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ANALYSIS OF THE CONSTRUCTION BEHAVIOUR OF WESTERN DESERT HORAN DAM H-2

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Abstract:

Horan Dam H-2 is earth dam located 18 km NE of Al- Rutba city one each of Anbar government. Horan wadi is located in stable zone of Iraq. No major folded and faulted structures exists in this area. The aim of this research involve the analysis of the construction behaviour for the dam body because of its important in saving the rainfall which used in agriculture and resist the desert increment in west of Iraq . The soil parameters which used in Geo-Slope program obtain from geological study and soil investigation report by (NCCL). The finite element method applied in this study with elastic-plastic soil model. The results analysis show that the dam body is stable and the choose of soil shear strength parameters have great effect on dam stability. The purpose of this analysis to reduce the risk of use this earth structures when engineering construction build on it.

تحليل التصرف الانشائي لسد حوران في الصحراء الغربية DAM H-2 باستخدام طريقة العناصر المحددة

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الكلمات المفتاحية: سد حوران، معاملات التربة، برنامج الانحدار الارضي.

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المستخلص:

سد حوران DAM H-2 هو سد ترابي يقع على بعد ١٨ كيلو من شمال شرق مدينة الرطبة وهي احدى مدن محافظة الانبار وهو ضمن منطقة من مناطق العراق المستقرة من الناحية الجيولوجية والخالية من التصدعات والفوالق الرئيسية. يهدف هذا البحث الى تحليل التصرف الانشائي لجسم السد وذلك لما لهذا المنشأ الهندسي من اهمية في خزن مياه الامطار لغرض استخدامها في الزراعة والتنمية المستدامة للاراضي الزراعية ومكافحة التصحر لمنطقة غرب العراق. تم الحصول على معاملات التربة التي استخدمت في برنامج حاسوب هندسي(Geo-Slope program) من تقرير الدراسة الجيولوجية وتحريات التربة الذي اعده المركز الوطني للفحوصات الانشائية. تم استخدام طريقة العناصر المحددة في هذا البحث من خلال استخدام الموديل المرن – اللدن للتربة. وقد بينت نتائج التحليل ان جسم السد مستقر جيداً وان اختيار معاملات مقاومة التربة له تأثير كبير على استقرارية السد. ان اجراء هذا التحليل هو لتقليل المخاطر التي من المحتمل ان يتعرض لها السد عند استخدامه.

INTRODUCTION

With increasing height of earth and rockfill dams the control of deformation becomes more critical, particularly with respect to zonal interactions and the prevention of cracking. The extension of experience to such situations is enhanced by making full evaluation of similar existing structures wherever possible[1].

Horan Dam H-2 is located 18 km north east of Al-Rutba city and 8 km from the high way Baghdad Jordan [12].

Soil investigation and geological studies were carried out by (NCCL)[12]. From the geological condition, Horan Wadi is located in stable zone of Iraq. No major folded and faulted structures exists in the area. The structure is U/S side slope 1V:3H, D/S side slope 1V:2.5H and approximately 14m high with a central core and shell shoulders. The soil of foundation dam consists of sand mixed with gravel which will be removed during construction. The weight of one cubic meter of saturated soil is assumed 20 kN/m^3 and the saturated soil of core material weight is assumed17.5 kN/m^3. More details foundation conditions have been reported by NCCL [12].

FINITE ELEMENT EQUATIONS

The finite element equation used in the SIGMA/W formulation for a given time increment is,[5,8,10,11]

$$\int_v [B]^T [C][B] dv \{a\} = b\int_v \langle N\rangle^T dv + p\int_A \langle N\rangle^T dA + \{Fn\} \quad \text{......(1)}$$

where:
[B] = strain-displacement matrix
[C] = constitutive matrix
{a} =column vector of nodal incremental x- and y-displacements
A = area along the boundary of an element
v = volume of an element
b = unit body force intensity
<N> = row vector of interpolating functions
p = incremental surface pressure
{Fn} =concentrated nodal incremental loads

Summation of this equation over all elements is implied. It should be noted the SIGMA/W is formulated for incremental analysis. For each time step, incremental displacements are calculated for the incremental applied load. These incremental values are then added to the values from the previous time step. Using this incremental approach, the unit body force is only applied when an element is included for the first time during an analysis.

For a two-dimensional plane strain analysis, SIGMA/W considers all elements to be of unit thickness. For constant element thickness, t, Equation 1 can be written as:

$$t\int_A [B]^T [C][B] dA \{a\} = bt\int_A \langle N\rangle^T dA + pt\int_L \langle N\rangle^T dL \quad \text{......(2)}$$

In an abbreviated form, the finite element equation is,

$$[K]\{a\} = \{F\} = \{Fb\} + \{Fs\} + \{Fn\} \quad \text{...........(3)}$$

where:
[K] = element characteristic(or stiffness) matrix= $t\int_A \left(\langle B\rangle^T [C][B]\right) dA$
{a} = nodal incremental displacements
{F} = applied nodal incremental force which is made up of the following:
{Fb} = incremental body forces
{Fs} = force due to surface boundary incremental pressures
= $pt\int_L \left(\langle N\rangle^T\right) dL$, for two-dimensional analysis
{Fn} = concentrated nodal incremental forces

SIGMA/W solves this finite element equation for each time step to obtain incremental displacements and calculates the resultant incremental stresses and strains.

STRAIN-DISPLACEMENT MATRIX

SIGMA/W uses engineering shear strain in defining the strain vector,

$$\{\varepsilon\}=\begin{Bmatrix}\varepsilon_x\\ \varepsilon_y\\ \varepsilon_z\\ \gamma_{xy}\end{Bmatrix} \quad \text{.................................(4)}$$

The field variable of a stress/ deformation problem is displacement which is related to the strain vector through:

$$\{\varepsilon\}=[B]\begin{Bmatrix}\mu\\ \nu\end{Bmatrix} \quad \text{..............................(5)}$$

where:
[B] = strain matrix,
u, v = nodal displacement in x- and y-directions, respectively.

SIGMA/W is restricted to performing infinitesimal strain analyses. For a two-dimensional plane strain problem, ε_Z is zero and the strain matrix is defined as:

$$[B]=\begin{bmatrix}\frac{\partial N_1}{\partial x} & 0 & \cdots & \frac{\partial N_8}{\partial x} & 0\\ 0 & \frac{\partial N_1}{\partial y} & \cdots & 0 & \frac{\partial N_8}{\partial y}\\ 0 & 0 & \cdots & 0 & 0\\ \frac{\partial N_1}{\partial x} & \frac{\partial N_1}{\partial y} & \cdots & \frac{\partial N_8}{\partial x} & \frac{\partial N_8}{\partial y}\end{bmatrix} \quad \text{........(6)}$$

ElASTIC CONSTITUTIVE RELATIONSHIP

Stresses are related to strains as follows, within the theory of elasticity,

$$\{\sigma\}=[C\{\varepsilon\}] \quad \text{.................................(7)}$$

where [C] is the constitutive (element property) matrix and is given by:

$$[C]=\frac{E}{(1+\nu)(1-2\nu)}\begin{bmatrix}1-\nu & \nu & \nu & 0\\ \nu & 1-\nu & \nu & 0\\ \nu & \nu & 1-\nu & 0\\ 0 & 0 & 0 & \frac{1-2\nu}{2}\end{bmatrix} \quad \text{..............(8)}$$

where:
E = Young's modulus
v = Poisson's ratio

BODY FORCES

SIGMA/W can model body forces applied in both the vertical and the horizontal directions. These forces are applied to all elements when they first become active. The body force in the vertical direction, b_v, is due to gravity acting on an element. For a given material, the unit body force intensity in the vertical direction is given by its unit weight, γ_s, which is in turn related to its mass density, ρ:

$$\gamma_s=\rho g \quad \text{...........(9)}$$

where g is the gravitational constant. When the unit weight, γ_s is non-zero, SIGMA/W evaluates the integral $\gamma_s\int_v\left(\langle N\rangle^T\right)dv$ by numerical integration and applies a vertically downward (negative) force at each node of the element.

Similarly, when the unit body force intensity in the horizontal direction, b_h, is nonzero, nodal forces in the horizontal direction are computed using.

LOAD AND DEFORMATION ANALYSIS

1. Dam Simulation

A load/deformation analysis can be used to establish the initial insitu stress if K_0 is less than 1.0. The reason for this limitation is that when there is no lateral movement, K_0 is related to Poisson's ratio by the equation:[5]

$$K_o=\frac{\nu}{1-\nu} \quad \text{..........(10)}$$

Since ν is limited to 0.49 in SIGMA/W, K_0 cannot be greater than 1.0.

The advantage of this method is that the ground surface can have any shape. The limitation is that the method can only be used for a particular value of K_0.

2. Constitutive Models

The elastic-plastic constitutive soil model is a very attractive model because it is so simple and easy to understand. The soil is deemed to behave in a linear-elastic fashion up to the point where it reaches its strength and after that the soil is deemed to be perfectly plastic as shown in Fig.(1) [11]. Describing this soil model requires only four common parameters. These are the elastic modulus E, the Poisson's ratio, υ, the friction angle (ϕ) and the cohesion (C) [6]. These are parameters that used in the study shown in Table (1).

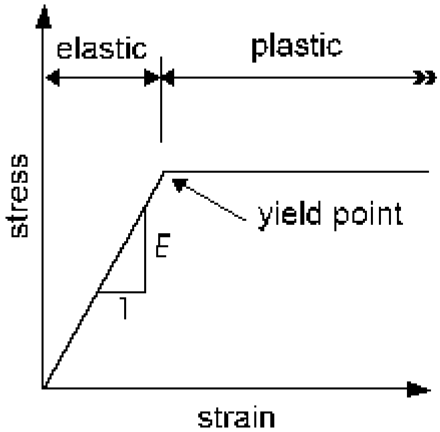

Figure- 1: Elastic-Perfectly Plastic Constitutive Relationship

Table -1: The parameters that used in the elastic-plastic soil model.

Type of Soil	Elastic Modulus E MN/m2	Poisson's ratio, υ	Friction Angle ϕ°	Cohesion C KN/m2
Shell	45	0.45	32	10
Foundation	20	0.4	31	50
Core	20	0.35	15	20

3. Total and Effective Stresses

Material properties can be specified in SIGMA/W. Using either effective stress parameters for analyses of drained soils, or total stress parameters for undrained soils. In materials specified using total stress parameters, undrained pore-water pressure changes can be computed from total stress changes using pore-pressure parameters A and B.

The pore-pressure parameters A and B are defined using functions. B is defined as a function of the pore-water pressure and A is defined as a function of the deviatoric stress. The B function can be defined for both positive and negative pore-water pressures, which makes it possible to analyze both saturated and unsaturated soil conditions. Example functions of these parameters are shown in Figures 2 and 3

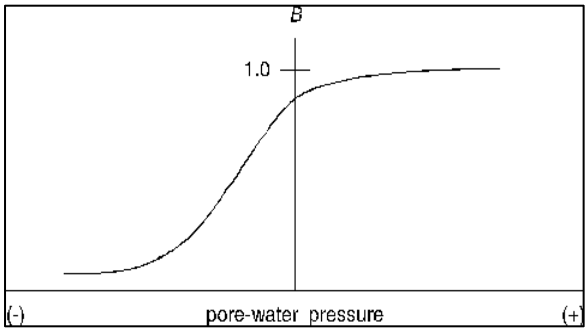

Figure-2: Example of Pore Pressure B Function.

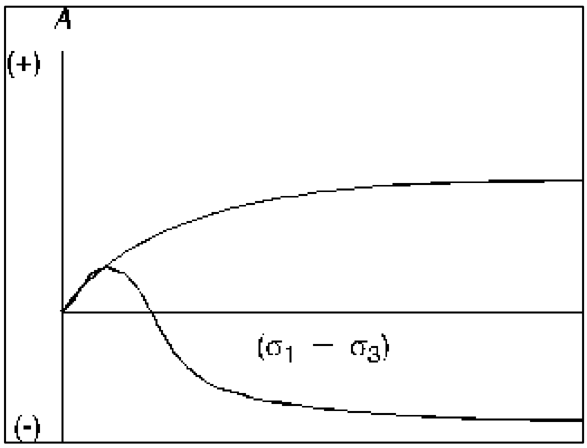

Figure (3): Examples of Pore Pressure A Function

4. Finite Element Implementation

• Isoparametric quadrilateral finite elements.

Isoparameteric quadrilateral finite elements are implemented and each may have various numbers of optional secondary nodes to provide higher order interpolation of nodal values within the element.

• Infinite elements.

Infinite elements can be used at the boundaries of the problem domain that are for practical purposes unbounded. An example of an unbounded problem is the analysis of stresses and displacements beneath Dam. Without infinite elements, many regular elements have to be used in the problem domain until the influence of the problem domain boundary becomes negligible. Using infinite elements allows the problem domain size to be decreased.

FINITE ELEMENT STRESS METHOD

SLOPE/W provides an alternative method of analysis using the stress state obtained from SIGMA/W. These are GEO SLOPE program for static and dynamic finite element stress analyses respectively. The following sections outline the theoretical basis and the solution procedures used by the SLOPE/W Finite Element Stress method [143].

1. Stability Factor

The stability factor (S.F.) of a slope by the finite element stress method is defined as the ratio of the summation of the available resisting shear force along a slip surface $\sum S_r$ to the summation of the mobilized shear force along a slip surface $\sum S_m$. In equation form, the stability factor (S.F.) is expressed as:

$$S.F.=\frac{\sum S_r}{\sum S_m} \quad \text{.........(11)}$$

The available resisting force of each slice is calculated by multiplying the shear strength of the soil at the base center of the slice with the base length. Therefore, from the Mohr-Coulomb equation for a saturated soil. The available resisting force is:

$$S_r = S\beta = (C' + (\sigma_n - \mu_w)\tan\phi')\,\beta \quad \text{.......(12)}$$

where:

S = effective shear strength of the soil at the base center of a slice

β = base length of a slice

σ_n = normal stress at base center of a slice

Similarly, the mobilized shear force of each slice is calculated by multiplying the mobilized shear stress (τ_m) at the base center of the slice with the base length.

$$S_m = \tau_m\,\beta \quad \text{...................................(13)}$$

Table-2: Material properties of Earth Dam H-2.[12]

Material	USCS* System	Description of Soil	Unit Weight γ_t kN/m³	Strength Parameters	
				C kN/m³	ϕ^o
Dry Shell	GW	Well graded gravel with sand	19	0	35
Partially Sat. Shell	GW	Well graded gravel with sand	20	0	33
Saturated Shell	GW	Well graded gravel with sand	21	0	32
Saturated Foundation	GW	Well graded gravel with sand	22	50	31
Core	SM	Poorly graded sand-silt mixture	20	20	15

A local stability factor of a slice can also be obtained when the available resisting shear force of a slice is compared to the mobilized shear force of a slice[7,4,10].

$$Local\, S.F. = \frac{S_r}{S_m} = \frac{S\beta}{\tau\beta} \quad \text{......................(14)}$$

2. Normal Stress and Mobilized Shear Stress

To do stability analysis using the Finite Element Stress method, you need to start by performing a finite element stress analysis (SIGMA/W). The information required from the stress analysis is the stress state as describe by σ_x, σ_y, and σ_{xy} at each Gauss point within each element. These stress values are used to compute the normal stress and the mobilized shear stress at the base center of each slice [8].

MATERIAL PROPERTIES

Soil investigation and geological studies carried out (NCCL) [9]. The material properties which used in Dam 2-H are shown in Table (2).

FINITE ELEMENT COMPUTER PROGRAM USED

A Geo-Slope program (SIGMA/W and SLOPE/W) was used in the finite element analysis carried out during this study. SIGMA/W program used to perform stress and deformation analysis of earth dam. The type of element considered in this work was the two dimensional quadrilateral element. The model which is considered in this work, is the elastic-plastic soil model.

Simulation of construction sequence could be achieved using incremental solution technique[5].

SLOPE/W program used to compute the factor of safety of earth dam slope by finite element stress method.

PROBLEM GEOMETRY

The basic problem chosen for this study shown in Figure (4), involves the construction of earth dam (14m) height and U/S side slope is 1V: 3H while D/S side slope is 1V: 2.5H.

The soil of foundation dam consists of sand mixed with gravel. [12].

The finite element mesh used in the analysis of the earth dam-H2 shown in Figure (4) consists of 254 nodes and 186 two dimensional quadrilateral elements.

The mesh allows five lifts when considering the construction stage [14].

The nodal points along the bottom boundary of the mesh were assumed to be fixed both horizontally and vertically, while the nodes on the right and left ends of the mesh were fixed in the horizontal direction while they were free to move in the vertical direction. All interior nodes were free to move horizontally and vertically.

RESULTS OF FINITE ELEMENT ANALYSIS

The finite element method of analyzing earth dam is a very powerful tool in the assessment of the expected behavior of the dam with regards to its deformation and the stresses, generated within structure.

The results of finite element analysis of earth dam are shown in Figures (5) to (9). The deformed shape of the earth dam is illustrated in Figure (5). The results in this Figure have no appreciable effect on the observed earth dam deformed shape.

From Figure (6), it can be found that the maximum shear stresses concentrate near the core. Figure (7) presents the excepted vertical displacements of the earth dam, while the contours of Figure (8) show the horizontal displacement of the earth dam body.

The stability of this case, is well assured since the minimum factor of safety is (5), Figure (9).

The earth dam is found to assure high degree of stability since:

- Minimum factor of safety=5
- Maximum vertical displacement =3.4cm (at the D/S side slope of earth dam)
- Maximum horizontal displacement= 2.04mm (at the D/S side slope of dam)
- Maximum shear stress= 8.6 kPa (at the center of core zone)

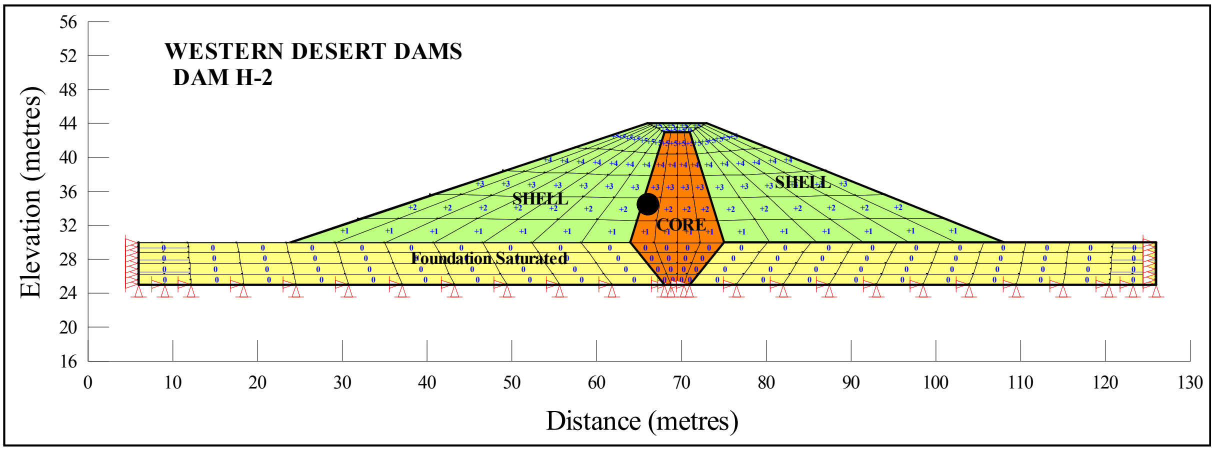

Figure (4): The finite element mesh used in the analysis of the earth dam-H2.

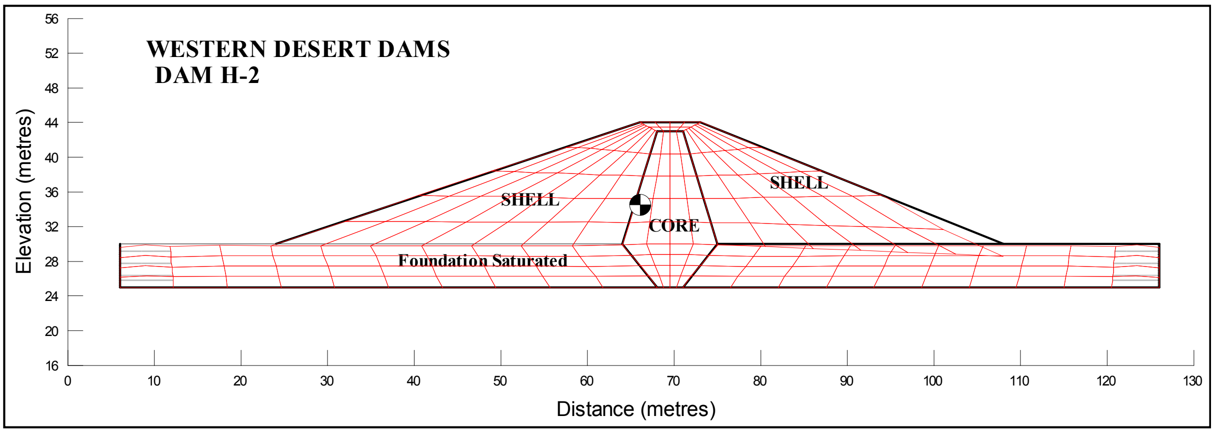

Figure (5): Deformed shape of the earth dam.

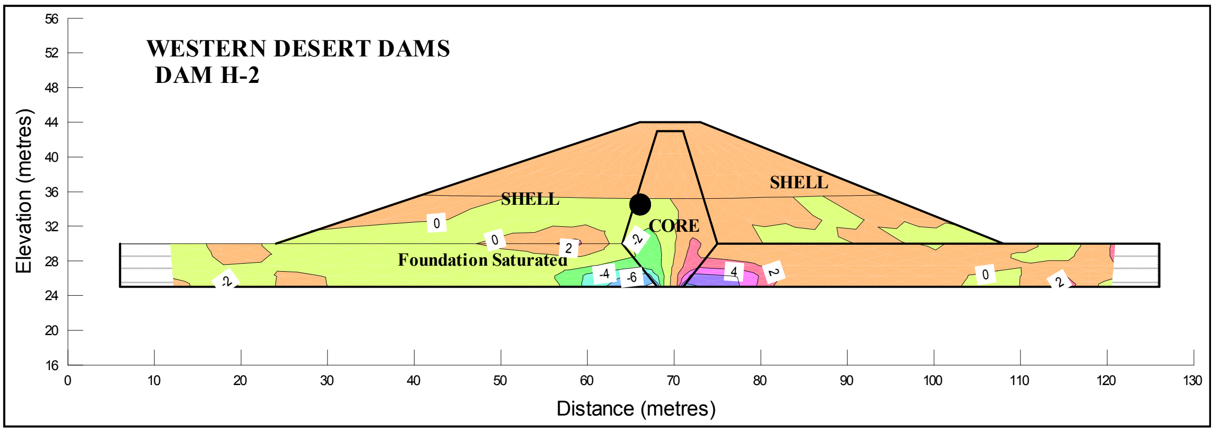

Figure (6): Contours of shear stress for earth dam.

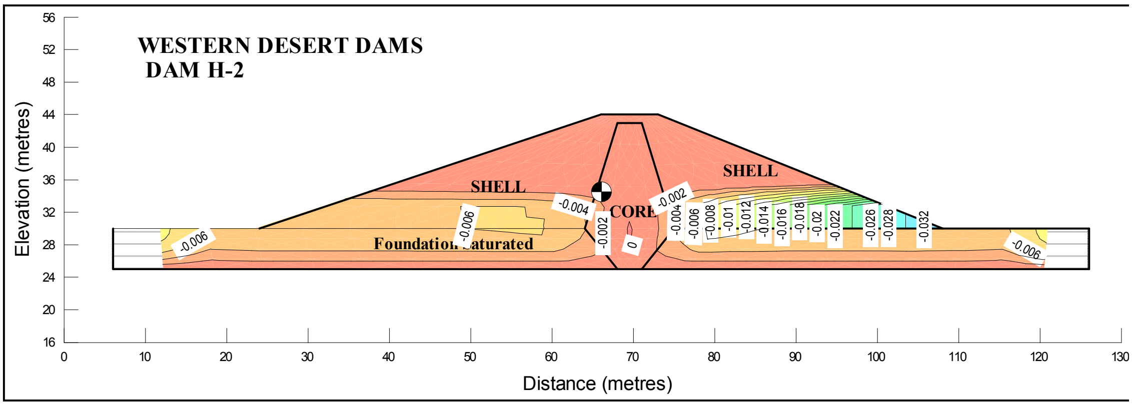

Figure (7): Contours of vertical displacement for earth dam.

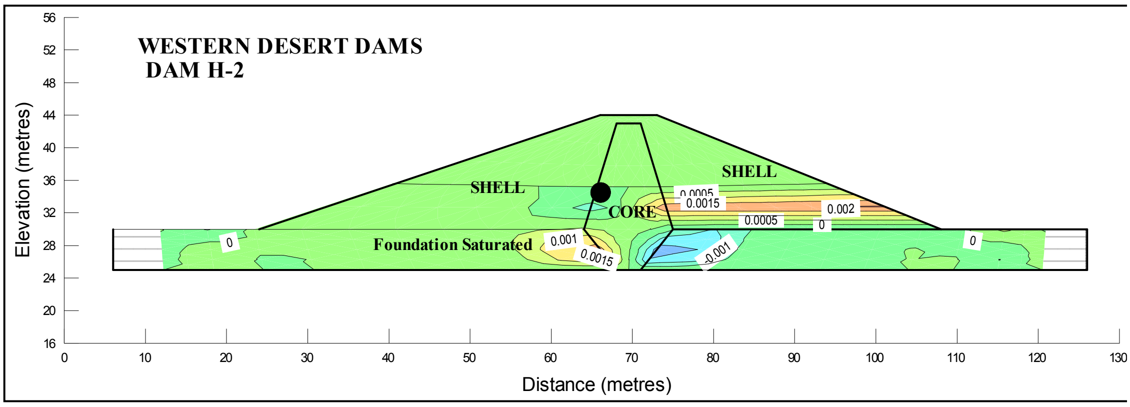

Figure (8): Contours of horizontal displacement for earth dam.

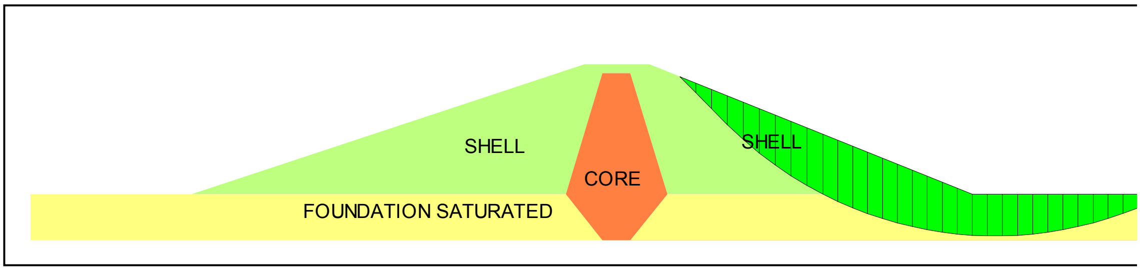

Figure (9): The factor of safety for earth dam.

CONCLUSIONS:

The following conclusions are derived from the results presented:

1) The stability of earth dam H2 is found high stability.
2) The finite element stability analysis method provides detailed information and an independent approach for determining the overall safety factor of the earth dam base on either total and effective stress.
3) The case study presented reduces the risk of dam failure during use it.

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