DESIGN OF TRENCH DRAIN FOR STRATIFIED SOIL USING FEM

A Dissertation submitted in partial fulfillment of the requirements for the award of the Degree of

MASTER OF ENGINEERING

in

CIVIL ENGINEERING
(With Specialization in Hydraulics and Flood Control Engineering)

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CERTIFICATE

It is to declare that the work that is being presented in this project entitled "***DESIGN OF TRENCH DRAIN FOR STRATIFIED SOIL USING FEM***" in partial fulfillment of requirement for the award of the degree of Master of Engineering in Hydraulics and Flood Control Engineering submitted by ***Siva Kumar Kumarapu*** (01/HYD/04) to the Department of Civil Engineering, Delhi College of Engineering, is an authentic record of the student's own work carried out under the guidance of ***Shri Amit Kumar Srivastava and Shri S.Anbukumar***.

I do hereby state that I have not submitted the matter embodied in this direction for the award of any other degree.

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ABSTRACT

Large number of landslides occurs quite often during rainy seasons primarily owing to the development of substantial pore water pressure in a slope mass. Rainfall induced failures are the most common ones causing many landslides. There is a need for developing suitable methodology for examining the effectiveness of different stabilizing techniques to be adopted. By applying hydraulics and seepage analysis we can develop different measures for controlling the occurrences of most of the landslides. To prevent the occurrence of landslides, trench drains are widely used for draining out water from the soil and to reduce the pore water pressure to restore stability of the slope.

Current project explains hazard ness of landslides, importance of hydraulics and seepage analysis in providing design guidelines of trench drains by numerical and statistical data. In this aspect we obtained variation of seepage velocities of the trench for various values of depth in a stratified soil medium by using FEM.

In order to provide design guidelines for designing trench drains placed in a more common isotropic/anisotropic and stratified soil media, we need to investigate the performance of two dimensional steady state flow of water within a parallel rectangular trench drainage system and obtained pore water pressures by applying finite element method (FEM) and discussed the relationship between the piezometric head and various other factors separately and explained the variation of piezometric head between the drains along the drain and the discharge of water flowing within the drains. It helps to draw various diagrams taking account of depth, width and spacing of trench drains for determining the magnitude of piezometric head within the flow domain and the discharge of water flowing into the drains. Secondly in the hilly regions soil consists of strata’s. Trench drains are for shallow depths, so if we design them by considering top two layers are helpful to implement this concept in the field for stratified soils. Different combinations of layers are allotted for present analysis.

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Chapter 1

INTRODUCTION

1.1 Definition of landslide

It donates the downward and outward movement of slope forming material under the action of its own weight.

1.2 Why to talk about landslides?

Landslides are a serious geologic hazard common to almost every state in the United States. It is estimated that nationally they cause up to $2 billion in damages and from 25 to 50 deaths annually. Globally, landslides cause billions of dollars in damage and thousands of deaths and injuries each year. Individuals can take steps to reduce their personal risk. Know about the hazard potential where you live, take steps to reduce your risk, and practice preparedness plans.

1.3 Hazardness of Land slides

Landslides and related slope instability phenomena plague many parts of the world. A wealth of experience has been accumulated in recent years in understanding, recognition and treatment of landslide hazards but our knowledge is still fragmentary. Large number of landslides occurs quite often during rainy season primarily owing to the development of substantial pore water pressure in the slopes mass. Part of rain fall flows away as surface run off, while balance of water infiltrates into the subsurface which increases the ground water. This ground water is responsible for increase in the surface pore water pressure. It is well known phenomenon that stability of slope decreases as the magnitude of pore water pressure increases. As a remedial measure for stabilizing the existing ground strata, drainage measures are employed to drain the subsurface water. These drains relive the pore water pressure and therefore by, result in the increase of the factor of safety.

1.4 Suitability of Trench Drains

Subsurface remedial measures are usually provided in the form of either trench drains or horizontal perforated pipe drains. Trench drains are normally adopted in situations where the ground water is located at relatively shallow depths with in the slope. Pipe drains are adopted where ground water level is at considerable depths and beyond the reach of interception of trench drains. Although the drainage measures in the form of horizontal and trench drains have been provided in a number of cases so as to stabilize slopes, their design is often carried out on experimental considerations. The quantity of water to be discharged from soil masses is the primary basis of design of horizontal drains. Where as the average lowering of peziometric pressure either along the slip surface or at level along the bottom of drains, required to attain the changes in the factor of safety and is used as the basis for the designing trench drains. Here Darcy's law is considered for this analysis, which is describing the rate of flow of water through porous media. Due to the complex geometry of the slopes, non-homogeneous nature of soil/rock media and three dimensional and unsteady flow of ground water, the design of trench drains entirely from theoretical considerations become extreme difficult task.

1.5 Aim of the Project

The aim of this project is to

1. Detail about application of hydraulics and seepage analysis in controlling seepage induced land slides.
2. Explain importance of trench drain in controlling seepage induced land slides.
3. Design trench drain for realistic field conditions like isotropic, anisotropic and saturated soil media. For this numerical data have to obtain from Finite Element Methods (FEM).
4. Develop mathematical model which will give relationship between optimum discharge of trench drain, various parameters and properties of the soil. maximum quantity of discharge of water flowing into the trench drain. This will be of great use for implementing the trench drainage designing system to the realistic field conditions like isotropic, anisotropic and stratified soil media.

5. Made an attempt to remove some limitations in design guide lines of trench drains which were available in literature.

Chapter 2

LITERATURE REVIEW

2.1 History of Trench Drains

Mallawaratchie, D.P [1] states that the trench drains have been used as slope stabilization measure since the first half of the 19th century in France and England. The drain originally used is referred to as a counter fort drain. This is strictly defined as drain which penetrates into the solid ground beneath the potential sliding surface of the slope. Apart from reducing the pore water pressure this drain provides additional mechanical buttressing to the slope. Trench drains, which do not penetrate beneath the surface of sliding, were originally considered of little use. However, case histories have shown that if considerable high pore water pressure generates closure to the ground surface, the trench drain even with shallow depths prevent slope failure in many cases. Some simple techniques such as trench drains and horizontal drains have been successfully used to control a landslide at Pussellawa on Peradeniya-Badulla-Chenkallady road (PBC). Similar techniques along with a 500 m long diversion drain have been successfully used to control another landslide at Bergala on Beragala-Haliela road.

2.2 Definition of landslide

It donates the downward and outward movement of slope forming material under the action of its own weight. IS 14680: 1999 [2]

2.3 History of Landslides

Jayalanth Jayamanne [3] explained that some of the major Highways in Sri Lanka run through landslide prone areas in the hilly terrain. These Highways had been damaged at several locations due to occurrence of landslides in the recent past. The most challenging task of a highway engineer is to eliminate the risk due to these landslides and to provide safe, as well as, comfortable highways by employing appropriate stabilisation techniques well in advance to the occurrence of such failures. There are number of techniques utilised successfully to stabilise soil slopes such as (a) Construction of restraining structures (b) Removal of overburden (c) Drainage and (d) Relocation, etc. Most of the landslides in Sri Lanka have been triggered off during or just after a heavy rainfall. As such landslides of large magnitude and road side slope failures in soil and rock are often caused by the presence of surface and subsurface water. Therefore, it is important to study the ground water regime and adopt appropriate surface and subsurface drainage techniques. Drainage of surface and subsurface water from a landslide area would enhance stability of the soil and rock slopes.

Mallawaratchie, Rajapakse and Bandara [4] states that in 1976 this landslide at Pussellawa has originally got activated due to removal of toe support in the process of cutting a land below the road to construct a public play ground. As a result, the road length of about 40m has been subjected to subsidence and sliding downwards during period of heavy rains. The landslide at Pussellawa is located in between culvert Nos.37/10 and 38/2 on PBC road, Fig. l. In order to keep the road motorable, highway authorities had been compelled to till the subsided area with tunnel muck from time to time. This, however, adversely affected the factor safety of this slope. The construction pertaining to remedial measures were commenced in 1989 by the Road Construction and Development Company Ltd. under the supervision of staff of Provincial Director (Central Province), Road Development Authority (RDA) and completed in 1990.

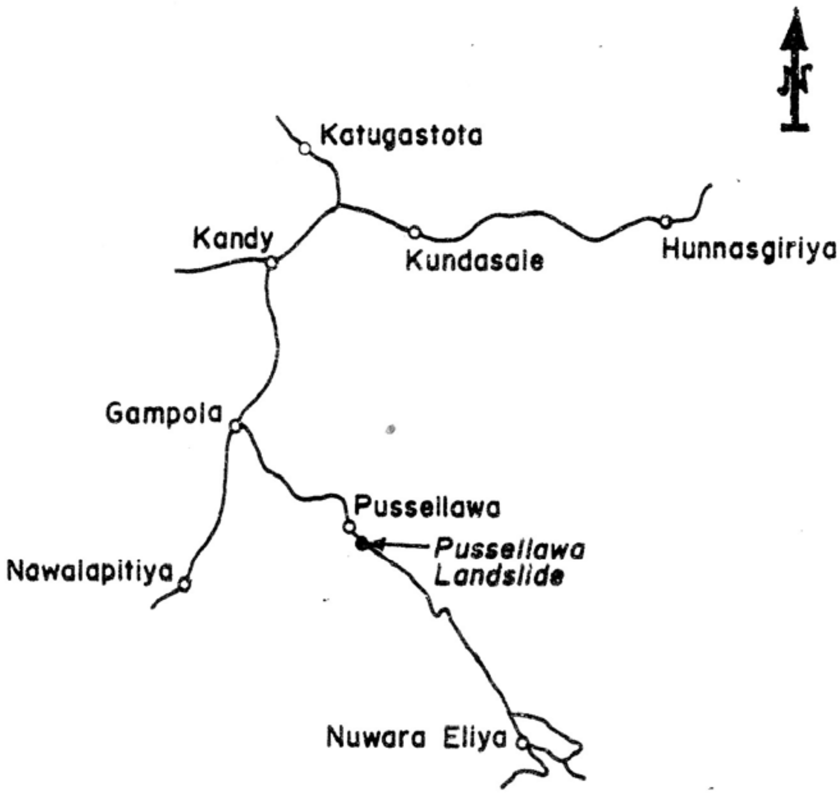


Fig. 1 : Location plan of the landslide area

In 1994 two wet patches were observed on both sides of the PBC road at this location, Fig. 2, Seepage of water has continued even during the dry season of the year. After the heavy rains in 1994, it was observed that the culvert No.38/1 located at the centre of the affected area has settled by few centimeters. Concrete pipe joints were cracked due to this settlement. To control these unfavorable conditions, the Research & Development (R&D) Division of' the RDA had taken immediate steps to carry out an investigation in order to ascertain the factor of safety of the road embankment.

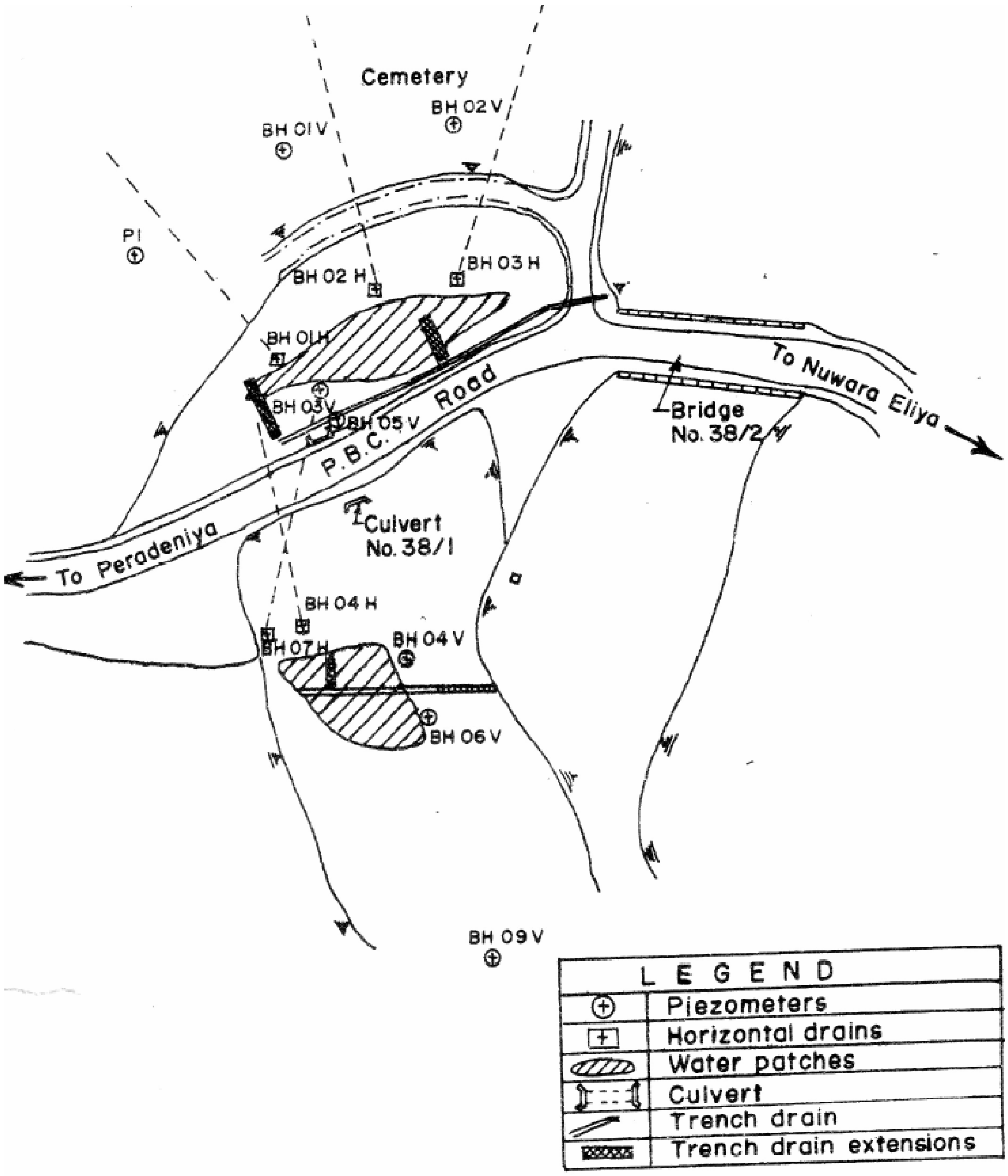


Fig.2: Remedial measures for Pussellawa landslide

The piezometer No.P1 installed at the upstream side of the road within the cemetery (Fig.2) indicated that the water table was about 1.8m below the ground level at that location. This appears to be a very high water table. Subsequently two vertical boreholes (BH O1 V and BH 0 2V) were driven in the cemetery area and piezometers were installed at different depths depending on the soil types and the standard penetration test values of different soil layers. In Borehole No.BH 01V, 3 Nos. of stand pipe piezometers were installed by the staff of R&D division and in Borehole No.BH 02V, 2 Nos. of Casagrande type piezometers were installed by the stiff of National Building Research Organization (NBRO). Subsequently it was planned to install two piezometers in borehole No.BH03V and No.BH05V to measure the ground water table on the upstream side and the downstream side respectively, of the trench drain constructed in 1990. During the drilling operation of borehole No.BH 03 V, it was found that there is an artesian pressure in the soil layer below the depth of 6.0m. This soil layer consisted of silty, sand with mica and traces of clay. From the drilling records it was found that the thickness of soil layer is 2.05m. As such, a piezometer was installed at the middle of the soil layer that is at a level of 7.2m below the ground level. After die installation o. this piezometer it was observed that the water level rose up to 1.02m above the ground level. After this valuable information, piezometer Nos.BH 04V, BH 05V, BH 06V and BH 09V were installed as shown in Fig.2. Laboratory testing was carried out on soil samples collected during this drilling operation at different elevations. These laboratory test results along with the available data from detailed investigations carried out in 1989, stability analyses were carried out in order to determine the factor of safety. In the slope stability analysis, considering the artesian pressure conditions were observed that the factor of safety calculated was 1.08. It reveals that to increase the factor of safety to a level of 1.30 the artesian pressure should be released and the ground water table should be lowered to a level 2 m below the ground surface. Then the control measures carried out at Pussellawa. Firstly based on the findings from the above investigation in order to enhance the stability of this area the following immediate control measures were carried out as per the proposal made by the R&D division of the RDA. (a). As an immediate step, sealing of cracked concrete pipe Joints of the culvert and construction of surface drains with half round concrete segments to prevent the water infiltration into the soil. (b). In order to increase the factor of safety by reducing the groundwater table the following - measures were carried out: (i). Construction of a trench drain with vertical drains within the area of wet patch below the PBC road. (ii). Construction of extensions of the trench drain constructed in 1990 with vertical drains. (iii). Construction of horizontal drains. The construction of remedial measures were carried out as explained by Mallawaratchie, D.P

[1]. Horizontal drain Nos. BH 01H, BH Q2H and BH 03H were constructed with a rising gradient of about 5° to the horizontal under the cemetery area. Due to the Geographical lin5itatikons at the site, horizontal drains Nos. BH 04H and BH 07H were constructed- with a falling gradient of about 5° to the horizontal under the PBC road. As these two falling horizontal drains were installed from the soil laver which was subjected to an artesian pressure, considerable amount of water flow was observed and there by artesian pressure was released successfully. After completion of the construction of these remedial measures, piezometer readings were taken regularly and it was found that the ground water tables always remained at safer levels, The water patches disappeared completely and the area became dry after the above control measures.

Yudhbir [5] has proposed that larger key issues related to landslide hazards and their mitigation are briefly reviewed. Importance of proper geotechnical investigation at design stage is emphasized and the need for education, research and development and training in disaster prevention, preparedness and mitigation is stressed. Methodology based on geology and engineering, is recommended and fundamentals or a sound approach for selection and design of landslide control measures, are discussed. Major control measures used for landslide hazard mitigation are reviewed and a critical discussion is presented on two important aspects: degrees of safety of existing old landslides and the appropriate degree of improvement to be provided by the control measures employed. Case histories of landslides in different engineering geologic- environments are used to illustrate various aspects. According to Yudhbir the term landslides describes many kinds of down slope movements of earth / rock comprising natural and / or man made slopes. Varieties of forms in which landslides manifest themselves vary from those:

- Undergoing rigid body movements with the slide material remaining intact: retrogressive failure in quick succession leading to total remoulding of slide mass into a mud flow and structural collapse of loose saturated granular deposits resulting in fluidization slides,

- Involving very small (10-100 m^3) to very large (10^9 m^3) volumes of displaced geologic materials,

- Moving at very slow (lm/sec) to very rapid (>=3m/sec. and as much as 50m/sec at the Vaijont slide in Italy) rates of movement and

- Where the sliding mass stops almost harmlessly near the toe of the slope (run-out distance 1-10m) to those where the debris may travel long distances (run-out distance > 10^3m) damaging houses, roads, bridges etc in its path.

In 1963, 240x lO^6m^3 of rockmass comprising the left abutment of Vaijont Dam in Italy slided into the reservoir at an estimated velocity of 20-50 m/sec, sending a 100m high wave over the crest of the dam into the valley downstream that destroyed five villages and killed more than 2000 people (Muller [6], 1964). In the United States annual landslide losses are believed to be between US $ 1-2 billion. Annual losses in Japan, Italy, India and few other countries are the same order of magnitude (Schuster and Felming [7], 1988). Clearly landslides are a costly hazard: they are widely spread and cause extensive damage to life and property. It is also commonly agreed that landslide can be controlled, losses can be reduced and landslide hazard mitigation programs are being carried out successfully in some countries. Probably, the most comprehensive and effective national program to mitigate landslide hazards, is that of Japan since world war Il, Hong Kong alter the 1972 disastrous slides and subsequent establishment of Geotechnical Control office (now called Civil Engineering Department), and that of the city of Los Angeles in California, USA where enactment of procedures of safe development of hill sides and enforcement of land grading code in 1963 has reduced the damages to sites developed after 1963 by a factor of ten compared to those developed before 1963 (NRC[8], 1987). For a detailed discussion on socio-economic significance of landslides, the reader is advised to refer two excellent publications: Schuster and Fleming [7] (1988) and Brabb and Flarrod [9] (1989).It is quite clear that landslide hazards have been and can be mitigated when it is realized that landsides are considered to be one of the most potentially predictable of geological hazards (Leighton [10], 1976).

Frontline [11] described Uttarkashi is in the grip of fear as the arunavat mountain on theedge of the town has cracked up and may collapse on it any time. The ancient religious centre of Uttarkashi in the hills of Uttaranchal faces a crisis of existence. The Varunavat Parvat (mountain) on the edge of the town began cracking up on September 24, 2003 and now threatens to bury the town. Three huge cracks, running from the top to the foothills, and many smaller cracks have caused massive landslides, displacing over 15 per cent of the population and burying under debris over 90 percent of prime commercial area. The Rishikesh-Gangotri highway running via Uttarkashi has been destroyed. Even more disconcerting is the fact that experts are clueless how to tackle the situation, which could turn catastrophic once it starts raining. There is a huge mass of debris deposited on the mountain slopes, caught between uprooted trees, which will be washed down, swamping the town. The administration continues to be in the dark about the potential danger, and people continue to live under a shroud of dust kicked up by the cracking mountain and the nagging fear that the mountain may crumble on them any day. Here people said the administration had evacuated as much of the area as it could and the police and paramilitary forces are on round-the-clock vigil, but in the absence of expert advice on the extent of the problem the administration is handicapped in taking preventive steps. Multidisciplinary expert teams have visited the city but so far no concrete suggestions have come. They would like to know how big a danger it is and how much of the town we should evacuate, besides how to handle the problem of the debris, which poses a bigger danger than the ongoing landslide. According to landslide experts from the Central Building Research Institute, IIT Roorkee, the Central Road Research Institute and the Geological Survey of India, the mountain had developed cracks during the earthquake in 1991, which had its epicenter near Uttarkashi. No one had noticed them then. One particular crack had been causing landslides for the last 10-12 years on the Tambakhai side of the town, but the problem did not get the attention it deserved because it was a forest area and the debris fell in the Bhagirathi river. Meanwhile, water kept getting accumulated in the cracks, loosening soil. A lightning strike around September

24, 2006 is said to have caused a huge crack, running the entire height of the mountain, triggering a landslide. Since then the number of cracks has increased and now it looks as though a big chunk of the mountain could come crumbling down any moment. Besides, the accumulated debris on the slopes poses a grave danger to the town. "About 40,000-50,000 cubic meters of debris is lying on the upslope. The area is completely unstable due to presence of several cracks, some of which are more than a meter deep. The debris has accumulated on the gentle slope because of the temporary support of uprooted trees and dense vegetation. To avoid further destruction of the city, the accumulated slide mass has to be removed," said a report prepared by a team from the Central Building Research Institute, which visited the site on September 30 and October 1.But the team, led by landslide expert Dr. S. Sarkar and including Dr. P.K.S. Chauhan and D.P. Kanungo, opined that "manual removal of the debris was not feasible considering the continuous flow of debris from the uphill slope, the volume of debris and the steepness of the downhill slope". It noted that even mechanical removal was not feasible because an "access road for the machinery will have to be built, which would involve cutting on the steep slope, which may aggravate the problem." The team finally decided that the best course would be to leave things as they are. "The situation was assessed carefully and the team was of the opinion that the accumulated debris should come down naturally, without any interference," the report said. Now the situation is grim and there is nothing that can be done, except wait for the "problem to abate". There have been no loss of lives because of the prompt evacuation of the area by the administration, but over 15 per cent of the population has been displaced and 90 per cent of the commercial activity in the town has come to a halt. The Rishikesh-Gangotri highway was the hub of commercial activity in the town. There were multi-storey hotels on the highway, including a three-star hotel, which have been destroyed. The bus stand and the taxi stand on the highway are buried under debris as are many houses and shops. The colonies that have been evacuated include the Collectorate Colony (of government officials) and those in the prime residential area on Bhatwari Road. Areas that have been wiped out or face the risk of destruction include Ramlila Ground, Masjid Mohalla and Horticulture Colony. As a precautionary measure, several areas, including those that house the treasury office, the State Bank of India office and the Cooperative Bank, have been evacuated. LIFE has been one big slide to suffering for the displaced people. Families living in relief tents have had to go without food for days. The administration has made arrangements for relief, still relief has not always reached the needy. As many as 46 families, comprising 155 people, had been without sufficient food since they took shelter in the Puri Khet relief tents on September 24, 2003. They were making do with whatever they could manage to get from the residents of the area, until an NGO working for the welfare of animals came to their aid. The Jai Ma Lok Vikas Pashu Sewa Samiti is feeding these hapless people even as Pant claims that "we are erring on the side of being too liberal". The administration has announced Rs.1,000 as compensation per family for the displaced, but it is given only to those who possess valid identity cards. The cards are not easy to get and many families have been denied even this meager amount. The fact that most of those living in the relief camps are daily-wage earners has compounded the problem because they have nothing to fall back upon. Without a livelihood what will happen to them once the government and other agencies stop relief work. Twenty families, with 100 people, at a camp at the Goswami Ganesh Dutt Vidyalaya, found themselves without food one day after the State Bank of India, which had adopted the camp, abandoned the relief work. The problem, however, is that people living in camps that are far away from this centre find it difficult to come all the way for food. Even the camps may not be safe once the rain comes and brings with it the debris.

In recent days Philippine disaster is an example. A landslide triggered by two weeks of heavy rain crashed through a village in the central Philippines on February 17, 2006Friday. Near about 1,800 people including 206 school children are lost there lives (Washington Post Foreign Service [12]).

2.4 Different approaches towards Trench Drains

Until recently, the design of trench drains carried out on a semi-empirical basis. The variation of peziometric pressure within the flow domain considering the effect of drains is usually predicted by flow nets. The trench drains are then positioned sop as to achieve the desired stability factor of slope. Bromhead [13], Hutchinson [14] and Dr. Pramada Valli [26] provide an analytical solution to the problem so as to predict the drains.

2.4.1 Bromhead approach

The design and effectiveness of different drains usually depend on:

- The amount of infiltrating ground water,
- Inflow of ground water form upslope,
- Soil characteristics and
- Excavation and construction aspect of drains.

2.4.2 Hutchinson approach

Hutchinson recommended the following guidelines for designing trench drains:

- Choose suitable values of depth and width of drains.
- From stability calculations determine the desired lowering of pieziometric head at the drains invert level assuming horizontal time invariant pounding surface.
- Select the depth, width and spacing of drains in such a way that the desired increase in the stability factor is achieved.

2.4.3 Dr. Pramada Valli approach

Pramada Valli (Scientist, Geotechnical Engineering Division, Central Road Research Institute-Delhi) recommended the following guidelines for designing trench drains:

- Depth of trench drain is not required up to impermeable layer.
- Different combinations made for optimum discharge.
- Comparison of analysis with Hutchinson results.

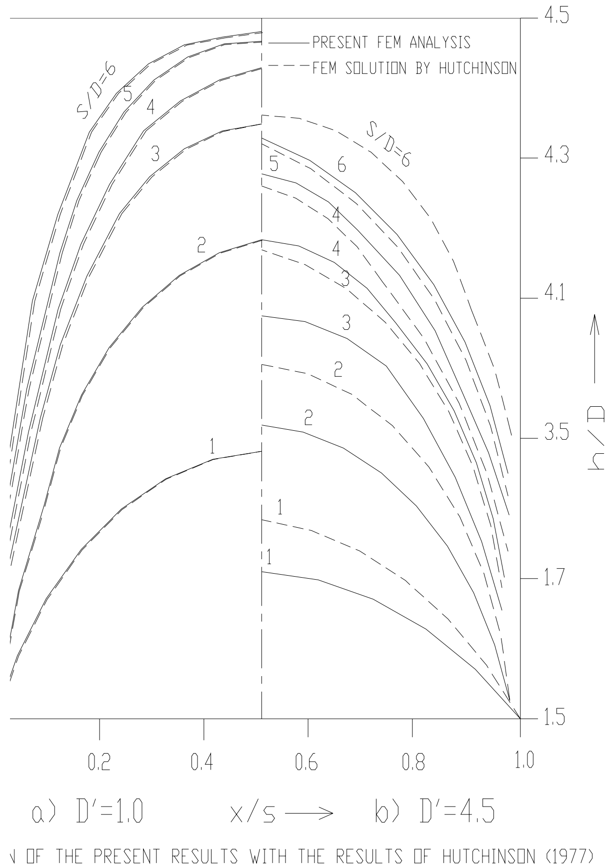


Fig .3: Comparison of Pramada Valli Results with Hutchinson Results

She mentioned some design guidelines for drainage systems of homogeneous, single layer soil systems. In her work she mentioned about equipotential lines, maximum spacing, variation of peziomtric heads, and discharge of water into drains and depth of drains. Main interest behind this work is to provide guidelines to slope stabilization in hilly region road networks, especially Himalayan regions. Pramada Valli discussed the relationship between the piezometric head and various other factors separately and explained the variation of piezometric head between the drains along the drain invert level and the discharge of water flowing within the drains. Various diagrams have been drawn, taking account of depth, width and spacing of trench drains for determining equipotential lines, the magnitude of piezometric head within the flow domain and the discharge of water flowing into the drains. The effect of soil anisotropy with reference to its permeability has also been investigated.

2.5 Construction of Trench Drains

Cooper [15] explained that the width of the trench drains usually depends on the size of the backhoe or excavator being used and it normally varies from .4m to .1m. The maximum depth of trench drain is limited by the ability of the available backhoe or excavator (3-4m backhoe, 5-6m normal excavator). The choice of material to be used for the drains depends on the required discharge capacity of drains, the availability of existing sand and gravel material on the site, and the construction method. In between the drains and existing slope materials, a suitable filter material is provided so as to prevent migration of soil fines into drain material; else otherwise these drains may easily get clogged.

Some related discussion about trench drains is in IS 14680: 1999 [3] section 6.1.7. In the sub topic of Sub Surface Drainage few aspects of trench drains has given. Here it is explained that subsurface drainage is usually more effective for deep seated landslides because it leads to a decrease in pore water pressure directly at the failure plane and tends to produce more stable condition for slide area. In this section part (b) detailed about trench. Here it is mentioned as deep trench drains are used where water can be intercept at depths less than 5 to 8 meters. Filter fabric covered trench drains consists of a permeable gravel core, surrounded by a filter fabric to prevent clogging. The gravel size is either 16-32 mm or 35-70 mm to ensure a sufficiently high void ratio. After the trench has been excavated, the filter fabric/geotextiles is spread out into the channel and then backfilled with clean gravel up to the top water bearing layer. The geotextile is the over layered before the top layer can be backfilled by local soil.

2.6 Finite Element Method

The finite element method was originally employed for structural analysis only. It was first introduced by Turner et al [16]. ,Topp, L.P. [17]. About ten years later, researchers started to use the finite element method also for the numerical solution of field equations in continuous media. However, only with the beginning of the 90's, did the finite element method gain popularity in the solution of the Euler and the Navier-Stokes equations. A good introduction into the classical finite element methodology can be found in The Finite Element Method., McGraw-Hill, Maidenhead, by Zienkiewicz, O.C.; Taylor, R.L.[18], Reddy, J.N.; Gartling, D.K [19], as it is in general applied to the solution of so many equations, starts with a subdivision of the physical space into triangular/quadrilaterals (in 2-D) or into tetrahedral (in 3-D) elements. Thus, an unstructured grid has to be generated. Depending on the element type and the required accuracy, a certain number of points at the boundaries and/or inside an element is specified, where the solution of the flow problem has to be found. The total number of points multiplied with the number of unknowns determines the number of degrees of freedom. Furthermore, the so-called shape functions have to be defined, which represent the variation of the solution inside an element. In practical implementations, linear elements are usually employed, which use the grid nodes exclusively. The shape functions are then linear distributions, whose value is zero outside the corresponding element. This results in a second-order accurate representation of the solution on smooth grids. Within the finite element method, it is necessary to transform the governing equations from the differential into an equivalent integral form. This can be accomplished in two different ways. The first one is based on the variational principle, i.e., a physical solution is sought, for which a certain functional possesses an extremum. The second possibility is known as the method of weighted residuals or the weak formulation. Here, it is required that the weighted average of the residuals is identically zero over the physical domain. The residuals can be viewed as the errors of the approximation of the solution. The weak formulation has the same advantage as the finite volume discretisation of the conservation laws - it allows the treatment of discontinuous solutions such as shocks. Therefore, the weak formulation is preferred over the variational methodology. The finite element method is attractive because of its integral formulation and the use of unstructured grids, which are both preferable for flows in or around complex geometries. The method is also particularly suitable for the treatment of non-Newtonian fluids. The finite element method has a very rigorous mathematical foundation, particularly for elliptic and parabolic problems. Although it can be shown in certain cases that the method is mathematically equivalent to the finite volume discretisation, the numerical effort is much higher. However, both finite element and finite volume methods are sometimes combined - particularly on unstructured grids. So for example, the treatment of the boundaries and the discretisation of the viscous fluxes are usually “borrowed” from the finite element method.

In most of the numerical methods, the solutions yield approximate values of the unknown quantities only at a discrete number of points in the body. The process of selecting only a certain number of discrete points in the body can be termed discretisation. The finite element is applicable in a wide range of boundary value problem in engineering (Desai, Abel [20]). There are 3 major categories of boundary value problems: equilibrium or steady state problems, eiganvalue problems and propagation or transient problems.

Field of Study	Equilibrium Problems	Eigenvalue Problems	Propagation Problems
Hydrodynamics, hydraulic engineering and water resources.	Solution for potential flow of fluids. Solutions for viscous flow of fluids. Steady-state seepage in aquifers and porous media. Analysis of hydraulic structures and dams.	Seiche of lakes and harbors (natural) periods and modes of oscillation). Sloshing of fluids in rigid and flexible containers.	Salinity and pollution studies and estuaries (diffusion). Sediment transport. Unsteady fluid flow. Wave propagation. Transient seepage in Porous media and aquifers.

Chapter 3

Field importance of the present work

3.1 Examples of Land Slides

Large number of landslides from major hazards occurs quite often during rainy season in Himalayas and hilly ranges in India. Large-scale denudation of forests, widening of roads and construction of new roads on the hill slopes, the incidence of landslides is on the increase. The western Himalayas have witnesses as many as 150 landslides in the year 1998.Malpa village in Uttar Pradesh experienced major landslide. More then 350 lives have been lost including those of 60 pilgrims who perished while on the way to Kailash Manasaarovar. Excessive rainfall may have been cause such a large number of landslides.

3.2 Principal Measures

Landslides may be corrected or controlled by one or any combination of four principle measures: modification of slope geometry, drainage, retaining structures and internal slope reinforcement. There are a number of levels of effectiveness and levels of acceptability that may be applied in the use of these measures, for while one slide may require an immediate and absolute long-term correction, another may only require minimal control for a short period. Here one more important aspect is developing effective procedure. Each major landslide is a case history in itself because the factors causing the landslide and their interplay differ from former events. That is the reason why case histories will continue to be of paramount importance in developing effective procedures to minimize the landslide impact optimizing the balance between safety and economy.

3.3 Slope stability

Study of slope stability consists of following aspects:

- Causes of instability
- Mechanics of slopes
- Analysis of translational slip
- Analysis of rotational slip
- Site investigation
- Remedial measures

3.3.1 Causes of instability

Soil or rock masses with sloping surfaces, either natural or constructed, are subject to forces associated with gravity and seepage, which cause instability. Resistance to failure is derived mainly from a combination of slope geometry and the shear strength of the soil or rock itself. The different types of instability can be characterized by spatial considerations, particle size and speed of movement. One of the simplest methods of classification is that proposed by Varnes [21]:

3.3.1.1 Varnes Classification

- Falls
- Topples
- Slides rotational and translational
- Lateral spreads
- Flows in Bedrock and in Soils
- Complex

3.3.1.1.1. Falls

In which the mass in motion travels most of the distance through the air. Falls include: free fall, movement by leaps and bounds, and rolling of fragments of bedrock or soil.

3.3.1.1.2 Topples

Toppling occurs as movement due to forces that cause an over-turning moment about a pivot point below the centre of gravity of the unit. If unchecked it will result in a fall or slide.

3.3.1.1.3 Lateral Spreads

Lateral spreads are disturbed lateral extension movements in a fractured mass. Two subgroups are identified:

- Where the spread is without a well defined controlling basal shear surface or zone of plastic flow.
- In which extension of rock or soil results from liquefaction or plastic flow of subjacent material.

3.3.1.1.4. Flows

Two subtypes are identified:

A. In Bedrock

Where flows include spatially continuous deformation and superficial as well as deep creep. They also involve extremely slow deep creep and extremely slow and generally non-accelerating differential movements among relatively intact units. Movements may:

- be along shear surfaces that are apparently not connected,
- result in folding, bending or bulging, or
- roughly simulate those of viscous fluids in distribution of velocities.

B. In Soils

In which the movement within the displaced mass is such that the form taken by moving material, or the apparent distribution of velocities and displacements, resemble those of viscous fluids. The slip surfaces within the moving material are usually not visible or are short-lived. The boundary between the moving mass and material may be a sharp surface or differential movement or a zone of distributed shear. Movement ranges from extremely rapid to extremely slow.

3.3.1.1.5. Complex

Complex movement is by a combination of one or more of the five other principal types of movement described by Varnes' Classification. Many landslides are complex, although one type of movement generally dominates over the others at certain areas within a slide or at a particular time.

3.3.1.2 Classification of Destabilization

"The processes involved in slope movements comprise a continuous series of events from cause to effect" (Varnes). When preparing a Landslide Report for a particular site, of primary importance is the recognition of the conditions which caused the slope to become unstable and the processes, which triggered that movement. Only an accurate diagnosis makes it possible to properly understand the landslide mechanisms and thence to propose effective remedial measures. Stable slopes are those where the margin of stability is sufficiently high to withstand all destabilizing forces. Marginally stable slopes are those which will fail at some time in response to the destabilizing forces attaining a certain level of activity. Finally, actively unstable slopes are those in which destabilizing forces produce continuous or intermittent movement. Very large falls can result in various types of flow involving fluidisation with either water or air. It must be appreciated that the causes of instability are often complex and any attempt at classification will be approximate and incomplete

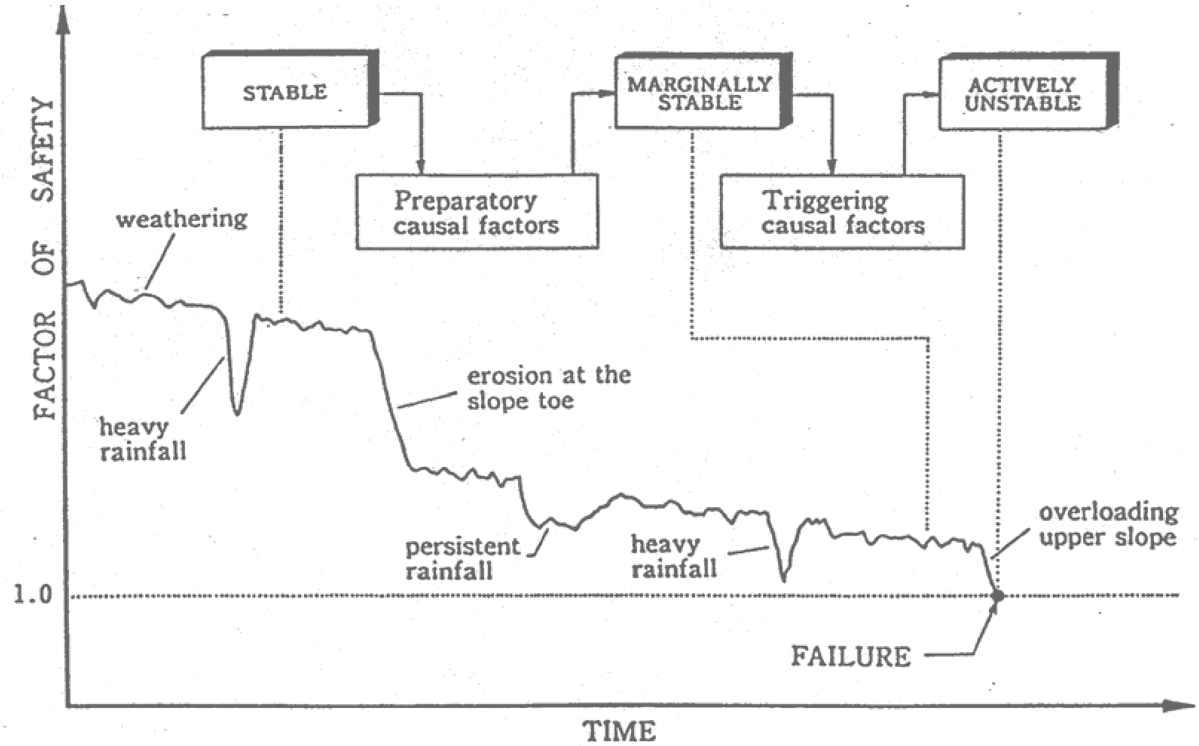


Fig.4: Effect of Rainfall on Factor of Safety

3.3.1.3 Effect of Rainfall on Factor of Safety

In the above Fig.4 we can observe that after every rainfall the factor of safety is effecting adversely. So it is clearly understood that rainfall effect is a major consideration in stabilizing the slopes. This project is presenting the drainage technique to stabilize the slopes.

3.3.1.4 List of causal factors

The Working party on World Landslide Inventory [25] has proposed a list of causal factors grouped under four main headings:

- GROUND CONDITIONS
  - Plastic weak material
  - Sensitive material
  - Collapsible material
  - Weathered material
  - Sheared material
  - Jointed or fissured material
  - Adversely oriented mass discontinuities (including bedding, schistosity, cleavage)

Adversely oriented structural discontinuities (including faults, unconformities, flexural shears,
sedimentary contacts)
Contrast in permeability and its effects on ground water contrast in stiffness (stiff, dense material over plastic material)

- GEOMORPHOLOGICAL PROCESSES
  - Tectonic uplift
  - Volcanic uplift
  - Glacial rebound
  - Fluvial erosion of the slope toe
  - Wave erosion of the slope toe
  - Glacial erosion of the slope toe
  - Erosion of the lateral margins
  - Subterranean erosion (solution, piping)
  - Deposition loading of the slope or its crest
  - Vegetation removal (by erosion, forest fire, drought)

- PHYSICAL PROCESSES
  - Intense, short period rainfall
  - Rapid melt of deep snow
  - Prolonged high precipitation
  - Rapid drawdown following floods, high tides or breaching of natural dams
  - Earthquake
  - Volcanic eruption
  - Breaching of crater lakes
  - Thawing of permafrost
  - Freeze and thaw weathering
  - Shrink and swell weathering of expansive soils

- MAN-MADE PROCESSES
  - Excavation of the slope or its toe
  - Loading of the slope or its crest
  - Drawdown (of reservoirs)
  - Irrigation
  - Defective maintenance of drainage systems
  - Water leakage from services (water supplies, sewers, stormwater drains)
  - Vegetation removal (deforestation)
  - Mining and quarrying (open pits or underground galleries)
  - Creation of dumps of very loose waste
  - Artificial vibration (including traffic, pile driving, heavy machinery)

Above list is a short checklist of landslide causal factors arranged in four practical groups according with the tools and procedures necessary for documentation. Ground conditions or the material and mass characteristics of the ground, can be mapped on the surface of the landslide and the surrounding ground and explored in the subsurface by drilling, trenching. Mechanical characteristics can be determined by testing. Geomorphological processes, or changes in the morphology of the ground, can be documented by pre-existing maps, aerial photographs, surveys of the landslide, or careful observation over time by the local population. Physical processes concern the environment and can be documented at the site by instrumentation, such as rainfall gauges, seismographs or piezometers. Careful local observations over time of water wells or damage from earthquakes may be acceptable substitutes. Variations in mechanical properties with distance from the surface may, in some circumstances, indicate changes of these properties with time. Man-made processes can be documented by site observations and from construction or excavation records at the site. Separate identification of artificial and natural landslides is useful for both administrative and theoretical reasons.

3.3.2 Mechanics

- Loads
- Pore pressure
- Earthquakes
- Peak, critical state and residual strength
- Stress changes in slopes
- Choice of strength parameters

In every slope there are forces which tend to promote down slope movement and opposing forces which tend to resist movement. A general definition of the factor of safety (F_s) of a slope results from comparing the down slope shear stress with the shear strength of the soil along an assumed or known rupture surface.

3.3.2.1 Loads

Changes produced by loading or unloading are widely recognised as being mechanisms by which instability can occur. The effects of variations in loading can be considered using the concept of the 'neutral point' developed by Hutchinson.

3.3.2.2 Pore pressures

- End of construction
- Steady seepage
- Rapid drawdown

In order to estimate the factor of safety F_s for a slope in terms of effective stress (i.e. in the long-term condition), the pore water pressure must be known. This is frequently the greatest source of inaccuracy in slope stability work, since the determination of the most critical conditions of pore water pressure is complex and costly. The following three sets of conditions are usually considered for constructed slopes:

· End of construction
· Steady seepage
· Rapid drawdown

In natural slopes, the distribution of pore water pressure may be highly complicated due to changes in soil type, anisotropy etc. The pore pressures are determined from site measurements using observation wells or piezometers. Monitoring must be continued over long periods of time in order to define the worst or most critical conditions. Methods for the in-situ measurement of pore water pressure are described by Clayton, Matthews and Simons.

3.3.2.3 Earthquakes

- Earthquakes and slope stability
- Earthquake mechanism

- Mercalli scale

Earthquakes result from the sudden release of elastic strain energy stored in the Earth's crust. Stress accumulates locally from various causes until it exceeds the strength of the rocks, when slip occurs by brittle failure on dislocations or fractures known as faults. Earthquakes give rise to two types of surface displacement: permanent offsets on the fault itself, and transient displacement resulting from the propagation of seismic waves away from the source. A small movement on a fault may produce a considerable shock because of the energy involved. Earthquakes range from slight tremors which do little damage, to severe shocks which can cause widespread damage including the initiation of landslides, collapse of buildings and fracturing of supply mains and lines of transport. The surface displacement associated with earthquakes may range from a few cms. upto several meters.

3.3.2.4 Peak, critical state and residual strength

- Typical results for a drained test on clay
- Typical values of strength parameters
- The significance of residual strengths
- Measurement of residual shear strength

When a soil is subjected to shear, an increasing resistance is built up. For any given applied effective pressure, there is a limit to the resistance that the soil can offer, which is known as the peak shear strength. Frequently the test is stopped immediately after the peak strength has been clearly defined. The value of peak shear strength has been referred to, in the past, as simply the shear strength of the clay, under the given effective pressure and under drained conditions.

If the shearing is continued beyond the point where the maximum value of the shear strength has been mobilized, it is found that the resistance of the clay decreases, until ultimately a steady value is reached, and this constant minimum value is known as the residual strength of the soil. The soil maintains this steady value even when subjected to very large displacements.

In the absence of pre-existing failures the choice is between the peak or critical state strength. In uncemented soils the peak strength is associated with dilation and occurs at relatively small strains or displacements of the order of 1% or 1mm. The critical state strength is the shearing resistance for constant volume straining and occurs at strains or displacements of the order of 10% or 10mm. In many slopes ground movements and strains are relatively large and exceed the small movements required to mobilize the peak state. In addition, there is evidence that the peak value reflects the nature of the laboratory test procedure and gives an unconservative result in slope stability analysis.

3.3.2.5 Stress changes in slopes

- Changes in stress during undrained slope excavation
- Comparison of cuttings with embankments
- General case

Any sudden changes in loading on a slope will lead to changes in the pore pressures. Natural slopes are usually eroded very slowly and the soil is essentially drained throughout the process. This means that the pore pressures are governed by steady seepage from the ground towards the excavation and their magnitude can be obtained from a flownet. Man-made slopes are constructed relatively quickly, and in soils with low permeability, such as clay, there will be inadequate time during the construction period for the pore pressures to adjust to the new loading conditions, and the soil will then be essentially undrained.

3.3.2.6 Choice of strength parameters

The choice between the undrained strength s_u and the drained strength is relatively simple and straightforward. For temporary slopes and cuts in fine-grained soils with low permeability the undrained strength s_u should be used and a total stress analysis performed. This analysis is only valid whilst the soil is undrained. The stability will deteriorate with time as the pore pressures increase and the soil swells and softens.

For any permanent slope the critical conditions are at the end of swelling when pore pressures have reached equilibrium with a steady state seepage flownet or with hydrostatic conditions. In this case effective stress strength is appropriate and the pore pressures are calculated separately.

3.3.3 Analysis of translational slip

- Drained soil with zero flow
- Drained soil with parallel flow
- General equation
- Stability of vertical cuts
- Translational slip in rock slopes

3.3.4 Site investigation

In relation to slope stability, the main aims of site investigation are:

to obtain an understanding of the development and nature of natural slopes, and of the processes which have contributed to the formation of different natural features;
to assess the stability of various forms of slopes under given conditions;
to assess the risk of instability in natural or artificial slopes, and to quantify the influence of engineering works or other modifications to the stability of an existing slope;
to facilitate the redesign of failed slopes, and the planning and design of prevention and remedial measures;
to analyse slope failures which have occurred and to define the causes of failure;
to assess the risk of special external factors on the stability of slopes, e.g. earthquakes.

3.3.5 Remedial measures

- Drainage
- Restraining structures
- Modification of slope geometry
- Replacement
- Trench drains

3.3.5.1 Drainage

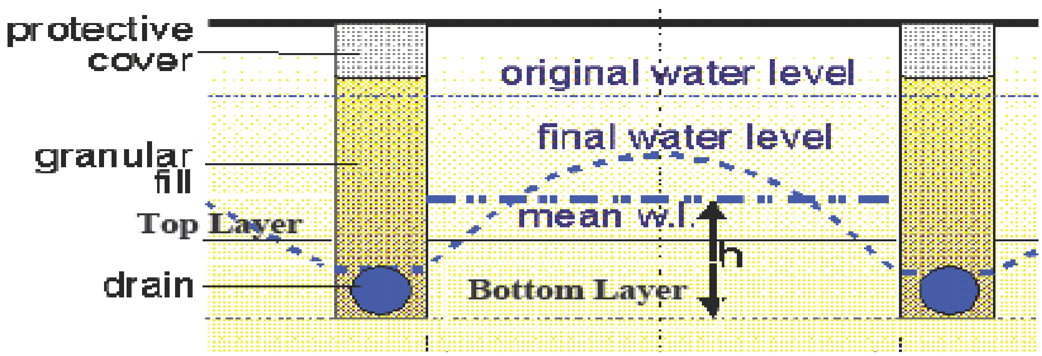


Fig.5 Effect of Trench on Phreatic Line

Drainage is one of the most widely used methods for improving stability. Clearly surface water must be removed and build-up of water pressures in tension cracks prevented. Subsurface drainage must be designed to reduce the water pressures acting on actual or potential slip surfaces; in this way, the value of the pore pressure (u) is reduced, thereby producing an increase in the factor of safety.

Several methods exist for subsurface drainage, including:
trench drains
horizontal drains
vertical drains (or wells)
galleries

Drainage may also be achieved by the use of electro-osmosis and by planting suitable vegetation.

Of these various methods, trench drains are frequently the cheapest and most widely used method. They are applicable to slips of moderate depth, but for deeper failures other methods may be more appropriate.

The factor of safety of a slope in soil possessing cohesion and friction can be written as

$$F_s = \frac{\sum\left[c'\ell + \left(W\cos\alpha - u\ell\right)\tan\phi'\right]}{\sum W\sin\alpha}$$

If, for a particular slope, the computed or actual factor of safety F_s is inadequate, clearly F_s can be increased by:
increasing the numerator, or
decreasing the denominator, or
a combination of the above.

The main methods for achieving this increase in Fs, are: replacement; modification of slope geometry; drainage; use of restraining structures.

Detailed reviews of the wide range of remedial methods used in improving the stability of slopes are given by Hutchinson and Zaruba and Mencl [24].

3.3.5.2 Restraining structures

Retaining structures such as piles, walls and anchors may be used to improve stability. It must be appreciated that the forces and moments to which these structures are subjected may be very large and hence careful design is essential. The detailed design of these structures is outside the scope of this section. Useful discussions are given by Zaruba and Mencl, Bromhead and Leventhal and Mostyn.

3.3.5.3 Modification of slope geometry

Changing the geometry of a slope to improve stability can involve the following:
excavation to unload the slope,
filling to load the slope,
reducing the overall height of the slope.

Where excavation and/or filling are used as remedial measures, it is essential that they are correctly positioned, and use should be made of the Neutral Point Concept.

3.3.5.4 Replacement

Where the slip surface is not unduly deep, removal of all (or part) of the slipped material and replacement provides a relatively simple and straightforward remedial measure. The removed soil may be replaced by free-draining material (in which case some additional benefit may be achieved by drainage) or by the recompacted slip debris. If shear surfaces exist at shallow depth, they can be destroyed by digging out, remolding and recompacting. A recent development has seen the incorporation of geotextile reinforcement within the replaced material.

3.3.5.5 List of remedial measures

- MODIFICATION OF SLOPE GEOMETRY
  - Removing material from the area driving the landslide (with possible substitution by lightweight fill)
  - Adding material to the area maintaining stability (counterweight berm or fill)
  - Reducing general slope angle
- DRAINAGE
  - Surface drains to divert water from flowing onto the slide area (collecting ditches and pipes)
  - Shallow or deep trench drains filled with free-draining geomaterials (coarse granular fills and geosynthetics)
  - Buttress counterforts of coarse-grained materials (hydrological effect)
  - Vertical (small diameter) boreholes with pumping or self draining
  - Vertical (large diameter) wells with gravity draining
  - Subhorizontal or subvertical boreholes

Drainage tunnels, galleries or adits
Vacuum dewatering
Drainage by siphoning
Electro-osmotic dewatering
Vegetation planting (hydrological effect)

- RETAINING STRUCTURES

Gravity retaining walls
Crib-block walls
Gabion walls
Passive piles, piers and caissons
Cast-in situ reinforced concrete walls
Reinforced earth retaining structures with strip/ sheet - polymer/metallic reinforcement
elements
Buttress counterforts of coarse-grained material (mechanical effect)
Retention nets for rock slope faces
Rockfall attenuation or stopping systems (rocktrap ditches, benches,fences and walls)
Protective rock/concrete blocks against erosion

- INTERNAL SLOPE REINFORCEMENT

Rock bolts
Micropiles
Soil nailing
Anchors (prestressed or not)
Grouting
Stone or lime/cement columns
Heat treatment
Freezing
Electroosmotic anchors
Vegetation planting (root strength mechanical effect)

Selection of an appropriate remedial measure depends on: a) engineering feasibility, b) economic feasibility, c) legal/regulatory conformity, d) social acceptability, and e) environmental acceptability.

3.4 Importance of Drainage

Drainage is often a crucial remedial measure due to the important role played by pore-water pressure in reducing shear strength. Because of its high stabilization efficiency in relation to cost, drainage of surface water and groundwater is the most widely used, and generally the most successful stabilization method. Surface water is diverted from unstable slopes by ditches and pipes. Drainage of the shallow groundwater is usually achieved by networks of trench drains. Drainage of the failure surfaces, on the other hand, is achieved by counterfort or deep drains which are trenches sunk into the ground to intersect the shear surface and extending below it. Structural solutions such as retaining walls involve opening the slope during construction and often require steep temporary cuts. Both these operations increase the risk of failure during construction for over-steeping or increased infiltration from rainfall. In contrast, the use of soil nailing as a non-structural solution to strengthen the slope avoids the need to open or alter the slope from its current condition.

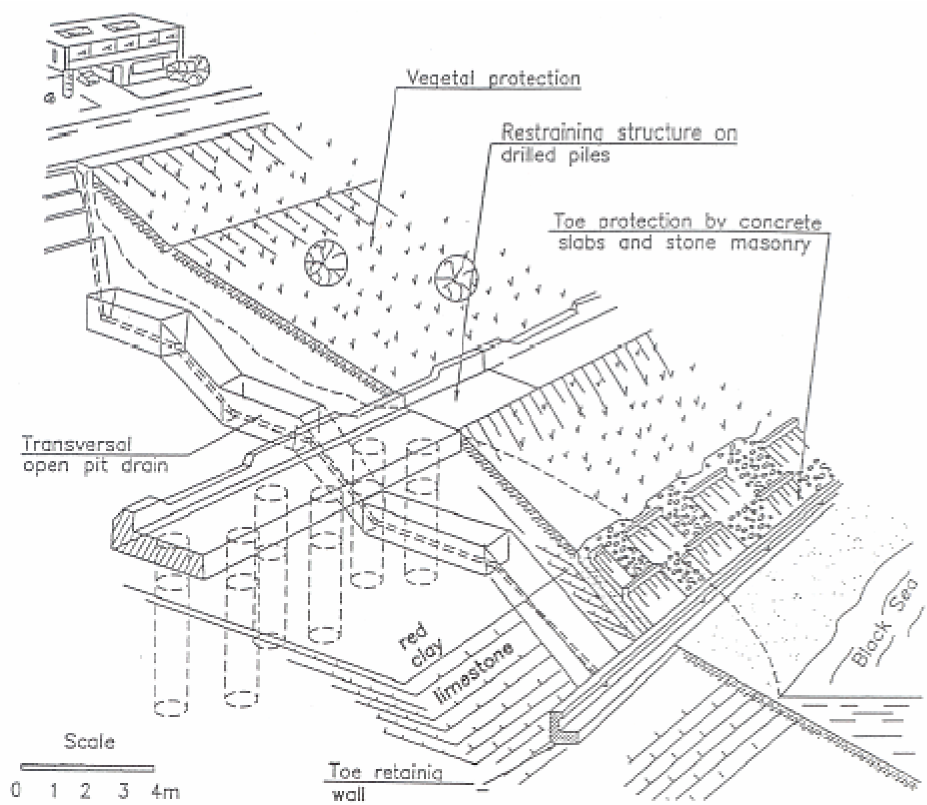
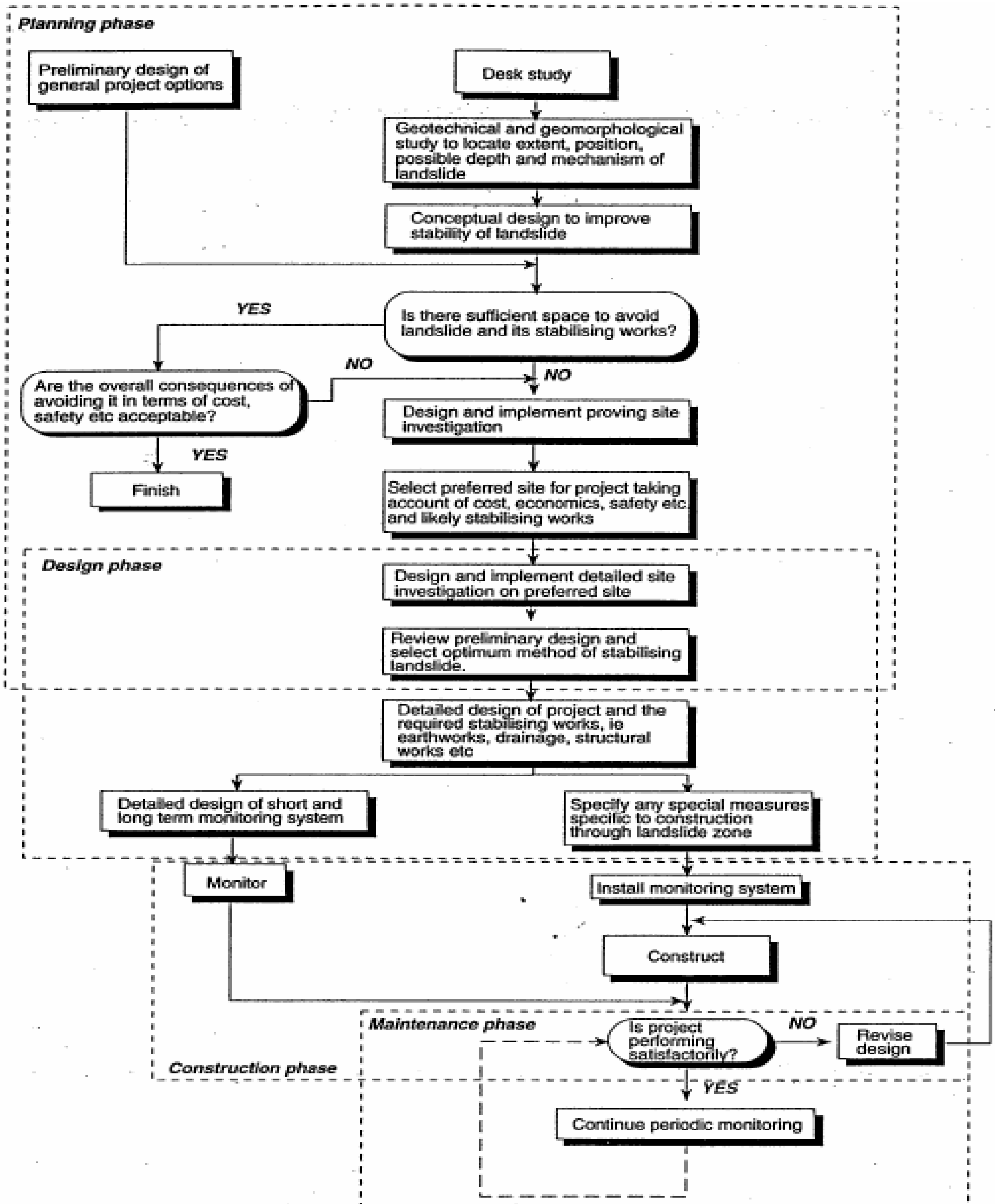


Fig.6: Typical diagram of Landslides remedial measures

3.5 Flow chart for remedial measures



Chapter 4

CONSTRUCTION ASPECTS OF TRENCH DRAIN

The width of the trench drains usually depends on the size of the backhoe or excavator being used and it normally varies from .4m to .1m. The maximum depth of trench drain is limited by the ability of the available backhoe or excavator (3-4m backhoe, 5-6m normal excavator). The choice of material to be used for the drains depends on the required discharge capacity of drains, the availability of existing sand and gravel material on the site, and the construction method.

In between the drains and existing slope materials, a suitable filter material is provided so as to prevent migration of soil fines into drain material; else otherwise these drains may easily get clogged.

Slotted PVC pipes may be laid to improve the discharge capacity of the drains. However, in many cases it is difficult to lay such pipes. If placed in sand, these pipes should be surrounded with filter fabric as to prevent inflow of sand through slots. The filter fabric used for this purpose should be of similar quality to that used on the trench periphery.

Where fabric is used as a substitute for the filter, non woven fabric is preferable to woven fabric since the former is less susceptible to damage during installation time.

Drains should preferably be constructed starting from the lowest point in the area to be stabilized, so that they start functioning even during the construction period.

If feasible, manholes or inspection points should be provided at suitable places to allow inspection and measurement of prevailing seepage flow, and also to perform the flushing of the installed slotted pipes.

Trench stability during construction is a major problem in many landslides. Without any support, trenches deeper than approximately 1.5m should never be constructed straightway. Trench instability can be minimized by backfilling the drainage material quickly as the trench is excavated so that the depth of unsupported trench remains smaller.

Chapter 5

TYPE OF THE PROBLEM

5.1 Theory of Problem

Examining entirely from theoretical considerations, the performance of any trench drainage system is, if not possible, an extremely complicated task. After these drainage measures are used, the nature of water flows within ground remains not only three dimensional but transient as well. As time progresses the water table recedes gradually and many cases the nature of ground water seepage becomes independent of time and steady state condition of flow develops. However, owing to the complex geometry of natural slopes, the nature of water flow still remains three dimensional with the water flowing towards trenches and along down slope. With the advent of high speed computers and with availability of many software packages in the market, mostly on the basis of finite element and boundary element methods, it is quite possible to deal with even three dimensional problems. However, such analysis proves quite costly. On the other hand, two dimensional formulations of these problems is still carried out often as it provides satisfactory answers with a much cheaper cost.

As was mentioned in the previous chapter, for the case of isotropic/anisotropic soil medium Hutchinson and Pramada Valli provided solution for two dimensional problem of trench drainage system. The present chapter, by using the finite element analysis, presents the performance of two dimensional rectangular trench drainage systems for a general isotropic/anisotropic soil medium in the steady state of ground water seepage.

5.2 Type of the Problem

In most of the numerical methods, the solutions yield approximate values of the unknown quantities only at a discrete number of points in the body. The process of selecting only a certain number of discrete points in the body can be termed discretisation. The finite element is applicable in a wide range of boundary value problem in engineering. There are 3 major categories of boundary value problems: equilibrium or steady state problems, eiganvalue problems and propagation or transient problems.

Field of Study	Equilibrium Problems	Eigenvalue Problems	Propagation Problems
Hydrodynamics, hydraulic engineering and water resources.	1. Solutions for potential flow of fluids. 2. Solutions for viscous flow of fluids. 3. Steady-state seepage in aquifers and porous media. 4. Analysis of hydraulic structures and dams.	1. Seiche of lakes and harbors (natural) periods and modes of oscillation). 2. Sloshing of fluids in rigid and flexible containers.	1. Salinity and pollution studies and estuaries (diffusion). 2. Sediment transport. 3. Unsteady fluid flow. 4. Wave propagation. 5. Transient seepage in Porous media and aquifers.

As mentioned in the above table, current field of study is hydrodynamics, hydraulic engineering and water resources. Present problem is equilibrium type steady-state seepage in aquifers and porous media.

5.3 Definition of the problem

It is assumed that the total rate of inflow of water from upslope and from infiltration of rainwater, if any, occurs such that its magnitude becomes equal to the net rate of water outflow, and the level of water remains stationary with respect to time. It is require determining (i) the discharge of pieziometric head in the trenches and; (ii) the variation of peiziometric head in the flow domain between the drains for various combinations of depth, width and spacing of trench, in addition to the effect of geometry of the flow domain. It is also require examining in detail the influence of soil anisotropy, with respect to its permeability on the results.

5.4 Assumptions

- Soil with in the flow domain is a homogeneous and incompressible.
- Below the water table, soil mass remains always fully saturated and there is no contribution to the flow from either partly saturated or from capillarity zone.
- The water flows in the soil media is laminar and obeys Darcy's law.
- Failure surfaces are pre defined.
- All the analysis are non-transient equilibrium steady-state seepage type
- Trench drain is in rectangular shape and all trench drains are symmetric.
- Every trench drain is symmetric about its central vertical axis.

Chapter 6

COMPUTATIONAL METHODOLOGY

6.1 Methodology for Considering Domain

System of parallel rectangular trench drains are shown in Fig.6. As per assumption all trench drains are symmetric so the system can resemble by designing one trench drain. Again every trench drain is symmetric about its central vertical axis so system domain is considered as shown in fig.7. From Node 131 onwards second layer has started.

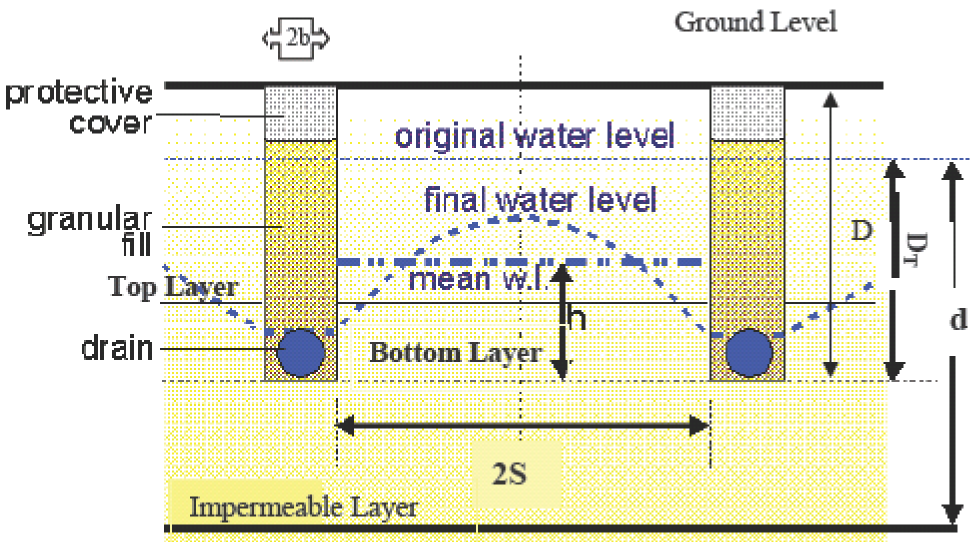


Fig.6 Geometry of the problem

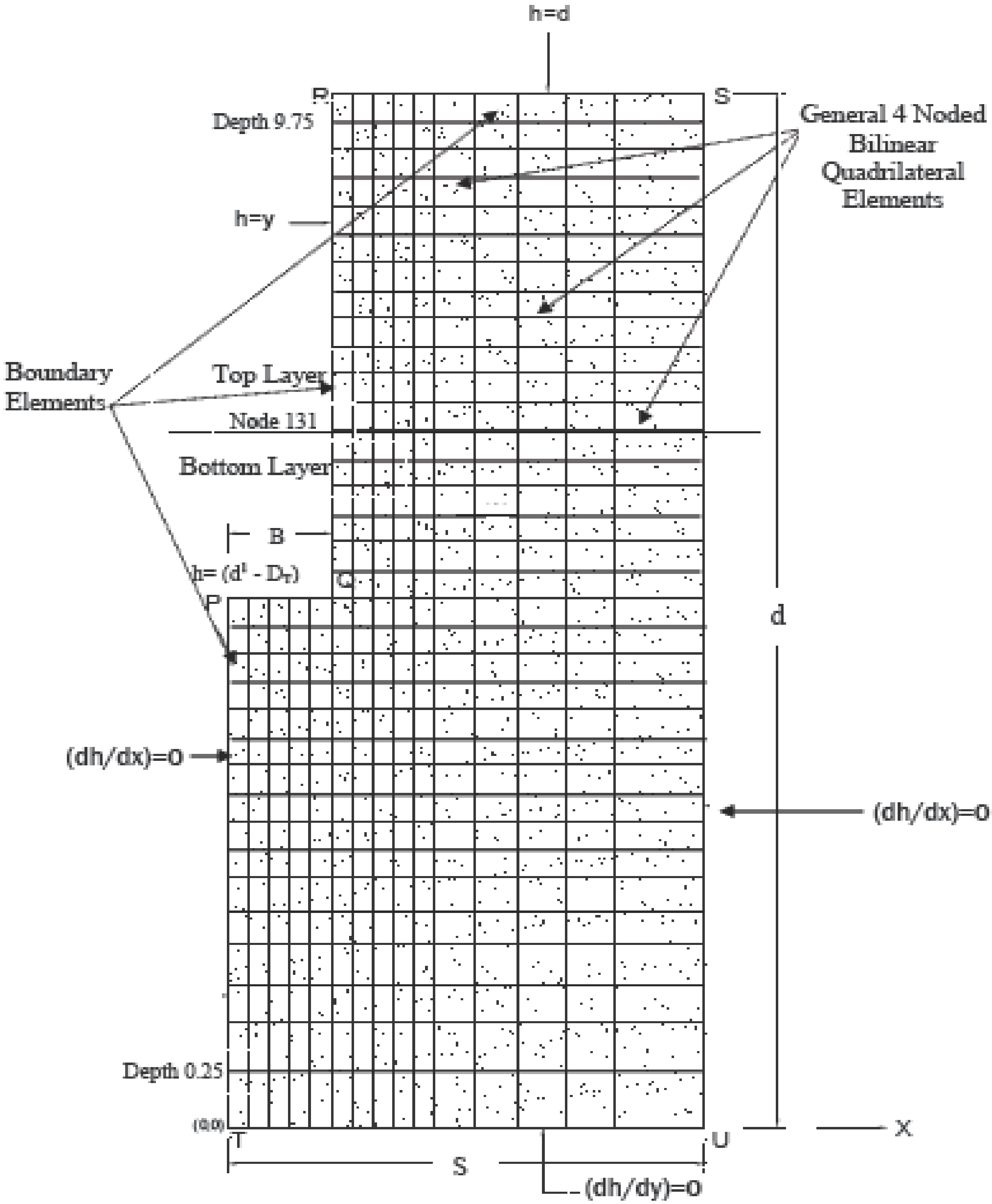


Fig. 7 Domain of Trench

6.2Differential Equation Development

Following are the symbols use in this approach:

B = Width of the trench.

S = Spacing between the trenches.

(S/B) = Maximum effective spacing.

D_T = Depth of trench below the water table.

d = Depth of impervious layer below the water table.

K_x = Permeability of the soil in x directions.

K_y = Permeability of the soil in y directions.

R_k = K_x / K_y

R_{kt} = Relative permeability of top layer

R_{kb} = Relative permeability of top layer

h = total head of water

h' = Non-dimensional total head of water

Q = Quantity of discharge of water.

Q' = Non- dimensional quantity of discharge of water.

$Q'_{max.}$ = Maximum quantity of discharge of water.

After considering B as characteristic dimension relation between symbols as followed:

$h' = h/B$

$x' = x/B$

$y' = y/B$

Considering the Darcy's law in the continuity equation, the differential equation of two dimensional steady state seepage through homogeneous, anisotropic and incompressible soil medium is as given below:

$$K_x (\partial^2 h/ \partial x^2) + K_y (\partial^2 h/ \partial y^2) = 0 \qquad \text{---------- (1)}$$

Rewriting the above equation in none-dimensional form

$$R_K (\partial^2 h'/ \partial x'^2) + (\partial^2 h'/ \partial y'^2) = 0 \qquad \text{----------- (2)}$$

6.3 Developing of Boundary Conditions

For the flow domain PQRSUT as shown in Fig. 2, the following boundary conditions need to be satisfied.

- Along the water table/phereatic surface RS, $h' = d/B$
- Along the seepage face RQ of the domain, $h' = y'$
- Along the bottom face PQ of trench, $h' = (d- D_T)/B$
- Along the impervious layer TU, $\partial h'/ \partial y' = 0$
- Along the axis of symmetry SU, $\partial h' / \partial x' = 0$

Where (D_T /B) =depth ratio of trench below the water table and (D/B)=depth ratio of impervious layer below the water table.

6.4 Finite Element Solution

The above problem has been solved by employing the Finite element discritisation technique. To solve the differential Equation (2) with the associated boundary conditions it is convenient to write the equivalent integral equation for Equation (2) using variational principle. The integral Equation is solved by employing the finite element descritisation technique.

$$\Pi (h') = 1/2 \int\int [R_k (\partial h'/ \partial x')^2 + (\partial h'/ \partial y')^2] dx'dy' \qquad \text{---------- (3)}$$

The functional Π in integral Equation (3) is required to be minimized over the entire domain for obtaining the solution. The integral is evaluated as a sum of integrals over each element in the domain for the steady flow condition. The number of elements and the number of nodes for the entire domain vary with the geometrical features (depth, width and spacing) of the trench drainage system. More number of elements was employed for higher spacing and depth values of the trench drainage system. The domains for the present analysis in all the cases have been descritised into bilinear four noded quadrilaterals. The labeling of the nodes and the location of the coordinate system are shown in the general bilinear quadrilateral element in Fig. 7. The general bilinear quadrilateral element has four corner nodes 1, 2, 3 and 4 and the corresponding nodal values are h'_1, h'_2, h'_3 and h'_4 which are unknowns to be determined. The number of unknowns finally involved in solving a set of linear algebraic equations, becomes equal to the number of nodes taken in the domain. In order to ascertain the convergence, smaller elements were being employed near the periphery of the domain.

6.5 Methodology of solving integral equation

By using Gauss Integration Formula equation (3) is solved.

Gauss Integration Formula:

Rectangular rule, trapezoidal rule, Simpson's rules and Gauss integration formula (or Gauss quadrature formula) are some of well known numerical integration techniques. Among these techniques Gauss quadrature formula have more degree of precision.

$$\int_{-1}^{1} f(t)dt = \sum_{j=1}^{n} A_j f_j$$

Here $f_j = f(t_j)$, n is fixed and $t = \underline{+}1$ obtained from x=a, b by setting x= ½[a(t-1)+b(t+1)] . n coefficients $A_1, A_2, \ldots, A_n$ and

$t_1, t_2, \ldots, t_n$ so that above equation gives exact results for polynomials of degree k as high as possible. Since n+n = 2n is the number of coefficients of a polynomial of degree 2n-1, it follows that $k \leq 2n-1$. Gauss has shown that exactness for polynomials of degree not exceeding 2n-1 can be attained, and he has given the location of the t_j and the coefficients A_j the above equation is called a Gauss Integration Formula. In this current work n is taken as 4. For this degree of precision is 7 and t_j , A_j are as follows

t_j	A_j
-0.8611363116	0.3478548451
-0.3399810436	0.6521451549
0.3399810436	0.6521451549
0.8611363116	0.3478548451

6.6 Methodology in obtaining results

After developing computer program for calculating discharge deferent combinations of domain parameters used for optimum discharge. For the case of double layer domain first considered top layer (upto node 13) relative permeability is constant and bottom layer relative permeability is varied from 1 to 20. Than increased the first layer relative permeability and again varied the bottom layer relative permeability. These results are shown in tabulated format. Apart from this, mathematical model is developed for the single layer problem. For this Gauss's method of least squares is used. This principal states that the straight line should be fitted through the given points so that the sum of the squares of the distances of those points from the straight line is measured in the vertical direction. The models developed through regression analysis for maximum quantity of discharge of water ($Q'_{max.}$), optimum spacing $(S/B)_{opt.}$, depth and R_k are presented below.

$$Q'_{max.} = e^{(24.62 - 2.23(S/B)\,opt. + 0.71\,Rk)\,D'} \text{-----------------(4)}$$

$$Q'_{max.} = (26.15 - 1.91(S/B)_{opt.} + 2.89\,R_k)\,D' \text{-----------------(5)}$$

$$Q'_{max.} = (33.70 - 2.23(S/B)_{opt.} + 6.44\,R_k)\,D' \text{-----------------(6)}$$

Above mentioned methodology is explained in flow chart in next chapter.

Chapter 7

RESULTS AND OBSERVATIONS

7.1 Mathematical models for the maximum quantity of discharge of water

Based on the numerical values obtained from the FEM an attempt has been made to develop relationships for the maximum quantity of discharge of water ($Q'_{max.}$) flowing into the trench drains, various dimensionless parameters such as depth (D_T/B), optimum spacing $(S/B)_{opt}$. and permeability of soil (R_k) of the trench soil.

The data for the maximum quantity of discharge, the optimum spacing and R_k are used from the results obtained from the finite element solution and presented in Table.1, Table.2, Table.3, and Table.4.

Equations (4),(5) and (6) provide the value for maximum quantity of discharge of water for D' = 3,5 and 8. A comparison of numerical and mathematical model values of maximum quantity of discharge of water for different depths D_T/B = 3, 5 and 8 are presented in Table.5. It can be seen that many of the values of $Q'_{max.}$ calculated by the above formulae differed only within 5 percent of their numerical values obtained from FEM solution and very few are within 10 percent and one is in 12.45 percent.

Table.1: Q' corresponding to S/B with various values of R_k for D_T/B =3.0

R_k	1	2	3	5	10	15
S/B	Discharge of Water Q'					
2	5.75	15.14	25.58	44.33	78.80	101.69
3	10.71	22.23	32.80	50.44	81.37	102.43
5	16.12	26.49	35.82	51.90	81.48	102.50
8	19.05	27.76	35.90	52.00		
10	19.83	28.13	35.92			
12	19.87	28.15				
14	19.90					

Table.2: Q' corresponding to S/B with various values of R_k for D_T /B =5.0

R_k	1	2	3	5	10	15	290	22
S/B	Discharge of Water Q'							
2	8.94	27.49	52.88	109.64	237.50	330.00	399.40	422.60
3	17.76	48.15	81.01	141.03	253.30	335.50	400.70	422.90
5	25.18	59.56	92.38	147.91	253.90			
8	30.87	65.83	97.02	149.38				
10	40.60	72.14	99.86	149.75				
12	44.58	72.96	100.01					
14	46.05	73.24	100.02					
16	46.83	73.27						

Table.3: Q' corresponding to S/B with various values of R_k for D_T /B =8.0

R_k	1	2	3	5	10	15	290	22
S/B	Discharge of Water Q'							
2	13.60	45.50	97.10	243.90	658.50	992.00	1254.00	1346.00
3	27.60	92.40	181.80	368.70	732.40	1016.00	1258.00	1350.00
5	53.80	150.10	245.30	405.10	735.50	1016.00		
8	79.90	174.80	257.10	406.70	735.50			
10	89.30	178.10	257.70	406.70				
12	97.60	179.30						
14	100.10	179.40						
16	100.20							

Table.4: Q'_{max} corresponding to $(S/B)_{maxf}$ for D_T /B =3,5,8

R_k	$D_T/B=3$		$D_T/B=5$		$D_T/B=8$	
	Q'_{max}	$(S/B)_{max}$	Q'_{max}	$(S/B)_{max}$	Q'_{max}	$(S/B)_{max}$
1	19.80	9.00	46.00	11.00	100.00	13.00
2	27.70	7.50	72.80	9.00	179.00	11.00
3	36.00	6.00	100.00	7.00	257.00	8.00
5	52.00	4.00	149.00	5.00	406.00	6.00
10	81.30	2.50	253.00	3.00	735.00	4.00
15	102.00	2.00	335.00	2.00	1016.00	3.00
20	102.30	2.00	400.00	2.00	1254.00	2.00
22	102.40	2.00	423.00	2.00	1346.00	2.00

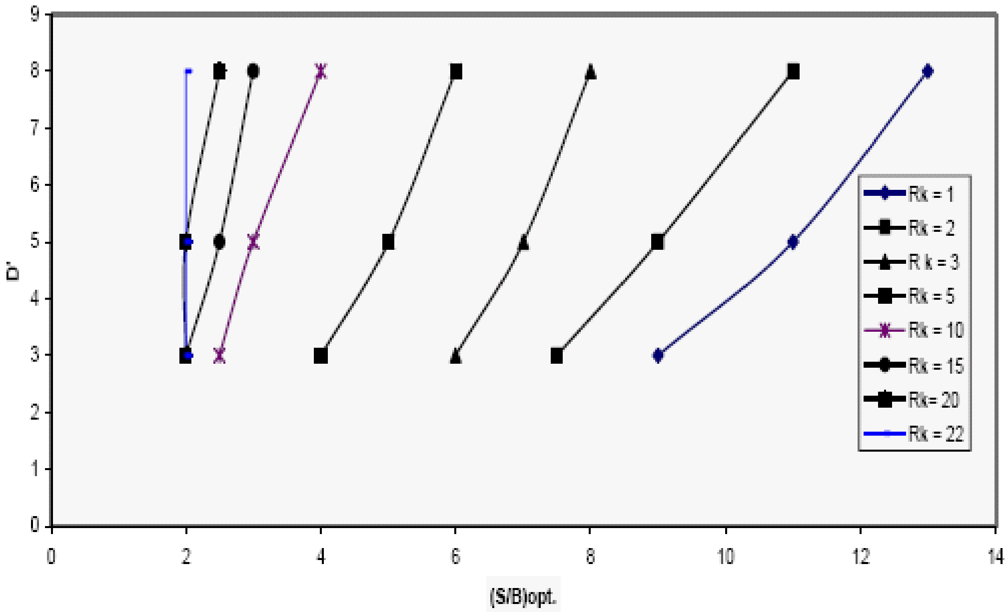


Fig.8: Variation of Maximum Effective Spacing with Dept D' and R_k

Table.5: Numerical solution and model values (for equations 1 to 3) of maximum quantity of discharge of water

	$D_T/B=3$			$D_T/B=5$			$D_T/B=8$		
R_k	Numerical $Q'_{max.}$	Model $Q'_{max.}$	P.D.	Numerical $Q'_{max.}$	Model $Q'_{max.}$	P.D.	Numerical $Q'_{max.}$	Model $Q'_{max.}$	P.D.
1.0	19.8	19.96	-0.83	46.0	40.27	-12.45	100.0	89.6	-10.43
2.0	27.7	26.87	-3.00	72.8	73.82	1.41	179.0	176.0	-1.28
3.0	36.0	33.44	1.25	100.0	107.37	7.37	257.0	281.0	9.59
5.0	52.0	55.30	6.36	149.0	155.40	4.29	406.0	420.0	3.52
10.0	51.3	79.88	-1.74	253.0	246.83	-2.44	735.0	713.0	-2.93
15.0	102.0	95.16	-6.71	335.0	323.96	-3.29	1016.0	988.0	-2.67
20.0	102.3	102.94	0.63	400.0	401.10	0.27	1254.0	1255.0	0.10
22.0	102.4	106.22	3.74	423.0	430.04	1.66	1346.0	1367.0	1.58

P.D. Represents Percentage Difference

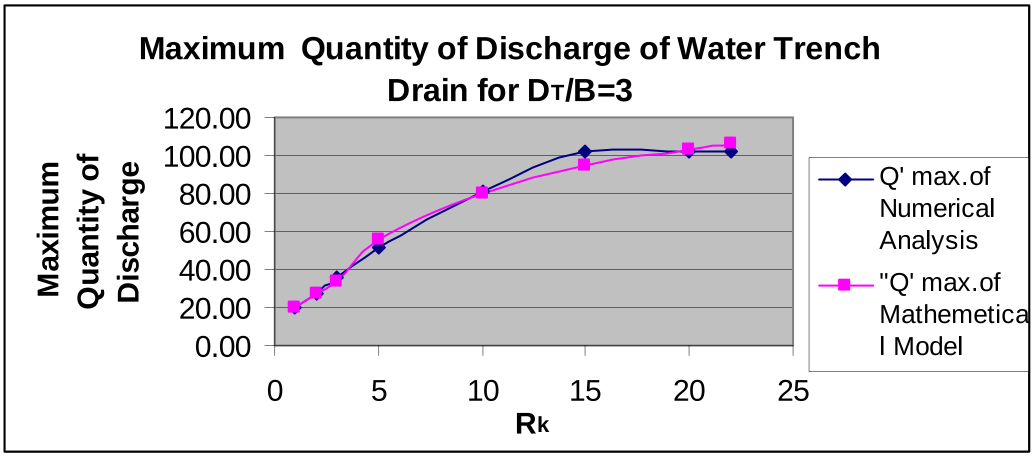


Fig.9: Comparison of Numerical and Model for $D_T/B=3$

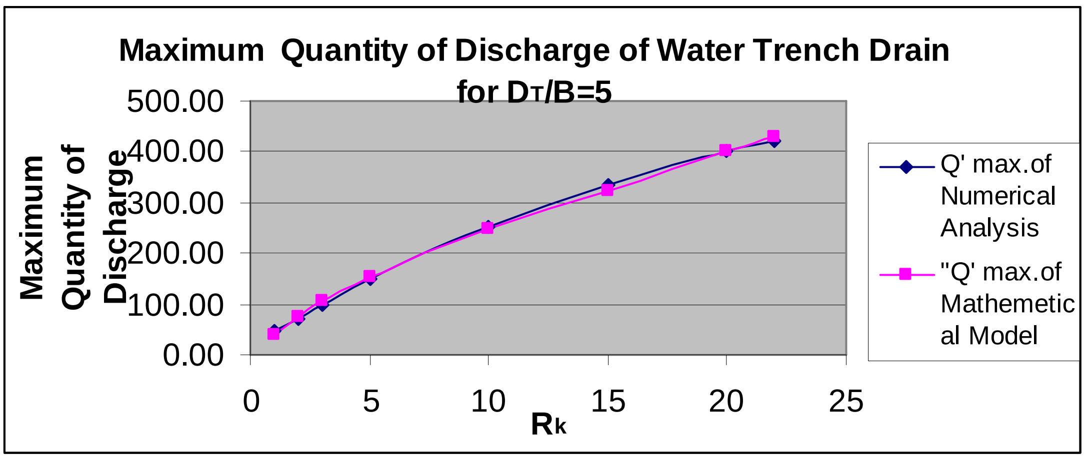


Fig.10: Comparison of Numerical and Model for $D_T/B=5$

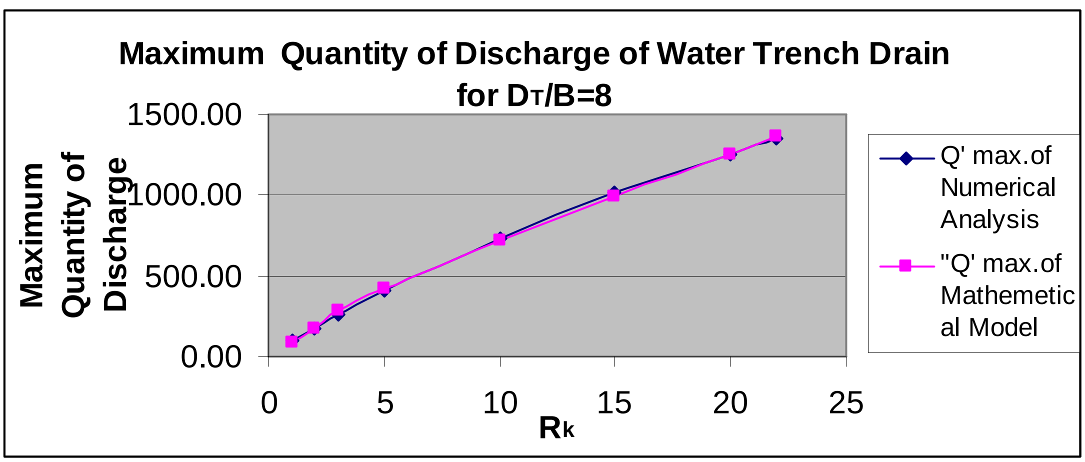


Fig.11: Comparison of Numerical and Model for $D_T/B=8$

7.2 Stratified layer analysis:

Following results obtained from FEM.This analysis has done in 6 sets.

Table.6: Horizontal Velocities for trail 1

Set 1: Horizontal Velocities						
Depth of Trench	R_{kt}=1					
	R_{kb}=1	R_{kb}=2	R_{kb}=5	R_{kb}=10	R_{kb}=15	R_{kb}=20
9.75	0.047	0.103	0.363	0.944	1.585	2.25
9.5	0.095	0.208	0.73	1.896	3.187	4.525
9.25	0.144	0.314	1.101	2.866	4.821	6.852
9	0.195	0.422	1.48	3.859	6.504	9.257
8.75	0.248	0.534	1.868	4.883	8.251	11.765
8.5	0.304	0.649	2.263	5.94	10.072	14.399
8.25	0.363	0.768	2.663	7.024	11.968	17.173
8	0.428	0.888	3.056	8.114	13.918	20.074
7.75	0.499	1.006	3.412	9.244	15.837	23.014
7.5	0.577	1.11	3.958	11.138	17.474	26.001
7.25	0.664	1.166	4.472	12.398	19.879	29.052
7	0.764	1.384	4.964	13.755	21.834	32.091
6.75	0.878	1.431	5.193	14.978	24.17	36.011
6.5	1.013	1.962	7.446	18.543	33.539	49.091
6.25	1.176	3.035	11.732	24.159	43.063	64.839
6	1.38	4.254	18.783	44.554	77.215	113.268
5.75	1.65	5.593	24.041	65.195	112.602	163.91
5.5	2.039	7.25	31.975	86.56	148.634	215.119
5.25	2.674	9.618	41.184	109.172	185.743	267.256
5	4.42	13.836	52.559	133.637	224.395	320.701

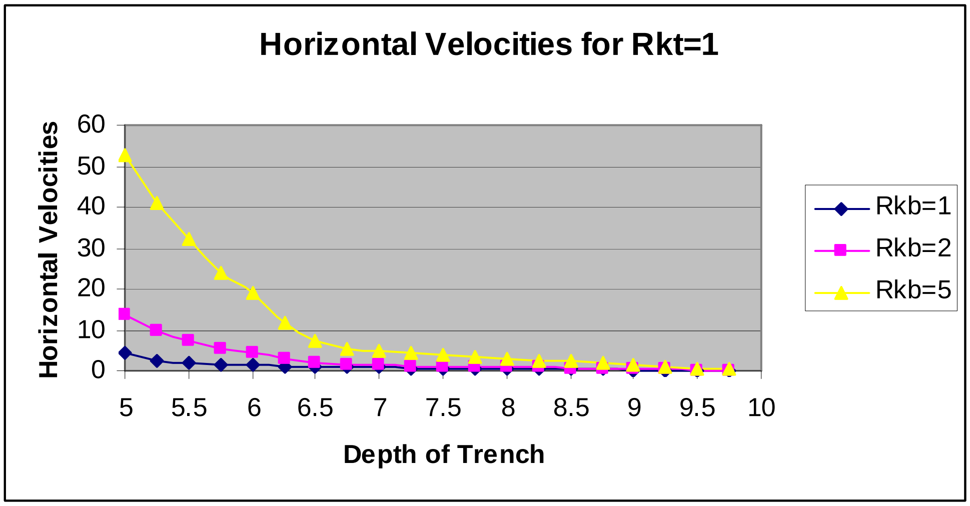


Fig.12: Horizontal Velocities for R_{kt}=1 and R_{kb}=1 to 5

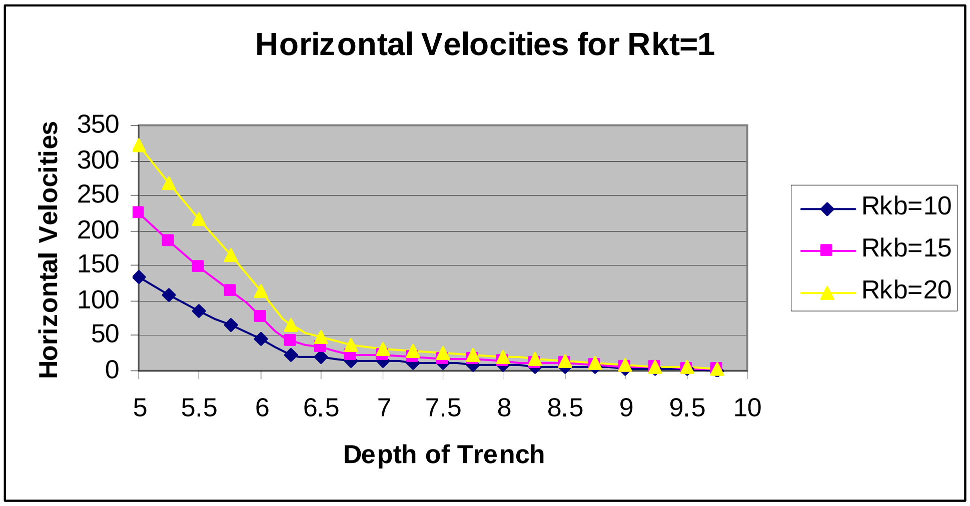


Fig.13: Horizontal Velocities for R_{kt}=1 and R_{kb}=10 to 20

Table.7: Vertical Velocities for trail 1

Set 2: Vertical Velocities						
Along PQ	R_{kt}=1					
	R_{kb}=1	R_{kb}=2	R_{kb}=5	R_{kb}=10	R_{kb}=15	R_{kb}=20
1.0	1.8779	3.1567	4.8541	6.2599	7.0806	7.6155
0.8	2.4257	3.7556	5.6433	7.1426	7.8427	8.2042
0.6	2.7094	3.9741	5.7942	7.0805	7.5392	7.6975
0.4	2.7838	3.9361	5.6912	6.8282	7.1209	7.1583
0.2	2.6906	3.7275	5.4237	6.3977	6.5615	6.5313

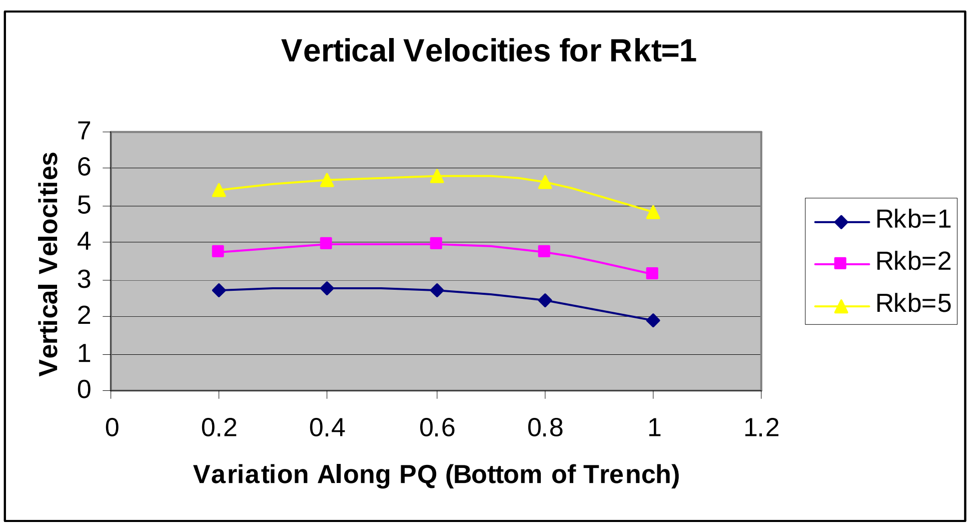


Fig.14: Vertical Velocities for R_{kt}=1 and R_{kb}=1 to 5

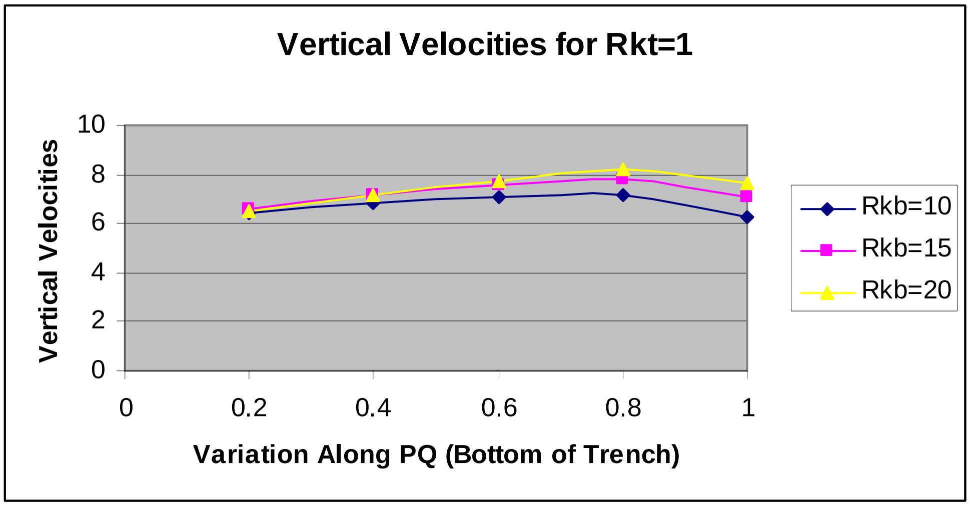


Fig.15: Vertical Velocities for R_{kt}=1 and R_{kb}=10 to 20

Table.8: Horizontal Velocities for trail 2

Set 3: Horizontal Velocities						
	R_{kt}=2					
Depth of Trench	R_{kb}=1	R_{kb}=2	R_{kb}=5	R_{kb}=10	R_{kb}=15	R_{kb}=20
9.75	0.142	0.145	0.838	1.964	3.228	4.567
9.5	0.286	0.291	1.679	3.935	6.471	9.159
9.25	0.432	0.438	2.526	5.921	9.742	13.8
9	0.583	0.589	3.383	7.926	13.055	18.513
8.75	0.74	0.744	4.25	9.952	16.414	23.312
8.5	0.906	0.905	5.129	11.996	19.818	28.202
8.25	1.083	1.072	6.014	14.042	23.243	33.158
8	1.278	1.249	6.897	16.047	26.623	38.099
7.75	1.495	1.437	7.749	17.916	29.794	42.805
7.5	1.747	1.639	8.507	19.815	32.348	46.71
7.25	2.056	1.859	9.409	21.948	35.214	50.969
7	2.467	2.101	10.591	23.743	38.102	55.023
6.75	3.112	2.373	11.613	26.149	41.253	59.457
6.5	2.412	2.685	13.275	34.717	49.573	71.03
6.25	2.266	3.052	19.855	46.722	77.398	111.178
6	2.291	4.499	26.408	66.642	112.144	161.256
5.75	2.451	6.07	33.345	86.94	147.218	211.616
5.5	2.779	9.855	41.125	108.098	183.036	262.614
5.25	3.404	12.06	50.367	130.647	220.035	314.617
5	5.307	14.321	62.009	155.207	258.685	368.007

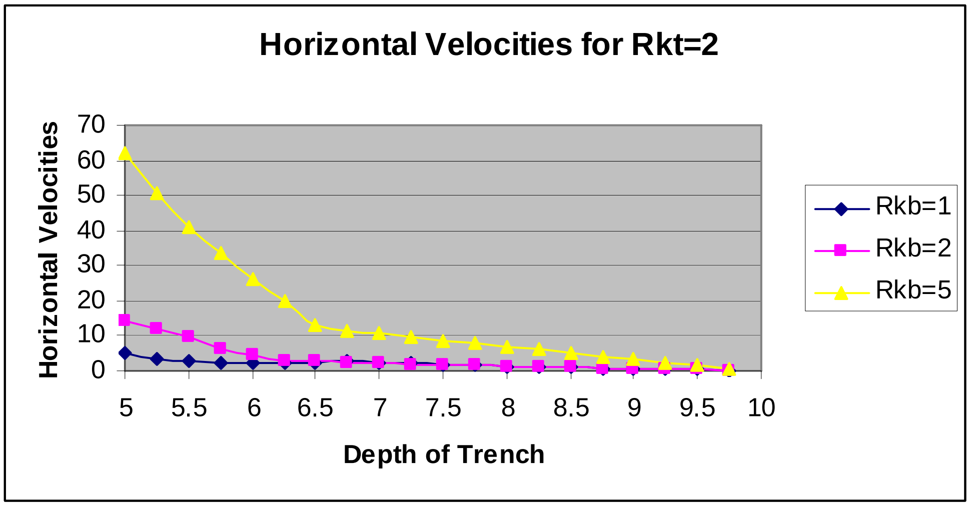


Fig.16: Horizontal Velocities for R_{kt}=2 and R_{kb}=1 to 5

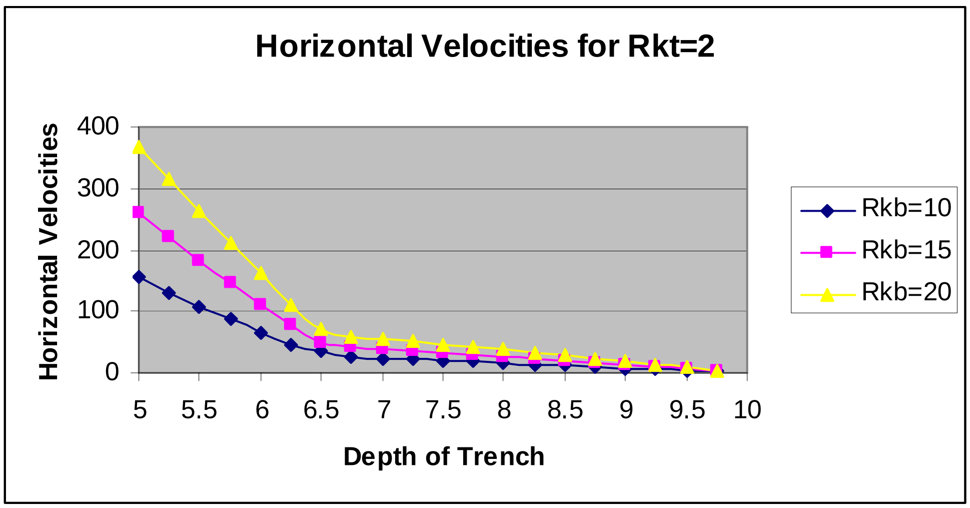


Fig.17: Horizontal Velocities for R_{kt}=2 and R_{kb}=10 to 20

Table.9: Vertical Velocities for trail 2

Set 4: Vertical Velocities						
Along PQ	R_{kt}=2					
	R_{kb}=1	R_{kb}=2	R_{kb}=5	R_{kb}=10	R_{kb}=15	R_{kb}=20
1.0	3.8505	5.7607	7.8877	9.4425	10.3548	10.9589
0.8	4.4764	6.2374	8.2712	9.7511	10.4439	10.801
0.6	4.6788	6.2018	8.0287	9.1789	9.5245	9.5913
0.4	4.5851	5.8856	7.595	8.5227	8.632	8.5257
0.2	4.2826	5.4002	7.0275	7.7234	7.6412	7.4253

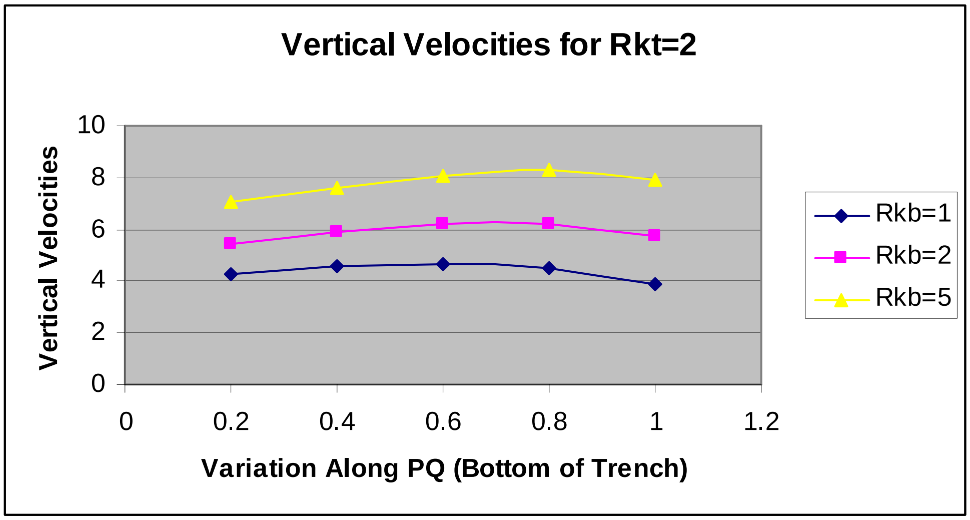


Fig.18: Vertical Velocities for R_{kt}=2 and R_{kb}=1 to 5

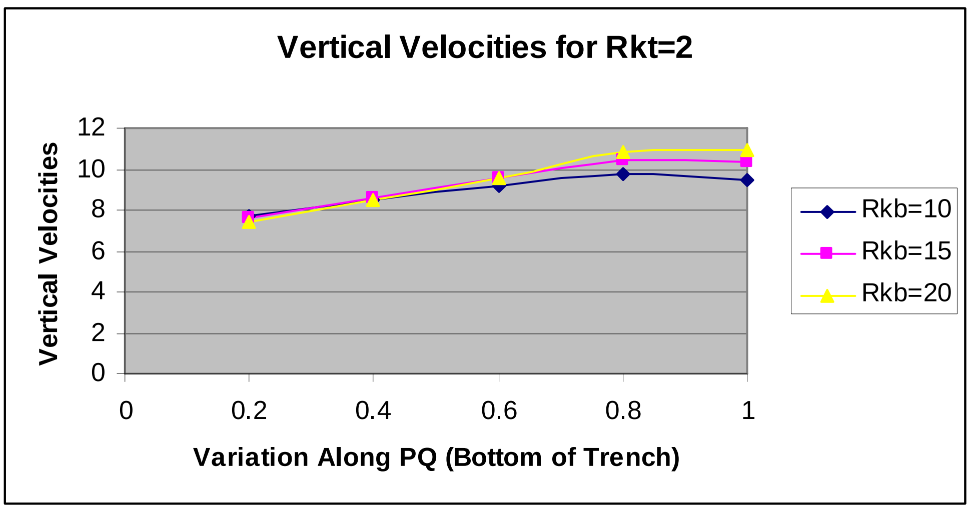


Fig.19: Vertical Velocities for R_{kt}=2 and R_{kb}=10 to 20

Table.10: Horizontal Velocities for trail 3

Set 5: Horizontal Velocities						
Depth of Trench	**R_{kt}=5**					
	R_{kb}=1	**R_{kb}=2**	**R_{kb}=5**	**R_{kb}=10**	**R_{kb}=15**	**R_{kb}=20**
9.75	0.409	0.792	2.195	4.172	6.646	9.331
9.5	0.822	1.591	4.192	8.359	13.314	18.692
9.25	1.243	2.403	5.293	12.577	20.023	28.111
9	1.676	3.235	6.2	16.84	26.794	37.614
8.75	2.126	4.097	8.417	21.163	33.64	47.219
8.5	2.601	4.998	12.446	25.555	40.57	56.932
8.25	3.107	5.951	14.89	30.025	47.577	66.736
8	3.656	6.975	17.353	34.571	54.635	76.576
7.75	4.262	8.093	19.839	39.175	61.67	86.325
7.5	4.946	9.339	21.354	43.79	68.535	96.324
7.25	5.739	10.763	22.906	48.312	75.938	106.274
7	6.688	12.442	23.502	52.529	83.316	117.027
6.75	7.87	14.503	25.156	56.024	91.596	129.173
6.5	4.881	12.162	27.883	73.218	115.699	161.67
6.25	3.992	11.386	31.706	90.451	147.749	209.091
6	3.615	11.383	39.658	108.11	180.118	256.766
5.75	3.541	11.962	47.786	126.594	213.183	305.029
5.5	3.734	13.198	57.165	146.341	247.335	354.22
5.25	4.308	15.496	67.913	167.859	282.994	404.693
5	6.365	20.26	82.224	191.762	320.624	456.826

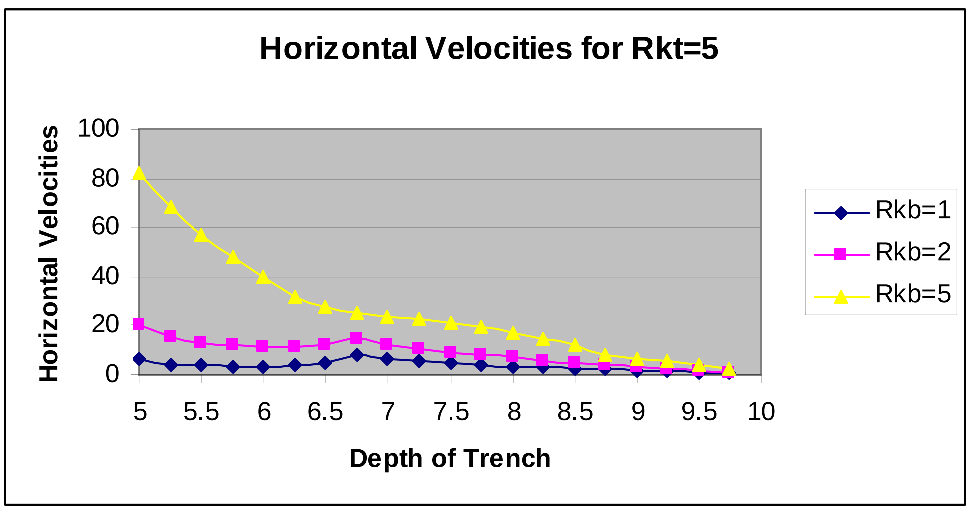


Fig.20: Horizontal Velocities for R_{kt}=5 and R_{kb}=1 to 2

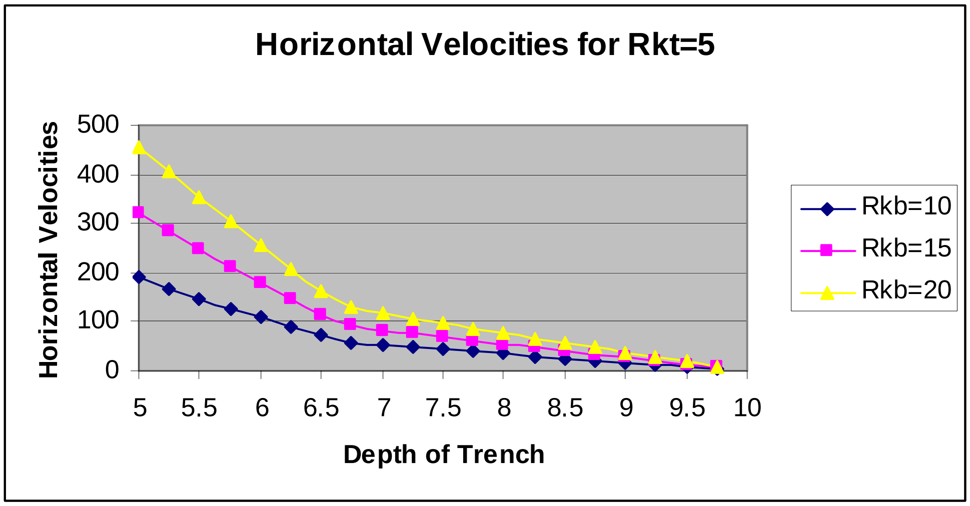


Fig.21: Horizontal Velocities for R_{kt}=5 and R_{kb}=10 to 20

Table.11: Vertical Velocities for trail 3

Set 6: Virtical Velocities						
Along PQ	R_{kt}=5					
	R_{kb}=1	R_{kb}=2	R_{kb}=5	R_{kb}=10	R_{kb}=15	R_{kb}=20
1.0	6.47216	9.27542	11.8426	13.4661	14.4221	15.055
0.8	6.80788	8.8225	10.3913	11.3381	11.7391	11.8932
0.6	6.51171	7.82551	8.8092	9.20489	9.1232	8.89417
0.4	5.90061	6.75895	7.4831	7.51377	7.11693	6.67777
0.2	5.15917	5.73821	6.3402	6.06454	5.45608	4.9192

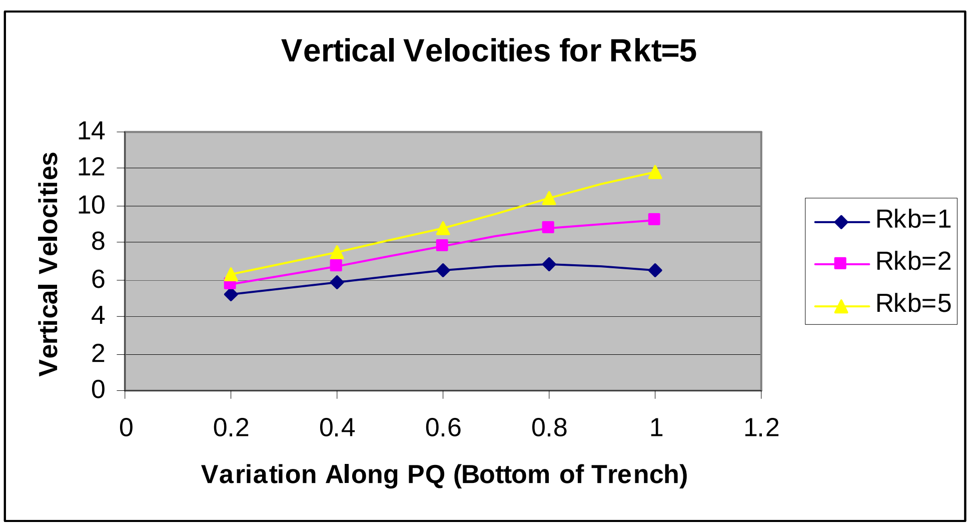


Fig.22: Vertical Velocities for R_{kt}=5 and R_{kb}=1 to 5

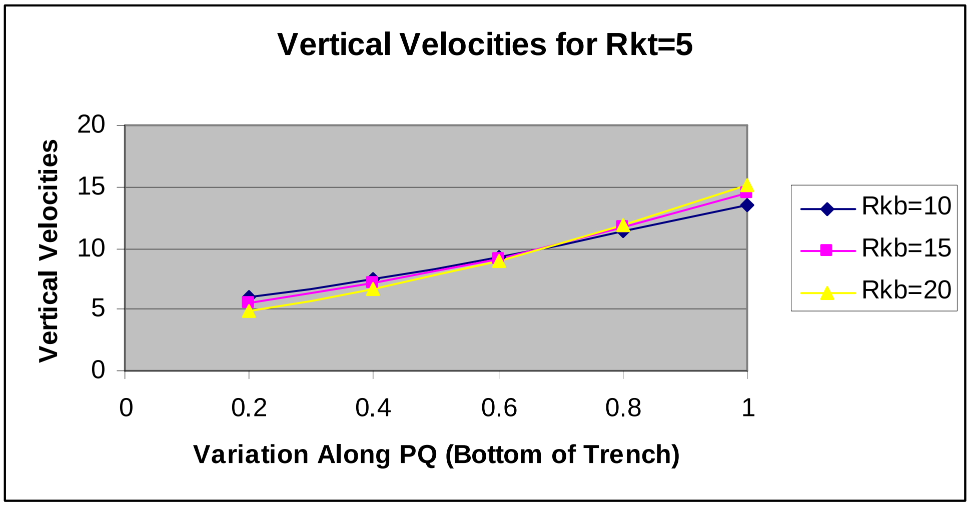


Fig.23: Vertical Velocities for R_{kt}=5 and R_{kb}=10 to 20

Table.12: Horizontal Velocities for trail 4

Set 7: Horizontal Velocities						
Depth of Trench	R_{kt}=10					
	R_{kb}=1	R_{kb}=2	R_{kb}=5	R_{kb}=10	R_{kb}=15	R_{kb}=20
9.75	0.798	1.551	3.72	9.747	11.525	15.85
9.5	1.602	3.112	7.46	18.498	23.094	31.756
9.25	2.418	4.695	11.243	26.255	34.751	47.774
9	3.251	6.311	15.09	35.023	46.542	63.96
8.75	4.108	7.973	19.027	44.804	58.516	80.373
8.5	4.997	9.694	23.081	53.603	70.722	97.075
8.25	5.927	11.493	27.284	61.425	83.216	114.128
8	6.908	13.388	31.672	70.274	96.056	131.598
7.75	7.952	15.404	36.291	78.156	109.307	149.554
7.5	9.076	17.57	41.194	87.079	123.039	168.065
7.25	10.297	19.922	46.446	99.049	137.329	187.202
7	11.639	22.506	52.13	110.077	152.264	207.035
6.75	13.134	25.382	58.351	121.173	167.939	227.627
6.5	7.005	18.783	56.772	132.352	194.742	269.97
6.25	5.284	16	57.199	143.632	222.197	312.795
6	4.503	14.872	59.286	152.033	250.594	356.384
5.75	4.211	14.764	62.974	165.583	280.242	401.031
5.5	4.281	15.575	68.455	183.316	311.478	447.041
5.25	4.796	17.647	76.226	200.276	344.683	494.741
5	6.907	22.426	87.232	226.522	380.29	544.484

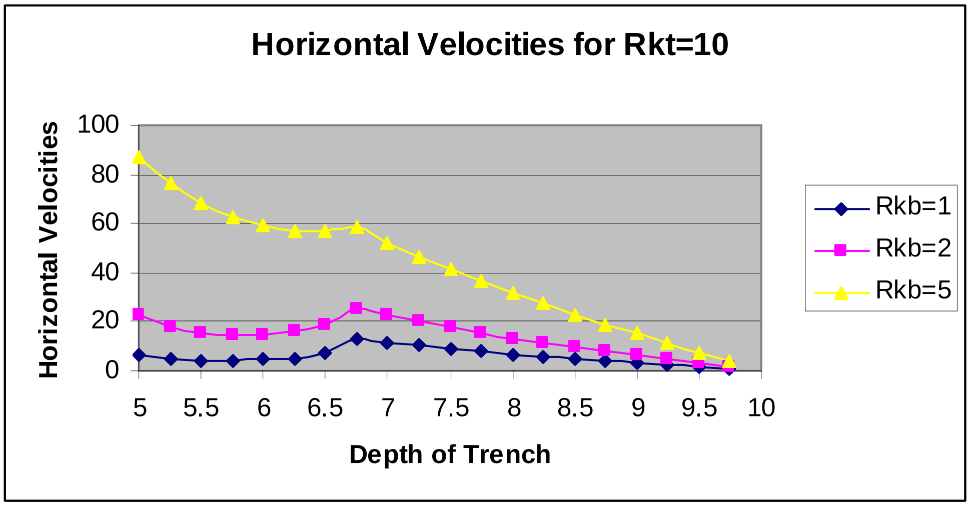


Fig.24: Horizontal Velocities for R_{kt}=10 and R_{kb}=1 to 5

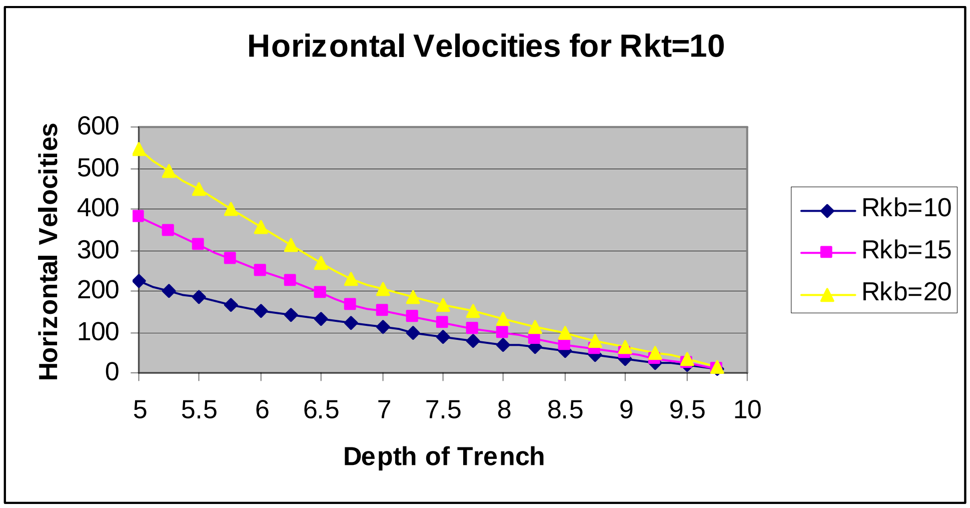


Fig.25: Horizontal Velocities for R_{kt}=10 and R_{kb}=10 to 20

Table.13: Vertical Velocities for trail 4

Set 8: Virtical Velocities						
Along PQ	**R_{kt}=10**					
	R_{kb}=1	**R_{kb}=2**	**R_{kb}=5**	**R_{kb}=10**	**R_{kb}=15**	**R_{kb}=20**
1.0	7.99677	11.3845	14.2182	15.7918	16.6456	17.1748
0.8	7.82195	9.64459	10.3955	10.63	10.6177	10.4872
0.6	6.97084	7.67951	7.62663	7.3265	6.90198	6.46292
0.4	5.92201	6.08931	5.83296	5.2525	4.61228	4.05452
0.2	4.90737	4.83807	4.56603	3.7947	3.05973	2.50267

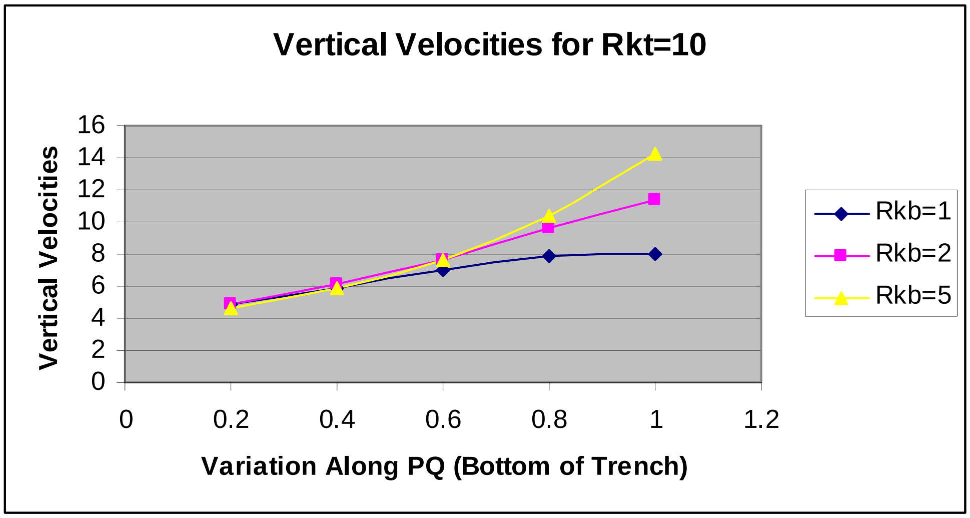


Fig.26: Vertical Velocities for R_{kt}=10 and R_{kb}=1 to 5

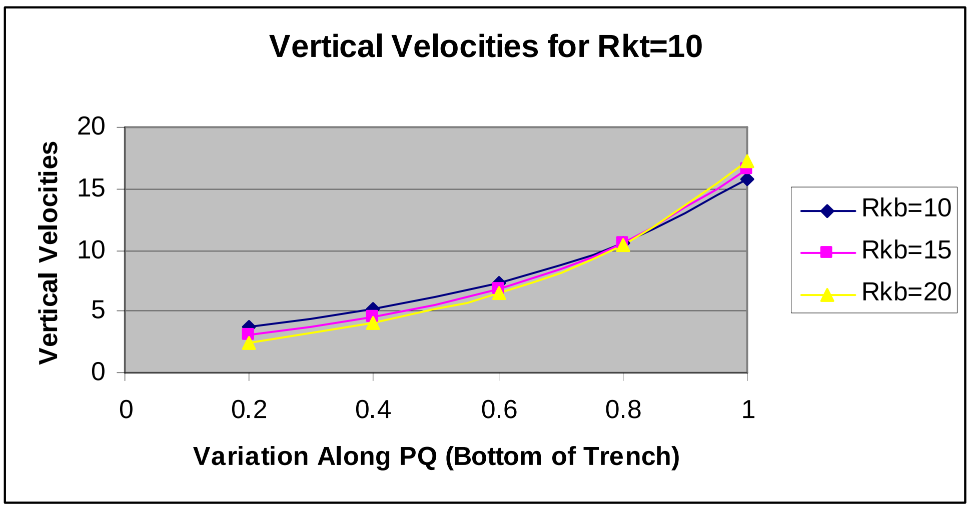


Fig.27: Vertical Velocities for R_{kt}=1 and R_{kb}=10 to 20

Table.14: Horizontal Velocities for trail 5

Set 9: Horizontal Velocities						
Depth of Trench	R_{kt}=15					
	R_{kb}=1	R_{kb}=2	R_{kb}=5	R_{kb}=10	R_{kb}=15	R_{kb}=20
9.75	1.109	2.178	5.223	10.349	15.05	21.413
9.5	2.224	4.367	10.47	20.738	31.103	42.896
9.25	3.35	6.578	15.764	31.207	46.163	64.52
9	4.493	8.823	21.13	41.798	63.235	86.358
8.75	5.659	11.113	26.594	52.554	79.322	108.485
8.5	6.855	13.463	32.184	63.524	95.428	130.982
8.25	8.088	15.887	37.933	74.756	111.559	153.935
8	9.367	18.401	43.873	86.308	130.718	177.436
7.75	10.7	21.023	50.043	98.242	148.912	201.585
7.5	12.099	23.774	56.488	110.628	166.146	226.496
7.25	13.574	26.678	63.258	123.545	184.428	252.29
7	15.14	29.764	70.411	137.083	205.765	279.109
6.75	16.813	33.064	78.016	151.349	228.165	307.107
6.5	8.201	22.983	72.017	158.444	253.64	344.859
6.25	5.946	18.691	69.398	167.409	277.201	383.596
6	4.923	16.772	69.33	178.289	302.861	423.552
5.75	4.511	16.205	71.465	191.229	327.637	464.976
5.5	4.515	16.738	75.828	206.482	353.548	508.14
5.25	4.998	18.653	82.813	224.423	383.616	553.341
5	7.124	23.399	93.32	245.58	419.867	600.907

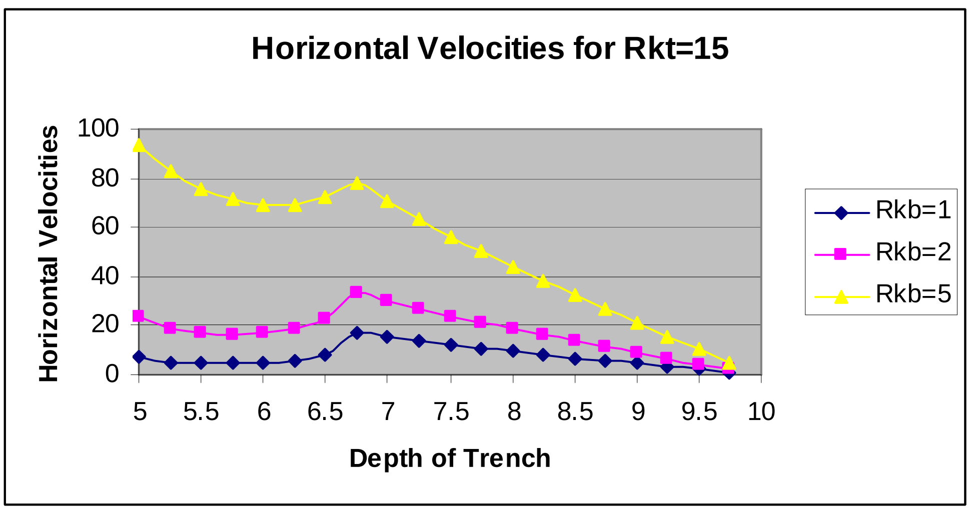


Fig.28: Horizontal Velocities for R_{kt}=15 and R_{kb}=1 to 5

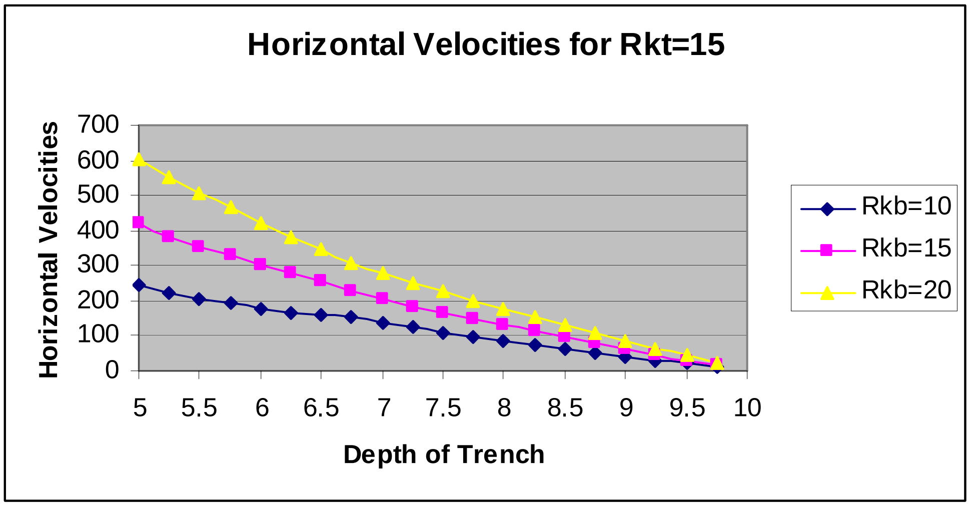


Fig.29: Horizontal Velocities for R_{kt}=15 and R_{kb}=10 to 20

Table.15: Vertical Velocities for trail 5

Set 10: Vertical Velocities						
Along PQ	R_{kt}=15					
	R_{kb}=1	R_{kb}=2	R_{kb}=5	R_{kb}=10	R_{kb}=15	R_{kb}=20
1.0	8.64472	12.2849	15.2048	16.6923	17.4383	17.8706
0.8	8.14515	9.72645	9.841	9.5646	9.2782	8.97762
0.6	6.99722	7.27227	6.5916	5.93537	5.3738	4.87481
0.4	5.74931	5.51311	4.77509	3.972	3.2934	2.74809
0.2	4.64173	4.2456	3.60484	2.71788	2.022	1.53027

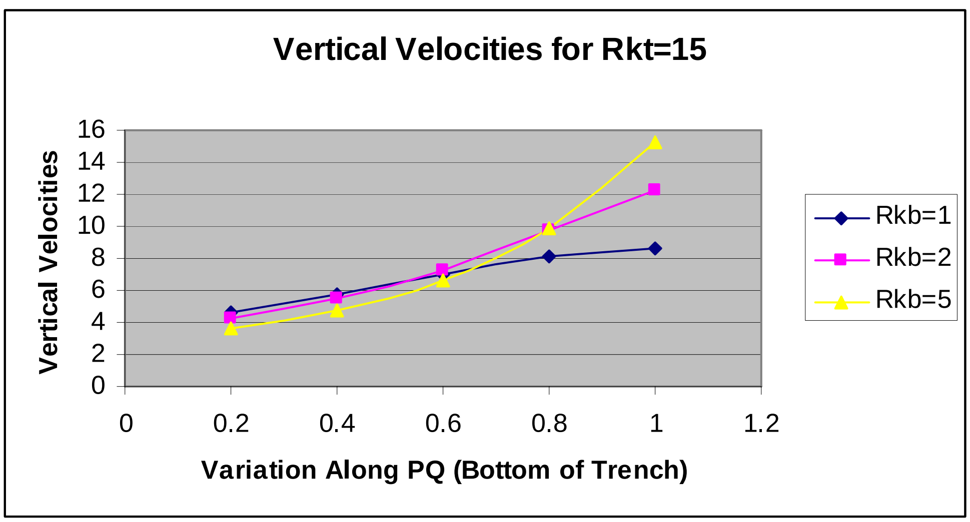


Fig.30: Vertical Velocities for R_{kt}=15 and R_{kb}=1 to 5

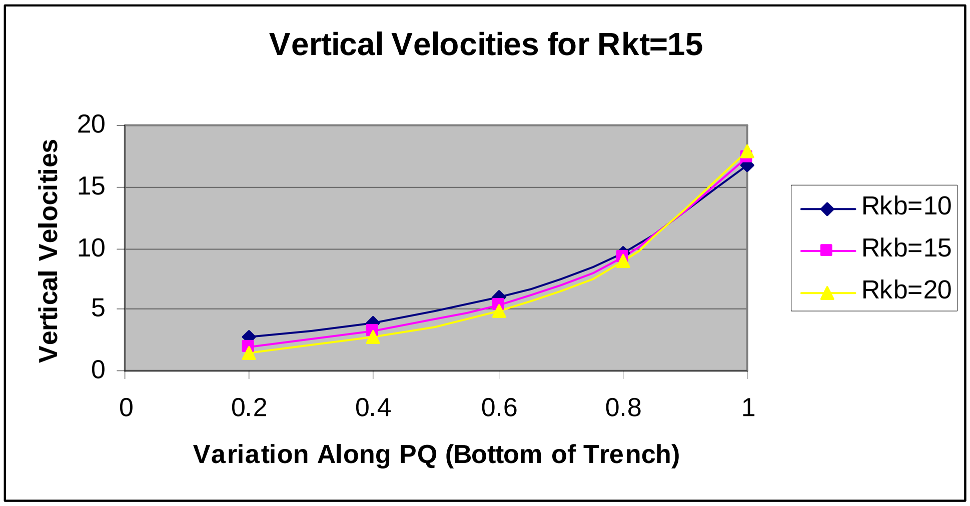


Fig.31: Vertical Velocities for R_{kt}=15 and R_{kb}=10 to 20

Table.16: Horizontal Velocities for trail 6

Set 11: Horizontal Velocities						
Depth of Trench	**R_{kt}=20**					
	R_{kb}=1	**R_{kb}=2**	**R_{kb}=5**	**R_{kb}=10**	**R_{kb}=15**	**R_{kb}=20**
9.75	1.353	2.68	6.46	12.75	19.278	26.304
9.5	2.712	5.37	12.942	25.539	38.611	51.611
9.25	4.08	8.08	19.468	38.407	58.056	77.925
9	5.463	10.82	26.063	51.394	77.668	104.25
8.75	6.866	13.601	32.749	64.543	97.509	130.59
8.5	8.295	16.435	39.552	77.898	117.639	157.948
8.25	9.756	19.332	46.499	91.506	138.124	185.329
8	11.255	22.307	53.618	105.417	159.034	213.738
7.75	12.799	25.373	60.942	119.685	180.443	241.178
7.5	14.395	28.545	68.503	134.369	202.433	270.656
7.25	16.052	31.841	76.341	149.534	225.093	301.177
7	17.779	35.279	84.496	165.25	248.52	331.746
6.75	19.586	38.881	93.016	181.598	272.823	363.371
6.5	8.973	25.939	83.3	184.677	290.909	395.06
6.25	6.353	20.486	78.176	190.397	310.848	428.82
6	5.171	17.988	76.371	198.645	332.768	464.661
5.75	4.683	17.097	77.278	209.45	356.846	503.593
5.5	4.646	17.438	80.763	222.973	383.312	544.629
5.25	5.109	19.245	87.134	239.527	412.46	585.781
5	7.242	23.959	97.239	259.592	444.655	632.065

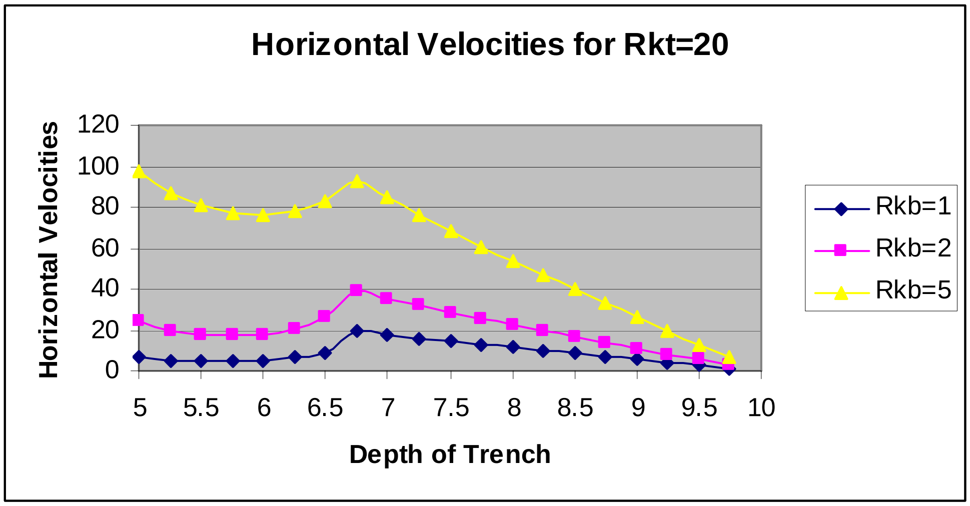


Fig.32: Horizontal Velocities for R_{kt}=20 and R_{kb}=1 to 5

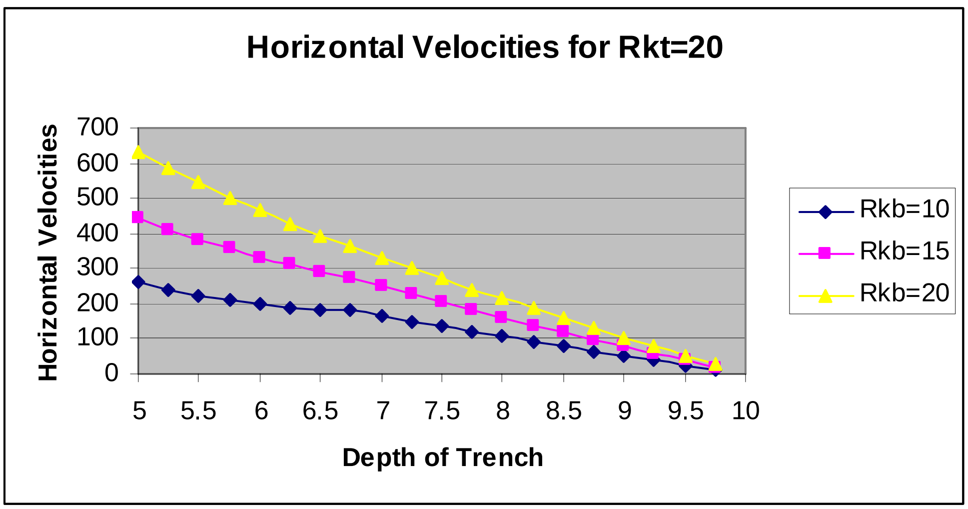


Fig.33: Horizontal Velocities for R_{kt}=20 and R_{kb}=10 to 20

Table.17: Vertical Velocities for trail 6

Set 12: Vertical Velocities						
Along PQ	R_{kt}=20					
	R_{kb}=1	R_{kb}=2	R_{kb}=5	R_{kb}=10	R_{kb}=15	R_{kb}=20
1.0	9.0031	12.7799	15.7312	17.1458	17.8109	18.1744
0.8	8.2897	9.6713	9.29433	8.63422	8.15532	7.7449
0.6	6.96273	6.93601	5.84848	4.9889	4.36887	3.8588
0.4	5.60486	5.11916	4.11268	3.21406	2.54503	2.0338
0.2	4.45767	3.87541	3.04654	2.13387	1.49133	1.0594

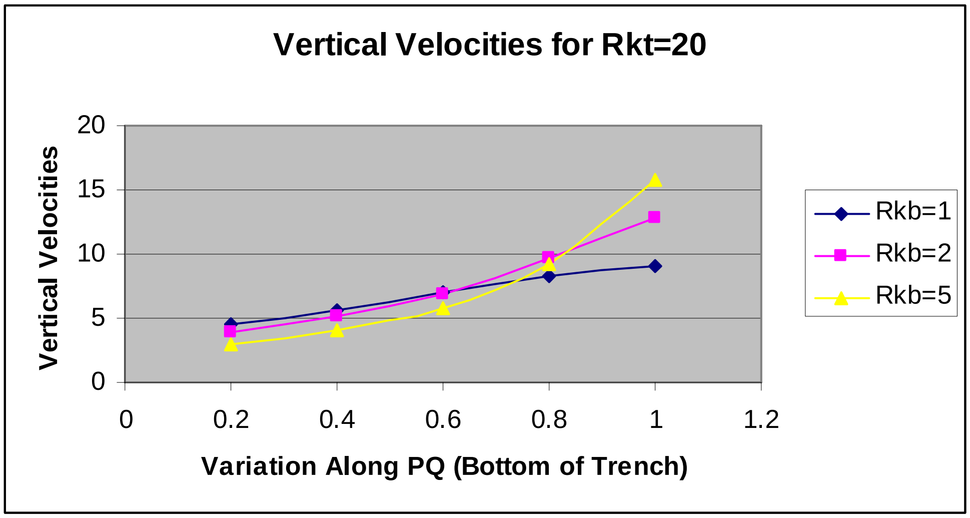


Fig.34: Vertical Velocities for R_{kt}=20 and R_{kb}=1 to 5

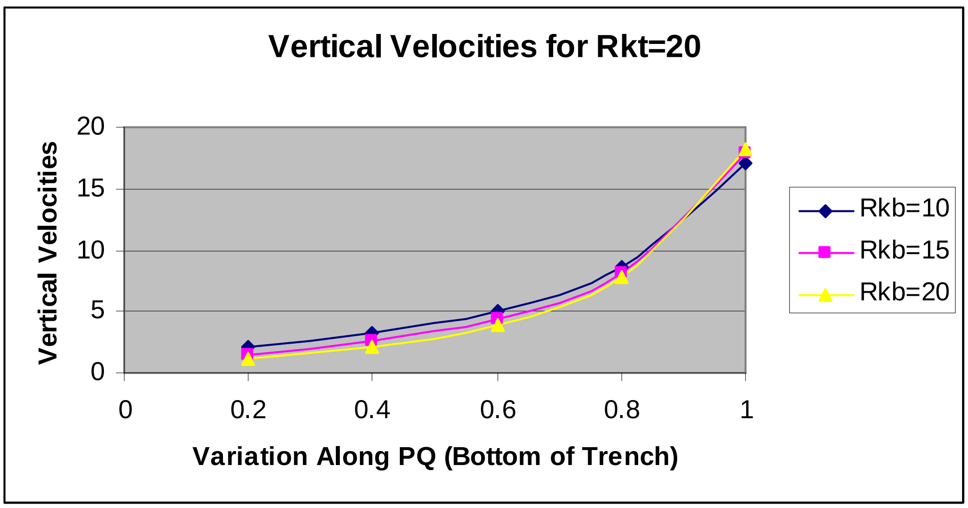


Fig.35: Vertical Velocities for R_{kt}=20 and R_{kb}=10 to 20

Table.18: Discharge from Trench Drain due to Horizontal Velocities

R_{kt}	R_{kb}=1	R_{kb}=2	R_{kb}=5	R_{kb}=10	R_{kb}=15	R_{kb}=20
1	19.558	55.531	223.243	578.859	984.691	1426.648
2	37.237	67.384	324.969	810.327	1343.394	1924.092
5	75.581	181.029	538.078	1297.427	2131.956	3024.629
10	119.094	279.068	841.133	2018.877	3098.526	4348.443
15	149.689	348.554	1045.558	2373.937	3824.364	5331.983
20	172.568	400.696	1200.91	2723.151	4367.029	6010.432

Table.19: Discharge from Trench Drain Due to Vertical velocities

Discharge from Trench Drain Due to Vertical velocities						
R_{kt}	R_{kb}=1	R_{kb}=2	R_{kb}=5	R_{kb}=10	R_{kb}=15	R_{kb}=20
1	12.4874	18.55	27.4065	33.7089	36.1449	37.2068
2	21.8734	29.4857	38.8101	44.6186	46.5964	47.3022
5	33.61894	39.63595	42.63935	42.7955	41.83727	40.68212
10	33.61894	39.63595	42.63935	42.7955	41.83727	40.68212
15	34.17813	39.04235	40.01733	38.88212	37.4057	36.00142
20	34.31806	38.38173	38.03323	36.11684	34.37149	32.8713

Table.20: Total Discharge from Trench Drain

R_{kt}	R_{kb}=1	R_{kb}=2	R_{kb}=5	R_{kb}=10	R_{kb}=15	R_{kb}=20
1	32.0454	74.081	250.6495	612.5679	1020.836	1463.855
2	59.1104	96.8697	363.7791	854.9456	1389.99	1971.394
5	106.4325	219.4496	582.9444	1345.014	2179.813	3072.068
10	152.7129	318.704	883.7724	2061.673	3140.363	4389.125
15	183.8671	387.5964	1085.575	2412.819	3861.77	5367.984
20	206.8861	439.0777	1238.943	2759.268	4401.4	6043.303

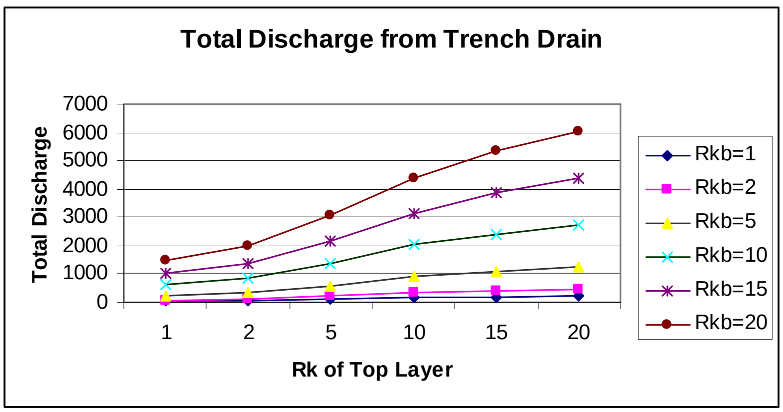


Fig.36: Accumulated Fig. 36: Accumulated Discharge of Horizontal and Vertical Velocities

From the above observations it is clear that the vertical flow of discharge is taking place from the bottom of the trench instead of water to be sinking in to soil. After observation this flow phenomena, it is also clear from the concepts of hydraulics. The pressure head upto the bottom of the trench is tending the water to flow outwards from the domain.

Chapter 8

CONCLUSIONS AND DISCUSSIONS

Drainage is one of the most widely used methods for improving stability of saturated soil slopes. Subsurface drainage must be designed to reduce the water pressures acting on actual or potential slip surfaces; in this way, the value of the pore pressure (u) is reduced, thereby producing an increase in the factor of safety. Out of various methods, trench drains are the cheapest and most widely used method. They are applicable to slips of moderate depth, but for deeper failures other methods may be more appropriate.

The quantity of water to be discharged from soil masses is the primary basis of design of horizontal drains. Where as the average lowering of peziometric pressure either along the slip surface or at level along the bottom of drains, required to attain the changes in the factor of safety and is used as the basis for the designing trench drains. Here Darcy's law is considered for this analysis which is describing the rate of flow of water through porous media. Due to the complex geometry of the slopes, non-homogeneous nature of soil/rock media and three dimensional and unsteady flow of ground water, the design of trench drains entirely from theoretical considerations become extreme difficult task.

By developing the Mathematical model with the help of the numerical data obtained from Finite Element Methods (FEM) on the maximum quantity of discharge of water flowing into the trench drain. The Mathematical model will be of great use for developing guidelines for designing the trench drainage system within the isotropic/anisotropic soil media. In order to provide design guidelines for designing trench drains placed in a more common isotropic/anisotropic soil media, we need to investigated the performance of two dimensional steady state flow of water within a parallel rectangular trench drainage system and obtained pore water pressures by applying finite element method (FEM) and discussed the relationship between the piezometric head and various other factors separately and explained the variation of piezometric head between the drains along the drain and the discharge of water flowing within the drains. It helps to draw various diagrams taking account of depth, width and spacing of trench drains for determining equipotential lines, the magnitude of piezometric head within the flow domain and the discharge of water (Q') flowing into the drains.

Numerical values in the Table will help in providing guidelines for designing the trench drainage system. The present work has attempted to show how the models are useful for understanding the relationship between the maximum quantity of discharge of water and various other factors separately.

1. The present model values compare quite favorably with the numerical results. Equations 4 to 6 are found to be statistically fit at 5% significant level.
2. It is revealed from the findings that to achieve maximum quantity of discharge of water, optimum spacing will have to be maintained within the flow domain.
3. It has also been found that the quantity of discharge of water flowing into the drain is directly proportional to the spacing, to the limit up to the optimum spacing beyond which it becomes constant. Therefore in a soil medium with deeper drains and higher optimum spacing more discharge of water is obtained.
4. For soils with higher ratios of horizontal to vertical permeability R_k, drains should be spaced comparatively at closer spacing as the value of $(S/B)_{opt}$. decreases with the increase in the R_k value.

Because of FEM no assumptions need to be made in advance about the shape or location of the failure surface. Failure occurs naturally the zone within the soil mass in which the shear is unable to sustain the applied shear stress due to mainly gravity i.e. gravity of the soil. Since there is no concept of slices in the FEM approach, there is no need for assumptions about the slice slide forces. The finite element method preserves global equilibrium until failure is reached. Since this method has possibility understanding failure limits, it can be able to monitor all kinds of failures.

SCOPE FOR FUTURE WORK

1. More parameters can be adopted.
2. Adjacent layer effect can be studied.
3. Trails can be made for some more combinations of trench dimensions.
4. Trails can be conduct for different depths of stratified soil.
5. Different number of stratifications can try depending upon field conditions.
6. Results of analysis can tally with existed trench drains.
7. Mathematical model can develop after analyzing for various combinations of trench parameters for double layer problem.
8. Transient analysis can try.
9. Trapezoidal shape trench drain can try.

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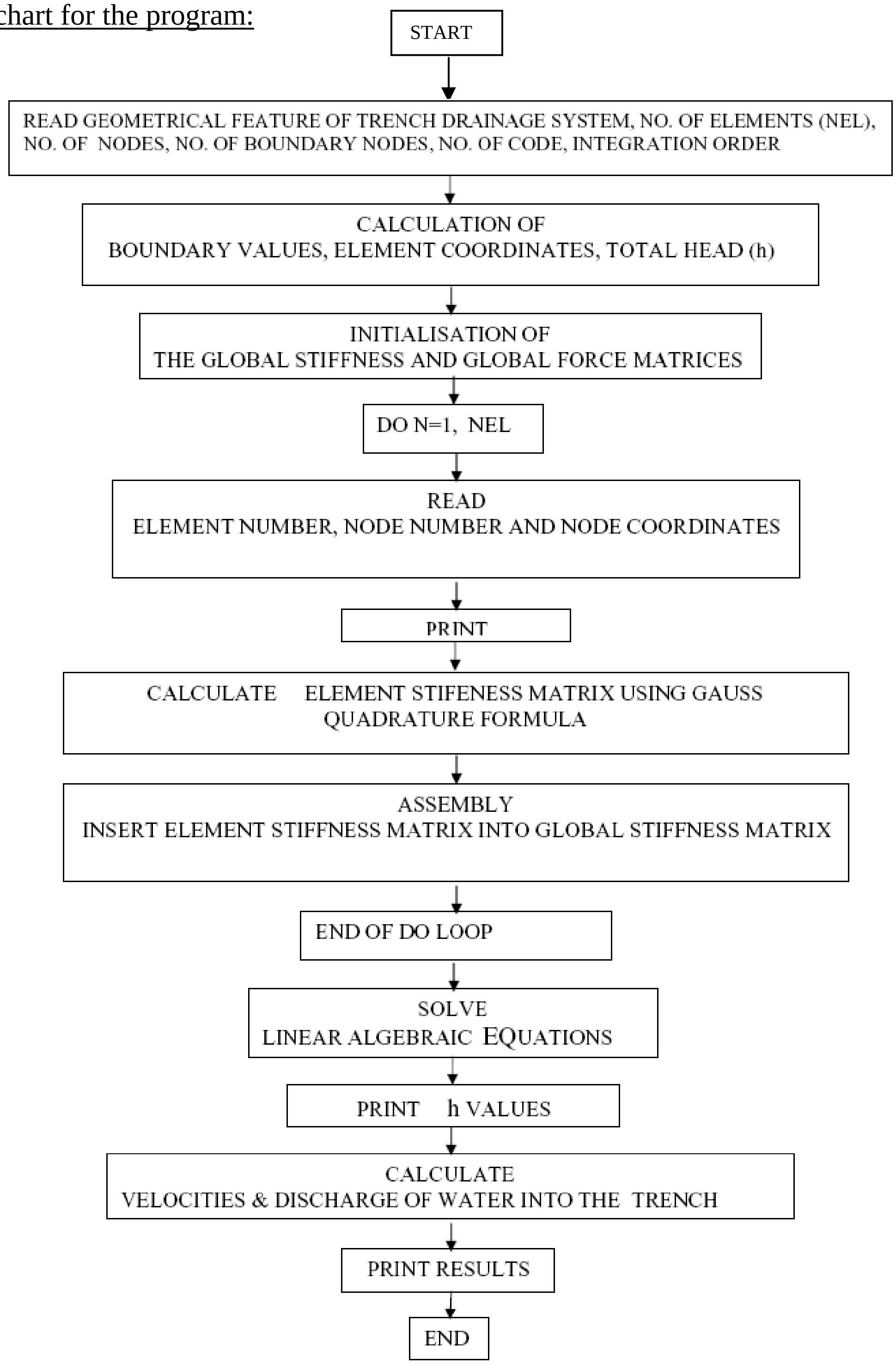
APPENDIX II

Flow chart for the program:



APPENDIX II

Output generated from the program:

```
 DW=10.000  D1= 5.000  BRE= 1.000  ACR= 5.000  RK= 1.00


    NEL    = 335
    NNODE  = 380
    NBN    = 36
    NBPT   = 8
    NBTU   = 16
    NBSU   = 28
    INTORD = 4
    NBRS   = 11
    NBRQ   = 20
    NBPQ   = 5
```

1	1.20	10.00	1.00	10.00	1.00	9.75	1.20	9.75	2	1	12	13
2	1.40	10.00	1.20	10.00	1.20	9.75	1.40	9.75	3	2	13	14
3	1.60	10.00	1.40	10.00	1.40	9.75	1.60	9.75	4	3	14	15
4	1.80	10.00	1.60	10.00	1.60	9.75	1.80	9.75	5	4	15	16
5	2.00	10.00	1.80	10.00	1.80	9.75	2.00	9.75	6	5	16	17
6	2.50	10.00	2.00	10.00	2.00	9.75	2.50	9.75	7	6	17	18
7	3.00	10.00	2.50	10.00	2.50	9.75	3.00	9.75	8	7	18	19
8	3.50	10.00	3.00	10.00	3.00	9.75	3.50	9.75	9	8	19	20
9	4.00	10.00	3.50	10.00	3.50	9.75	4.00	9.75	10	9	20	21
10	5.00	10.00	4.00	10.00	4.00	9.75	5.00	9.75	11	10	21	22
11	1.20	9.75	1.00	9.75	1.00	9.50	1.20	9.50	13	12	23	24
12	1.40	9.75	1.20	9.75	1.20	9.50	1.40	9.50	14	13	24	25
13	1.60	9.75	1.40	9.75	1.40	9.50	1.60	9.50	15	14	25	26
14	1.80	9.75	1.60	9.75	1.60	9.50	1.80	9.50	16	15	26	27
15	2.00	9.75	1.80	9.75	1.80	9.50	2.00	9.50	17	16	27	28
16	2.50	9.75	2.00	9.75	2.00	9.50	2.50	9.50	18	17	28	29
17	3.00	9.75	2.50	9.75	2.50	9.50	3.00	9.50	19	18	29	30
18	3.50	9.75	3.00	9.75	3.00	9.50	3.50	9.50	20	19	30	31
19	4.00	9.75	3.50	9.75	3.50	9.50	4.00	9.50	21	20	31	32
20	5.00	9.75	4.00	9.75	4.00	9.50	5.00	9.50	22	21	32	33

21	1.20	9.50	1.00	9.50	1.00	9.25	1.20	9.25	24	23	34	35
22	1.40	9.50	1.20	9.50	1.20	9.25	1.40	9.25	25	24	35	36
23	1.60	9.50	1.40	9.50	1.40	9.25	1.60	9.25	26	25	36	37
24	1.80	9.50	1.60	9.50	1.60	9.25	1.80	9.25	27	26	37	38
25	2.00	9.50	1.80	9.50	1.80	9.25	2.00	9.25	28	27	38	39
26	2.50	9.50	2.00	9.50	2.00	9.25	2.50	9.25	29	28	39	40
27	3.00	9.50	2.50	9.50	2.50	9.25	3.00	9.25	30	29	40	41
28	3.50	9.50	3.00	9.50	3.00	9.25	3.50	9.25	31	30	41	42
29	4.00	9.50	3.50	9.50	3.50	9.25	4.00	9.25	32	31	42	43
30	5.00	9.50	4.00	9.50	4.00	9.25	5.00	9.25	33	32	43	44
31	1.20	9.25	1.00	9.25	1.00	9.00	1.20	9.00	35	34	45	46
32	1.40	9.25	1.20	9.25	1.20	9.00	1.40	9.00	36	35	46	47
33	1.60	9.25	1.40	9.25	1.40	9.00	1.60	9.00	37	36	47	48
34	1.80	9.25	1.60	9.25	1.60	9.00	1.80	9.00	38	37	48	49
35	2.00	9.25	1.80	9.25	1.80	9.00	2.00	9.00	39	38	49	50
36	2.50	9.25	2.00	9.25	2.00	9.00	2.50	9.00	40	39	50	51
37	3.00	9.25	2.50	9.25	2.50	9.00	3.00	9.00	41	40	51	52
38	3.50	9.25	3.00	9.25	3.00	9.00	3.50	9.00	42	41	52	53
39	4.00	9.25	3.50	9.25	3.50	9.00	4.00	9.00	43	42	53	54
40	5.00	9.25	4.00	9.25	4.00	9.00	5.00	9.00	44	43	54	55
41	1.20	9.00	1.00	9.00	1.00	8.75	1.20	8.75	46	45	56	57
42	1.40	9.00	1.20	9.00	1.20	8.75	1.40	8.75	47	46	57	58
43	1.60	9.00	1.40	9.00	1.40	8.75	1.60	8.75	48	47	58	59
44	1.80	9.00	1.60	9.00	1.60	8.75	1.80	8.75	49	48	59	60
45	2.00	9.00	1.80	9.00	1.80	8.75	2.00	8.75	50	49	60	61
46	2.50	9.00	2.00	9.00	2.00	8.75	2.50	8.75	51	50	61	62
47	3.00	9.00	2.50	9.00	2.50	8.75	3.00	8.75	52	51	62	63
48	3.50	9.00	3.00	9.00	3.00	8.75	3.50	8.75	53	52	63	64

49	4.00	9.00	3.50	9.00	3.50	8.75	4.00	8.75	54	53	64	65
50	5.00	9.00	4.00	9.00	4.00	8.75	5.00	8.75	55	54	65	66
51	1.20	8.75	1.00	8.75	1.00	8.50	1.20	8.50	57	56	67	68
52	1.40	8.75	1.20	8.75	1.20	8.50	1.40	8.50	58	57	68	69
53	1.60	8.75	1.40	8.75	1.40	8.50	1.60	8.50	59	58	69	70
54	1.80	8.75	1.60	8.75	1.60	8.50	1.80	8.50	60	59	70	71
55	2.00	8.75	1.80	8.75	1.80	8.50	2.00	8.50	61	60	71	72
56	2.50	8.75	2.00	8.75	2.00	8.50	2.50	8.50	62	61	72	73
57	3.00	8.75	2.50	8.75	2.50	8.50	3.00	8.50	63	62	73	74
58	3.50	8.75	3.00	8.75	3.00	8.50	3.50	8.50	64	63	74	75
59	4.00	8.75	3.50	8.75	3.50	8.50	4.00	8.50	65	64	75	76
60	5.00	8.75	4.00	8.75	4.00	8.50	5.00	8.50	66	65	76	77
61	1.20	8.50	1.00	8.50	1.00	8.25	1.20	8.25	68	67	78	79
62	1.40	8.50	1.20	8.50	1.20	8.25	1.40	8.25	69	68	79	80
63	1.60	8.50	1.40	8.50	1.40	8.25	1.60	8.25	70	69	80	81
64	1.80	8.50	1.60	8.50	1.60	8.25	1.80	8.25	71	70	81	82
65	2.00	8.50	1.80	8.50	1.80	8.25	2.00	8.25	72	71	82	83
66	2.50	8.50	2.00	8.50	2.00	8.25	2.50	8.25	73	72	83	84
67	3.00	8.50	2.50	8.50	2.50	8.25	3.00	8.25	74	73	84	85
68	3.50	8.50	3.00	8.50	3.00	8.25	3.50	8.25	75	74	85	86
69	4.00	8.50	3.50	8.50	3.50	8.25	4.00	8.25	76	75	86	87
70	5.00	8.50	4.00	8.50	4.00	8.25	5.00	8.25	77	76	87	88
71	1.20	8.25	1.00	8.25	1.00	8.00	1.20	8.00	79	78	89	90
72	1.40	8.25	1.20	8.25	1.20	8.00	1.40	8.00	80	79	90	91
73	1.60	8.25	1.40	8.25	1.40	8.00	1.60	8.00	81	80	91	92
74	1.80	8.25	1.60	8.25	1.60	8.00	1.80	8.00	82	81	92	93
75	2.00	8.25	1.80	8.25	1.80	8.00	2.00	8.00	83	82	93	94
76	2.50	8.25	2.00	8.25	2.00	8.00	2.50	8.00	84	83	94	95
77	3.00	8.25	2.50	8.25	2.50	8.00	3.00	8.00	85	84	95	96

78	3.50	8.25	3.00	8.25	3.00	8.00	3.50	8.00	86	85	96	97
79	4.00	8.25	3.50	8.25	3.50	8.00	4.00	8.00	87	86	97	98
80	5.00	8.25	4.00	8.25	4.00	8.00	5.00	8.00	88	87	98	99
81	1.20	8.00	1.00	8.00	1.00	7.75	1.20	7.75	90	89	100	101
82	1.40	8.00	1.20	8.00	1.20	7.75	1.40	7.75	91	90	101	102
83	1.60	8.00	1.40	8.00	1.40	7.75	1.60	7.75	92	91	102	103
84	1.80	8.00	1.60	8.00	1.60	7.75	1.80	7.75	93	92	103	104
85	2.00	8.00	1.80	8.00	1.80	7.75	2.00	7.75	94	93	104	105
86	2.50	8.00	2.00	8.00	2.00	7.75	2.50	7.75	95	94	105	106
87	3.00	8.00	2.50	8.00	2.50	7.75	3.00	7.75	96	95	106	107
88	3.50	8.00	3.00	8.00	3.00	7.75	3.50	7.75	97	96	107	108
89	4.00	8.00	3.50	8.00	3.50	7.75	4.00	7.75	98	97	108	109
90	5.00	8.00	4.00	8.00	4.00	7.75	5.00	7.75	99	98	109	110
91	1.20	7.75	1.00	7.75	1.00	7.50	1.20	7.50	101	100	111	112
92	1.40	7.75	1.20	7.75	1.20	7.50	1.40	7.50	102	101	112	113
93	1.60	7.75	1.40	7.75	1.40	7.50	1.60	7.50	103	102	113	114
94	1.80	7.75	1.60	7.75	1.60	7.50	1.80	7.50	104	103	114	115
95	2.00	7.75	1.80	7.75	1.80	7.50	2.00	7.50	105	104	115	116
96	2.50	7.75	2.00	7.75	2.00	7.50	2.50	7.50	106	105	116	117
97	3.00	7.75	2.50	7.75	2.50	7.50	3.00	7.50	107	106	117	118
98	3.50	7.75	3.00	7.75	3.00	7.50	3.50	7.50	108	107	118	119
99	4.00	7.75	3.50	7.75	3.50	7.50	4.00	7.50	109	108	119	120
100	5.00	7.75	4.00	7.75	4.00	7.50	5.00	7.50	110	109	120	121
101	1.20	7.50	1.00	7.50	1.00	7.25	1.20	7.25	112	111	122	123
102	1.40	7.50	1.20	7.50	1.20	7.25	1.40	7.25	113	112	123	124
103	1.60	7.50	1.40	7.50	1.40	7.25	1.60	7.25	114	113	124	125
104	1.80	7.50	1.60	7.50	1.60	7.25	1.80	7.25	115	114	125	126
105	2.00	7.50	1.80	7.50	1.80	7.25	2.00	7.25	116	115	126	127

106	2.50	7.50	2.00	7.50	2.00	7.25	2.50	7.25	117	116	127	128
107	3.00	7.50	2.50	7.50	2.50	7.25	3.00	7.25	118	117	128	129
108	3.50	7.50	3.00	7.50	3.00	7.25	3.50	7.25	119	118	129	130
109	4.00	7.50	3.50	7.50	3.50	7.25	4.00	7.25	120	119	130	131
110	5.00	7.50	4.00	7.50	4.00	7.25	5.00	7.25	121	120	131	132
111	1.20	7.25	1.00	7.25	1.00	7.00	1.20	7.00	123	122	133	134
112	1.40	7.25	1.20	7.25	1.20	7.00	1.40	7.00	124	123	134	135
113	1.60	7.25	1.40	7.25	1.40	7.00	1.60	7.00	125	124	135	136
114	1.80	7.25	1.60	7.25	1.60	7.00	1.80	7.00	126	125	136	137
115	2.00	7.25	1.80	7.25	1.80	7.00	2.00	7.00	127	126	137	138
116	2.50	7.25	2.00	7.25	2.00	7.00	2.50	7.00	128	127	138	139
117	3.00	7.25	2.50	7.25	2.50	7.00	3.00	7.00	129	128	139	140
118	3.50	7.25	3.00	7.25	3.00	7.00	3.50	7.00	130	129	140	141
119	4.00	7.25	3.50	7.25	3.50	7.00	4.00	7.00	131	130	141	142
120	5.00	7.25	4.00	7.25	4.00	7.00	5.00	7.00	132	131	142	143
121	1.20	7.00	1.00	7.00	1.00	6.75	1.20	6.75	134	133	144	145
122	1.40	7.00	1.20	7.00	1.20	6.75	1.40	6.75	135	134	145	146
123	1.60	7.00	1.40	7.00	1.40	6.75	1.60	6.75	136	135	146	147
124	1.80	7.00	1.60	7.00	1.60	6.75	1.80	6.75	137	136	147	148
125	2.00	7.00	1.80	7.00	1.80	6.75	2.00	6.75	138	137	148	149
126	2.50	7.00	2.00	7.00	2.00	6.75	2.50	6.75	139	138	149	150
127	3.00	7.00	2.50	7.00	2.50	6.75	3.00	6.75	140	139	150	151
128	3.50	7.00	3.00	7.00	3.00	6.75	3.50	6.75	141	140	151	152
129	4.00	7.00	3.50	7.00	3.50	6.75	4.00	6.75	142	141	152	153
130	5.00	7.00	4.00	7.00	4.00	6.75	5.00	6.75	143	142	153	154
131	1.20	6.75	1.00	6.75	1.00	6.50	1.20	6.50	145	144	155	156
132	1.40	6.75	1.20	6.75	1.20	6.50	1.40	6.50	146	145	156	157
133	1.60	6.75	1.40	6.75	1.40	6.50	1.60	6.50	147	146	157	158
134	1.80	6.75	1.60	6.75	1.60	6.50	1.80	6.50	148	147	158	159

135	2.00	6.75	1.80	6.75	1.80	6.50	2.00	6.50	149	148	159	160
136	2.50	6.75	2.00	6.75	2.00	6.50	2.50	6.50	150	149	160	161
137	3.00	6.75	2.50	6.75	2.50	6.50	3.00	6.50	151	150	161	162
138	3.50	6.75	3.00	6.75	3.00	6.50	3.50	6.50	152	151	162	163
139	4.00	6.75	3.50	6.75	3.50	6.50	4.00	6.50	153	152	163	164
140	5.00	6.75	4.00	6.75	4.00	6.50	5.00	6.50	154	153	164	165
141	1.20	6.50	1.00	6.50	1.00	6.25	1.20	6.25	156	155	166	167
142	1.40	6.50	1.20	6.50	1.20	6.25	1.40	6.25	157	156	167	168
143	1.60	6.50	1.40	6.50	1.40	6.25	1.60	6.25	158	157	168	169
144	1.80	6.50	1.60	6.50	1.60	6.25	1.80	6.25	159	158	169	170
145	2.00	6.50	1.80	6.50	1.80	6.25	2.00	6.25	160	159	170	171
146	2.50	6.50	2.00	6.50	2.00	6.25	2.50	6.25	161	160	171	172
147	3.00	6.50	2.50	6.50	2.50	6.25	3.00	6.25	162	161	172	173
148	3.50	6.50	3.00	6.50	3.00	6.25	3.50	6.25	163	162	173	174
149	4.00	6.50	3.50	6.50	3.50	6.25	4.00	6.25	164	163	174	175
150	5.00	6.50	4.00	6.50	4.00	6.25	5.00	6.25	165	164	175	176
151	1.20	6.25	1.00	6.25	1.00	6.00	1.20	6.00	167	166	177	178
152	1.40	6.25	1.20	6.25	1.20	6.00	1.40	6.00	168	167	178	179
153	1.60	6.25	1.40	6.25	1.40	6.00	1.60	6.00	169	168	179	180
154	1.80	6.25	1.60	6.25	1.60	6.00	1.80	6.00	170	169	180	181
155	2.00	6.25	1.80	6.25	1.80	6.00	2.00	6.00	171	170	181	182
156	2.50	6.25	2.00	6.25	2.00	6.00	2.50	6.00	172	171	182	183
157	3.00	6.25	2.50	6.25	2.50	6.00	3.00	6.00	173	172	183	184
158	3.50	6.25	3.00	6.25	3.00	6.00	3.50	6.00	174	173	184	185
159	4.00	6.25	3.50	6.25	3.50	6.00	4.00	6.00	175	174	185	186
160	5.00	6.25	4.00	6.25	4.00	6.00	5.00	6.00	176	175	186	187
161	1.20	6.00	1.00	6.00	1.00	5.75	1.20	5.75	178	177	188	189
162	1.40	6.00	1.20	6.00	1.20	5.75	1.40	5.75	179	178	189	190

163	1.60	6.00	1.40	6.00	1.40	5.75	1.60	5.75	180	179	190	191
164	1.80	6.00	1.60	6.00	1.60	5.75	1.80	5.75	181	180	191	192
165	2.00	6.00	1.80	6.00	1.80	5.75	2.00	5.75	182	181	192	193
166	2.50	6.00	2.00	6.00	2.00	5.75	2.50	5.75	183	182	193	194
167	3.00	6.00	2.50	6.00	2.50	5.75	3.00	5.75	184	183	194	195
168	3.50	6.00	3.00	6.00	3.00	5.75	3.50	5.75	185	184	195	196
169	4.00	6.00	3.50	6.00	3.50	5.75	4.00	5.75	186	185	196	197
170	5.00	6.00	4.00	6.00	4.00	5.75	5.00	5.75	187	186	197	198
171	1.20	5.75	1.00	5.75	1.00	5.50	1.20	5.50	189	188	199	200
172	1.40	5.75	1.20	5.75	1.20	5.50	1.40	5.50	190	189	200	201
173	1.60	5.75	1.40	5.75	1.40	5.50	1.60	5.50	191	190	201	202
174	1.80	5.75	1.60	5.75	1.60	5.50	1.80	5.50	192	191	202	203
175	2.00	5.75	1.80	5.75	1.80	5.50	2.00	5.50	193	192	203	204
176	2.50	5.75	2.00	5.75	2.00	5.50	2.50	5.50	194	193	204	205
177	3.00	5.75	2.50	5.75	2.50	5.50	3.00	5.50	195	194	205	206
178	3.50	5.75	3.00	5.75	3.00	5.50	3.50	5.50	196	195	206	207
179	4.00	5.75	3.50	5.75	3.50	5.50	4.00	5.50	197	196	207	208
180	5.00	5.75	4.00	5.75	4.00	5.50	5.00	5.50	198	197	208	209
181	1.20	5.50	1.00	5.50	1.00	5.25	1.20	5.25	200	199	210	211
182	1.40	5.50	1.20	5.50	1.20	5.25	1.40	5.25	201	200	211	212
183	1.60	5.50	1.40	5.50	1.40	5.25	1.60	5.25	202	201	212	213
184	1.80	5.50	1.60	5.50	1.60	5.25	1.80	5.25	203	202	213	214
185	2.00	5.50	1.80	5.50	1.80	5.25	2.00	5.25	204	203	214	215
186	2.50	5.50	2.00	5.50	2.00	5.25	2.50	5.25	205	204	215	216
187	3.00	5.50	2.50	5.50	2.50	5.25	3.00	5.25	206	205	216	217
188	3.50	5.50	3.00	5.50	3.00	5.25	3.50	5.25	207	206	217	218
189	4.00	5.50	3.50	5.50	3.50	5.25	4.00	5.25	208	207	218	219
190	5.00	5.50	4.00	5.50	4.00	5.25	5.00	5.25	209	208	219	220
191	1.20	5.25	1.00	5.25	1.00	5.00	1.20	5.00	211	210	226	227

192	1.40	5.25	1.20	5.25	1.20	5.00	1.40	5.00	212	211	227	228
193	1.60	5.25	1.40	5.25	1.40	5.00	1.60	5.00	213	212	228	229
194	1.80	5.25	1.60	5.25	1.60	5.00	1.80	5.00	214	213	229	230
195	2.00	5.25	1.80	5.25	1.80	5.00	2.00	5.00	215	214	230	231
196	2.50	5.25	2.00	5.25	2.00	5.00	2.50	5.00	216	215	231	232
197	3.00	5.25	2.50	5.25	2.50	5.00	3.00	5.00	217	216	232	233
198	3.50	5.25	3.00	5.25	3.00	5.00	3.50	5.00	218	217	233	234
199	4.00	5.25	3.50	5.25	3.50	5.00	4.00	5.00	219	218	234	235
200	5.00	5.25	4.00	5.25	4.00	5.00	5.00	5.00	220	219	235	236
201	0.20	5.00	0.00	5.00	0.00	4.75	0.20	4.75	222	221	237	238
202	0.40	5.00	0.20	5.00	0.20	4.75	0.40	4.75	223	222	238	239
203	0.60	5.00	0.40	5.00	0.40	4.75	0.60	4.75	224	223	239	240
204	0.80	5.00	0.60	5.00	0.60	4.75	0.80	4.75	225	224	240	241
205	1.00	5.00	0.80	5.00	0.80	4.75	1.00	4.75	226	225	241	242
206	1.20	5.00	1.00	5.00	1.00	4.75	1.20	4.75	227	226	242	243
207	1.40	5.00	1.20	5.00	1.20	4.75	1.40	4.75	228	227	243	244
208	1.60	5.00	1.40	5.00	1.40	4.75	1.60	4.75	229	228	244	245
209	1.80	5.00	1.60	5.00	1.60	4.75	1.80	4.75	230	229	245	246
210	2.00	5.00	1.80	5.00	1.80	4.75	2.00	4.75	231	230	246	247
211	2.50	5.00	2.00	5.00	2.00	4.75	2.50	4.75	232	231	247	248
212	3.00	5.00	2.50	5.00	2.50	4.75	3.00	4.75	233	232	248	249
213	3.50	5.00	3.00	5.00	3.00	4.75	3.50	4.75	234	233	249	250
214	4.00	5.00	3.50	5.00	3.50	4.75	4.00	4.75	235	234	250	251
215	5.00	5.00	4.00	5.00	4.00	4.75	5.00	4.75	236	235	251	252
216	0.20	4.75	0.00	4.75	0.00	4.50	0.20	4.50	238	237	253	254
217	0.40	4.75	0.20	4.75	0.20	4.50	0.40	4.50	239	238	254	255
218	0.60	4.75	0.40	4.75	0.40	4.50	0.60	4.50	240	239	255	256
219	0.80	4.75	0.60	4.75	0.60	4.50	0.80	4.50	241	240	256	257

220	1.00	4.75	0.80	4.75	0.80	4.50	1.00	4.50	242	241	257	258
221	1.20	4.75	1.00	4.75	1.00	4.50	1.20	4.50	243	242	258	259
222	1.40	4.75	1.20	4.75	1.20	4.50	1.40	4.50	244	243	259	260
223	1.60	4.75	1.40	4.75	1.40	4.50	1.60	4.50	245	244	260	261
224	1.80	4.75	1.60	4.75	1.60	4.50	1.80	4.50	246	245	261	262
225	2.00	4.75	1.80	4.75	1.80	4.50	2.00	4.50	247	246	262	263
226	2.50	4.75	2.00	4.75	2.00	4.50	2.50	4.50	248	247	263	264
227	3.00	4.75	2.50	4.75	2.50	4.50	3.00	4.50	249	248	264	265
228	3.50	4.75	3.00	4.75	3.00	4.50	3.50	4.50	250	249	265	266
229	4.00	4.75	3.50	4.75	3.50	4.50	4.00	4.50	251	250	266	267
230	5.00	4.75	4.00	4.75	4.00	4.50	5.00	4.50	252	251	267	268
231	0.20	4.50	0.00	4.50	0.00	4.25	0.20	4.25	254	253	269	270
232	0.40	4.50	0.20	4.50	0.20	4.25	0.40	4.25	255	254	270	271
233	0.60	4.50	0.40	4.50	0.40	4.25	0.60	4.25	256	255	271	272
234	0.80	4.50	0.60	4.50	0.60	4.25	0.80	4.25	257	256	272	273
235	1.00	4.50	0.80	4.50	0.80	4.25	1.00	4.25	258	257	273	274
236	1.20	4.50	1.00	4.50	1.00	4.25	1.20	4.25	259	258	274	275
237	1.40	4.50	1.20	4.50	1.20	4.25	1.40	4.25	260	259	275	276
238	1.60	4.50	1.40	4.50	1.40	4.25	1.60	4.25	261	260	276	277
239	1.80	4.50	1.60	4.50	1.60	4.25	1.80	4.25	262	261	277	278
240	2.00	4.50	1.80	4.50	1.80	4.25	2.00	4.25	263	262	278	279
241	2.50	4.50	2.00	4.50	2.00	4.25	2.50	4.25	264	263	279	280
242	3.00	4.50	2.50	4.50	2.50	4.25	3.00	4.25	265	264	280	281
243	3.50	4.50	3.00	4.50	3.00	4.25	3.50	4.25	266	265	281	282
244	4.00	4.50	3.50	4.50	3.50	4.25	4.00	4.25	267	266	282	283
245	5.00	4.50	4.00	4.50	4.00	4.25	5.00	4.25	268	267	283	284
246	0.20	4.25	0.00	4.25	0.00	4.00	0.20	4.00	270	269	285	286
247	0.40	4.25	0.20	4.25	0.20	4.00	0.40	4.00	271	270	286	287
248	0.60	4.25	0.40	4.25	0.40	4.00	0.60	4.00	272	271	287	288

249	0.80	4.25	0.60	4.25	0.60	4.00	0.80	4.00	273	272	288	289
250	1.00	4.25	0.80	4.25	0.80	4.00	1.00	4.00	274	273	289	290
251	1.20	4.25	1.00	4.25	1.00	4.00	1.20	4.00	275	274	290	291
252	1.40	4.25	1.20	4.25	1.20	4.00	1.40	4.00	276	275	291	292
253	1.60	4.25	1.40	4.25	1.40	4.00	1.60	4.00	277	276	292	293
254	1.80	4.25	1.60	4.25	1.60	4.00	1.80	4.00	278	277	293	294
255	2.00	4.25	1.80	4.25	1.80	4.00	2.00	4.00	279	278	294	295
256	2.50	4.25	2.00	4.25	2.00	4.00	2.50	4.00	280	279	295	296
257	3.00	4.25	2.50	4.25	2.50	4.00	3.00	4.00	281	280	296	297
258	3.50	4.25	3.00	4.25	3.00	4.00	3.50	4.00	282	281	297	298
259	4.00	4.25	3.50	4.25	3.50	4.00	4.00	4.00	283	282	298	299
260	5.00	4.25	4.00	4.25	4.00	4.00	5.00	4.00	284	283	299	300
261	0.20	4.00	0.00	4.00	0.00	3.50	0.20	3.50	286	285	301	302
262	0.40	4.00	0.20	4.00	0.20	3.50	0.40	3.50	287	286	302	303
263	0.60	4.00	0.40	4.00	0.40	3.50	0.60	3.50	288	287	303	304
264	0.80	4.00	0.60	4.00	0.60	3.50	0.80	3.50	289	288	304	305
265	1.00	4.00	0.80	4.00	0.80	3.50	1.00	3.50	290	289	305	306
266	1.20	4.00	1.00	4.00	1.00	3.50	1.20	3.50	291	290	306	307
267	1.40	4.00	1.20	4.00	1.20	3.50	1.40	3.50	292	291	307	308
268	1.60	4.00	1.40	4.00	1.40	3.50	1.60	3.50	293	292	308	309
269	1.80	4.00	1.60	4.00	1.60	3.50	1.80	3.50	294	293	309	310
270	2.00	4.00	1.80	4.00	1.80	3.50	2.00	3.50	295	294	310	311
271	2.50	4.00	2.00	4.00	2.00	3.50	2.50	3.50	296	295	311	312
272	3.00	4.00	2.50	4.00	2.50	3.50	3.00	3.50	297	296	312	313
273	3.50	4.00	3.00	4.00	3.00	3.50	3.50	3.50	298	297	313	314
274	4.00	4.00	3.50	4.00	3.50	3.50	4.00	3.50	299	298	314	315
275	5.00	4.00	4.00	4.00	4.00	3.50	5.00	3.50	300	299	315	316
276	0.20	3.50	0.00	3.50	0.00	3.00	0.20	3.00	302	301	317	318

277	0.40	3.50	0.20	3.50	0.20	3.00	0.40	3.00	303	302	318	319
278	0.60	3.50	0.40	3.50	0.40	3.00	0.60	3.00	304	303	319	320
279	0.80	3.50	0.60	3.50	0.60	3.00	0.80	3.00	305	304	320	321
280	1.00	3.50	0.80	3.50	0.80	3.00	1.00	3.00	306	305	321	322
281	1.20	3.50	1.00	3.50	1.00	3.00	1.20	3.00	307	306	322	323
282	1.40	3.50	1.20	3.50	1.20	3.00	1.40	3.00	308	307	323	324
283	1.60	3.50	1.40	3.50	1.40	3.00	1.60	3.00	309	308	324	325
284	1.80	3.50	1.60	3.50	1.60	3.00	1.80	3.00	310	309	325	326
285	2.00	3.50	1.80	3.50	1.80	3.00	2.00	3.00	311	310	326	327
286	2.50	3.50	2.00	3.50	2.00	3.00	2.50	3.00	312	311	327	328
287	3.00	3.50	2.50	3.50	2.50	3.00	3.00	3.00	313	312	328	329
288	3.50	3.50	3.00	3.50	3.00	3.00	3.50	3.00	314	313	329	330
289	4.00	3.50	3.50	3.50	3.50	3.00	4.00	3.00	315	314	330	331
290	5.00	3.50	4.00	3.50	4.00	3.00	5.00	3.00	316	315	331	332
291	0.20	3.00	0.00	3.00	0.00	2.00	0.20	2.00	318	317	333	334
292	0.40	3.00	0.20	3.00	0.20	2.00	0.40	2.00	319	318	334	335
293	0.60	3.00	0.40	3.00	0.40	2.00	0.60	2.00	320	319	335	336
294	0.80	3.00	0.60	3.00	0.60	2.00	0.80	2.00	321	320	336	337
295	1.00	3.00	0.80	3.00	0.80	2.00	1.00	2.00	322	321	337	338
296	1.20	3.00	1.00	3.00	1.00	2.00	1.20	2.00	323	322	338	339
297	1.40	3.00	1.20	3.00	1.20	2.00	1.40	2.00	324	323	339	340
298	1.60	3.00	1.40	3.00	1.40	2.00	1.60	2.00	325	324	340	341
299	1.80	3.00	1.60	3.00	1.60	2.00	1.80	2.00	326	325	341	342
300	2.00	3.00	1.80	3.00	1.80	2.00	2.00	2.00	327	326	342	343
301	2.50	3.00	2.00	3.00	2.00	2.00	2.50	2.00	328	327	343	344
302	3.00	3.00	2.50	3.00	2.50	2.00	3.00	2.00	329	328	344	345
303	3.50	3.00	3.00	3.00	3.00	2.00	3.50	2.00	330	329	345	346
304	4.00	3.00	3.50	3.00	3.50	2.00	4.00	2.00	331	330	346	347
305	5.00	3.00	4.00	3.00	4.00	2.00	5.00	2.00	332	331	347	348

306	0.20	2.00	0.00	2.00	0.00	1.00	0.20	1.00	334	333	349	350
307	0.40	2.00	0.20	2.00	0.20	1.00	0.40	1.00	335	334	350	351
308	0.60	2.00	0.40	2.00	0.40	1.00	0.60	1.00	336	335	351	352
309	0.80	2.00	0.60	2.00	0.60	1.00	0.80	1.00	337	336	352	353
310	1.00	2.00	0.80	2.00	0.80	1.00	1.00	1.00	338	337	353	354
311	1.20	2.00	1.00	2.00	1.00	1.00	1.20	1.00	339	338	354	355
312	1.40	2.00	1.20	2.00	1.20	1.00	1.40	1.00	340	339	355	356
313	1.60	2.00	1.40	2.00	1.40	1.00	1.60	1.00	341	340	356	357
314	1.80	2.00	1.60	2.00	1.60	1.00	1.80	1.00	342	341	357	358
315	2.00	2.00	1.80	2.00	1.80	1.00	2.00	1.00	343	342	358	359
316	2.50	2.00	2.00	2.00	2.00	1.00	2.50	1.00	344	343	359	360
317	3.00	2.00	2.50	2.00	2.50	1.00	3.00	1.00	345	344	360	361
318	3.50	2.00	3.00	2.00	3.00	1.00	3.50	1.00	346	345	361	362
319	4.00	2.00	3.50	2.00	3.50	1.00	4.00	1.00	347	346	362	363
320	5.00	2.00	4.00	2.00	4.00	1.00	5.00	1.00	348	347	363	364
321	0.20	1.00	0.00	1.00	0.00	0.00	0.20	0.00	350	349	365	366
322	0.40	1.00	0.20	1.00	0.20	0.00	0.40	0.00	351	350	366	367
323	0.60	1.00	0.40	1.00	0.40	0.00	0.60	0.00	352	351	367	368
324	0.80	1.00	0.60	1.00	0.60	0.00	0.80	0.00	353	352	368	369
325	1.00	1.00	0.80	1.00	0.80	0.00	1.00	0.00	354	353	369	370
326	1.20	1.00	1.00	1.00	1.00	0.00	1.20	0.00	355	354	370	371
327	1.40	1.00	1.20	1.00	1.20	0.00	1.40	0.00	356	355	371	372
328	1.60	1.00	1.40	1.00	1.40	0.00	1.60	0.00	357	356	372	373
329	1.80	1.00	1.60	1.00	1.60	0.00	1.80	0.00	358	357	373	374
330	2.00	1.00	1.80	1.00	1.80	0.00	2.00	0.00	359	358	374	375
331	2.50	1.00	2.00	1.00	2.00	0.00	2.50	0.00	360	359	375	376
332	3.00	1.00	2.50	1.00	2.50	0.00	3.00	0.00	361	360	376	377
333	3.50	1.00	3.00	1.00	3.00	0.00	3.50	0.00	362	361	377	378

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334     4.00  1.00  3.50  1.00  3.50  0.00  4.00  0.00      363 362 378 379
335     5.00  1.00  4.00  1.00  4.00  0.00  5.00  0.00      364 363 379 380
  BV( 1)= 10.00  BV( 2)= 10.00  BV( 3)= 10.00  BV( 4)= 10.00
BV( 5)= 10.00  BV( 6)= 10.00  BV( 7)= 10.00  BV( 8)= 10.00
BV( 9)= 10.00  BV(10)= 10.00  BV(11)= 10.00  BV(12)=  9.75
BV(13)=  9.50  BV(14)=  9.25  BV(15)=  9.00  BV(16)=  8.75
BV(17)=  8.50  BV(18)=  8.25  BV(19)=  8.00  BV(20)=  7.75
BV(21)=  7.50  BV(22)=  7.25  BV(23)=  7.00  BV(24)=  6.75
BV(25)=  6.50  BV(26)=  6.25  BV(27)=  6.00  BV(28)=  5.75
BV(29)=  5.50  BV(30)=  5.25  BV(31)=  5.00  BV(32)=  5.00
BV(33)=  5.00  BV(34)=  5.00  BV(35)=  5.00  BV(36)=  5.00

 NTBN( 1)=    1  NTBN( 2)=    2  NTBN( 3)=    3  NTBN( 4)=    4
NTBN( 5)=    5  NTBN( 6)=    6  NTBN( 7)=    7  NTBN( 8)=    8
NTBN( 9)=    9  NTBN(10)=   10  NTBN(11)=   11  NTBN(12)=   12
NTBN(13)=   23  NTBN(14)=   34  NTBN(15)=   45  NTBN(16)=   56
NTBN(17)=   67  NTBN(18)=   78  NTBN(19)=   89  NTBN(20)=  100
NTBN(21)=  111  NTBN(22)=  122  NTBN(23)=  133  NTBN(24)=  144
NTBN(25)=  155  NTBN(26)=  166  NTBN(27)=  177  NTBN(28)=  188
NTBN(29)=  199  NTBN(30)=  210  NTBN(31)=  221  NTBN(32)=  222
NTBN(33)=  223  NTBN(34)=  224  NTBN(35)=  225  NTBN(36)=  226

 NPT( 1)=  237  NPT( 2)=  253  NPT( 3)=  269  NPT( 4)=  285
NPT( 5)=  301  NPT( 6)=  317  NPT( 7)=  333  NPT( 8)=  349

 NSU( 1)=   22  NSU( 2)=   33  NSU( 3)=   44  NSU( 4)=   55
NSU( 5)=   66  NSU( 6)=   77  NSU( 7)=   88  NSU( 8)=   99
NSU( 9)=  110  NSU(10)=  121  NSU(11)=  132  NSU(12)=  143
NSU(13)=  154  NSU(14)=  165  NSU(15)=  176  NSU(16)=  187
NSU(17)=  198  NSU(18)=  209  NSU(19)=  220  NSU(20)=  236
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NSU(21)=  252  NSU(22)=  268  NSU(23)=  284  NSU(24)=  300

NSU(25)=  316  NSU(26)=  332  NSU(27)=  348  NSU(28)=  364

 NTU( 1)=  365  NTU( 2)=  366  NTU( 3)=  367  NTU( 4)=  368

NTU( 5)=  369  NTU( 6)=  370  NTU( 7)=  371  NTU( 8)=  372

NTU( 9)=  373  NTU(10)=  374  NTU(11)=  375  NTU(12)=  376

NTU(13)=  377  NTU(14)=  378  NTU(15)=  379  NTU(16)=  380


   MAXBW= 18


   TOTAL HEAD

 1  0.100E+02   2  0.100E+02   3  0.100E+02   4  0.100E+02

 5  0.100E+02   6  0.100E+02   7  0.100E+02   8  0.100E+02

 9  0.100E+02  10  0.100E+02  11  0.100E+02  12  0.975E+01

13  0.975E+01  14  0.976E+01  15  0.976E+01  16  0.977E+01

17  0.977E+01  18  0.978E+01  19  0.979E+01  20  0.980E+01

21  0.980E+01  22  0.981E+01  23  0.950E+01  24  0.951E+01

25  0.952E+01  26  0.953E+01  27  0.954E+01  28  0.955E+01

29  0.957E+01  30  0.958E+01  31  0.960E+01  32  0.961E+01

33  0.962E+01  34  0.925E+01  35  0.926E+01  36  0.928E+01

37  0.929E+01  38  0.931E+01  39  0.932E+01  40  0.935E+01

41  0.938E+01  42  0.940E+01  43  0.941E+01  44  0.943E+01

45  0.900E+01  46  0.902E+01  47  0.904E+01  48  0.906E+01

49  0.908E+01  50  0.909E+01  51  0.914E+01  52  0.917E+01

53  0.920E+01  54  0.922E+01  55  0.924E+01  56  0.875E+01

57  0.877E+01  58  0.880E+01  59  0.882E+01  60  0.885E+01

61  0.887E+01  62  0.892E+01  63  0.897E+01  64  0.900E+01

65  0.903E+01  66  0.905E+01  67  0.850E+01  68  0.853E+01

69  0.856E+01  70  0.859E+01  71  0.862E+01  72  0.865E+01
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73	0.871E+01	74	0.877E+01	75	0.881E+01	76	0.884E+01
77	0.887E+01	78	0.825E+01	79	0.829E+01	80	0.832E+01
81	0.836E+01	82	0.839E+01	83	0.843E+01	84	0.850E+01
85	0.857E+01	86	0.862E+01	87	0.866E+01	88	0.869E+01
89	0.800E+01	90	0.804E+01	91	0.809E+01	92	0.813E+01
93	0.817E+01	94	0.821E+01	95	0.830E+01	96	0.837E+01
97	0.843E+01	98	0.848E+01	99	0.851E+01	100	0.775E+01
101	0.780E+01	102	0.785E+01	103	0.790E+01	104	0.794E+01
105	0.799E+01	106	0.809E+01	107	0.818E+01	108	0.825E+01
109	0.830E+01	110	0.834E+01	111	0.750E+01	112	0.756E+01
113	0.761E+01	114	0.767E+01	115	0.773E+01	116	0.778E+01
117	0.790E+01	118	0.800E+01	119	0.807E+01	120	0.813E+01
121	0.817E+01	122	0.725E+01	123	0.732E+01	124	0.738E+01
125	0.745E+01	126	0.751E+01	127	0.757E+01	128	0.770E+01
129	0.781E+01	130	0.790E+01	131	0.796E+01	132	0.801E+01
133	0.700E+01	134	0.708E+01	135	0.715E+01	136	0.723E+01
137	0.730E+01	138	0.736E+01	139	0.752E+01	140	0.764E+01
141	0.774E+01	142	0.780E+01	143	0.786E+01	144	0.675E+01
145	0.684E+01	146	0.692E+01	147	0.701E+01	148	0.709E+01
149	0.717E+01	150	0.734E+01	151	0.747E+01	152	0.758E+01
153	0.765E+01	154	0.771E+01	155	0.650E+01	156	0.660E+01
157	0.670E+01	158	0.680E+01	159	0.689E+01	160	0.698E+01
161	0.716E+01	162	0.731E+01	163	0.743E+01	164	0.750E+01
165	0.756E+01	166	0.625E+01	167	0.637E+01	168	0.648E+01
169	0.659E+01	170	0.670E+01	171	0.679E+01	172	0.700E+01
173	0.716E+01	174	0.728E+01	175	0.736E+01	176	0.743E+01
177	0.600E+01	178	0.614E+01	179	0.627E+01	180	0.640E+01
181	0.652E+01	182	0.663E+01	183	0.685E+01	184	0.702E+01

185	0.715E+01	186	0.724E+01	187	0.730E+01	188	0.575E+01
189	0.591E+01	190	0.607E+01	191	0.622E+01	192	0.635E+01
193	0.647E+01	194	0.672E+01	195	0.690E+01	196	0.703E+01
197	0.711E+01	198	0.718E+01	199	0.550E+01	200	0.570E+01
201	0.589E+01	202	0.606E+01	203	0.621E+01	204	0.634E+01
205	0.660E+01	206	0.678E+01	207	0.691E+01	208	0.700E+01
209	0.707E+01	210	0.525E+01	211	0.552E+01	212	0.576E+01
213	0.594E+01	214	0.610E+01	215	0.623E+01	216	0.649E+01
217	0.668E+01	218	0.681E+01	219	0.690E+01	220	0.697E+01
221	0.500E+01	222	0.500E+01	223	0.500E+01	224	0.500E+01
225	0.500E+01	226	0.500E+01	227	0.544E+01	228	0.568E+01
229	0.587E+01	230	0.602E+01	231	0.615E+01	232	0.641E+01
233	0.659E+01	234	0.672E+01	235	0.681E+01	236	0.687E+01
237	0.516E+01	238	0.516E+01	239	0.517E+01	240	0.519E+01
241	0.524E+01	242	0.536E+01	243	0.550E+01	244	0.569E+01
245	0.585E+01	246	0.598E+01	247	0.610E+01	248	0.634E+01
249	0.651E+01	250	0.664E+01	251	0.672E+01	252	0.679E+01
253	0.530E+01	254	0.531E+01	255	0.533E+01	256	0.536E+01
257	0.542E+01	258	0.550E+01	259	0.561E+01	260	0.573E+01
261	0.585E+01	262	0.597E+01	263	0.607E+01	264	0.628E+01
265	0.645E+01	266	0.657E+01	267	0.665E+01	268	0.671E+01
269	0.543E+01	270	0.544E+01	271	0.546E+01	272	0.549E+01
273	0.554E+01	274	0.561E+01	275	0.569E+01	276	0.578E+01
277	0.588E+01	278	0.597E+01	279	0.605E+01	280	0.624E+01
281	0.639E+01	282	0.650E+01	283	0.658E+01	284	0.664E+01
285	0.555E+01	286	0.555E+01	287	0.557E+01	288	0.560E+01
289	0.564E+01	290	0.570E+01	291	0.576E+01	292	0.583E+01
293	0.590E+01	294	0.598E+01	295	0.605E+01	296	0.621E+01
297	0.635E+01	298	0.645E+01	299	0.652E+01	300	0.658E+01

301	0.572E+01	302	0.572E+01	303	0.574E+01	304	0.576E+01
305	0.578E+01	306	0.582E+01	307	0.586E+01	308	0.591E+01
309	0.595E+01	310	0.600E+01	311	0.605E+01	312	0.617E+01
313	0.628E+01	314	0.636E+01	315	0.642E+01	316	0.647E+01
317	0.584E+01	318	0.584E+01	319	0.585E+01	320	0.586E+01
321	0.588E+01	322	0.591E+01	323	0.593E+01	324	0.596E+01
325	0.600E+01	326	0.603E+01	327	0.607E+01	328	0.615E+01
329	0.623E+01	330	0.630E+01	331	0.635E+01	332	0.639E+01
333	0.598E+01	334	0.598E+01	335	0.598E+01	336	0.599E+01
337	0.600E+01	338	0.601E+01	339	0.602E+01	340	0.604E+01
341	0.605E+01	342	0.607E+01	343	0.609E+01	344	0.614E+01
345	0.618E+01	346	0.622E+01	347	0.625E+01	348	0.628E+01
349	0.604E+01	350	0.604E+01	351	0.604E+01	352	0.604E+01
353	0.605E+01	354	0.606E+01	355	0.606E+01	356	0.607E+01
357	0.608E+01	358	0.609E+01	359	0.610E+01	360	0.613E+01
361	0.616E+01	362	0.619E+01	363	0.621E+01	364	0.623E+01
365	0.605E+01	366	0.605E+01	367	0.606E+01	368	0.606E+01
369	0.606E+01	370	0.607E+01	371	0.608E+01	372	0.608E+01
373	0.609E+01	374	0.610E+01	375	0.611E+01	376	0.613E+01
377	0.616E+01	378	0.618E+01	379	0.620E+01	380	0.621E+01

```
F1( 1)= 0.0472
F1( 2)= 0.0950
F1( 3)= 0.1439
F1( 4)= 0.1945
F1( 5)= 0.2475
F1( 6)= 0.3035
F1( 7)= 0.3634
F1( 8)= 0.4281
F1( 9)= 0.4988
F1(10)= 0.5769
F1(11)= 0.6644
F1(12)= 0.7636
F1(13)= 0.8780
F1(14)= 1.0127
F1(15)= 1.1756
F1(16)= 1.3799
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F1(17)= 1.6496
F1(18)= 2.0387
F1(19)= 2.6735
F1(20)= 4.4201
F2( 1)= 1.8779
F2( 2)= 2.4257
F2( 3)= 2.7094
F2( 4)= 2.7838
F2( 5)= 2.6906

HV=19.5551  VEV=12.4875  DISCHARGE=32.0426
```