OPTIMUM DESIGN OF CONTROL DEVICES FOR SAFE SEEPAGE THROUGH EARTH DAM

A Thesis

Submitted to the College of Engineering of the University of Babylon in Partial Fulfilment of the Requirements for the Degree of Master of Science in Civil Engineering

By

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٢٠٠٦

TO

MY FAMILY

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Praise is to ALLAH HIS MAJESTY for this work .has been completed under His benediction
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I record my sincere gratitude to my family for their encouragement and support during the study .years
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□
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We certify that we have read this thesis, titled (Optimum Design of Control Devices for Safe Seepage through Earth Dam), and as examining committee examined the student Zahra Abd Saleh in its contents and in what is connected with it, and that in our opinion it meets the standard of thesis for the Degree of Master of Science in Civil Engineering (Water Resources).

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التصميم الأمثل لوسائل السيطرة لتسرب آمن خلال السد الترابي

الخلاصة

فكرة هذا البحث هي إيجاد التصميم الأمثل لوسائل السيطرة المستخدمة في تقليل التسرب خلال السد الترابي.
لتحليل التسرب المستقر ثنائي الأبعاد خلال **(finite elements)** استخدمت طريقة العناصر المحددة
.السد الترابي المختلف النفاذية

.(Seep٢d) تلك التحليلات طبقت على حاله عمليه هي سد القادسية من خلال برنامج جاهز تحت عنوان
للتأكد من صحة و دقة البرنامج فقد تم مقارنة نتائج تجربة لسد مختبري مع نتائج النموذج الرياضي. وبذلك تم
.تطبيق البرنامج على الحالة العملية
النموذج الرياضي طبق على(١٢٥) مقطع تصميمي بوسائل سيطرة على التسرب مختلفة الأنواع و الأبعاد وهي
القاطع الرأسي الكونكريتي و ستارة التحشية و اللب الطيني. النموذج الرياضي استخدم للتحري عن تأثير هذه
.الوسائل على التسرب و ضغط الماء المسامي
إن مجموعة من الأشكال رسمت لبيان توزيع شحنة الضغط و الشحنة الكلية و كذلك موقع السطح الحر لبعض
.الحالات
تشير نتائج تطبيق النموذج على هذه المقاطع إلى إن زيادة أبعاد و سائل السيطرة يعني تقليل كمية التسرب وتقليل
ضغط الماء المسامي و كذلك انخفاض موقع السطح الحر. وبشكل عام أن استخدام و سائل سيطرة أكثر يعني
.تقليل لكمية التسرب وتقليل لضغط الماء المسامي
الجزء الثاني من هذا البحث يتضمن مسألة الأمثلية. مجموعة من المنحنيات رسمت لبيان العلاقة بين التسرب و
ضغط الماء المسامي من جهة وبين أبعاد و سائل السيطرة على التسرب من جهة أخرى. ثم تم الحصول على
مجموعة من العلاقات بين أبعاد و سائل السيطرة التي تعطي نضح امن وضغط مسامي امن واستخدمت كمحددات
.لمسألة الأمثلية
لحل مسألة **(Lagrange Multiplier)** و طريقة **(Simplex)** استخدمت طريقة
.الامثلية وذلك لإيجاد اقل كلفة لوسائل السيطرة مع المحافظة على تسرب أمين وضغط مسامي أمين
مع ستارة تحشية **(m** دلت نتائج البحث أن أكثر المعالجات اقتصادية هي عند استخدام اللب بعرض (٣٥.٣٣
ولكن **(m** مع قاطع رأسي بعمق (٣.٩٤ **(m** أو عند استخدام اللب بعرض (٥٦.٢٨ **(m** بعرض (٠.٧٢
النتيجة الاخيره لعرض اللب كبيره إلى حد ما إذا ما قورنت بالعرض الكلي لجسم السد. عرض اللب يجب أن لا
ولذلك هذه النتيجة تتطلب زيادة عرض القشره. الحالة الأولى أفضل لأنها اقل كلفة واقل **(m)٤٠)** يتجاوز
نضح واقل ضغط مسامي. وكذلك موقع السطح الحر أوطأ من الحالة الثانية. بينما دلت النتائج على إن استخدام
.اللب الطيني مع ستارة التحشية مع القاطع الرأسي سويا يعطي حلا غير مقبول

ABSTRACT

This research aims at determining the optimal design of control devices for safe seepage through earth dam. The finite element method has been used to analyze two-dimensional steady state seepage through .nonhomogenous isotropic earth dam

This analysis is performed for a practical case study, Al-Qadisiya Dam under a package program .(titled as (seep٢d

The validity of the program was evaluated by using existing experimental results measured in a .laboratory model dam

This model is applied for (١٢٥) design cross sections with different dimensions of concrete cut-off, grout curtain and dolomite core as seepage control devices. This model is used to investigate the effect of .these devices on seepage flow and pore water pressure

A set of figures is presented to show the distribution of pressure and total head, as well as, .location of the free surface for some cases

The results of the application of the model on these cross sections indicate that the increasing of the dimensions of the control devices leads to decreasing seepage discharge and pore water pressure. Also, the location of free surface was lowered. In general, using more seepage control devices means decreasing the .seepage quantity and pore pressure

The second part of this work presents formulation of the optimization problem. A set of curves has been obtained showing the relationships between seepage flow and pore pressure for various dimensions of seepage control devices. Then, the

relationships between the dimensions of these devices which achieve safe seepage and pore pressure have .been applied as constrains
The optimization problem has been solved by the simplex and Lagrange multiplier methods to find .the minimum cost of control devices
The results of the analysis have indicated that the minimum total cost could be achieved when using core width of ٣٥.٣٣ m with grout curtain width of ٠.٧٢ m or using core width of ٥٦.٢٨ m with cut-off depth of ٣.٩٤ m. However, this value of core width is rather too large when compared with the total width of the embankment and the core width should not exceeds ٤٠ m. This result required increasing the width of shell. The first case is preferable because it is less expensive and seepage flow and pore pressure are less. Also, the location of free surface was lowered. Using of dolomite core, grout curtain and concrete cut-off together is .infeasible solution

PAGE ADDRESS SECTION

Most of the commonly symbols are listed below; others are defined where they appear in the research.

Dimension	Definition	Symbol
L^2	Area of the problem domain	A
	Cost of one cubic meter of concrete cut-off unit cost	c_1
	Cost of one cubic meter of grout curtain unit cost	c_2
	Cost of one cubic meter of dolomite core unit cost	c_3
	Percentage of error between calculated data and observed data	Er.
L	Piezometric head at any point in the domain	H
L	Approximate solution for piezometric head distribution in the element (e)	He
L	Nodal value of head, H, of element (e)	Hi
	The vector matrix of nodal values	{Hi}
	Hydraulic gradient	i
L/T	Hydraulic conductivity	k

Element matrix ke]]
Hydraulic conductivity in x, y and z- kx, ky, kz
L/T directions respectively
Direction cosines Lx, Ly
(Number of nodes in element (e n
Dimension Definition Symbol
Total number of element in the problem ne
domain
(Shape function of element (e Ni
Surface boundaries of the element p
Reservoir boundaries p١
Impermeable boundaries p٢
Element residual Re
Reynolds number Re
L Distance a long the flow line s
Velocity components in x, y and z-direction u, v, w
L/T respectively
L/T Seepage velocity of fluid in porous media Vs
Weighted function Wj
L Depth of upstream concrete cut-off x١
L Width of grout curtain x٢
L Width of dolomite core x٣
unit cost Objective functions z١, z٢, z٣
Stream function ψ
FT٢/L٤ Fluid density ρ
FT/L٢ Coefficient of viscosity μ
F/L٣ Unit weight of water γw

Chapter One
Introduction

General ١.١

It is probably safe to say that few engineering projects have a greater ability to stir men's minds than the design and construction of a large dam. Within the engineering profession there is the excitement that a .massive integrated engineering endeavor creates

The ability of civil engineering profession to produce successful designs has promoted precedent as the most significant factor influencing the design of new dams. Dams designed on the base of precedent tend to be conservative, especially where uncertainties regarding the material properties or structural behavior exist. Performance of a new dam is estimated from previous experience and simple analysis rather than as a result of a truly fundamental understanding of the structure .[(itself [Al-Qaisi, (١٩٩٩

The present work searches for the optimum design of control devices for safe seepage through an earth dam to find the best possible solution among the many potential solutions satisfying the chosen criteria. Simplex and Lagrange multiplier methods are used to .ensure aforementioned objective

One of the most important problems that causes damage to hydraulic structures is seepage through and under dams, which occurs due to the difference in water level between the upstream and downstream .sides of the dams

Seepage of water through the embankment or foundations has been responsible for more than one

third of earth dams failures. Seepage is inevitable in all earth dams and ordinarily it does not harm. Uncontrolled seepage may, however, cause erosion within the embankment or in the foundation, which may lead to piping. Piping is the progressive erosion, which develops through the dam. Seepage failures are generally caused by pervious foundations, leakage through embankment, conduit leakage and sloughing .[(Varshney and Gupta, (١٩٧٢

Seeping water may prove harmful to the stability of the dam by causing softening and sloughing of slopes due to the development of pore pressures and thereby which lead to the weakling of the mass and even failure .[(by shear [Garg and Garg, (١٩٧٨)] and [Punima, (١٩٨١

So, the study of seepage through earth dams is one of the important analysis in dam design to calculate the quantity of losses from reservoir, estimating the pore water pressure distribution, locating the position of the free surface which is used in analysis of the dam stability against the shear failure. Finally, studying the hydraulic gradient which gives a general idea about the .[(potential piping [Sherard et al, (١٩٦٣

There are a number of methods for solving steady-state seepage problems. Most of these methods are only convenient for homogenous soil conditions. The finite element method provides a powerful tool for seepage analysis in nonhomogenous anisotropic situations .[(Naylor and Pande, (١٩٨١

In this research a finite element method was used to analyze the seepage through and under Al-Qadisiya .Dam

Seepage Control ١.٢

Uncontrolled seepage results in two types of trouble in hydraulic structures: (a) excess leakage and (b) excess pressures or gradients. Seepage control is the correction of the conditions which lead to these .troubles

Control of Quantity of Seepage. Excess quantity of seepage is caused by high permeabilities, short seepage paths, defects such as cracks and fissures and by uneven settlements which produce gaps or cracks in the soil or between the structure and the soil. The discharge can be reduced by using soils of low permeability, pacing cores in earth structures, cut-offs in the foundations, and by increasing the seepage path .by employing upstream blankets

Control of Pressures and Gradients. Excessive uplift pressures, particularly at the points where there is little weight of structure to resist them, lead to boiling and piping. Control of these pressures and gradients can be effected in many ways such as by changing the direction of the seepage, incorporation of internal drains, relief walls, and by increasing the external load. In addition, the upstream blanket, cut-offs are also effective in reducing gradients and .[(pressures [Sowers and Sally, (١٩٦٢

The use of these devices in controlling the seepage through and under hydraulic structures depends on the nature of the foundation, type of the structure and .the cost of the devices to be used

Objectives of Study ١.٣

The main objectives of this study can be :summarized as follows

١. Evaluating the effect of using single and combinations of different seepage control devices on .pore water pressure and seepage flow

٢. Determination of the optimum design (hydraulic and economical) for the control devices in order to .satisfy the safe seepage through earth dam

٣. Applying this study to one of the Iraqi earth dam.

Chapter Two
Theoretical Seepage Analysis and Review of Literature

٢.١ General

The amount of water seeping through and under an earth dam, together with the distribution of the water pressure, can be estimated by using the theory of flow through porous media. In this chapter the basic flow equations with indication how they may be solved and the previous studies on the seepage through earth dams will be explained.

٢.٢ Theory of Seepage flow in porous Media

Seepage problems are generally classified as the percolation of water due to head difference under hydraulic structures or through earth dams, riverbanks or into excavations.

Any seepage problem involves three principal factors: the soil media, the type of flow, and the boundary [Rushton and Redshaw, (١٩٧٩)].

The soil media through which seepage takes place represents porous media which may be homogenous if the hydraulic conductivity is independent of position; otherwise it is called heterogeneous, and it may be isotropic if the hydraulic conductivity is independent of direction; otherwise it is called anisotropic [Ruadkivi and Callander, (١٩٧٦)].

Seepage flow through permeable soil may be either steady or time-variant, in the latter case; its characteristics are effected by the lapse of time; whereas the steady state occurs when the condition at the boundary of the region must remain fixed with time. Also, the seepage flow is said to be confined if the boundary of flow region is fixed otherwise it is called unconfined where one boundary is a free surface. A general-class of unconfined flow problems is the problem of seepage through earth dams [Taylor and Brown, (١٩٦٧)].

٢.٢.١ Darcy's Law

The "Darcy's law of seepage " establishes a linear relationship between the seepage velocity and hydraulic head gradient. This law, which is a simple consequence of viscous flow neglecting inertia effects, can obviously be written in the form:

Vs = ki …(٢-١)

or

Vs = - k … (٢-٢)

where:

Vs : seepage velocity of fluid in porous media,(L/T);

k : hydraulic conductivity,(L/T);

i : hydraulic gradient = - dh/ds

h : piezometric head = (p/□w) + z , (L);

p : hydrostatic pressure,(F/L٢);

□w : unit weight of water,(F/L٣);

z : elevation head ,(L);

and s : distance along the flow line,(L).

Darcy's law is valid when the flow is laminar, i.e. Reynolds number is taken equal to or less than one [Harr, (١٩٦٢)]. That is:

…(٢-٣)

where:

Vs : flow velocity, (L/T);
d : average diameter of soil particles, (L);
ρ : fluid density, (FT٢ /L٤);
μ : coefficient of viscosity, (FT/L٢);

٢.٢.٢ Laplace's Equation

The components of seepage flow through porous media according to the general Darcy's law form are [Freeze and Cherry, (١٩٧٩)].

… (٢-٤a)

… (٢-٤b)

… (٢-٤c)

where:

u,v,w : velocity components in the x, y, and z-direction, respectively, (L/T);
kx,ky,kz : hydraulic conductivity in the x, y, and z-direction, respectively, (L/T).

The continuity equation for three-dimensional and incompressible flow is:

…(٢-٥)

Substituting Darcy's law, Eq. (٢-٤); in Eq. (٢-٥) results in:

…(٢-٦)

For homogenous and isotropic soil, the permeability is independent of the direction of the flow, thus:

kx =ky =kz =k

Then equation (٢-٦) may be written as:

...(٢-٧)

Equation (٢-٧) is the Laplace equation; it is similar to Laplace equation of velocity potential for ideal fluid flow.

For the analysis of seepage flow through and under earth dams, the flow is considered to be two-dimensional and the equation is used in the form:

...(٢-٨)

Consequently, for the conditions of steady-state laminar flow, the seepage pattern can be completely determined by solving Eq. (٢-٨), subject to the boundary conditions of the flow domain. Family of streamlines and equipotential lines can represent the solution of this equation.

For equipotential lines
H (x, y) = Constant

For stream lines
ψ (x, y) = Constant

where ψ is a stream function, which satisfies Laplace's equation:

...(٢-٩)

Line H and ψ present flow pattern and are directed orthogonally to each other.

٢.٣ Boundary Conditions

Referring to figure (٢-١), the boundary conditions associated with seepage through earth dam is as follows:

a. Impervious Boundary

At impervious boundaries the fluid can neither penetrate the boundary nor leave gaps, thus, the velocity component normal to the boundary must be zero, so this boundary is a streamline. Defining n as the perpendicular direction to this line,   at the boundary.

b. Boundary of the Reservoirs

Along the boundaries of the reservoir the pressure distribution may be taken as hydrostatic; that is, the pressure must be function of depth only; i.e., constant head. This type of boundary represents equipotential lines.

c. Free Surface (Phreatic Line)

The line of seepage is the upper streamline in the flow domain. The determination of its locus is one of the major objectives of unconfined seepage problems. The pressure at any point along its surface is constant and equal to atmospheric pressure. Thus, along this line:

$H=Y$

…(٢-١٠)

Figure (٢-١): Seepage through earth dam with boundary conditions

d. Seepage Face

The free surface ends at the down stream face, not at the water surface. This is the portion where the water seeps out of the soil into air, therefore, it is named seepage face. Because the pressure is atmospheric, the only condition on this boundary is that the total head equals the elevation head.

٢.٤ Methods for Solution of Seepage Equations

In order to do seepage analysis, a general model describing the phenomena of seepage must be available. Supplied with specific boundary conditions and soil properties, this model can be used to determine heads and flow distribution and seepage quantities. The Laplace's equation is a mathematical basis for several methods have been developed to solve exactly or approximately Laplace's equation for various cases of seepage [U.S. Army Crops. of Engineers, (١٩٨٦)].

Many methods have been developed for analyzing the seepage problems such as graphical method (The flow net), analytical methods and experimental methods of which are the electrical analogy method, viscous flow method and sand tank method. These methods of solution are well applicable when the boundary of the region of seepage is clearly defined and the soil medium is homogenous and isotropic with respect to permeability.

However, it is cumbersome for problems involving unconfined flow in non-homogeneous soil. For solving such types of problems, the use of computer aided methods seems to be more appropriate. Three different numerical procedures

have been used in computer methods for unconfined seepage analysis; the finite difference method, the finite element method and the boundary element method. [Chang, (١٩٨٨)] and [Bear and Verruijt, (١٩٩٠)].

٢.٤.١ The Finite Difference Method (F.D.M)

A numerical finite difference solution to steady state flow situations was first presented by Show and Southwell in ١٩٤١ but the development of this method accelerated with advance of computers [Al-Qaisi, (١٩٩٩)].

The finite difference method solves the flow equations by approximating them with a set of linear algebraic equations. The flow region is divided into a discrete rectangular grid with nodal points, which are assigned values of head. Using Darcy's law and the assumption that the head at a given node is the average of the surrounding nodes, a set of N linear algebraic equation with N unknown values of head are developed [U.S. Army Crops. of Engineers, (١٩٨٦)].

٢.٤.٢ The Finite Element Method (F.E.M)

The finite element method is more usable in solving complex problems than the finite difference method for the following reasons:

١. In finite element method anisotropy and non-homogenous problems are taken into account quite easily in comparison with the finite difference method.

٢. The boundary conditions are easily handled by the finite element method, where formulas must be developed for each condition by finite difference method [Al-Obaidi, (٢٠٠١)].

More detailed definitions and explanation of this method will be given later in chapter three.

٢.٤.٣ The Boundary Element Method (B.E.M)

The boundary element method, which could be considered as one of the new methods that are used in analyzing the unconfined flow problems of both steady-state and non-steady state conditions. The boundary element method requires discritization only on the boundary rather than over the whole region as that required in finite element method, so, the effort of input preparation and requirement for computer are greatly reduced [Chang, (١٩٨٨)].

٢.٥ Previous Studies on F.E.M

The finite element method was first applied to boundary value problems by Zienkiewicz and Cheung (١٩٦٥) and their method was later extended to obtain a solution for a steady state seepage in an isotropic foundation under a concrete dam [Zienkiewicz etal., (١٩٦٦)].

Solutions to unconfined flow problems were presented by Finn (١٩٦٧) and Taylor and Brown (١٩٦٧) shortly after. In the unconfined case the free surface in the dam is unknown at the start of the analysis and an assumption has to be made as to its position. In this analysis the free surface is assumed to define the upper boundary of the mesh and an iterative procedure is adopted to adjust the position of nodes on this boundary until all boundary conditions are satisfied.

Finn's solution can be described in a number of steps:

i. A free surface line is assumed for the section to be analyzed.

ii. The saturated region below that line is divided into finite elements.

iii. The coordinate and element data are then supplied to the program with the other boundary conditions. (The pressures within the and on the free surface are assumed unknown.

iv. A solution to the Laplace equations is obtained and the potentials printed.

v. If the boundary condition of the pressure head (ψ) being zero on the free surface is not met at any node (to a reasonable degree of accuracy) the coordinate data is modified so that the second guess would satisfy the (ψ=٠) condition along the surface. If the first guess was poor, the mesh would be also modified by adding or subtracting elements to avoid any unreasonable deformation.

vi. A second solution is obtained and iteration continues until the boundary condition on the free surface is satisfied.

Neuman and Witherspoon (١٩٧٠) studied a new iterative approach to steady seepage of groundwater with a free surface by using the finite element method. The method was applied to heterogeneous porous media with complex geometric boundaries and arbitrary degrees of anisotropy, it could handle problems where the free surface was discontinuous and where portions of the free surface were vertical or near vertical. For example they studied a homogeneous dam with a toe

drain and they found that the position of the free surface by this method after to iterations was the same as that obtained by flow net analysis.

Dunglas (reported by Sing-Bharat ١٩٧٦) also studied unconfined flow in a homogenous dam (١٥m height) having a vertical drain (٨m height) by using the finite element method. He calculated the position of the free surface by changing the position of drain and the permeability coefficient ratio in x and y direction.

His results indicated that when the drain position is at the start of down stream slope, the free surface location is above the drain for greater than ١٠. When the position of the drain changed ٧ m from downstream slope, the ratio increased to ٢٠. Figure (٢-٢) represents the results.

Lacy and Prevost (١٩٨٧) developed a finite element procedure to locate accurately the free surface of unconfined seepage flow through porous media. The procedure allowed solution in non-homogeneous materials and complex geometrical shapes. Accuracy of the procedure was demonstrated by solving various unconfined seepage flow problems through earth structures.

Muhammad (١٩٩١) conducted a study on the seepage through earth dams by using the finite element method, first he prepared a program in Fortran language to examine the seepage through earth dams and to locate the phreatic surface position and then to find out the quantity of seepage. Assuming the soil is isotropic and the permeability coefficient equals one. He operated his programming times on this case, table (٢-١) represents the results that have been occurred by changing the equipotential lines number for the same number of the flow channels and the seepage quantity which results from it and the error ratio. All the results indicated that the increasing in accuracy was gained by increasing the number of equipotential lines while keeping the number of flow channel constant, and increasing the accuracy is also by increasing the number of flow channels while keeping the number of equipotential lines constant.

Table (٢-١): The seepage quantity results by changing the equipotential lines number [data from Muhammad J.R, (١٩٩١)]

The flow channels number

N١ The equipotential lines number

N٢ The seepage quantity m٣/day Error percent ٪ according to the theoretical value(٤.٣ m٣ /day)

٣	١٠	٤.٦	٩.٧
٣	١٣	٤.٥١	٧.٤
٣	١٥	٤.٤٦	٦.٣
٣	١٧	٤.٤٢	٥.٣
٣	٢٠	٤.٣٨	٤.٣
٤	١٠	٤.٥٢	٧.٥
٤	١٣	٤.٤٦	٦.٣
٤	١٥	٤.٤٤	٥.٧
٤	١٧	٤.٤٢	٥.٢
٤	٢٠	٤.٣٦	٣.٨
٥	١٠	٤.٤٥	٥.٩
٥	١٣	٤.٤	٤.٧
٥	١٥	٤.٣٩	٤.٤
٥	١٧	٤.٦٦	٣.٩
٥	٢٠	٤.٣٣	٣.١
٦	١٠	٤.٣٦	٣.٩
٦	١٣	٤.٣٤	٣.٤
٦	١٥	٤.٣٤	٣.٢
٦	١٧	٤.٣٣	٣.١
٦	٢٠	٤.٣٢	٣.٦

Huang (١٩٩٦) used an efficient finite element procedure to locate the free surface of steady state flow through an earth dam for evaluating the pressure distribution within an earth dam. Using these procedures, the seepage forces on each element in the finite element mesh can be estimated for stability analysis.

Al-Qaisi (١٩٩٩) applied a finite element program to analyze the steady seepage condition in Liyn Brianne Dam. The pressure head was predicated from the finite element program. The researcher noticed from his results that pore water pressures during the steady

state seepage condition occur at higher concentrations near the upstream of the clay core. He plotted the phreatic line by intersecting the elevation and the contour which had the same value of the total head.

Abo (٢٠٠١) studied seepage in earth dam by using F.E.M. He used a package program written in Fortran language. The program computed quantity of seepage and the phreatic line, pore water pressure and total head in homogeneous and zoned dams. The accuracy of the program was investigated. The program was applied to several dams and the results showed acceptable accuracy. In addition to this, the efficiency of the filter in earth dam and its importance in decreasing pressure in the dam and its effect on the amount of seepage was studied.

Subuh (٢٠٠٢) studied a two-dimensional steady state seepage through stratified an isotropic earth dam by using the finite element method to predict the piezometric head distribution, seepage quantity, pore water pressure and locating the free surface profile. This study was applied to Al-Qadisiya Dam and the applicability of this method has been evaluated based on a comparison between the numerical solutions and measured field data. He found that using a D/S drain would decrease the pressure in the D/S shell and using the grout curtain and the asphaltic concrete diaphragm means decreasing the seepage discharge and also, the pore water pressure and the head gradient behind the curtain.

Ahmed (٢٠٠٣) used a two-dimensional steady state finite element model with linear triangular elements to analyze seepage of water through Mosul Dam and its foundation. This model is written under a package program titled as (Seep٢d). She used this program to estimate the permeability of each material in seven cross sections of Mosul Dam body by using trail and error calibration and the average permeability of foundation, but this permeability was changed from time to time according to solution of gypsum or due to grouting. She studied the efficiency of grouting and filter with their effects on phreatic surface and their importance in reducing pore pressure.

٢.٦ Previous Studies on Optimization Problem

Optimization is a mathematical technique that selects the best solution from a set of feasible alternatives. Many studies were used the optimization model in hydraulic structures problems. Some of them are as given below:

Gill (١٩٨٠) used the theoretical ideas presented by Bennet (١٩٤٦) criteria for optimal design of rectangular, triangular and trapezoidal blankets. It is shown that a triangular blanket is more effective, hence more economical than rectangular and trapezoidal blankets, in reducing under seepage and uplift force. The uplift force is reduced in the same proportion as the seepage.

Jawad (١٩٩٦) presented the coupling of the hydraulic behavior of an unconfined aquifer system with an optimization model.

Hamed (١٩٩٦) used Rosenbrock constrained optimization and Sequential Unconstraint Minimization Technique methods in order to solve the non-linear programming problem. He found the

optimum design of barrage floor (area of concrete and reinforcement).

Al-Musawi (٢٠٠٢) studied the optimum design of control devices for safe seepage under hydraulic structures and used the finite element method to analyze seepage below hydraulic structures.

The results indicated that the use of an upstream blanket would reduce the uplift pressure and exit gradient. However, the use of a downstream blanket would increase the uplift pressure and exit gradient. Also, for a hydraulic structure with different control devices, the minimum total cost could be achieved when using a filter trench while the maximum total cost was when a downstream cut-off is used.

Chapter Three
Finite Element Formulations

٣.١ General

Wide range of techniques is available for the study of seepage problems. Many developments in recent years in the analysis of seepage have been made by means of mathematical models. They are usually based on analog or digital computers [Rushton, and Redshow, (١٩٧٩)].

The finite element method is a very powerful and relatively modern computation tool. It requires the use of a digital computer because of the large number of computations involved [Stas, (١٩٨٦)].

This chapter presents the principles of the finite element method and the finite element formulations for two-dimensional flow through porous media using Galerkin weighted residual method.

In addition, this chapter includes an explanation for the finite elements computer program that has been used in this study and its general structure chart.

٣.٢ Fundamental Concept of the Finite Element Method

The finite element method is a numerical procedure for obtaining solutions to many of the problems encountered in engineering analysis. In ground water flow problems, one could imagine that a region is subdivided into small elements, these elements may be two, or three-dimensional and joined to each other by nodes existing on the element boundaries. The flow of each element is described in terms of the head in the nodal points, and then a system of equations is obtained from the conditions that the flow must be .[(continuous at each node [Bear, and Verruijt, (١٩٩٠

The field variable model describing an approximate variable model describing an approximate variation of piezometric head (He) within the element is

:Where (١-٣)...

;Hi: Nodal value of head; H, of the element

;n: Number of nodes per element

.Ni: Shape function of the element

It is possible to write Equation (٣-١) in matrix form

:[(as follows [Zienkiewicz etal., (١٩٦٦

He =[Ni]{Hi}

(...(٣-٢

:Where

;Ni]: shape function matrix]

.Hi}: vector matrix of nodal values}

The approximate solution for head variation, H,

:over the whole domain is given as follows

or (٣-٣)...

(٤-٣)...

:Where

ne: is the total number of elements in the problem .domain

The methods that are used to obtain the approximate solution, are as follows: [Zienkiewicz, (١٩٧٧) and Rao, .[(١٩٨٢

١- Direct approach.

٢- Variational approach.

٣- Weighted Residual approach.

The weighted residual method is the most widely used in the finite element work [Smith, (١٩٩٨)].

٣.٢.١ Weighted Residual Method

The weighted residual method is a technique, which can be used to obtain approximate solutions to linear and non-linear differential equations. In such method the finite element equations can be derived directly from governing differential equation of the problem [Zienkiewicz, (١٩٧٧)].

If (A) is a problem domain and (h) is the field variable then the governing equation can be written as follows:

F (h)=٠ in A

(٣-٥)...

If the approximate solution as (ha) then, by substituting it in Eq. (٣-٥), the equation does not equal zero, but there is a residual (R):

(٣-٦)...

The best solution is the one, which makes this residual a minimum or maintains it small at all points of the domain. In order to reach this aim, Eq. (٣-٦) should be integrated on the problem domain after weighting by a certain function and should be equal zero as follows:

(٣-٧a)...

or

(٣-٧b)...

Where:

Wj: Weighted function;

.Re: element residual

There are different approaches, which can be used, depending on the choice of the weighted function. The best is the one which is known as Galerkin technique where the weighted function is taken equal .[(to the shape function (i.e., Wj=Nj) [Segrlind, (١٩٨٤

The Galerkin Principle ٣.٢.٢

The Galerkin principle is applied to derive the :(elements matrix. From equation (٣-١

Where (Hi) is the value of the piezometric head in node .((i

The finite element approximation is applied to the general equation for seepage flow in porous media as mentioned in chapter two, is for two-dimensional, :anisotropic and nonhomogenous

(٨-٣) ...

:And substituting Eq. (٣-١) in Eq. (٣-٨) gives

(٩-٣)...

Now, by applying Galerkin principle and :substituting Eq. (٣-٩) in Eq. (٣-٧b) yields

(١٠-٣)...

:Where

(dA= dx.dy; (j=١,٢,..., n

.n: number of nodes for each element

To reduce the continuity requirements for the shape function, N, from C١ to C٠ continuities [Zienkiewicz, (١٩٨٢)], integration by parts with Green's theorem is applied to the second order derivatives terms, where C١ and C٠ are the continuity for the shape function for the first and zero stage, respectively .[([Burnett, (١٩٨٧

:The first term of equation (٣-١٠) will be as follows

(١١-٣)...

The second term of equation (٣-١٠) will be as :follows

(١٢-٣)...

Substituting equations (٣-١١) and (٣-١٢) in equation :(٣-١٠) gives

(١٣-٣)...

Where represents the surface boundaries of the .element

:The boundary conditions are

H = H٠

(...(٣-١٤a

On p١ which represents the domain boundaries, and

(b١٤-٣)...

On p٢ which represents the impermeable boundaries by applying finite element method to :equation (٣-١٤b) it becomes

(١٥-٣)...

.Where Re is element boundary residual

Using Galerkin Weighted residual method, equation (٣-١٥) becomes:

(...(٣-١٦

Where: dx = Lxdp, dy = Lydp

Multiplying equation (٣-١٣) by (-١), then adding it :to equation (٣-١٦) gives

(١٧-٣)...

:And in matrix form

(١٨-٣)...

Where [Ke] represents the element matrix and its :typical coefficient is

(١٩-٣)...

The surface integral on in the equation (٣-١٩) is unknown. This condition does not cause any difficulties in solving the simultaneous equation because this equation does not form in the node, which lies in the boundaries on the surface and the equation (٣-١٩) does not apply in this part because the value of piezometric head is known. Therefore, equation of element matrix :can be simplified as

(٢٠-٣)...

It is possible to represent [Ke] in matrix form as :follows

(٢١-٣)...

:Where

Assembling the equations or matrices of the finite :element [Ke] to form the global matrix gives

K]{H}=٠]

(... (٣-٢٢

= Where, [K] is the global matrix

Solving the assembled equation (٣-٢٢) by using the .[(frontal solution [Hinton and Owen, (١٩٧٧

٣.٣ Derivation of Element Matrix (Linear Triangular Element (

The linear triangular element shown in Figure (٣-١) has straight sides and three nodes, one at each corner. A constant labeling of the nodes is a necessity and the labeling here proceeds counter clockwise from

node ١ which is arbitrarily specified. The nodal values of H are $H_{١}$, $H_{٢}$ and $H_{٣}$, whereas the nodal coordinates .(are $(x_{١}, y_{١})$, $(x_{٢}, y_{٢})$ and $(x_{٣}, y_{٣}$

:The interpolation polynomial is

$$H = a_{٠} + a_{١}x + a_{٢}y$$

(... (٣-٢٣

To find the constant values $a_{٠}$, $a_{١}$, $a_{٢}$ substitute x, y :and H for the three node results

$$H_{١} = a_{٠} + a_{١}x_{١} + a_{٢}y_{١}$$

$$H_{٢} = a_{٠} + a_{١}x_{٢} + a_{٢}y_{٢}$$

$$H_{٣} = a_{٠} + a_{١}x_{٣} + a_{٢}y_{٣}$$

In matrix form

(٢٤-٣) ...

Solving the equation (٣-٢٤) for the constant and substituting the constants values in the equation (٣-٢٣) :and expressed it in a matrix form results

Figure (٣-١): Parameters for the linear triangular .[(element [Segerlind, (١٩٨٤

(٢٥-٣)...

$$H = (a_{١} + b_{١}x + c_{١}y)H_{١} + (a_{٢} + b_{٢}x + c_{٢}y)H_{٢} + (a_{٣} + b_{٣}x + c_{٣}y)H_{٣}$$

$$H = N_{١}H_{١} + N_{٢}H_{٢} + N_{٣}H_{٣}$$

or

:Where

,I: number of nodes in the element = ٣

,Ni: interpolation function

.Hi: values of domain variable at node i

:The interpolation function is

Ni =ai + bix + ciy

(...(٣-٢٦

(a٢٧-٣)...

(b٢٧-٣)...

(c٢٧-٣)...

(d٢٧-٣)...

.Where: A is the area of the triangle

The interpolation functions derivative with :respect to x and y gives

(٢٨-٣)...

Substituting the above values in the equation (٣-٢٠) :results

(a٢٩-٣)...

(b٢٩-٣)...

The above equation represents the element matrix .(elements and it is rectangular matrix (٣*٣

Steps of the Solution ٣.٤

The general steps, which are used to solve the unconfined seepage problems through earth dam by :using the finite element method are as follows

.١ Discretization the flow region into triangular elements numbering the elements and the nodes for .each element

.٢ .Assuming the initial position of the free surface

.٣ Evaluating the element matrix for each element by .(using the formulations in section (٣.٣

.٤ Assembling the element matrices from (local) to .((Global

.٥ Applying the boundary conditions in the global .matrix

٦. Solving the system of equations to find the head values (H) at each node.

٧. Adjusting the position of the free surface in order to satisfy the free surface boundary [y=H].

٨. Repeating the trials until the condition in step (٧) is satisfied.

٩. Calculating the necessary parameters such as seepage quantity and pore water pressure.

For the above steps, a general package under the name of “Seep٢d” is used to execute the above calculations.

٣.٥ Outline of the Computer Program

The computer program which is used in this study is entitled “Seep٢d”. This program is in Fortran language and it is a ٢-D finite element flow model designed to compute seepage in earthen dam. Seep٢d can be used to model confined and unconfined flow situations. For unconfined flow situation, the phreatic surface is determined. Seep٢d can model complicated ٢-D seepage problems involving complex model geometries and soils that are nonhomogenous and anisotropic.

Seep٢d is a steady state flow model and will compute the piezometric head value at each node of the finite element mesh. From these values, flow lines and equipotential lines are plotted showing the resulting seepage flow net. Figure (٣-٢) is a structure chart for the computer program, showing the solution procedure.

٣.٥.١ Mesh Generation

At first, the region is subdivided into triangular element by hand or by using computer program such as (GMS “Ground Water Modeling System” program

which is used in this study, Nastran program). After mesh generation, the number of nodes, number of elements and the number of different materials of the .dam are indicated

Input File ٣.٥.٢

The input file for "Seep٢d" program is prepared under :extension (.dat) as follows

.١ Input the number of nodes, elements and the .number of different materials of the region

.٢ Input the values of soil permebilities (kx and ky) .for each material

.٣ Place all the node coordinates and all elements of .the mesh

.٤ Place all the boundary conditions (known head) at some nodes, (upstream and down stream nodes) of .earth dam

Output Files ٣.٥.٣

There are three files obtained as output from operating :"Seep٢d" program and they are as follows

.١ First file contains flow lines, flow rate, pressure head, pore pressure, velocity and total head for each .node

.٢ .Second file includes adjusting mesh

.٣ Third file includes coordinates of free surface and .seepage flow

Figure (٣-٢): Overall structure chart of computer program "Seep٢d".

Chapter Four
”The Case Study “Al-Qadisiya Dam

General ٤.١

Al-Qadisiya dam is a multi-purpose hydro-development designed to control the Euphrates River flow in the interests of irrigation, electric power generation and for partial accumulation of extreme .Euphrates River inflows into Al-Qadisiya reservoir

Al-Qadisiya dam was constructed on the Euphrates River in the Middle West of Iraq ٧km upstream from Haditha town. In ١٩٨٨ the project was completed. The project generates (٦٦٠ Mw) of electrical power a side from performing its flood control function. Central and southern parts of Iraq get the benefit of irrigation water from its reservoir. Figure (٤-١) shows a general layout of the project [Hydroprojekt, .[(١٩٨٨)

The project comprises mainly of an earth dam, ٩ km long, because of its considerable length and diversity of its topography and geological conditions, the design of the dam embankment varies from section to section but in general it preserves the features of the basic type which cover most of the dam length as .[(shown in figure (٤-٢) [Irzooki, (١٩٩٨

The body of the dam consists of a central dolomite core and shells made of sand/gravel material and/or a rock muck (random rock material) [Salih, (٢٠٠٠)]. An asphaltic concrete diaphragm through the core was provided as an antiseepage measure through the body

of the dam. A grout curtain was constructed to provide .treatment for the foundation against seepage

Various instruments were installed in the body of the dam for safety measure of the dam. Piezometers and observation wells were installed in the body of the dam and adjacent area to monitor the ground water movement and for detecting any seepage that could .occur

The general features of the dam and reservoir are :[(outlined in the following [Hydroprojekt, (١٩٧٨

Table (٤-١): Design values of the parameters of interest [(of Al-Qadisiya Dam. [Hydroprojekt, (١٩٧٨

Body of the dam

m ٥٧ Maximum height

m ٢٠ Top width

m ١٥٤ Top elevation

m ٣٣٦٨.١ Length of the right bank

m ٤٣١ Length of the river section

m ٥١٤٠ Length of the left bank

The water level in the reservoir

m.a.s.l ١٤٧ Maximum design level

ma.s.l ١٢٩.٥ Minimum water level

m.a.s.l ١١٢ Dead-storage level

٤.٢ Geological Conditions of the Project Area

The area of the project is located in the Euphrates River valley, ٧km to the north of Haditha town. The geology of the dam site is rather complex. It is characterized by Miocene dolomites and limestone.

Limestone rocks are of medium strength which are fissured, cavernous and karsted. Most of the caverns are filled with dense carbonaceous clays.

Dolomites are predominated rocks in the area and formed by the dolomization of limestone and preserve the various texture of the initial rock [Salem, (١٩٨٥)]. The upward succession of the litho logical rock varieties through the geological section is as follows [Hydroproject, (١٩٧٨)]:

In the bottom part of the geological section the rocks of the "Baba" formation occur (١٠٠ m) thick in total and they are divided into two horizons (bench ١ and benches ٢-٤) and composed primarily of the "Ana" formation, (١٧-٢٤ m) in thickness. The rocks are hard (bench ٦) and jointly to a variable degree, cavernous and karstified with bonnies and lenses of marls, clays and dreccia bound with weak argillaceous cement. Total clay content (up to ٢٠٪) grows as approaching the stratum foot (bench ٥) and in this case lenses and bonnies of clay become (٣-٥ m) in size. In the roof of the "Ana" formation breccia and conglomerate-breccia (bench ٧), (٠.٢-٥ m), rarely up to (١٠ m) in thickness and composed of fragment of hard aphanitic limestones bound with weak argillaceous or marly cement.

The "Euphrates" formation deposits (٨٠ m) thick in total, over the deposits of the "Ana" formation and they are subdivided into three representative horizons. The lower horizon, (١٩-٢٧ m) thick is represented by (bench ٨-١١) composed of the limestones having different hardness and alternating with dolomite .interlayers

The deposits of the middle horizon, (bench ١٢-١٣),
of the "Euphrates" formation (١٨-٢٢ m) thick, are represented by detritus dolomites which are intensively leached the rocks of the upper horizon of the "Euphrates" formation (١٨-٣٣ m) thick, feature lithological variability and intensive crumpling, (bench ١٤-١٥) are singled out, figure (٤-٣) shows longitudinal section along axis of the dam and the geological .condition of the benches

The characteristics of rock permeability of the mean stratigraphic horizons from the bottom to the top are .(given in table (٤-٢

Table (٤-٢): Coefficient of permeability of the geological [(sections at dam site [Hydroprojekt, (١٩٧٨

.No	Rock Formations	(Permeability Coefficient (m/d
.١	"Baba" Formation	
•	The lowers part of upper Baba	
•	The upper part of upper Baba	
		١-٠.٥ ٥
.٢	"Ana" Formation	٣٢.٥-٠.٠٠٨

٣. "Euphrates" Formation

- Lower horizon
- Middle horizon
- Upper horizon

٢
٠.١-٠.٠١
٥-٠.٥

٤. "Lower Fars" Formation

- Lower horizon
- Middle horizon
- Upper horizon

١
٥-١
٣٨.٦-٠.٢

٥. Alluvial deposits ٥٠-٠.٥

٤.٣ Engineering Properties of Materials Used in the Dam

٤.٣.١ Dolomite

Dolomite, as semirock soils, are available in large quantities in central and western part of Iraq. Very often they are deposited close to the ground surface and considerably higher than the water table [Salih, (٢٠٠٠)].

The "Euphrates" formation is the potential source for dolomite fill that has been selected for the core. It consists of detrious powdery dolomite with interlayers of clay and marl. Limestone exists at the top and bottom of this formation which is cavernous and karstified.

Table (٣-٤) summarizes the physical and mechanical properties of the dolomite used [Hydroprojekt, (١٩٨٨)].

Table (٤-٣): Physical and mechanical properties of dolomite

Value	Item	No.
%١٢.٥-٣.٥	Natural moisture content	.١
ton/m٣ ٢.١١-١.٥٥	Natural bulk density	.٢
%٠.٣	Swelling	.٣
None	Shrinkage	.٤
%١٨-١٥	Optimum moisture content (W)	.٥
ton/m٣ ١.٨٥-١.٧٦	Max. dry density (γd)	.٦
o ٣٠	Angle of internal friction φ	.٧
kg/cm٢ ٠.٨-٠.١٣	Cohesion (C)	.٨
kg/cm٢ ١.٠٠	Modulas of deformation	.٩
cm/s ٤-١٠*(٠.٦١-١.٤٤)	Permeability coefficient	.١٠

.١
.٢
.٣
Design and control γd .٤
Parameters: w
C
ton/m٣ ١.٨ ≤ φ
%٢± %١٨
٠
٣٠

The seepage water passing from the dam embankment and foundation is drained into the drainage system provided in the dam embankment and foundation. The seepage water passing from the dam embankment is drained into a sandy-gravel interlayer placed on the .downstream side of the central dolomite zone

The drainage water is collected and diverted through a drainage ditch (an open drain running along .(the down stream slope

Asphaltic Concrete Diaphragm ٤.٣.٢

In the center of the dolomite core, an asphaltic concrete diaphragm was provided to preclude the seepage through the core. The diaphragm wall has a variable cross section, it was located (١٠ m) upstream from the center line of the dam. The top of the diaphragm is brought to elevation of (١٥٠.٨ m) i.e., above the maximum flood level. From the base to elevation (١٢٥ m) the diaphragm is (٠.٨ m) thick while from elevation (١٢٥ m) up to (١٥٠.٨ m) its thickness is (٠.٥ m).

The asphaltic concrete mixture used for foundation sealing was the same as that for center antiseepage. It had the properties given in the table (٤-٤) below [Hydropojekt, (١٩٧٨)].

Table (٤-٤): Properties of asphaltic concrete mixture

No.	Item	Value
١.	Residual porosity	<٣٠%
٢.	Compressive strength at ٢٠o C	< ١٠ kgf/cm٢
٣.	Consistency at ١٥٠o C	١٠-٢٥٥
٤.	Bitumen excess over dry material	< ١%
٥.	Segregation while heating to ١٥٠o C	١.٠١-١.٠٦
٦.	Water saturation while heating at ٨٠ o C for ٧٥ hr	> ٢.٥%

Mixture of the asphaltic concrete has the following proportioning by weight:

Gravel (٥-٣٠) mm in size	٤٩٪
Sand up to ٥ mm in size	٢٦٪
Bitumen of (٦٠/٧٠) Gaira or Dora brand with mineral filler	٨.٦٪
	١٠٠%

٤.٣.٣ Sand and Gravel Mixture (SGM)

Al-Qadisiya project is essentially an earth dam with hydraulic fill shell on the left side and dry filled sand .and gravel mixture on the right side

Shell of the dam is from sand and gravel mixture (SGM) hydraulically filled into the dam body or into .stockpiles

The (SGM) of the stocks piles is transported to the dam body too and filled in the dry. Right side shell of the dam is filled hydraulically up to elevation (١٤٠ m), while the left side shell is filled in layers and normal .compaction procedures are followed

Table (٤-٥) summarizes the physical and mechanical .properties of the (SGM) used

Table (٤-٥): Physical and mechanical properties of ((SGM

No.	Item	Hydraulic Fill	Fill in Dry
.١	Average bulk density (ton/m٣)	١.٩	٢.٠
.٢	Particles > ١ mm	%٨٠-٥٠	%٧٠-٣٠
.٣	Moisture content	%٩-٦	%٥-٢
.٤	Permeability coefficient (cm/s)	(٣-١٠*(٧-٤	٣-١٠*(٥-٤)
.٥	φ Average (٣٣-٤١) (٣١-٤٨(o) ٣٩) (o ٤٥)		

In the channel sections, the rock fines were used to build the upstream prism of the shell. Table (٤-٦) .concludes the engineering properties of the rock fines

Three layers of rock muck protect the upstream shell of the dam, the downstream is protected by one .layer of rock muck

Table (٤-٦): Engineering properties of rock fines

No.	Item	Value
.١	Clay content	%٥ ≥
.٢	Unit weight (γd)	ton/m٣ ٢.١٥≥
.٣	Coefficient of permeability (K)	cm/s ٣-١٠*(١٠-١(
.٤	Angle of internal friction (φ)	o ٣٥
.٥	Cohesion (C)	٠

Grout Curtain ٤.٣.٤

The main purpose of the grout curtain is to reduce the seepage losses from the reservoir, seal the concentrated seepage paths and provide the seepage-erosion resistance on the contact of the detritus dolomites of the dam central portion and foundation .rocks

The maximum depth of the grout curtain is in the river channel section and under the power house where the grout curtain was extended to the lower horizon of the "Baba" formation with coefficient of permeability of about (١١.٥٧*١٠-٣ cm/s). The deep grout curtain on the flood plain sections, ٢٠+٠٠-٣٥+٥٠ and ٤٠+٠٠-٥٩+٠٠, then it was extended into the "Baba" formation upper horizon with the permeability coefficient of (١١.٥٧*١٠-٤ cm/s) .[(Salih, (٢٠٠٠

The deep grout curtain is of two constructed rows, the distance between the rows is (١.٥ m). The in-line bore holes are spaced at (٣ m) centers and offset by (١.٥ m) with respect to bore holes of the other row.

Chapter Five
Verification and Application

General ٥.١

The computation procedure for seepage water through earth dam is presented in the preceding chapter. It is thought that the verification of these procedures is very important, thus, it should be done before applying the present approaches to any practical problem. The main aims of the verification are; to check the reliability of the theoretical aspects utilized in the derivation of the present approaches, and then examine the proper working of the computer program that have been prepared to execute the computation in .the approach

The verification is performed by applying the computation procedure to experimental results .measured in laboratory model dams

Also, this chapter describes the application of (Seep٢d) program, a finite element model shown in chapter three to analyze seepage problem through Al-Qadisiya Dam and its foundation and analyze (١٢٥) design cross sections that are suggested to obtained the .optimum design of control devices through earth dam

(Accuracy of Mathematical Model (F.E.M ٥.٢

The validity of the program was evaluated by using experimental results measured in laboratory .model dams

Data from a laboratory model dam (Kellogg, ١٩٤١), [Ching and Chang, (١٩٨٧)] was used for the evaluation of the program. The model dam is made of sand with a permeability of (٠.١ cm/s) as in Fig. (٥-١). Seven pore pressures cells were embedded in the model at various locations so that the measured results would show the spatial variation of pore pressure. The height of the model is (٣٨ cm) and the width is (٦٨ cm). The reservoir .(was filled to a height of (٣٨ cm

Seep٢d program was applied for this laboratory model to determine the position of the phreatic surface and total head. Fig. (٥-٢) shows the finite element mesh, Fig. (٥-٣) shows the phreatic surface position and total head contour lines. Table (٥-١) shows the percentage error between the calculated value of head and :observed head at cell position that was computed from

(١-٥) ...

:Where

,Er. : Percentage error in calculated head

,Hc : Calculated head

.Ho : Observed head

The results indicate good agreement between the calculated total head and the observed total head at cell position as shown in table (٥-١), also these results indicate acceptable agreement between the calculated .and observed pressure head

Table (٥-١): The percentage error for total head and pressure head between the calculated and observed .data at Kellogg Dam

% Error in pressure K=٠.١ (cm/s)	Error in calculate total head %	Calculated total head (m)	Observed total head (m)	Cell position y (cm)	Cell position x (cm)	Cell No.
٠.٤٨+	٠.٤٣+	٣٧.٥	٣٧.٣٤	٣.٩٣	٧.٨٦	١
٩.٧٧-	٥.٥١-	٣١.٢	٣٣.٠٢	١٤.٤١	٣١.٢٦	٢
٧.٠٦-	٥.٩٣-	٢٩.٨	٣١.٦٨	٥.٠٦	٣١.٣٢	٣
١٧.٤٢-	٧.٤٥-	٣٠.٣	٣٢.٧٤	١٨.٧٤	٣٥.٠٣	٤
٨.٨٩-	٦.٧٢-	١٩.٧	٢١.١٢	٥.١٦	٤٧.٧٥	٥
٠.٦٧+	٠.١٣+	٧.٤	٧.٣٩	٥.٩٠	٦١.٨١	٦
١١.٥٢-	٥.٣١-	٢٣	٢٤.٢٩	١٣.١٠	٤٤.٥٥	٧

Figure (٥-١): Laboratory dam (Kellogg Dam) cross section

٥.٣ Application of the Mathematical Model to Al-Qadisiya Dam

٥.٣.١ Seepage Through and Under Al-Qadisiya Dam

Seepage through the dam embankment is controlled by the dolomite core and the asphaltic-concrete diaphragm. The core is built of mealy dolomite with low permeability of (٠.١-١) m/day. It serves the purpose of the main water tight feature of .the dam embankment

Seepage studies of the dam embankment and foundation were conducted at the typical cross section of the left bank dam which closed with river channel because of its critical cross section. The typical cross section of the dam at station ٤٢ Km was used to investigate the basic seepage parameters (head loss across the curtain, residual head downstream of curtain, the seepage quantity, pore pressure under asphaltic-concrete diaphragm and locating the phreatic surface). Fig. (٤-١) shows the location of the .(section (plan view

Seven material types were used in the analysis of this station; the properties of each material type are shown in table (٥-٢). Typical cross section of the dam at .(station ٤٢ is shown Fig. (٥-٤

Table (٥-٢): Coefficient of permeability of each material [(in Al-Qadisiya Dam at station ٤٢ [Hydroprojekt, (١٩٧٨

Material Type		Kx (m/s)	Ky (m/s)
Asphaltic concrete diaphragm	K١	١٠-١٠*٠.١	١٠-١٠*٠.١
Dolomite core	K٢	٥-١٠*٠.١	٥-١٠*٠.١
Sandy gravel shell	K٣	٣-١٠*٠.٢	٣-١٠*٠.٢
Foundation materials	K٤	٣-١٠*٠.٥	٣-١٠*٠.٥
	K٥	٣-١٠*٠.١	٣-١٠*٠.١
	K٦	٤-١٠*٠.٣	٤-١٠*٠.٣
Grout curtain	K٧	٥-١٠*٠.٢	٥-١٠*٠.٢

Model Grid ٥.٣.٢

Finite element idealization of the vertical cross section of Al-Qadisiya Dam was used, in this idealization linear elements (three nodal triangular elements) were used with (٩٥٢) elements and (٥٣١) nodal points. This mesh used in the program for representing problem domain was carefully selected so several trails have been made. Fig. (٥-٥) indicates the finite element .mesh for this section at station ٤٢

The Results ٥.٣.٣

The program was applied to the Al- Qadisiya Dam with U/S water level of (١٤٧ m.a.s.l) and D/S water level of (١٠٩.١٥ m.a.s.l). The mesh was modified many times in order to obtained acceptable results and minimize the time required for the analysis process. Figure (٥-٦) represents the phreatic surface position, it was plotted by intersecting the elevation by the contour that has the same value of total head after (٢٢) iteration. This is because of the phreatic surface has a pressure head equals to zero by definition. Figure (٥-٧) represents the pressure head contour lines. Figure (٥-٨) represents the total head contour lines. This figure indicates that the total head in the u/s shell equals to reservoir level. It can be seen from this figure that most of seepage head loss occurs in the control devices and the foundation. The seepage flow at station ٤٢ is (١.٤٨٦٦ l/s/m) and the

pore water pressure down the asphaltic-concrete diaphragm is (٣٤.١٣٥ mH٢O).

These results are somewhat safe and acceptable from the General Establishment of the Dams and Reservoirs in Iraq point view [G.E.D.R, (٢٠٠٥)]. In addition, it should be noted that Subuh [Subuh, (٢٠٠٢)] found that for heads of (١٣٣.٥٥ and ١٣٨.٠٩ m.a.s.l.) the seepage flow equals to ٠.٩١ l/s/m and ١.٠٤١ l/s/m respectively.

٥.٤ Effect of Different Seepage Control Devices on Pore Pressure and Seepage Flow

In this section the effect of dimensions of dolomite core, grout curtain and concrete cut-off on pore pressure and seepage flow are analyzed. The effect of using different combinations of these devices on pore pressure and seepage flow are studied by (١٢٥) design cross sections as shown in table (٥-٣).

The Core ٥.٤.١

The top width of dolomite core (x٣) is varied from ١ to ٢٤ m in steps of ٠.٧٥ m to investigate its effect on pore pressure and seepage flow as shown in Fig. (٥-٩). This figure is chosen from five cross sections as example to show the typical cross section. Then, the mathematical model is applied for these design cross sections and the results are shown in table (٥-٣). Figures (٥-١٠), (٥-١١) and (٥-١٢) represent the phreatic surface position, pressure head and total head contour .lines respectively as example for this case

The Core and Grout Curtain ٥.٤.٢

The width of grout curtain (x٢) is varied from ٠ to ٦ m in steps of ١.٥ m with different core widths to investigate the effects of using. Figure (٥-١٣) is chosen from (٢٥) cross sections as example to show the typical cross section. Then, the mathematical model is applied for these design cross sections and the results are shown in table (٥-٣). Figures (٥-١٤), (٥-١٥) and (٥-١٦)

represent the phreatic surface position, pressure head and total head contour lines respectively as example .for this case

The Core and Cut-off ٥.٤.٣

The depth of cut-off (x١) is varied from ٠ to ١٢ m in steps of ٣ m with different core widths to investigate the effects of using. Figure(٥-١٧) is chosen from (٢٥) cross sections as example to show the typical cross section. Then, the mathematical model is applied for these design cross sections and the results are shown in table (٥-٣). Figures (٥-١٨), (٥-١٩) and (٥-٢٠) represent the phreatic surface position, pressure head and total head .contour lines respectively as example for this case

The Core, Grout Curtain and Cut-off ٥.٤.٤

The effect of different combinations of the above dimensions of the seepage control devices (core, grout curtain and cut-off) is investigated. Figure (٥-٢١) is chosen from (٧٥) design cross sections as example to show the typical cross section. Then, the mathematical model is applied for these design cross sections and the results are shown in table (٥-٣). Figures (٥-٢٢), (٥-٢٣) and (٥-٢٤) represent the phreatic surface position, pressure head and total head contour lines respectively as .example for this case

Table (٥-٣): The Results of Mathematical Model (F.E.M) for Seepage flow and Pore Pressure

Number of iteration   Cross section No.

X١

(m)

X٢

(m)

X٣

Pore Pressure   Seepage Flow (l/s/m)   m))

m H٢O

٣٥.٩٩١٩٩	٢.٢٦٦٤	١	٠	٠	١١	١
٣٥.٩٤٥٩٢	٢.١٢٠٢٦.٧٥		٠	٠	١٠	٢
٣٥.٧١٩	١.٩٩١٣	١٢.٥	٠	٠	١١	٣
٣٥.٣٩٥٠٥	١.٩٤٣٢	١٨.٢٥	٠	٠	١١	٤
٣٥.٣٧٣٤٤	١.٩٤٤٧	٢٤	٠	٠	٨	٥
٣٤.٨٥١٧٨	٢.١١٦٩	١	١.٥	٠	١١	٦
٣٤.٥٦٩٨٩	١.٧٧٦٢٦.٧٥		١.٥	٠	١٢	٧
٣٤.١٦٧٥٤	١.٧٠٢٨	١٢.٥	١.٥	٠	١٥	٨
٣٤.٠٨٥٢٥	١.٥٢٥٦	١٨.٢٥	١.٥	٠	١٥	٩
٣٣.٩١٦٧٦	١.٥٢٢٩	٢٤	١.٥	٠	١١	١٠
٣٤.٧٧٧١	١.٧١٢٦	١	٣	٠	١٣	١١
٣٤.٢٧٩٩٥	١.٦٦٠١٦.٧٥		٣	٠	٢٢	١٢
٣٣.٩٥٩١٤	١.٤٨٣	١٢.٥	٣	٠	١٥	١٣
٣٣.٧٣٠٦٨	١.٤٣٩٥	١٨.٢٥	٣	٠	١١	١٤
٣٣.٤٧٠٣٧٤	١.٣٦١٥	٢٤	٣	٠	١٠	١٥
٣٤.٧٥٠٢	١.٧١٥٤	١	٤.٥	٠	١٢	١٦
٣٤.٠٦٨٦٣	١.٦٥٩٢٦.٧٥		٤.٥	٠	١١	١٧
٣٣.٩٢	١.٤١٧٢	١٢.٥	٤.٥	٠	١١	١٨
٣٣.٣٨٥١٥	١.٤٠٧٨	١٨.٢٥	٤.٥	٠	١١	١٩
٣٣.١٨٣٥٨٥	١.٢٤٧٤	٢٤	٤.٥	٠	١٢	٢٠
٣٤.٢٧٠٣١	١.٧٠٥٣	١	٦	٠	١٦	٢١
٣٣.٨٠٨٩٦	١.٥٦٩٦٦.٧٥		٦	٠	١١	٢٢
٣٣.٣٣٧١٦	١.٥٤٧٩	١٢.٥	٦	٠	٢١	٢٣

٣٣.١١٣٦٩ ١.٤٢٧٤ ١٨.٢٥ ٦ ٠ ١٠ ٢٤

٣٢.٩٤٠٦٧٥ ١.٠٨٢٥ ٢٤ ٦ ٠ ٢٢ ٢٥

٣٥.٨٢٢٤٦ ٢.١٨٨٩ ١ ٠ ٣ ١٩ ٢٦

٣٥.٦٣٨٤٣ ٢.١١١٨٦.٧٥ ٠ ٣ ١٣ ٢٧

Number of iteration Cross section No.

X١

(m)

X٢

(m)

X٣

Pore Pressure Seepage Flow (l/s/m) m))

m H٢O

٣٥.٧٢٨١٦ ٢.٠٠٧ ١٢.٥ ٠ ٣ ١٢ ٢٨

٣٥.٣٩٢٥ ١.٩٣٧٥ ١٨.٢٥ ٠ ٣ ١٢ ٢٩

٣٥.٠٦٥٩١٥ ١.٩٢٤٣ ٢٤ ٠ ٣ ١٦ ٣٠

٣٤.٨٥٢١٣ ٢.١١٦٢ ١ ١.٥ ٣ ١١ ٣١

٣٤.٨٠٤٨٦ ١.٩٠٦٢٦.٧٥ ١.٥ ٣ ١٦ ٣٢

٣٤.٥٥٨٤٦ ١.٧٥٧٤ ١٢.٥ ١.٥ ٣ ١٠ ٣٣

٣٤.٠٩٤٦٧ ١.٥٢٦٦ ١٨.٢٥ ١.٥ ٣ ١٤ ٣٤

٣٣.٩١١٣٠٥ ١.٦٦٠٦ ٢٤ ١.٥ ٣ ١٣ ٣٥

٣٤.٧٨٤٨٤ ١.٨٧٠٦ ١ ٣ ٣ ١٣ ٣٦

٣٤.١١٦١٥ ١.٩٨٩٣٦.٧٥ ٣ ٣ ٢١ ٣٧

٣٤.٢٥٦٧١ ١.٦٩٦٤ ١٢.٥ ٣ ٣ ٩ ٣٨

٣٣.٩٨٢٦٥ ١.٥٤١ ١٨.٢٥ ٣ ٣ ٩ ٣٩

٣٣.٤٦٧٣٥٥ ١.٣٦٤٧ ٢٤ ٣ ٣ ١٠ ٤٠

٣٤.٥٦٧٢٩٥ ١.٧٦٢١ ١ ٤.٥ ٣ ٩ ٤١

٣٤.٣٠٩٢ ١.٦٩٨٥٦.٧٥ ٤.٥ ٣ ١١ ٤٢

٣٤.١٠٥٦٤ ١.٤٦٤٥ ١٢.٥ ٤.٥ ٣ ١٠ ٤٣

٣٣.٢٨٦٤٨ ١.٣٤٣٨ ١٨.٢٥ ٤.٥ ٣ ٩ ٤٤

٣٣.١٨٠٧٢٥ ١.٢٤٤١ ٢٤ ٤.٥ ٣ ١٤ ٤٥

٣٤.٦٣٤٨٤ ١.٦٩٤٧ ١ ٦ ٣ ١٢ ٤٦

٣٣.٥٧٠٢٦ ١.٦٥٣٢٦.٧٥ ٦ ٣ ١٩ ٤٧

٣٣.٥٩٣١ ١.٥٨١٤ ١٢.٥ ٦ ٣ ١٢ ٤٨

٣٣.٣٧٣٩٦ ١.٢٩٥١ ١٨.٢٥ ٦ ٣ ٩ ٤٩

٣٢.٩٣٧٢٥٥ ١.٠٨٦٩ ٢٤ ٦ ٣ ٢٢ ٥٠

٣٦.٢٥٢١٨ ٢.٤٨٧٩ ١ ٠ ٦ ٢٢ ٥١

٣٥.٧٥١٣٩ ٢.٣٢٧٨٦.٧٥ ٠ ٦ ٢٢ ٥٢

٣٥.٧١٢٥١ ٢.١٢٦٢ ١٢.٥ ٠ ٦ ١١ ٥٣

٣٥.٤٥٩٩٣ ٢.١١٢٢ ١٨.٢٥ ٠ ٦ ٧ ٥٤

٣٥.٣٥٩٦ ٢.٠٩٨٢ ٢٤ ٠ ٦ ١٠ ٥٥

٣٤.٨٥٦٨٤ ٢.١١٢ ١ ١.٥ ٦ ١١ ٥٦

Number of iteration Cross section No.

X١

(m)

X٢

(m)

X٣

Pore Pressure Seepage Flow (l/s/m) m))

m H٢O

٣٤.٥٦٧٧٣ ١.٧٧٦٦٦.٧٥ ١.٥ ٦ ١٢ ٥٧
٣٤.٥٦٤٣٨ ١.٦٥١ ١٢.٥ ١.٥ ٦ ١٠ ٥٨
٣٤.٠٧٨٤ ١.٥٢٣٦ ١٨.٢٥ ١.٥ ٦ ١٥ ٥٩
٣٣.٩٢٠٧ ١.٥١٧ ٢٤ ١.٥ ٦ ١٢ ٦٠
٣٤.٣٣٧٩٧ ١.٥٤١ ١ ٣ ٦ ٢٢ ٦١
٣٤.٠٥٧٦ ١.٨١٢٦٦.٧٥ ٣ ٦ ١٣ ٦٢
٣٣.٩٥٢١٣ ١.٤٨٥٩ ١٢.٥ ٣ ٦ ١٢ ٦٣
٣٣.٧٣٥٥٨ ١.٤٦٣٢ ١٨.٢٥ ٣ ٦ ١٠ ٦٤
٣٣.٤٦٤٧٧ ١.٣٥٦٢ ٢٤ ٣ ٦ ١١ ٦٥
٣٤.٤٥٣٨٩ ١.٤٣٧١ ١ ٤.٥ ٦ ٢٢ ٦٦
٣٣.٩٧٨ ١.٦٨١٧٦.٧٥ ٤.٥ ٦ ١٤ ٦٧
٣٣.٦٩٣٦ ١.٣٩٣٨ ١٢.٥ ٤.٥ ٦ ١٢ ٦٨
٣٣.١٦٨٩ ١.٣٦٥٥ ١٨.٢٥ ٤.٥ ٦ ٩ ٦٩
٣٣.١٨٤٤٥٥ ١.٢٤٣٣ ٢٤ ٤.٥ ٦ ١٣ ٧٠
٣٤.٢٧٥٤١ ٢.٣٠٢٧ ١ ٦ ٦ ١٠ ٧١
٣٣.٨٢١٦٩ ١.٧٥٦٦٦.٧٥ ٦ ٦ ١٣ ٧٢
٣٣.٣٧٧٠٨ ١.٤٢٧٥ ١٢.٥ ٦ ٦ ٩ ٧٣
٣٣.١١٣٥٩ ١.٥٣٦٨ ١٨.٢٥ ٦ ٦ ١٠ ٧٤
٣٢.٩٣٤٠١٥ ١.٠٨٥٤ ٢٤ ٦ ٦ ٢٢ ٧٥
٣٦.٣٨٥٢ ٢.٤٢٠٣ ١ ٠ ٩ ١١ ٧٦
٣٥.٩٥٩٣٥ ٢.٢٤٠٤٦.٧٥ ٠ ٩ ١١ ٧٧
٣٥.٨٣٨٨٢ ٢.١٦٦٥ ١٢.٥ ٠ ٩ ١١ ٧٨
٣٥.٥٩١٧٨ ٢.١٣٩٩ ١٨.٢٥ ٠ ٩ ٩ ٧٩
٣٥.٤٣٩٢٥ ١.٩٣٧٢ ٢٤ ٠ ٩ ٨ ٨٠
٣٤.٨٥٠٠٥ ٢.١١٥ ١ ١.٥ ٩ ١١ ٨١
٣٤.٥٦١١٧ ١.٧٨٠٤٦.٧٥ ١.٥ ٩ ١٢ ٨٢
٣٤.٥٦١٢٨ ١.٦٦٧٥ ١٢.٥ ١.٥ ٩ ٩ ٨٣
٣٤.٠٧٨٧٢ ١.٥٢٠٦ ١٨.٢٥ ١.٥ ٩ ١٥ ٨٤
٣٣.٩٢٢٢٦٥ ١.٥٢٦٢ ٢٤ ١.٥ ٩ ١٢ ٨٥

Number of iteration Cross section No.

X١

(m)

X٢

(m)

X٣

Pore Pressure Seepage Flow (l/s/m) m))

m H٢O

٣٤.٢٦٥٦٨	١.٩٩١٩	١	٣	٩	١٩	٨٦
٣٤.٢٨٨٧٧	١.٧٥٣٥٦.٧٥	٣	٩	١٢	٨٧	
٣٤.٢٦٩٧١	١.٧٠١٢	١٢.٥	٣	٩	١٠	٨٨
٣٣.٧٣٨٨٣	١.٤٦١٧	١٨.٢٥	٣	٩	١٠	٨٩
٣٣.٤٦٥٩٦	١.٣٥٨١	٢٤	٣	٩	١١	٩٠
٣٤.٤٤٧٠١	٢.٠٩٩٣	١	٤.٥	٩	٢٢	٩١
٣٤.٣١٢٤٥	١.٧٠٧٨٦.٧٥	٤.٥	٩	١٢	٩٢	
٣٣.٨٦٢٥٦	١.٤١٣	١٢.٥	٤.٥	٩	١١	٩٣
٣٣.٣٨٦٠٢	١.٤٠٥٧	١٨.٢٥	٤.٥	٩	١١	٩٤
٣٢.٩٩١٩٣	١.٢٤٧٣	٢٤	٤.٥	٩	١٧	٩٥
٣٤.٢٧٠٦٣	٢.١٨٦٤	١	٦	٩	٢١	٩٦
٣٣.٨٢٦٩٧	١.٨٢٢٦.٧٥	٦	٩	١١	٩٧	
٣٣.٦٣٢٤٥	١.٤٤٧٣	١٢.٥	٦	٩	١٠	٩٨
٣٣.٣٧٢٥٩	١.٢٦٧٥	١٨.٢٥	٦	٩	١١	٩٩
٣٢.٩٤٠٤٥٥	١.٠٨٨٥	٢٤	٦	٩	٢٢	١٠٠
٣٦.٣٢٤٥٥	٢.٣٥٤٣	١	٠	١٢	٢٢	١٠١
٣٥.٩٧٤٩	٢.١٠٨١٦.٧٥	٠	١٢	١١	١٠٢	
٣٥.٧٩٤٠٢	١.٩٩٩٧	١٢.٥	٠	١٢	١١	١٠٣
٣٥.٥٧٢٧٨	١.٩٩٨٤	١٨.٢٥	٠	١٢	٩	١٠٤
٣٥.٤٣٥٠٧	١.٩٣٧١	٢٤	٠	١٢	٨	١٠٥
٣٤.٨٦٠٥	٢.١٤٤٥	١	١.٥	١٢	١٠	١٠٦
٣٤.٥٧٤٧٥	١.٨١٤٧٦.٧٥	١.٥	١٢	١٢	١٠٧	
٣٤.٥٦٦٥٧	١.٦٥٦٣	١٢.٥	١.٥	١٢	١٠	١٠٨
٣٤.٠٥٧٣٨	١.٧٤٩٣	١٨.٢٥	١.٥	١٢	١٤	١٠٩
٣٣.٩٢٣٦٨٥	١.٥٢٧٧	٢٤	١.٥	١٢	١٢	١١٠
٣٤.٣٣٩٤٨	١.٩٩١٦	١	٣	١٢	١٩	١١١
٣٤.١٠٠٣٤	١.٧٤٨١٦.٧٥	٣	١٢	١٤	١١٢	
٣٣.٩٣٧٦١	١.٥١٩	١٢.٥	٣	١٢	١٦	١١٣
٣٣.٧٢٩٩٥	١.٤٣٨١	١٨.٢٥	٣	١٢	١١	١١٤

Number of iteration Cross section No.

X١

(m)

X٢

(m)

X٣

Pore Pressure Seepage Flow (l/s/m) m))

m H٢O

٣٣.٤٦٠٥٨٥	١.٣٥٣٥	٢٤	٣	١٢	١١	١١٥
٣٤.٥٩٣٢	١.٧٢٠١	١	٤.٥	١٢	١٢	١١٦
٣٣.٩٩٧٣	١.٧٠٩٣٦.٧٥	٤.٥	١٢	١٢	١١٧	
٣٣.٧٠٤٥٩	١.٤٠١١	١٢.٥	٤.٥	١٢	١١	١١٨
٣٣.١٦٧٦٢	١.٣٤٩٥	١٨.٢٥	٤.٥	١٢	١٠	١١٩
٣٣.١٧٩٠٤	١.٢٤٣٣	٢٤	٤.٥	١٢	١٤	١٢٠

٣٤.٢٧٩٥١	٢.٣٠٥٦	١	٦	١٢	١٠	١٢١
٣٣.٨١٦٨	١.٧٨٨٨٦.٧٥		٦	١٢	١١	١٢٢
٣٣.٩١٢٩	١.٤٦١	١٢.٥	٦	١٢	١٦	١٢٣
٣٣.٠٣٤٤١	١.٢٨٥٢	١٨.٢٥	٦	١٢	٩	١٢٤
٣٢.٩٤٠٢٤	١.٢١٥٧	٢٤	٦	١٢	٢١	١٢٥

Chapter Six

Formulation of the Optimization Problem and Analysis of the Results

General :٦.١

The purpose of optimization is to find the best possible solution among the many potential solutions satisfying the chosen criteria. Designers often base their designs on the minimum cost as an objective, taking into account mainly the costs of foundation, .safety and serviceability

A general mathematical model of the optimization :problem can be represented in the following form

,A certain function (Z), called the objective function

Z = f {xi}   i=١, ٢, …, n

(…(٦-١

which is usually the expected benefit (or the involved cost), involves (n) design variables {x}. Such function is to be maximized (or minimized) subject to certain

equality or inequality constraints in their general :forms

(i=١, ٢, …, I …(٦-٢

(j=١, ٢, …, J …(٦-٣

The constrain reflects the design and functional requirements. The vector {x} of the design variables will have optimum values when the objective function .reaches its optimum value

Methods of Optimization :٦.٢

The available methods of optimization can be subdivided into three categories as briefly discussed .below

(The Linear Programming (LP :٦.٢.١

The main characteristic of a linear programming (LP) problem is that the objective function and all the constraints form linear relationships with the design .variables

Several algorithms are available to solve LP-problems. However, the simplex method, developed by C.B. Dantzig in ١٩٤٦, is the most widely used [Dantzig, (١٩٦٣)]. More detailed definitions and explanation of this method will be given later in Sec. (٦.٤.٣a). Some other methods are available such as graphical methods, revised simplex method and transportation method .[([Phillips et al., (١٩٧٦

(The Non-Linear Programming Methods (NLP :٦.٢.٢

If the objective function or any of the constraints is non-linear the optimization problem will term a non-linear problem. This formulation is more important than (LP) since most of real-world design problems are .in fact non-linear

There are a large number of algorithms and .techniques for solving NLP- problems

The Analytical Approach :٦.٢.٢.١

In this approach, the problem is represented by a number of mathematical relationships from which certain equations can be developed which aid in the search for an optimum. The methods of this approach usually require the use of differential calculus and the optimum solution is theoretically found exactly [Gallagher and Zienkiewicz, (١٩٧٣)]. The most familiar :methods underlying this approach are

a. Differential Calculus

This method generally uses the laws of differential .calculus to solve simple unconstrained NLP-problems

b. Lagrange Multiplier

This method is used to solve constrained non-linear optimization. More detailed definitions and explanation of this method will be given later in Sec. .(٦.٤.٣b)

The Numerical Approach :٦.٢.٢.٢

In this approach, a near optimum solution is automatically generated in an iterative manner. An initial guess is used as a starting point for searching the better solutions. The search continues until no further improvement in the objective function is possible or until a certain convergence criterion is satisfied, which indicates that the optimum solution has been achieved .within the desired accuracy

The two distinguished methods in these respect are the direct-search method and the gradient – search .method

a. Direct Search

Here, the search proceeds with the evaluation of the objective function only in an iterative manner until a local or an approximate optimum solution is reached. The step sizes and the direction of moves at each iteration represent the main features of this approach. Many methods are proposed as standard algorithms such as the pattern search of Hooke and Jeeves, the complex method, the Fletcher and Powell method, and .[(the Rosenbrock method [Bunday, (١٩٨٤

b. Gradient Search

The basic idea, here, is to evaluate the gradient of the objective function at a point and utilize it to improve and accelerate the search. The acceleration is gained by finding the direction of the steepest descent, following this direction until no further improvement is possible, then, the direction is changed again. The search continues until the gradient becomes zero .indicating that the optimum solution is reached

The most widely used method following this approach is the Sequential Unconstraint Minimization Technique, Rosen method and Fletcher and Powell method. These methods require smaller number of .iterations than the direct search methods

Dynamic Programming :٦.٢.٣

Dynamic programming is used to solve special types of optimization problems, which involve multistage decision processes. The optimization of each stage will affect the next stage and the final optimum decision is ensured to be the sum of all the optimization .decision of all stages

The method is very powerful and used to solve continuous and discrete non-linear programming .[(problems [Slaby, (١٩٨٧

Design Variables ٦.٣

The preliminary design of an earth dam is done on the basis of past experience and on the basis of the .performance of the dams built in the past

: [(The design variables are taken as follows [see Fig.(٦-١

.Depth of the upstream cut-off ($x_{١}$)=٠ - ١٢; step ٣ m-١

Figure (٦-١): Schematic Representation of the design Variables

.Width of grout curtain ($x_{٢}$)=٠ - ٦; step ١.٥ m-٢

.Width of core ($x_{٣}$)=١ - ٢٤; step ٥.٧٥ m-٣

The Optimization Model ٦.٤

The Objective Functions ٦.٤.١

There are three cost objective functions of the :present research

The cost objective function ($Z_{١}$) deals with two -١ control devices, concrete cut-off which is (١m) width and dolomite core. Such function is formulated as :follows

$$Z_{١}=c_{١}x_{١}+c_{٣}x_{٣}$$

(.... (٦- ٤

:Where

($c_{١}$=cost of one cubic meter of cut-off, (٢٥٠ $/m٣

;(x١=depth of upstream cut-off, (m
(c٣=cost of one cubic meter of dolomite core, (٢٠ $/m ٣
.(x٣=width of core, (m
The cost objective function (Z٢) deal with another two -٢ control devices, grout curtain and dolomite core, that :is
Z٢=c٢x٢+c٣x٣
(….. (٦ –٥
:Where
(c٢=cost of one cubic meter of grout curtain, (٤٠٠ $ /m٣
.(x٢=width of grout curtain, (m
The cost objective function (Z٣) deal with all control -٣ :devices that used in this research together, that is
Z٣=c١x١+c٢x٢+c٣x٣
(….(٦ - ٦
Constraints ٦.٤.٢
The objective function (Z١) is minimum and subject to :the following constraints
The relationship between core width and cut-off .١ depth for safe pore pressure (٣٤.١٣٥ m H٢O) as [(mentioned in Sec. (٥.٣.٤), is given by: [see Fig. (٦-٧
x٣= - ٠.٠٦٢٧x١ + ٥٦.٥٢٨
(… (٦-٧
The relationship between core width and cut-off .٢ depth for safe seepage flow (١.٤٨٦٦ l/s/m) as mentioned [(in Sec. (٥.٣.٤), is given by: [see Fig. (٦-١٣
x٣= - ٠.٩٩٤٣x١ + ٦٠.١٩٦
(…. (٦-٨
The cut-off depth should be equal or less than (١٢ .٣ .(m
The objective function (Z٢) is minimum and subject to :the following constraints

The relationship between core width and grout .١ curtain width for safe pore pressure (٣٤.١٣٥ m H٢O), is [(given by : [see Fig. (٦-١٩

(٩-٦)...

The relationship between core width and grout .٢ curtain width for safe seepage flow (١.٤٨٦٦ l/s/m), is [(given by: [see Fig. (٦-٢٥

(١٠-٦) ...

The objective function (Z٣) is minimum too and subject :to the following constraints

The relationship between core width, cut-off depth -١ and grout curtain width for safe pore pressure (٣٤.١٣٥ m :H٢O), is given by

x٣ = ٤٣.٠٢٧-٠.٠٨٩٣x١-٧.٩٣x٢

(... (٦-١١

The relationship between core width, cut-off depth -٢ and grout curtain width for safe seepage flow (١.٤٨٦٦ :l/s/m), is given by

x٣= ٤٤.٧٠٥+٠.٠٥٥٩٣x١-٦.٧١١x٢

(... (٦-١٢

Both equation (٦-١١) and (٦-١٢) are obtained by using a software entitled " SPSS" with applying .multiple linear regression

.(The cut-off depth should be equal or less than (١٢ m .٣

Methods of Optimization ٦.٤.٣

The methods of optimization employed in this research are the simplex and the Lagrange multiplier .methods

a. Simplex Method

The simplex method is an iterative procedure for solving linear programming problems expressed in standard form. The general steps of the simplex :method are as follows

State the linear programming problem in standard .١
.form

Select a set of m variables (where m = number of .٢
constraints) that form an initial basic which is feasible. All other variables are non-basic and are sets equal to .zero, calculate the value of the objective function

Improve the initial solution if possible by finding .٣
another basic feasible solution with a better objective function value. At this step the simplex method implicitly eliminates from consideration all those basic feasible solution whose objective function values are .worse than the present one

Continue to find better basic feasible solutions .٤
improving the objective function values. When a particular basic feasible solution cannot be improved further, it becomes an optimal solution and the simplex method terminates. [Phillips et al., (١٩٧٦)] and [Wu and .[(Coppins, (١٩٨١

b. Lagrange Multiplier Method

The procedure is to convert the problem into unconstrained one by multiplying each of the constraint equations by (□١,□٢,…,□m), respectively, :and adding them to the objective function to obtain
(١٣-٦)….

where (m) denotes the total number of constraint equations and (□١, □٢, …, □m) are called Lagrange multipliers. The above equation is often called the (Lagrangian) and is denoted by (L). Taking

the (m+n) (where n is total number of variables) derivatives of the new objective function (L) and :setting them equal to zero, gives

(١٤-٦).....

and

(١٥-٦)....

Solving Eqs. (٦-١٤) and (٦-١٥) simultaneously gives .[(the required solution [Dimitri, (١٩٨٢

Analysis of the Results ٦.٥

Different cases were analyzed to investigate the effect of dimensions of control devices (dolomite core, concrete cut-off and grout curtain) on pore pressure and seepage flow by using the finite element method as .mentioned in chapter five

In order to determine the optimum design of :control devices, three cases were examined

The First Case ٦.٥.١

Al-Qadisiya dam is operated with two seepage control devices (concrete cut-off and dolomite core) for different dimensions and studied the effect of these devices on pore pressure and seepage flow by using a finite element method. Figures from (٦-٢) to (٦-٦) show the relationship between pore pressure and core width .for different cut-off depths

Figure (٦-٢): Pore pressure versus core width relationship for grout curtain width=٠ and cut-off depth=٠

Figure (٦-٣): Pore pressure versus core width relationship for grout curtain width=٠ and cut-off depth=٣ m

Figure (٦-٤): Pore pressure versus core width relationship for grout curtain width=٠ and cut-off depth=٦ m

Figure (٦-٥): Pore pressure versus core width relationship for grout curtain width=٠ and cut-off depth=٩ m

Figure (٦-٦): Pore pressure versus core width relationship for grout curtain width=٠ and cut-off depth=١٢ m

From these relationships, we obtained relationship between core width and cut-off depth for safe pore pressure, which is mentioned in Sec. (٥.٣.٤) (٣٤.١٣٥ H٢O), .(as shown in Fig. (٦-٧

Figure (٦-٧): Core Width Versus Cut-off Depth Relationship for Pore Pressure = ٣٤.١٣٥ m H٢O

Figures from (٦-٨) to (٦-١٢) show the relationship between seepage flow and core width for different cut-.off depths

From these relationships, we obtained relationship between core width and cut-off depth for safe seepage flow, which is mentioned in Sec. (٥.٣.٤) (١.٤٨٦٦ l/s/m), as shown in Fig. (٦-١٣).

The Second Case ٦.٥.٢
Using different devices, Al-Qadisiya dam is operated with other two seepage control devices (grout curtain and dolomite core) for different dimensions and studied the effect of these devices on pore pressure and seepage flow by using a finite element method. Figures from (٦-١٤) to (٦-١٨) show the relationship between pore pressure and core width for different .grout curtain widths

Figure (٦-١٤): Pore Pressure Versus Core Width Relationship for Cut-off Depth=٠ and Grout Curtain Width = ٠
Figure (٦-١٥): Pore Pressure Versus Core Width Relationship for Cut-off Depth=٠ and Grout Curtain Width =١.٥ m

Figure (٦-١٦): Pore Pressure Versus Core Width Relationship for Cut-off Depth=٠ and Grout Curtain Width =٣ m
Figure (٦-١٧): Pore Pressure Versus Core Width Relationship for Cut-off Depth=٠ and Grout Curtain Width =٤.٥ m
Figure (٦-١٨): Pore Pressure Versus Core Width Relationship for Cut-off Depth=٠ and Grout Curtain Width =٦ m

From these relationships, we obtained relationship between core width and grout curtain width for safe

pore pressure, which is mentioned in Sec. (٥.٣.٤) (٣٤.١٣٥ .(H٢O), as shown in Fig. (٦-١٩

Figures from (٦-٢٠) to (٦-٢٤) show the relationship between seepage flow and core width for different .grout curtain widths

From these relationships, we obtained relationship between core width and grout curtain width for safe seepage flow, which is mentioned in Sec. (٥.٣.٤) (١.٤٨٦٦ .(l/s/m), as shown in Fig. (٦-٢٥

The Third Case ٦.٥.٣

Al-Qadisiya dam is operated with three seepage control devices (concrete cut-off, grout curtain and dolomite core) for different dimensions and studied the effect of these devices on pore pressure and seepage flow by using a finite element method. Figures from (٦-٢٦) to (٦-٣٠) show the relationship between pore pressure and core width for different grout curtain widths and different cut-off depths. From these relationships, we obtained a correlation between cut-off depth, grout curtain width and core width for safe

pore pressure which is (٣٤.١٣٥ H٢O), as shown in .(equation (٦-١١

Figure (٦-٢٥): Core Width Versus Grout Curtain Width Relationship for Seepage Flow=١.٤٨٦٦ l/s/m

Figure (٦-٢٦): Pore Pressure Versus Core Width Relationship for Different Grout Curtain Width and Cut-off Depth=٠ m

Figure (٦-٢٧): Pore Pressure Versus Core Width Relationship for Different Grout Curtain Width and Cut-off Depth=٣ m

Figure (٦-٢٨): Pore Pressure Versus Core Width Relationship for Different Grout Curtain Width and Cut-off Depth=٦ m

Figure (٦-٢٩): Pore Pressure Versus Core Width Relationship for Different Grout Curtain Width and Cut-off Depth=٩ m

Figure (٦-٣٠): Pore Pressur٠e Versus Core Width Relationship for Different Grout Curtain Width and Cut-off Depth=١٢ m

Figures from (٦-٣١) to (٦-٣٥) show the relationship between seepage flow and core width for different grout curtain widths and different cut-off depths. From these relationships, we obtained a correlation between cut-off depth, grout curtain width and core

width for safe seepage flow which is (١.٤٨٦٦ l/s/m), as .(shown in equation (٦-١٢

Figure (٦-٣١): Seepage Flow Versus Core Width Relationship for Different Grout Curtain Width and Cut-off Depth=٠ m

Figure (٦-٣٢): Seepage Flow Versus Core Width Relationship for Different Grout Curtain Width and Cut-off Depth=٣ m

Figure (٦-٣٣): Seepage Flow Versus Core Width Relationship for Different Grout Curtain Width and Cut-off Depth=٦ m

Figure (٦-٣٤): Seepage Flow Versus Core Width Relationship for Different Grout Curtain Width and Cut-off Depth=٩ m

Figure (٦-٣٥): Seepage Flow Versus Core Width Relationship for Different Grout Curtain Width and Cut-off Depth=١٢

Figures from (٦-٢٦) to (٦-٣٠) indicate that the pore pressure decreases with increasing the dimension of .the control devices

Figures from (٦-٣١) to (٦-٣٥) indicate that the seepage flow decreases with increasing the dimension .of the control devices

Optimum Design of the Control Devices ٦.٦

For the first case the objective function (Z١), as in equation (٦-٤) and all the constraints form linear relationships with the design variables, therefore the .simplex method is used to solve this problem

Minimize: Z١=c١x١ +c٣x٣

(...(٦-٤

Minimize: Z١= ٢٥٠x١ + ١٠٢٦x٣

Subject to: ٠.٠٦٢٧x١ + x٣ = ٥٦.٥٢٨

x١ + x٣ = ٦٠.١٩٦٠.٩٩٤٣

x١ ≤ ١٢

x١, x٢ ≥ ٠

Minimize: Z١= ٢٥٠x١ + ١٠٢٦x٣ + MA١ + MA٢ + ٠S

Subject to: ٠.٠٦٢٧x١ + x٣ + A١ = ٥٦.٥٢٨

x١ + x٣ + A٢ = ٦٠.١٩٦٠.٩٩٤٣

x١ + S = ١٢

x١, x٣, A١, A٢, S ≥ ٠

First Tableau

٠ M M ١٠٢٦ ٢٥٠ Min Z١

x٣ x١ xB CB i

θi bi S A٢ A١

٥٦.٥٢٨ ٠ ٠ ١ ١ ٠.٠٦٢٧ **A١ M** ١

٥٦.٥٢٨

٦٠.١٩٦ ٠ ١ ٠ ١ ٠.٩٩٤٣ **A٢ M** ٢
٦٠.١٩٦

∞ ١٢ ١ ٠ ٠ ٠ ١ **S** ٠ ٣

M١١٦.٧٢٤ ٠ **M M M**٢ **M**١.٠٥٧ **Zj**

٠ ٠ ٠ **M**٢-١٠٢٦**M**١.٠٥٧-٢٥٠ **Cj - Zj**

:**The solution by the first tableau is**

x١= ٠ , x٣= ٠ , S= ١٢ , A١= ٥٦.٥٢٨ , A٢= ٦٠.١٩٦ , Z١= ١١٦.٧٢٤M $/m

The solution is non-feasible because there is an .artificial variable in the basic variable

The solution is not optimal because we have a (-ve) reduced value of a non-basic variable in a .minimization problem

Second Tableau

٠ **M M** ١٠٢٦ ٢٥٠ **Min Z١**

θi bi S A٢ A١ x٣ x١ xB CB i

٥٦.٥٢٨ ٠ ٠ ١ ١ ٠.٠٦٢٧ **X٣** ١٠٢٦ ١
٩٠١.٥٦

٣.٩٣٧ ٣.٦٦٨ ٠ ١ ١- ٠ ٠.٩٣١٦ **A٢ M** ٢

١٢ ١٢ ١ ٠ ٠ ٠ ١ **S** ٠ ٣

٥٧٩٩٧.٧٢٨ ٠ **M M**-١٠٢٦ ١٠٢٦ **M**٠.٩٣١٦+٦٤.٣٣٠٢ **Zj**
M٣.٦٦٨+

٠ ٠ **M**٢+١٠٢٦- ٠**M**٠.٩٣١٦-١٨٥.٦٦٩٨ **Cj - Zj**

:**The solution by the second tableau is**

, x١= ٠ , x٣= ٥٦.٥٢٨ , S= ١٢ , A١= ٠ , A٢= ٣.٦٦٨

Z١= ٥٧٩٩٧.٧٢٨ +٣.٦٦٨M $/m

The solution is non-feasible because there is an .artificial variable in the basic variable

The solution is not optimal because we have a (-ve) reduced value of a non-basic variable in a .minimization problem

Third Tableau

٠ M M ١٠٢٦ ٢٥٠ Min Z١

θi bi S A٢ A١ x٣ x١ xB CB i

٠ ٠.٩٣١٦/٠.٠٦٢٧- ١+(٠.٩٣١٦/٠.٠٦٢٧) ١ ٠ X٣ ١٠٢٦ ١
٥٦.٥٢٨+(٠.٩٣١٦/٠.٠٦٢٧*٣.٦٦٨-)

٠ ٠.٩٣١٦/١ ٠.٩٣١٦/١- ٠ ١ X١ ٢٥٠ ٢
٠.٩٣١٦/٣.٦٦٨

/٣.٦٦٨-) ١ ٠.٩٣١٦/١- ٠.٩٣١٦/١ ٠ ٠ S ٠ ٣
١٢+(٠.٩٣١٦

٥٨٧٢٨.٧٦٨ ٠ ١٩٩.٣٠٢٠٦ ٨٢٦.٦٩٨ ١٠٢٦ ٢٥٠ Zj

٠ M-١٩٩.٣٠٢٠٦ M-٨٢٦.٦٩٨ ٠ ٠ Cj - Zj

:The solution by the third tableau is

x١*= ٣.٩٤ m , x٣*= ٥٦.٢٨ m , S*= ٨.٠٦ , Z١*= ٥٨٧٢٨.٧٦٨ $/m

.The solution is feasible

The solution is optimal because we don't have a (-ve) reduced value of a non-basic variable in a .minimization problem

.This result required increasing the width of shell

For the second case the objective function (Z٢) is linear relationship as in equation (٦-٥) but all the constraints form non-linear relationship with the design variables, therefore, the Lagrange multiplier .method is used to solve this problem

Minimize: Z٢=c٢x٢ +c٣x٣

(...(٦-٥

Minimize: Z٢= ١٨٠٠٠x٢ + ١٠٢٦x٣

:Subject to

(١)...

(٢)...

(٣)...

(٤)...

:By solve these equations the results are obtained

x٢*=٠.٧٢ m, x٣*=٣٥.٣٣ m, λ١*=٩٠١.٠١, λ٢*=١٢٤.٩٩

$Z_{٣}$*= ٤٩٢٠٨.٥٨ $/m

For the third case the objective function ($Z_{٣}$), as in equation (٦-٦) and all the constraints form linear relationship with the design variables, therefore, the .simplex method is used to solve this problem

Minimize: $Z_{٣}=c_{١}x_{١} + c_{٢}x_{٢} + c_{٣}x_{٣}$

(…(٦-٦

Minimize: $Z_{٣}$= ٢٥٠$x_{١}$ + ١٨٠٠٠$x_{٢}$ + ١٠٢٦$x_{٣}$

Subject to: ٠.٠٨٩٣$x_{١}$ + ٧.٩٣$x_{٢}$ + $x_{٣}$ = ٤٣.٠٢٧

$x_{١}$ +٦.٧١١$x_{٢}$ + $x_{٣}$ = ٤٤.٧٠٥٠.٠٥٥٩٣-

$x_{١}$ ≤ ١٢

$x_{١}, x_{٢}, x_{٣}$ ≥ ٠

Minimize: $Z_{٣}$= ٢٥٠$x_{١}$ + ١٨٠٠٠$x_{٢}$+ ١٠٢٦$x_{٣}$ + M$A_{١}$ + M$A_{٢}$ + ٠S

Subject to ٠.٠٨٩٣$x_{١}$ + ٧.٩٣$x_{٢}$ + $x_{٣}$+ $A_{١}$ = ٤٣.٠٢٧

$x_{١}$ + ٦.٧١١$x_{٢}$ + $x_{٣}$ + $A_{٢}$ = ٤٤.٧٠٥٠.٠٥٥٩٣-

$x_{١}$ + S = ١٢

$x_{١}, x_{٢}, x_{٣}, A_{١}, A_{٢}$, S ≥ ٠

First Tableau

٠ M M ١٠٢٦ ١٨٠٠٠ ٢٥٠ Min $Z_{٣}$

$x_{٢}$ $x_{١}$ xB CB i

θi bi S $A_{٢}$ $A_{١}$ $x_{٣}$

٤٣.٠٢٧ ٠ ٠ ١ ١ ٧.٩٣ ٠.٠٨٩٣ $A_{١}$ M ١

٥.٤٢٦

٤٤.٧٠٥ ٠ ١ ٠ ١ ٦.٧١١ ٠.٠٥٥٩٣- $A_{٢}$ M ٢

٦.٦٦

∞ ١٢ ١ ٠ ٠ ٠ ٠ ١ S ٠ ٣

M٨٧.٧٣٢ ٠ M M M٢ M١٤.٦٤١ M٠.٠٣٣٣٧ Zj

٠ ٠ M٢-١٠٢٦ M ١٤.٦٤١-١٨٠٠٠ M٠.٠٣٣٣٧-٢٥٠ Cj - Zj

٠

:The solution by the first tableau is

x١= ٠ , x٢=٠, x٣= ٠ , S= ١٢ , A١= ٤٣.٠٢٧ , A٢= ٤٤.٧٠٥, Z٣= ٨٧.٧٣٢M $/m

The solution is non-feasible because there is an .artificial variable in the basic variable

The solution is not optimal because we have a (-ve) reduced value of a non-basic variable in a .minimization problem

Second Tableau

٠ **M M** ١٠٢٦ ١٨٠٠٠ ٢٥٠ **Min Z٣**

x٣ x٢ x١ xB CB i

θi bi S A٢ A١

٠ ٠ ٧.٩٣ /١ ٧.٩٣ /١ ١ ٧.٩٣ /٠.٠٨٩٣ **X٢** ١٨٠٠٠ ١

٤٣.٠٢٧ ٧.٩٣ /٤٣.٠٢٧

٢

M

٠.٠٥٥٩٣- (٦.٧١١-) (٧.٩٣ /٠.٠٨٩٣) **A٢**

٠

١+ (٧.٩٣ /٦.٧١١-)

٧.٩٣ /٦.٧١١-

١

٤٤.٧٠٥+(٦.٧١١-) ٧.٩٣ /٤٣.٠٢٧ ٠

٥٣.٩٤

∞ ١٢ ١ ٠ ٠ ٠ ٠ ١ **S** ٠ ٣

M٠.١٣١٥- ٢٠٢.٦٩٩ **Zj**

١٨٠٠٠

M٠.١٥٤+٢٢٦٩.٨٦

M٠.٨٤٦-٢٢٦٩.٨٦

M

٠

M٨.٢٩٢+٩٧٦٦٥.٣٢

M٠.١٣١٥ +٤٧.٣٠١ **Cj - Zj**

٠

M١.٨٤٦+٢٢٦٩.٨٦- **M**٠.١٥٤- ١٢٤٣.٨٦-

٠
٠

:The solution by the second tableau is
,x١= ٠ ,x٢ = ٥.٤٢٦ m, x٣= ٠ , S= ١٢ , A١= ٠ , A٢= ٨.٢٩٢
Z٣=٩٧٦٦٥.٣٢+٨.٢٩٢M $/m
The solution is non-feasible because there is an .artificial variable in the basic variable
The solution is not optimal because we have a (-ve) reduced value of a non-basic variable in a .minimization problem

Third Tableau

٠ M M ١٠٢٦ ١٨٠٠٠ ٢٥٠ Min Z٣
θi bi S A٢ A١ x٣ x٢ x١ xB CB i
٤٣.٠٢٧ ٠ ٠ ١ ١ ٧.٩٣ ٠.٠٨٩٣ X٣ ١٠٢٦ ١
١.٦٧٨ ٠ ١ ١- ٠١.٢١٩- ٠.١٤٥٢٣- A٢ M ٢
١٢ ١ ٠ ٠ ٠ ٠ ١ S ٠ ٣
٠ M M-١٠٢٦ ١٠٢٦ M١.٢١٩-٨١٣٦.١٨M٠.١٤٥٢٣-٩١.٦٢١٨ Zj
M١.٦٧٨+٤٤١٤٥.٧٠٢
M١.٢١٩ +٩٨٦٣.٨٢ M٠.١٤٥٢٣+١٥٨.٣٧٨ Cj - Zj
M٢+ ١٠٢٦- ٠
٠
٠

:The solution by the third tableau is
x١* = ٠, x٢* = ٠, x٣*= ٤٣.٠٢٧ m , S*= ١٢ , A١* = ٠, A٢* =١.٦٧٨ Z٣*= ٤٤١٤٥.٧٠٢+١.٦٧٨M $/m
The solution is non-feasible because there is an .artificial variable in the basic variable
The solution is optimal because we don't have a (-ve) reduced value of a non-basic variable in a .minimization problem

Table (٦-١) shows the summary results of optimum design of control devices.

Table (٦-١): The summary results of optimum design of control devices

Total cost*١٠٤ ($/m)	Core width,x٣(m)	Grout curtain width,x٢(m)	Cut-off depth, x١(m)	case No.
٥.٨٧٢٨	٥٦.٢٨	__	٣.٩٤	١
٤.٩٢٠٨	٣٥.٣٣	٠.٧٢	__	٢
Infeasible problem	__	__	__	٣

Using core width of ٣٥.٣٣ m with grout curtain with of ٠.٧٢ m is cheaper than using core width of ٥٦.٢٨ m with cut-off depth of ٣.٩٤ m as shown in table (٦-١). In addition, the first case is preferable because seepage flow and pore pressure are less as in figures (٦-٣٦) and (٦-٣٧) respectively. Also, the location of free surface was lowered as in figure (٦-٣٨).

Chapter Seven

Conclusions and Recommendations

Conclusions ٧.١

In this study, the finite element method was used to analyze unconfined seepage through earth dam which is provided with dolomite core, asphaltic concrete diaphragm, grout curtain and concrete cut-off as seepage control devices. The simplex and Lagrange multiplier methods were used to find the optimum design for the control devices from hydraulic and economical point views. The following conclusions :were reached

The computer program (seep٢d) and the used linear triangular element have been given acceptable .results to solve the existing case .١

Several trails must be done in order to select the best mesh which can be used in the finite element model for accurate results, and to comply with the existing condition of Al-Qadisiya Dam. Small elements must be used in areas of rapid changes (regions of .(grout curtain, cut-off and the asphaltic diaphragm .٢

The head values are influenced by the dimensions .٣
of the control devices. Therefore, the parameters such as pressure head, total head …etc. are also influenced .by changing the dimensions

The results of application of the model on (١٢٥) .٤
design cross sections indicate that increasing of the dimensions of the control devices and using more devices leads to decreasing seepage discharge and pore water pressure. Also, the location of free surface was .lowered

Minimum total cost could be achieved when using .٥
.core width of ٣٥.٣٣ m with grout curtain width of ٠.٧٢ m

Minimum total cost could be obtained too when .٦
using core width of ٥٦.٢٨ m with cut-off depth of ٣.٩٤ m. .This result required increasing the width of shell

Using core width of ٣٥.٣٣ m with grout curtain with .٧
of ٠.٧٢ m is cheaper than using core width of ٥٦.٢٨ m with cut-off depth of ٣.٩٤ m. In addition, the first case is preferable because seepage and pore pressure are less. .Also, the location of free surface was lowered

Using of dolomite core, grout curtain and cut-off .٨
.together presented infeasible problem

Recommendations ٧.٢

Further developments of the present work are :suggested as follows

Extending both the present model and the .١
computer program to analyze the effect of earthquake .and dam stability

Extension of the present analysis to include .٢
structures with various soil stratification including soil .anisotropy

Applying the present analysis to another case .٣
.studies

Extension of the present analysis to include .٤
another seepage control devices such as filter, blanket
.and relief well

The analysis can be modified further if three- .٥
dimensional analysis of the seepage problem under
transient conditions is added

REFERENCES

Abo, A.A., (٢٠٠١), "Calculation seepage through .١
earth dams by finite element method", M.Sc., Thesis,
Department of Civil Engineering, University of
.Baghdad

Ahmed, C.H., (٢٠٠٣), "Mathematical model for .٢
evaluation and management of seepage control in
Mosul Dam", M.Sc., Thesis, Department of Water
.Resources Engineering, University of Baghdad

Bear, J., and Verruijt A., (١٩٩٠), "Modeling .٣
ground water flow and pollution", D.Reidal Publishing
.Company, Dordrecht. Holland

Bunday, B.D., (١٩٨٤), "Basic optimization .٤
.methods", Edward Arnold, London

Burnett, D.S., (١٩٨٧), "Finite element analysis .٥
form concepts to applications", Addison-Wesley
.Publishing Company

Chang, S.C., (١٩٨٨), "Boundary element analysis .٦
for unconfined seepage problems", Journal of
Geotechnical Engineering, ASCE, Vol.١١٤, No.٥, pp.٥٥٦-
.٥٧١

Ching, S. and Chang, M., (١٩٨٧), "Boundary .٧
element method in draw-down seepage analysis for earth dams", Journal of Computing in Civil .Engineering, Vol.١, No.٢, April

Dantzig, C.B., (١٩٦٣), "Linear programming and .٨
.extension", Princeton University Press

Dimitri, P.B., (١٩٨٢), "Constrained optimization .٩
and Lagrange multiplier methods", Academic Press, .New York

Finn, W.D.L., (١٩٦٧), "Finite element analysis of .١٠
seepage through dams", Journal of the Soil Mechanics and Foundations Divisions, ASCE, Vol.٩٣, No.SM٦, .pp.٤١-٤٨

Freeze, R.A. and Cherry, J.A., (١٩٧٩), "Ground .١١
water", Prentice-Hall, Inc. Englewood Cliffs, New .Jersey

Gallagher, R.H. and Zienkiewicz, O.C., (١٩٧٣), .١٢
"Optimum structural design, theory and applications", .John Wiley and Sons, London

Garg, S.K. and Garg, R., (١٩٧٨), "Elementary .١٣
."irrigation engineering

G.E.D.R.(General Establishment of the Dams and .١٤
.Reservoirs in Iraq), (٢٠٠٥), Personal Connections

Gill, M.A., (١٩٨٠), "Theory of blanket design for .١٥
dams on pervious foundation", Journal of Hydraulic .Research, No. ٤, pp.٢٩٩-٣١١

Hamed, W., (١٩٩٦), "Optimum design of barrage .١٦
floors", M.Sc., Thesis, Department of Civil .Engineering, University of Baghdad

Harr, M.E., (١٩٦٢), "Ground water and seepage", .١٧
.McGraw Hill, New York

١٨. Hinton, E. and Owen, D.R.J., (١٩٧٧), "Finite element programming", Academic Press.

١٩. Huang, T., (١٩٩٦), "Stability analysis of an earth dam under steady state seepage", Journal of Computers and Structures, Vol. ٥٨, No. ٦, pp. ١٠٧٥-١٠٨٢.

٢٠. Hydroprojekt, (١٩٧٨), "Haditha project on the Euphrates River", Technical design, Vol. ٢, Nutural Conditions, Hydroprojekt, Moscow.

٢١. Hydroprojekt, (١٩٨٨), "Al-Qadisiya project on the Euphrates River, operation and maintenance manual for earth-fill dam", Book١, No.٩٥٠-١٠-٧٦, Moscow.

٢٢. Irzooki, R.H., (١٩٩٨), "Investigation and analysis of seepage problems on the left side of Al-Qadisiya Dam", M.Sc. Thesis, University of Technology.

٢٣. Jawad, B.M., (١٩٩٦), "Finite element optimization model for unconfined aquifer floor", M.Sc., Thesis, Department of Civil Engineering, University of Basrah.

٢٤. Lacy, S.J. and Prevost, J.H., (١٩٨٧), "Flow through porous media: The procedure for locating the free surface", International Journal for Numerical and Analytical Methods in Geomechanics, Vol. ١١.

٢٥. Muhammad, J.R., (١٩٩١), "Calculating seepage through earth dams by finite element method", M.Sc. Thesis, Department of Civil Engineering, College of Engineering, University of Salah Al-ddin.

٢٦. Al-Musawi, W.H., (٢٠٠٢), "Optimum design of control devices for safe seepage under hydraulic structures", M.Sc. Thesis, Department of Civil Engineering, University of Babylon.

٢٧. Naylor, D.J. and Pande, G.N., (١٩٨١), "Finite elements in geotechnical engineering".

٢٨. **Neuman, S.P. and Witherspoon, P.A., (١٩٧٠), "Finite element method of analysis steady seepage with a free surface", Water Resources Research, Vol. ٦, No. ٣, pp.٨٨٩-٨٩٧.**

٢٩. **Al-Obaidi, S.R.R., (٢٠٠١), "Seepage analysis for hydraulic structures: Using different methods of analysis", M.Sc. Thesis, Department of Building and Construction, University of Technology.**

٣٠. **Phillips, D.T., Ravindran, A. and James J., (١٩٧٦), "Operations research: Principles and Practice", John Wiley and Sons, Canada.**

٣١. **Punima, B.C., (١٩٨١), "Introductory irrigation engineering", Standard Publishers Distributors, Nai Sarak, Delhi.**

٣٢. **Al-Qaisi, K.A., (١٩٩٩), "Analysis of earth dam by finite element method", M.Sc. Dissertation, Department of Civil Engineering University of Baghdad.**

٣٣. **Rao, S.S., (١٩٨٢), "The finite element method in engineering", Pergamon Press.**

٣٤. **Ruadkivi, A.J. and Callander, R.A., (١٩٧٦), "Analysis of ground water flow", Edward Arnold Pub. Ltd., London.**

٣٥. **Rushton, K.R. and Redshow, S.C., (١٩٧٩), "Seepage and ground water flow", John Wiley and Sons, New York.**

٣٦. **Salem, A.K., (١٩٨٥), "Foundation treatment problem encountered in the construction of Haditha Dam", I COLD, ١٥th Cong., Q٥٨, R٢٠, Lausanne.**

٣٧. **Salih, R.A., (٢٠٠٠), "Performance of the right side of Al-Qadisiya Dam", M.Sc. Thesis, Department of**

Civil Engineering, College of Engineering, University
.of Tikrit
Segrlind, L.J., (١٩٨٤), "Applied finite element .٣٨
.analysis", John Wiley and Sons, Inc., New York
Sherard, J.L., Woodward, R.J., Gizienski, S.F. .٣٩
and Clevenger, W.A., (١٩٦٣),"Earth and earth rock
.dams", John Wiley and Sons, Inc., New York
."Sing-Bharat, (١٩٧٦), "Earth and rock fill dams .٤٠
Slaby, A.A.H., (١٩٨٧), "Optimum design of .٤١
reinforced concrete frames", M.Sc. Thesis, College of
.Engineering, University of Baghdad
Smith, I.M., (١٩٩٨), "Programming the finite .٤٢
element method with application to geomechanics",
.John Wiley and Sons, Inc., New York
Sowers, G.F. and Sally, H.L., (١٩٦٢), "Earth and .٤٣
rock fill dam engineering", Asia Publishing House,
.India
Stas, F.L., (١٩٨٦), "Applied finite element analysis .٤٤
.for engineering", CBS publishing, Japan Ltd
Subuh, M.A., (٢٠٠٢), "Finite element solution for .٤٥
unconfined seepage problem with reference to Al-
Qadisiya Dam", M.Sc. Thesis, Department of Civil
.Engineering, University of Babylon
Taylor, R.L. and Brown, C.B., (١٩٦٧), "Darcy flow .٤٦
solution with a free surface", Journal of the Hydraulics
.Division, ASCE, Vol.٩٣, No. HY٢, pp.٢٨٣-٣٠٢
U.S. Army Crops. Of Engineers, (١٩٨٦). "Seepage .٤٧
.principles", Manual, EM١١١٠-٢-١٩٠١, Chapter ٤
Varshney, R.S., Gupta, S.C. and Gupta, R.L., .٤٨
(١٩٧٢), "Theory and design of irrigation structures",
.Vol.II, Chand and Bros, Roorkee (V.P.), India

٤٩. Wu, N. and Coppins, R., (١٩٨١), "Linear programming and extensions", McGraw-Hill, Inc., New York.

٥٠. Zienkiewicz, O.C., (١٩٧٧), "The finite element method", ٣rd. Edition, McGraw-Hill, London.

٥١. Zienkiewicz, O.C., (١٩٨٢), "The finite element in engineering sciences", McGraw-Hill.

٥٢. Zienkiewicz, O.C., and Cheung, Y.K., (١٩٦٥), "Finite element in the solution of field problems", The Engineer, Sept. pp.٥٠٧-٥١٠.

٥٣. Zienkiewicz, O.C., Mayer, P. and Cheung, Y.K., (١٩٦٦), "Solution of anisotropic seepage by finite elements", Journal of the Engineering Mechanics Division, ASCE, Vol.٩٢, No.EM١, pp.١١١-١٢٠..