International Journal of Engineering and Information Systems (IJEAIS)
ISSN: 2643-640X
Vol. 3 Issue 11, November – 2019, Pages: 30-33

Influence of Cavities and Gypsum Soils on Hydraulic Structures: Review

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Abstract— *Hydraulic structures are a feasible structure used to store, distribute and manage the quantity of water. Generally hydraulic structure is a massive build rested or supported by soil so the soil that has direct contact with structure. The soil may be homogenous or non-homogenous, isotropic or non-isotropic and therefore the hydraulic structure has direct linkage with water and soil so the flow through porous media must be considered in the design calculation to give satisfactory results in the stability of this structure during working life. Overall the presence of cavities will be associated on the evaluation of seepage under this structure, uplift pressure and exit hydraulic gradient. Also when this structure is supported by soil with a high quantity of gypsum it will suffer from problems especially regarding the stability of this structure. Gypsum soil is more sensitive to the water and this will reflect on coefficient of permeability of the soil, soil compressibility and soil volume change and these factors will be reflected on soil behavior which is shared with the stability of these hydraulic structures. Sometime hydraulic structures resting on soil contain cavities and this soil is described as gypsum soil therefore the structure undergo resist instability due to pass of water into cavities of gypsum soil therefore many problem appears like crack in structure, soil settlement, variation in seepage quantity under structure and contrast in uplift pressure and exit hydraulic gradient as compared with normal situation.*

Keywords— Cavity, Gypsum soil, Hydraulic Structures, Seepage, Uplift Pressure

1. INTRODUCTION

Hydraulic structures have an important role in the past, present and future life so the stability of these structures prevents the development or growth of any problem which reflect on the required functionality from these structures. The difficult challenge which appears in the site and reflects on the stability of hydraulic structures refers to presence of cavities. These cavities dominate the quantity of seepage, uplift pressure and exit hydraulic gradient. Also, cavities lead to the collapse of the hydraulic structure in some cases so the existence of cavities in homogenous and non-homogenous soil respectively must be considered in design calculation, analysis calculation and assessed correctly with accuracy to avoid damage of hydraulic structures. When hydraulic structures are constructed on gypsum soil or soil containing high quantity of gypsum these structures undergo to encounter many problem during its serviceability life.

2. LITERATURE REVIEW

This section consists of a brief state-of-the art review of research on (1) Impact of cavities on hydraulic structures regardless its distribution under or neighboring hydraulic structure. (2) Impact of gypsum soil on hydraulic structure regardless the type of hydraulic structure which is constructed above the soil type.

2.1 Impact of Cavities on Hydraulic Structures

Reference [1] investigated the response of hydraulic structure due to presence of cavity under hydraulic structure. This work based on (SEEP/W) software to simulate the model of hydraulic structure with a sheet pile located at an upstream of hydraulic structure. Many results for the uplift pressure discharge and exit hydraulic gradient are obtained from this study. It depended on dimensional analysis which is employed to achieve the required analysis between different variables the authors determine the variables which prevalent the problem and have direct relevant with problem. Also based on SPSS the authors derived three equations with coefficient of determination and correlation as listed below

$$q = o.112 K_x\, Y \left(\frac{X}{Y}\right)^{-0.001} \left(\frac{D}{Y}\right)^{0.016} \left(\frac{h}{Y}\right)^{0.718} (K)^{0.099} \left(\frac{B}{Y}\right)^{0.23} \left(\frac{L}{Y}\right)^{0.239} \left(\frac{D_S}{Y}\right)^{-1.01} \left(\frac{d_1}{Y}\right)^{0.827} \quad (1)$$

$$P = o.224\, Y \left(\frac{X}{Y}\right)^{0.002} \left(\frac{D}{Y}\right)^{-0.017} \left(\frac{h}{Y}\right)^{0.721} (K)^{0.004} \left(\frac{B}{Y}\right)^{0.207} \left(\frac{L}{Y}\right)^{-0.761} \left(\frac{D_S}{Y}\right)^{-0.256} \left(\frac{d_1}{Y}\right)^{1.127} \quad (2)$$

$$i = 0.191 - 0.00024X - 0.000198Y + 0.00594D + 0.0686h - 0.0152k \quad (3)$$

In which:

q: seepage discharge, X: horizontal distance measured from cavity center to the structure downstream.
Y: cavity depth measured from the hydraulic structure base, K_x : Soil coefficient of permeability in horizontal direction, K: coefficient of permeability, D: cavity diameter, D_s : Depth to impervious layer.
h: head at upstream, B: hydraulic structure base width, L: horizontal distance from the upstream structure to the upstream sheet pile, d_1 : sheet pile depth at upstream, P: uplift pressure, i: exit hydraulic gradient.
The influence of the presence of the cavities on discharge, uplift pressure and exit hydraulic gradient are investigated regardless the location of cavities or depth of cavities from the ground surface. Also this work included comparative study between results with and without cavities respectively.
Reference [2] studied the influence of a single cavity presence into homogenous soil at a specific location. The behavior of uplift pressure and seepage quantity under hydraulic structure are investigated. From the obtained result of uplift pressure and seepage quantity a deterministic formula was obtained. This work based on experimental investigation included many samples with different diameters of cavities. This paper discovered that the impact of cavity on seepage altered between positive to negative based on the location of cavity. A statistical program has been performed to derive the deterministic formula for seepage and uplift pressure.

$$\frac{q}{kD} = 0.0377 + 0.0018\left(\frac{H}{D}\right)^3 - 0.0086\frac{X}{L} + 0.0364\frac{Y}{L} \quad (4)$$

$$\frac{h}{D} = -0.410 + 0.735\frac{H}{D} + 0.081\frac{X}{L} \quad (5)$$

In which:
X: horizontal distance between the center line of the cavity and the dam, Y: vertical distance between cavity center line and dam base, D: cavity diameter, L: dam base length, H: water head, k: hydraulic conductivity, q: seepage quantity.
Reference [3] generated a formula to determine seepage start time with the presence of a single cavity in homogenous soil at a specific location under hydraulic structure. This study revealed the effect of size and location of cavity on seepage start time. This work based on experimental investigation which included many samples with different diameters of cavities. The results imply that the presence of cavity has positive effect on start time of seepage. A statistical program has been performed to derive the deterministic formula for seepage start time.

$$\frac{t}{t_\circ} = 0.3062\left(\frac{q}{kD}\right)^{-0.5082} \quad (6)$$

In which
t: the record seepage start time with existence of cavity, $t_\circ$:considered the base quantity of the seepage start time, D: cavity diameter, k: hydraulic conductivity, q: seepage quantity.
Reference [4] studied the characteristics of seepage by adopting experimental work. The tested model consisted of a dam and sheet pile located at different positions (at the heel of dam, at mid. span of dam floor, at the toe of dam). The model was supported by sandy soil containing cavities at different locations and directions. About thirty three models are tested in the laboratory to estimate seepage quantity and direction of flow line by using the experimental work. It was founded that the suitable location of sheet pile at the toe of dam considering cavity with ($X_c/B = 0\ and\ 0.5$) while that the suitable location of sheet pile at the heel of dam considering cavity with ($X_c/B \geq 1$) and for negative location of the cavity that the suitable location of sheet pile at mid. Span of floor dam.
Reference [5] achieved an experimental work to investigate the effect of cavities on dam stability during flow of water. The result determined the suitable position of sheet pile considering the existing of cavity with different position horizontally and vertically.
Reference [6] adopted experimental work to investigate the influence of several factors (like cavity size and location) on seepage quantity, flow line and steady time. These factors will be reflected on interference between cavity and neighboring hydraulic structure which rest on sandy soil. Depending on experimental data which is supported by dimensional analysis and statistic software the authors obtained an equation to compute seepage quantity.

$$q/_{k.D} = 0.061\left\{\left(X/_D\right)^{0.0014}\left(Yu/_D\right)^{2.455}\left(Yd/_D\right)^{-0.995}\right\} \quad (7)$$

With coefficient of determination equal to (0.86).
In which
X: horizontal distance between cavity center line and sheet pile center line in upstream side and downstream side, Y_u: vertical distance between cavity center line and water level at upstream , Y_d: vertical distance between cavity center line and water level at downstream, D: cavity diameter, k: hydraulic conductivity, q:seepage quantity.

2.2 Impact of Gypsum Soil on Hydraulic Structure

Reference [7] mentioned that the gypseous soil covered about 31.7% from the area of Iraq with percentage of gypsum between (10%-70%).

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Reference [8] achieved a theoretical work to investigate the behavior of gypsiferous soils. Also she made a comparison between results and experimental work. This comparison reviews the relation between dissolution of gypsum and time of leaching which reflects on pore water pressure, displacement and concentration. Reference [9] explained the influence of leaching and content of gypsum on gypsiferous soil properties. Reference [10] examined the behavior of three gypsiferous soils type from different region in Iraq during leaching under variable hydraulic gradients. They are obtained from the test that the conventional test method is not convenience to the gypsiferous soils owing to influence of dissolution gypsum and leaching due to soaking or/and flowing of water through porous media.
With that in mind, a new Soil Leaching Apparatus was developed. This Apparatus' defining qualities include having a large diameter and being modified. It was used in studying the effects of leaching on the behavioral qualities of gypsiferous soils under different stresses of this leaching using two flow directions. These flow directions are upward flow (UWF) and downward flow (DWF), with both of them being conducted under different hydraulic gradients. In addition to that, they are also used to study values of the permeability coefficient in these soils under the condition of leaching. The results have shown that as times passes, leaching strain and accumulative dissolved gypsum increases. Meanwhile, a gradual decrease is seen in the permeability coefficient (k) as time passes and with an increase in leaching stress. Furthermore, the permeability that was gained through the upward flow direction was less than the permeability obtained downward flow direction. Aside from that, the samples that were leached showed increases in the collapse potential (CP), most commonly with soils that contain a high percentage of gypsum. Results also shows an inverse relationship between collapse potential and diameter to height ratio (D: H). In conclusion, the soils have direct shear tests carried out on them in conditions of before and after leaching. The results show that shear strength parameters (c & Ø) decrease after leaching as in [10].

Reference [11] examined the potential collapse of unsaturated Iraqi gypseous soil considering different initial conditions like initial dry density and degree of saturation respectively. They adopted three different gypsiferous soils types. They concluded the increase in dry density lead to a decrease in potential collapse. Also, as the initial water content increasing leads to a decreasing in potential collapse value. When void ratio increases the potential collapse increases for each soil. For each soil, the collapse potential decreases when the initial degree of saturations increases.

Reference [12] investigated the behavior of gypsiferous soil which is improved by using soil-cement mixture (to make stabilization of gypsum soil by cement-soil mixture). Samples of soil are brought from Karbla Governorate. The experimental tests were carried out into flume with constant velocity.

3. Conclusion

The following noticeable point can be obtained from the present review.

1. The size and location of cavities will reflect on seepage quantity, value of uplift pressure and exit hydraulic gradient.
2. Cavities and permeability coefficient can be considered independent variables leading to change in seepage quantity, value of uplift pressure and exit hydraulic gradient.
3. In general the upstream head is affected by the presence of cavities.
4. The presence or absence of cavities under hydraulic structures gives a comparable result in theoretical and/or experimental work.
5. Determining the seepage start time represent very important matter due to fluctuation in seepage quantity with time.
6. The trend of flow lines depends on geometry of hydraulic problem regardless of presence or absence of cavities under or neighboring hydraulic structures.
7. The flow line shapes based on cavity location and size.
8. Gypsum soil causes many problems to hydraulic structures which is rested on the soil regardless of presence or absence of cavities in these soil.
9. Gypsum soil suffers from damage especially when this soil has direct contact with water.
10. Hydraulic conductivity, soil compressibility, and volume change represent major factors which dominate the behavior of gypsum soil.

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