 4

infiltration (y) and time (t) is represented by the equation

$$y = 0.29\ t^{0.81} + 0.17$$

The method of averages used to determine this equation is presented in Appendix III Goodness of fit was also evaluated

4 2 Advance time

Advance time observations collected as described in section 3 4 are presented in Tables 7 to 15 A comparative study of the advance time observations show that with increase in stream size the advance time decreases for all the treatments and their replications The same trend was observed for all the irrigations The results are in conformity with the studies conducted by Visalakshi (1983)

It was also observed that increase in slope also had a negative effect on the advance time This effect was same for all the treatments and replications for all the irrigations

Considerable d fference in advance time was not observed for the three irrigations The third and fourth irrigation showed little difference in advance time This is because of the fact that cow pea is a thin stalked plant Effective stalk length causing resistance to flow is the bottom one or two centimetres only The flow is affected only by the increase in diameter of the stalk which is small Any increase in advance time due to increase in crop resistance might have been compensated by the slight changes in infiltration chraoteristics

A slight increase in the time of advance was noted for the

Table 7 Advance time , slope 0 4 %   stream size 4 lps/m

Distance from upstream end m	Advance time sec						Mean advance time, sec	Predicted advance time sec
	Replication 1			Replication 2				
	Irrgn 3	Irrgn 4	Irrgn 5	Irrgn 3	Irrgn 4	Irrgn 5		
0	0	0	0	0	0	0	0	0
5	51	46	47	44	39	52	47	54
10	128	106	128	116	111	124	119	129
15	225	203	243	207	213	242	226	216
20	296	297	315	310	305	318	307	311
25	423	382	441	385	375	438	407	412
30	490	476	518	482	468	514	491	518
35	577	575	621	583	584	625	594	629
40	733	702	757	693	698	761	724	745

Table 8 Advance time , slope 0 4 % , stream size 3 lps/m

Distance from upstream end, m	Advance time , sec						Mean advance time, sec	Predicted advance time sec
	Replication 1			Replication 2				
	Irrgn 3	Irrgn 4	Irrgn 5	Irrgn 3	Irrgn 4	Irrgn 5		
0	0	0	0	0	0	0	0	0
5	70	74	92	76	82	97	82	70
10	200	189	201	183	192	206	195	168
15	302	303	344	319	312	341	320	280
20	436	418	446	421	406	441	428	402
25	568	531	615	547	542	618	570	533
30	671	673	734	682	682	739	697	671
35	816	818	878	808	805	872	833	815
40	948	956	1032	975	978	1040	988	964

Table 9 Advance time, slope 0.4 %, stream size 2 lps/m

Distance from upstream end m	Advance time, sec						Mean advance time sec	Predicted advance time sec
	Replication 1			Replication 2				
	Irrgn 3	Irrgn 4	Irrgn 5	Irrgn 3	Irrgn 4	Irrgn 5		
0	0	0	0	0	0	0	0	0
5	83	79	112	82	88	110	92	101
10	215	202	226	205	212	221	214	241
15	392	368	397	371	372	402	384	402
20	574	542	578	550	557	581	564	578
25	764	732	771	722	725	762	746	767
30	930	913	971	899	908	978	933	965
35	1085	1012	1181	1053	1036	1178	1091	1172
40	1318	1301	1426	1298	1282	1434	1343	1387

Table 10 Advance time , slope 0 3 % , stream size 4 lps/m

Distance from upstream end, m	Advance time , sec						Mean advance time sec	Predicted advance time sec
	Replication 1			Replication 2				
	Irrgn 3	Irrgn 4	Irrgn 5	Irrgn 3	Irrgn 4	Irrgn 5		
0	0	0	0	0	0	0	0	0
5	53	45	75	52	48	66	57	57
10	126	117	169	123	119	179	139	137
15	217	228	260	222	206	252	231	229
20	322	313	355	302	313	358	327	329
25	400	411	422	407	412	419	412	437
30	505	527	533	532	518	537	525	550
35	609	631	672	620	612	677	637	668
40	752	728	817	736	745	812	765	790

Table 11 Advance time slope 0 3 % , stream size 3 lps/m

Distance from upstream end m	Advance time sec						Mean advance time sec	Predicted advance time sec
	Replication 1			Replication 2				
	Irrgn 3	Irrgn 4	Irrgn 5	Irrgn 3	Irrgn 4	Irrgn 5		
0	0	0	0	0	0	0	0	0
5	88	79	132	81	76	126	97	74
10	194	206	256	196	189	248	215	178
15	345	320	368	332	318	372	343	297
20	445	466	483	449	454	490	465	426
25	621	595	632	588	610	624	612	565
30	755	728	785	736	721	794	753	711
35	858	869	910	868	862	901	878	864
40	1012	1043	1091	952	982	1102	1030	1023

Table 12 Advance time , slope 0 3 % stream size 2 lps/m

Distance from upstream end m	Advance time sec						Mean advance time sec	Predicted advance time sec
	Replication 1			Replication 2				
	Irrgn 3	Irrgn 4	Irrgn 5	Irrgn 3	Irrgn 4	Irrgn 5		
0	0	0	0	0	0	0	0	0
5	86	94	98	92	85	109	94	107
10	235	211	261	222	214	256	233	256
15	404	387	439	366	378	445	403	427
20	604	632	671	607	592	662	628	613
25	793	776	809	757	775	812	787	813
30	1086	1048	1063	975	963	1058	1032	1023
35	1248	1272	1330	1204	1222	1338	1269	1243
40	1534	1503	1622	1455	1424	1607	1524	1471

Table 13 Advance time slope 0 2 % stream size 4 lps/m

Distance from upstream end m	Advance time sec						Mean advance time, sec	Predicted advance time sec
	Replication 1			Replication 2				
	Irrgn 3	Irrgn 4	Irrgn 5	Irrgn 3	Irrgn 4	Irrgn 5		
0	0	0	0	0	0	0	0	0
5	63	51	69	45	56	66	49	58
10	138	121	172	117	122	167	140	149
15	229	232	255	228	236	257	240	249
20	341	323	380	329	318	382	346	358
25	430	425	492	421	436	488	449	474
30	529	518	588	528	534	580	546	597
35	622	640	701	652	645	706	661	725
40	735	761	836	749	768	841	782	858

Table 14 Advance time slope 0 2 % stream size 3 lps/m

Distance from upstream end m	Advance time sec						Mean advance time sec	Predicted advance time sec
	Replication 1			Replication 2				
	Irrgn 3	Irrgn 4	Irrgn 5	Irrgn 3	Irrgn 4	Irrgn 5		
0	0	0	0	0	0	0	0	0
5	83	94	116	86	78	110	95	88
10	218	201	235	206	215	246	220	193
15	356	335	402	334	342	398	361	322
20	478	463	507	491	482	515	489	463
25	635	627	738	629	642	726	666	614
30	782	765	808	782	769	813	787	773
35	923	928	1015	928	936	1003	956	939
40	1083	1112	1183	1084	1102	1176	1123	1111

Table 15 Advance time , slope 0 2 % stream size 2 lps/m

Distance from upstream end m	Advance time sec						Mean advance time sec	Predicted advance time sec
	Replication 1			Replication 2				
	Irrgn 3	Irrgn 4	Irrgn 5	Irrgn 3	Irrgn 4	Irrgn 5		
0	0	0	0	0	0	0	0	0
5	114	92	128	86	92	131	107	116
10	238	222	285	207	198	279	238	278
15	395	417	475	389	403	463	424	464
20	631	629	648	627	638	650	637	666
25	869	902	937	875	865	945	899	883
30	1028	977	1228	1139	1156	1231	1127	1112
35	1429	1454	1491	1455	1437	1504	1462	1350
40	1752	1865	2035	1738	1752	2010	1858	1598

last irrigation which can be attributed to the increased resistance offered by the crop as well as the weeds

4 3 Recession time

Recession time data collected as described in section 3 5 are presented in Tables 16 to 24 A study of these observations reveal that increase in slope and stream size have negative effects on the recession time It was observed that the effect of stream size on recession time is less prominent than the slope within the ranges of slopes and stream sizes considered The above results are in confirmity with the results of the studies conducted by Vinod Kumar and Tyagi (1971) and Mishra (1975)

4 4 Advance curves

Figure 6 shows the advance curves for a slope of 0 4 percent for the three stream sizes viz 4 lps/m, 3 lps/m and 2 lps/m Figure 7 and 8 show the curves for slopes of 0 3 percent and 0 2 percent respectively

A critical analysis of the above curves showed a prominent decrease in advance time with increase in stream size the relationship being non linear

Figures 9 10 and 11 present the advance curves for the three different stream sizes at various slopes From the curves it can be observed that the impact of slope on advance time is less profound than stream size within the ranges of slopes considered viz 0 2 % to 0 4 %

Considerable difference in the trend of advance curves

Table 16 Recession time , slope 0 4 % stream size 4 lps/m

Distance from upstream end m	Recession time sec						Mean Recession time, sec	Predicted Recession time sec
	Replication 1			Replication 2				
	Irrgn 3	Irrgn 4	Irrgn 5	Irrgn 3	Irrgn 4	Irrgn 5		
0	0	0	0	0	0	0	0	0
5	57	60	62	64	54	48	58	50
10	72	83	85	74	76	78	78	96
15	118	130	118	131	120	125	124	141
20	152	145	138	145	149	140	145	185
25	212	197	212	197	208	192	203	229
30	268	253	267	258	271	251	261	273
35	302	298	305	321	304	311	307	316
40	405	414	418	375	401	386	400	359

Table 17 Recession time , slope 0 4 % , stream size 3 lps/m

Distance from upstream end, m	Recession time , sec						Mean Recession time, sec	Predicted Recession time, sec
	Replication 1			Replication 2				
	Irrgn 3	Irrgn 4	Irrgn 5	Irrgn 3	Irrgn 4	Irrgn 5		
0	0	0	0	0	0	0	0	0
5	58	68	61	54	58	61	60	54
10	97	113	104	95	102	108	103	104
15	176	168	182	168	185	174	176	153
20	210	198	195	212	202	208	204	201
25	264	278	281	268	263	274	271	249
30	302	310	314	298	304	294	304	296
35	352	361	352	338	348	336	348	343
40	417	408	435	422	425	406	419	389

Table 18 Recession time , slope 0 4 % , stream size 2 lps/m

Distance from upstream end m	Recession time sec						Mean Recession time sec	Predicted Recession time sec
	Replication 1			Replication 2				
	Irrgn 3	Irrgn 4	Irrgn 5	Irrgn 3	Irrgn 4	Irrgn 5		
0	0	0	0	0	0	0	0	0
5	68	74	73	69	62	70	69	60
10	107	98	94	108	101	90	100	117
15	145	154	142	126	138	150	143	172
20	212	206	213	205	203	198	206	226
25	248	236	250	237	242	246	243	279
30	321	304	318	331	326	312	317	332
35	347	361	348	362	365	354	356	385
40	448	455	441	437	458	442	447	437

Table 19 Recession time , slope 0 3 % , stream size 4 lps/m

Distance from upstream end, m	Recession time sec						Mean Recession time, sec	Predicted Recession time, sec
	Replication 1			Replication 2				
	Irrgn 3	Irrgn 4	Irrgn 5	Irrgn 3	Irrgn 4	Irrgn 5		
0	0	0	0	0	0	0	0	0
5	68	79	76	70	68	75	73	59
10	110	122	112	126	102	111	114	114
15	155	174	158	175	167	174	167	168
20	205	218	204	211	119	207	207	221
25	270	275	269	281	262	277	272	273
30	330	308	325	332	329	314	323	325
35	442	428	441	418	435	420	431	376
40	512	494	515	502	504	485	502	427

σ

Table 20 Recession time , slope 0 3 % , stream size 3 lps/m

Distance from upstream end, m	Recession time , sec						Mean Recession time sec	Predicted Recession time sec
	Replication 1			Replication 2				
	Irrgn 3	Irrgn 4	Irrgn 5	Irrgn 3	Irrgn 4	Irrgn 5		
0	0	0	0	0	0	0	0	0
5	86	78	92	78	84	76	82	64
10	126	109	104	108	123	117	115	124
15	211	198	208	188	204	192	200	182
20	261	145	245	262	258	241	252	240
25	301	298	303	287	296	305	298	297
30	412	397	412	398	408	395	404	353
35	441	455	449	451	456	446	450	409
40	541	532	536	528	540	520	533	464

Table 21 Recession time slope 0 3 % stream size 2 lps/m

Distance from upstream end m	Recession time sec						Mean Recession time sec	Predicted Recession time sec
	Replication 1			Replication 2				
	Irrgn 3	Irrgn 4	Irrgn 5	Irrgn 3	Irrgn 4	Irrgn 5		
0	0	0	0	0	0	0	0	0
5	86	78	90	84	87	84	85	72
10	155	148	156	148	152	144	151	139
15	176	188	184	179	172	187	181	205
20	216	232	218	228	226	237	226	269
25	318	296	302	287	295	311	302	333
30	411	398	398	387	382	408	397	398
35	467	452	467	455	458	476	463	459
40	537	515	518	543	508	555	529	521

Table 22 Recession time , slope 0 2 % stream size 4 lps/m

Distance from upstream end m	Recession time sec						Mean Recession time, sec	Predicted Recession time sec
	Replication 1			Replication 2				
	Irrgn 3	Irrgn 4	Irrgn 5	Irrgn 3	Irrgn 4	Irrgn 5		
0	0	0	0	0	0	0	0	0
5	71	75	73	75	69	72	73	76
10	119	132	126	141	138	125	130	146
15	168	175	190	182	192	174	184	215
20	253	242	251	238	246	256	248	283
25	318	331	312	318	326	339	324	350
30	438	444	452	440	432	438	441	416
35	482	468	481	465	478	456	472	482
40	550	563	570	556	568	554	560	547

Table 23 Recession time slope 0 2 % , stream size 3 lps/m

Distance from upstream end m	Recession time sec						Mean Recession time sec	Predicted Recession time sec
	Replication 1			Replication 2				
	Irrgn 3	Irrgn 4	Irrgn 5	Irrgn 3	Irrgn 4	Irrgn 5		
0	0	0	0	0	0	0	0	0
5	87	79	88	76	84	76	82	82
10	138	141	154	149	145	151	146	159
15	218	207	202	215	212	200	209	233
20	255	268	265	247	253	270	260	307
25	352	367	352	378	345	366	360	380
30	458	470	478	451	474	462	466	452
35	571	548	562	541	568	552	557	523
40	670	678	668	681	675	660	672	594

Table 24 Recession time slope 0 2 % stream size 2 lps/m

Distance from upstream end m	Recession time sec						Mean Recession time sec	Predicted Recession time sec
	Replication 1			Replication 2				
	Irrgn 3	Irrgn 4	Irrgn 5	Irrgn 3	Irrgn 4	Irrgn 5		
0	0	0	0	0	0	0	0	0
5	90	93	94	98	96	88	93	92
10	149	164	161	147	156	168	158	178
15	252	249	238	252	243	257	249	262
20	413	395	382	402	395	409	399	345
25	461	472	486	468	468	477	472	426
30	568	541	550	537	557	544	550	507
35	617	632	622	631	615	602	620	587
40	692	714	728	706	703	686	702	666

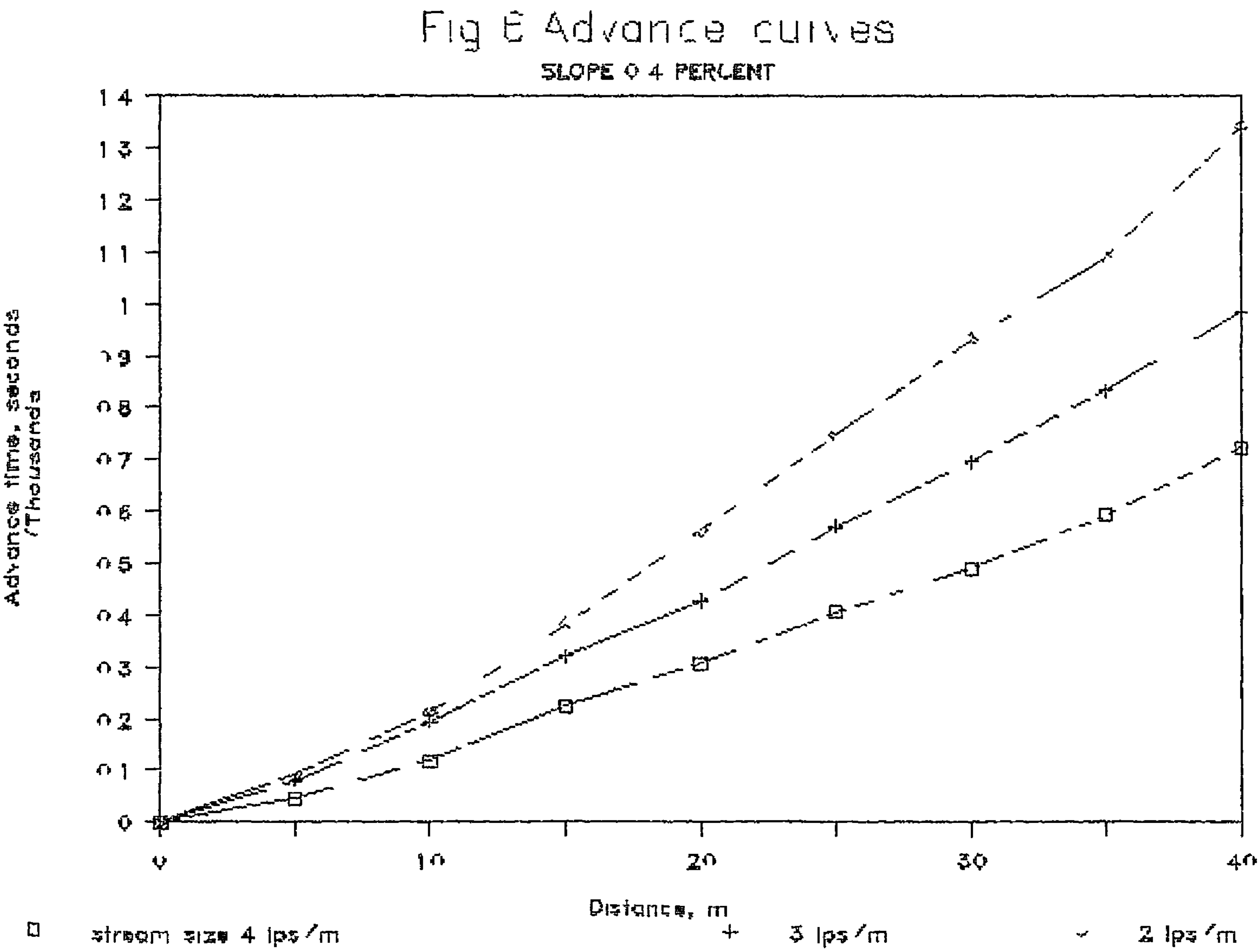
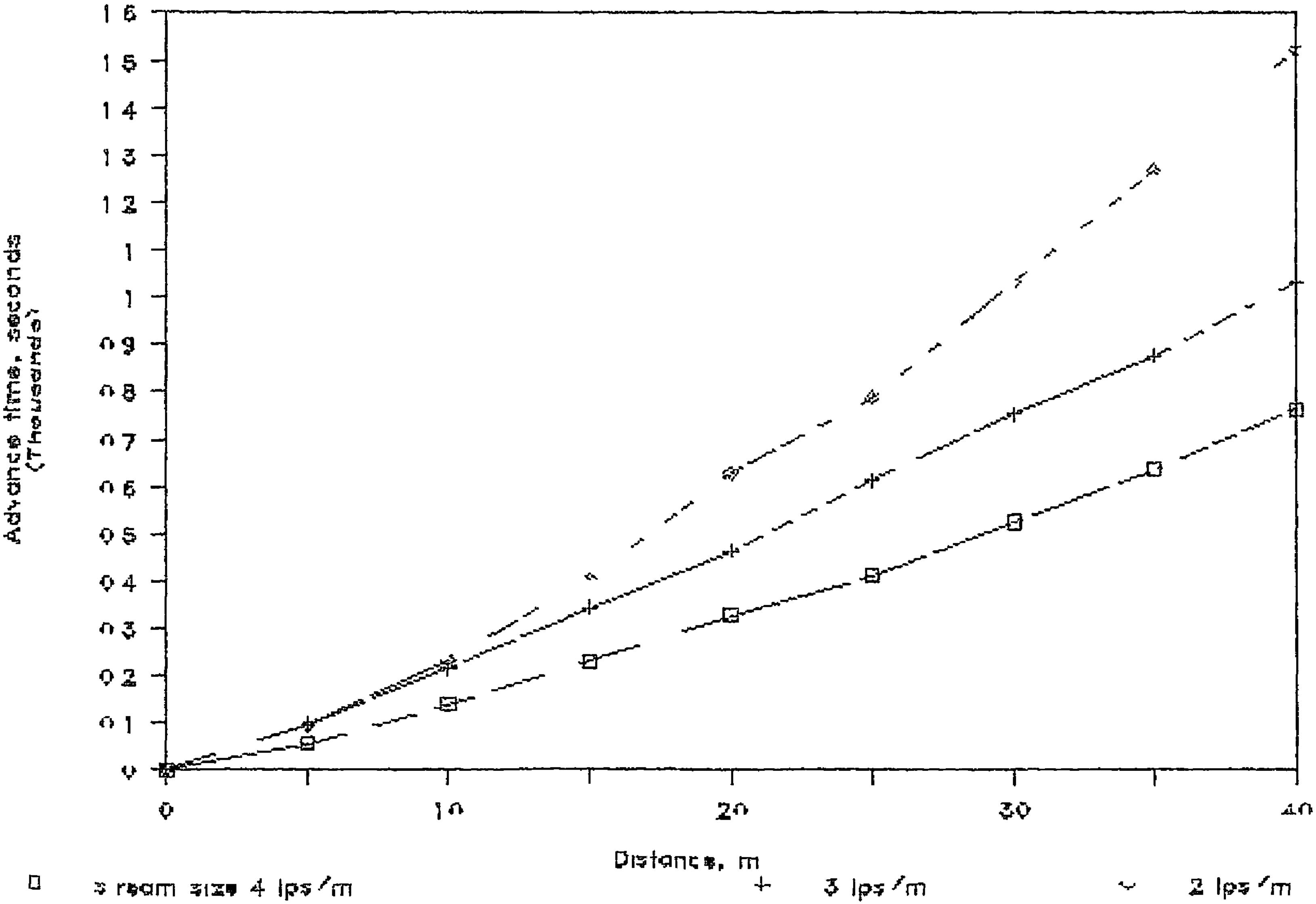


Fig E Advance curves
SLOPE 0 4 PERCENT
Advance time, seconds (Thousands)
Distance, m
stream size 4 lps/m
3 lps/m
2 lps/m

Fig 7 Ad ance curves

SLOPE 0 3 PERCENT



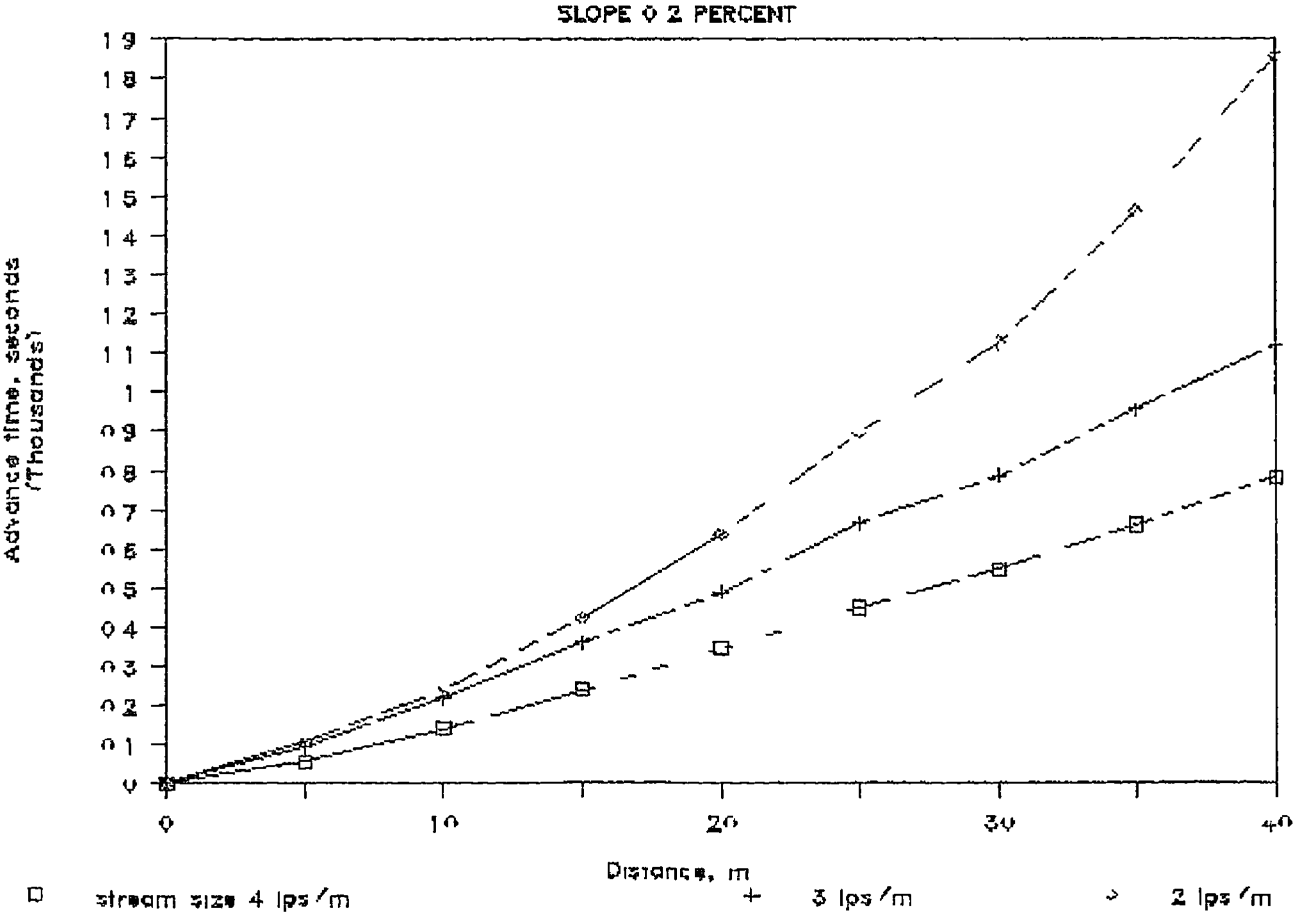
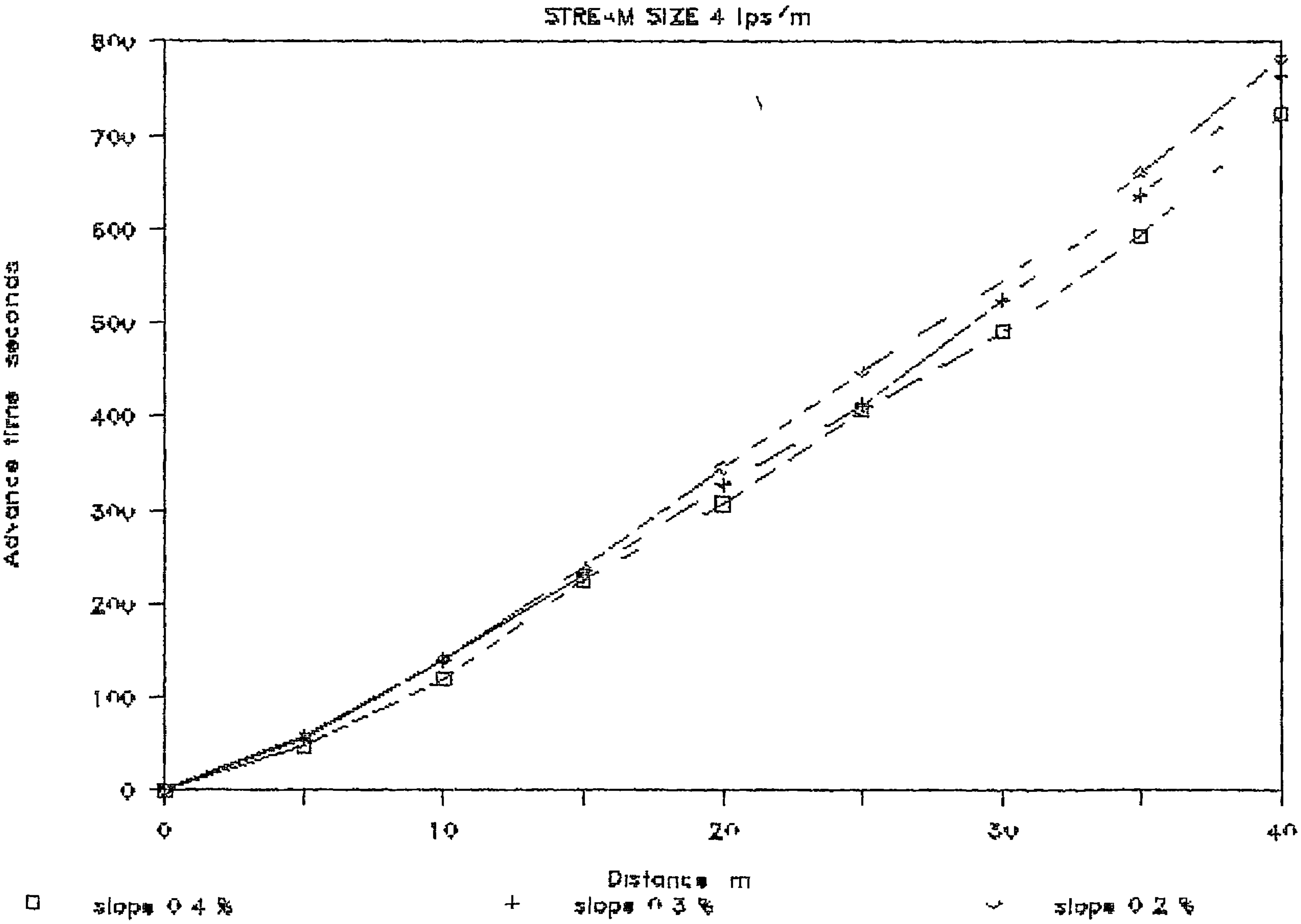


Fig 2 Advance curves

Fig 9 Advance curves



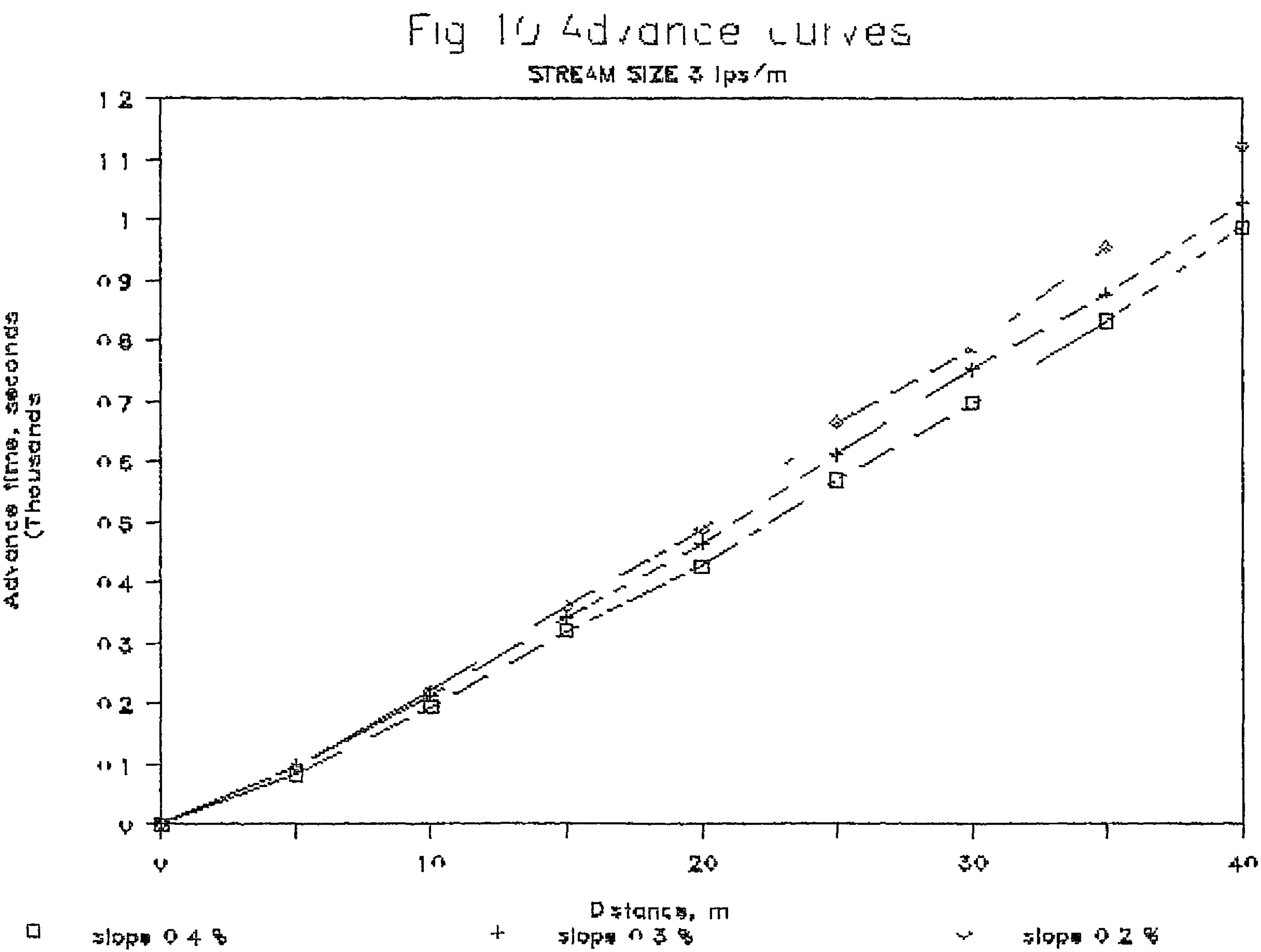
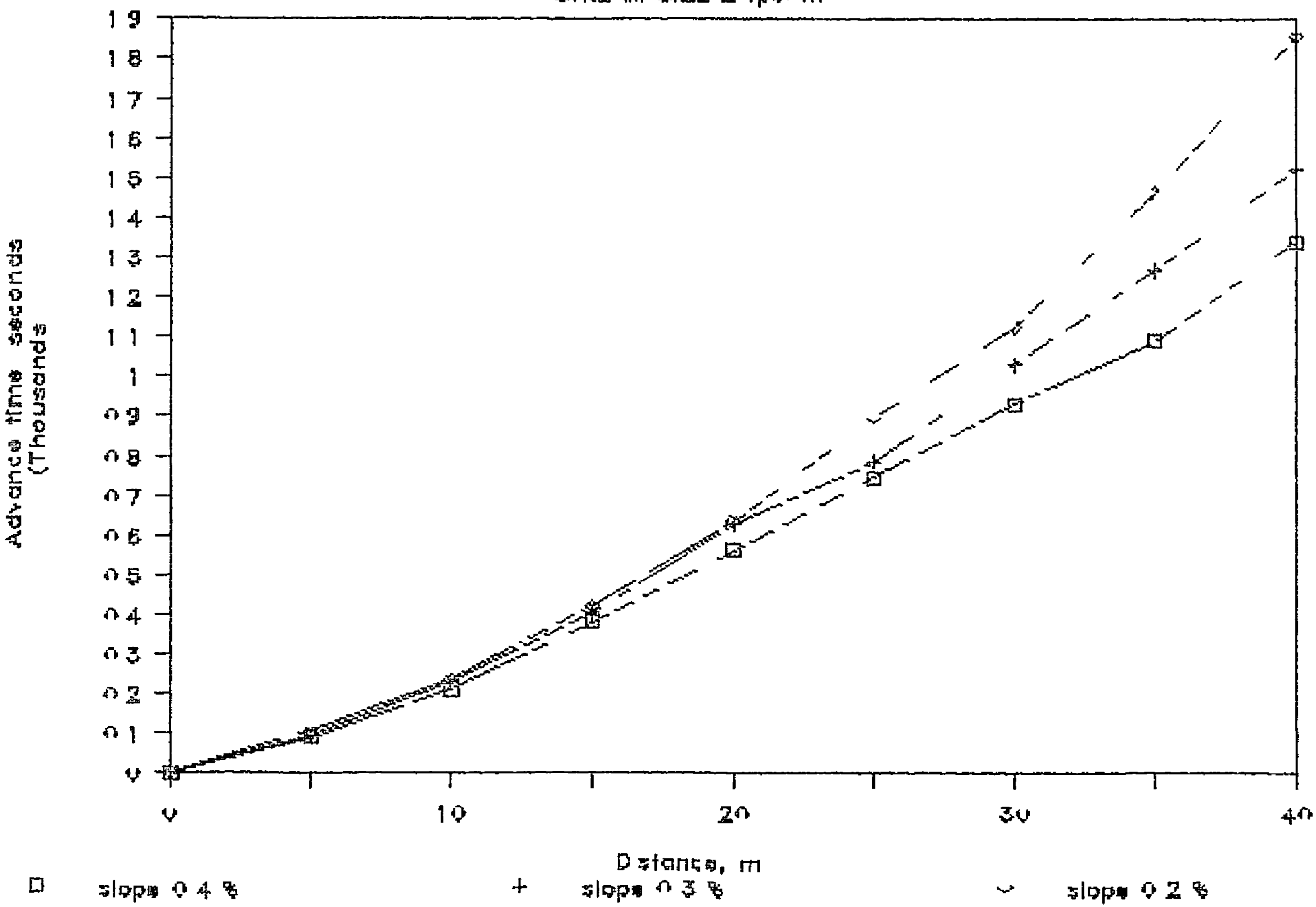


Fig 10 Advance curves
STREAM SIZE 3 lps/m
Advance time, seconds
(Thousands)
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
Distance, m
slope 0.4 %
slope 0.3 %
slope 0.2 %

Fig 11.4 Advance curves

STREAM SIZE 2 lps/m



were not observed for the different irrigations considered

4 5 Recession curves

Figures 12 13 and 14 show the recession curves for the three different slopes of 0 4 % , 0 3 % and 0 2 % respectively A negative relationship of recession time with stream size can be observed from the curves Even though a negative non-linear relationship is observed the effect is not much significant

Figures 15 16 and 17 show the curves of different slopes for the three different stream sizes of 4 lps/m 3 lps/m and 2 lps/m respectively A profound negative effect of slope on recession time can be observed from the curves

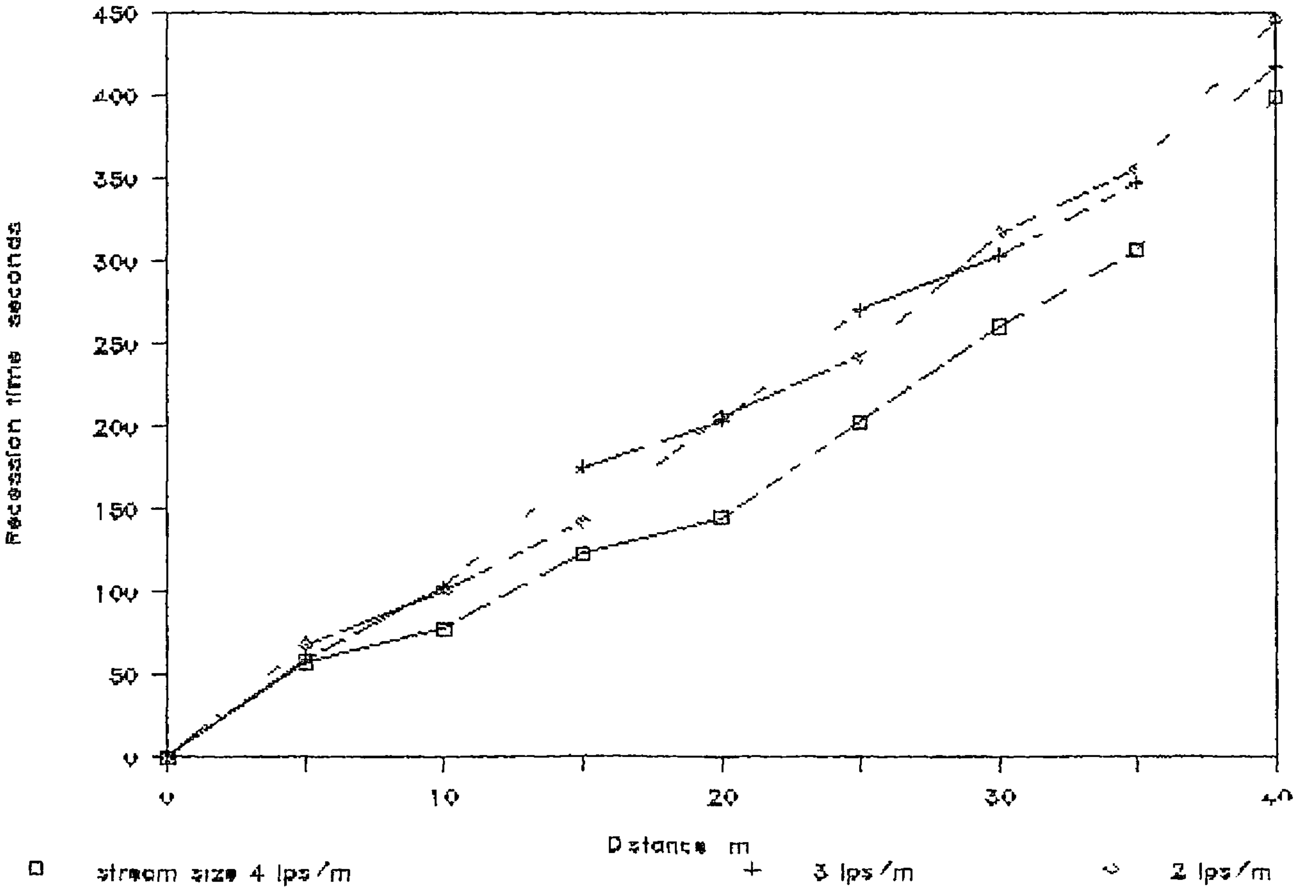
The above figures show that in a particular slope the horizontal recession time does not change significantly with stream size the reason for which may be attributed to the fact that at the end of vertical recession the receding tail water will have a horizontal profile which give rise to nearly same depth and velocity for different stream sizes

3 6 Uniformity of irrigation

Figures 18 to 26 present the mean curves of advance and recession plotted together for different treatments From the plots it can be observed that the stream size of 2 lps/m gives non uniform irrigations and 4 lps/m gives nearly uniform irrigations The treatment combination of 0 2 % slope and 4 lps/m stream size gave the most uniform and treatment with 0 4 % slope and 2 lps/m stream size gave the least uniform irrigations

Fig 12 Recession curves

SLOPE 0.4 %



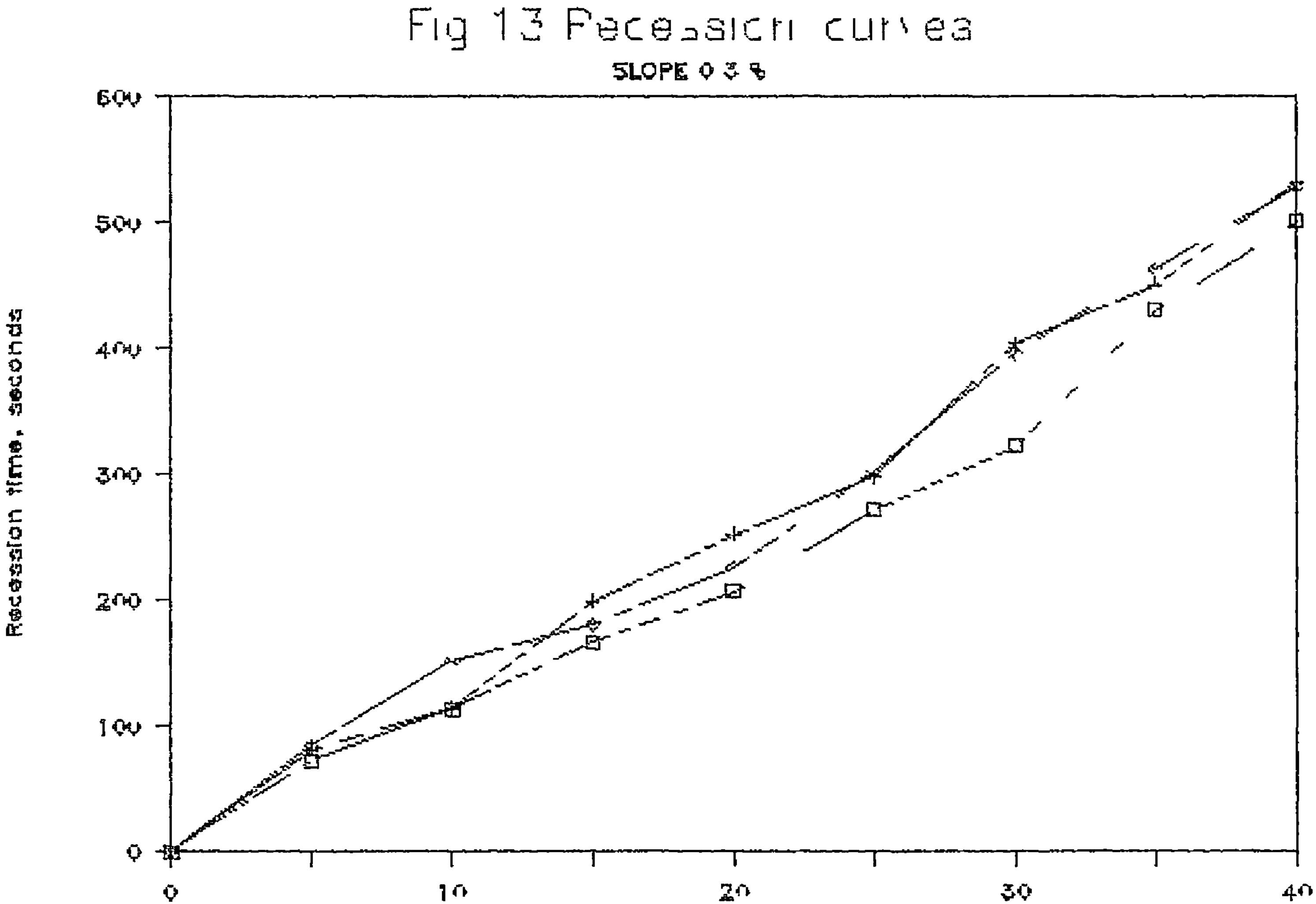
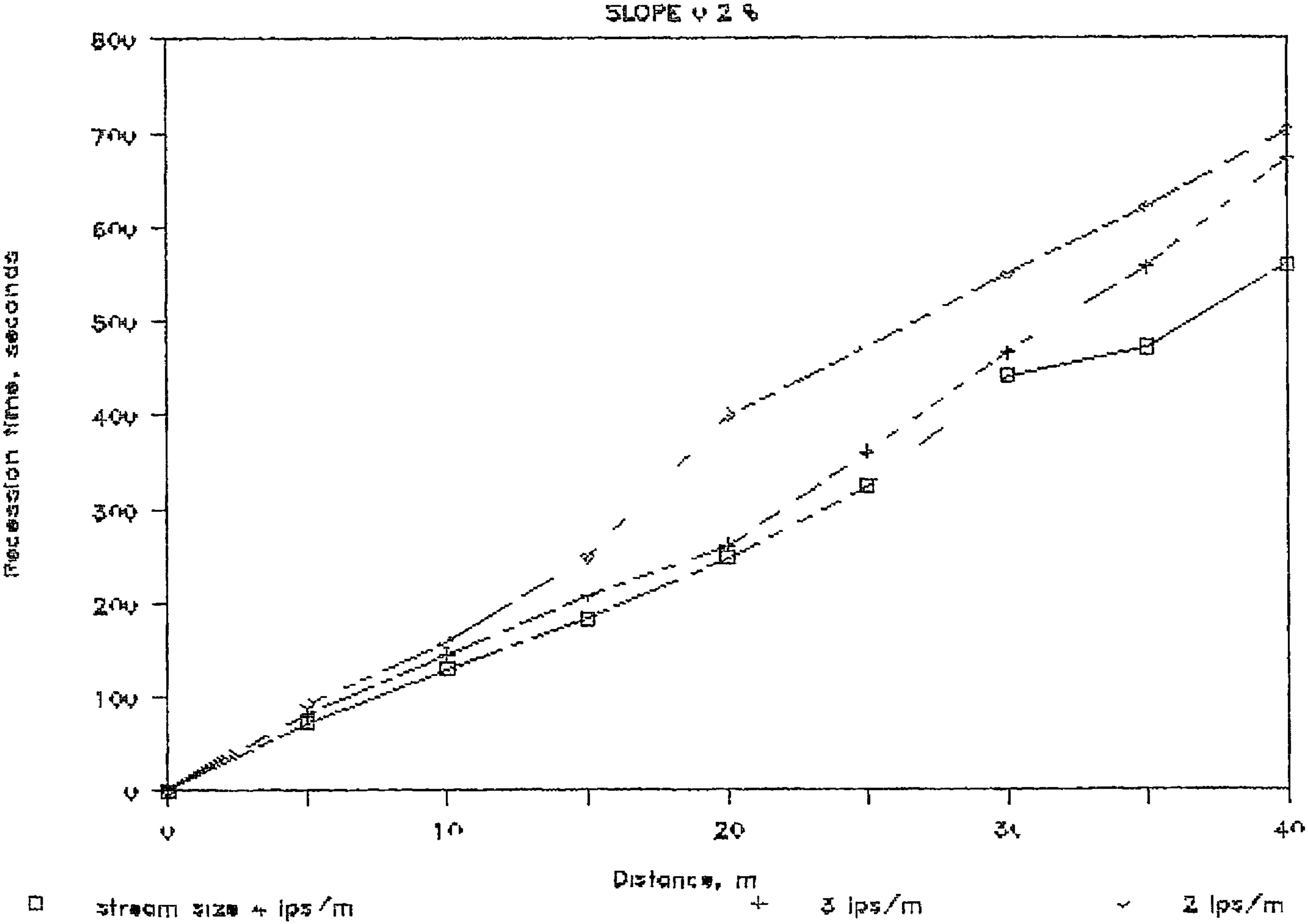


Fig 13 Recession curves
SLOPE 0.3 %
Recession time, seconds
0
100
200
300
400
500
600
0
10
20
30
40

Fig 14 Recession curves



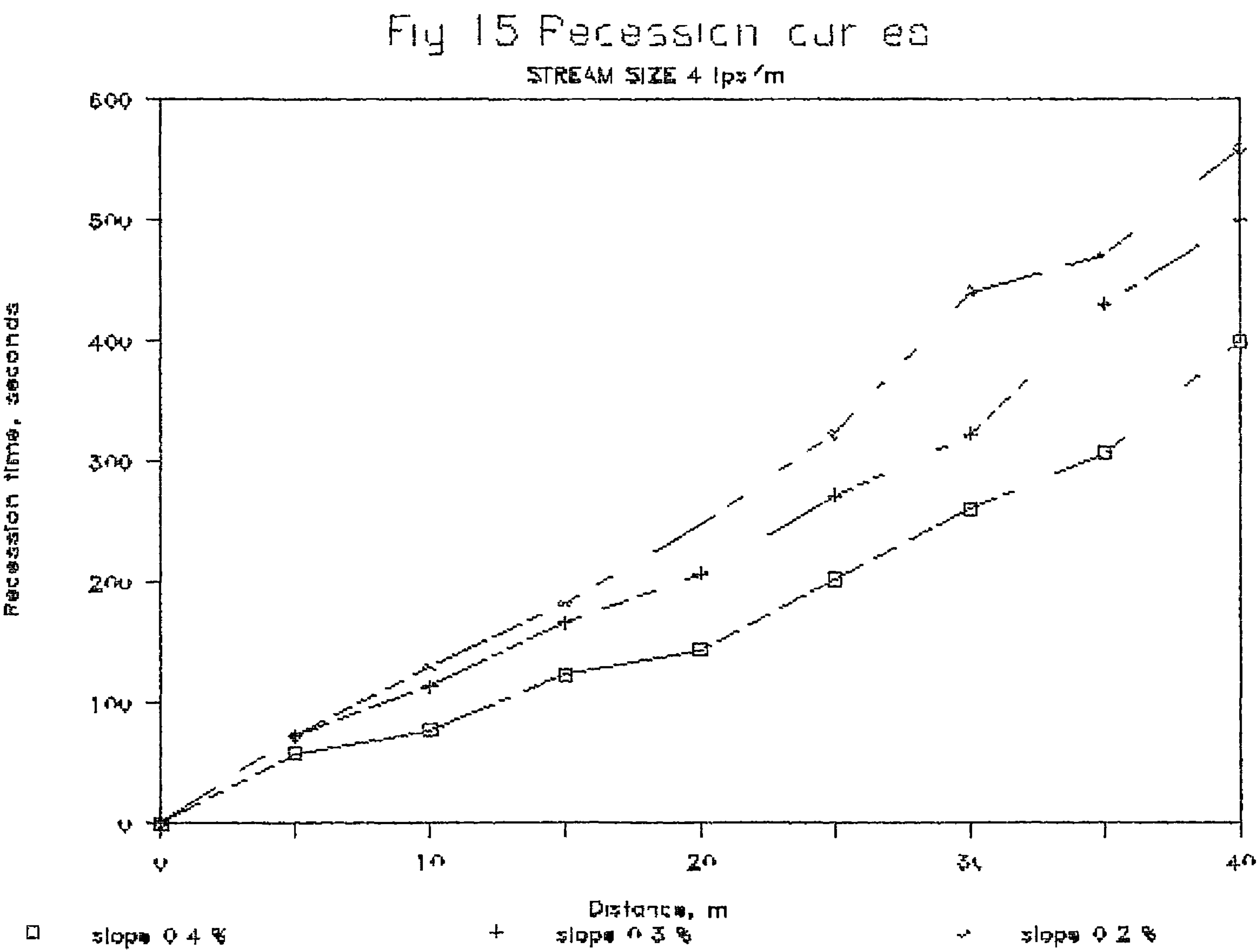
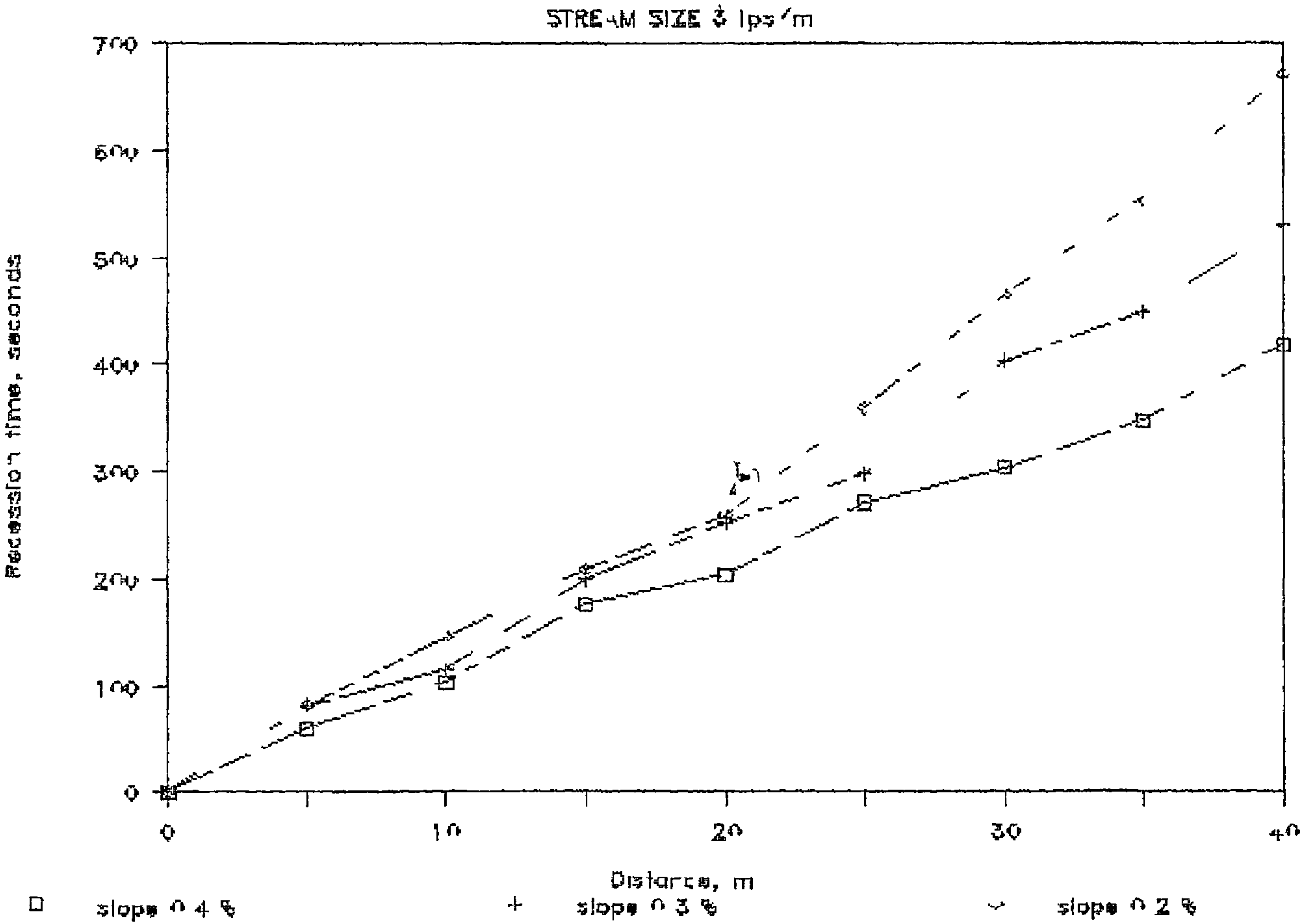


Fig 15 Recession curves
STREAM SIZE 4 lps/m
600
500
400
300
200
100
0
Recession time, seconds
0
10
20
30
40
Distance, m
slope 0.4 %
slope 0.3 %
slope 0.2 %

Fig 16 Recession curves



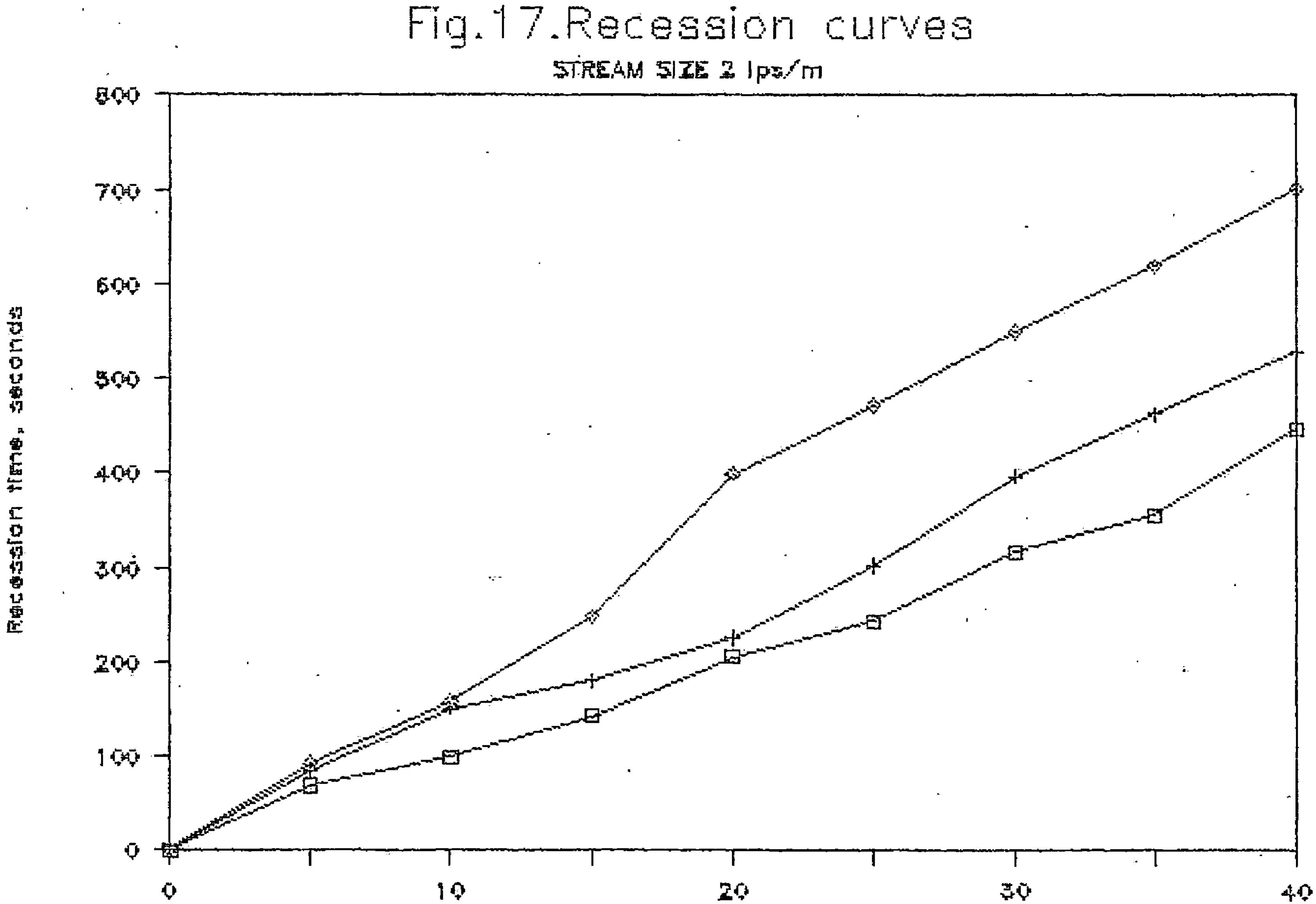


Fig.17.Recession curves
STREAM SIZE 2 lps/m
Recession time, seconds
800
700
600
500
400
300
200
100
0
0
10
20
30
40

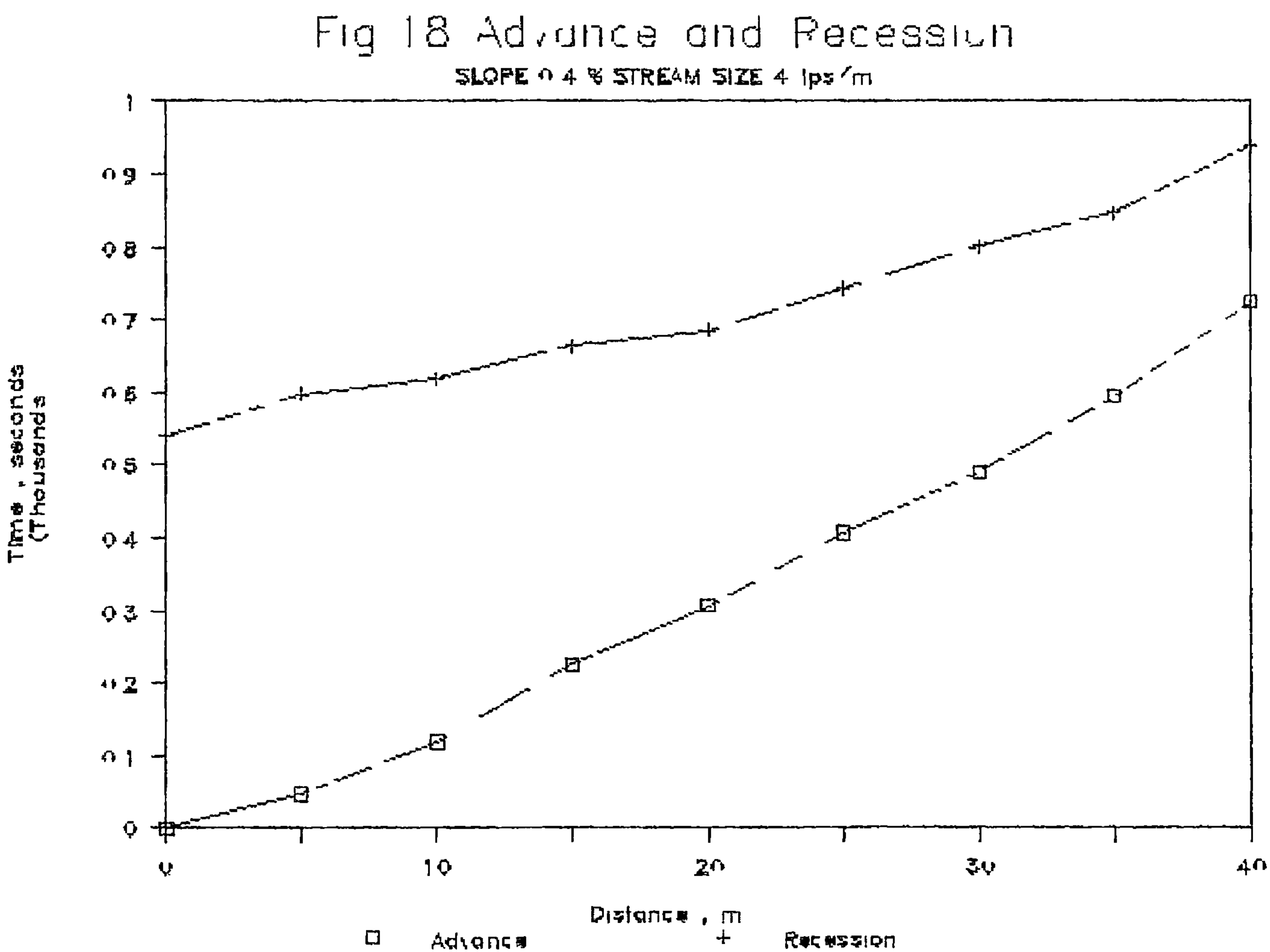


Fig 18 Advance and Recession
SLOPE 0 4 % STREAM SIZE 4 lps/m
Time , seconds
(Thousands
1
0 9
0 8
0 7
0 6
0 5
0 4
0 3
0 2
0 1
0
0
10
20
30
40
Distance , m
Advance
Recession

Fig 13 Advance and Recession

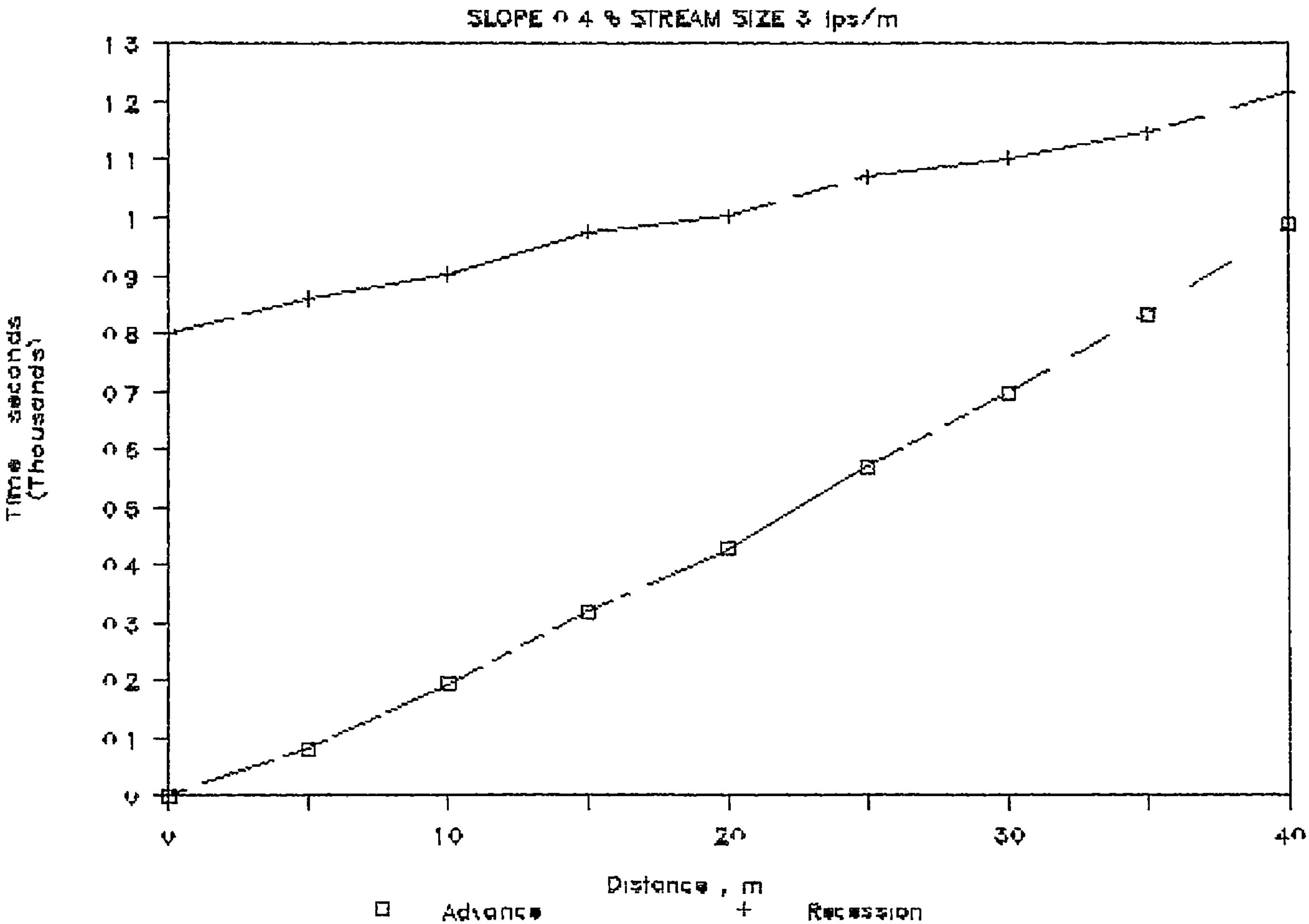


Fig 20 Advance and Recession

SLOPE 0.4 % STREAM SIZE 2 lps/m

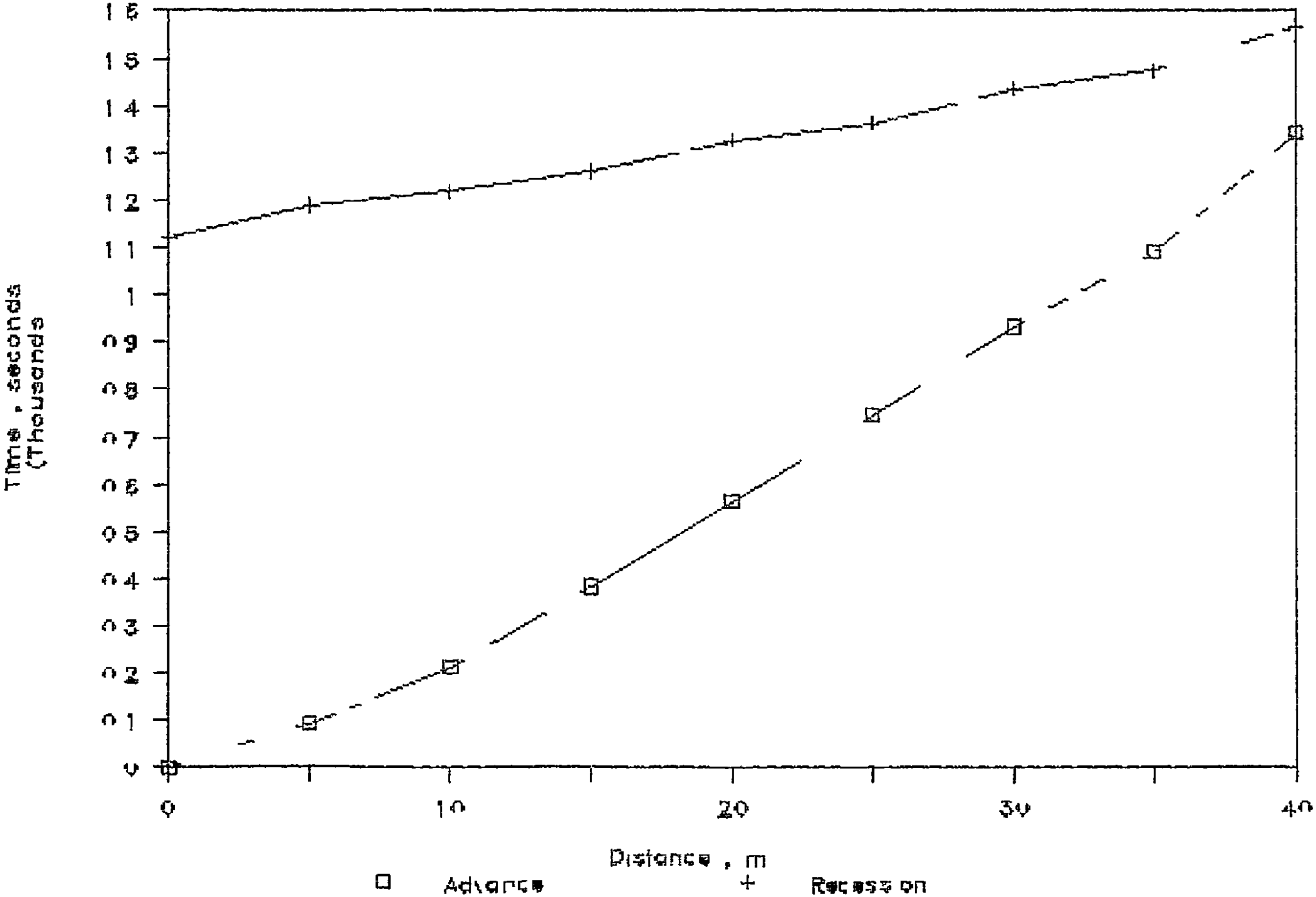


Fig 21 Advance and Recession

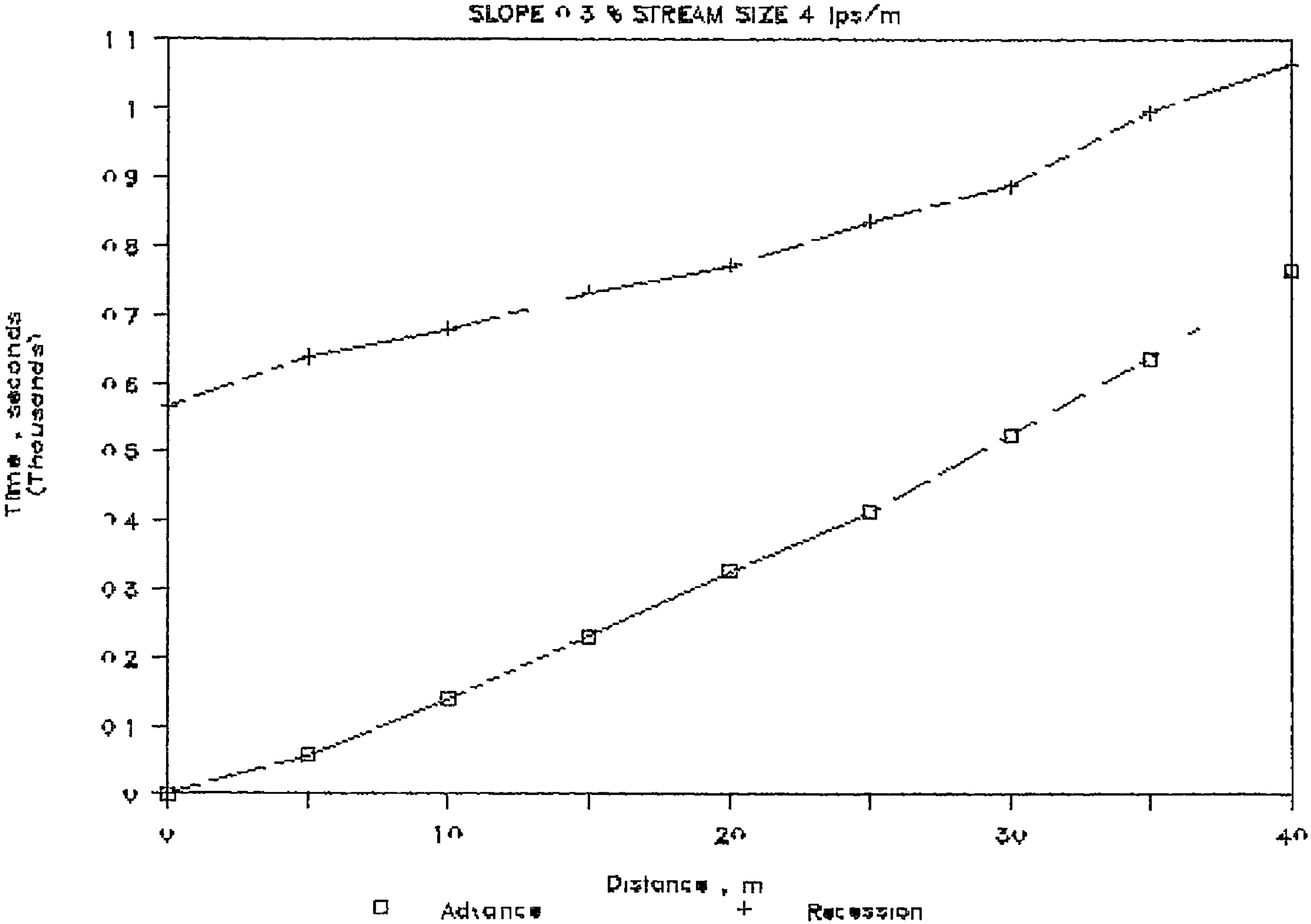


Fig 22 Advance and Recession

SLOPE 0.3 % STREAM SIZE 3 lps/m

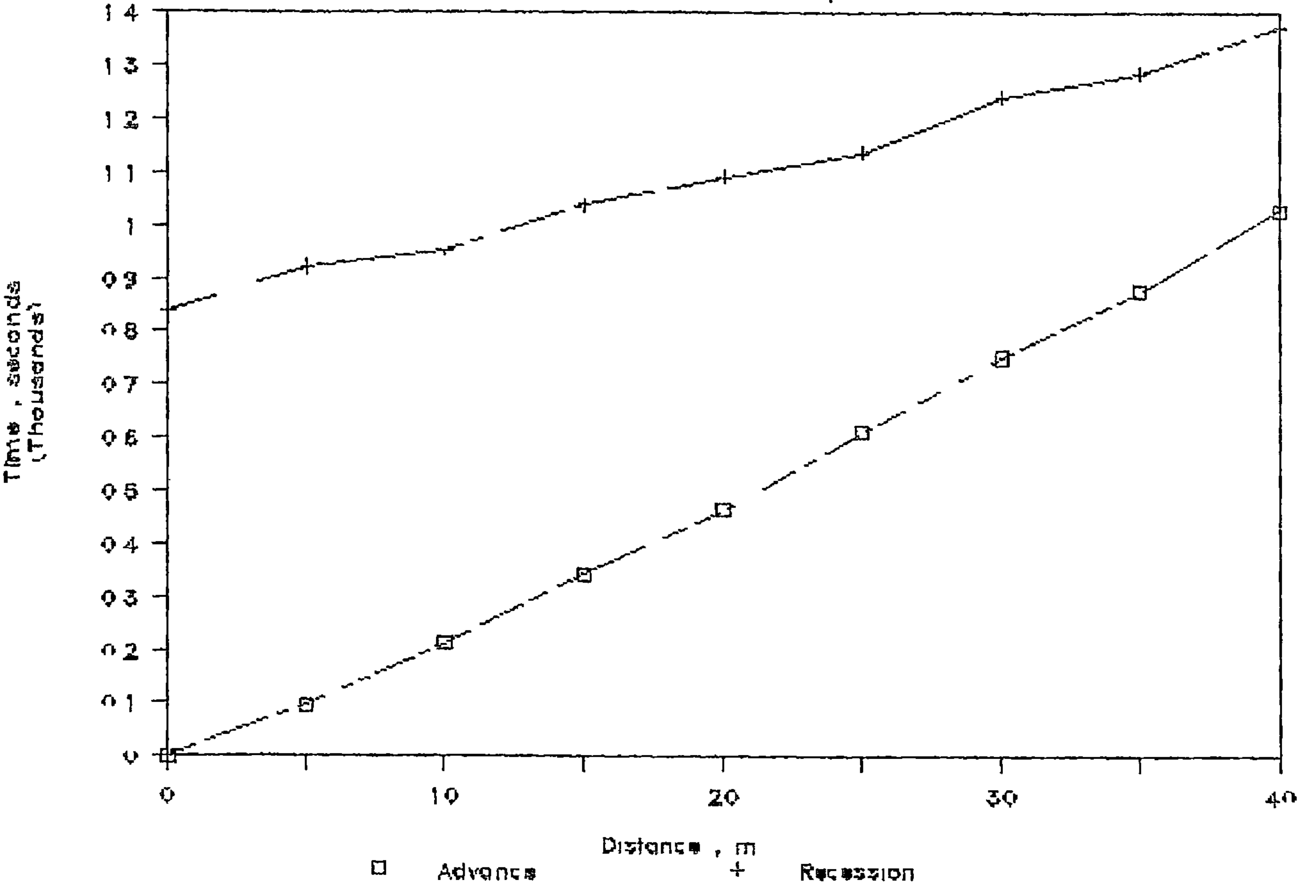


Fig 23 Advance and Recession

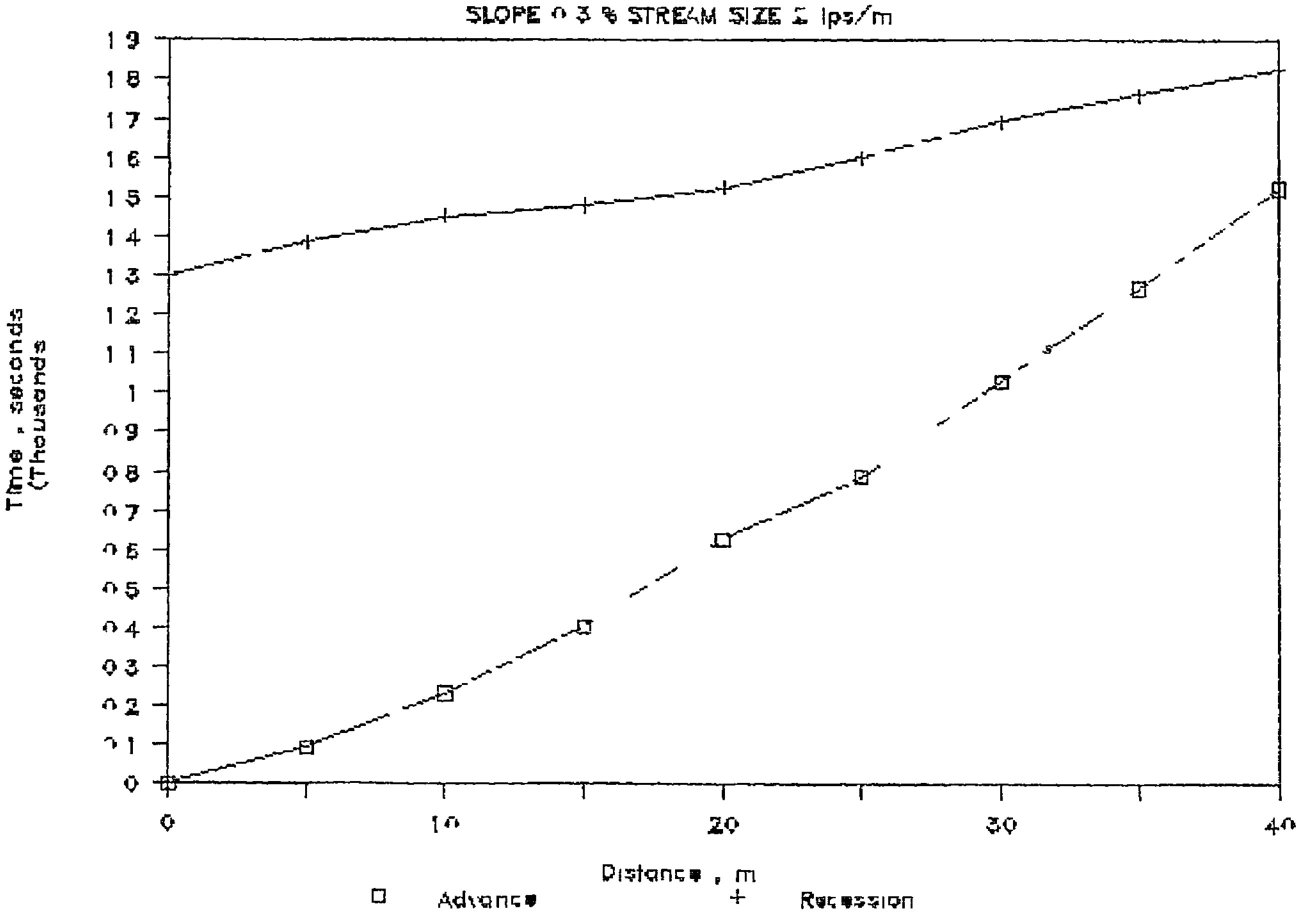


Fig 24 Advance and Recession

SLOPE 0 2 % STREAM SIZE 4 lps/m

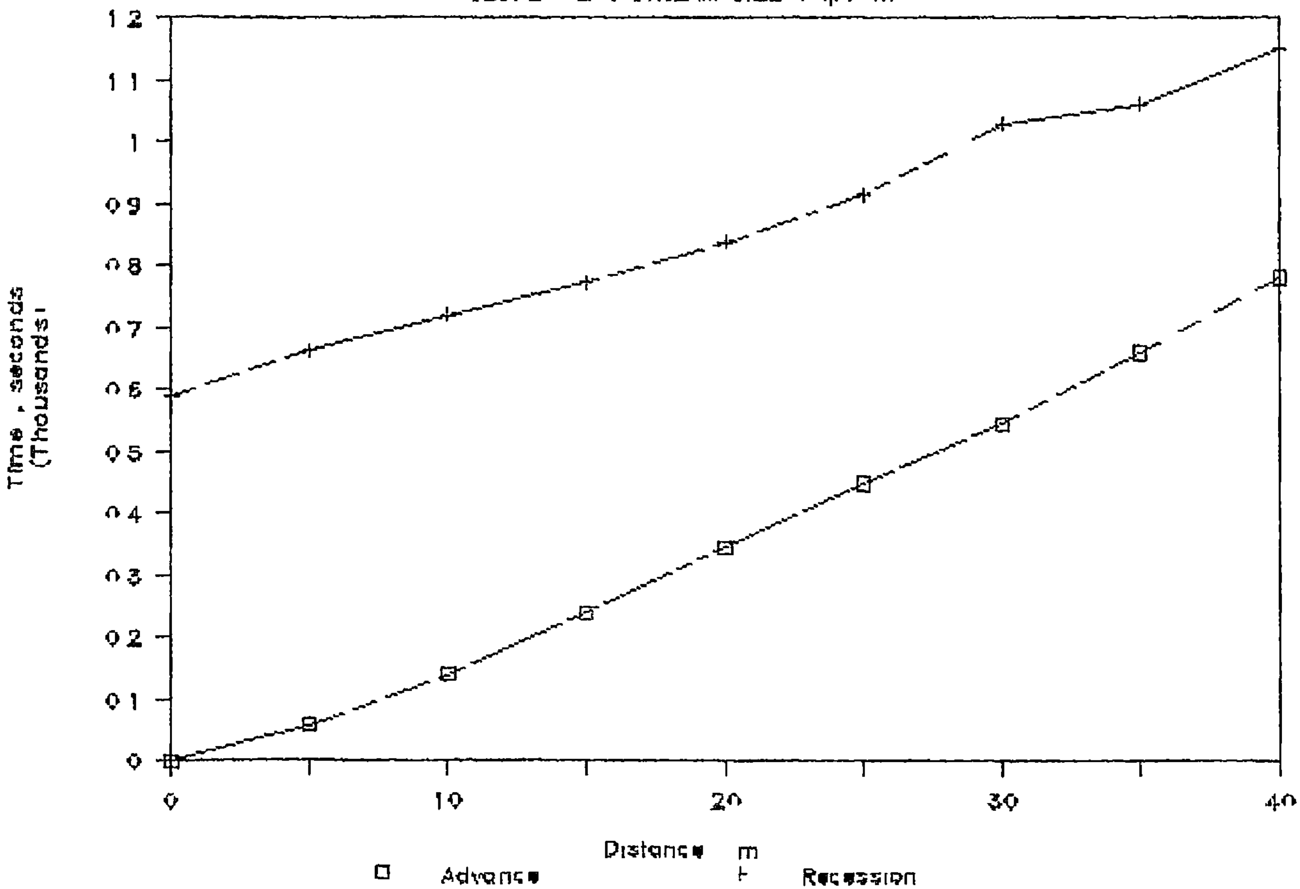
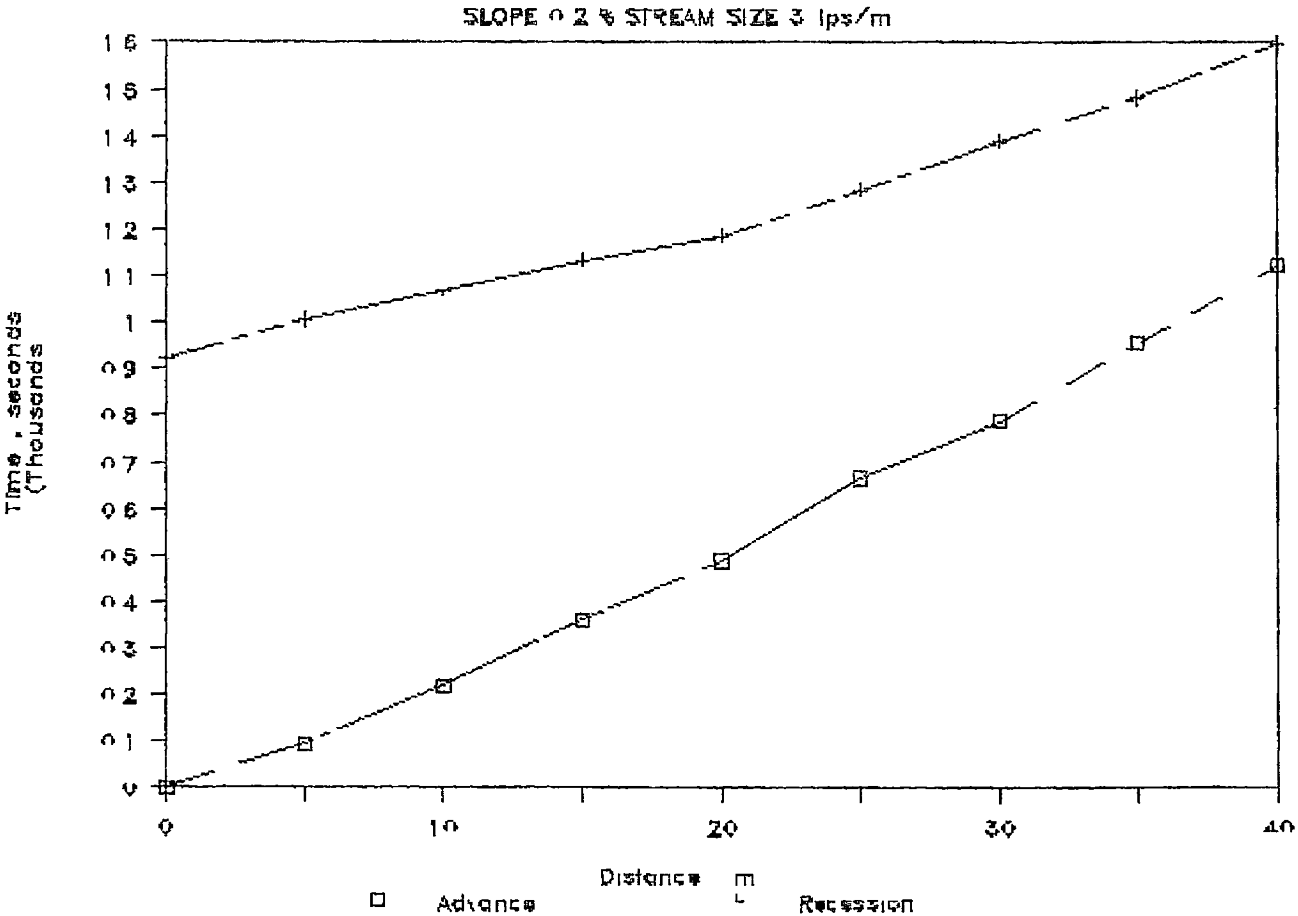


Fig 25 Advance and Recession



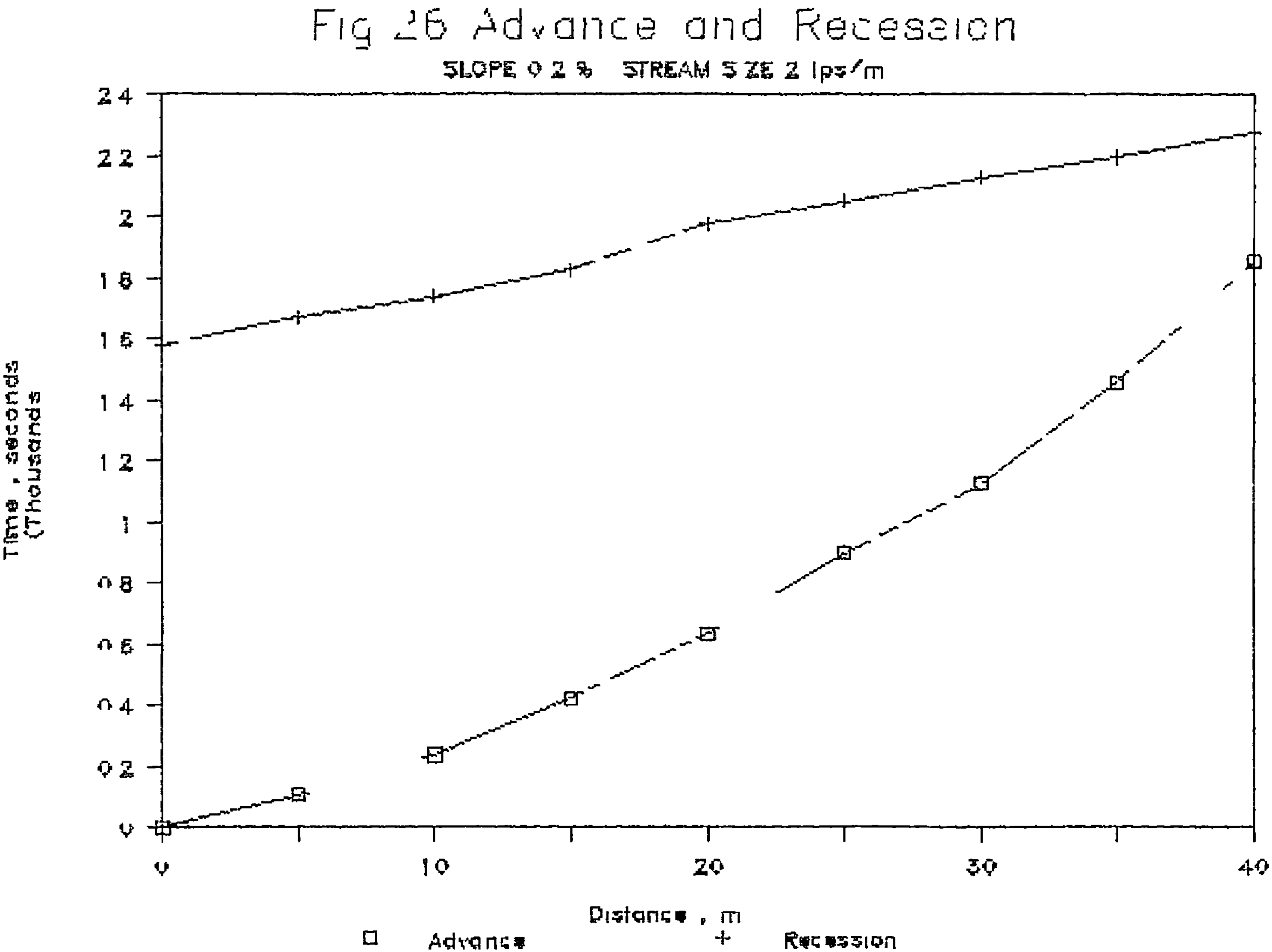


Fig 26 Advance and Recession
SLOPE 0 2 %   STREAM SIZE 2 lps/m
Time , seconds (Thousands)
2 4
2 2
2
1 8
1 6
1 4
1 2
1
0 8
0 6
0 4
0 2
0
10
20
30
40
Distance , m
Advance
Recession

4 7 Development of rational formula for advance flow

The results of the multiple linear regression analysis gave the following results

K 20 3865

a = 0 8969

b 0 20427

c 1 261808

The coefficient of determination was 0 98299 and the standard error of estimate was 0 11504 which assures a moderately good predictability with the equation

The developed rational formula for advance is

$$t_a = 20\ 3865\ Q^{-0\ 8969}\ S^{-0\ 20427}\ X^{1\ 261808}$$

where

t_a time of advance in seconds

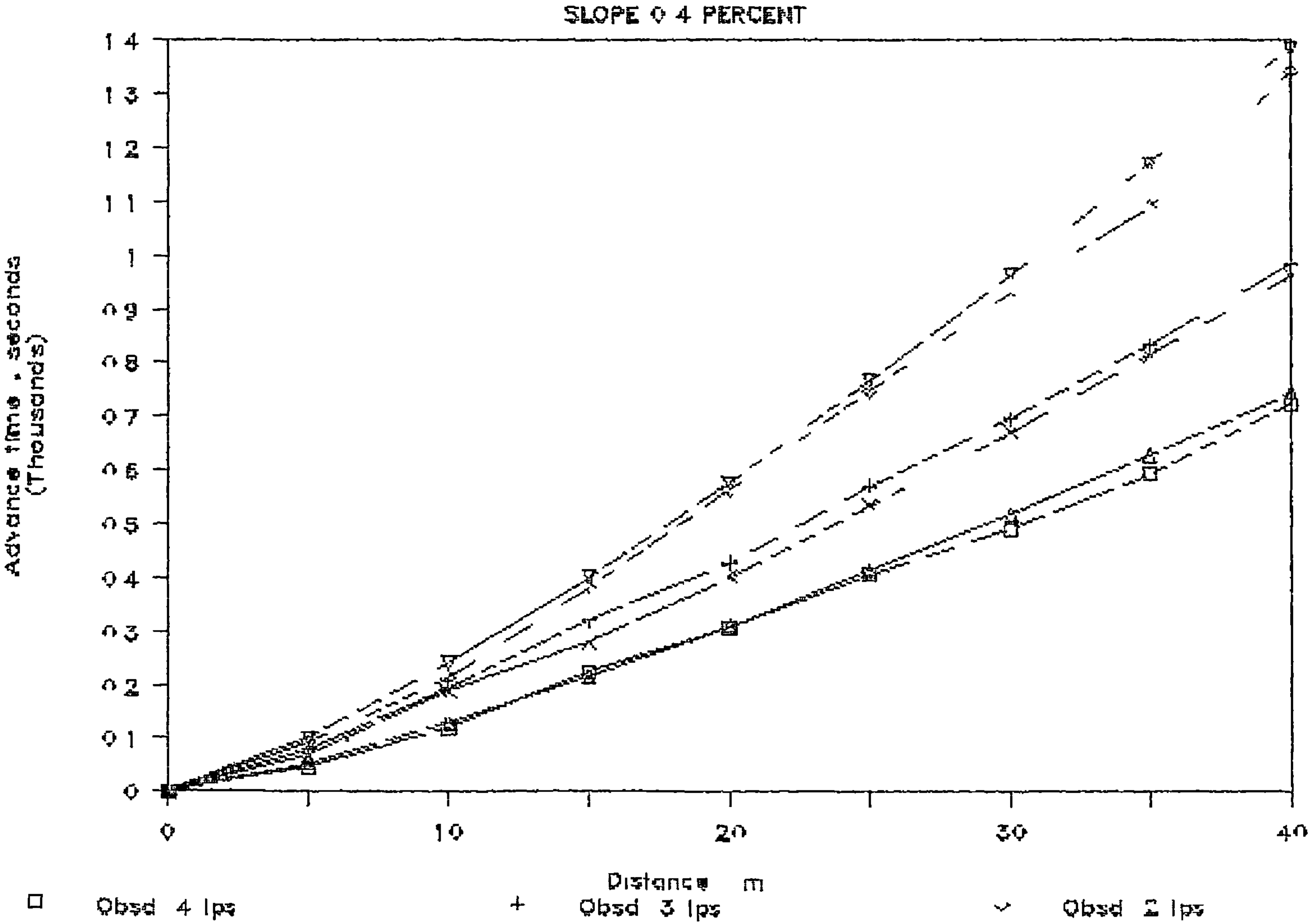
Q stream size in lps/m width of border strip

S slope in percentage and

X advance distance from upstream end in metres

The value of advance time predicted with the developed rational formula for each treatment is presented in Tables 7 to 15 Graphs were plotted for observed and predicted advance time and are presented in Figures 27 to 29 The curves show only small deviation which assures good predictability with the developed formula Even though accurate prediction of advance time with the developed rational formula may not be possible, the predicted values could be very useful in the design of border

Fig 27 Observed & predicted Advance



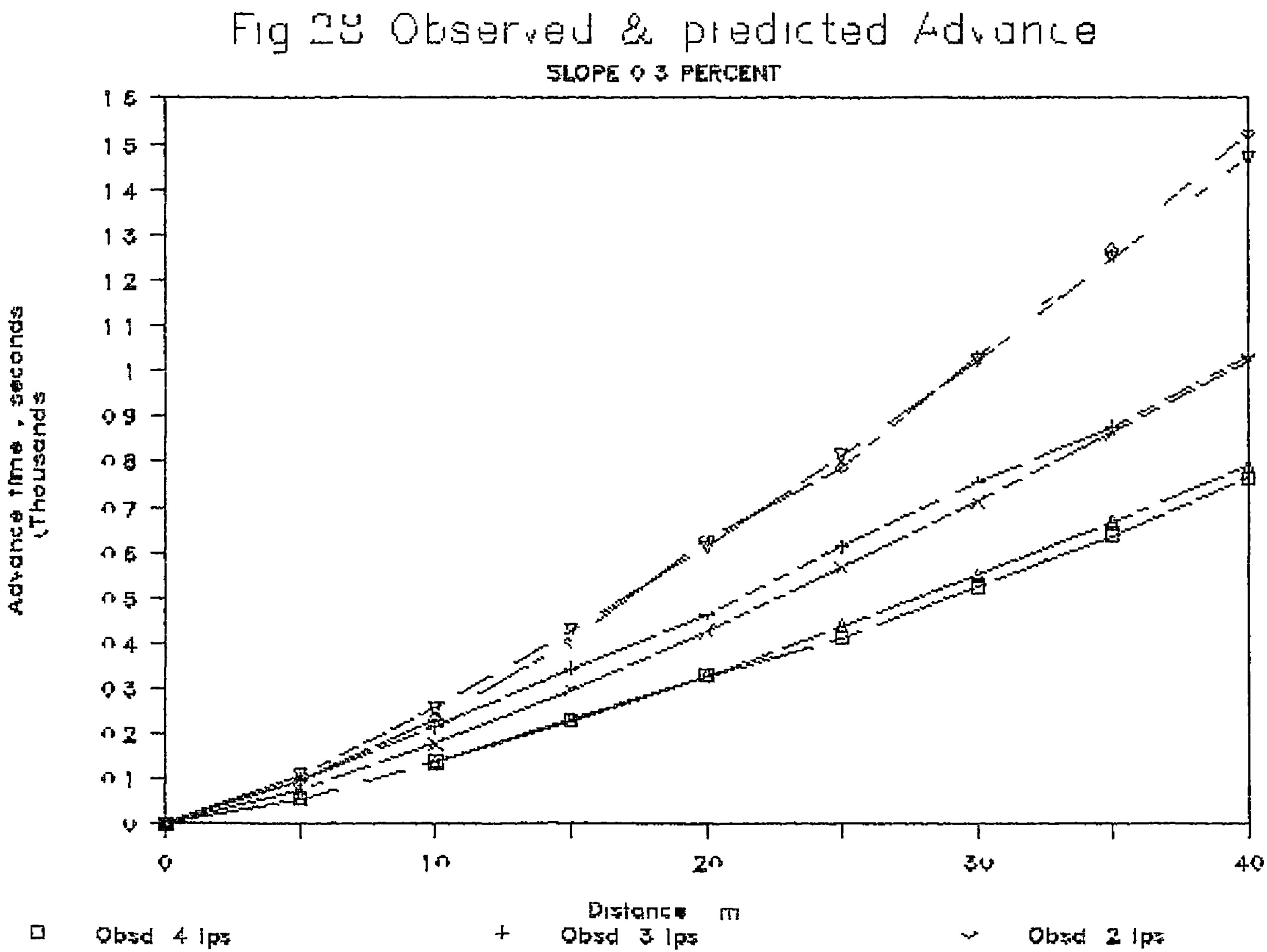


Fig 28 Observed & predicted Advance
SLOPE 0 3 PERCENT
Advance time , seconds
(Thousands)
Distance m
Obsd 4 lps
Obsd 3 lps
Obsd 2 lps
0
0 1
0 2
0 3
0 4
0 5
0 6
0 7
0 8
0 9
1
1 1
1 2
1 3
1 4
1 5
1 6
10
20
30
40

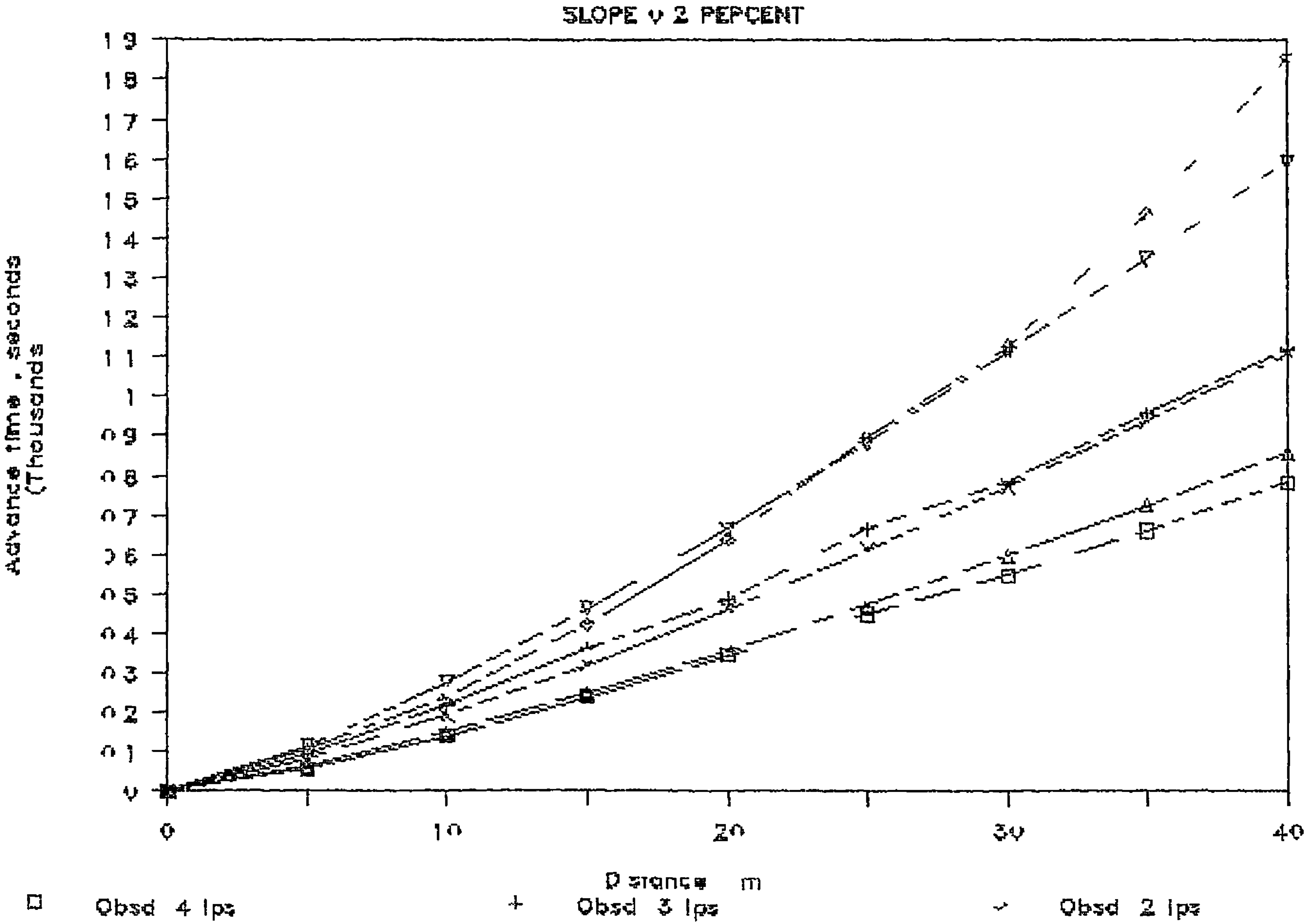


Fig 29 Observed & predicted Advance

irrigation systems under similar conditions of stream sizes, slopes, and length of strip

4 8 Development of rational formula for recession

Results of the multiple linear regression analysis done as discussed in section 3 6 5 are as follows

K' 9 1063

a' -0 2850

b' 0 6089

c' 0 9517

The coefficient of determination is 0 96989 and the standard error of estimate is 0 11588 which assures moderate predictability for the formula The rational formula developed is

$$t_r = 9\ 1063\ Q^{-0.2850}\ S^{-0\ 6089}\ X^{0.9517}$$

where

t_r recession time in seconds

Q - stream size in lps/m width of border strip

S slope in percentage and

X distance from the upstream end of the border in metres

Recession time predicted for the different treatments with the developed rational formula are presented in Tables 16 to 24 Due to the complexities in the recession flow, accurate prediction of recession may not be possible The predicted recession times are moderately consistent within the given ranges of stream sizes, slopes, and border strip length The

Fig 3u Observed & predicted Recession

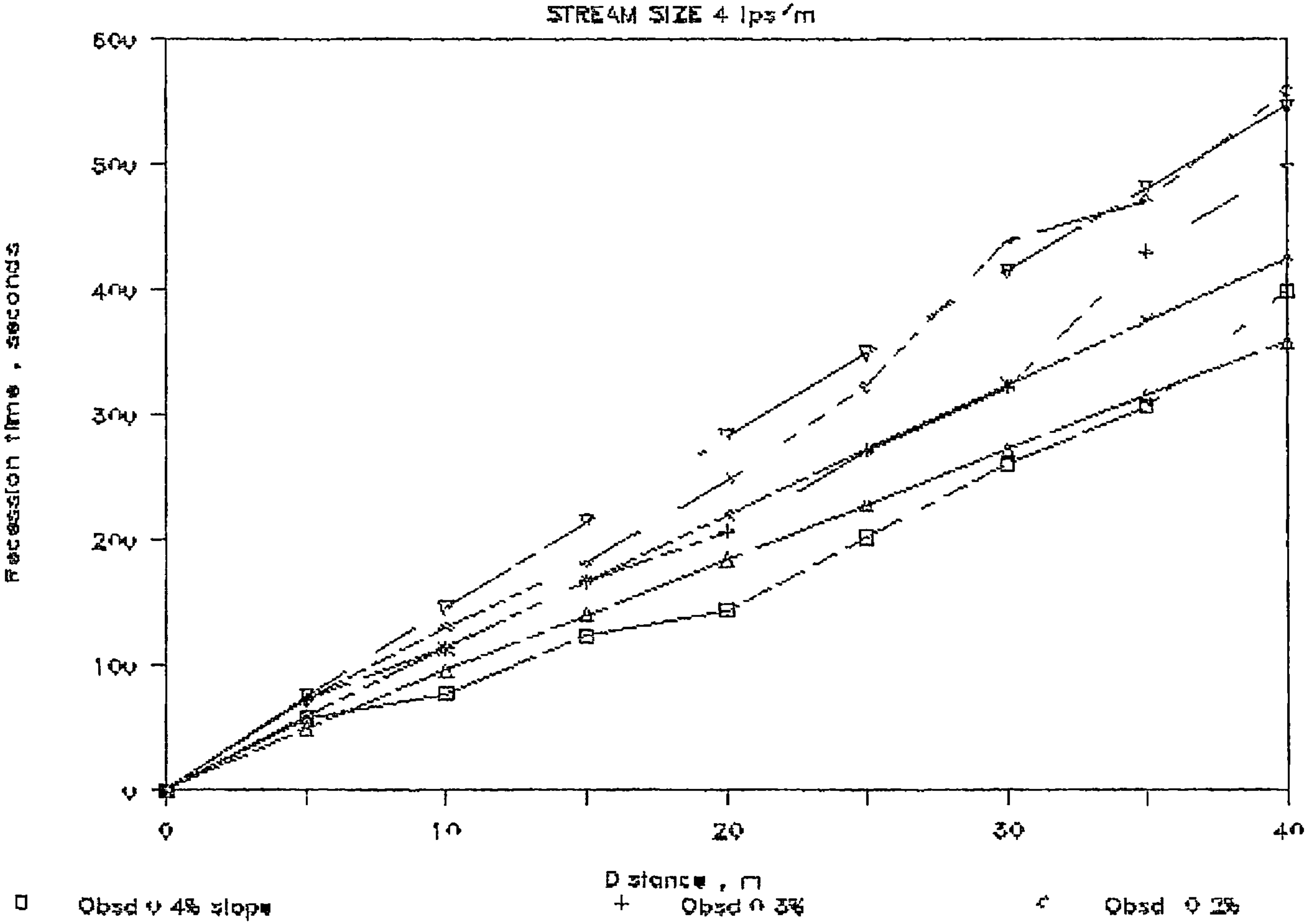
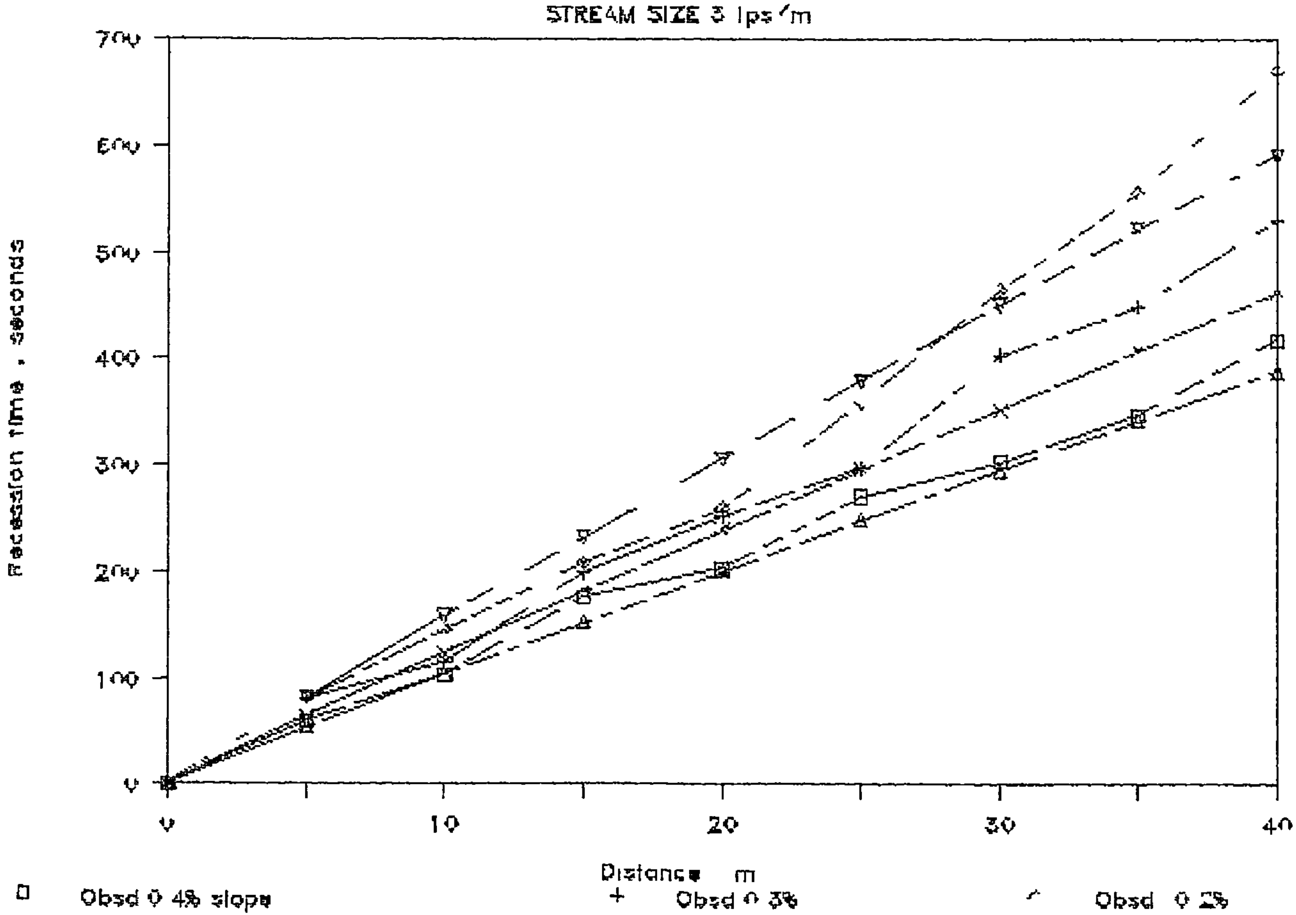


Fig 31 Observed & predicted Recession



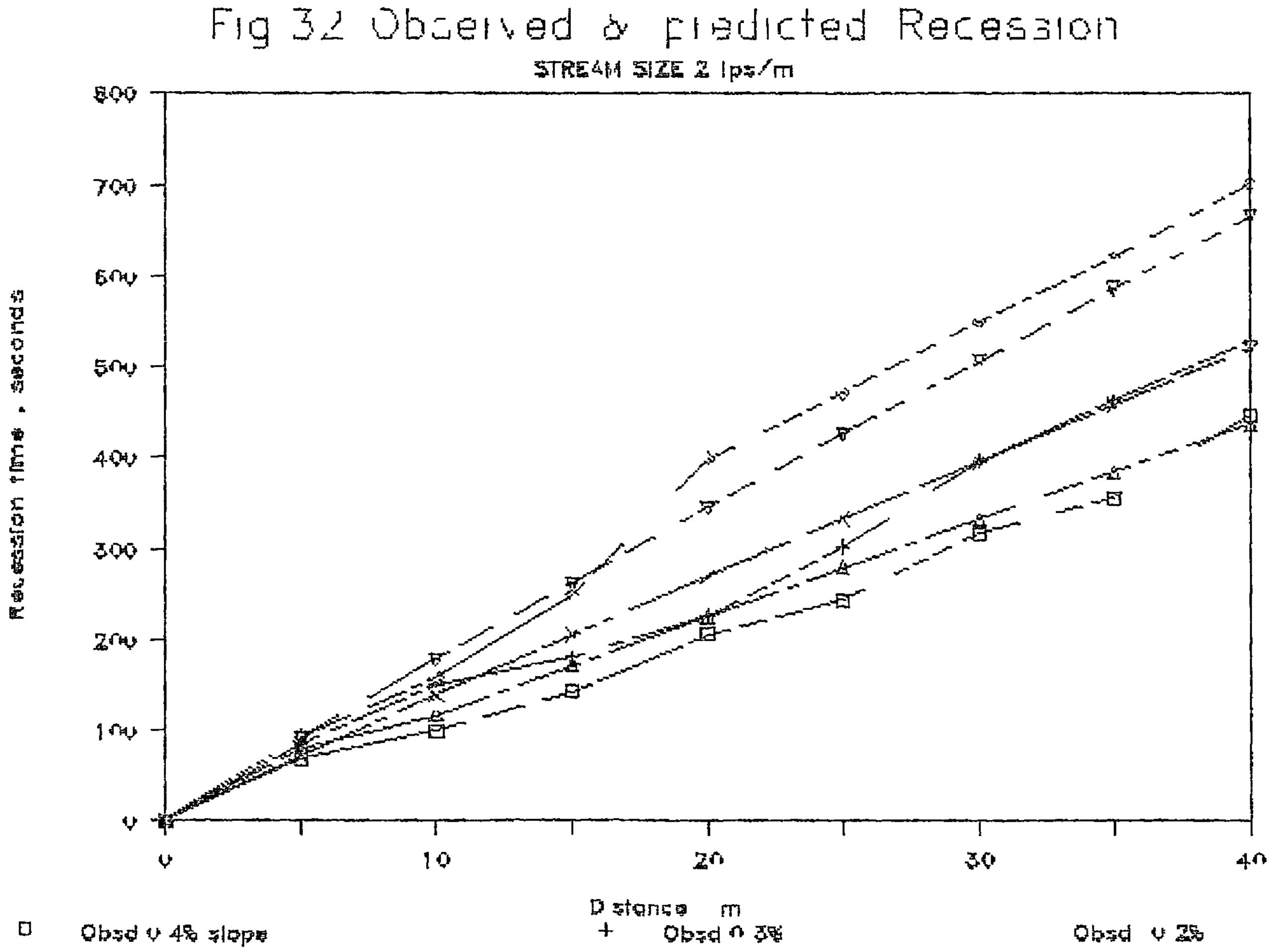


Fig 32 Observed & predicted Recession
STREAM SIZE 2 lps/m
800
700
600
500
400
300
200
100
0
Recession time, seconds
0
10
20
30
40
Distance m
Obsd 0 4% slope
Obsd 0 3%
Obsd 0 2%

plots of observed and predicted recession times which are presented in Figures 30 to 32, further confirms this

4 9 Limitations of the study

The rational formula developed may not give consistent predictive values beyond the ranges of stream sizes, slopes and strip lengths cosidered in the present study Accurate prediction beyond these ranges are above the scope of the present study and may be taken as a limitation of the study

Further the developed rational formula may not hold good in soils with characteristics other than that described in the present study The predictability with the formula may seriously be affected for crops other than cow pea Field conditions like presence of exessive weeds may also affect the accuracy of prediction with the formula

Summary

SUMMARY

Proper design of border irrigation system is essential for uniform distribution of water and high water application efficiencies and is based on advance and recession functions This investigation was undertaken to develop the predictive relationship for water front advance and recession in field borders with cow pea as the crop

The experiment was conducted in the Instructional farm KCAET Tavanur and the main features of the experimental procedure are as follows

1 Field and laboratory tests were conducted to determine the physical characteristics of the soil of the experimental site

2 Border strips of 2 m width and 40 m length were used for the study The strips were laid out on three different slopes 0 4 %, 0 3 % and 0 2 % Stream sizes of 4 lps/m width 3 lps/m width and 2 lps/m width were used to irrigate the border strips Thus 3 x 3 9 treatments were utilised for the study

3 The time of advance was noted for every 5 m distance from the upstream end of the border after diverting the measured inflow into the border

4 Horizontal recession time for every 5 m along the border strip length was also noted for all the cases as described above

5 Advance and recession times were tabulated and curves were plotted with distance from upstream end on X axis and time on Y axis

6 Advance and recession times were taken as functions of three independent variables viz stream size slope and distance from the upstream end Multiple linear regression technique was used for analysis of the data

The following results were obtained from the analysis of the data collected

1 With increase in stream size the advance time decreases for all the treatments

2 Increase in slope also had a negative effect on the advance time

3 Considerable differences in advance time were not observed between irrigations

4 It was observed from the advance curves that the impact of slope on advance time is less prominent than stream size within the ranges of slopes considered

5 Recession time observations revealed that increase in slope and stream size have negative effect on recession time

6 The effect of stream size on recession time was less prominent than slope within the ranges of slopes and stream sizes considered

7 Analysis of recession curves showed a negative non linear relationship of recession time with slope and stream size

8 The mean curves of advance and recession plotted together were analysed for uniformity of irrigation and the treatment combination of 0 2 percent slope and 4 lps/m stream size showed

best uniformity

9 The following rational formulae for advance and recession were evolved from the results of the multiple linear regression analysis

$$t_a \quad 20\ 3865\ Q^{0\ 8969}\ S^{0\ 2043}\ X^{1\ 2618}$$

and

$$t_r \quad 9\ 1063\ Q^{0\ 2850}\ S^{0\ 6089}\ X^{0\ 9517}$$

where,

t_a time of advance in seconds

t_r recession time in seconds

Q stream size in lps/m width of border

S slope in percentage

and

X distance from upstream end in metres

References

REFERENCES

Chauhan H S (1978) Philips solutions for rate of water advance in border J. soil and water conservation in India. Vol 28 No 1 4 pp 19 23

Christiansen J E Bishop A Keifer E and Fok, Y S (1966) Evaluation of the intake rate constants as related to advance of water in surface irrigation Transactions of the ASAE 9 (5) pp 671 674

Clemmens J Albert (1981) Evaluation of infiltration measurements for border irrigation Agricultural water management 3 (1980/1981) Elsevier scientific publishing company Amsterdam pp 251 257

*Criddle, W D Davis, S A Pair C H and Shockley D G (1956) Method of evaluating irrigation water Agri Hand Book 82 Soil Conservation Service USDA 24

Fangmeir D D and Strelkoff T (1979) Mathematical models and border irrigation design Transactions of the ASAE Vol 22 pp 93 99

*Gray D M and Ahmed M (1965) Rational approach to the design of border dyke systems Canadian Agricultural Engineering 7(1) 30 33 & 44

*Israelson O W (1932) Irrigation Principles and Practices John Wiley and Sons Inc New York

Israelson O W and Hansen V E (1962) Irrigation Principles and Practices John Wiley and Sons, Inc New York pp 288 294

Jobbling A Graham and Turner A Keith (1973) Physical model study of border strip irrigation J. Irrign and Drainage Div Vol 99 No IR 4, pp 493 509

Kumar Vinod and Tyagi, N K (1971) Advance and recession studies in border irrigation J soil and water conservation in India Vol 18 No 3 & 4 pp 62 67

Lal Radhey (1968) Water advance in irrigated borders and furrows The Harvester, January 1968 IIT, Kharagpur pp 46 49

Lewis M R and Milne M E (1938) Analysis of border irrigation Agricultural Engineering 19 (3) 267 272

Michael A M (1985) Irrigation Theory and Practice Vikas publishing house Pvt Ltd , New Delhi pp 585 685

*Parker P A M (1912) The control of water Van Nostrand and Co New York

*Petrasovits (1971) Investigations on surface irrigation methods in the Ephrates basin Report of the FAO/UNDP Regional Seminar on Effective Use of Irrigation Water at the Farm Level

Demascous, Syria

*Philip J R and Farrel D A (1964) General solution of the infiltration advance problem in irrigation hydraulics, Journal of Geophysical Research Vol 69 pp 621 631

Ram R S Singh V P and Prasad S N (1986) A quasi steady state integral model for border irrigation Irrigation Science (1986) 7 113-141

Sachan R C and Somalingam N K (1972) Effect of stage of crop on advance time in border irrigation The Harvester XIV IIT Kharagpur pp 42 44

Senapati S C Nayak S C and Sharma S D (1986) A mathematical model for selection of border length J. Agric Engng ISAE, XXIII (2) 157 162

Singh P and Chauhan H S (1973) Determination of water intake rate from rate of advance Transactions of the ASAE Vol 16 No 6 1081-1084

Singh R K and Mishra A P (1975) Recession of water in irrigation borders The Harvester 17 (1975) IIT Kharagpur pp 42 44

*USDA (1970) Irrigation guide for Southern and South Eastern Idaho United States Department of Agriculture

Verma, S C (1981) Predicting Recession in a Check Basin Irrigation System J Agrl Engng Research 26 pp 379 386

Visalakshi, (1983) Hydraulics of border strip irrigation on level or nearly level rice fields Un-published M Sc thesis College of Horticulture, KAU, Vellanikkara Trichur

Wilke, O and Smerdon, E T (1965) Solution of irrign advance problem ASCE. Proc. J. Irrgn. and Drainage Division 91 (IR 3) 23 24

Zimmerman, J D (1966) Irrigation John Wiley and Sons Inc New York pp 38-128

*Original not seen

Appendices

Date	Ra[illegible] mm	Evaporation mm
10 2 92	0	6
11 2 92	0	4
12 2 92	0	4
13 2 92	0	6
14 2 92	0	4
15 2 92	0	4
16 2 92	0	2
17 2 92	0	8
18 2 92	0	6
19 2 92	0	6
20 2 92	0	4
21 2 92	0	6
22 2 92	0	6
23 2 92	0	6
24 2 92	0	4
25 2 92	0	N A
26 2 92	0	8
27 2 92	0	6
28 2 92	0	6
29 2 92	0	6
01 3 92	0	6
02 3 92	0	6
03 3 92	0	4
04 3 92	0	N A
05 3 92	0	N A
06 3 92	0	4
07 3 92	0	6
08 3 92	0	N A
09 3 92	0	8
10 3 92	0	8
11 3 92	0	5
12 3 92	0	6
13 3 92	0	N A
14 3 92	0	N A
15 3 92	0	N A
16 3 92	0	10
17 3 92	0	8
18 3 92	0	6
19 3 92	0	4
20 3 92	0	4
21 3 92	0	4
22 3 92	0	N A
23 3 92	0	N A
24 3 92	0	N A
25 3 92	0	6
26 3 92	0	4
27 3 92	0	6
28 3 92	0	6
29 3 92	0	6
30 3 92	0	8
31 3 92	0	6
01 4 92	0	6
02 4 92	0	4
03 4 92	0	8
04 4 92	0	2
05 4 92	0	10
06 4 92	0	N A
07 4 92	0	6
08 4 92	0	4
09 4 92	0	6
10 4 92	0	N A
11 4 92	0	10
12 4 92	0	6
13 4 92	0	8
14 4 92	0	6
15 4 92	0	8

N A - Data not available

APPENDIX II

Bio-metrical observations of the crop

Treatment	*Plant height (cm)	*Pod length (cm)	*No of seeds/pod	100 seed weight (gm)	Yield/ plot (gm)
T1	44 5	12 5	11 2	10 2	1584
T2	39 0	15 1	9 8	9 5	1612
T3	40 2	13 2	10 3	8 6	1530
T4	42 3	14 3	13 4	8 8	1542
T5	38 4	16 0	12 2	9 2	1625
T6	39 6	13 8	10 8	9 6	1570
T7	42 6	14 5	11 7	10 1	1640
T8	41 5	15 2	12 1	9 4	1486
T9	46 0	13 5	11 5	8 8	1560

* Mean of 10 observations

APPENDIX III

Curve fitting for infiltration

From the plot of accumulated infiltration against time (Fig 4)

for t1 5 min y1 1 2 cm and

for t2 120 min y2 - 14 4 cm

The ratifying value

t3 t1 x t2 24 49 min

The corresponding value of y3 from Fig 4 is 4 0 cm The value of the constant b is obtained as follows

$$b \quad \frac{y1\ y2 \quad y3^{2}}{y1+y2\ 2y3} \qquad \frac{1\ 2x14\ 4 \quad (4\ 0)^{2}}{1\ 2 + 14\ 4 \quad 2x4}$$

1 28/7 6 - 0 17

The value of 0 17 Of b is subtracted from each value of y in Table 4 The logarith of (y-0 17) and t are taken The variables are related by the expression,

$$y \quad 0\ 17 \qquad at^{\alpha}$$

The logarithmic form of which is

$$\log\ (y - 0\ 17) \quad \log\ a + \alpha \log\ t$$

substituting the data

$0\ 0128 \qquad \log\ a + 0\ 6989\ \alpha$

$0\ 2855 \qquad \log\ a + 1\ 0000\ \alpha$

$0\ 4362 \qquad \log\ a + 1\ 1761\ \alpha$

0 6702 log a + 1 4771 α

0 8082 log a + 1 6532 α

0 9074 log a + 1 7782 α

1 0503 log a + 1 9542 α

1 1532 log a + 2 0792 α

solving

α 0 807 ~ 0 81

and

a 0 29 b 0 17 α 0 81

Goodness of fit

To determine the goodness of fit the values of y are calculated by substituting the values of a and b in the equation

$y \quad at^{\alpha} + b$

for each observed value of t

at t	5 min	y1	1 256 cm
t	10 min ,	y2	2 074 cm
t	15 min	y3	2 815 cm
t	30 min ,	y4	4 807 cm
t	45 min	y5	6 610 cm
t	60 min	y6	8 300 cm
t	90 min ,	y7	11 46 cm
t	120 min	y8	14 42 cm

The results are tabulated below

Observed y cm	t (min)	log (y-0 05)	log t	calculated y cm	Deviation %
1 2	5	0 0128	0 6989	1 26	+5
2 1	10	0 2855	1 0000	2 07	1 43
2 9	15	0 4362	1 1761	2 81	3 10
4 85	30	0 6702	1 4771	4 81	0 82
6 6	45	0 8082	1 6532	6 61	+0 15
8 25	60	0 9074	1 7782	8 30	+0 60
11 4	90	1 0503	1 9542	11 46	+0 53
14 4	120	1 1532	2 0792	14 42	+0 14
				Mean	1 465

APPENDIX IV

Observations of first two irrigations Advance

1 Slope 0 4 %

Stream size lps/m	Distance from upstream end m	Advance time sec Replication 1 Irrgn 1	Replication 1 Irrgn 2	Replication 2 Irrgn 1	Replication 2 Irrgn 2
	0	0	0	0	0
	5	42	27	38	32
	10	115	73	95	102
	15	206	154	196	190
4	20	356	261	284	278
	25	416	358	357	349
	30	498	477	437	465
	35	629	609	535	550
	40	1030	840	624	638
	0	0	0	0	0
	5	92	58	56	56
	10	225	126	150	146
	15	382	297	260	270
3	20	523	427	382	392
	25	620	522	484	496
	30	750	643	630	642
	35	840	781	720	766
	40	1080	942	900	918
	0	0	0	0	0
	5	102	67	108	*
	10	276	211	279	*
	15	480	413	461	168
2	20	648	575	656	340
	25	780	736	826	483
	30	960	905	1020	703
	35	1140	1093	1304	858
	40	1320	1611	1436	1060

* missing observation

2 Slope 0 3 %

Stream size, lps/m	Distance from upstream end, m	Advance time, sec			
		Replication 1		Replication 2	
		Irrgn 1	Irrgn 2	Irrgn 1	Irrgn 2
	0	0	0	0	0
	5	57	36	50	45
	10	76	86	120	101
	15	162	166	210	192
4	20	270	266	310	291
	25	364	410	405	402
	30	450	490	510	490
	35	579	626	645	611
	40	799	812	795	737
	0	0	0	0	0
	5	66	42	98	43
	10	180	115	260	108
	15	330	237	397	226
3	20	473	386	473	352
	25	630	567	640	521
	30	772	738	806	654
	35	920	884	*	797
	40	*	*	*	983
	0	0	0	0	0
	5	46	58	90	57
	10	220	163	245	154
	15	360	*	420	313
2	20	570	409	615	495
	25	760	645	845	720
	30	1008	890	1080	887
	35	1265	1160	1310	1154
	40	*	1440	1640	1442

3 Slope 0 2 %

Stream size, lps/m	Distance from upstream end, m	Advance time, sec			
		Replication 1		Replication 2	
		Irrgn 1	Irrgn 2	Irrgn 1	Irrgn 2
	0	0	0	0	0
	5	37	34	57	47
	10	100	79	167	164
	15	196	156	290	238
4	20	304	238	418	364
	25	415	348	644	559
	30	515	477	844	765
	35	630	581	990	912
	40	782	800	1165	1104
	0	0	0	0	0
	5	92	42	90	51
	10	222	108	229	138
	15	346	182	378	310
3	20	510	334	535	510
	25	760	498	732	756
	30	1014	690	1086	1050
	35	1214	855	1355	1230
	40	1482	1005	1563	1429
	0	0	0	0	0
	5	56	55	64	71
	10	210	196	270	253
	15	477	397	510	*
2	20	646	597	*	*
	25	985	1080	*	*
	30	1328	1278	*	*
	35	1632	1500	*	*
	40	*	*	*	*

APPENDIX V

Observations of first two irrigations - Recession

1 Slope 0 4 %

Stream size, lps/m	Distance from upstream end, m	Recession time , sec			
		Replication 1		Replication 2	
		Irrgn 1	Irrgn 2	Irrgn 1	Irrgn 2
	0	0	0	0	0
	5	40	52	34	61
	10	87	73	58	93
	15	134	99	102	121
4	20	164	129	142	173
	25	202	159	198	218
	30	278	210	256	271
	35	318	378	314	345
	40	479	496	385	416
	0	0	0	0	0
	5	76	101	52	81
	10	132	150	96	112
	15	231	192	176	200
3	20	259	267	218	251
	25	316	303	292	286
	30	349	339	324	371
	35	402	386	391	387
	40	476	411	493	425
	0	0	0	0	0
	5	75	86	92	68
	10	110	129	131	89
	15	162	142	171	114
2	20	241	258	201	238
	25	301	312	261	282
	30	371	336	356	320
	35	421	397	385	341
	40	475	454	413	387

APPENDIX VI

Computer programme used for multiple regression analysis

```
25 OPEN "DATA FILE NAME"  FOR INPUT AS #1
30 DIM X(9) , S (9) , T(9), A(9,10)
50 INPUT #1 , N
70 INPUT #1,V
80 X(1)   1
90 FOR I   1 TO N
110 FOR J   1 TO V
130 INPUT #1   X(J+1)
135 PRINT "VARIABLE"  J  " "  X(J+1)
140 X(J+1)   LOG(X (J+1))
150 NEXT J
170 INPUT #1   X(V+2)
175 PRINT "         DEP  VAR   " X(V+2)
180 X(V+2)   LOG (X(V+2))
190 FOR K   1 TO V+1
200 FOR L   1 TO V+2
210 A (K L)   A (K L) + X (K) * X(L)
220 S (K)   A (K  V+2)
230 NEXT L
240 NEXT K
250 S (V+2)   S (V+2) + X (V+2)   2
260 NEXT I
270 FOR I   2 TO V+1
280 T (I)   A (1 I)
290 NEXT I
300 FOR I   1 TO V+1
310 J  I
320 IF A (J  I) <> 0 THEN 370
330 J   J + 1
340 IF J <   V+1 THEN 320
350 PRINT  NO UNIQUE SOLUTION"
360 GOTO 860
370 FOR K 1 TO V+2
380 B   A (I K)
390 A (I K)   A (J K)
400 A (J K)   B
410 NEXT K
420 Z   1/ A (I  I)
430 FOR K   1 TO V+2
440 A (I K)   Z * A (I K)
450 NEXT K
460 FOR J  1 TO V+1
```

2 Slope 0 3 %

Stream size lps/m	Distance from upstream end m	Recession time sec — Replication 1, Irrgn 1	Replication 1, Irrgn 2	Replication 2, Irrgn 1	Replication 2, Irrgn 2
	0	0	0	0	0
	5	85	76	68	51
	10	112	103	125	98
	15	178	180	145	126
4	20	210	231	248	186
	25	310	276	285	231
	30	366	309	321	288
	35	438	426	392	351
	40	541	476	438	405
	0	0	0	0	0
	5	90	69	57	78
	10	120	98	85	102
	15	208	126	113	149
3	20	252	175	161	183
	25	308	220	218	231
	30	392	256	237	261
	35	441	322	*	363
	40	*	*	*	452
	0	0	0	0	0
	5	76	59	83	61
	10	131	167	142	121
	15	203	196	182	172
2	20	252	226	203	218
	25	350	301	296	321
	30	410	396	367	335
	35	478	431	412	403
	40	*	518	502	482

* missing observation

3 Slope 0 2 %

Stream size, lps/m	Distance from upstream end, m	Recession time, sec			
		Replication 1		Replication 2	
		Irrgn 1	Irrgn 2	Irrgn 1	Irrgn 2
	0	0	0	0	0
	5	78	89	92	61
	10	113	101	145	96
	15	201	162	188	151
4	20	248	223	219	203
	25	305	296	328	264
	30	376	348	396	338
	35	451	397	465	405
	40	518	472	538	465
	0	0	0	0	0
	5	48	66	87	93
	10	148	97	108	121
	15	261	231	212	230
3	20	298	281	275	264
	25	342	338	361	308
	30	427	441	405	396
	35	498	536	471	465
	40	573	585	548	514
	0	0	0	0	0
	5	90	62	82	77
	10	161	151	143	158
	15	258	231	201	222
2	20	401	375	292	*
	25	485	423	*	*
	30	538	492	*	*
	35	602	586	*	*
	40	682	*	*	*

* missing observation

```
470 IF J   I THEN 520
480 Z   -A (J I)
490 FOR K   1 TO V+2
500 A (J K)   A (J K) + Z * A (I,K)
510 NEXT K
520 NEXT J
530 NEXT I
540 PRINT
545 PRINT  EQUATION COEFFICIENTS
555 PRINT "    CONSTANT  , A  (1  V+2)
557 LPRINT      CONSTANT     A (1  V+2)
570 FOR I 2 TO V+1
575 PRINT "VARIABLE ("  I-1 ")    ",A (I  V+2)
577 LPRINT " VARIABLE (",I-1 ")     " A(I, V+2)
590 NEXT I
600 P   O
610 FOR I 2 TO V+1
620 P   P+A (I V+2)* (S(I)   T (I) * S (1)/N)
630 NEXT I
640 R S (V+2)   S( 1 ) ^ 2/N
650 Z   R P
660 L   N-V 1
670 PRINT
680 I   P/R
685 PRINT "COE  OF DETERMINATION(R^2)  " I
686 LPRINT "COEFFICIENT OF DETERMINATION    I
695 PRINT "COE  OF MULTIPLE CORRELATION  "  SQR (I)
705 PRINT "STD ERR OF ESTIMATE  "  SQR (ABS (Z/L))
707 LPRINT "   STD ERR OF ESTIMATE " SQR (ABS(Z/L))
725 PRINT
735 PRINT "INTERPOLATION  (PROGRAMME ENDS IF INPUT   0)
736 LPRINT "PREDICTED VALUES"
738  OPEN "PREDICT DATA FILE NAME" FOR INPUT AS #2
740  P  A (1  V+2)
750  FOR J 1 TO V
770  INPUT #2 X
775  PRINT  VAR " J  " "   X
780  X   LOG (X)
790  IF X   O THEN 860
800  P   P+A (J+1, V+2) * X
810  NEXT J
820  P   EXP (P)
825  PRINT "DEP  VAR     P
826 LPRINT "DEP  VAR    ,P
850  GOTO 740
855  CLOSE #1
858  CLOSE #2
860  END
```

DEVELOPMENT OF RATIONAL FORMULAE TO PREDICT THE ADVANCE AND RECESSION FLOW IN BORDER IRRIGATION METHOD

By

MARY REGINA F.

ABSTRACT OF A THESIS

Submitted in partial fulfilment of the requirement for the degree

Master of Technology in Agricultural Engineering

Faculty of Agricultural Engineering
Kerala Agricultural University

Department of Irrigation and Drainage Engineering
Kelappaji College of Agricultural Engineering and Technology
Tavanur 679 573
Malappuram

1992

ABSTRACT

This investigation was undertaken to develop the predictive relationship for water advance and recession in field borders with cow pea as the crop The experiment was conducted at the KCAET Tavanur during February-April 1992 Border strips of 2m width and 40m length were used for the study The strips were laid out on three different slopes, 0 4 % , 0 3 % , and 0 2 % Stream sizes of 4 lps 3 lps and 2 lps per metre widths were used to irrigate the strips There was nine treatments each replicated twice Advance and recession times were noted at every 5m distance from the upstream end of border Advance and recession curves were plotted to draw conclusions on the effect of the three parameters viz stream size, slope and distance on advance and recession times Uniformity of irrigation was also analysed for the different treatments and the treatment with 0 2 % slope and 4 lps/m width stream size showed the best uniformity Multiple linear regression was done considering stream size, slope and distance from upstream end as independent variables Advance and recession times were taken as dependent variables Rational formulae to predict the advance and recession times were developed from the results of the multiple regression analysis