

1 **Determine the height of the vertical filter for in heterogeneous earth dams**
2 **with vertical clay core**

3 **Abstract:**

4 In order to determine the height of the filter in heterogeneous earth dam, three embankment
5 models were provided in a flume laboratory, with the length of 4.2 m at the base of dam, the
6 width of 60 cm and the height of 1 m and body slope 1H: 2V. For embankment of model, two
7 types of fine and coarse grained soils were used. The texture of the soil was made using
8 hydrometer method. In the first model, the fine-grained and coarse-grained soils were used in
9 downstream and upstream of the dam crest respectively. In Models 2 and 3 with cutting fine
10 grained soil from the toe of the dam to the dam crest, vertical clay core was replaced. Index
11 of a / L (a thickness of clay core and L is the length of base dam) was 1.7 and 1.10 in the
12 second and third models respectively. Seepage experiments in 3 water height of 80 and 55
13 and 30 were performed. The phreatic surface was determined using wells and 30 embedded
14 Piezometer in the models. Then rate of falling head due to clay core was measured and it
15 compared with software PLAXIS V 8.5 results. Height of filter the clay core with safety factor
16 1.2 (Encounter Line Leak with 20% of the bottom filter) was introduced. The thickness and hydraulic
17 conductivity of the clay were affected decline of water level.

18
19 **Keywords:** Model of heterogeneous earth dam, Height Filter, thickness of the clay core, software
20 PLAXIS V8.5

۲۲ **Introduction:**

۲۳ Ghahremani and sahebzade surveyed the rate of leakage and Static and dynamic
۲۴ sustainability in the earth dam Black –rock with using of The finite element method and
۲۵ Using software PLAXIS and GEO-SLOP in 1383.then Based on analysis For leak ,Best
۲۶ injection depth in the dam foundation 28 meters was recommended. Fatholahi Marani and
۲۷ Sabagh Yazdi harvested the effect of having drainage in upstream slope on the pore pressure
۲۸ and upstream slope stability. During the rapid depletion of the reservoir, Since entering bar of
۲۹ water On the upstream slope The effective stress and Safety factor are reduced in this region .
۳۰ In This article has been expressed If incompressibility shell, pore pressure distribution will
۳۱ follow the Laplace equation (Jiang et al. 2014). But if it is compressible Due to the relatively
۳۲ large volume change of shell during the drop in water levels in the reservoir and changes in
۳۳ porosity and permeability of the material Laplace's equation cannot be used unless this
۳۴ changes to be considered. Results on a hypothetical model of earth dam with a height of 25 m
۳۵ showed the use of drains in the dam located on rigid foundation that all wedge Rupture is in
۳۶ the body, had a more impact. In the case of dams located on non-rigid foundations the use of
۳۷ drains in upstream will not work. It also recommended.
۳۸ Due to the focus of the pore pressure As much as possible embedded drainage should be
۳۹ placed in higher elevation than the Foundation. More importantly, piping effects in these
۴۰ areas should not be neglected (Kazemzadeh-Parsi and Daneshmand 2013).
۴۱ Mirghasemi and Pakzad in 2005 examined Permeability in Foundation of Karkheh Dam in
۴۲ Iran plus Uncertainty associated with the results of the surveys.
۴۳ To determine the permeability, Lejeune tests and pumping tests and finite element method
۴۴ was used. by comparing the results Was determined that The permeability obtained of
۴۵ Lejeune method About 100 times lower than the permeability obtained from other methods.

٤٦ This is due to areas with high permeability in the foundation. Pumping test methods and
٤٧ indirect methods due to consider a whole pile of stones display this phenomenon better. In the
٤٨ Lejeune method because the obtained data associated with a point cannot represent the whole
٤٩ permeability layer (Garcia et al. 2011).

٥٠ Rakhshanderoo and Bagherie Investigated How leak on Panzdah Khordad earth dam after
٥١ dewatering in 2006.this investigation by SEEP3D software and with using of Finite element
٥٢ method and in three-dimensional was performed. Water head in the upper crust was assumed
٥٣ equal to the water level in the reservoir. And downstream of the core was removed from the
٥٤ calculations. Finite element analysis was performed for a constant pore pressure. Whereas
٥٥ According to The observed results in some months. In the construction process and
٥٦ dewatering, Pore pressure was variable And it was not sustainable.

٥٧ Based on the results observed when increasing the water level in the reservoir Piezometers
٥٨ near the upstream dam were immediately impressed and showed this increase faster. Well as
٥٩ the waste water pressure near Piezometers that were near the downstream filter were faster
٦٠ displayed. The pore pressure observed with the results of finite element analysis showed good
٦١ coordination (Fredlund et al. 2011).

٦٢ Finally, it was observed that the leakage characteristics of the dam and rate of that Almost are
٦٣ determined by saturated zone and unsaturated zone or Suction area have very little impact on
٦٤ that. And even can be said that had no effect.

٦٥ Bagheripur and Marandi in 2005, with modelling Homogenous and isotropic earth dam, the
٦٦ model Nomorof evaluated to Control of seepage from Homogenous and isotropic earth dam.
٦٧ Nomorof model was compared with built model and good results have been obtained.

٦٨ Mohammad Vali Samani and the Nabavianpoor in 2009 determined the exact location of the
٦٩ leak by the boundary element method. Require less time and memory for modelling problem.

70 Solve Equation as analytical and Limitation of approximations to the borders is The
71 advantages of this method.

72 Researchers with modelling of homogeneous earth dam investigated effect of tiller drainage
73 with different angles and length and height on the leak. Modelling was performed with
74 software SAS and PLAXIS Version 8. That with 95% confidence level, there wasn't error
75 between experimental data and software. Finally, the height of drainage increase (Wang et al.
76 2014).

77 Length towards the height of the water behind the earth dam And also reduce the angle α the
78 rate of Leak flow Rises. Considering these results to choose the best high drain Toward the
79 water behind the dam embankment, and The optimum angle for design of toe drains, After
80 ensuring

81 Crossing Line free of leaks from inside the drain, Drainage design should be such Be
82 minimized leakage flow rate (Chen et al. 2011).

83 **Materials and method:**

84 Laboratory flume: the experiment was performed in a height laboratory flume, which was 6
85 meter long, 60 centimetres wide and 1.2 meter high, in Soil Mechanics Laboratory of
86 Shahrekord university of Iran. The structure of flume was consisted of a 2-millimetre thick
87 galvanized sheet on the floor and on the back wall and 15 millimetres Plexiglas on the other
88 septum. To avoid galvanized sheets developing in the bottom, some metal backrests were
89 used. An entrance door was placed on the ending of the home for the ease of access; and two
90 evacuation valves were placed at the bottom of the flume (on starting and ending) to be
91 embedded in the water.

92 Draining Box: To collect the drainage water, a draining box with the length of 0.6 meter,
93 width of 0.9 meter and the height of 0.4 meter was prepared. It consisted of an access hatch
94 and an evacuation valve on the bottom. The box was filled with sand up to a height of 20

90 centimetres for the filtration of drainage water. This was installed and isolated at the end of
96 flume's bottom. Some 3 mm diagonal holes (up side of drainage box) with 2.5 centimetre
97 distance from each other were applied in the box, 0.9 long and 0.6 meter wide, to enter
98 drainage. It should be noted that according to USBR standards, some 3 mm diagonal drainage
99 holes were used.

100 Piezometers and observation wells: To measure water pressure into the flume, 30 piezometers
101 were reticulated from the middle to the end of Plexiglas septum which were embedded and
102 isolated as well. These had inbound filter and plastic tube. The inbound filter of these
103 piezometers was sunk into the clay in a depth of 5centimetres.

104 **Device Multimeter:** To read the water in the wells of a multi-meter device was used. That is the
105 positive and negative poles of the device without connecting to the bar together were placed in
106 isolation and when you connect this area with the Multimeter water resistance survey, resistance
107 shows that the water level is indicated. Also the entry of water into the soil fines into the wells of a
108 filter cloth was used that the entry of water into the well in the fine increased.

109 **Soil Mechanics Tests:**

110 Grading: In order to determine the aggregation curve of used soil in body dam, standard sieves and
111 hydrometer method was applied (Fig. 1 and Table 1). Using a hydrometer test the grading of fine
112 grain size (diameter less than 0.075 mm) was determined. For fine-grained soils after grading standard
113 elks, The fine (diameter passing through a sieve of 200) after drying and weighing aggregation,
114 aggregation was determined by hydrometer tests and then by buffering of the three samples drawn
115 diagrams It was clear that about 20 percent coarse soil and about 60% of the second soil had Fine-
116 grained. This amount fine-grained includes clay and silt .It is noteworthy that the position of this
117 elks is according to the table 1. Used soils specifications were shown in table 2.

118 **Density testing:** To assess the density of dams, test weight per unit volume of dry soil in place was
119 donning. With this test can be surveyed true or false of density testing. Also by this test can
120 determinate the amount of energy required to compress the soil layers. As was mentioned the purpose

۱۲۱ of this experiment is calculate γ_d of soil. There are several ways to do this. But the most common of
 ۱۲۲ them that is handled in most projects, is Sand Cone Method and Rubber Balloons method (Askorchi).
 ۱۲۳ In many soil cases, it is necessary to dry density of soil in place being 90 to 95% dry density that is
 ۱۲۴ obtained in lab. Sometimes this topic defined as the relative density and shown as R

Equation.1

$$R(\%) = \frac{\gamma_d}{\gamma_{dmax}} \times 100$$

γ_d : dry density of soil in place

γ_{dmax} : dry density of soil in Laboratory

۱۲۵ In this research to reach an acceptable density, first by Proctor test standard the damp of Soil samples
 ۱۲۶ whit 20 and 60 percent fine were determined. That is cleared Laboratory Equipment and also graphs
 ۱۲۷ of dry density and Optimum damp for tow soil samples are shown in Figs 2 and 3.

۱۲۸ After determining dry density and Optimum damp for tow soil samples, to reach required density we
 ۱۲۹ do in this way: we divided section of dam to different trapezoid and with this trapezoid layer within
 ۱۳۰ dam, (that was 0.6 meters) Their volumes were calculated and by dry density and required volume of
 ۱۳۱ soil; Weight of dry soil obtained. And by adding Optimum damp to the soil, and Condense it(using
 ۱۳۲ Standard hammer) as far as total weight to be placed in the desired volume.

۱۳۳ In this case, since the specific gravity of the volume reached percent concentration is reached
 ۱۳۴ to one hundred percent. But often some of the weight of the soil remains that According to the
 ۱۳۵ following relations dividing the weight of dry soil to the total weight of soil on the volume
 ۱۳۶ soil compaction is achieved.

Equation 3

$$\gamma_{d \max} = \frac{W_s}{V} \Rightarrow W_s = \gamma_{d \max} \times V$$

$$R(\%) = \frac{\gamma_d}{\gamma_{d \max}} \times 100 = \frac{\frac{W_s}{V}}{\frac{W_t}{V}} = \frac{W_s}{W_t} \times 100$$

Equation 3 : relative compression percentage
determination of layers

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۱۳۸ Used soil parameters: The measured characteristics of the soils used are described below.

۱۳۹ **Types of materials used in the main body of the model:**

۱۴۰ In order to reduce permeability and prevent excessive leakage of water heterogeneous earth dam of
۱۴۱ SC (sand and clay) was selected. Range size of sand used to build the model was 0.5 to 5 mm. In this
۱۴۲ study, two sources of clay were used to supply clay: According to the available sediment in
۱۴۳ reservoirs of dams properties are fully accessible; the first source of sediment accumulated in the
۱۴۴ reservoir of Pirbalut dam located 20 kilometres from Shahrekord and the second source of clay soil on
۱۴۵ the Campus. According to clay minerals used due to viscosity and high compressibility should be
۱۴۶ made of kaolinite. The two amount of clay was combined and liquid limit of them was determined
۱۴۷ using Casagrande. Humidity of 25 beats of it was 48 percent.

۱۴۸ **Laboratory hydraulic conductivity:** Two soil types using Proctor Experiment were beaten and
۱۴۹ reached to laboratory maximum density. Hydraulic conductivity tests were performed on samples in
۱۵۰ their terms. For 20% fine-grained soil is located in the coarse range constant head-method was
۱۵۱ perfumed. Falling head-method was perfumed for fine-grained soils (60% fine-grained).at the end
۱۵۲ Hydraulic conductivity was determined using this Equation and $k_2=0.035\text{m/day}$ $k_1=0.2\text{m/day}$
۱۵۳ Obtained.

۱۵۴ **Performed experiment:**

۱۵۵ In this study, three executive models were used (Figs 4 and 5). The first model was included of
۱۵۶ fine-grained and coarse-grained soils .that from dam crest to upstream coarse-grained soils
۱۵۷ was used and from dam crest to downstream fine-grained soil was used. The second model was
۱۵۸ included of three parts: $\frac{a}{L} = \frac{1}{7}$ base of the dam consist of fine-grained soil and on both sides of that
۱۵۹ coarse-grained soils was used. Due to the use of the second and third models was the effect of the
۱۶۰ thickness On-line free of leaks Located in The body of the dam. In this model, three experiments
۱۶۱ were performed without drainage. In The second model same as the first model, experiments for the
۱۶۲ maximum height with $\frac{a}{L} = \frac{1}{7}$ was performed. And the volumetric flow rate of leakage was measured.
۱۶۳ Also phreatic line was drawn using Observation wells. In The third model same as the first model,

164 experiments for the maximum height with $\frac{a}{L} = \frac{1}{10}$ without drainage claws was performed. Also
165 phreatic line was drawn using Observation wells.

166 **Flow rate:** Discharge leak Came from the body of the earth dam with Using the volumetric
167 method was measured. Line free leak at the First with using the observation wells and then
168 with using resistance - high was drawn. In resistance – high method with using Resistance
169 between two metal bars in the water column and the relationship between the height and
170 Resistance readings by the device resistance thermometers The water height in the body of
171 earth dams was determined. In this study, Metal rods calibrated In parallel with a diameter of
172 10 mm and height of 120 Cm inside the insulating sheath in The observation wells were
173 placed . But because of the high resistance of the device; Welding wire was used too. Long
174 rods, Genus bars, the spacing between the bars, Impurities of water and the semiconductor
175 between two rods was fixed. In a series of experiments to investigate the leak without water
176 drainage, Water upstream of the dam for the first model In 3 heights 30, 60 and 80 was
177 considered. And For other models maximum height of the water that is 80 cm was
178 considered. It should be noted that in each experiment the water gradually reached the desired
179 height and until the end of each experiment, the water level at the three height mentioned was
180 kept constant. With the passage of water leakage flow, the water Inside Piezometers
181 Gradually rose. And with saturation of the soil environment was fixed. It should be noted that
182 Saturation of the Soil porous medium About 72 hours and sometimes up to 96 hours was
183 performed. And every 15 hours, the water height was adjusted at the desired height. That it
184 was performed with the constant flow of drainage, Drop in upstream water level and the
185 height of water in Piezometers. In 30, 60, 55 cm height of the first model, The first line
186 (Phreatic line) At a height of 80 cm of upstream water did not cut No point of downstream
187 slope , Phreatic line cut downstream slope from dam claw.

۱۸۸ **Results:**

۱۸۹ **The results of Laboratory models of heterogeneous earth dams:** Phreatic lines with using
۱۹۰ observation wells and Piezometers Installed in the flume, in experimental models of
۱۹۱ heterogeneous dam Was determined as follows. Experiments when the water level in the
۱۹۲ experimental model is 80 cm in height on the model of in homogeneous earth dams in the
۱۹۳ laboratory were performed.

۱۹۴ **Definition Model and determine the initial conditions and Border in Software:** After harvest
۱۹۵ and survey data obtained from experiments, modelling in PLAXIS software was performed. First, a
۱۹۶ geometric model of a section of the dam must be created. To do this work According to the Executive
۱۹۷ section of laboratory model in flume, geometric model in PLAXIS program was created. In the
۱۹۸ second step is required data related to the materials used in the body of the dam. It is noted that the
۱۹۹ data relating to hydraulic conductivity was measured with using constant head experiment and falling
۲۰۰ head experiment. And by comparing these values with the table and different relations finally the
۲۰۱ acceptable value was considered.

۲۰۲ **Discussion**

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۲۰۴ **Comparison of experimental results in heterogeneous model with software model**

۲۰۵ **PLAXES V8.5:** With Measuring the hydraulic conductivity of the shell and core of earth
۲۰۶ dams that was performed with using constant head-method and Falling head-method.
۲۰۷ Modelling in software PLAXES V8.5 was performed. Phreatic line of software models and
۲۰۸ laboratory models were compared together (Figs 6,7 and 8). Using statistical software SAS,
۲۰۹ P-values were calculated. Accordingly, there is no significant difference in the level of
۲۱۰ confidence of 90 to 98 percent. Also, some root mean square error (RMSE), was calculated
۲۱۱ for all conditions that the results are given in Table 3.

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۲۱۴ **The results of the software for the heterogeneous model:**

۲۱۵ The results for the inhomogeneous model with using the software are provided. With changing
۲۱۶ various design parameters were suggested. That, with changing the hydraulic conductivity of the
۲۱۷ core and shell heterogeneous earth dam and also changing the thickness of the clay core as shown
۲۱۸ in Fig. 10 and Measure the rate of decline in the clay core in software(Fig. 11). Therefore with having
۲۱۹ k_2/k_1 Optimum height of the filter with safety factor 1.2 can be determined.

۲۲۰ **Obtaining the rate of decline in fine-grained soils with using software model:**

۲۲۱ According to the rate of decline in water level in fine-grained soils with using of software data Fig. 10
۲۲۲ was drawn that in heterogeneous state the rate of decline in water level in fine-grained soils
۲۲۳ According to the ratio of hydraulic conductivity for shell to core is shown.

۲۲۴ So it is harvested when $\frac{k_2}{k_1} \leq 0.002$ layer thickness of fine-grained have little effect on the rate of
۲۲۵ decline in water level

۲۲۶ **Determine the height of Suggested filter with Using of software model:**

۲۲۷ Analysis and comparison between water failure in interface of fine-grained and coarse-grained soils,
۲۲۸ both of software model and laboratory model have a relatively well fit. To obtain the height of
۲۲۹ suggested filter (Fig. 9), the software model was used to simulate the experiments and Subtracting the
۲۳۰ thickness of the fine-grained. Finally, given that in the engineering design of earth dam, After the clay
۲۳۱ core, usually the height of the filter layer is used as the height of clay and due to decline in free
۲۳۲ leakage line in fine-grained soil and encounter with soil in shell of dam with height h_2 (The height
۲۳۳ of the free leakage line from the bottom of impermeable layer in interface of coarse-grained and fine-
۲۳۴ grained soil in downstream.) In Fig. 11 values according to the thickness of the fine-grained and
۲۳۵ hydraulic conductivity ratio of core to shell dam and the maximum height of the dam dewatering was
۲۳۶ introduced. By applying safety factor of 1.2, height was designed to filter and after the clay core was
۲۳۷ introduced.

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240 **References**

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Table.1: Percentage of Fine-grained of coarse grained soil

Number of layer	1	2	3
Percent of fine soil	19	20	22

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Table 2: used soils specifications

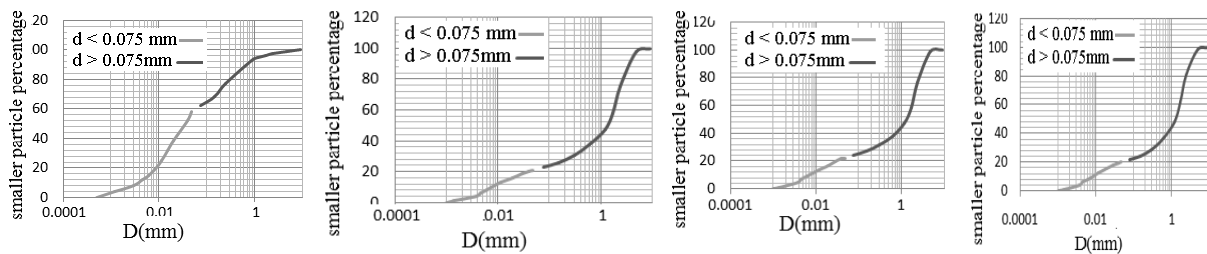
Parameter	Curse	Core	Filter & Drain
γ_{dry} (KN/m ³)	17.5	18.5	17.5
γ_{sat} (KN/m ³)	19	20	19
K_x (m/day)	0.2	0.035	30
K_y (m/day)	0.2	0.035	30
$E_{ref} * 10^4$ (KN/m ²)	11	200	7
ν	0.35	0.3	0.3
C_{ref} (KN/m ²)	1	2	1
ϕ (phi)	40	35	45
ψ (psi)	10	10	10

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Table.3: Comparison between measured piezometers and calculated using PLAXIS software

model	1	2	3
P-value	0.03	0.095	0.062
Confidence limit	97	91	94
RMSE	0.561	0.424	0.475

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(d):Fine-grained soil(60%)

(c): Third layer of coarse grained soil

(b):Second layer of coarse grained soil

(a):First layer of coarse grained soil

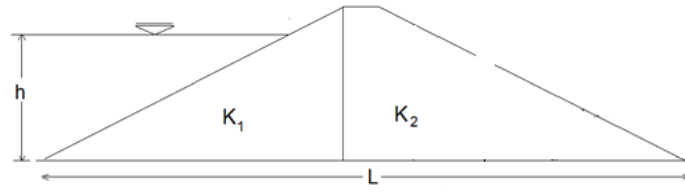
Fig.1 : Aggregation curves of fine and coarse grained soil

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Figure 2: dry density and Optimum damp of 60% fine

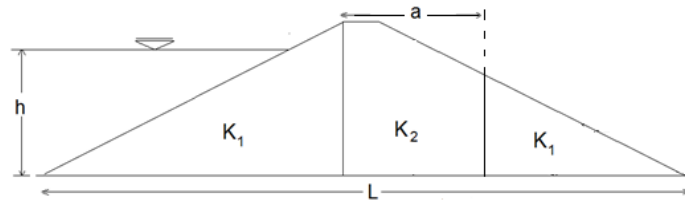
Fig.3: dry density and Optimum damp of 20% fine.



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Fig.4:Scheme of the first operational heterogeneous earth dam model



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Fig.5:Scheme of the second and third operational heterogeneous earth dam models($a/L=1/7, 1/10$ in the second and third models respectively)

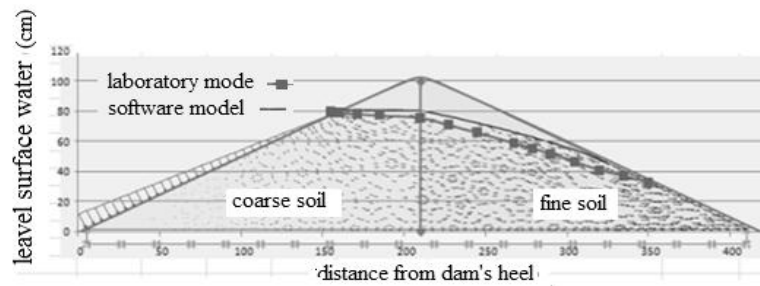


Fig.6 : Comparison of laboratory model No.1 with PLXIS model

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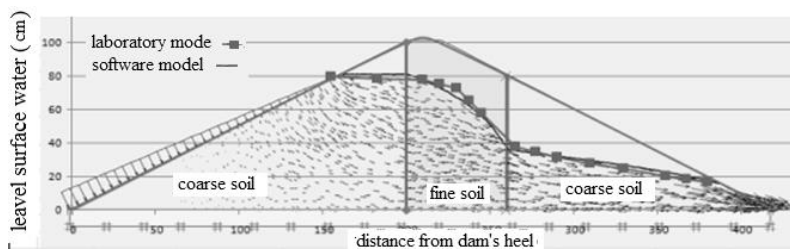


Fig.7 : Comparison of laboratory model No.2 with PLXIS model

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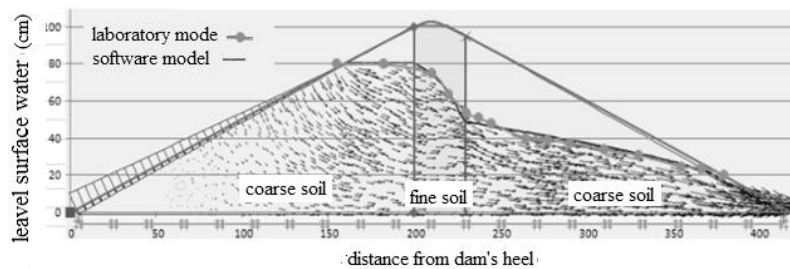


Fig.8 : Comparison of laboratory model No.3 with PLXIS model

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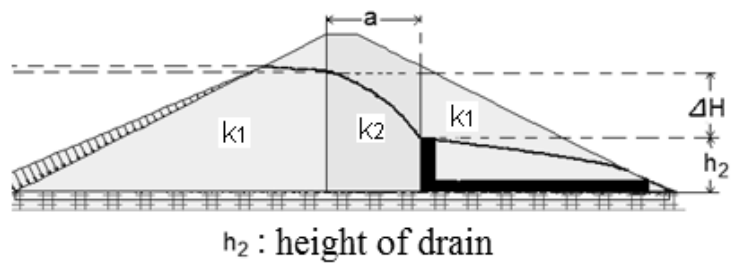


Fig. 9: Scheme of vertical filter

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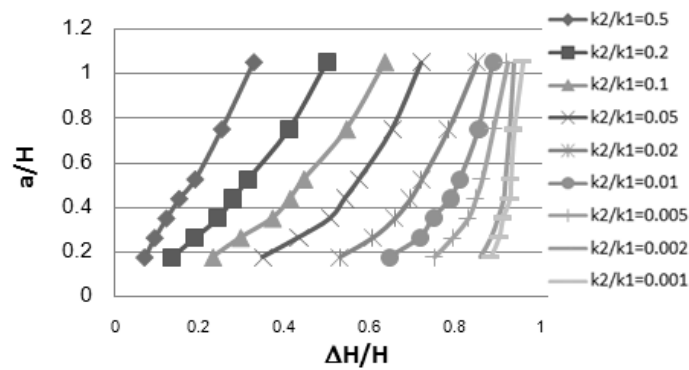


Fig.10: Effect of thickness and hydraulic conductivity of the clay on decline of water level

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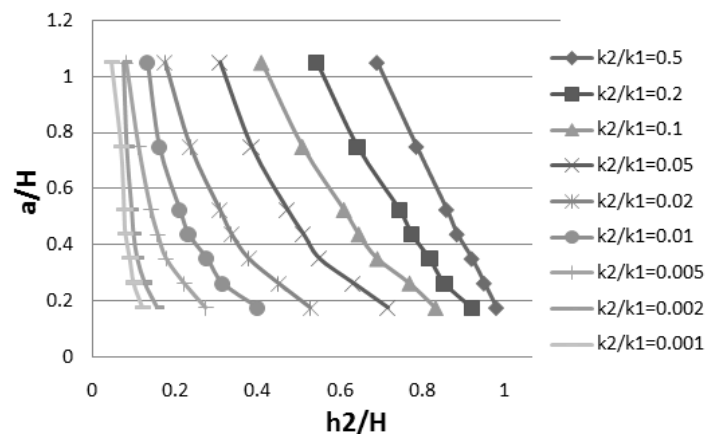


Fig.11: Height of filter with safety factor of 1.2

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