SEEPAGE ANALYSIS UNDERNEATH DIYALA WEIR FOUNDATION

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ABSTRACT

In this research GEO-SLOPE, SEEP/W finite element package was used to analyze seepage flow under Diyala weir foundation. Two dimensional model of quadrilateral finite element was used to solve the problem.

Seepage of water is one of the major problems, which has an effect upon hydraulic structures. Diyala weir structure is suffering from such engineering problems. It was taken as a case study and it had been drawn and checked against piping and uplift pressure by using numerical model. The effect of removing one of the three sheet piles rows was studied and evaluated to investigate the quantity of seepage, uplift pressure and expected exit hydraulic gradient for these cases.

It was found that the weir foundation and downstream floor problems (cracks and displacement) were due to defect or corrosion of the sheet piles especially in upstream. These problems were not happening when all parts of the Diyala weir structure were fulfilling their functions.

1. INTRODUCTION

Weirs are one of the important hydraulic structures which are considered as low-level dams constructed across a river to raise the river sufficiently and to divert the flow in full, or in part, into a supplying canal or conduit for the purposes of irrigation, power generation, flood control, domestic and industrial uses. Diversion structures usually provide a small storage capacity. Weirs provided with or without gates are also used to divert flash floods to the irrigated areas or for ground water recharging purposes. They are also sometimes used as flow measuring structures.[2, 7]

Weirs may either be founded on an impervious solid rock foundation or on pervious foundation, whenever such a weir is founded on pervious foundation. It is subjected to seepage of water beneath it.

Any seepage problem involves three principal factors: the soil media, the type of flow, and the boundary conditions. Seepage of water is one of the major problems which effect on hydraulic structures. It has the same importance of human necessity for water, but when water exists with big amounts in the non-suitable area would cause a great damage. Therefore, the seepage under the hydraulic structures can be considered one of the most important objects in the hydraulic structures safety. The seepage usually occurs in the impervious soils because of the variation of differential pressures due to differences in water level between upstream and downstream.[10]

Seepage flowing below the foundation of hydraulic structures founded on permeable soils exerts pressure on the structure and tends to wash away soil under it. Excessive uplift pressure and piping are often the main cause of damage of the stability of the structure and may cause its failure.

The aim of this research paper is to examine and evaluate the above dominant causes of failure for Dyiala weir foundation upon permeable soils.

2. DIYALA WEIR DESCRIPTION AND BASIC DATA

The construction of the present Diyala weir commenced in 1966 and was completed in 1969.The structure includes a road bridge and new canal head works. This structure is located 7km downstream from the Hamren dam, approximately 130 Km northeast of Baghdad, near the town of Sidor as shown in Figure 1. [4]

The following data represent the important information which can be used to solve the seepage problems underneath Diyala weir structure and will be the input data for the numerical model:[4, 8]

- Weir crest elevation equals 66.5 m.
- Bed level (B.L), at upstream, equals 61.5 m.
- Weir foundation elevation, at downstream, equals 61.5 m.
- Total length of a weir foundation with the downstream floor equals 24.5 m.
- Maximum water level at upstream (M.W.L) equals 68m.
- Depth of 1st row of sheet piles (upstream sheet pile) equals 4.5 m.
- Depth of 2nd row of sheet piles (middle sheet pile) equals 2.5 m.
- Depth of 3rd row of sheet piles (downstream sheet pile) equals 3.5 m.
- Unit weight of the soil (γ_w) underneath Diyala weir structure equals 18 kN/m^2.
- Permeability for clay soil underneath Diyala weir structure equals 1E-5 m/s.
- Depth of impervious layer below Diyala weir foundation equals 11m from the bed level (B.L).
- Soil foundation underneath the weir is saturated, isotropic and homogenous soil.

Moreover, Figure 2 illustrates the dimensions of Diyala weir structure with the three sheet piles locations.

Fig. 1: Satellite image shows the location of Diyala Weir

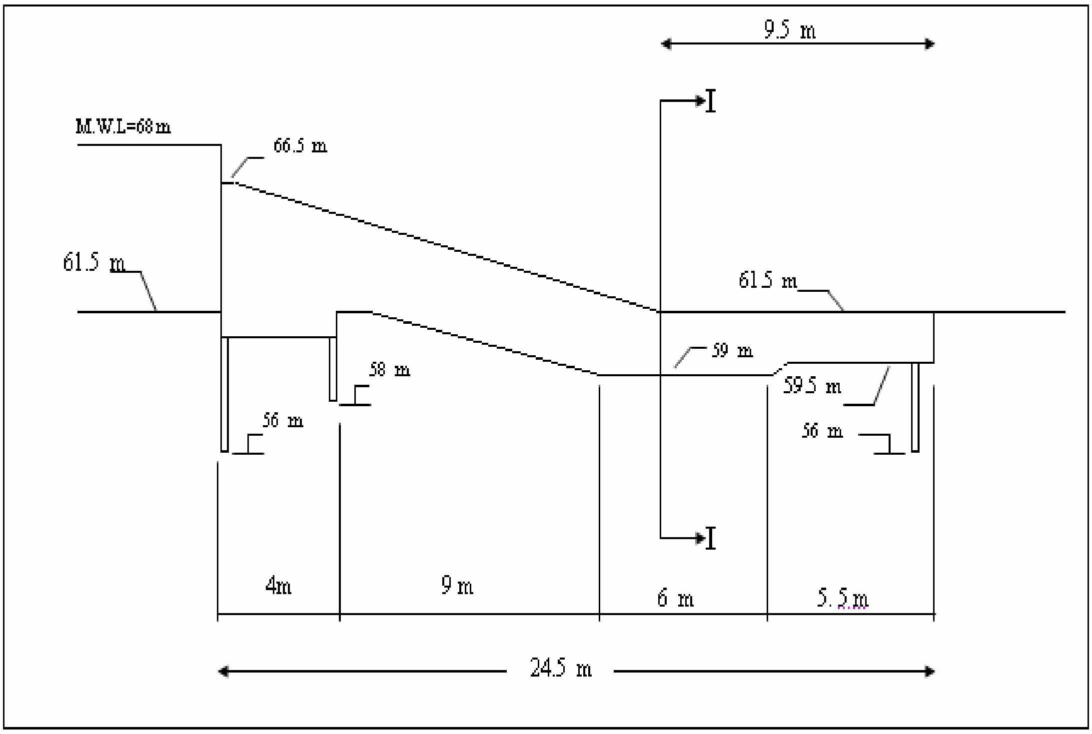

Fig. 2: Dimensions of Diyala Weir Structure

3. METHODOLOGY OF THE MODEL

GEO-SLOPE, SEEP/W (Version 5) is a finite element package that can be used to model the fluid flow and pore-water pressure distribution within porous materials such as soil and rock. Its comprehensive formulation makes it possible to analyze both simple and highly complex seepage problems.

The inclusion of unsaturated flow in groundwater modeling is important for obtaining physically realistic analysis results. In soils, the hydraulic permeability and the water content, or water stored, changes as a function of pore-water pressure.

The discretization of this model into a finite element mesh is calculated as quadrilateral regions and drawn in the problem domain. Inside each region, any number of finite elements can automatically be generated.
The steps of this model are;

i. Defining problems (input);
ii. Solving problems;
iii. Contouring and Graphing Results (output).

However, Diyala weir model have been carried out by using this model and the above steps to predict the seepage under the weir foundation.

4. ANALYSIS OF THE PROBLEM

The study tackles water seepage below Diyala weir structure (on the weir foundation), the quantity of seepage, pressure head and exit gradient were calculated using (GEO-SLOPE, SEEP/W) model.

The four nodal quadrilateral elements were used to idealize the vertical cross section of permeable soil underneath Diyala weir with 358 elements and 425 nodes. Figure 3 shows the finite element mesh for Diyala weir pervious foundation.

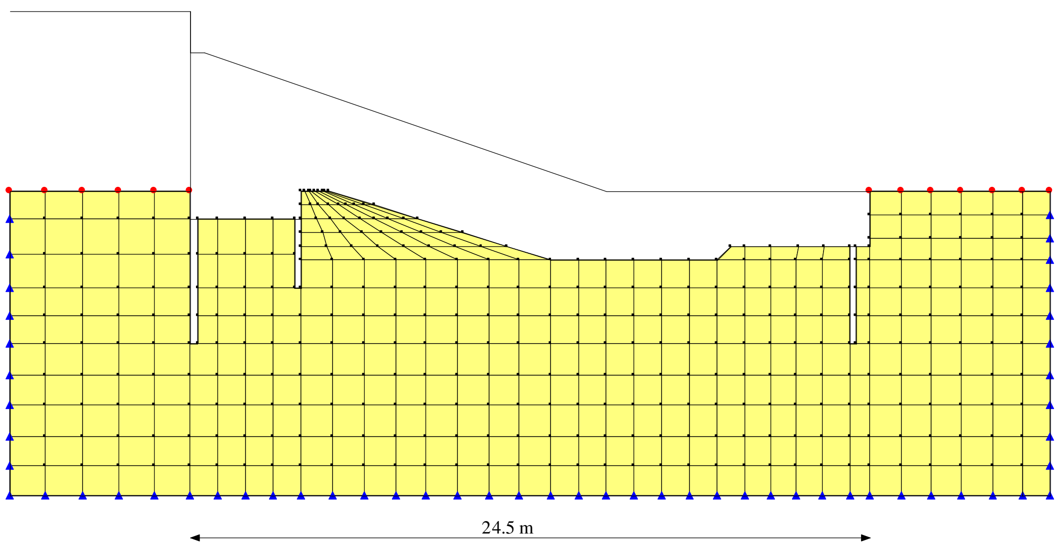

Fig. 3: Finite element mesh for Diyala Weir resting on pervious soil foundation

The value of quantity of total seepage (q) is 9.51E-6 m^3/sec/m (0.82 m^3/day/m), and Figure 4 illustrates the seepage flow path underneath the weir foundation and the quantity of seepage, (Numbers in the Figure referred to the head at each location with respect to the soil depth under weir is 11 m).

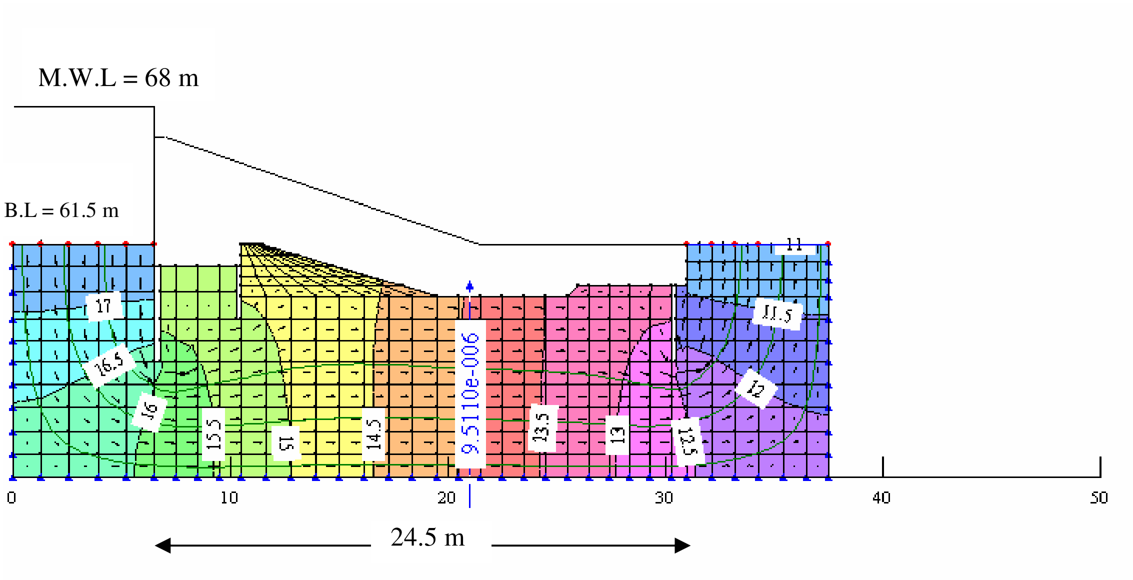

Fig. 4: Seepage of water underneath Diyala Weir Foundation

While, Figure 5 shows the total pressure head distribution underneath Diyala weir floor in downstream for region of section (I-I) as shown in Figure 2.

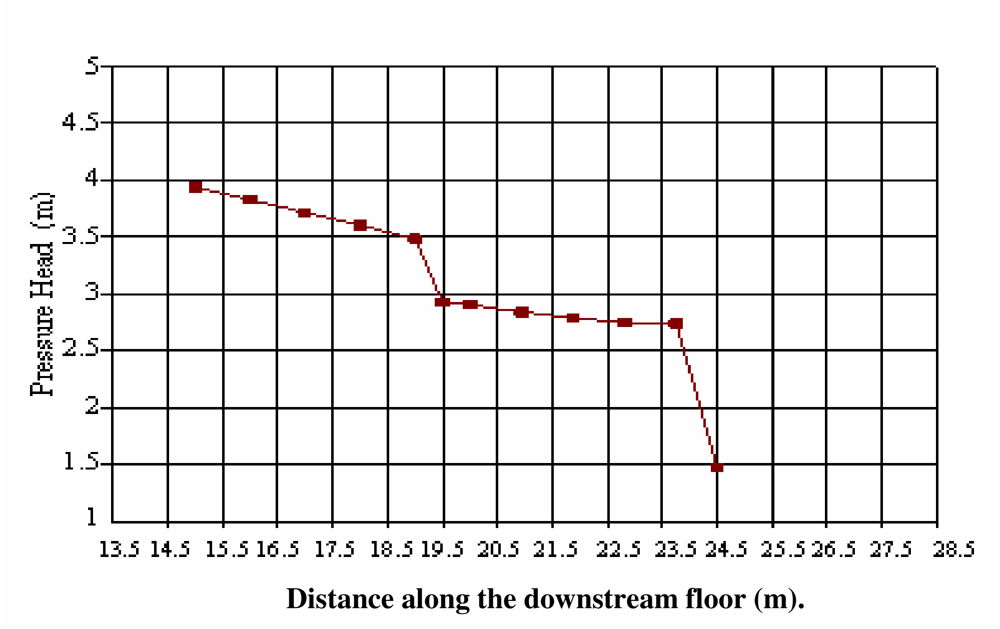

Fig. 5: The total pressure head distribution underneath Diyala Weir floor along the downstream apron

For checking the thickness of the weir impervious floor, the equation below [5];

$$t = (2/3 \times \text{uplift pressure}) \quad (1)$$

Equation (1) can be used to calculate the required thickness of floor according to Ref. No. [5] and compare it with the provided thickness which must be equal to or larger than values of the required thickness.

Table 1 shows the required floor thickness for points below downstream floor-below section I-I, and the provided floor thickness for these points. The distance values of these points were calculated from the weir structure from upstream side. The floor into downstream is divided in two values of thickness. The first part has thickness which equals 2.5 m and the thickness of the second part equals 2 m. All provided thicknesses are larger than the required thickness.

The analysis showed that the downstream floor of Diyala weir is protected against uplift pressure.

In order to check the value of exit hydraulic gradient when the maximum total head loss (*H*) equals 6.5 m. The depth of the last sheet pile at downstream (d) equals 5.5 m, and the length of the hydraulic structure floor (b) equals 24.5 m.

Table 1 Required thickness for downstream floor of Diyala Weir

Distance along the downstream floor (m)	Uplift pressure head below the floor (m)	Required floor thickness (t) (m)	Provided floor thickness (m)
15	3.80	2.49	2.5
16	3.76	2.41	2.5
17	3.71	2.34	2.5
18	3.65	2.26	2.5
19	3.5	2.22	2.5
19.5	2.93	1.95	2
20	2.90	1.93	2
21	2.84	1.89	2
22	2.78	1.85	2
23	2.75	1.83	2
24.5	1.47	1.00	2

The critical hydraulic gradient (i_{cr}) was calculated from:

$$i_{cr} = \frac{\gamma_{sat} - \gamma_w}{\gamma_w} \tag{2}$$

Also, by using value of unit weight of saturated soil underneath the weir structure (γ_{sat}) equals 18 kN/m^2 [1], and unit weight of water 9.807 kN/m^2. The calculated value of the critical hydraulic gradient (i_{cr}) equals:

$$i_{cr} = 0.835$$

This lead to factor of Safety against piping equals;

$$F_s = \frac{i_{cr}}{i_e} \tag{3}$$

and using the exit gradient from Fig. 4 (this value = 0.17), lead to $\boldsymbol{F_s = 4.9}$.

A factor of safety (F_s) of 4.9 is considered adequate for the safe performance of the Diyala weir structure against piping because the factor of safety (F_s) is more than 3. [10]

5. RESULTS AND DISCUSSIONS

From previous checking of uplift pressure and piping, the weir has no engineering problems and is safe. Due to ancientness constructed Diyala weir and the lack of maintenance to the sheet piles, the defect in one or more of the three sheet piles may increase the quantity of seepage, uplift pressure and exit gradient. The defect in one or more of the three sheet piles may be occurring in Diyala weir.

Table 2 shows the results of quantity of seepage and exit gradient for each case as one sheet pile assumed to be removed. It is noted from the results of removing the first sheet pile is more effective on increasing of seepage while removing the third sheet pile is more effective on increasing of exit gradient values but the factor of safety against piping (F_s) for all values represent safe situation.

Table 3 illustrates the total uplift pressure head for the same points of Table 1, for each case (if one sheet pile was removed). However, If the first sheet pile is removed the results shows that this sheet pile is the most effective on increasing uplift pressure, but all cases show that if sheet piles cancellation are failed by uplift pressure and the downstream floor, then it needs thickness more than what is provided.

From this fact, the problems of displacement of the downstream floor (apron slab) and piping underneath the weir are due to defect in the sheet piles (especially the first sheet pile). Scouring upstream of the sheet pile has apparently occurred, exposing the row of sheet piles, also, it could be expected that the end part of sheet piles has corroded. The water passing under the weir or entering the cracks in the weir structure and passing under downstream floor, may lead to erosion of the foundation soils undermining under the weir structure. Solutions are suggested for the weir foundation problems which might include: (*a*) improving the seal between elements of the sheet piles and repairing any defects that may exist in the sheet piles that may have been caused by corrosion; (*b*) sealing cracks in the weir foundation by injection of chemical materials or cement grout.

Table 2 Results of quantity of seepage and exit gradient for each case of one sheet pile was canceled

	Diyala weir without 1^{st} sheet pile	**Diyala weir without 2^{nd} sheet pile**	**Diyala weir without 3^{rd} sheet pile**
Quantity of seepage (m^3/s/m)	1.09E-5	9.62E-6	1.05E-5
Exit gradient (i_e)	0.19	0.17	0.21
Factor of safety against piping (F_s)	4.4	4.9	3.9

Table 3 Results of total uplift pressure head and required downstream floor thickness for each case of one sheet pile was canceled

x-values along the downstream floor (m)	Provided thickness (m)	Uplift pressure head below the floor (m)			Required thickness t (m)		
		without 1st sheet pile	without 2nd sheet pile	without 3rd sheet pile	without 1st sheet pile	without 2nd sheet pile	without 3rd sheet pile
15	2.5	4.29	3.97	3.59	2.86	2.65	2.40
16	2.5	4.20	3.85	3.47	2.80	2.56	2.33
17	2.5	4.06	3.74	3.33	2.67	2.50	2.25
18	2.5	3.90	3.63	3.20	2.60	2.42	2.13
19	2.5	3.79	3.51	3.03	2.53	2.34	2.00
19.5	2	3.19	2.95	2.45	2.13	1.96	1.63
20	2	3.20	2.93	2.42	2.13	1.95	1.61
21	2	3.15	2.86	2.30	2.10	1.91	1.53
22	2	3.00	2.80	2.17	2.00	1.86	1.45
23	2	2.89	2.76	2.04	1.93	1.84	1.36
24.5	2	1.54	1.48	1.78	1.03	1.00	1.19

6. CONCLUSIONS

From the analysis of results obtained by using two-dimension finite element model which calculates quantity of seepage, uplift pressure and exit gradient underneath the weir foundation, the following conclusions can be derived:

1. The present study demonstrates a successful application of GEO-SLOPE in such problems of seepage flowing below the foundation of hydraulic structures founded on permeable soils.
2. Foundation of Diyala weir is safe against piping and any excessive uplift pressures when all the weir structure parts are executing their work successfully.
3. The defect in one or more of the three sheet piles has caused displacement of the downstream floor (apron slab), cracking in weir foundation and scour of soil underneath the weir, due to increasing the quantity of seepage, uplift pressure and exit gradient.
4. Investigation of failure leads to suspect that the sheet piles in upstream is exposing, and could be corroded and defected.
5. The defects in the first row of sheet piles are more effective on increasing uplift pressure and quantity of seepage than the other two rows of sheet piles while defects in the last rows of sheet piles are the most effective on increasing the exit hydraulic gradient.
6. This research suggests solutions for preventing expected weir foundation failure problems by: (*a*) improving the seal between elements of the sheet piles and

repairing any defects; (*b*) sealing any cracks in the weir foundation by injection of chemical materials or cement grout.

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