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SEEPAGE IN FILYOS LEVEES WHOSE UPSTREAM FACE IS COVERED

ABSTRACT

Filyos River Basin covers an area of 13.000 km^2 in the Western Black Sea Region in Zonguldak. The project area is 203 km in the east-west direction and 120km north-south direction and the slope of the river is quite small. The flood protection project of Filyos River included construction of a total 7km of levee. The aim of this study is to investigate the seepage on covered surface and under the levee when its surface is covered with various materials. The covered materials involve riprap (andesite rock), filter layer (uniform sand) and geocomposite (geomembrane and geotextile). The PlaxFlow module was used for this study and the points of the seepage on covered surface and under the levee are investigated with this software. In the sections at the drilling points, the piping condition expected to be under the levees was investigated. Besides, drilling was carried out at 11 different distances under the Filyos Levee. As a result of the analysis, the most critical cross-section of TSK-13 was found.

Keywords: Levee, Transient Flow, Geocomposite, Seepage, Piping

1. INTRODUCTION

Levees are constructed along rivers to protect the surrounding areas. Soil properties are important factors for determining seepage in protected structures. Seepage analysis is a very important part of geotechnical and hydrological engineering. It involves basic geotechnical problems which are seepage failures, contamination of ground water, slope stability issues, foundations and design of earthfill structures [13]. These seepage failures are generally protected with levees of clay material, rock fill, concrete bags, breakwaters, sheet pile walls etc. and geosynthetics materials are used to inhibit seepage under levees and into levees [6]. The aim of this paper is to study the transient flow caused by flood for levee of Filyos River. A steady-state seepage occurs when hydraulic head, flow rate or given soil hydraulic properties don't change within time. In transient flows, the variables depend on time. Numerical modeling based on finite element method was performed in the analysis. PlaxFlow, an add-on module to Plaxis 2-D [2], is used for the time variation of seepage in several points of interest within the levee. Geosynthetics are used by civil engineering, geotechnical engineering, transportation, hydraulic and environmental projects nowadays. There are several functions of geosynthetics such as filter, drainage, protecting, erosion control separation, reinforcement and impermeability [12]. Types of geosynthetic are geotextiles, geonets, geocomposites, geogrids and geosynthetics clay layers etc. ASTM (2005)

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is defined that a geocomposite is "a product composed two or more materials, at least one of which is geosynthetic [3]. The following are illustrative examples:

Geomembrane/Geotextile Composite
Geonet/Geotextile Composite
Geogrid/Geotextile Composite
Geomat/Geotextile Composite

Riprap covering has a good granulometry and rock material should be diameter of grain max 90mm and grain volume max 0.75 meter cubic [1]. It has a mixture of hard, solid and durable rock fragments. Sand gravel filter criteria should be compared between the aquifers producing seepage and the soil being protected. Composite geomembrane has the lowest permeability value, so this material is prevented. Figure 1 shows examples of levee covering types. There will be occured failures which are piping, sand boil and heaving on the levee surface and under the levees. Each levee is analyzed using PlaxFlow module in Plaxis-2D in case unsteady state and upstream face of levee is covered materials. Critical hydraulic gradients are compared values of different soil types within covered materials.

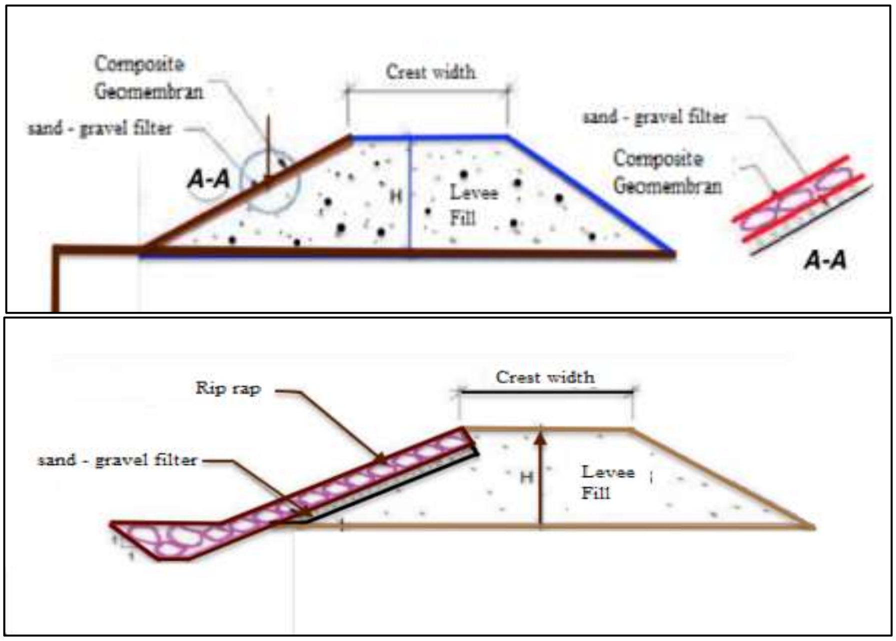

Figure 1. Composite geomembrane and riprap covering

The hydraulic gradient is a vector gradient between two or more hydraulic head measurements over the length of the flow path and it is shown 'i' [10]. The critical hydraulic gradient is related to soil porosity and density. It is required to cause a quick condition. It occurs in upward flow (for cohesionless soil) and when the total stress equals to pore water pressure [15]. Soil particles outflow from soil surface, so it is called critical hydraulic gradient [14]. Hydraulic gradient compares to critical hydraulic gradient of soil. If hydraulic gradient reaches critical gradient, formation of sand boiling is occurred. A sand boil generally occurs sand, silty sand, sandy silt and silty soils. It is calculated according to equation 1.

$$i_{cr} = \frac{\gamma'}{\gamma_w} = \frac{G_s - 1}{1+e} \tag{1}$$

where;

i_{cr} =critical hydraulic gradient

γ' =submerged unit weight of soil

γ_w =unit weight of water

G_s =specific gravity of soil

e =void ratio of soil

If the water pressure grows enough, it may lift the top layer upward a mechanism. This generally is called as heave. And then, the top layer may crack and sand boil formation can from there. According to Salem (2010), boiling occurs sand soil types in case quick condition and heave observes clay soil types. Exit gradient is that calculated using hydraulic head data from the top two to three rows of elements below the ground surface [5]. In the second failure mechanism case is the factor of safety against heave. F_{heave} is calculated according to equation 2. Safety factor has to be higher than 3 against to heaving potential.

$$F_{heave} = \frac{H.\gamma_{sat}}{H_m.\gamma_w} > 3 \quad (2)$$

If the hydraulic gradient reaches the critical hydraulic gradient, the balance in the soil mass is distorted and it moves up. The soil - water mixture exits on the surface [7]. This is called piping or internal erosion. Heaving is observed when seepage forces push the substrata upward. F_{piping} is calculated according to equation 3. Safety factor has to be higher than 5 against to heaving potential.

$$F_{piping} = \frac{i_{cr}}{i_{max}} > 5 \quad (3)$$

where;

H = thickness of overlying top layer (m)

γ_{sat} = saturated unit weight of overlying top layer (kN/m^2)

H_m = average hydraulic head at the point(m)

γ_w = water unit wight (kN/m^2)

i_{max} = maximum exit gradient

2. RESEARCH SIGNIFICANCE

Levees are embankments constructed of compacted earthen material. These materials can be impervious and semi impervious, but sometimes they may be pervious levee fill such as sands or gravels. Levees are generally constructed for floods of range of frequencies 50 years (average between 25 or 100 years). The aim of this study is to investigate the seepage on covered surface and under the levee when its surface is covered with various materials. The materials involve riprap (andesite rock), filter layer (uniform sand) and geocomposite (geomembrane and geotextile). The PlaxFlow module is used for analysis and the points of the seepage on covered surface and below the levee are examined with this software. Soil permeability is a property of the soil transmitting water and it is one of the most important qualities to consider for seepage analyses. Permeable materials generally contain continuous voids. The more permeable the soil is, the greater the seepage [9]. Some soils are so permeable hence it is not possible to build hydraulic structures without techniques. The permeability of soils is really important to determine the effect on stability of foundations, seepage loss through embankments of reservoirs, drainage of subgrades, excavation of open cuts in water bearing sand, rate of flow of water into wells and many others [8]. Soil permeability is influenced by many factors such as pore size, particle shape, particle density, fluid density and number of pores. Finer soil texture shows slow permeability.

Figure 2. Filyos River Basin [4]

3. FINDINGS AND DISCUSSIONS

3.1. Datas of Filyos River (Determining unit Hydrograph and Flow Hydrograph)

Unit hydrograph is the most popular and widely used method for predicting flood hydrograph. Snyder method is used due to the fact that flood basin of Filyos river is larger than 1000km^2. The basin characteristics which are area, shape, topography, channel slope, stream density are affected by the shape of unit hydrograph and this is the main idea of this method. The unit hydrograph graph is obtained with the help of (q_v) yield value. Figure 3 is used to find width of hydrograph. 0.75 q_p and 0.50 q_p is equal to Tw_{75} and Tw_{50} to obtain unit hydrograph. Peak discharge is calculated according to equation 9.

L =195km

L_c =92km

$t_p = C_t * (L * L_c) 0.3 = 30.8 hr$ (4)

$t_r = t_p / 5.5 = 5.5 hr$ (5)

$q_p = 2760 * C_p / t_p = 54.8 (lt/s/km^2/cm)$ (6)

$Q_p = q_p * A * 10^{-3} = 72.8 (m^3/s/mm)$ (7)

$N = 0.9 * A * 0.2 = 6 days$ (8)

$Q_p = q_p * A * 10^{-3} = 72.8 (m^3/s/mm)$ (9)

Tw_{50}=58 hr 1/3.Tw_{50}=19.3 hr 2/3.Tw_{50}=38.7 hr

Tw_{75}=35 hr 1/3.Tw_{75}=12 hr 2/3.Tw_{75}=23 hr

where;

L = Length of levee

L_c = Length of between the centry of gravity of basin and exit point of basin

C_t = Basin coefficient

C_p = Basin coefficient

t_p = The time of duration for peak discharge

t_r = The time of effective precipitation

q_p = Peak discharge per unit area

A = Area of basin

N = Fall time of the flood level

Table 1. Filyos river flood peak calculation

Filyos River Flood Peak Calculation	
100-Year Precipitation Height of the Basin (mm)	85.82
Critical Rainfall Time (hr)	24
Total Flow (mm)	29.12
Q_p (m^3/s/mm)	72.8
Peak Discharge of Hydrograph (m^3/s)	2120

Figure 3 shows a relation between the discharge and time. Figure 4 presents relation river level and time during the flood. Peak discharge is 2120m^3/s at 6.5 meter high of levee and the time of duration for peak discharge (T_p) completes 30.8 hours. The fall time of the flood level is 144 hours. Time of duration of hydrograph of Filyos River is approximately completed within 7.5 days. The levee height is designed as 6.7 meters and air share of levee is 0.2 meters. The maximum discharge reaches 6.5 meters of the levee. In PlaxFlow, data of the change of flood height depending on time is entered. Consequently, seepage is investigated the change of flood height depending on time (transient analysis) in Filyos levees whose upstream face is covered. Therefore, in each seepage analysis, flood height-time graph data is used.

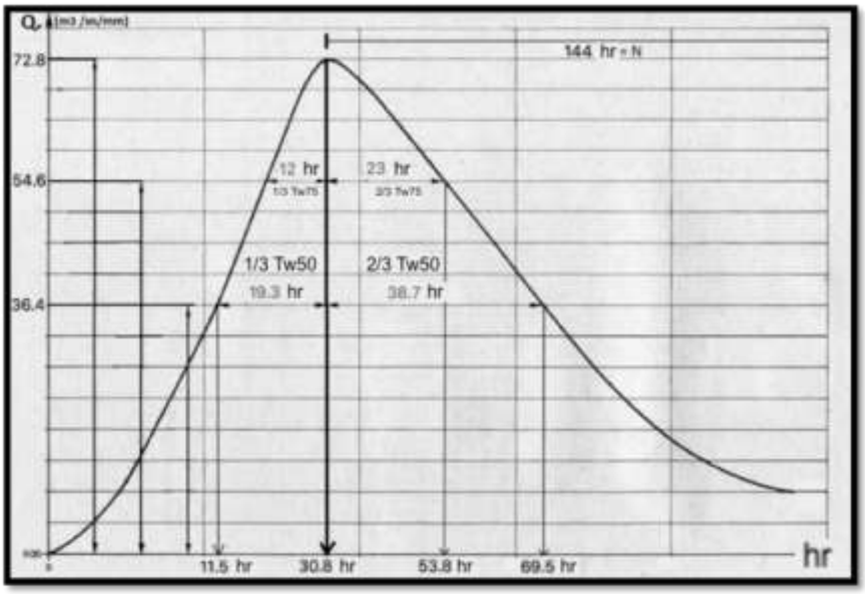

Figure 3. Unit hydrograph of Snyder method [16]

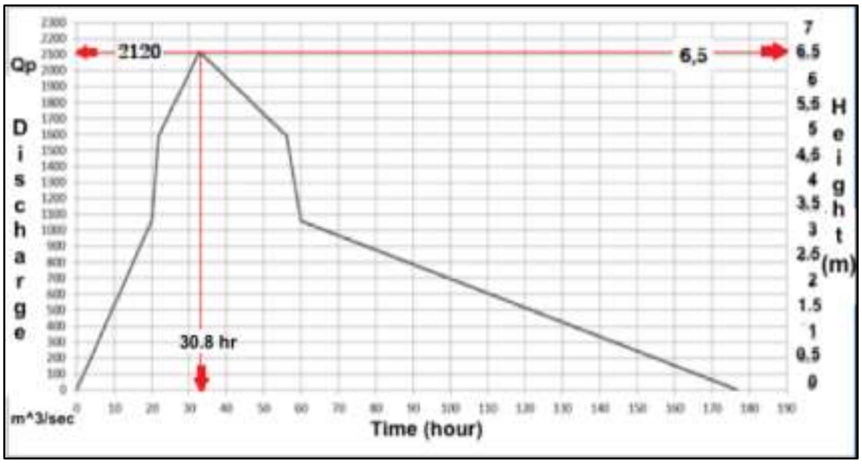

Figure 4. Flow Hydrograph Relation between the River Height, discharge and time

PlaxFlow enables many features for analysis of transient groundwater flow problems with several conditions in time. Also, time-dependent conditions are only used for transient analysis. Irregular variations like a flood in water levels are modelled using harmonic, linear or user-defined time distributions to enable time-dependent water level.

3.2. Soil Properties of Filyos Basin

Drilling must be made in order to know the soil properties. Since the alluvium forming the basement floor is very variable in Filyos basin, it is better to perform shallower and frequent foundation drilling. Six drillings drilled at 30 meters deep on the left shore. On the right shore, a total of five drillings drilled at depths of 30m. TSK is a drilling no name. The sample drilling analysis is in the Table 2 at below.

Table 2. Soil properties of TSK-1

Depth(m)	Soil Type	Permeability (k) (m/sec)	Specific Gravity (G_s)	Void Ratio (e)
0.0-6.0	Clayey Silt	$1x10^{-7}$	2.70	0.90
6.0-27.5	Silty Clay	$5x10^{-8}$	2.75	1.78
27.5-29.0	Clayey Silt	$1x10^{-7}$	2.70	0.90
29.0-30.0	Silty Clay	$5x10^{-8}$	2.75	1.78

The general information about soil properties are defined at Table 3 and used inputs are permeability (k), specific gravity (G_s) and void ratio (e) that are important for both levee and under seepage of levee. There are soil properties of Filyos basin in Table 4.

Table 3. Soil properties of levee members

	Soil Type/ Material	Permeability (k) (m/sec)	Specific Gravity (G_s)	Void Ratio (e)
Levee	Gravelly Sand	$5x10^{-4}$	2.66	0.62
Filter	Uniform Sand	$1x10^{-3}$	2.67	0.70
Riprap	Andesite Rock	0.645	2.65	0.34
Geocomposite Material	Geotextile and Geomembrane	$1x10^{-13}$	-	0.02

Table 4. Soil properties of Filyos basin

Soil Type	G_S	e	γ_{sat} (kN/m^3)	γ_s (kN/m^3)
Clayey Silt	2.70	0.90	18.6	26.5
Silty Clay	2.75	1.78	16.0	27.0
Clayey Sand	2.67	0.43	21.3	26.2
Sand	2.68	0.55	20.4	26.3
Gravelly Sand	2.66	0.62	19.9	26.1
Gravel	2.65	0.27	22.6	26.0
Silty Sand	2.69	0.43	21.4	26.4
Sandy Silt	2.68	0.85	18.7	26.3
Sandy Clay	2.72	0.47	21.3	26.7
Sandy Gravel	2.65	0.50	20.6	26.0
Clay	2.80	1.85	16.0	27.5
Silt	2.70	1.10	17.8	26.5
Gravelly Clay	2.71	0.80	19.1	26.6
Gravelly Silt	2.69	0.75	19.3	26.4

4. ANALYSIS

Numerical modeling based on finite element method performed the analyses [2]. In particular, PlaxFlow is an add-on module to Plaxis 2D and it was used for the transient variation of flow in several points of interest within these structures. Transient exit velocities at the levee toe, seepage forces, and hydraulic gradients were investigated according to levee contains geomembrane.

4.1. Filyos Levee at 44.24m on the left shore of Filyos River (Upstream face is covered)

The schematic representation of Filyos Levee and soil profile are given in Figure 5. Filyos levee includes gravelly sand soil type and cover materials against piping and sand boil formations. The cover materials are riprap which is andesite, uniform sand filter layer and geocomposite layer. There is a clayey silt layer under the levee and this layer is 6m thick. The layer below the levee is the critical layer and the phenomenon of piping and sand boiling is observed in these layers. Since critical conditions were not observed in the layer under the embankment, other layers were not investigated.

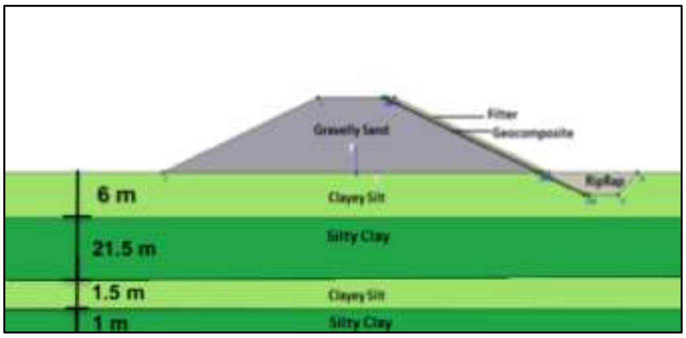

Figure 5. Filyos Levee with cover materials at 44.24m on left shore of Filyos River

Figure 6 shows that each soil layers have saturated unit weight under the levee with cover materials for transient analysis and area of under the flow line is saturated during h_{max}. Saturation rates of red areas are high and saturation rates of other areas are almost zero with riprap, filter and geocomposites. It is seen that flow values are high at the red area because of h_{max} under the flow line according to PlaxFlow (Figure 4). There is not a risk that is observed piping into through levee.

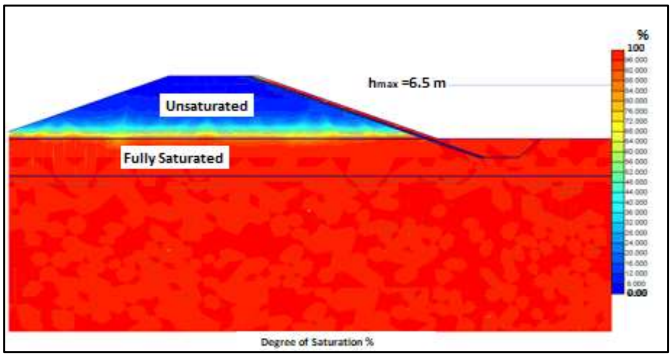

Figure 6. Degree of Saturation of Filyos Levee with cover materials at 44.24m on left shore of Filyos River during h_{max}

4.2. Analysis of Clayey Silt at Under The Levee and on The Levee

Figure 7 shows that location of points near the ground surface for finding extreme velocity and Figure 8 presents that results of flow velocity at K, L, M, N, O, P and Q. K point is on the Filyos levee and this point is under the phreatic line and piping formation is observed at this point. L point is at levee toe and the other points are under the levee.

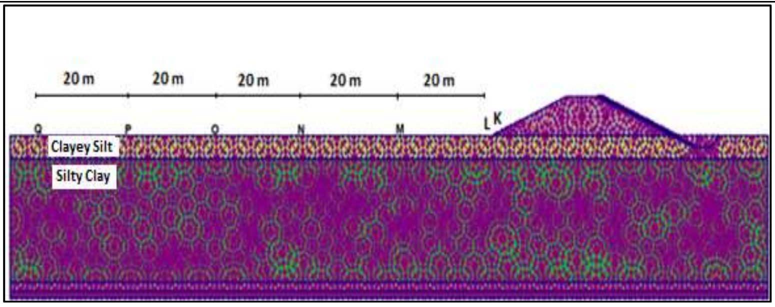

Figure 7. Location of points near the ground surface for finding extreme velocity

Piping formations, sand boil formations and heaving potential may be observed at these points. Piping formations simply compate as;

v=k.i [11] (10)

$$i_{cr} = \frac{\gamma'}{\gamma_w} = \frac{G_s-1}{1+e} = \frac{2{,}66-1}{1+0{,}62} = 1.02 \quad \text{(for gravelly sand)}$$

$$i_{cr} = \frac{\gamma'}{\gamma_w} = \frac{G_s-1}{1+e} = \frac{2{,}7-1}{1+0{,}9} = 0.89 \quad \text{(for clayey silt)}$$

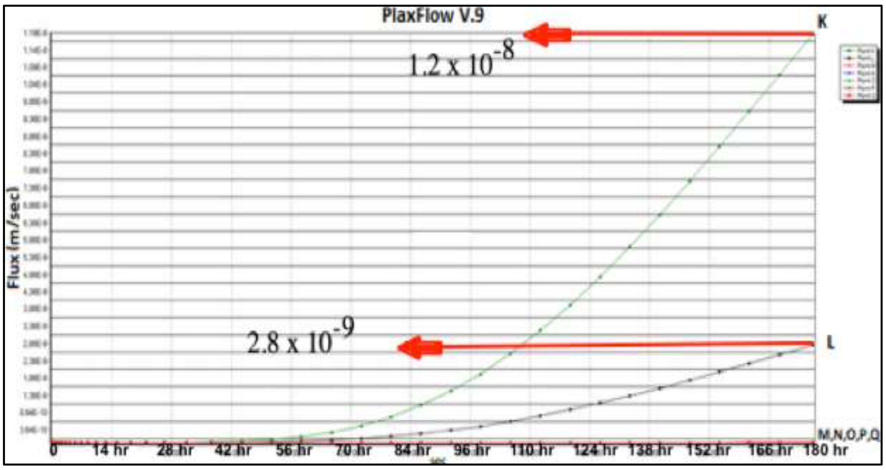

Figure 8. Extreme velocity graph relation time Filyos Levee

Table 5 shows that piping is not observed at any points due the fact that exit gradient is zero.

Table 5. Piping status

Symbol	Max Seepage Velocity (m/s)	Permeability (m/s) (k)	Exit Gradient (*i*)	Piping
K	1.2×10^{-8}	1×10^{-7}	0	Not
L	2.8×10^{-9}	1×10^{-7}	0	Not
M	3.5×10^{-10}	1×10^{-7}	0	Not
N	3.0×10^{-10}	1×10^{-7}	0	Not
O	3.0×10^{-10}	1×10^{-7}	0	Not
P	3.0×10^{-10}	1×10^{-7}	0	Not
Q	3.0×10^{-10}	1×10^{-7}	0	Not

In order for the sand boiling to occur, the piping must take place. As can be seen in the Table 6, it did not reach critical gradient for the formation of boiling. Heaving potential is not observed because levee has cover materials along river, so the exit gradients approach zero.

Table 6. Sand boil status

Symbol	Max Seepage Velocity (m/s)	Permeability (m/s) (k)	Exit Gradient (*i*)	Sand Boil
L	2.8×10^{-9}	1×10^{-7}	0.03	Not
M	3.5×10^{-10}	1×10^{-7}	0	Not
N	3.0×10^{-10}	1×10^{-7}	0	Not
O	3.0×10^{-10}	1×10^{-7}	0	Not
P	3.0×10^{-10}	1×10^{-7}	0	Not
Q	3.0×10^{-10}	1×10^{-7}	0	Not

5. CONCLUSION AND RECOMMENDATIONS

The study is a part of the research with the aim to reveal a methodology about soil mechanical behavior of levees during flood. PlaxFlow V9 provides inputs of hydrological and soil properties data in transient analysis. Filyos levees were designed according to steady state but this study investigated transient effects of seepage flow on Filyos levees and under levees associated with sand boil, piping and heaving formation.

Table 7. Conclusions

Drilling No	Soil Type on Top Layer	Max Exit Gradient					Heave and Piping Analysis on Top Layer
		K	L	M	N	i_{cr}	
TSK-2	Silty Clay	0	0	0	0	0.63	Since approximately $i_{max}=0$, heaving and piping are not likely to occur
TSK-3	Silty Clay	0	0	0	0	0.63	Since approximately $i_{max}=0$, heaving and piping are not likely to occur
TSK-4	Sand	0	0	0	0	1.1	Since approximately $i_{max}=0$, heaving and piping are not likely to occur
TSK-5	Sandy Silt	0	0.04	0	0	1.1	Since approximately $i_{max}=0$, heaving and piping are not likely to occur
TSK-6	Silty Sand	0	0	0	0	1.2	Since approximately $i_{max}=0$, heaving and piping are not likely to occur
TSK-9	Clayey Sand	0	0.03	0	0	1.2	Since approximately $i_{max}=0$, heaving and piping are not likely to occur
TSK-10	Clayey Silt	0.12	0.04	0.01	0	0.89	Since approximately $i_{max}=0$, heaving and piping are not likely to occur
TSK-11	Clayey Silt	0	0	0	0	0.89	Since approximately $i_{max}=0$, heaving and piping are not likely to occur
TSK-12	Clayey Silt	0	0	0	0	0.89	Since approximately $i_{max}=0$, heaving and piping are not likely to occur
TSK-13	Clayey Silt	0	0.37	0.32	0.22	0.89	F_{heave} is higher than 3.0 and F_{piping} is smaller than 5.

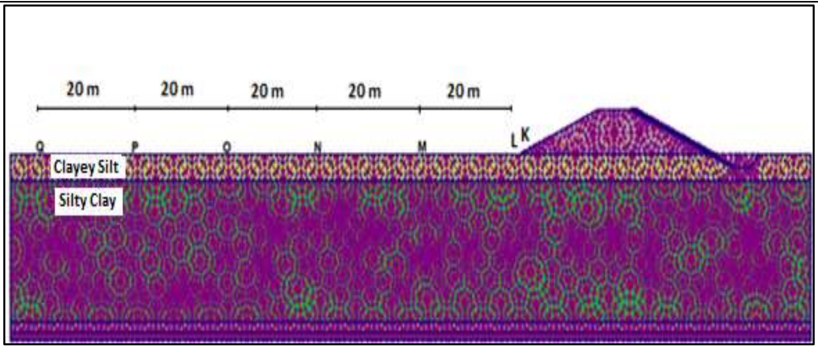

Figure 9. Points of analysis

Fallowing conclusions are drawn from this study:

- Maximum exit gradient doesn't exceed critical hydraulic gradient, so sand boil formations are not observed at levee toe (Point L).
- Maximum exit gradients are 1.02 for gravelly sand soil type and 1.2 for silty sand soil type, but these values are approximately zero, so piping formation doesn't occur (K point) thus geocomposite materials are useful to bloke seepage. The maximum exit gradient is respectively 0.78 and 1.0 through into levee and into through filling (silty sand layer), so piping formations aren't observed in here.
- Since factor of safety is higher than 3, heaving potential aren't observed at ground surface.

Overall, geocomposite materials are useful to bloke seepage for all analyses. If the top layer is thin and same grain size, it increases the risk of piping and sand boil formation for only TSK 13. In addition, this study can be repeated frequently with up-to-date data.

CONFLICT OF INTEREST

The authors declared no conflict of interest.

FINANCIAL DISCLOSURE

The authors declare that this study has received no financial support.

DECLARATION OF ETHICAL STANDARDS

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

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