Republic of Iraq
Ministry of Higher Education
and Scientific Research
University of Babylon
College of Engineering
Civil Engineering Department

Predicting Seepage Generated In Earth Fill Dam With Horizontal Toe Filter Using Artificial Neural Network Technique

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In partial fulfillment of the requirements for the degree of high Diploma in Civil Engineering / Hydraulic Structures College of Engineering / University of Babylon

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2023 1444

بسم الله الرحمن الرحيم

أَمَّنْ هُوَ قَانِتٌ آنَاءَ اللَّيْلِ سَاجِدًا وَقَائِمًا يَحْذَرُ الآخِرَةَ وَيَرْجُو رَحْمَةَ رَبِّهِ قُلْ هَلْ يَسْتَوِي الَّذِينَ يَعْلَمُونَ وَالَّذِينَ لا يَعْلَمُونَ إِنَّمَا يَتَذَكَّرُ أُولُواْ الأَلْبَابِ

{سورة الزمر الآية 9}

CERTIFICATE

I certify that the proportion of this research entitled "Predicting Seepage Generated in Earth Fill Dam with Horizontal Toe Filter Using Artificial Neural Network Technique" prepared by "Ali Abbas Abd Alzhra" under my supervision at the college of Engineering University of Babylon in partial fulfillment requirements for the degree of High Diploma in Civil Engineering.

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Date: / /2022

ACKNOWLEDGEMENTS

"In the name of Allah, the most Gracious, the most merciful"

First, praise be to "Allah" who gave me the strength and health to work and enable me to finish this work.

I would like to express my greatest and sincere thanks to my supervisor Assist. Dr. Shaml for his guidance, valuable advice, cooperation and support throughout this research project. his dedication to his research and his students is unparalleled and I am grateful to have had the opportunity to work with him and look forward to my future work with him.

I would like to express my deepest feeling to my family for their care. Patience and their support during the study period.

Thanks a lot, to the college of engineering / Babylon university

Ali Abbas Abd Alzhra

ABSTRACT

In this study, a mathematical equations formula are developed to find the seepage discharge amount and side slope factor of safety value for homogenous earth fill embankment dam with horizontal rectangular toe drain filter established on impervious foundation exhibition to full reservoir water level. The statistical with regression for multiple nonlinear relationship techniques have been used in these equations for solution.

Given the fact that the subject of pores media flow analysis for the behavior of the embankment dams when exposed to reservoir water level, includes many variables. Such as those variables related to the geometrical dimensions and those that related to the mechanical and physical properties of the dam and foundation materials. Therefore, there are no explicit equations that relate these variables as inputs with the seepage discharge and sliding factor of safety resulting. It requires the solution of a system of simultaneous partial differential equations governing phenomenon, taking into account the cross section dimensions and soil properties.

Using the statistical technique to find the mathematical equations needs a calculation of the seepage discharge and factor of safety for a large number of randomly generated inputs sets. Therefore, in this study a database of inputs and outputs is build using linearly two dimensional analysis program Geo Studio with SEEP/W model to estimate seepage discharge amounts and SLOPE/W model to estimate side slope factor of safety values.

This database included 300 different cases for varying values of each variable depending on the recommendations of authorized sources relevant to this issue. The dam body (soil) is assumed homogenous and has linear isometric properties as well as the drain filter.

The statistical software IBM SPSS 23 “Statistical Product and Service

Solutions" with the database mentioned above is used to build a model of Artificial Neural Networks (ANN) to explain the influence weight of each variable in this issue and results obtained. The influence effect of each input variable, on the output variables [seepage discharge (q) and side slope factor of safety (F.S)] of the dam section are investigated. The results showed the capability of the model to guess the values of the outputs, seepage discharge (q) and factor of safety (F.S), with high accuracy. The correlation coefficients between the observed outputs values and the predicted values model are 99.3% for (q) and 99.5% for (F.S). The results also show that the best division for the data into training, testing and holdout (verification) subsets is 68.7%, 20.3% and 11% respectively for (q) and 69.3%, 21.7% and 9% respectively for (F.S). In addition, the best number of the nodes in the hidden layer is 7 for both (q) and (F.S), where the average overall relative error is 0.7%, 0.9% and 1% for the training, testing and holdout subsets respectively for (q) and 0.5%, 0.6% and 0.5% for the training, testing and holdout subsets respectively for (q). Finally, the best activation functions used for the hidden and output layers are hyperbolic tan (tanh), and linear function (Identity) respectively for both (q) and (F.S).

Two mathematical equations are predicting using regression technic for multiple nonlinear relationship for 75% of input and output sets using the SPSS 23 software for obtaining the seepage discharge amount and sliding factor of safety value for any set of input variables mentioned above, instead of using the long process of Geo Studio modeling. For checking the performance of the equations, it was applied to a 25% of input data sets that are not used in the database that was used to predict the equations. The comparison of the results of these 25% cases obtained by the Geo Studio software with those obtained by using the mathematical equations had showed an excellent capability of the equations to predict the outputs with high accuracy. The correlation coefficients for these 25% sets are 96.6% and 99.4% for the seepage discharge (q) and the side slope factor of safety (F.S) respectively.

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CHAPTER ONE

INTRODUCTION

1.1 General

Earth dam is one of the most important infrastructures that have a crucial role in human civilization, and is the most popular kinds of dam, resulting in much research attention in recent decades. The construction of earth dam has increased rapidly in many countries, especially in Middle-East, due to increasing demand for water and decreasing reserves of clean water. Earth embankments have been used since the earliest times to impound and divert water. They are simple compacted structures of earth or rock fill that rely on their mass to resist sliding and overturning and are the most common type of dam found worldwide. The natural fill materials are placed and compacted without the addition of any binding agent.

Embankment dams are suitable for river valleys of any type, steep gorges or wide valleys and uses naturally available materials on its location. In addition, foundation requirements are less stringent than for other types of dam. The broad base of an earth dam spreads the load on the foundation, so that it is resist settlement and movement better than more rigid structures and can be more suitable for areas where earth movements are common by relatively less costly. However, earth embankment is easily damaged or destroyed by water flowing on over or against it. A further disadvantage of the embankment dam if not adequately compacted during construction; the dam will offer weak structural integrity, offering possible pathways for preferential seepage. So earth dams require continual maintenance to prevent erosion, tree growth, subsidence, animal and insect damage and seepage.

To construct an economical and stable earth dam, a comprehensive study on several aspects of earth dam is necessary. Stability analysis is one of the most important aspects that should be considered in construction and analysis of earth dam. It is reported that 30% of the past earth dam failures were due to structural failure, and most of these were related to structural geometry (*Punmia 1992*). Therefore, study on the stability and safety of earth dam is very crucial because of the significant investment (in time and money) required to construction an earth dam, as well as the detrimental effects on the surrounding in case of failure.

Earth dams are important structures used as artificial reservoirs consists from impervious compacted layers of soils for its core and permeable materials on their upstream and downstream faces to be safe against sliding and overturning forces. The earliest embankments were constructed on the principle of a solid wall of earth, whether impervious or not, across a stream or river. When built properly, such homogeneous embankments can still be cheap and reliable. Most dams, homogenous or zoned, can benefit from the construction of a cutoff in the foundation. A cutoff will reduce seepage and improve stability. Whether stable clay or other material is being used, the cutoff trench must be excavated to a depth that will minimize all possible seepage. Ideally, the cutoff trench should be dug down to solid rock that extends to great depths. Seepage is the quantity of water through an earth dam starts from upstream of the reservoir level to the downstream toe of the dam. The upper surface of this stream of percolating water is known as the phreatic surface or top flow line separating saturated and unsaturated zones. For controlling this phenomenon in the dam, different types of filters should be designed.

The Laplace equation that governs water seepage cannot be solved analytically, except for cases with very simple and special boundary conditions. In the literature reviews, the numerical example that proposed equations is simple to use; hence, the designers may find these equations as an additional check to their design by the conventional flow net method (*Chahar, 2004*). While, a series of tests and different drain sizes including different filter thicknesses and lengths were applied to a physical model of an embankment dam to check the stability in steady and transient seepage conditions using a number of piezometers and pressure sensors (*Malekpour et al., 2012*).

1.2 Statement of the problem

Homogeneous earth fill dam is one of the older types of embankment dam that constructed of uniform soil material throughout. With this dam, the buildup of excess pore pressures within the embankment and seepage can be a problem, especially for a reservoir having high, or rapidly fluctuating water levels for long periods, or for a dam having impervious foundations. If seepage is excessive, this can lead to instability and eventual failure of all or part of the downstream face. Forty percent of embankment dams failure are due to hydraulic failure such as overtopping water due to underestimated design level, erosion of upstream face by wave action and downstream face by rain action, cracking in upper portion of dam due to frost action. While thirty percent embankment dams fail due to uncontrolled seepage which causes scour through downstream wet zone or piping through dam foundation, which present the problem that this study deals with. Also twenty five percent structurally fail by sliding either at upstream and downstream of the body slope, which present the problem that this study deals with also, or foundation slide by soft soil such as fine silt or soft clay soils. Residual five percent embankment dams are failing by external causes.

1.3 Aims and Objectives of the study

1.3.1 Aims

The aim of this study is to investigate the influence of structural geometries and soil materials properties of homogeneous earth fill embankment dam with rectangular horizontal toe drain filter on seepage discharge, stability, and deformation during steady state condition and safety for sides slope sliding due to rapidly drop of reservoir water level. Also develop an empirical mathematical equations may be used to estimate the seepage discharge amount through earth fill embankment dams and factor of safety for side slope sliding.

1.3.2 Objectives

In order to achieve the aims of this study, the main objective of this research study is investigate influence of changing the various parameters represented by the dimensions of the dam cross section, the properties of its components material, and water level in the reservoir on the amount of seepage discharge generated in the dam body and phreatic line shape. In addition to the stability of the upstream and the downstream dam faces, and factor of safety against sliding value, and evaluate the influence importance of each parameter. Then create two mathematical equations using database with statistical methods to calculate each of the amounts of seepage discharge and the sliding safety factor, directly from the available information on the dam without the need for the use of softwares, graphical methods, or other long numerical methods known.

1.4 Research methodology

The following is the methodology of the research:

1- Appling numerical method by finite element method model (Geo Studio 2012 software) analyzing the response of the dam to different cross section and drain filter dimensions and material properties, and investigating the change in seepage discharge amount, phreatic line shape, and sliding factor of safety value. This analysis includes:

   i) Two dimensional seepage flow problem.

   ii) Predicting the seepage discharge amount and phreatic line shape using SEEP/W software model.

   iii) Predicting the sliding factor of safety value using SLOPE/W software model.

iv) Models predicted used to build up an observed database.

2- Calibrating the observed models using Artificial Neural Network method (ANN) (SPSS 26 software) for statement various parameter impact factor.

3- Appling statistical method model using multiple nonlinear regression method (SPSS 26 software) to predict mathematical equations for quick estimation of the seepage discharge amount and sliding factor of safety value.

4- Verifying mathematical equations using observed database mentioned in (1) above.

1.5 limitations

This research study subjected to the following limitations:

1- The dam and his rectangular horizontal drain filter are assumed homogeneous and isotropic soil material that is the permeability coefficient is constant at any direction and everywhere.

2- No volume change occurs that soil and water are incompressible.

3- The unconfined aquifer is fully saturated.

4- Seepage discharge is assumed to be under steady state condition that is reservoir water level is constant.

5- Flow is laminar that Darcy's law is valid.

6- Dam foundation is assumed to be impervious.

1.6 Organizing of the research

This research includes five chapters. A brief outline of each chapter is presented below:

Chapter one furnishes a brief general introduction about the subject as well as the problem statement, the objective of this research study, research methodology, and the adopted limitations.

Chapter two includes literature review details covered a number of researchers previous works in this field. First the mathematical analysis studies, second the analytical solution, and third the experimental studies. In addition, this chapter consist the GeoStudio and SPSS softwares procedure studies, and a brief summary of these studies.

Chapter three describe the theory of flow through pores media, finite element numerical application for the second order differential equations (Laplace Equation) solution, an overview of GeoSTudio software, and (ANN) artificial neural network method. This includes description, operation and methods of computation for the modeling using this technique. Also, present a brief description about regression and correlation methods used in statistical applications in engineering.

Chapter four explains the modeling of the problem to analyze with GeoStudio software and the details of the various parameters adopted for the study, such as reservoir water level, dimensions, properties, flow conditions. The application of the (ANN) model to model the results obtained by GeoStudio software application and some of the results obtained from the analysis in addition to the extracted empirical equations and their verification are presented in this chapter too.

Chapter five provides a summary mentions the main conclusions extracted from this research study in addition to several recommendations for further researches in this field.

CHAPTER TWO

LITERATURE REVIEW

2.1 General

British Dam Society (2010) defined the dam as “a man-made barrier usually built across a river to hold back water and forming a lake, or reservoir, behind it. It can be constructed from concrete or natural materials like earth and rock”. The dam is one of the crucial hydraulic structures that have been constructed for several purposes such as controlling flood water, diverting the direction of water, and storing water for irrigation, water supply, electricity, fishing and recreation. Dams can be classified into five sorts according to the materials used in the construction: concrete, masonry, earth and rock-fill, steel and timber (*Punmia 1992*).

Earth dam is the most common type; according to International Commission on Large Dams (*ICOLD 2012*), earth dam comprises 63% of the total large dams in the globe as shown in the pie chart below (note: according to *ICOLD*, any dam whose height is greater than 15m, can be classified as large).

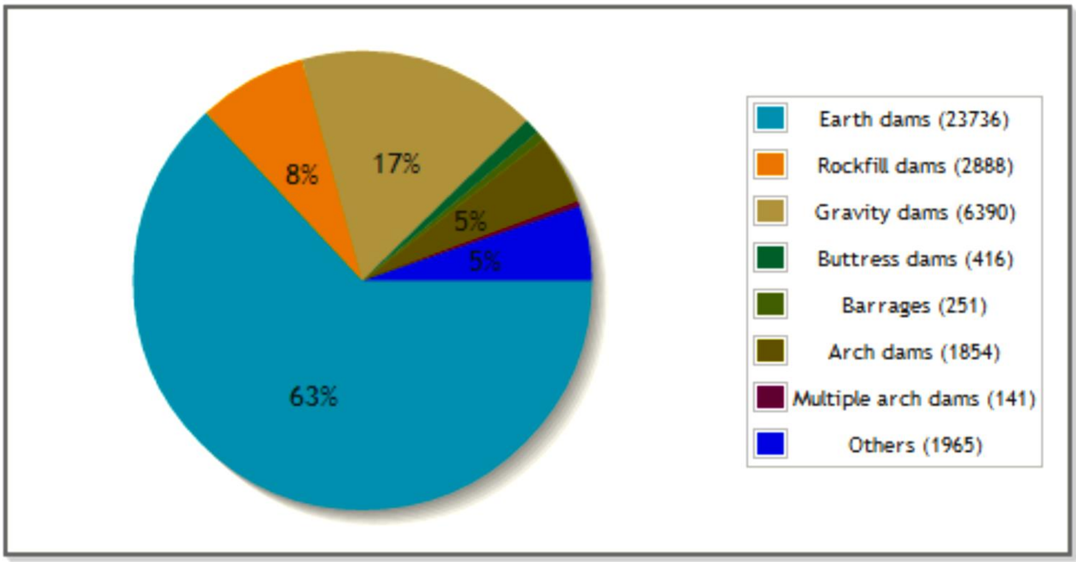


Fig. 2 … LD
(*ICOLD 2012*).

(*ICOLD 2012*) defined an embankment dam (earth-fill and rock-fill dam) as "any dam constructed of excavated materials placed without addition of binding materials other than those inherent in the natural material. The materials are usually obtained at or near the dam site". Earth dams are the oldest types of dams, which have been built since the beginning of civilization and can be categorized into two kinds according to method of construction as hydraulic fill dam and rolled fill dam that can be sub-divided into three main sorts, homogenous, zoned earth and diaphragm, as outlined below (*Punmia 1992, and Mehrdad et al. 2004*).

The problem of seepage through earth dams has attracted the attention of many authors all over the world. There are many factors, which influence the stability of earth dam such as shear strength parameters and elastic properties of the soil, dam's geometry, the level of regional seismicity, the water level in the reservoir, topography and the economic considerations of the project (*Mehrdad et al. 2004*).

Structural geometry is the most effective factors. (*Mehrdad et al. 2004*) mentioned that the geometry of earth dam has a significant effect on the economy of the dam project because it has a considerable influence on the total volume of the fill materials. Side slopes explain the effects of geometrical factors. (*Bell 2004*) explained that both upstream and downstream slopes depend on the strength properties of materials of the dam and the foundation. If the foundation is strong, the slopes can be constructed steeper than those in weak foundation. (*Punmia 1992*) claims that side slope also depend on the height of the dam and types of earth dam (i.e. homogenous, zoned and diaphragm). (*British Standard 1992*) specified that both upstream and downstream slopes should not be steeper than 1:3 for earth dams up to 5m height. (*Lakehal et al. 2011*) studied the effect of side slope on the stability of earth dam, fixing all other parameters except side slope. They concluded that if the steepness of the side slope is decreased, it is helpful to improve the stability of earth dam and it increases the factor of safety. In addition, for the same side slope, but for different height, the factor of safety is decreased with increasing the height of the dam.

2.2 Types of Earth Dam

2.2.1 Homogenous earth dam

Homogenous earth dams are built with one type of materials. The materials are impervious or semi-pervious to prevent or reduce seepage through the dam body. This type of earth dam is usually constructed when this material is available on the site by adequate quantity. This type is used in low to moderate height. The figure below shows pure homogenous earth dam and modified homogenous earth dam with horizontal drainage filter (*Punmia 1992*).

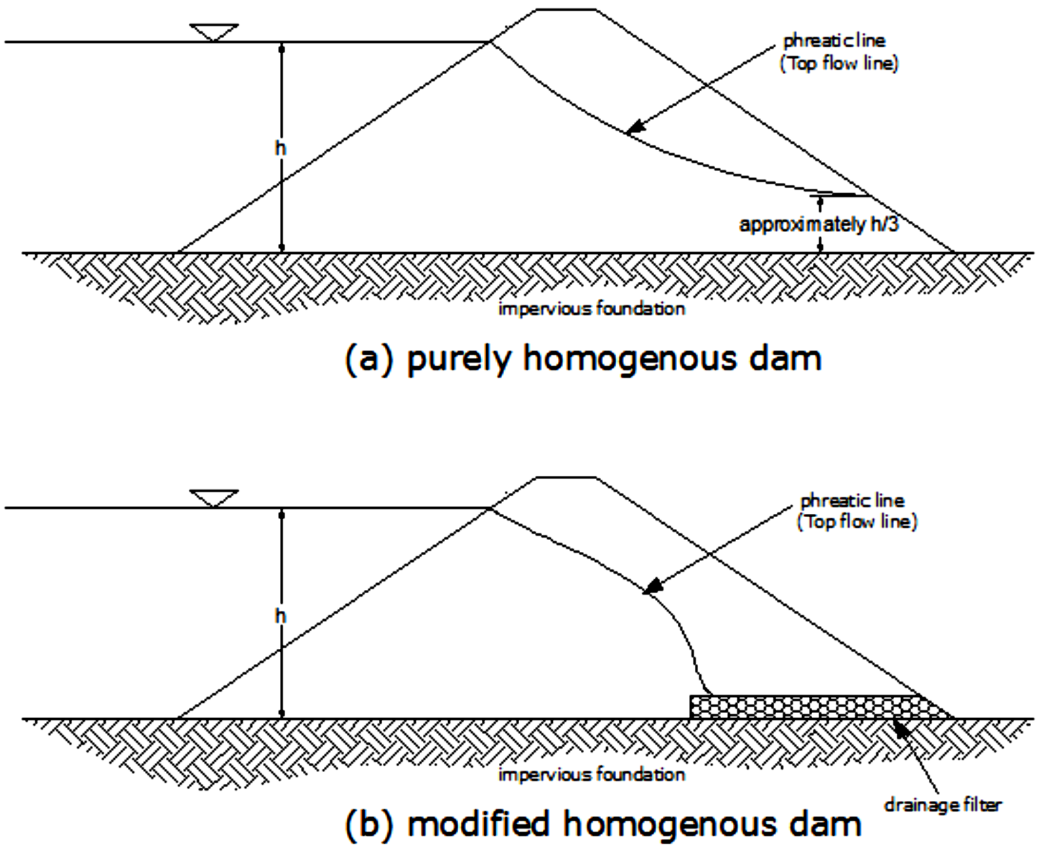


Fig. 2.2: Earth dam (a) the purely homogenous. (b) the modified homogenous. (*modified after Punmia 1992*)

2.2.2 Zoned earth dam

This type is the most popular types around the world and it is more economic compared with the other types. Zoned earth dam consists of a core and two shells. A core is constructed of impervious soil to minimize the seepage and the shells are built of pervious materials to stabilize the core and distribute the load into a greater area (*Punmia 1992*).

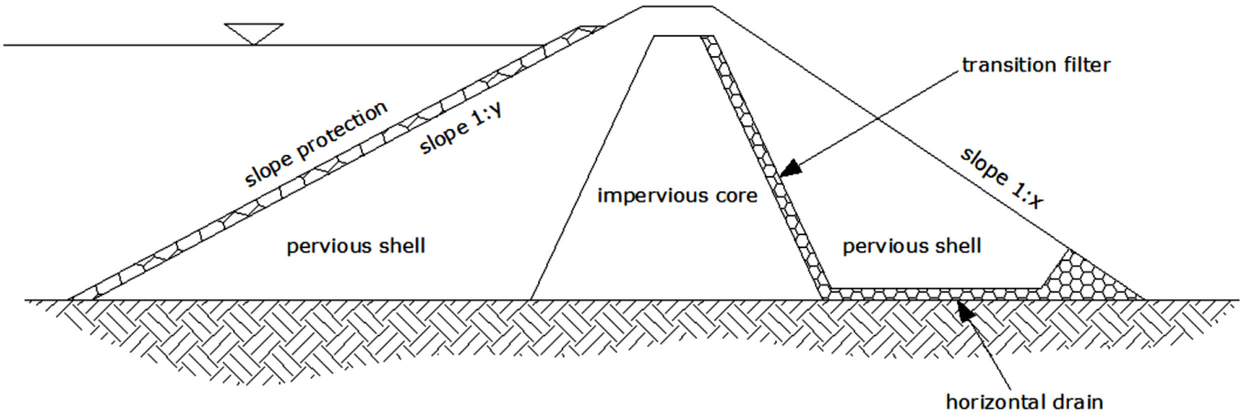


Fig. 2.3: Section of central core zoned earth dam (*modified after Punmia 1992*).

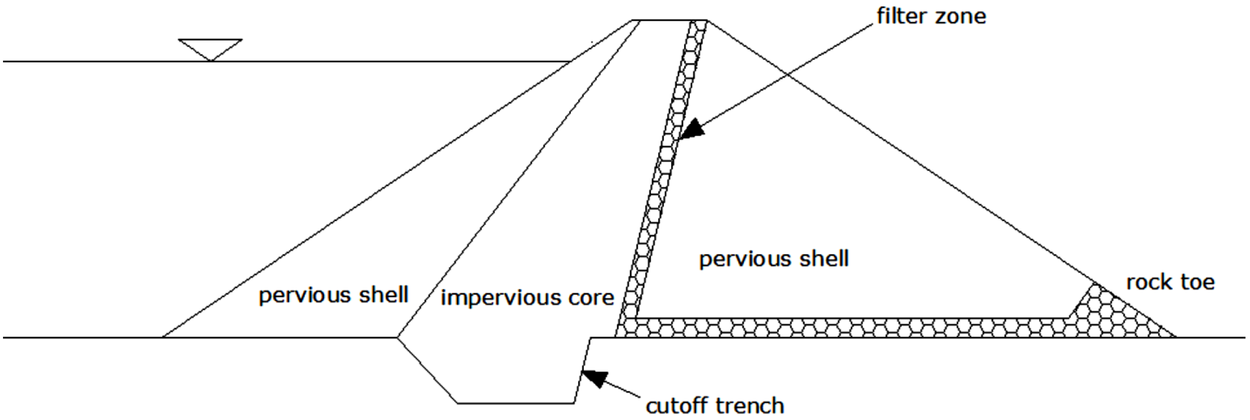


Fig. 2.4: Section of sloping core zoned earth dam (*modified after Punmia 1992*).

2.2.3 Diaphragm earth dam

Diaphragm earth dam consists of pervious materials and a thin diaphragm to control seepage which is made of impervious materials such as impervious soils, cement concrete and bituminous concrete. The diaphragm might be built either at the center of the dam or as a blanket at the upstream face (*Punmia 1992*). According to

British Standard, this type may be used when the adequate quantity of impervious soil is unavailable at the site.

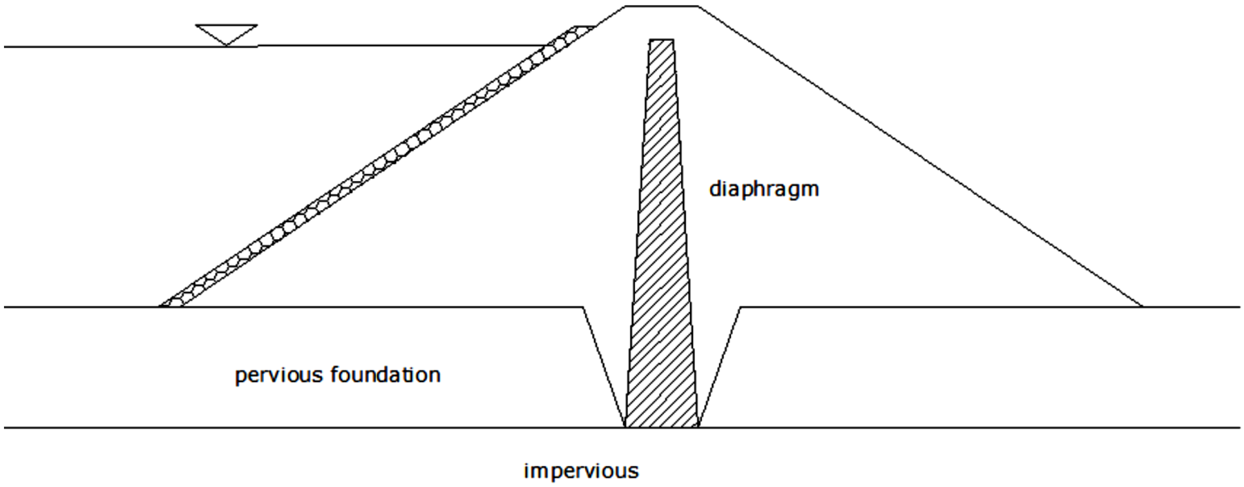


Fig. 2.5: Section of diaphragm earth dam (*modified after Punmia 1992*).

2.3 Numerical solution

Two numerical methods have been widely used in stability analysis: Finite Difference Method (FDM) and Finite Element Method (FEM). FDM may be the first numerical technique used to solve sets of differential equations, given initial values and/or boundary values and each derivative in the set of governing equations is substituted by an algebraic expression written in terms of the field variables (e.g., stress or displacement) at discrete points in space; these variables are undefined within elements. FLAC (Fast Lagrangian Analysis of Continua), one of the most common programs used in slope stability analysis, is based on the FDM. Although FDM and FEM are derived in different ways, the results of both methods are very similar (*Itasca 2005*). FEM is one of the best methods of numerical analysis used in engineering practices and it can solve many complicated problems (*Maula and Zhang 2011*). (*Griffiths and Lane 1999*) strongly recommended using finite element in slope stability analysis as a modern and robust alternative to the classical limit equilibrium methods. Over the past two decades, some finite element methods have been used in stability analysis such as gravity increase method and strength reduction method (*Albataineh 2006*).

Nowadays, due to the advancement of information technology, FEM is a strong alternative to the traditional method in stability analysis because it does not need any assumptions in terms of the slip surface and it finds the critical slip surface naturally due to the stress-strain analysis, and failure occurs globally. However, it has many advantages compared with LEM, but still is not widely used in stability analysis (*Griffiths and Lane 1999*).

Finite element method is really important and essential for irregular shapes because it has the ability to define any shapes and when various materials are available, Traditional methods do not have ability to solve in such complex conditions; they are useful in dealing with simple and regular geometrical shapes. Another advantage of finite element is the ability to show the displacement and deformation results by graphs or charts, which facilitates understanding the behavior of the structure. In addition, regarding the forces between the slices, assumption is not necessary because it does not depend on the slices technique (*Griffiths and Lane 1999*).

Both (*Cheng et al. 2007*) and (*Maula and Zhang 2011*) pointed out that the period which is essential to analyze and set up the computer model is long, but nowadays due to the development of computers it can be carried out in a suitable time.

(*Maula and Zhang 2011*) stated that the stability analysis has been developed and applied by many researchers by using different analytical procedures. The main approaches are Limit Equilibrium Method (LEM) and Limit Analysis Method (LAM) (*Shang-jie et al. 2009*). LAM is used in slope stability analysis. The applications of this method are only for simple problems, because it has many limitations for complicated conditions. Therefore, this approach is rarely used and it gives the factor of safety, which is slightly more than those by LEM (*Cheng et al. 2007*). The most common analytical method is LEM which has many versions such as the ordinary method of slices (*Fellenius, 1936*), Bishop's Modified Method

(*Bishop, 1955*), Janbu's generalized procedure of slices (*Janbu, 1968*), Morgenstern and Price's method (*Morgenstern & Price, 1965*) and Spencer's method (*Spencer, 1967*) (*Griffiths and Lane 1999 and Vaughan et al. 2004*).

Not all these methods satisfy all static equilibrium conditions. Even though the Spencer's method is more accurate and gives the reliable results, the other methods are commonly used and many writers have explained the other methods in detail (*Griffiths and Lane 1999*). The ordinary slice method is the simplest method and factor of safety can be calculated by hand. In contrast, Spencer’s method needs a computer for calculating factor of safety (*Abramson et al. 2002*). With regard to analysis, the sliding mass either is divided into slices or wedges. The majority of the well-known LEMs have used slice technique to perform stability analysis. The sliding soil mass is divided into a number of vertical slices. Sometimes may be horizontal or inclined according to the methods. Slope stability analysis statically is indeterminate problem. Therefore, it needs some assumptions in order to be determinate. Each method has different procedures and assumptions (*Abramson 2002*). (*Albataineh 2006*) pointed out that these assumptions form the fundamental differences between methods, and have an important effect on the accurate result of safety factor.

The strength reduction method is one of the popular finite element methods and been extensively used and accepted by many engineers. Many famous geotechnical commercial programs such as FLAC, PLAXIS and Phase2 have used this technique (*Cheng et al. 2007*). In this method, the shear strength parameters of the soil are reduced gradually until failure occurs. To explain this, for instance, in PLAXIS, PLAXIS calculates the factor during reducing the parameters RF (*Albataineh 2006*). The comparison is not only for factor of safety, but also for critical slip plane; the study also showed that critical slip planes in both methods are similar (*Cheng et al. 2007*). The results of this study have shown that the finite element method offers an accurate result of factor of safety, which is very useful in complex conditions in which conventional methods cannot be used (*Shang-jie et al. 2009*).

2.4 Analytical solution

Seepage and Stability of earth dam were analyzed using Ansys and GeoStudio Softwares, the significant difference of two programs is related to safety factor deducted that Ansys answer is more acceptable (*Kamanbedast and Delvari, 2012*). SEEP/W simulation compared with field observations for seepage analysis. Calibration of the material properties is made based on minimization of error while comparing observed hydraulic heads with the simulated ones (*Arshad and Babar, 2014*). (*Alnealy and Alghazali 2015*) analyzed of seepage under hydraulic structures using slide program. Single and multi- layers soils and its effect on structures with inclined cut-off were studied. Casagrandi and Dupuits assumptions were analyzed to estimate seepage through homogeneous earth dam without filter (*Jamel, 2016*). (*Çalamak et al. 2016*) investigated the suitability and the effectiveness of blanket and chimney drains in earth fill dams for various properties of the drainage system. (*Irzooki, 2016*) was used SEEP/W code to run on homogenous earth dam models with horizontal toe drain, a new equation was found for computing the quantity of seepage. (*Omofunmi et al., 2017*) reviewed on effects and control of seepage through earth-fill dams. San Luis dam used to evaluate the unsaturated and transient seepage analysis in which pore-water pressures at failure and progression of the phreatic surface through the fine-grained core for drawdown stability analyses (*Stark et al., 2017*).

(*Hnang, T. K. 1996*) analyzed the stability of an earth dam under steady state seepage in Taiwan, the factor of safety against stability failure for the dam was adequate. (*Elshemy, M. M. 2002*) studied the soil blockage effect on the seepage through earth dams, the block gave a slight effect if it was closed to the exit face, that effect was vanished when that was located at the upstream side. (*Mohammed et al. 2006*) investigated the seepage through two earth dams in Malaysia, the introduced numerical model, successfully predicted the seepage and phreatic surfaces of the studied dams. (*Soleimanbeigi and Jafarzadeh 2008*) analyzed the seepage through rock-fill dams in narrow valleys, the 2D seepage analysis was far from reality, while 3D modelling of such sites was vital. (*Flores and Lopez 2011*) presented several recommendations for preventing damages due to soil erosion in earth embankments. (*Jamel 2016*) investigated the seepage through homogenous earth dam without filter, her suggested equation when compared using artificial neural network showed an error less than 3%, and with numerical results showed an error less than 2%, it was noticed that, Dupuit's solution showed an error more than 20%, while with Casagrande's solution gave an error more than 15%. (*Vaezinejad et al. 2018*) introduced a new method for leakage modeling of Baft dam in Iran, the results showed the possibility of using the introduced method in locating leakage in such problems. (*Behzad and Farjad 2017*) examine the effect of different materials quality on stability of rock fill zoned embankment dams by applying computer modeling using from GeoStudio, finite element software. They observed that increasing internal friction angle of soil of the upstream layer, the rate of confidence coefficient increased slowly. Increasing the special weight of soil of filter layer causes confidence coefficient to decrease.

N. Himanshu and A. Burman 2018) using geotechnical software GEOSTUDIO 2007 (SEEP/W in Seepage analyses and SLOPE/W in Stability Analysis software), to analyze both seepage and slope stability analyses of the earthen embankment dam of Durgawati reservoir project in the region of Kaimur–Bihar. It has been observed that the Factor of safety against slope failure at the upstream face is substantially greater than that of the downstream slope because of resisting effect of the reservoir water on the upstream slope. A pseudo-static analysis has been performed using different horizontal earthquake coefficient in combination with both steady state as well as transient-state seepage condition.

2.5 Experimental studies

The more accurate results can be achieved if the materials behavior is simulated properly (*Griffiths and Lane 1999*). (*Azadmanesh and Arafati 2012*) evaluated the stability of a dam in Iran. They used three methods of Limit Equilibrium, Finite Element Method and Finite Difference Method. The results of their studies are that the result of FEM is smaller than FDM by 12%. The reason for this, they pointed out, is that the parameter of elasticity modulus is taken into account in FEM, but not in FDM. Whereas (*Cala and Flisiak 2003*) investigated that, the effect of elastic properties on the factor of safety is less than 1%. The other investigation performed the numerical simulation to find the effect of horizontal drain length and cutoff wall on seepage and uplift pressure in heterogeneous earth dam (*Mansuri and Salmasi, 2013*). The case study on "Hub" earthen dam located on (*Karachi city-Pakistan*) also investigated.

(*Zeidan et al. 2018*) simulated seepage of Mandali Dam in Iraq, the model results confirmed the safety of the dam against seepage. (*Sazzad and Islam 2020*) observed that, the performance of inclined rock toe was better than vertical rock toe, the trapezoidal shape of internal core was better than other shapes. (*Ghazaleh and Gholamreza 2020*) indicated that the cut off wall under the clay core produced the most seepage reduction, while increasing horizontal drain length decreased the uplift pressure. (*Sazzad and Alam 2019*) studied the seepage characteristics of different types of earth dams and proved that the seepage was high in case of zoned type dam compared to other types.

2.6 Statistical studies

It is important to design and optimize the dimensions of the dam drainage system to keep the dam's downstream shell dry and to prevent the increase of pore water pressure in the earth dam body. (*Bhagu 2004*) obtained explicit equations to calculating the downstream slope cover and the length of the downstream horizontal drain in homogeneous isotropic and anisotropic earth dams. Similar equations have also been obtained for maximum downstream slope cover, minimum, and maximum effective length of the filtered drainage. The numerical example demonstrates that the proposed equations are simple to use, hence the designers may find these equations as an additional check to their design by the conventional flownet method.

(*Mehdi et al. 2019*) modeled Marvak earth dam by GeoStudio software with real material parameters, and the minimum factor of safety of the dam was obtained by changing the dimensions of drainage, the material of the material, and slope of the dam. By training the neural network from the data obtained from the modeling of the Marvak dam, the minimum factor of safety for horizontal drainage was obtained. The results of the study show that the two factors of the internal friction angle of the drainage material and the slope of the dam have the greatest impact on determining the minimum factor of safety of the dam.

(*Seyed 2017*) modeled the leakage from Shahr Chai Dam using artificial neural networks (ANN) and the model was verified. They found that there is no need for the physical details of the dam in the artificial neural network (ANN) model like other models, and the verification of presented models for each piezometer was carried out only by using multiyear static data on the dam body and water height in the upstream and in the downstream of the dam. In addition, using a dynamic model, which is based on the observations data and present conditions, can be useful because those most natural conditions of an embanked dam would not be ideal after the construction due to executive problems.

2.7 Summary of literature review

The stability of earth dam is influenced significantly by the structural geometry. The considerable effect of structural geometry on safety and economy of earth dam makes it necessary to do many research and investigations in this field. In this literature review, the key factors that affect the stability of earth dam have been presented. It was demonstrated that the shear strength parameters has a substantial role in stability of earth dam.

In addition, earth dam has been defined and its types have been described. This literature review has explained the most critical loading conditions of earth dam and suitable shear strength parameters are recommended. The minimum acceptable factors of safety for each critical loading condition were suggested.

Furthermore, analytical and numerical methods such as two more popular approaches in stability analysis have been illustrated. The variety and wide range of methods of stability analysis has led to doing more research to investigate the accuracy and reliability of those methods. It was found that the Finite Element Method is a powerful tool to evaluate stability analysis and it is particularly recommended for complicated conditions when accurate results cannot be obtained from traditional methods.

Finally, in order to achieve the stable and cost-effective earth dam, it is recommended that more research and investigations are required concerning aspects such as; the effect of single berm and two berms in stability analysis of earth dam, finding economical upstream and downstream side slopes and the effect of side slope and size of the clay core in stability analysis point of view. In the light of this conclusion, it is expected that many numerical solutions might be done to examine the effects of each factor.

Investigating the previous mentioned researches, indicate the need for a general equations including structural geometrical dimensions and effective material properties, may be used to estimate the seepage discharge amount through a homogeneous earth fill embankment dam with horizontal toe filter section under statically condition, and the factor of safety for side slope sliding under rapidly reservoir water level drop. Hence, it is essential to develop such equations that perform this task, in forms of input and output variables. The needed equations is to be general, easy to apply for any homogeneous earth fill with horizontal toe filter dam, assigned the knowing parameters given as input and the results are according to the case of study.

CHAPTER THREE

THEORY AND SOFTWARES

3.1 General

Any given mass of soil consists of solid particles of various sizes with interconnected void spaces. The continuous void spaces in a soil permit water to flow from a point of high energy to a point of low energy. Permeability is defined as the property of a soil that allows the seepage of fluids through its interconnected void spaces.

Seepage through an earth dam is the continuous movement of water from the upstream face toward its downstream face. The top seepage line of percolating water is known as the phreatic surface. In order to allow adequate embankment and to eliminate seepage problems in the downstream areas of an embankment on impervious foundation, the phreatic surface should be kept within the dam by providing a horizontal drainage filter. The amount of water seeping through and under an earth dam, together with the location of the phreatic surface, can be estimated by considering the flow through porous media.

All earth dams have seepage resulting from water permeating slowly through the dam and its foundation. Seepage must be controlled in both velocity and quantity. Seepage failure in earth dams if uncontrolled, it can progressively erode soil from the embankment or its foundation, resulting in rapid failure of the dam. Erosion of the soil begins at the downstream side of the embankment, either in the dam proper or the foundation, progressively works toward the reservoir, and eventually develops a direct connection to the reservoir. This phenomenon is known as "piping." Piping action can be recognized by an increased seepage flow rate, the discharge of muddy or discolored water, sinkholes on or near the embankment, or a whirlpool in the reservoir. Once a whirlpool (eddy) is observed on the reservoir surface, complete failure of the dam will probably follow in a matter of minutes. As with over topping, fully developed piping is virtually impossible to control and will likely cause failure. Seepage can cause slope failure by creating high pressures in the soil pores or by saturating the slope. The pressure of seepage within an embankment is difficult to determine without proper instrumentation. A slope which becomes saturated and develops slides may be showing signs of excessive seepage pressure.

3.2 Seepage

There are various methods for calculating discharge rate (i.e., seepage) through the dam body. Using analytical solutions, the seepage through an earth dam can be estimated. Many researchers have used analytical methods to calculate the seepage through the dam body. Among the analytical methods, Schaffernak (1917), Casagrande (1937), Dupit (1983), Stello (1987), Rezk and Senoon (2010), Fakhari and Ghanbari (2013) are worthy of noting. The disadvantage of the analytical solution is that, it requires many assumptions and only simple and straightforward seepage problem can be solved. Apart from this analytical approach, numerical approaches such as finite element method, finite difference method and finite volume method are also used to determine the seepage through the earth dam. Among these numerical methods, finite element method is the most popular and widely used method. An important advantage of using finite element method (FEM) in seepage analysis is that the solution of seepage problem is faster and complex seepage problems can be solved using FEM. Several authors have used FEM to solve the seepage problem of earth dam, *Papagianakis and*

Fredlund (1984), Lam et al. (1988),Potts and Zdravkovic (1999). In the last graphical method termed flow net is preferred by many because it is very versatile and simple.

3.3 Theoretical Consideration

As clearly explained by *Harr (1962)*, there were many different assumptions for determining the seepage quantity as explained below:

1- Dupuit's Assumptions: Both discharge quantity and free surface are independent of the slopes of the dam. The discharge (per unit width) through any vertical section of the dam for the condition of tail water at potential seepage face are shown in Figure (3.1).

$$q = \frac{k(h_1^2 - h_2^2)}{2l} \qquad (1)$$

q= discharge

k= permeability coefficient

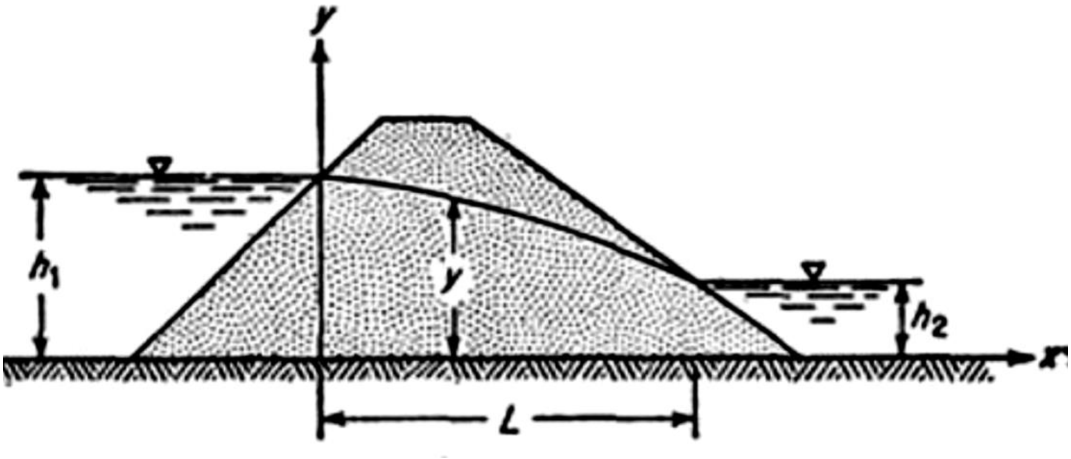


Fig. 3.1: Dupuit’s method for seepage calculating (Harr,1962).

2- Schaffernak & Van Iterson (1917): The first approximate method that accounts for the development of the surface of seepage considering an earth dam on an impervious base shown in Figure (3.2) with no tail water.

$$q = kasin(\alpha)\tan(\alpha) \qquad (2)$$

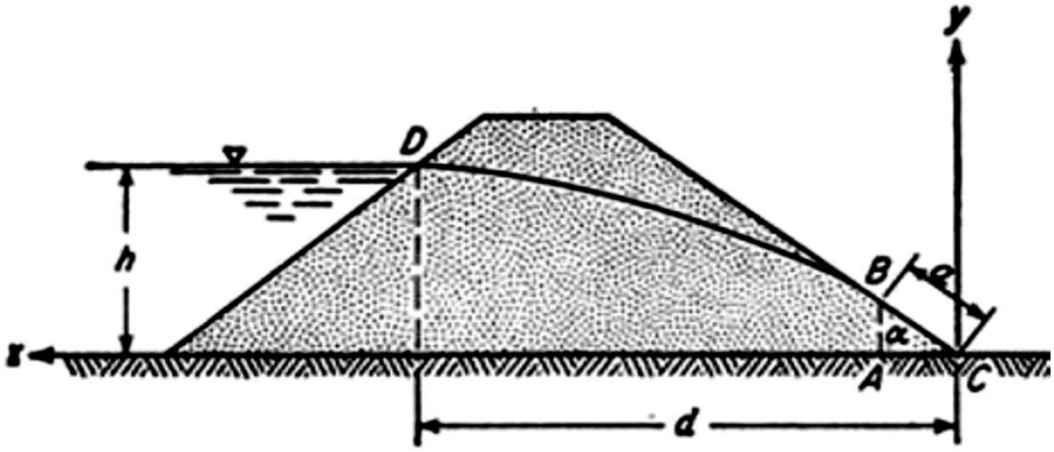


Fig. 3.2: Schaffernak & Van Iterson method for seepage calculating(Harr,1962).

3- L.Casagrande's (1932): Recommended that point D_o shown in Figure (3.3) instead of point *D* be taken as the starting point of the line of seepage (*Do* is 0.3Δ from point *D* at the upstream reservoir surface). The actual entrance condition is then obtained by sketching in the arc DF normal to the upstream slope and tangent to the parabolic free surface.

$$q = k\ a\ sin^2\ \alpha \qquad (3)$$

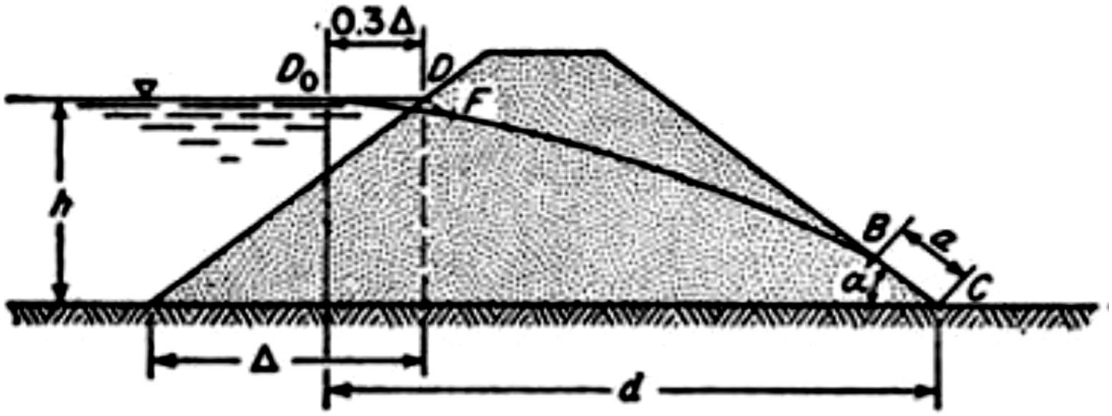


Fig. 3.3: L.Casagrande's method for seepage calculating(Harr,1962).

4- Pavlovsky's Solution: Considered the dam divided into three zones as shown in Figure (3.4). The upper section (I) bounded by the upstream slope and y-axis, the central section (II) by the y-axis and a vertical line through the discharge point of the free surface and the lower section (III) by the latter vertical line and the downstream slope. The streamline in zone (I) are known to be curvilinear (dotted curves cd); however, Pavlovsky assumed that they may be replaced by horizontal streamline of almost equivalent length (ed) then assuming purely horizontal flow in zone (I).

$$dq = k \frac{a_1}{cot\beta(hd - v)} dy \qquad (4)$$

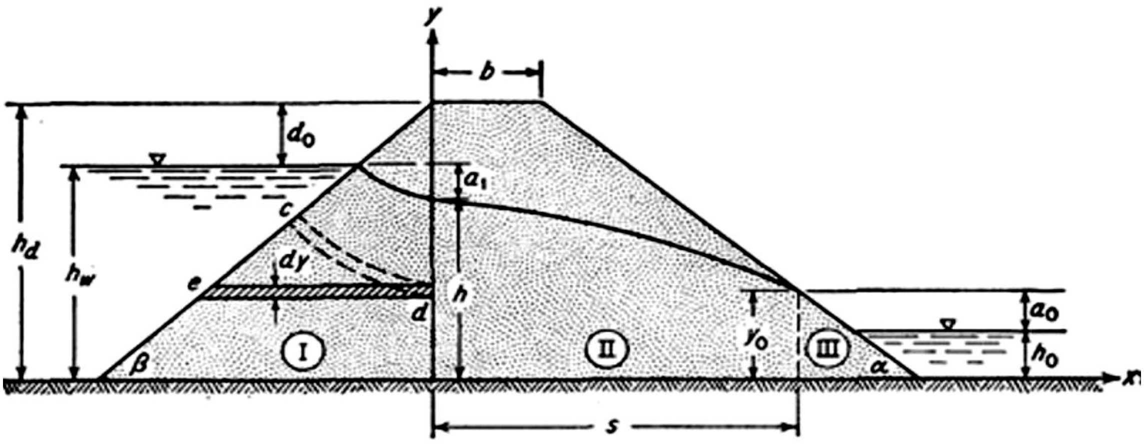


Fig. 3.4: Pavlovsky's method for seepage calculating(Harr,1962).

5- Casagrande's suggest the following method to establish the phreatic surface for flow through homogeneous earth dam with horizontal drainage blanket at its toe.

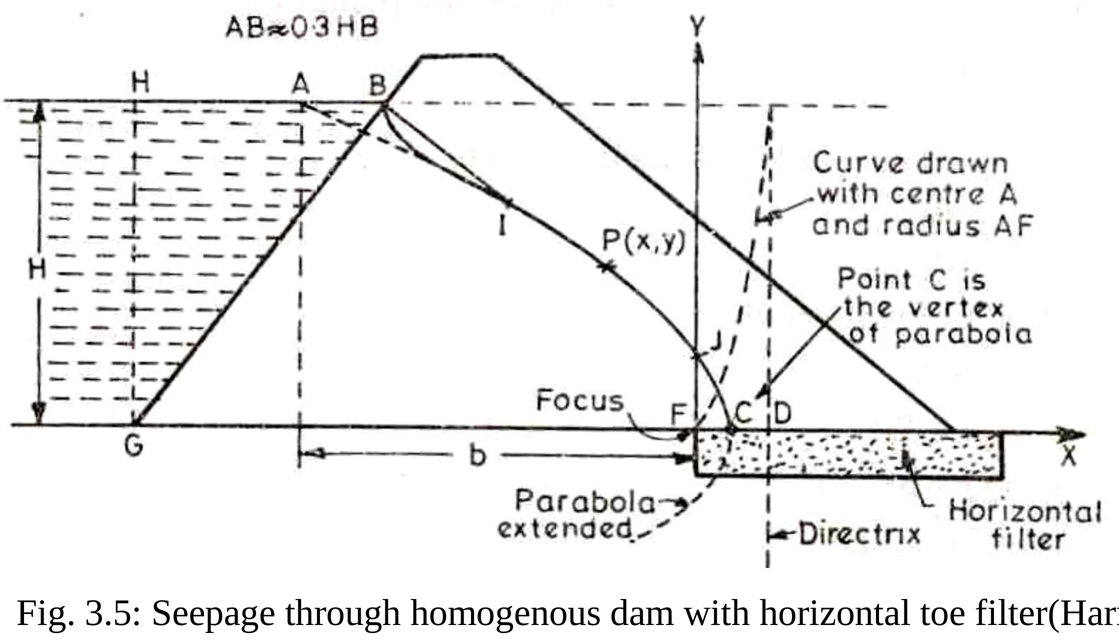


Fig. 3.5: Seepage through homogenous dam with horizontal toe filter(Harr,1962).

Let a base parabola with focus at F is drawn and produced so as to intersect the water surface at a point A as shown in Figure (3.5)1.Taking the focus (F) as the origin, equation of the parabola p(x, y) can be written as:

$$\sqrt{x^2 + y^2} = x + FD \qquad (5)$$

where: FD is the distance of the focus from the directrix, called focal distance and is represented by S.

Hence, the equation of the parabola of the seepage line becomes:

$$\sqrt{x^2 + y^2} = x + S \qquad (6)$$

Location of A is approximately 0.33HB horizontal distance upstream from point B according to Cassagrande. Where, H is the projection of the point G on the water surface. If the horizontal distance between the already determined point A and the focus (F) is taken as say b, then (b, H) represents the coordinates of the point A on the parabola. And hence:

$$\sqrt{b^2 + H^2} = b + S \qquad (7)$$

$$S = \sqrt{b^2 + H^2} - b \qquad (8)$$

The center point (C) of FD will then be the vertex of the parabola. When x = 0, y= S. Hence the vertical ordinate FJ at F will be equal to S.

Knowing the points A, C, and J and working out a few more points from the equation, the parabola can be easily drawn and corrected for the curve BI, so as to get the seepage line BIJC.

The amount of seepage can also be calculated easily from the equation of the seepage line as derived below.

Darcy‟s law is defined as, q = KiA. When steady conditions have reached, the discharge crossing any vertical plane across the dam section (unit width) will be the same. Hence, the value i and A can be taken for any point on the seepage line:

$$q = k\,\frac{dy}{dx}\,y \qquad (9)$$

But from the equation of the parabola,

$$y = \sqrt{S^2 + 2xS} \qquad (10)$$

$$q = k\left[\frac{1}{2}\left(S^2 + 2xS\right)^{\frac{1}{2}-1}.\,2S\right]\left[\sqrt{S^2 + 2xS}\right] \qquad (11)$$

$$q \;=\; k\,S \qquad (12)$$

3.4 Sliding Failure

One of the most serious dam safety concerns is the stability of the earthen embankment. Unsafe conditions could lead to a major slide that threatens the safety of the dam. A key factor to stability is the location of the phreatic line, or the fully saturated zone of the soils within the embankment. In safe dams, this level is well contained below the surface. Since soils that are fully saturated are not as strong, a higher phreatic line can reduce the ability of the embankment to resist sliding. This is often noted by seepage exiting on the downstream face of the dam. Weak or poorly compacted soils can increase both seepage and the phreatic level as well as weaken the embankment, contributing to a sliding failure of the dam. Properly designed dams often include an internal drainage system, such as a sand chimney and blanket drain. They serve as a filter to keep seepage from moving any soil as well as allowing seepage to be removed in a controlled fashion. This lowers the phreatic line and improves the stability of the embankment. For existing dams with a high phreatic line, two alternatives can improve the dam's stability. One is to add a drain near the toe to both filter the seepage and lower the phreatic line through a controlled release of the seepage. The second is to add a berm for added resistance and Improved stability of the embankment. This does not lower the phreatic line, but improves the dam's stability by adding weight to prevent slides in the embankment.

Slope stability analysis is evaluated by factor of safety which is equal to the ratio of the shear strength of the soil to the maximum shear stress driving at the slip surface failure, *Lowe (1988), and Novak et al. (2001)*. Failure happens when the driving force at any plane through the dam is greater than the resisting force at that plane. At first, the critical slip surface is assumed, and then the factor of safety is calculated. This is repeated for different possible planes. The surface which gives the minimum factor of safety is the critical slip plane, *Lowe (1988)*.

Azadmanesh and Arafati (2012), described Janbu's method as one of the most exact methods. Janbu's Generalised procedure of slices is one of the most popular approaches, which use the vertical slice technique and satisfy both horizontal and vertical forces, and moment equilibrium of the slices, and moment equilibrium for the entire slide mass but the last slice, *Albataineh (2006)*.

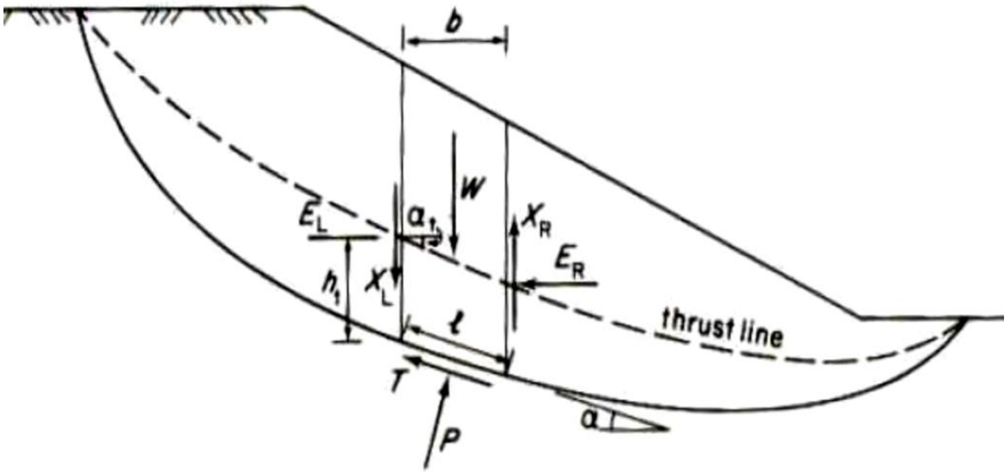


Figure 3.6: Explanation of the terms of Janbu's generalized procedure, *Albataineh (2006).*

For the slice shown in Figure (3.5), the Mohr-Coulomb failure criterion is, *Albataineh (2006)*:

$$S = C' + (\sigma - u)\tan\emptyset \qquad (13)$$

where S = Shear stress(N/m).

C' = effective cohesion intercept(kPa).

σ = total normal stress(N/M^2).

u = pore water pressure(pa).

Φ = effective friction angle.

Using safety factor (F_S):

$$F_S = \frac{S(\text{Assumption})}{\tau\ (fact)} \quad (14)$$

3.5 Methods of Stability Analysis

In order to ensure the stability of earth dam, slope stability analysis should be performed for every dam before the construction. Slope soil can be defined as a soil that its surface makes an angle with the horizontal. There are two types of slopes, *Ramamurthy and Sitharam (2011)*:

1) Natural slope
2) Man-made slope

The slope is also divided into two types for the aim of stability analysis; infinite slope and finite slope.

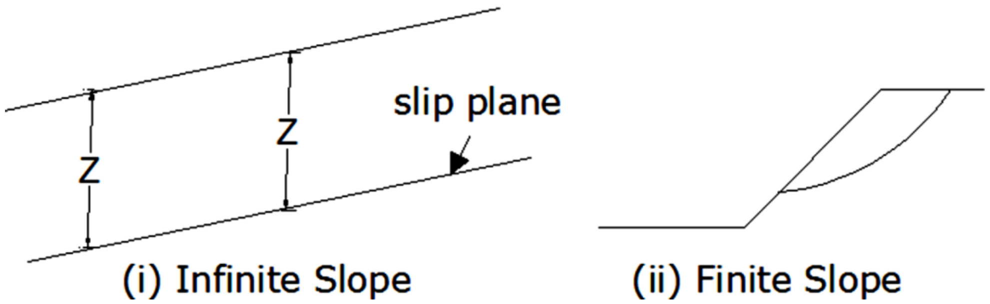


Fig. 3.7: Types of slope, *Ramamurthy and Sitharam (2011)*.

There are three types of slip surface of finite slopes; face failure, toe failure and base failure

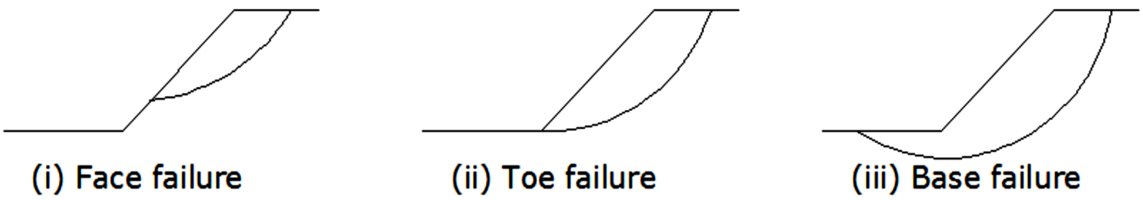


Fig. 3.8: Types of failure of finite slope, *Ramamurthy and Sitharam (2011*).

3.6 Geo Studio Software

Geo Studio is a suite of software products that can be used to evaluate the performance of dams and levees with varying levels of complexity. The seepage, settlement, filling/draining, and stability performance of the structure can be simulated during the entire construction sequence. Pore water pressures and stresses can be included in an advanced stability analysis. The response of the structure to earthquake loading, ground freezing/thawing or other land-climate interactions can also be investigated. SEEP/W is a software product for modeling groundwater flow in porous media using the finite element method (FEM). SEEP/W can be used to analyze a variety of technical issues related to groundwater flow. Analyze and design seepage and uplift control measures such as stabilizing berms, cut-off walls and deflowering systems. Evaluate the risk of initiating internal erosion using seepage and exit gradients. From Geostudio it can be Analysis homogenous earth dam to find Potential drop and seepage, shape of phreatic line, factor of safety by applications Geo Studio SLOPE/W, SEEP/W programs.

3.6.1 SEEP/W

SEEP/W is one of the subprograms of the Geo-Studio program, which is an analytical model that can mathematically represent the physical processes of water flow through the intermediate parts. The tools of the mathematical analysis program (SEEP/W) are effectively used for the intended purpose and are an effective means of complex numerical analysis. These tools have led to an understanding of physical processes and have enabled an understanding of saturated and unsaturated flow modeling.

The program (SEEP/W) is based on the flow equation during the saturated and unsaturated soil of the Darcy law

$$v = k\ i \qquad (15)$$

Since Q = v A

$$Q = k\ i\ A \qquad (16)$$

Where A = B y

$$q = k\ i\ y \qquad (17)$$

Where is:-

k = The permeability coefficient, its units are speed units (L / T).

I = Hydraulic gradient, without units.

Q = Drainage discharge (L^3/ T).

A = Area of the flux (L^2).

B = Flow width (L).

Y = Flow depth (L).

q = The amount of discharge per unit displayed (L^3 /T /L)

The differential equation used for running is arranged in seep/w program as follows:

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial x} + \left(k_y \frac{\partial h}{\partial y}\right) + Q = \frac{\partial \theta}{\partial t} \qquad (18)$$

h = The height of the water at the front of the dam (L).

kx = Permeability towards the x-axis (L^2/T).

ky = Permeability towards the y-axis (L^2/T).

Q = Volumetric content (L^3/T).

T = Time (T).

This equation represents the difference between the inward discharge and the external discharges mainly during a certain period equal to the volumetric change as a result of changing the moisture content.

In the case of steady state, the amount of inward and outward flow is equal in all times and thus the equation becomes as follows:-

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial x} + \left(k_y \frac{\partial h}{\partial y}\right) + Q = 0 \qquad (19)$$

The change in moisture content depends on the state of stress and soil properties (saturated or unsaturated).

3.6.2 SLOPE/W

The SLOPE/W program is a comprehensive and simple program that can be easily used to analyze lateral slope stability problems of soil (simple inclinations and complex tendencies), where the program has a set of methods to calculate the safety factor (Factor of safety) for the surface level of sliding soil. SLOPE/W uses the theory of "Limit Equilibrium" to calculate the safety coefficient of the sliding surface level of the soil as well as the rocks. The SLOPE/W program is used in civil engineering projects as well as in mining projects and other projects in Geotechnical engineering.

3. 7 SPSS Software

Statistics is a powerful statistical software platform. It offers a user-friendly interface and a robust set of features that lets your organization quickly extract actionable insights from your data. Advanced statistical procedures help ensure high accuracy and quality decision making. All facets of the analytics lifecycle are included, from data preparation and management to analysis and reporting.

3.7.1 Artificial Neural Network (ANN) Model

Artificial Neural Network (ANN) or Neural Network (NN) has provided an exciting alternative method for solving a variety of problems in different fields of science and engineering. There are different ways of defining what the ANN are, from short and generic definitions to the ones that try to explain in detailed way what means a neural network or neural computing. For this situation, the definition that was proposed by Teuvo Kohonen, appears below:

Artificial Neural Networks are massively interconnected networks in parallel of simple elements (usually adaptable), with hierarchic organization, which try to interact with the objects of the real world in the same way that the biological nervous system does.

The Perceptron, which is historically possibly the earliest artificial neuron that was proposed, *Rosenblatt (1958)*, is also the basic building block of nearly all ANNs. Here, it suffices to say that its basic structure is a very gross but simple model of the biological neuron. In addition, the artificial neuron has a bias term w_0, a threshold value 'Ɵ' that has to be reached or extended for the neuron to produce a signal, a nonlinear function '*F*' that acts on the produced signal '*net*' and an output '*y*' after the nonlinearity function. It should be noted that the input to the bias neuron is assumed to be 1, *Sivanandam and Paulraj (2003)*.

The basic model of a neuron is shown in Figure (3.9). It obeys the inputs/outputs relations:

$$y = F\,(\text{net}) \qquad (20)$$

where $$\text{net} = w_0 + x_1 w_1 + x_2 w_2 + x_3 w_3 + \ldots\ldots + x_n w_n \qquad (21)$$

or $$\text{net} = w_0 + \sum_{i=0}^{n} x_i w_i \qquad (22)$$

and the neuron firing condition is:

$\sum_{i=0}^{n} x_i w_i \geq \theta$ [for linear activation function], $x_0 = 1$

Or $F(\text{net}) \geq \theta$ [for nonlinear activation function]

If conceive of each node in an artificial neural network as a primitive function capable of transforming its input in a precisely defined output, then artificial neural networks are nothing but networks of primitive functions. Different models of artificial neural networks differ mainly in the assumptions about the primitive functions used, the interconnection pattern, and the timing of the transmission of information, *Rojas (1996)*.

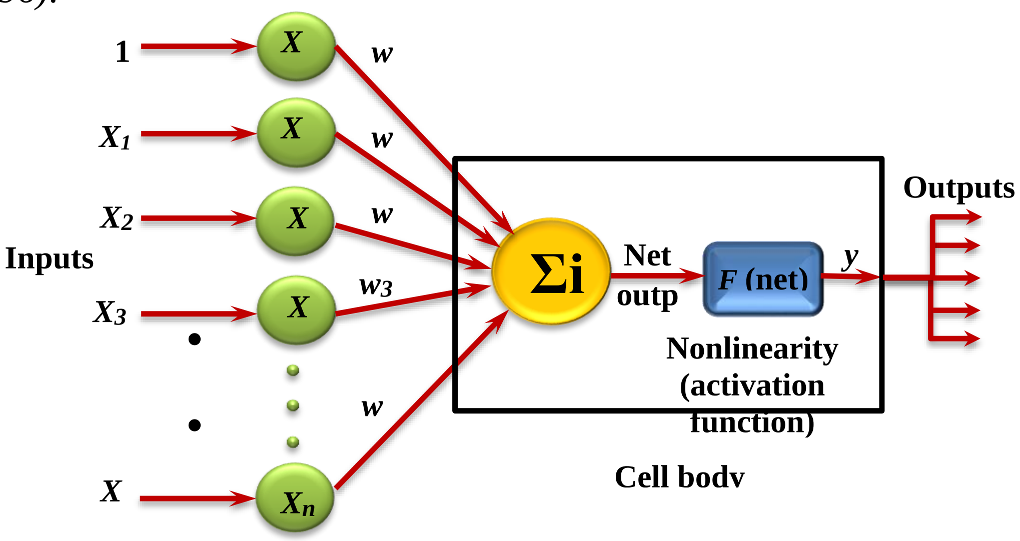


Fig. 3.9: Schematic of neuron model, analog of a biological neural cell Rojas (1996).

Typical artificial neural networks have the structure shown in Figure (3.10). The network can be thought of as a function Φ which is evaluated at the point (x,y,z). The nodes implement the primitive functions f_1, f_2, f_3, f_4 which are combined to produce Φ. The function Φ implemented by a neural network will be called the network function. Different selections of the weights $\alpha_1, \alpha_2, \ldots, \alpha_5$ produce different network functions.

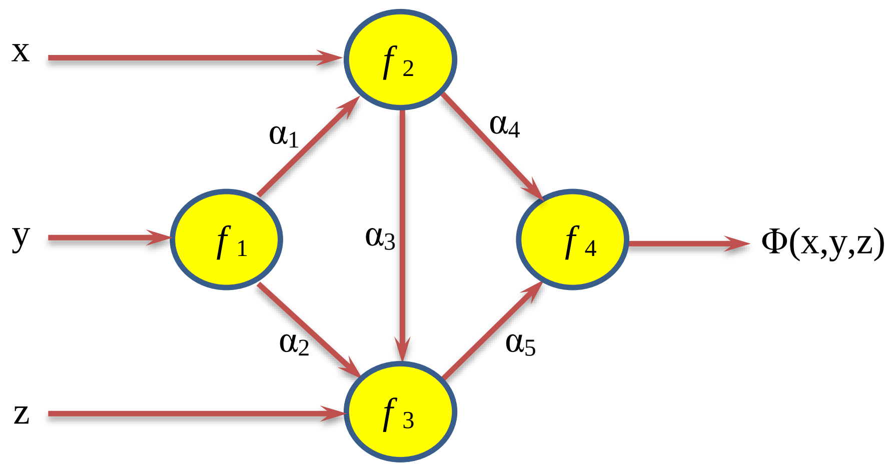


Fig. 3.10: Functional model of an artificial neural network Rojas (1996).

Therefore, three elements are particularly important in any model of artificial neural networks:

a. the structure of the nodes.
b. the topology of the network.
c. the learning algorithm used to find the weights of the network.

3.7.2 Basic Network Structures

The structure of an artificial neural network means the way in which computational neurons are organized in the network. Also describes how the nodes are connected and in how the information is transmitted through the network. The neural network consist number of levels or layers of a determined number of nodes (computational neurons). There is an input layer, an output layer and one or several hidden layers as shown in Figure (3.11). The numbers of hidden layers and hidden neurons are usually determined by trial and error according to the complexity of the problem, *Shamil (2014)*.

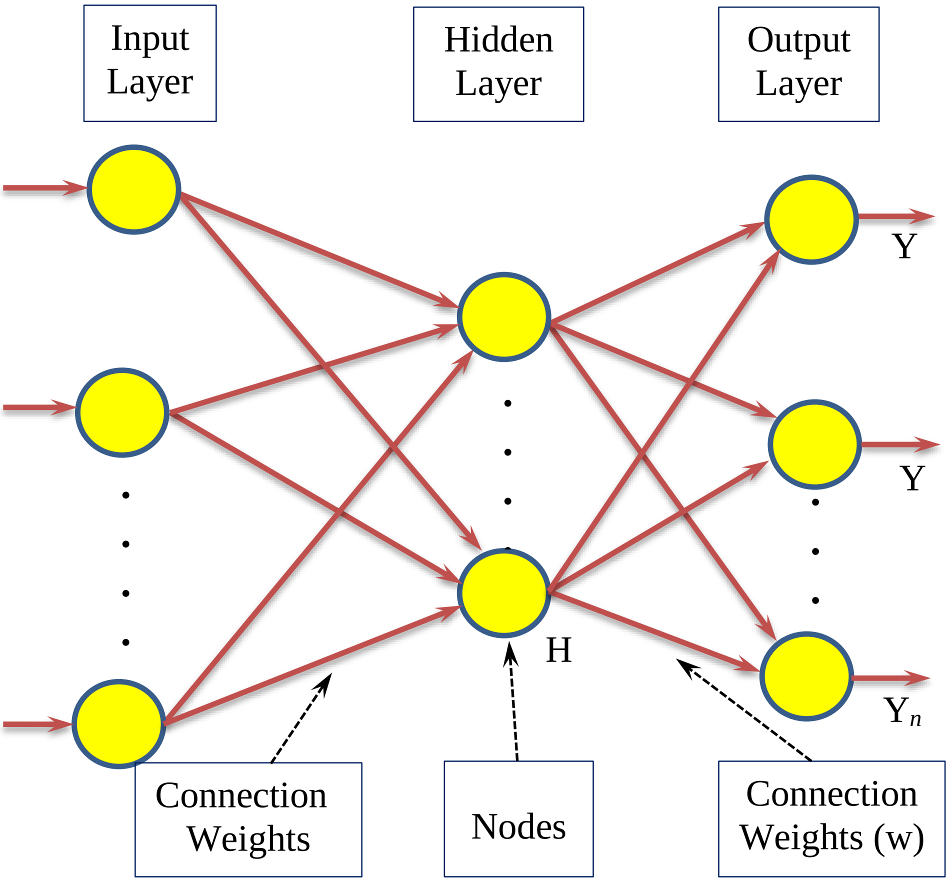


Fig. 3.11: A Simple Artificial Neural Network Structure, *Shamil (2014)*.

3.7.3 Network Classification

The manner in which the neurons of a neural network are structured is intimately linked with the learning algorithm used to train the network. In general, may identify three fundamentally different classes of network architectures, *Shamil et al. (2014)*:

1. Single-Layer Feed-forward Networks: In a layered neural network the neurons are organized in the form of layers.
2. Multilayer Feed-forward Networks: The second class of a feed-forward neural network distinguishes itself by the presence of one or more hidden layers, whose computation nodes are correspondingly called hidden neurons or hidden units.
3. Recurrent Networks: A recurrent neural network distinguishes itself from a feed-forward neural network in that it has at least one feedback loop.

3.7.4 Types of Perceptron's activation functions

The activation function f is also known as a squashing function. It keeps the cell's output between certain limits as is the case in the biological neuron. Different functions $f(z_i)$ are in use, all of which have the above limiting property. The most common activation function is the sigmoid function which is a continuously differentiable function for a perceptron, *Graupe (2007)*:

1) Gaussian activation functions.
2) A unipolar activation function.
3) A binary (0,1) activation function.
4) Bipolar activation functions.

3.7.5 Regression and Correlation

Many problems in engineering and science involve exploring the relationships between two or more variables. Regression analysis is a statistical technique that is very useful for these types of problems. To determine the real relationship between (x) and (y) and to put it in an equation that can be predicted (y) from (x), this is called regression.

To measure the degree of relationship between the two variables and the extent of correlation or interdependence between two independent variables, and this is called correlation, *Shamil (2018)*.

The Independent variable, symbolized by (x) and the dependent variable symbolized by (y). The relationship between these two variables can be represented by [y = f (x)] and this relationship means (y) dependent on (x). For example [$\tau = \mu \frac{dv}{dy}$], this relationship is a linear relationship between the stress (τ) and the velocity gradient ($\frac{dv}{dy}$) in the laminar flow where the slope of the line is equal to the constant (μ), which represents the viscosity, the dependent shear stress and the velocity gradient are independent and as shown in the scatter plot.

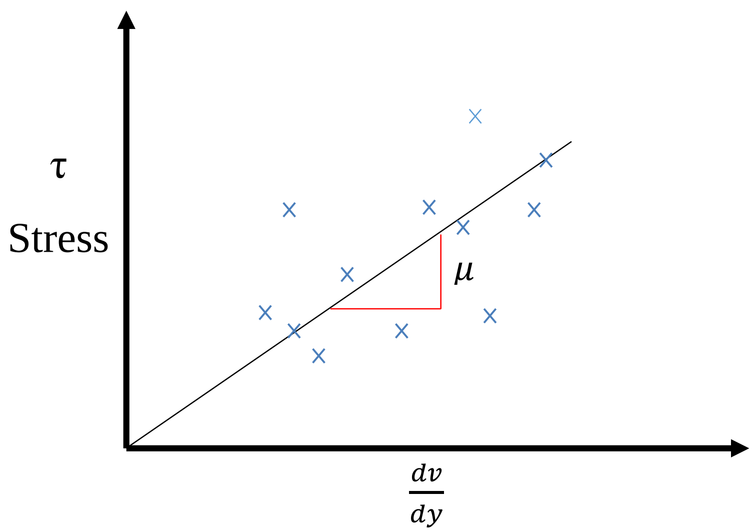


Fig. 3.12: relationship between the stress (τ) and the velocity gradient ($\frac{dv}{dy}$) in the laminar flow.

The case of simple linear regression considers a single predictor independent variable x and a dependent or response variable y. Suppose that the true relationship between y and x is a straight line and that the observation y at each level of x is a random variable.

The expected value of y, can be described by the model:

$$y = \beta_0 + \beta_1 + \varepsilon \qquad (23)$$

where the intercept β_0 and the slope β_1 are unknown regression coefficients, ε is a random error with mean zero, *Shamil (2018)*.

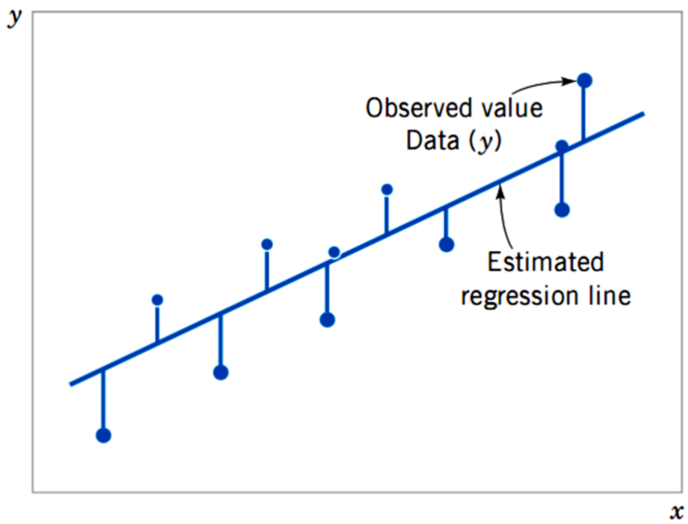


Fig. 3.13: Deviation of data from the estimated regression model *Shamil (2018)*.

We call this criterion for estimating the regression coefficients the method of least squares. We may express the n observations in the sample and the sum of the squares of the deviations of the observations from the true regression line.

The solution to the normal equations results in the least squares estimators β_0 and β_1:

$$\beta_0 = \frac{\Sigma y_i \, \Sigma x_i^{\,2} - \Sigma x_i \, \Sigma x_i y_i}{n \, \Sigma x_i^{\,2} - (\Sigma x_i)^2} \qquad (24)$$

$$\beta_1 = \frac{n \, \Sigma x_i y_i - \Sigma x_i \, \Sigma y_i}{n \, \Sigma x_i^{\,2} - (\Sigma x_i)^2} \qquad (25)$$

There are two known equations can be used to express variables relationship:

1) Equation of the straight line. $y = a + bx$

Where: A = The value of the intersection.

B = Line slope.

2) Equations simplifies to linear equation:

a) Using the normal logarithm of both sides of the nonlinear equation:

$y = a\,x^b$

ln (y) = ln (a) + b ln (x)

Or log (y) = log (a) + b log (x)

Assume Z = log (y) or ln (y)

A = log (a) or ln (a)

t = log (x) or ln (x)

So the equation becomes the following form: Z = A + b t

And after obtained the normal equations of this equation and solved them, find the value of (A) and (b) and then find the value of (a).

Whereas $a = ln^{-1}A = e^A$

Or $a = log^{-1}A = 10^A$

b) Using the assumptions where the variable (x) or (y) or both (which powered to the force more than 1) are replaced by other variable powered to force (1) and as follows:

1- $y^2 = a + b\,x$

let $y^2 = z$ then $z = a + b\,x.$

2- $y^3 = a + b\,x^2$

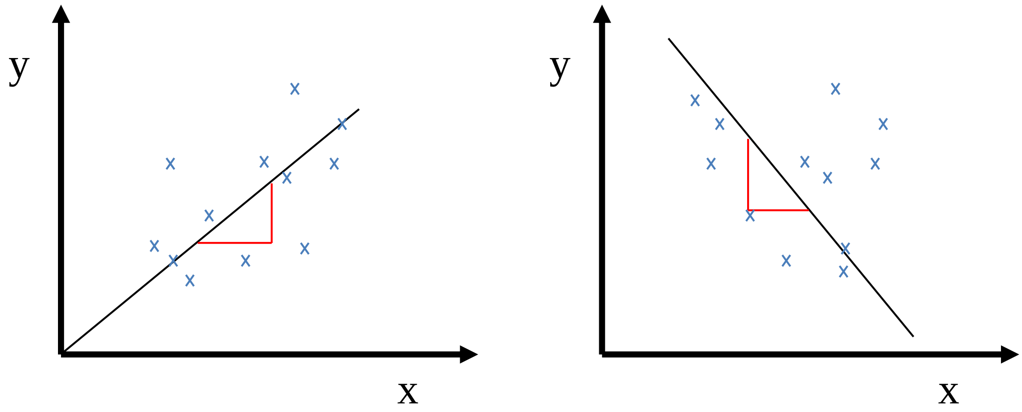
let $y^3 = z$ and $x^2 = t$ then $z = a + b\,t.$

3- $y = \sqrt{a + b\,\frac{x-2}{x^3}}$

$y^2 = a + b\,\frac{x-2}{x^3}$

let $y^2 = z$ and $\frac{x-2}{x^3} = t$ then $z = a + b$

In the research and field studies and engineering issues, there is a need to know the correlation between the dependent variable and the independent variable. In laboratory experiments, for example, the scatter plot drawing on (yx) axis between the velocity gradient and stress or between water depth and velocity, may be not complete (perfect correlation) as between the radius and the size of the ball. Sometimes there is no correlation if the independent variable does not affect the dependent variable. The correlation between (y) and (x) variables is called a simple liner correlation if the expressed equation is liner and may be positive or negative.



a) Positive. b) Negative.

Fig. 3.14: Simple linear correlation Shamil(2018).

The correlation coefficient between the independent variable (x) and (y) is expressed by the linear correlation coefficient, which is called the Pearson's moment correlation, denoted by (r), and the equation formula can be written as follows:

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n(\sum x^2) - (\sum x)^2][n(\sum y^2) - (\sum y)^2]}}$$

The correlation coefficient obtained from the equation above is for best linear equation, where (x) and (y) represents the value given in the table.

The (r) value ranges are: $[-1 \leq r \leq 1]$, *Shamil (2018)*. Where when:

1) (r = 1) is a complete and positive correlation between (x) and (y). The increase in (x) values, causes increase in (y) values and the straight line passes through all the points.
2) (r = -1) is a complete and negative correlation between (x) and (y). The decrease in (x) values, causes increase in (y) values and the straight line passes through all the points.
3) (r = 0) there is no linear correlation between (x) and (y), that (y) values are not dependent on (x) values.
4) In case $[-1 < r < 1]$, that mean of the correlation is incomplete and as shown below:
   a) In the case (r) is very close to (-1, 1) for example (r = 0.95) this is called a good correlation and the values are between (0.8 and 0.95).
   b) In the case (r) is at intermediate distance of (-1, 1) for example (r = 0.7) is called a not-good correlation and the values are between (0.5 and 0.8).
   c) In case (r) is very far from (-1, 1), the relationship is not linear, which mean in the case of (r < 0.5), the relationship is of another type (not linear relationship).

CHAPTER FOUR

APPLACTION OF SOFTWARES FOR THE CASE STUDY

4.1 Modeling Procedure

The case of study model that is adopted here is to estimate the seepage discharge amount and side slope factor of safety for the homogeneous earth fill embankment dam section, hence, the model is solved using the Geo Studio software for every time. Since this model needs frequent estimation for the seepage discharge amount and the factor of safety and each solution needs to be analyzed using Geo Studio software to obtain the corresponding output, which is impractical and make the process indirect and cumbersome. For these reasons, the following steps are conducted to make the process of estimation using mathematical equations direct and easy:

1- Building a data base for different cases, i.e. different sets of input-output variables using the Geo Studio (23) software by SEEP/W and SLOPE/W model. The input variables range are selected according to the limitations of dam section variables given in dam design recommendation references. This data base building will be explained in section (4.2).

2- Obtain the relationship between the sets of input variables and output variables and the influence's weight of each input variable on the output variable using SPSS software by Artificial Neural Network (ANN) Model. This model is verified using comparison of results obtained from the ANN model and these obtained from Geo Studio analysis, using some selected cases not included in the data base developed in step (1) above. This verification process is done to ensure the capability of the ANN model to produce acceptable results, even though the ANN model processing divide the data set into three sub-division, training, testing and holdout (verification) subset, and evaluate the performance of the model using the third set, which is not used for model parameters estimation. The details of this model will be presented in section (4.3).

3- Predict mathematical equations using the SPSS software, which uses the SEEP/W and SLOPE/W analysis results developed in step (1) above as a direct estimation of the output variables for a given set of input variables. Make verification for these equations to ensure the capability of these mathematical equations to produce acceptable results with high correlation. These equations will allow the designers to obtain the amount of the seepage discharge and factor of safety for side slope sliding. These equations will be presented in section (4.4).

4.2 Geo Studio Applications

4.2.1 Study Case Description

The study case to be analyzed is a homogeneous earth fill embankment dam with rectangular horizontal filter, which impounds a reservoir extending to truncation line in the upstream direction and rests on an impervious bounded foundation. The problem of analyzing the dam section needs identification of section geometry and material properties. The section includes the dam, the reservoir and the foundation geometry. General schematic section geometry of the dam is shown in Figure (4.1) below:

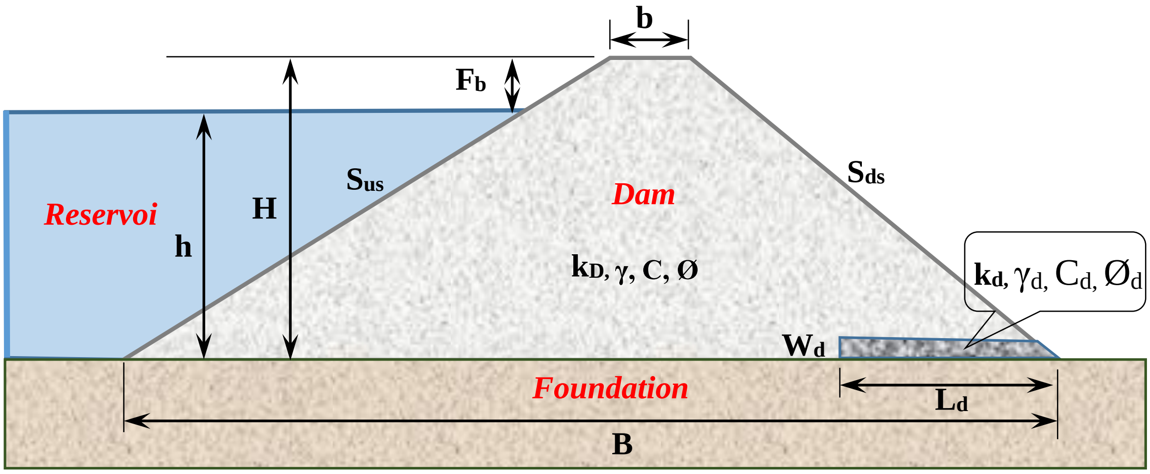


Fig. 4.1: Schematic presentation of the dam-reservoir-foundation system analyzed using Geo Studio.

where:

H = Total high of the dam(m).

h = Water height in the reservoir(m).

b = Dam crest width(m).

B = Total dam base width(m).

F_b = Free board height(m).

S_{us} = Upstream slope.

S_{ds} = Downstream slope.

k_D = Permeability of the dam(m/s).

k_d = Permeability of the drain filter(m/s).

L_d = Total length of the drain filter(m).

W_d = Total width of the drain filter(m).

γ = Unit weight of the dams' material(soil)(N/m³).

C = Cohesion strength for the dam(pa).

Ø = Internal friction angle for the dam.

γ_d = Unit weight of the drain filters' material (N/m³).

C_d = Cohesion strength for the drain filter(pa).

$Ø_d$ = Internal friction angle for the drain filter.

The analysis needs to identify other variables in addition to those geometric dimensions variables presented in Figure (4.1). These variables can be properties variables concerning domains properties such as coefficient of permeability, weight density, internal friction angle, cohesion strength…etc., for the dam body and its drain filter. In order to obtain a general model for analyzing, the variables should be put in some value range. This is conducted as follows, with the range of each variable limitation. These limitations were decided upon the limitations of the dam design practice and recommendations to satisfy stability and overturning control.

Table (4.1) shows the input variables that were adopted to build a database for the cases analyzed using Geo Studio software (SEEP/W and SLOPE/W models) for the seepage discharge and factor of safety response of the dam.

4.2.2 Results of Geo Studio Application

The Geo Studio software used to find the seepage discharge amount and side slope sliding factor of safety response of given homogeneous earth fill embankment dam to varying geometrical dimensions and materials properties, to build the database required for the analyzing and regression process. SEEP/W model software is used to estimate the seepage discharge value and phreatic line shape, while SLOPE /W model software is used to estimate side slope sliding factor of safety. Three hundred cases selected due to variation of the dimensions and properties input variables that cover the variations shown in Table (4.1).

Tab. 4.1: input variables selected for analysis of the dam.

Item	Range	Description			
Total dam height	25-35	H	25	30	35
Dam crest length	5-9	b	5	7	9
Free board	2-3	F_b	2	2.5	3
Upstream slope	1:2-1:3	S_{us}	1:2	1:2.5	1:3
Downstream slope	1:1.5-1:2.5	S_{ds}	1:1.5	1:2	1:2.5
Dam permeability	0.00001-0.0001	k_D	0.00001	0.00005	0.0001
Drain permeability	0.05-0.9	k_d	0.05	0.5	0.9
Drain length	20-30	L_d	20	25	30
Drain width	1-3	W_d	1	2	3
Dam unit weight	17-20	γ	17	19	20
Dam cohesion	5-18	C	5	10	18
Dam friction angle	25-35	Ø	25	30	35
Drain unit weight	19-21	γ_d	19	20	21
Drain cohesion	0-5	C_d	0	0	5
Drain friction angle	35-45	Ød	35	40	45

In the (Geo- studio) program, the network partition is automate and does not require finite elements. There is no concern that the network partitioning in multiple regions or the boundary conditions and material properties will disappear once the partition. Where the current study was to divide the soil within the earth dam into specific elements and divide it in quadrilateral and triangular forms and the number of (elements) to (1065), the number of points that surrounds in each division (Nodes) to (1142) points.

As the Geo Studio capabilities of graphical representation of the result are excellent, one case is select for results presentation purposes and the graphical presentations of the results are shows in Figures (4.2) to (4.9) for one case selected.

Total results obtained from SEEP/W and SLOPE/W softwares analysis for all three hundred models are recorded in tabular form in the appendix A with models geometry dimensions and properties input variables.

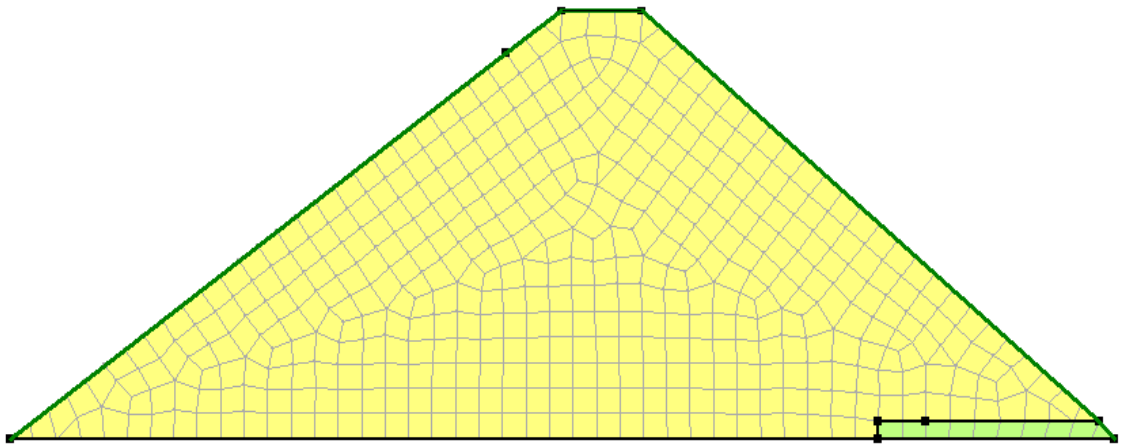


Fig. 4.2: Finite element mesh for dam and drain filter.

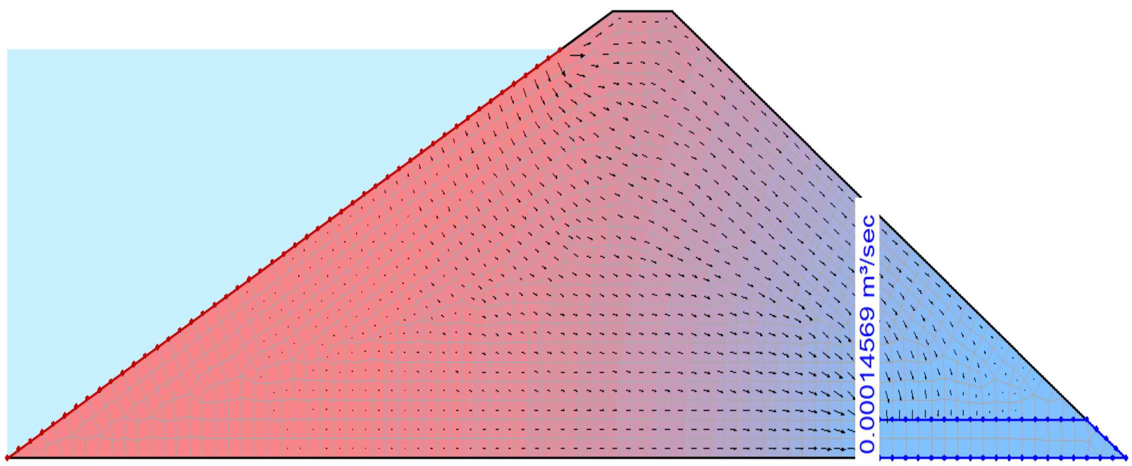


Fig. 4.3: Seepage discharge density and value recorded.

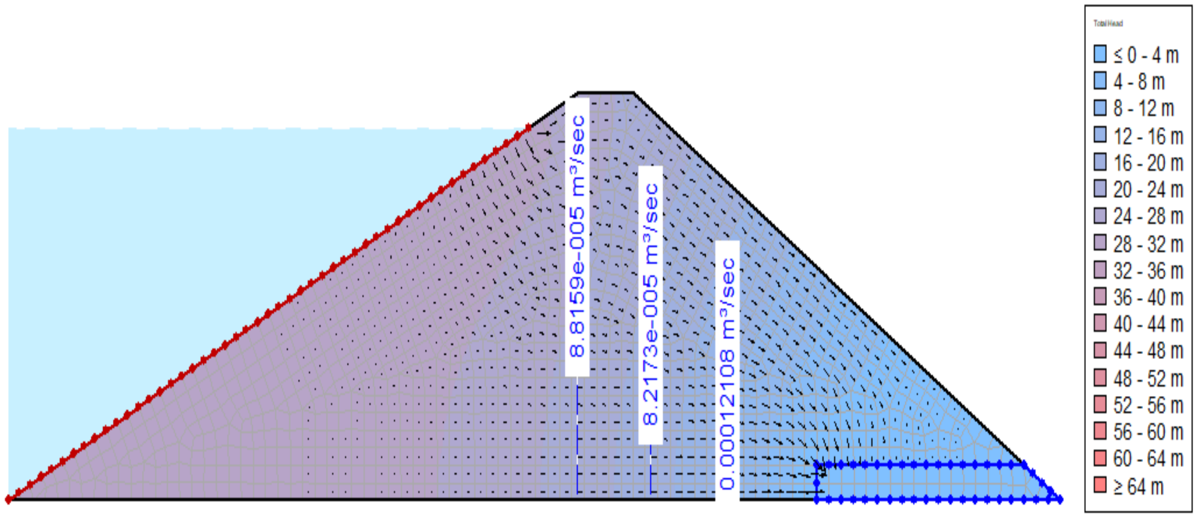


Fig. 4.4: Seepage water head.

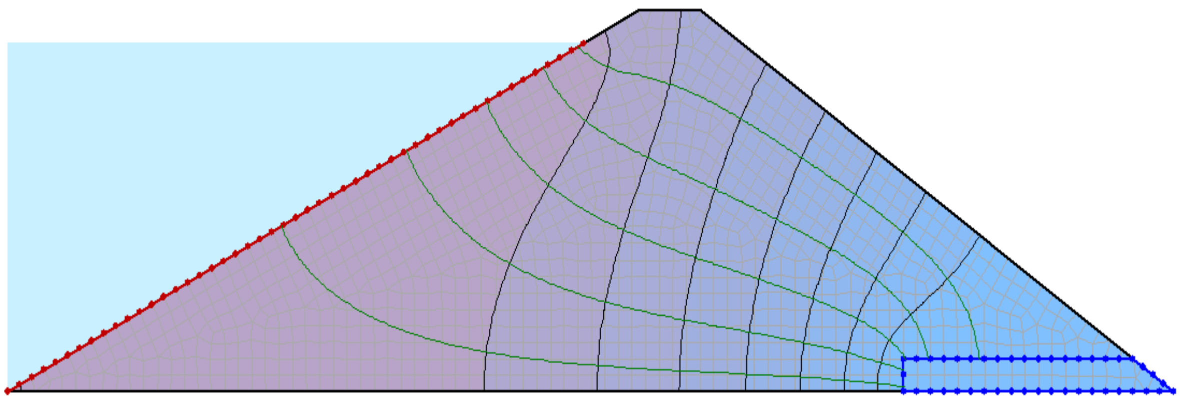


Fig. 4.5: Flow net.

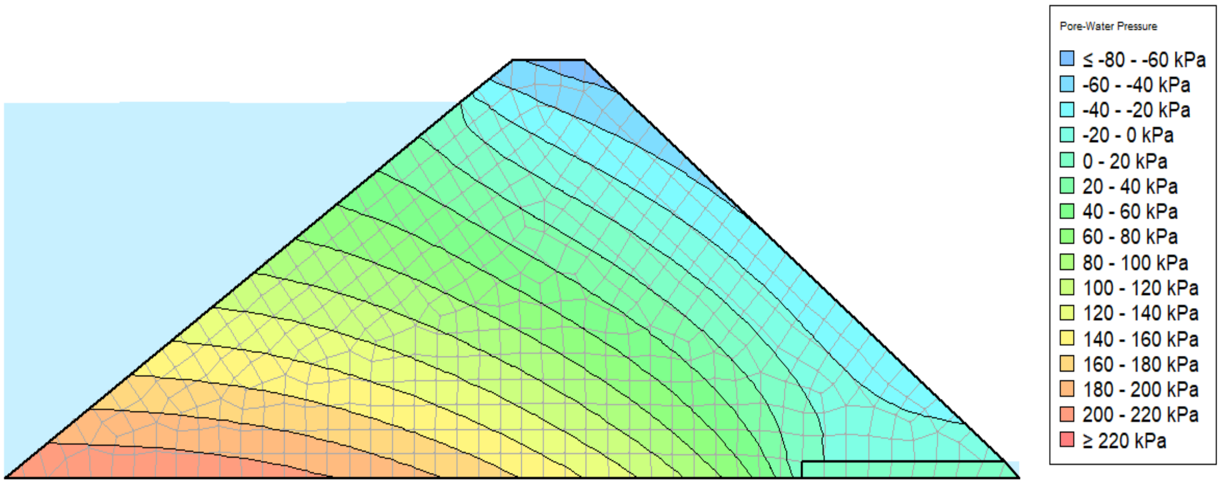


Fig 4.6: Pore water pressure distribution.

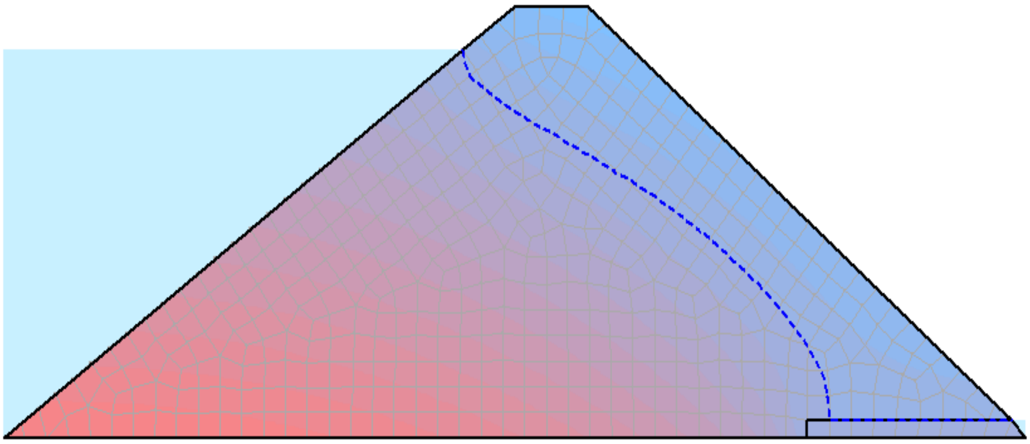


Fig 4.7: Phreatic line.

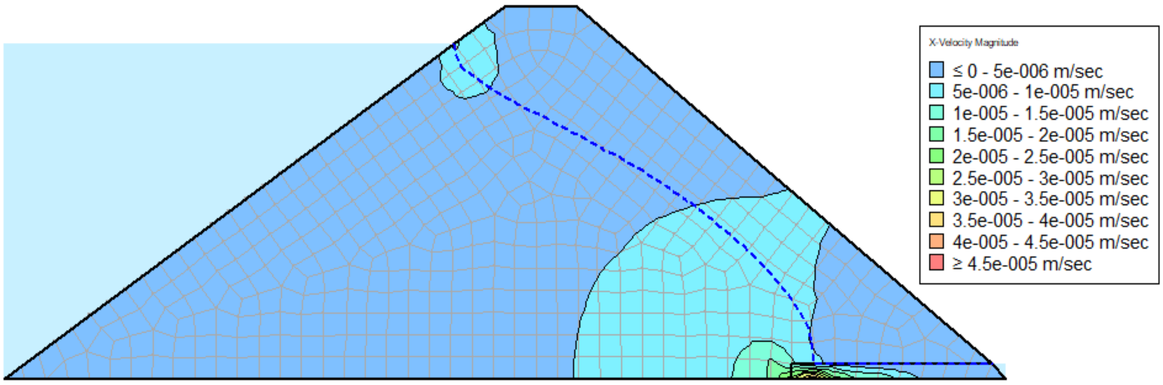


Fig 4.8: Velocity gradient distribution.

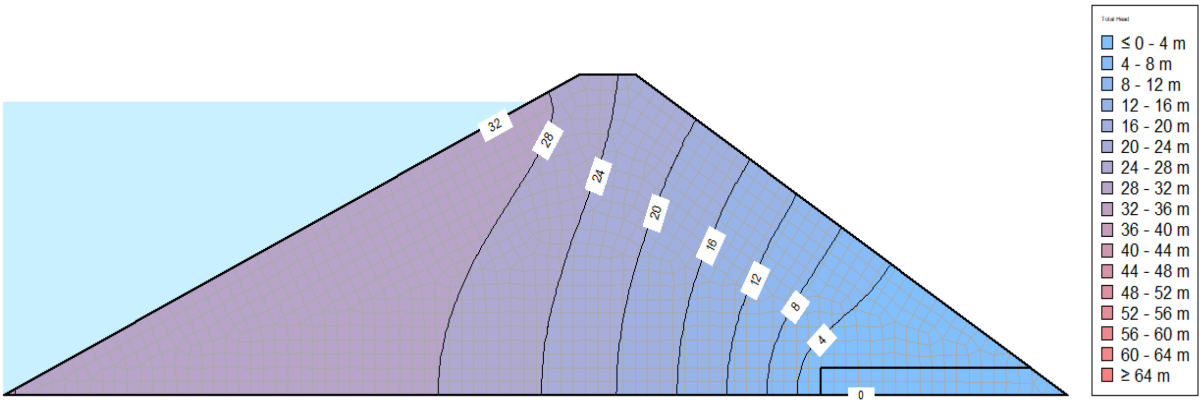


Fig 4.9: Head gradient distribution.

4.3 SPSS Application

4.3.1 The ANN Model

To explain the influence of each input variable varying on the output variables values, (seepage discharge, side slope factor of safety), must using an ANN model, which needs a database of the output variables related to the input variables that results from the SEEP/w and SLOPE/W programs application. The IBM SPSS statistics 23 “Statistical Product and Service Solutions” software is used in this study. The database is subdivided in three subsample sets, training, testing and holdout subsets as (70%, 20%, 10%) respectively. To reduce the sum of square errors between the observed outputs and these predicted by the model, the software will select the best percentages subdivision. Moreover, the software select optimum number of the hidden nodes in the hidden layer (p) and the best type of the activation functions for the hidden and output layers, depending on the same criteria mentioned before. The standardization process is used in this study for the modeling process and automatic architecture selection uses the default activation functions, which are hyperbolic tangent for the hidden, and identity for the output layers. The application results are shown below:

Tab. 4.2: Case for seepage processing summary.

		N	Percent
Sample	Training	206	68.7%
	Testing	61	20.3%
	Holdout	33	11.0%
Valid		300	100.0%
Excluded		0	
Total		300	

Tab. 4.3: Network information for seepage processing.

Input Layer	Covariates	1	K_d
		2	K_D
		3	W_d
		4	L_d
		5	B
		6	b
		7	S_{ds}
		8	S_{us}
		9	h
		10	F_b
		11	H
	Number of Units[a]		11
	Rescaling Method for Covariates		Standardized
Hidden Layer(s)	Number of Hidden Layers		1
	Number of Units in Hidden Layer 1[a]		7
	Activation Function		Hyperbolic tangent
Output Layer	Dependent Variables	1	q M3/sec
	Number of Units		1
	Rescaling Method for Scale Dependents		Standardized
	Activation Function		Identity
	Error Function		Sum of Squares

a. Excluding the bias unit

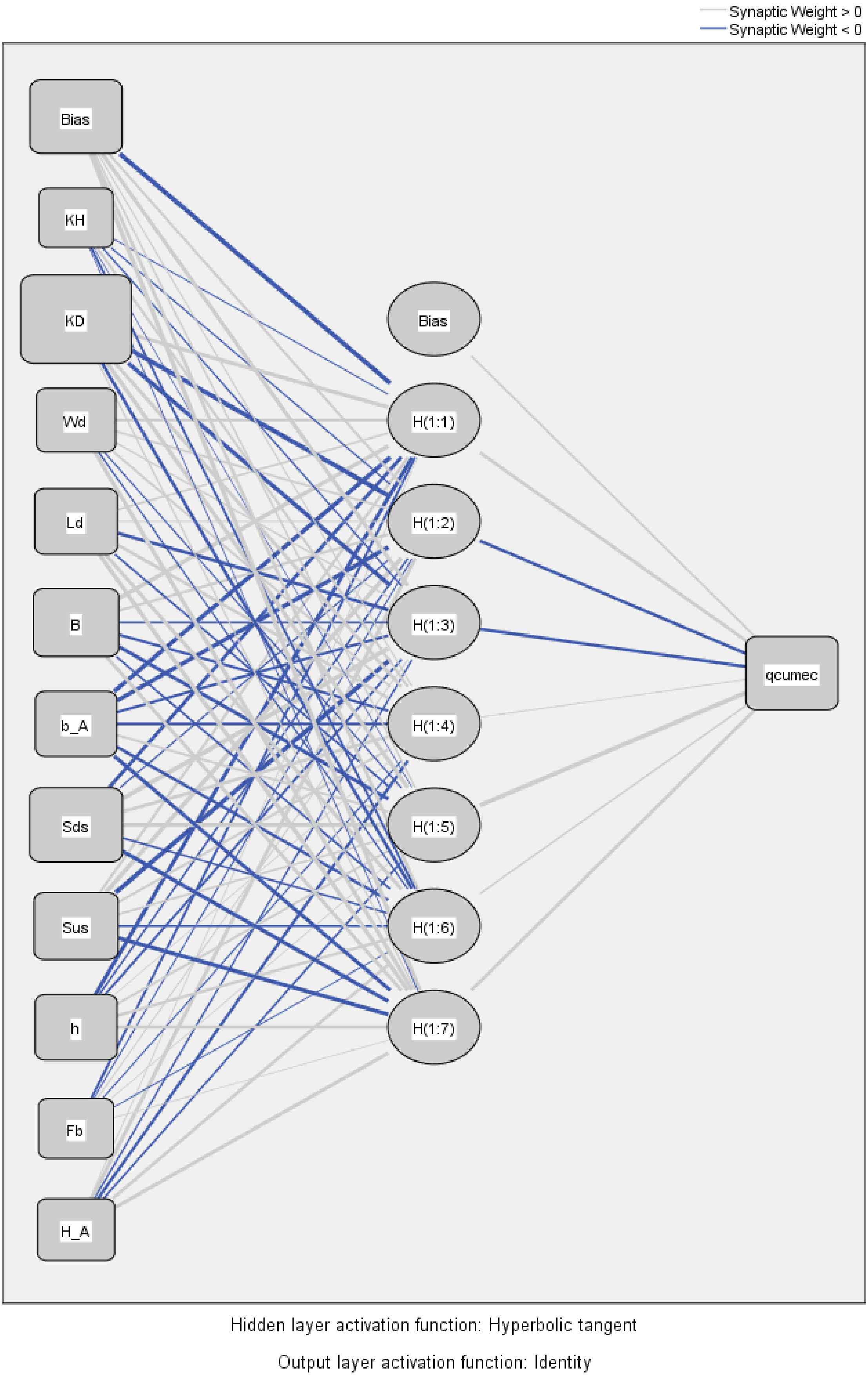


Fig. 4.10: Architecture of the ANN model network for seepage.

Tab. 4.4: Seepage model summary.

Training	Sum of Squares Error	.686
	Relative Error	.007
	Stopping Rule Used	1 consecutive step(s) with no decrease in error
	Training Time	00:00:00.141
Testing	Sum of Squares Error	.286
	Relative Error	.009
Holdout	Relative Error	.010

Dependent Variable: q M^3/sec

a. Error computations are based on the testing sample.

Tab. 4.5: Parameter estimates for seepage model.

Predictor		**Predicted**							
		Hidden Layer 1							**Output Layer**
		H(1:1)	H(1:2)	H(1:3)	H(1:4)	H(1:5)	H(1:6)	H(1:7)	qcumec
Input Layer	(Bias)	-1.629-	.234	.774	.065	.127	.443	1.073	
	K_d	-.035-	-.067-	-.075-	.241	-.003-	-.197-	-.026-	
	K_D	.761	-1.672-	-.871-	.496	.846	-.415-	.095	
	W_d	.317	.194	.110	.225	-.066-	-.074-	.817	
	L_d	.164	.036	-.440-	.424	-.162-	.577	1.029	
	B	.884	.293	-.105-	-.284-	-.515-	-.150-	.489	
	b	-1.018-	-.969-	-.311-	-.349-	.234	-.380-	-.559-	
	S_{ds}	-.485-	-.067-	1.447	.448	1.261	-.137-	-.706-	
	S_{us}	.337	1.037	-1.331-	.234	.183	-.185-	-.787-	
	h	-.604-	-.123-	-.205-	.008	.231	.352	.383	
	F_b	-.232-	-.058-	.038	-.059-	.019	-.032-	.015	
	H	.029	.585	-.104-	-.350-	-.147-	.428	.518	
Hidden Layer 1	(Bias)								.193
	H(1:1)								.459
	H(1:2)								-.400-
	H(1:3)								-.395-
	H(1:4)								.029
	H(1:5)								1.273
	H(1:6)								.117
	H(1:7)								.482

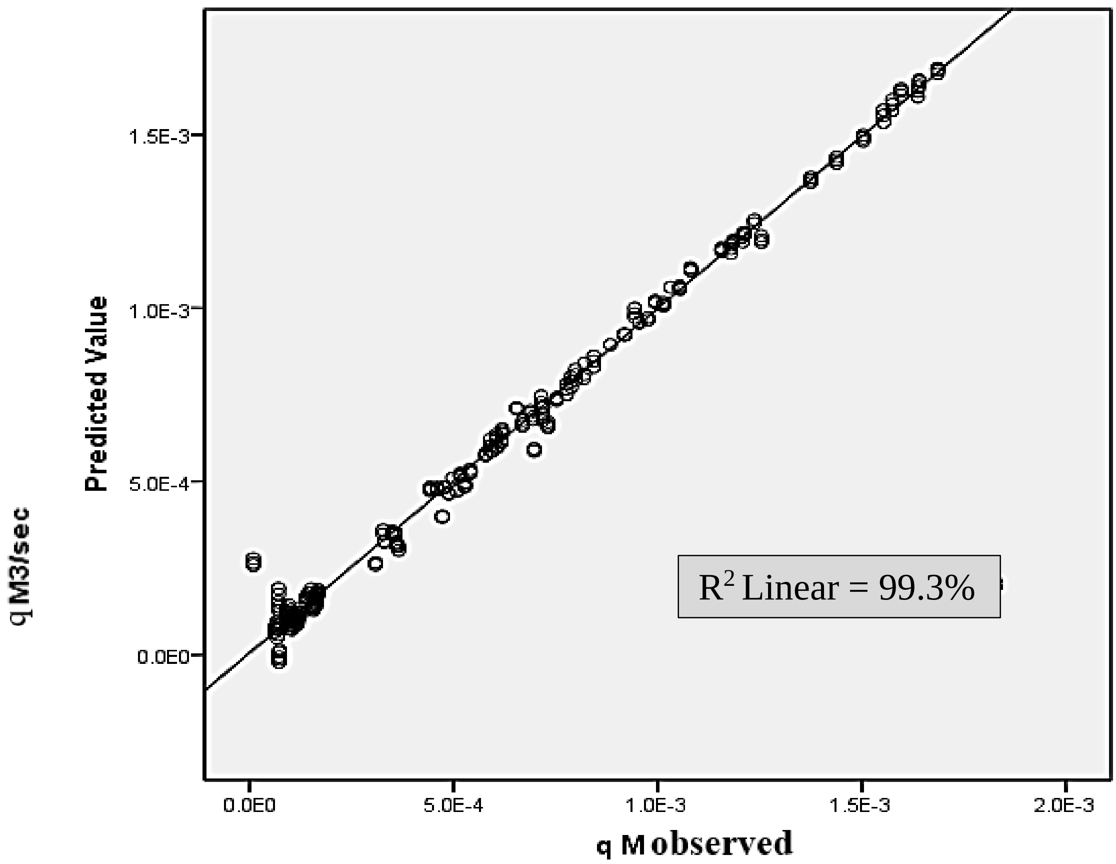


Fig. 4.11: Comparison of the predicted and observed seepage discharge.

Tab. 4.6: Independent Variable Importance on seepage procesing.

	Importance	**Normalized Importance**
K_d	.005	1.6%
K_D	.323	100.0%
W_d	.050	15.5%
L_d	.079	24.3%
B	.102	31.7%
b	.067	20.8%
S_{ds}	.167	51.7%
S_{us}	.091	28.2%
h	.071	22.1%
F_b	.011	3.5%
H	.032	9.8%

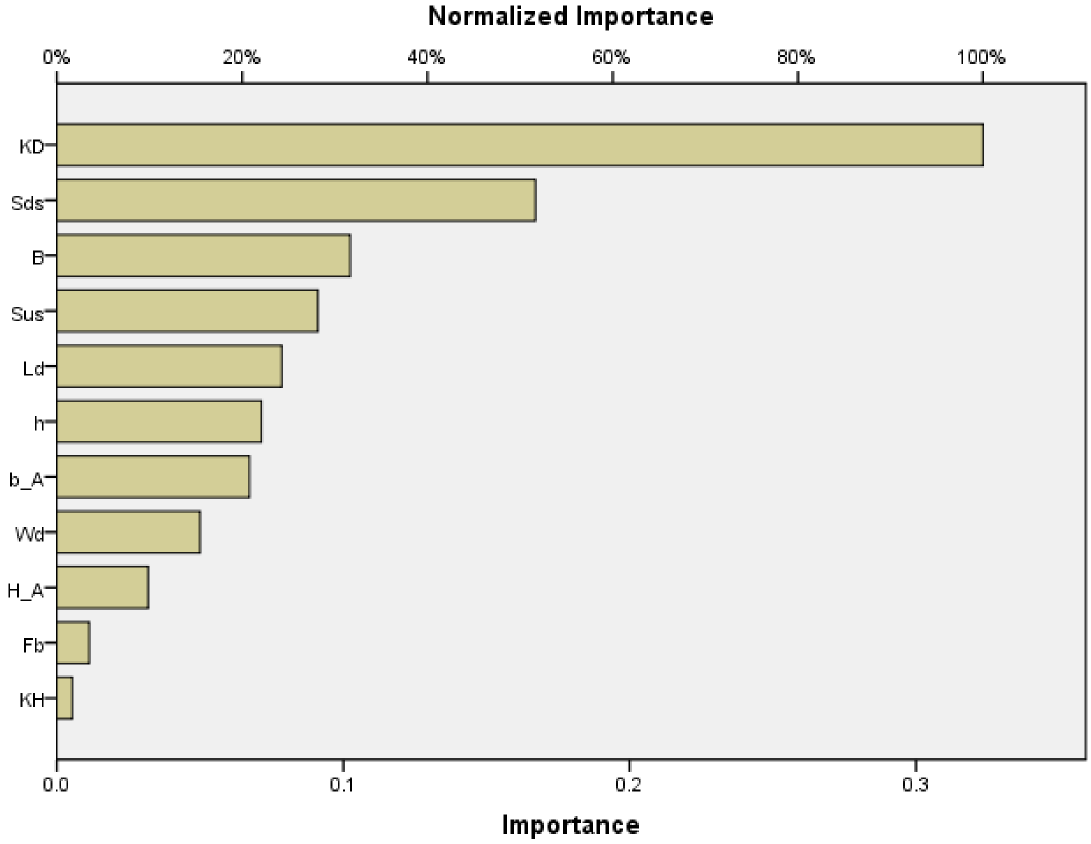


Fig. 4.12: Normalized importance for input variables on seepage discharge.

Tab. 4.7: Case factor of safety for sliding processing summary.

		N	Percent
Sample	Training	208	69.3%
	Testing	65	21.7%
	Holdout	27	9.0%
Valid		300	100.0%
Excluded		0	
Total		300	

Tab. 4.8: Network information for sliding factor of safety processing.

Input Layer	Covariates	1	K_d
		2	K_D
		3	W_d
		4	L_d
		5	B
		6	b
		7	S_{ds}
		8	S_{us}
		9	h
		10	F_b
		11	H
		12	phi_d
		13	C_d
		14	U_d
		15	phi
		16	c
		17	u
	Number of Units[a]		17
	Rescaling Method for Covariates		Standardized
Hidden Layer(s)	Number of Hidden Layers		1
	Number of Units in Hidden Layer 1[a]		7
	Activation Function		Hyperbolic tangent
Output Layer	Dependent Variables	1	F.S
	Number of Units		1
	Rescaling Method for Scale Dependents		Standardized
	Activation Function		Identity
	Error Function		Sum of Squares

a. Excluding the bias unit

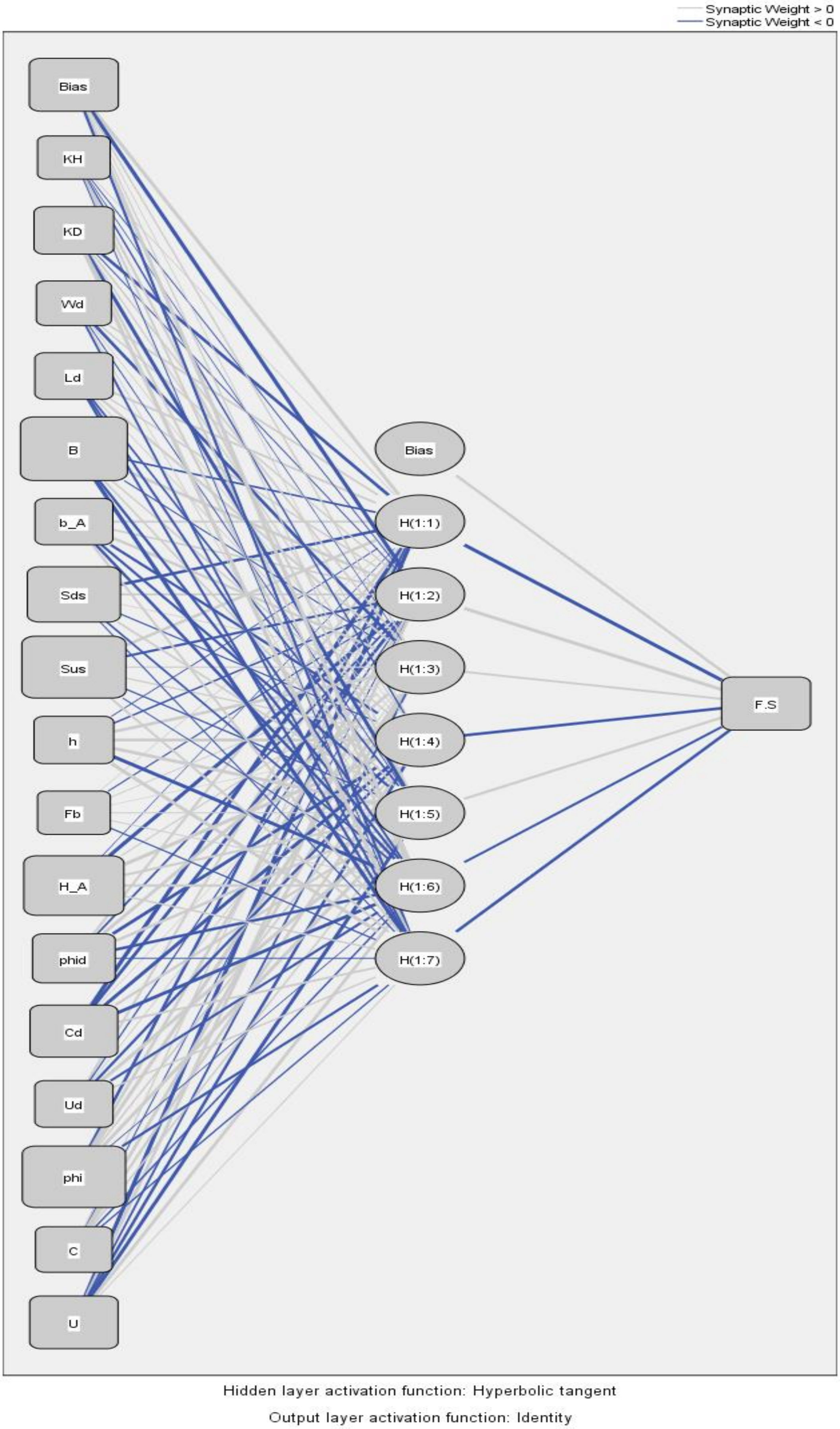


Fig. 4.13: Architecture of the ANN model network for sliding F.S.

Tab. 4.9: Model of sliding factor of safety summary.

Training	Sum of Squares Error	.504
	Relative Error	.005
	Stopping Rule Used	1 consecutive step(s) with no decrease in error
	Training Time	00:00:00.109
Testing	Sum of Squares Error	.222
	Relative Error	.006
Holdout	Relative Error	.005

Dependent Variable: F.S
a. Error computations are based on the testing sample.

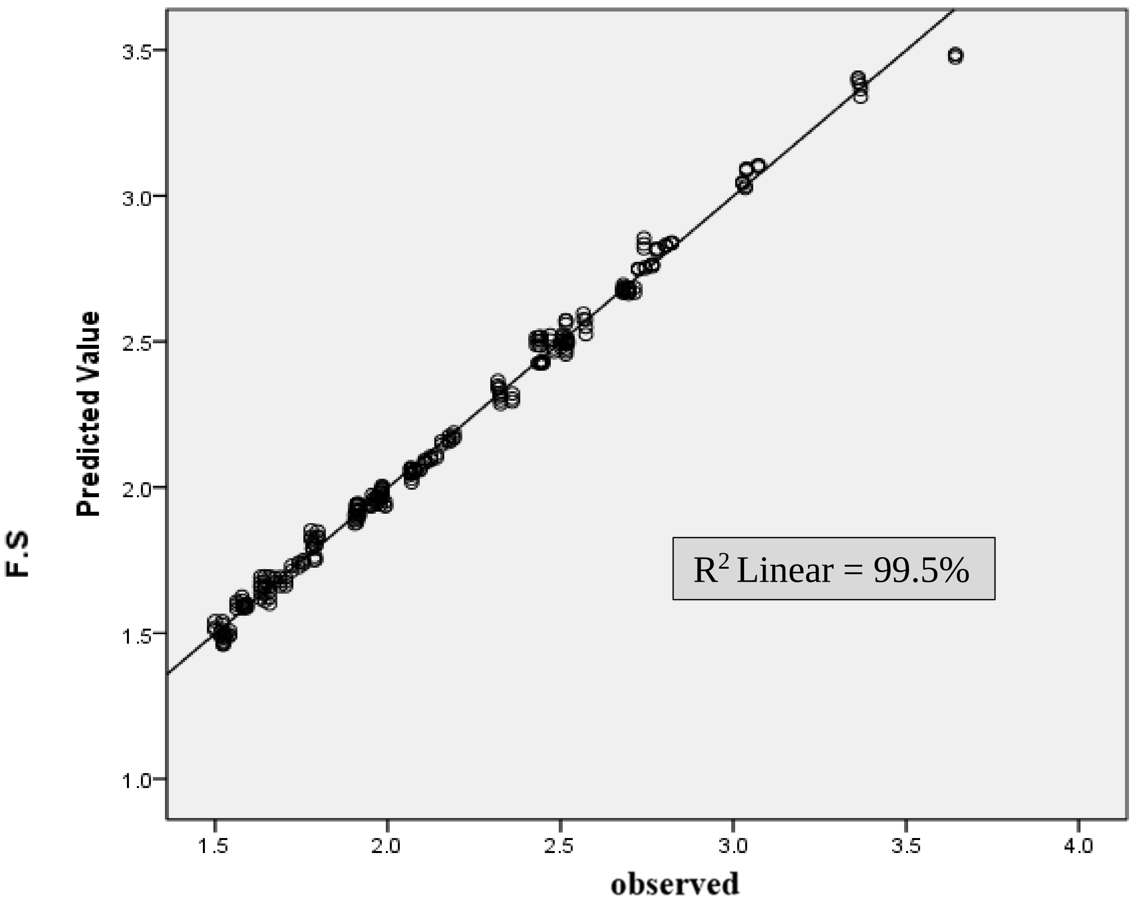


Fig. 4.14: Comparison of the predicted and observed sliding F.S.

Tab. 4.10: Parameter estimates for sliding factor of safety processing.

Predictor		Predicted							
		Hidden Layer 1							Output Layer
		H(1:1)	H(1:2)	H(1:3)	H(1:4)	H(1:5)	H(1:6)	H(1:7)	F.S
Input Layer	(Bias)	.400	-.495-	.131	.041	.085	.421	-.236-	
	KH	.040	-.055-	-.035-	-.123-	.201	.176	-.054-	
	KD	-.363-	-.058-	.150	.087	-.402-	.206	.460	
	Wd	.190	.134	-.359-	.036	-.054-	.044	-.186-	
	Ld	.241	.148	.234	.053	-.162-	-.209-	-.213-	
	B	-.197-	.385	-.081-	.138	.160	-.265-	-.571-	
	b_A	.263	.192	.351	-.308-	-.285-	-.334-	.212	
	Sds	-.396-	.224	.039	-.091-	.191	-.182-	-.084-	
	Sus	.380	-.316-	.135	.147	-.132-	-.072-	.213	
	h	-.057-	-.169-	.425	.483	.575	-.629-	.525	
	Fb	.035	-.090-	.062	.025	.074	.077	-.122-	
	H_A	-.033-	-.573-	.107	.757	.333	.353	.169	
	phid	.252	-.178-	.401	-.404-	.355	-.385-	-.082-	
	Cd	-.660-	-.371-	.012	-.453-	.292	-.512-	.260	
	Ud	.201	-.090-	.053	-.290-	.502	-.290-	.155	
	phi	-.324-	.349	.448	.151	.430	-.049-	-.296-	
	C	.119	-.071-	.358	.292	.146	-.144-	-.128-	
	U	-.520-	.353	-.172-	-.314-	-.404-	.359	.070	
Hidden Layer 1	(Bias)								.333
	H(1:1)								-.602-
	H(1:2)								.659
	H(1:3)								.255
	H(1:4)								-.383-
	H(1:5)								.345
	H(1:6)								-.274-
	H(1:7)								-.359-

Tab. 4.11: Independent Variable Importance on sliding F.S processing.

	Importance	Normalized Importance
K_d	.006	3.8%
K_D	.034	23.6%
W_d	.015	10.3%
L_d	.028	19.5%
B	.145	100.0%
b	.027	18.3%
S_{ds}	.089	60.9%
S_{us}	.134	91.8%
h	.034	23.5%
F_b	.007	4.5%
H	.118	81.1%
phi_d	.046	31.9%
C_d	.067	45.9%
U_d	.028	19.5%
phi	.130	89.7%
C	.022	15.1%
U	.070	48.2%

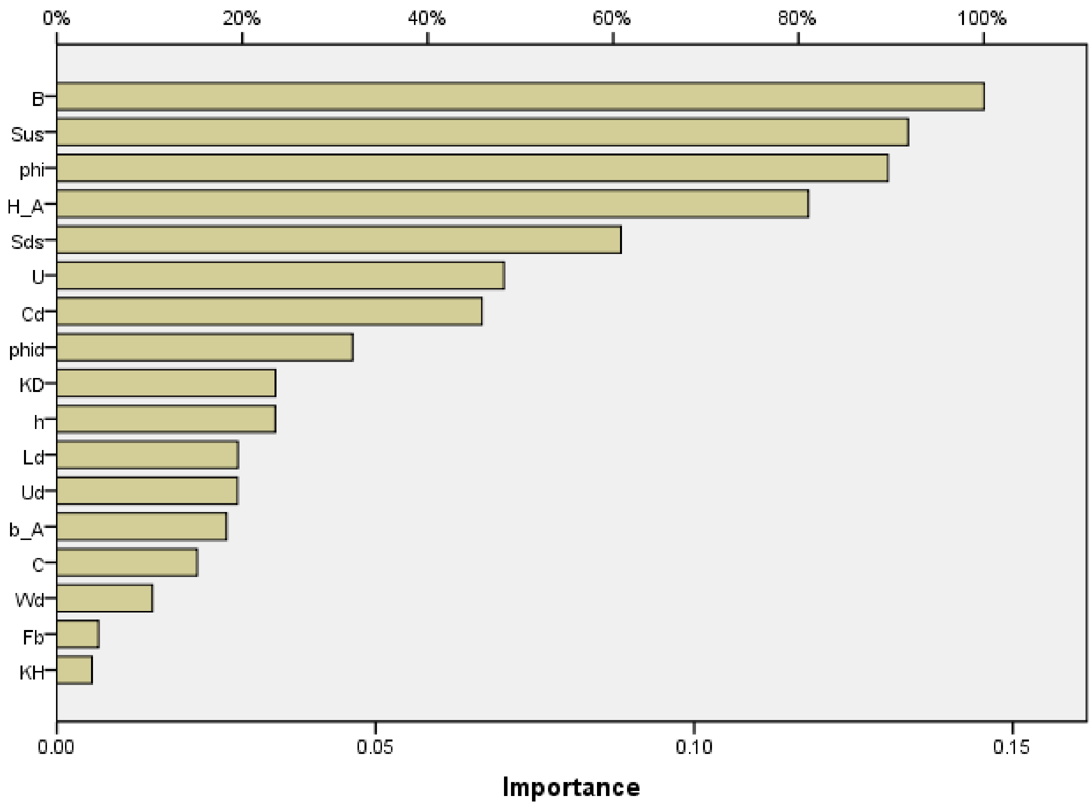


Fig. 4.15: Normalized importance for input variables on sliding F.S.

4.3.2 Regression Model

Regression analysis is a statistical technique that is very useful for determine the real relationship between a set of dependent and independent variables. To determine the real relationship between the dependent variable seepage discharge (q) and the independent variables geometrical dimensions and material properties (H, b, F_b, S_{us}, S_{ds}, L_d, w_d, k_D, and k_d) and to put them in an equation that can be used directly, may be used regression model for the data base predicted from Geo Studio software analysis.

The Independent variable, symbolized by (q) and the dependent variables symbolized by (H, b, F_b, S_{us}, S_{ds}, L_d, w_d, k_D, and k_d) can be represented by [q = f (H b F_b S_{us} S_{ds} L_d w_d k_D k_d)], this relationship is a multiple nonlinear relationship. Therefore, we can wright the equation as:

$$q = a0\,(H^{a1}\, b^{a2}\, F_b^{a3}\, S_{us}^{a4}\, S_{ds}^{a5}\, L_d^{a6}\, w_d^{a7}\, k_D^{a8}\, k_d^{a9})$$

can estimate the regression coefficients [a(0-9)] for this equation using SPSS 23 software to predict the mathematical equation by assuming random values for these coefficients and made correction for them by iteration till get the acceptable error. This method is done by using 75% of the database only and verifies the equation with the residual 25%. This process is repeated to predict sliding factor of safety mathematical equation and the results are shown as the following:

Tab. 4.12: Iteration history for seepage discharge equation.

Iteration Number[a]	Residual Sum of Squares	Parameter									
		a1	a2	a3	a4	a0	a5	a6	a7	a8	a9
1.0	40.235	.500	.500	.500	.500	.500	.500	.500	.500	.500	1.000
1.1	.002	.501	.499	.501	.499	.499	.501	.500	.499	.500	.008
2.0	.002	.501	.499	.501	.499	.499	.501	.500	.499	.500	.008
2.1	.000	.578	.394	.589	.357	.326	.604	.526	.351	.531	.008
3.0	.000	.578	.394	.589	.357	.326	.604	.526	.351	.531	.008
3.1	.000	.738	.212	.720	.120	.111	.818	.562	.092	.580	.018
4.0	.000	.738	.212	.720	.120	.111	.818	.562	.092	.580	.018
4.1	.000	1.017	-.010-	.824	-.127-	-.037-	1.209	.553	-.215-	.613	.077
4.2	.000	.758	-.022-	.729	.065	-.035-	1.209	.597	-.060-	.578	.032
5.0	.000	.758	-.022-	.729	.065	-.035-	1.209	.597	-.060-	.578	.032
5.1	.000	.793	.023	.746	.031	.005	1.275	.533	-.140-	.577	.051
6.0	.000	.793	.023	.746	.031	.005	1.275	.533	-.140-	.577	.051
6.1	.000	.829	.022	.761	.004	-.001-	1.284	.497	-.152-	.577	.074
7.0	.000	.829	.022	.761	.004	-.001-	1.284	.497	-.152-	.577	.074
7.1	.000	.865	.025	.775	-.017-	3.248E-5	1.274	.482	-.153-	.579	.102
8.0	.000	.865	.025	.775	-.017-	3.248E-5	1.274	.482	-.153-	.579	.102
8.1	.000	.901	.026	.786	-.032-	-1.508E-5	1.260	.481	-.153-	.582	.139
9.0	.000	.901	.026	.786	-.032-	-1.508E-5	1.260	.481	-.153-	.582	.139
9.1	.000	.937	.027	.794	-.042-	-8.875E-7	1.246	.487	-.152-	.586	.190
10.0	.000	.937	.027	.794	-.042-	-8.875E-7	1.246	.487	-.152-	.586	.190
10.1	.000	.955	.027	.797	-.046-	8.342E-5	1.240	.491	-.152-	.589	.230
11.0	.000	.955	.027	.797	-.046-	8.342E-5	1.240	.491	-.152-	.589	.230
11.1	.000	.990	.028	.798	-.051-	-5.209E-6	1.230	.501	-.152-	.592	.311
11.2	.000	.961	.027	.799	-.047-	-2.328E-5	1.238	.493	-.152-	.590	.246
12.0	.000	.961	.027	.799	-.047-	-2.328E-5	1.238	.493	-.152-	.590	.246
12.1	.000	.973	.028	.799	-.049-	-8.641E-6	1.234	.496	-.152-	.592	.274
13.0	.000	.973	.028	.799	-.049-	-8.641E-6	1.234	.496	-.152-	.592	.274
13.1	.000	.985	.028	.799	-.051-	-7.068E-6	1.231	.500	-.152-	.593	.307
14.0	.000	.985	.028	.799	-.051-	-7.068E-6	1.231	.500	-.152-	.593	.307
14.1	.000	.997	.028	.798	-.052-	-4.147E-6	1.229	.504	-.152-	.592	.348
14.2	.000	.990	.028	.799	-.051-	-1.073E-5	1.230	.501	-.152-	.593	.325
15.0	.000	.990	.028	.799	-.051-	-1.073E-5	1.230	.501	-.152-	.593	.325
15.1	.000	.997	.028	.798	-.052-	8.935E-6	1.228	.504	-.152-	.592	.350
16.0	.000	.997	.028	.798	-.052-	8.935E-6	1.228	.504	-.152-	.592	.350
16.1	.000	.997	.028	.798	-.052-	4.226E-6	1.228	.504	-.152-	.592	.351
17.0	.000	.997	.028	.798	-.052-	4.226E-6	1.228	.504	-.152-	.592	.351
17.1	.000	.997	.028	.798	-.052-	9.863E-6	1.228	.504	-.152-	.592	.351

Derivatives are calculated numerically.
a. Major iteration number is displayed to the left of the decimal, and minor iteration

number is to the right of the decimal.

b. Run stopped after 37 model evaluations and 17 derivative evaluations because the relative reduction between successive residual sums of squares is at most SSCON = 1.00E-008.

Tab. 4.13: Parameter estimates.

Parameter	Estimate	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
a1	.997	.020	.958	1.037
a2	.028	.021	-.013-	.069
a3	.798	.040	.718	.877
a4	-.052-	.061	-.172-	.068
a0	4.226E-6	.005	-.011-	.011
a5	1.228	.082	1.067	1.390
a6	.504	.082	.343	.665
a7	-.152-	.041	-.232-	-.072-
a8	.592	.050	.493	.691
a9	.351	.097	.160	.542

Tab. 4.14: Correlations of parameter estimates.

	a1	a2	a3	a4	a0	a5	a6	a7	a8	a9
a1	1.000	-.003-	.001	-.004-	.001	-.029-	.060	.007	.003	.687
a2	-.003-	1.000	-.307-	-.643-	.001	-.301-	-.182-	.011	.147	.204
a3	.001	-.307-	1.000	.193	.000	.078	.046	-.005-	-.184-	-.405-
a4	-.004-	-.643-	.193	1.000	.000	.526	.346	.047	-.445-	-.063-
a0	.001	.001	.000	.000	1.000	.000	.000	.000	.000	.025
a5	-.029-	-.301-	.078	.526	.000	1.000	-.292-	-.049-	-.260-	-.032-
a6	.060	-.182-	.046	.346	.000	-.292-	1.000	-.064-	-.176-	.186
a7	.007	.011	-.005-	.047	.000	-.049-	-.064-	1.000	-.032-	-.140-
a8	.003	.147	-.184-	-.445-	.000	-.260-	-.176-	-.032-	1.000	-.427-
a9	.687	.204	-.405-	-.063-	.025	-.032-	.186	-.140-	-.427-	1.000

Tab. 4.15: Analysis of variance (ANOVA[a]).

Tab. 4.15: Analysis of variance (ANOVA[a]).

Source	Sum of Squares	df	Mean Squares
Regression	.000	10	.000
Residual	.000	290	.000
Uncorrected Total	.000	300	
Corrected Total	.000	299	

Dependent variable: q M^3/sec

a. R^2 = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) = .966.

Then the predicted mathematical equation in (m/sec) is:

$$q = \frac{0.351 \times K_D \times H^{0.592} \times S_{us}{}^{0.504} \times S_{ds}{}^{1.228} \times L_d{}^{0.798} \times W_d{}^{0.028} \times K_d{}^{4.2\times10^{-6}}}{F_b{}^{0.152} \times b^{0.052}} \quad (A)$$

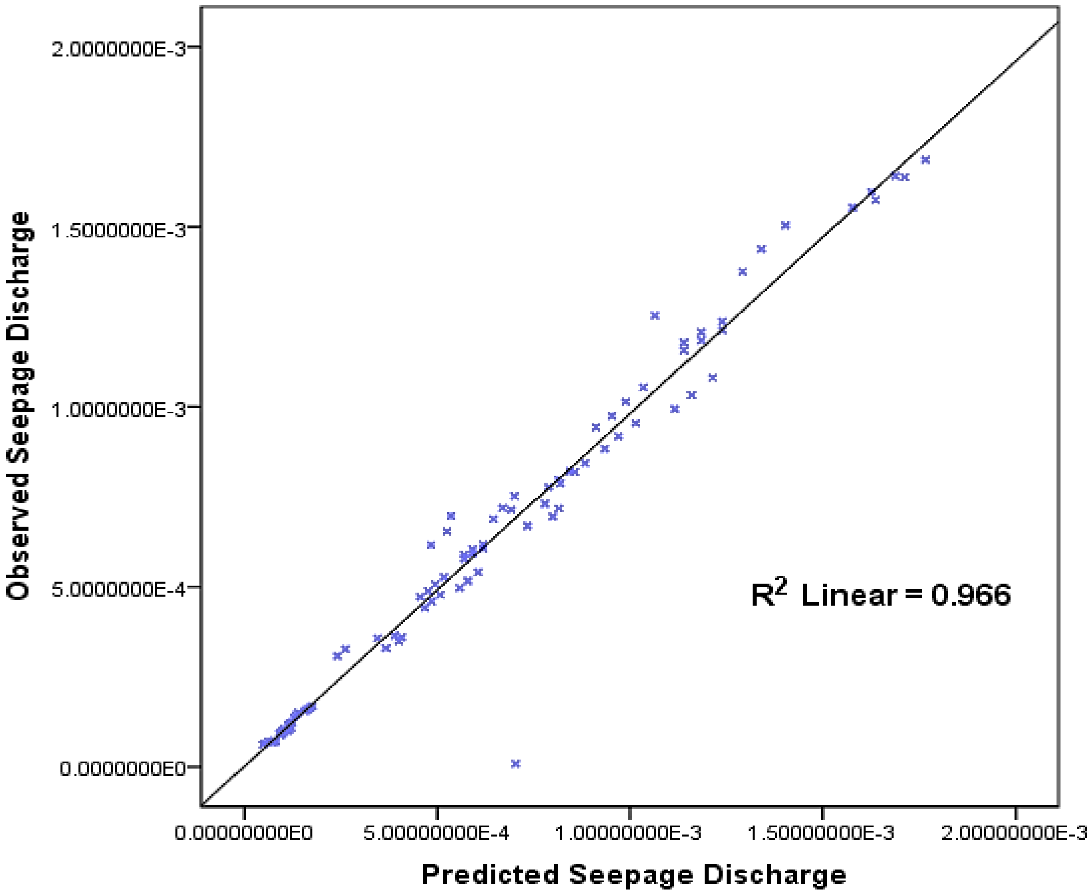


Fig. 4.16: Comparison of the predicted and observed seepage discharge (q).

Tab. 4.16: Iteration history for sliding factor of safety equation.

Iteration Number[a]	Residual Sum of Squares	Parameter										
		a1	a2	a3	a4	a9	b2	b3	b4	b5	b6	b7
1.0	45.105	.500	1.000	.300	-1.000-	-.030-	.100	.100	.100	-.500-	-.020-	-.300-
1.1	2.042E269	-149.842-	109.639	-28.093-	-2.082-	-.032-	.089	.057	.148	-.666-	-.019-	-.319-
1.2	1.612E32	-14.521-	11.870	-2.543-	-1.043-	-.032-	.089	.057	.148	-.666-	-.019-	-.319-
1.3	2442983.109	-.989-	2.093	.012	-.939-	-.032-	.089	.057	.148	-.666-	-.019-	-.319-
1.4	.595	.390	1.097	.272	-.928-	-.032-	.089	.057	.148	-.666-	-.019-	-.319-
2.0	.595	.390	1.097	.272	-.928-	-.032-	.089	.057	.148	-.666-	-.019-	-.319-
2.1	32.234	.209	1.290	.223	-.954-	-.032-	.091	.065	.139	-.634-	-.019-	-.316-
2.2	.454	.405	1.105	.271	-.949-	-.032-	.091	.065	.139	-.634-	-.019-	-.316-
3.0	.454	.405	1.105	.271	-.949-	-.032-	.091	.065	.139	-.634-	-.019-	-.316-
3.1	.491	.447	1.069	.281	-.949-	-.032-	.091	.065	.140	-.635-	-.019-	-.316-
3.2	.454	.409	1.102	.272	-.949-	-.032-	.091	.065	.140	-.635-	-.019-	-.316-
4.0	.454	.409	1.102	.272	-.949-	-.032-	.091	.065	.140	-.635-	-.019-	-.316-
4.1	.454	.418	1.094	.274	-.949-	-.032-	.091	.065	.139	-.635-	-.019-	-.316-
4.2	.454	.410	1.101	.273	-.949-	-.032-	.091	.065	.139	-.635-	-.019-	-.316-
5.0	.454	.410	1.101	.273	-.949-	-.032-	.091	.065	.139	-.635-	-.019-	-.316-
5.1	.454	.409	1.103	.272	-.949-	-.032-	.091	.065	.139	-.635-	-.019-	-.316-
5.2	.454	.410	1.101	.273	-.949-	-.032-	.091	.065	.139	-.635-	-.019-	-.316-
6.0	.454	.410	1.101	.273	-.949-	-.032-	.091	.065	.139	-.635-	-.019-	-.316-
6.1	.454	.410	1.101	.273	-.949-	-.032-	.091	.065	.139	-.635-	-.019-	-.316-

Derivatives are calculated numerically.

a. Major iteration number is displayed to the left of the decimal, and minor iteration number is to the right of the decimal.

b. Run stopped after 19 model evaluations and 6 derivative evaluations because the relative reduction between successive residual sums of squares is at most SSCON = 1.00E-008.

Tab. 4.17: Parameter estimates.

Parameter	Estimate	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
a1	.410	51853.156	-102057.306-	102058.126
a2	1.101	45675.122	-89896.968-	89899.170
a3	.273	11936.216	-23492.665-	23493.210
a4	-.949-	485.542	-956.596-	954.698
a9	-.032-	.005	-.042-	-.021-
b2	.091	.007	.076	.106
b3	.065	.007	.051	.079
b4	.139	.011	.118	.161
b5	-.635-	.011	-.656-	-.614-
b6	-.019-	.006	-.031-	-.006-
b7	-.316-	.009	-.333-	-.299-

Tab. 4.18: Analysis of variance (ANOVA[a]).

Source	Sum of Squares	df	Mean Squares
Regression	1478.344	11	134.395
Residual	.454	289	.002
Uncorrected Total	1478.798	300	
Corrected Total	71.851	299	

Dependent variable: F.S

a. R^2 = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) = .994.

Then the predicted mathematical equation is:

$$\boldsymbol{F.S} = \frac{\mathbf{0.41} \times \emptyset^{\mathbf{1.101}} \times \boldsymbol{C}^{\mathbf{0.273}} \times \boldsymbol{L_d}^{\mathbf{0.091}} \times \boldsymbol{b}^{\mathbf{0.065}} \times \boldsymbol{S_{ds}}^{\mathbf{0.139}}}{\boldsymbol{U}^{\mathbf{0.949}} \times \boldsymbol{F_b}^{\mathbf{0.019}} \times \boldsymbol{k_d}^{\mathbf{0.032}} \times \boldsymbol{H}^{\mathbf{0.316}} \times \boldsymbol{S_{us}}^{\mathbf{0.653}}} \quad \text{(B)}$$

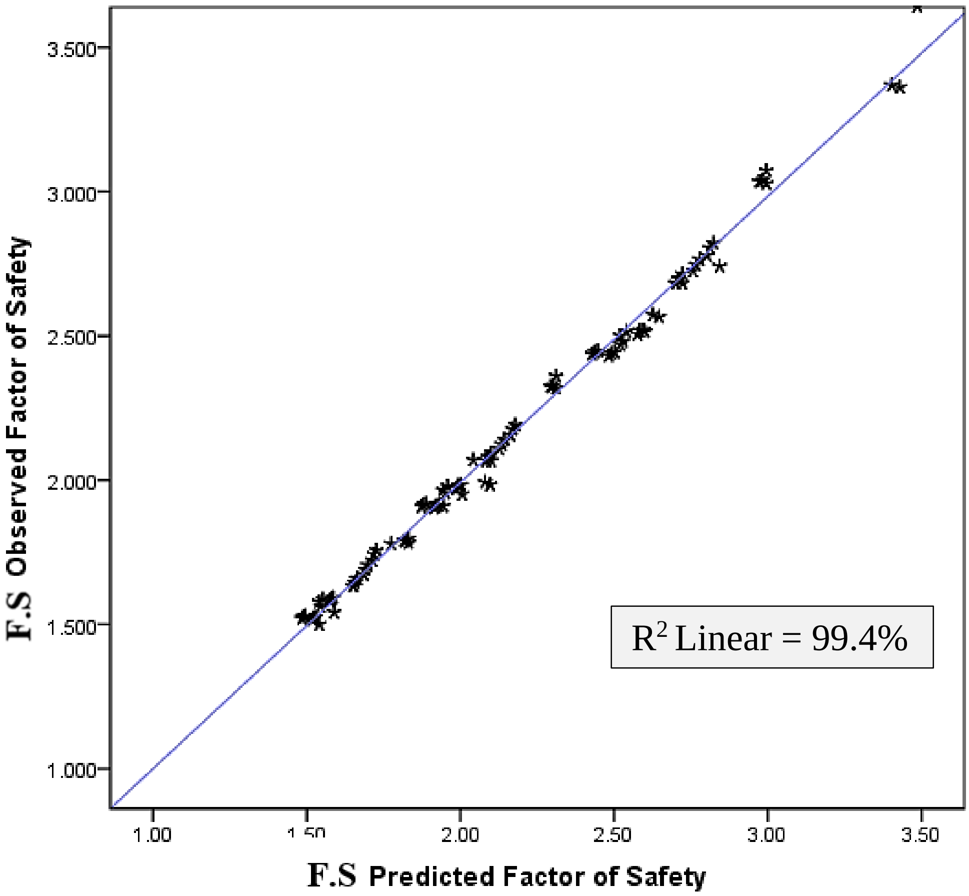


Fig. 4.17: Comparison of the predicted and observed sliding factor of safety (F.S).

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

From the results obtained in this conducted study, the following conclusion can be deduced:

1- Results for the Geo Studio analysis for the homogeneous earth fill embankment dam with horizontal rectangular toe drain filter established on impervious foundation indicates that the behavior of the dam section seepage discharge and factor of safety increase or decrease are different for the cases of given geometrical dimensions and physical and mechanical properties of soils and filter. These results necessitate the use of the known ranges of these properties to build a representative database to describe the behavior variation of the embankment dam section. Hence many cases were used includes the variation of the independent variables. Three hundred cases were analyzed using Geo Studio software was found to be an enough sample size for representation.

2- It was found that is necessary to analyze the sample cases with two models, one using SEEP/W model for seepage discharge amount and phreatic line shape only and the other is SLOPE/W model for the side slope factor of safety value.

3- The weight of the influence effect of each input variable in this issue on the output variables [seepage discharge (q) and side slope factor of safety (F.S)] of the dam section are investigated using the ANN modeling technique and it was found to be capable to estimate the dependent variables accurately. The correlation coefficients of the dependent variables are 99.3% for (q) estimation and 99.5% for (F.S) estimation.

4- The data division into training, testing and holdout (verification) subsets as 68.7%, 20.3% and 11% respectively for (q) and 69.3%, 21.7% and 9% respectively for (F.S) in the ANN model to develop a credible results, that is the minimum number of the hidden nodes in the hidden layer is seven (7). The average relative error for the training, testing and holdout subsets are 0.7%, 0.9% and 1% for the respectively for (q) and 0.5%, 0.6% and 0.5% respectively for (q) . The activation functions type for the hidden layer is hyperbolic tangent function (tanh) and for output layer is linear function (identity).

5- Artificial neural network model results indicate the capability of this model to estimate very accurate results comparing with Geo Studio analysis results where the correlation coefficients are 99.3% for (q) and 99.5% for (F.S).

6- Using 75% of the input and output sets in the Statistical Product and Service Solutions (IBM SPSS 23) software by multiple nonlinear regression technic predict an accurate mathematical equations used to estimating seepage discharge amount and side slope factor of safety value directly instead of using the long process of Geo Studio modeling.

7- The predicted mathematical equations are (A) & (B)

8- The predicted mathematical equations verifying by applying it to the residual 25% input sets and compare results with Geo Studio analysis results and the accuracy were very high and the correlation coefficients are 96.6% and 99.4% for the seepage discharge (q) equation and the side slope factor of safety (F.S) equation respectively.

9- The mathematical equation results show that the seepage discharge amount highly is affected by any change in the geometrical dimensions and mechanical material properties and with varying rates, directly proportion with all variables except the free board height and the crest width, which are inversely proportions.

10- While the sliding slope factor of safety value for the embankment dam cross section is highly affected by any change in the geometrical dimensions and mechanical and physical material properties for the dam body and with less effect of the toe drain filter, directly or inversely proportional and with varying rates.

8.2 Recommendations

The following are recommended for further research of this work:

1- Develop a similar equations considering the non-homogeneity and anisotropic of the dam cross section body material.

2- Predict similar equations for earth fill embankment dam established on pervious foundation.

3- Develop similar equations considering the effect of the reservoir surface wave generated due to seismic excitation and shape of the reservoir on the seepage discharge and side slope factor of safety applied on the dam.

4- Applying the same technique adopted in this study to develop a mathematical equation for estimation seepage discharge amount and factor of safety for dam section for zoned earth dams.
5- Using the artificial neural network modeling with MATLAB programing to developed a program model to estimate the output variables from the input variables sets (cross section geometrical dimensions and materials properties variables) directly instead of using other long methods.
6- Using the multiple nonlinear regressions to develop a mathematical equation can be used to estimate the phreatic line for homogenous earth fill embankment dams.
7- Develop mathematical equations for estimation seepage discharge and exit gradient under solid hydraulic structures founded on pervious foundations.

REFERENCES

Abramson, L.W. (2002) Slope Stability and Stabilization Methods. John Wiley & Sons, Hoboken.

Albataineh, N. (2006) slope stability analysis using 2D and 3D methods

Alnealy H.K.T. and Alghazali N.O.S. (2015), 'Analysis of Seepage Under Hydraulic Structures Using Slide Program', American Journal of Civil Engineering. Vol. 3, Issue 4, pp. 116-124.

Amir Malekpouri, Davod Farsadizadeh, Ali Hosseinzadeh Dalir, Jamshid Sadrekarimi, 2012, "Effect of horizontal drain size on the stability of an embankment dam in steady and transient seepage conditions", Turkish J. Eng. Env. Sci., Vol. 36, Pages 139 – 152.

Behzad Kalantari and Farjad Nazeri, "Effect of Materials Quality on Stability of Embankment Dam", Electronic Journal of Geotechnical Engineering, Vol. 21 bound 15, Pages 5061-5071.

Bhagu R. Chahar, 2004, "Determination of Length of a Horizontal Drain in Homogeneous Earth Dams", Journal of Irrigation and Drainage Engineering, November /December, Pages 530-536.

Bishop A.W. 1955. The use of the slip circle in the stability analysis of slopes. Géotechnique, 5(1): 7–17.

British Dam Society (2010) Types of Dam.

British Standards Institution (1992) planning, design and installation of irrigation schemes: Guide of water resources. BS 5762: 1992. London: British Standard Institution.

Cala, M. and Flisiak, J. (2003) 'Slope stability analysis with numerical and limit equilibrium methods' Computer Methods in Mechanics 6, 3-6.

Çalamak M., Bingöl A. N. and Yanmaz A. M. (2016), 'Effect of Drainage Properties on Seepage Behavior of Earth-Fill Dams', Conference: 12th International Congress on Advances in Civil Engineering, Istanbul, Turkey.

Chahar B.R. (2004), 'Determination of Length of a Horizontal Drain in Homogeneous Earth Dams', Journal of Irrigation and Drainage Engineering, Vol. 130, Issue 6, pp. 530-536.

Cheng, Y., Lansivaara, T., and Wei, W. (2007) 'Two-dimentional slope stability analysis by limit equilibrium and strength reduction methods' Computers and Geotechnics 34 (1), 137-150.

Elshemy, M. M. (2002), "Study of soil blockage effect on the seepage through earth dams’’, Master Thesis, Tanta University, Egypt.

Flores-Berrones R., Lopez-Acosta N, "Internal erosion due to water flow through earth dams and earth structures", Rijeka, Intech open, 2011, pp. 284–294.

Ghazaleh, K., Hamed, J., & Gholamreza, S. (2020), "A numerical modeling study on the seepage under embankment dams", Modeling Earth Systems and Environment, 6(2), 1075-1087.

Graupe D., (2007), “Principles of Artificial Neural Networks”, Second Edition, Advanced Series on Circuits and Systems, Published by World Scientific Publishing Company Pte. Ltd., Volume 6.

Griffiths, D., and Lane, P. (1999) ‘Slope stability analysis by finite elements’ Geotechnique 49 (3), 387-403.

Harr M.E. (1962), 'Ground water and seepage-book', school of civil engineering, purdue university, McGraw Hill, New York 91-37779.

Hnang, T. K. (1996), "Stability analysis of an earth dam under steady state seepage", Computers & structures, 58(6), 1075-1082.

ICOLD Bulletin 95, “Embankment Dams,” Granular Filters and Drains, International Commission on Large Dams, Paris, 1994.

Irzooki R.H.(2016), 'Computation of Seepage through Homogenous Earth Dams with Horizontal Toe Drain', Engineering and Technology Journal, Vol. 34, Issue 3 part (A), pp. 430-440.

Itasca, (2005) FLAC3D – User’s Manual. Itasca Consulting Group Inc., Minneapolis, MN.

Jamel, A.A.J. (2016). Analysis and estimation of seepage through homogenous earth dam without filter. Diyala Journal of Engineering Sciences, 9(2), 38-94.

Kamanbedast, A.; Shahosseini, M.: Determination of seepage and analysis of earth dams(Case study: Karkheh dam), Iranica Journal of Energy & Environment, Vol. 2, No. 3, pp. 201-207, (2011). doi: 10.5829/idosi.ijee.2011.02.03.682.

Lakehal, R., Djemili, L., and Belkhiri, L., (2011) ‘A study of the long-term effect of geometrical factors on stability of homogenous earth dams’ Journal of Geography and Regional Planning 4 (5), 279-286.

Lowe, J., and Karafiath, L. (1980). Effect of anisotropic consolidation of the undrained shear strength of compacted clays, Proc Research Conference on Shear Strength of Cohesive Soils, 1-2 Feb, Boulder, Colorado. 237-258.

Malekpour A., Farsadizadeh D., Dalir A. H. and Sadrekarimi J. (2012), 'Effect of horizontal drain size on the stability of an embankment dam in steady and transient seepage conditions', Turkish Journal of Engineering and Environmental Sciences, Vol. 36, No. 2, pp.139-152.

Mansuri B., Salmasi F. (2013), 'Effect of Horizontal Drain Length and Cutoff Wall on Seepage and Uplift Pressure in Heterogeneous Earth Dam with Numerical Simulation', Journal of Civil Engineering and Urbanism, Vol. 3, No. 3, pp.114-121.

Maula, B., and Zhang, L. (2011) 'Assessment of Embankment Factor Safety Using Two Commercially Available Programs in Slope Stability Analysis' Procedia Engineering 14 (1), 559-566

Mehdi Komasi, Ali Mohammadzadeh, Behrang Beiranvand, 2019," Optimization of horizontal drain dimensions in heterogeneous earth dams using Artificial Neural Network (ANN): A case study on Marvak dam", Journal of Applied Research in Water and Wastewater, Vol. 12, Pages109-116.

Mehrdad, M., Eslami, A., Taghavi, J., and Karami M. (2004) 'Geotechnical parameters effect on embankment dam analysis and design – applied to four case studies'. in Wieland M., Ren Q. and Tan J.S. (ed) proceedings of the 4th International Conference on Dam Engineering, 'New developments in dam engineering'. held 18-20 October 2004 at Nanjing China. London: A.A. Balkema, 601-609.

Mohammed, T. A., Huat, B. B. K., Aziz, A. A., Omar, H., Maail, S., Johari, M., & Noor, M. M.(2006), "Seepage through homogenous and non-homogenous earth dams: Comparison between observation and simulation", Electronic Journal of Geotechnical Engineering, 11.

Morgenstern N.R. and Price V. 1965. The analysis of the stability of general slip surface. Géotechnique, l5(1): 79–93.

N. Himanshu, and A. Burman, 2017," Seepage and Stability Analysis of Durgawati Earthen Dam: A Case Study", Indian Geotechnical Jurnal.

Omofunmi O. E., Kolo J. G., Oladipo A. S., Diabana P. D., and Ojo A. S. (2017), 'A Review on Effects and Control of Seepage through Earth-fill Dam' Journal of Applied Science and Technology, Vol. 22, No. 5, pp.1-11.

Punmia, B. (1992) Irrigation and water power engineering. New Delhi: Laxmi Publications.

Rojas R., (1996), “Neural Networks A Systematic Introduction”, Neural Networks, Springer-Verlag, Berlin, Heidelberg, A member of Berteismann Springer Science & Business Media GmbH.

Sazzad, M. M., & Alam, S. (2020), "Numerical investigation of seepage through earth dam by FEM", International Conference on Advances in Civil Engineering.

Sazzad, M. M., & Islam, M. M. (2019), "A comprehensive study of different types of seepage control measures for earth dam using FEM", Journal of Civil and Construction Engineering, 5(1),24-37.

Sazzad, M.M.; and Islam, M.M. (2019). Effect of width, length and position of cutoff wall on the seepage characteristics of earth dam. Journal of Geotechnical Studies, 4(1), 1-11.

Seyed Abolfazl Heidari1, Behzad Kalantari, and Mohammad Ghvidel, 2019, “Case Study: Method Artificial Neural Network for Earthfill Dams Seepage Analysis: Shahrchay Dam in Iran” Electronic Journal of Geotechnical Engineering, Vol. 22, Pages 1387-1396.

Shamil A. Behaya, (2014), “Optimum Dimensions of concrete gravity dam with fluid-structure-foundation interaction under seismic Effect”, D. Ph. Thesis, College of Engineering, University of Baghdad.

Shamil A. behaya, Rafe H.& Ahmed A., (2014), “Artificial Neural Network Modeling for Dynamic Analysis of a Dam- Reservoir-Foundation System”, Int. Journal of Engineering Research and Applications ISSN : 2248-9622, Vol. 4, Issue 1(Version 8), Pages 10-32.

Shang-jie, X., Fa-ning, D., and Qing, H. (2009) ‘Analysis of stability of Dam Slope During Rapid Drawdown of Reservoir Water Level’. in Yang, P. (ed) proceedings of 2009 International Conference on Engineering Computation , ‘2009 International Conference on Engineering Computation’. held 2-3 May 2009 at Hong kong China. Los Alamitos: Institute of Electrical and Electronics Engineers, 221-224.

Sivanandam S.N. & Paulraj M., (2003), “Introduction to Artificial Neural Networks”, Viskas Publishing House Pvt. Ltd.

Soleimanbeigi, A., & Jafarzadeh, F. (2008), "Seepage through rockfill dams in narrow valleys", From Research to Practice in Geotechnical Engineering (pp. 522-539).

Stark T.D., Jafari N.H., Zhindon J.S.L. and Baghdady A. (2017), 'Unsaturated and Transient Seepage Analysis of San Luis Dam', Journal of Geotechnical and Geoenvironmental Engineering, Vo.143, Issue. 2.

Vaezinejad, S. M., Marandi, S. M., & Salajegheh, E. (2018), "Inverse modelling of leakage through earth dams (case study: Baft dam, Iran), "Geotechnical Research, 5(4), 218-230.

Zeidan, B. A., Shahien, M., Elshemy, M., & Kirra, M. (2018), "Seepage and slope stability analysis of earth dams", In ICOLD 2018 26th Congress–86th Annual Meeting.

الخلاصة

في هذه الدراسة ، تم تطوير صيغة معادلات رياضية لإيجاد كمية تصريف التسرب وعامل الانحدار الجانبي لقيمة السلامة لسد ترابي متجانس مع مرشح تصريف أفقي مستطيل الشكل تم إنشاؤه على أساس معرض غير منفذة لمستوى مياه الخزان الكامل. تم استخدام الإحصاء مع الانحدار للعديد من تقنيات العلاقات غير الخطية في هذه المعادلات من أجل الحل. بالنظر إلى حقيقة أن موضوع تحليل تدفق وسائط المسام لسلوك السدود عند تعرضها لمستوى مياه الخزان ، يتضمن العديد من المتغيرات. مثل تلك المتغيرات المتعلقة بالأبعاد الهندسية والمتغيرات المتعلقة بالخواص الميكانيكية والفيزيائية للسد ومواد الأساس. لذلك ، لا توجد معادلات صريحة تربط هذه المتغيرات كمدخلات بتصريف التسرب وعامل انزلاق الأمان الناتج. يتطلب حل نظام المعادلات التفاضلية الجزئية المتزامنة التي تحكم الظاهرة ، مع مراعاة أبعاد المقطع العرضي وخصائص التربة.

يحتاج استخدام التقنية الإحصائية لإيجاد المعادلات الرياضية إلى حساب تصريف التسرب وعامل الأمان لعدد كبير من مجموعات المدخلات المتولدة عشوائيًا. لذلك ، في هذه الدراسة ، يتم إنشاء قاعدة بيانات للمدخلات والمخرجات باستخدام برنامج التحليل الخطي ثنائي الأبعاد Geo Studio مع نموذج SEEP / W لتقدير كميات تصريف التسرب ونموذج SLOPE / W لتقدير عامل الانحدار الجانبي لقيم السلامة. تضمنت قاعدة البيانات هذه 300 حالة مختلفة لقيم مختلفة لكل متغير بناءً على توصيات المصادر المعتمدة ذات الصلة بهذه القضية. يُفترض أن جسم السد (التربة) متجانس وله خصائص متساوية القياس بالإضافة إلى مرشح الصرف. يتم استخدام البرنامج الإحصائي" IBM SPSS 23 حلول المنتجات والخدمات الإحصائية" مع قاعدة البيانات المذكورة أعلاه لبناء نموذج من الشبكات العصبية الاصطناعية (ANN) لشرح وزن التأثير لكل متغير في هذه المسألة والنتائج التي تم الحصول عليها. تم دراسة تأثير تأثير كل متغير مدخل على متغيرات المخرجات]تصريف التسرب (q) وعامل المنحدر الجانبي للسلامة [(F.S) لقسم السد. أظهرت النتائج قدرة النموذج على تخمين قيم المخرجات وتصريف التسرب (q) وعامل الأمان (F.S) بدقة عالية. معاملات الارتباط بين قيم المخرجات المرصودة ونموذج القيم المتوقعة هي 99.3٪ لـ (q) و 99.5٪ لـ .(F.S) أظهرت النتائج أيضًا أن أفضل تقسيم للبيانات إلى مجموعات فرعية للتدريب والاختبار والانتظار (التحقق) هو 68.7٪ و 20.3٪ و 11٪ على التوالي لـ (q) و 69.3٪ و 21.7٪ و 9٪ على التوالي لـ .(F.S) بالإضافة إلى ذلك ، فإن أفضل عدد من العقد في الطبقة المخفية هو 7 لكل من (q) و (F.S) ، حيث يبلغ متوسط الخطأ النسبي الإجمالي 0.7٪ و 0.9٪ و 1٪ لمجموعات فرعية للتدريب والاختبار والانتظار على التوالي من أجل (ف) و 0.5٪ و 0.6٪ و 0.5٪ للتدريب والاختبار والمجموعات الفرعية الرافضة على التوالي لـ .(q) أخيرًا ، فإن أفضل وظائف التنشيط المستخدمة للطبقات المخفية والمخرجة هي التان الزائدي (tanh) ، والوظيفة الخطية (الهوية) على

التوالي لكل من (q) و .(F.S) تتنبأ معادلتان رياضيتان باستخدام تقنية الانحدار لعلاقة غير خطية متعددة لـ 75٪ من مجموعات المدخلات والمخرجات باستخدام برنامج SPSS 23 للحصول على كمية تصريف التسرب وعامل الانزلاق لقيمة الأمان لأي مجموعة من متغيرات الإدخال المذكورة أعلاه ، بدلاً من استخدام عملية طويلة لنمذجة .Geo Studio للتحقق من أداء المعادلات ، تم تطبيقه على 25٪ من مجموعات بيانات الإدخال التي لم يتم استخدامها في قاعدة البيانات التي تم استخدامها للتنبؤ بالمعادلات. أظهرت مقارنة نتائج هذه الحالات البالغة 25٪ التي حصل عليها برنامج Geo Studio مع تلك التي تم الحصول عليها باستخدام المعادلات الرياضية قدرة ممتازة لهذه المعادلات على التنبؤ بالمخرجات بدقة عالية. معاملات الارتباط لهذه المجموعات 25٪ هي 96.6٪ و 99.4٪ لتصريف التسرب (q) وعامل المنحدر الجانبي للسلامة (F.S) على التوالي.

جمهورية العراق

وزارة التعليم العالي

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قسم الهندسة المدنية

التنبؤ بالتسرب المتولد في سد ترابي مع مرشح تصريف افقي باستخدام تقنية الشبكة العصبية الاصطناعية

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