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PERFORMANCE STUDY OF GEOTEXTILE FILTER IN EARTHEN DAM WITH FLYASH AND BENTONITE AS BASE SOIL

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ABSTRACT

Filters are integral part of earthen dams. which are provided to lower the phreatic surface within the dam. A geotextile filter constitute an attractive solution and can be used as a replacement to conventional granular filter, particularly for those areas where quarry material is available only in limited quantity. The present study is based on model tests where an earthen dam is made by flyash (a freely available material in abundance in any part of India) and bentonite, which is also easily available in some parts of India. Thus, the base soil as flyash and bentonite and geotextile as a filter have been used in the present model study.

Experimental test results obtained by model tests have been validated by SEEP/W– GeoStudio 2007 software.

Keywords: *Earthen dam Flyash, Bentonite, Geotextile Filter, SEEP/W*

INTRODUCTION

Chimney Filters and horizontal filters are used for lowering the phreatic surface and to ensure safety and integrity of the whole dam structure. Satisfying the filter requirements in the earthen dams is of primary importance. Projects, where granular material is not available in abundance at or around site or where the aggregate of appropriate sizes cannot be obtained in adequate quantities, the design and construction of filter can be a tedious and uneconomic task.In such cases, graded filter can be either expensive or difficult to construct. It may even lead to compromising the filtration efficiency. In such situations, geotextile filter may provide an attractive solution and can be used as a replacement to granular filter.Recent ban by Hon'ble Supreme court in India (and may be in other countries also) on stone and sand quarrying has caused the price of sand gone up because of its becoming a rather rare material. In the present scenario geotextile filters, supported by proper design consideration can be a cost effective solution without compromising the safety of hydraulic structures (Mittal, 2014, FEMA 2011, Koerner et al.,1984, Sato et al.,1986, Zobernberg, 2012, Giroud, 1996).

Flyash is a freely available material as it is almost a waste material from thermal power stations Millions of tonnes of flyash and bottom ash material are available at each thermal power station. Similarly, in some parts of India, bentonite is available in abundance (such soils are available in many countries). Therefore if small earthen dams have to be made, such soils may be used as a base material also. In the present paper, these 2 materials are used as base material and geotextile is used as a filter material. The results of model tests have been compared with software also, as mentioned above.

DESIGN OF GRANULAR FILTER

Cedergren (1977) suggested that the filter material should satisfy two conflicting requirements:

1. Piping Requirement

The pore spaces in drains and filters that are in contact with erodible soils and rocks must be small enough to prevent particles from being washed in or through them.

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2. Permeability Requirement

The pore spaces in drains and filters must be large enough to impart sufficient permeability to permit seepage to escape freely and thus provide a high degree of control over seepage forces and hydrostatic pressures.

Grading of the protective filter can be related to that of the soil being protected by the following relationships (Ranjan & Rao, 2002):

$$\frac{(D_{15})\ \text{Filter}}{(D_{85})\ \text{Base Soil}} < 5 \qquad \text{.....(1)}$$

$$4 < \frac{(D_{15})\ \text{Filter}}{(D_{15})\ \text{Base Soil}} < 20 \qquad \text{.....(2)}$$

$$\frac{(D_{50})\ \text{Filter}}{(D_{50})\ \text{Base Soil}} < 25 \qquad \text{.....(3)}$$

Few Other Specifications for Granular Filter (Mittal, 2013) are as follows:

(i) $(D_{15})_{\text{Filter}} \geq 5\ (D_{15})_{\text{Base Soil}}$ or 0.1 mm whichever is higher ..... (4)

(ii) $(D_{15})_{\text{Filter}} \leq 9\ (D_{85})_{\text{Base Soil}}$ or 0.2 mm whichever is higher ..... (5)

(iii) $(D_{15})_{\text{Filter}} \leq 0.7$ ..... (6)

(iv) $(D_{15})_{\text{Filter}} \leq 4\ (D_{85})_{\text{Base Soil}}$ ..... (7)

(v) Material passing 75 □ should not exceed 5% ..... (8)

Limits of $(D_{10})_{\text{Filter}}$ and $(D_{90})_{\text{Filter}}$ for preventing segregation are here as under (Table 1):

Table 1: Limits of (D_{10}) Filter and (D_{90}) Filter for Preventing Segregation

(D_{10}) Filter (Min) (mm)	(D_{90}) Filter (Max) (mm)
< 0.5	20
0.5 – 1.0	25
1 – 2	30
2 – 5	40
5 – 10	50
10 – 50	60

MODEL TESTS

Tests On Earthen Dam Model – Without Any Filter

Earthen dam model was constructed using flyash and bentonite as base soil separately in different models. This model dam was tested for the seepage flow through the downstream side of the cross-section in the absence of filter. Schematic of cross sectional profile of the model and the model constructed in the laboratory has been shown in Fig. 1. The Fig. 2 illustrates the photograph of model test. The earthen dam model was prepared in a steel tank with following dimensions:

Height = 850 mm, Length = 3000 mm, Width = 635 mm. The upstream side of the embankment was filled with water upto a height of 0.5m (Fig. 2). A constant head was maintained at the upstream side by providing an outlet for water in the tank at 0.5m height. At the downstream side whole width of the tank was sealed with a brick wall in which a steel pipe was provided as an outlet to collect the water seeping through downstream side which was measured with time (Fig. 3). More details are given elsewhere (Anamika, 2015).

Thus, the dam section had following dimensions :

Cross-sectional area = 1.02 m^2 , Slope angle (□) = 26.56 degrees

Volume of Earthen Embankment = 1.02 x 0.635 = 0.6477 m^3. The

weight of flyash required for the construction of the model embankment was = 1.31 x 0.6477 x 1000 ≃849 kg. Density of the embankment (for 65% relative density) = 1.31 kN/m^3 . The grain size analysis of the base soils, with which dam model were made, are shown in Fig. 4 (A) & 4 (B).

The engineering properties of flyash were as follows:

(a) Gravel Content = 0%
(b) Sand Content = 20%
(c) Fines Content = 80%
(d) Liquid Limit & Plastic Limit - Zero each
(e) Hydraulic Conductivity = 1.6 X 10^{-11} cm/sec

The soil properties for bentonite were as below:

(a) Gravel Content = 0%
(b) Sand Content = 2.5%
(c) Fines Content = 97.5%
(d) Liquid Limit = 480%
(e) Plastic Limit = 22%
(f) Hydraulic Conductivity = 1.5x10^{-12} cm/sec.

Based on above properties of 2 different materials as base soil, following parameters were obtained :

Parameter	Flyash	Bentonite
$(D)_{85}$	0.13	0.13 mm
$(D)_{50}$	0.021	0.055
$(D)_{15}$	0.06	0.016
$(D)_{10}$	0.013	0.009

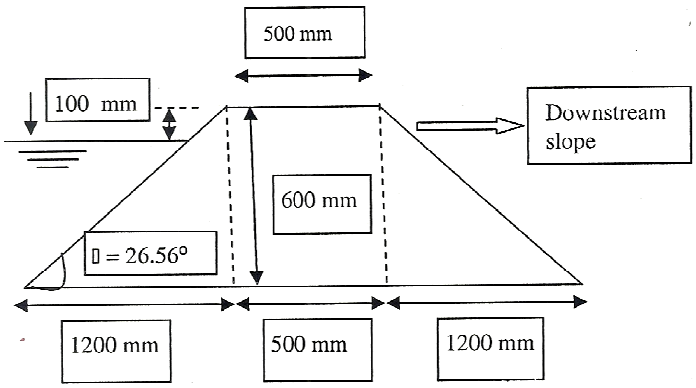

Fig. 1: Cross-Section of Earthen Dam Model without Any Filter

Fig. 2: Filling of Water at the Upstream Side

Fig. 3. Collecting the Water Seeped Through Earthen Dam Cross- Section

Test On Earthen Dam Model With Filter As Conventional Granular Filter

The test was conducted on earthen dam model using either flyash or bentonite as base soil (Fig.4) and granular filter, as per conventional practices (Fig. 5). Its fabrication was also done as described in para 3.1 above. In this model tests, filter had to be made as per conventional laws (Eqns. 1-3). Thus, following properties of the granular filter were adopted in present study:

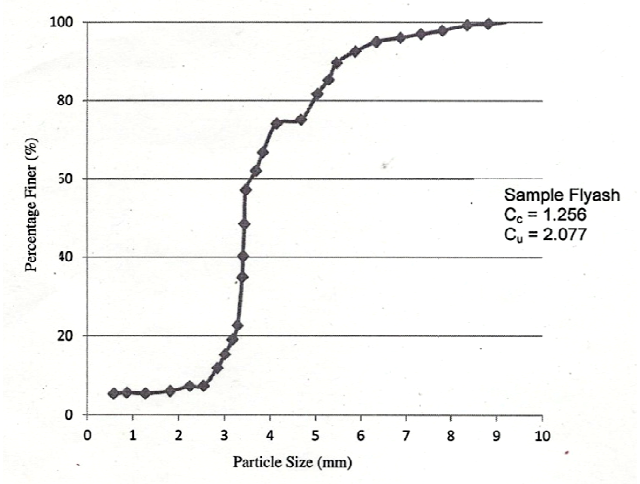

Fig. 4(A): Grain Size Analysis Curve of Flyash Used as Base Soil

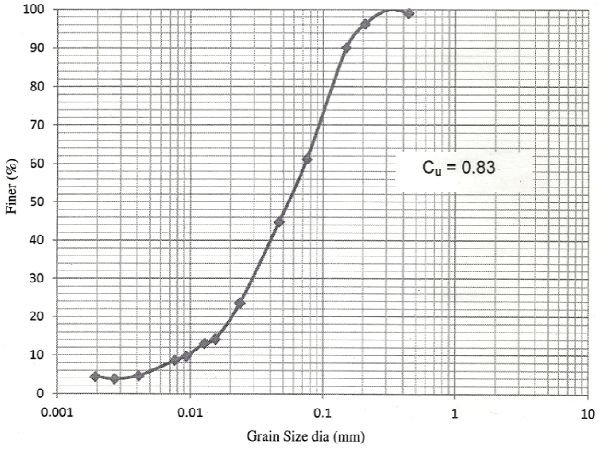

Fig. 4(B): Grain Size Distribution Curve of Bentonite Used as Base Soil

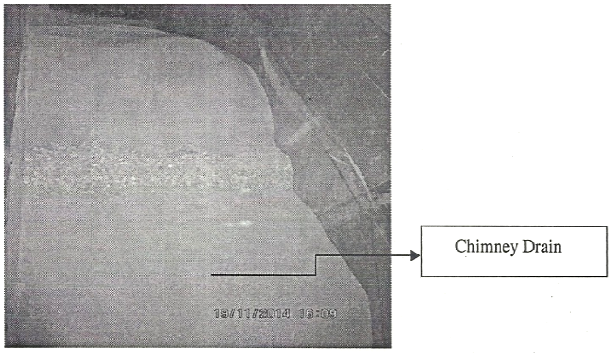

Fig. 5: Construction of Chimney Filter

$(D_{15})_{Filter}$ < 650 µ, $(D_{50})_{Filter}$ <525µ (For Flyash)

$(D_{15})f$ < 650 µ, $(D_{50})f$ < 1.375 mm (For Bentonite)

In this model, as shown in Fig. 6, a chimney filter and a horizontal blanket drain were also provided with granular filter soil material, with specifications, as mentioned above. With this model, no failure of downstream slope was observed. The test results obtained from this model are shown in tabular form in the end of this paper.

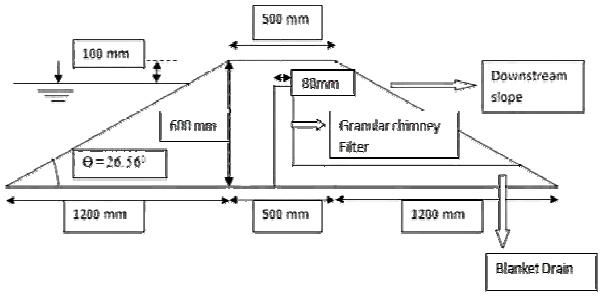

Fig. 6: Schematic of Model Test with Granular Filter

Tests On Earthen Dam Model With Geotextile Filter

In these model tests, earthen dam model were constructed with the same 2 materials (used differently) sand as base soil (Fig. 4) and were tested for the seepage flow through the downstream side of the cross-section through the geotextile filter. The various geotextile filters, used in study are illustrated in Fig. 7. The schematic layout is shown in Fig. 8.

Giroud (1996) has proposed soil retention criteria for steady state flow conditions through dam bodies. The same has been followed in present study also. According to that criterion,

$O_{95} < 2\ C_u\ .D_{50}$ where, $C_u = D_{60}/D_{10}$ ..... (9)

Thus, for flyash as base soil, O_{95} < 2 x 2.077 x 0.021 (= 0.087 mm) and for bentonite as base soil, $O_{95} \simeq 0.09$ mm

These both values are < 0.2 mm, hence OK (Refer Fig. 9)

Minimum allowable geotextile permeability using permeability criteria is:

$k_g > I_s . k_s$ (After Giroud, 1998) ..... (10)

Where,

I_S = Hydraulic gradient (= 2 for dam with toe drain, 3-10 for dam with clay cores)

k_s = Soil hydraulic conductivity.

The soil permeability, determined from falling head permeability method are mentioned in para 3.1. Hence, based on present model test,

$k_g > 1.6 \times 10^{-10}$ cm/sec for flyash and 1.5×10^{-11} cm/sec for bentonite. Using these conditions, the non woven geotextile sample had been selected for model tests. The properties of geotextile (Fig. 10) selected for model tests were determined in IIT Roorkee labs. The same are as follows :

Apparent Opening Size (O_{95}) = 250 microns

Coeff. of permeability = 3.4×10^{-3} cm/sec

Thickness = 1.4 mm, Permittivity = 0.0223 sec^{-1}

The permittivity tests were conducted on 6 geotextile samples (as shown in Fig. 10). The results of the same are shown in following Table 2:

Table 2: Data Sheet for Permittivity Test of Non-Woven Geotextile Samples

Headdifference betweentwo limbs, h (cm)			10		
Volume ofwatercollected, Q(ml)			600		
Diameter ofthe Geotextilesample (cm)			10.28		
Cross-sectionalarea ofGeotextile sample, A(cm^2)			82.99		
Sample I	**S. No.**	**Time Elapsed, t_m(sec)**	**Permittivity, P(/sec) (Q/A*h*t_m)**	**Thickness, t(mm)**	**Coefficient of permeability, k_n(cm/sec) (P*t)**
	1	15	**0.04694**	**1.024**	**4.81 x 10^{-3}**
	2	17			
	3	14			
	4	15			
	5	16			
		Avg = 15.4			
Sample II	**S. No.**	**Time Elapsed, t_m(sec)**	**Permittivity, P(/sec) (Q/A*h*t_m)**	**Thickness, t (mm)**	**Coefficient of permeability, k_n(cm/sec)(P*t)**
	1	30	**0.02426**	**0.36**	**8.73 x 10^{-4}**
	2	31			
	3	29			
	4	30			
	5	29			
		Avg =29.8			
Sample III	**S. No.**	**Time Elapsed, t_m(sec)**	**Permittivity, P(/sec) (Q/A*h*t_m)**	**Thickness, t(mm)**	**Coefficient of permeability, k_n(cm/sec)(P*t)**
	1	30	**0.02330**	**1.224**	**2.85x 10^{-3}**
	2	30			
	3	32			
	4	31			
	5	32			
		Avg =31			
Sample IV	**S. No.**	**Time Elapsed, t m (sec)**	**Permittivity, P(/sec) (Q/A*h*t_m)**	**Thickness, t(mm)**	**Coefficient of permeability, kn(cm/sec)(P*t)**
	1	18	**0.03929**	**0.862**	**3.39 x 10^{-3}**
	2	19			
	3	18			
	4	19			
	5	18			
		Avg =18.4			
Sample V	**S. No.**	**Time Elapsed, t_m(sec)**	**Permittivity, P(/sec) (Q/A*h*t_m)**	**Thickness, t(mm)**	**Coefficient of permeability, k_n(cm/sec)(P*t)**
	1	30	**0.02820**	**0.340**	**9.58 x 10^{-4}**
	2	29			
	3	29			
	4	28			
	5	29			
		Avg =29			

Sample VI	**S. No.**	**Time Elapsed, t_m(sec)**	**Permittivity, P(/sec) (Q/A*h*t_m)**	**Thickness, t(mm)**	**Coefficient of permeability, k_n(cm/sec)**
	1	30	**0.02236**	**1.430**	**3.197×10^{-3}**
	2	31			
	3	30			
	4	32			
	5	31			
		Avg = 30.8			

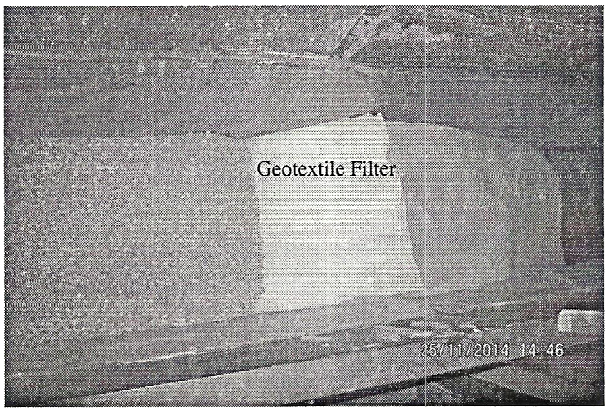

Fig. 7: Model Test Showing Geotextile Filter, As a Replacement To Conventional Granular Filter

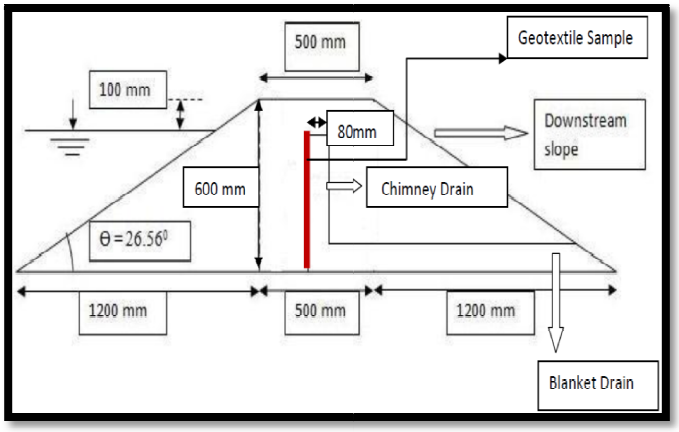

Fig. 8 Schematic of Earthen Dam Model With Geotextile As Filter

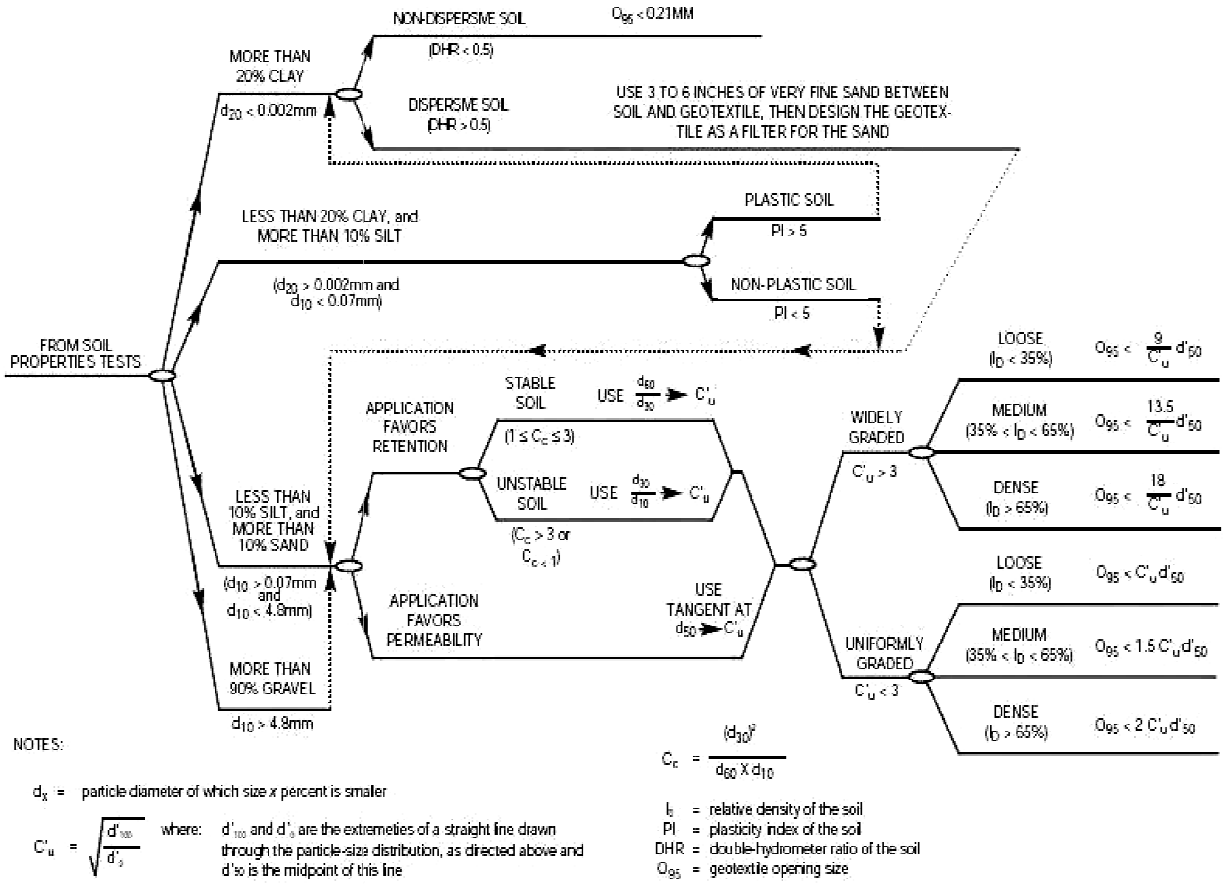

Fig. 9: Soil retention criteria of steady state flow conditions

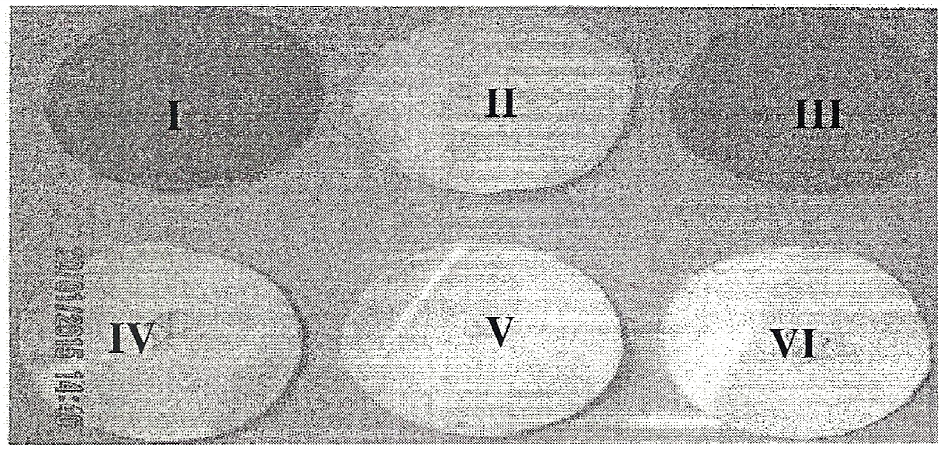

Fig. 10: Various Samples Of Geotextile Used For Permeability Tests. Finally, Sample No. VI Was Used For Model Tests

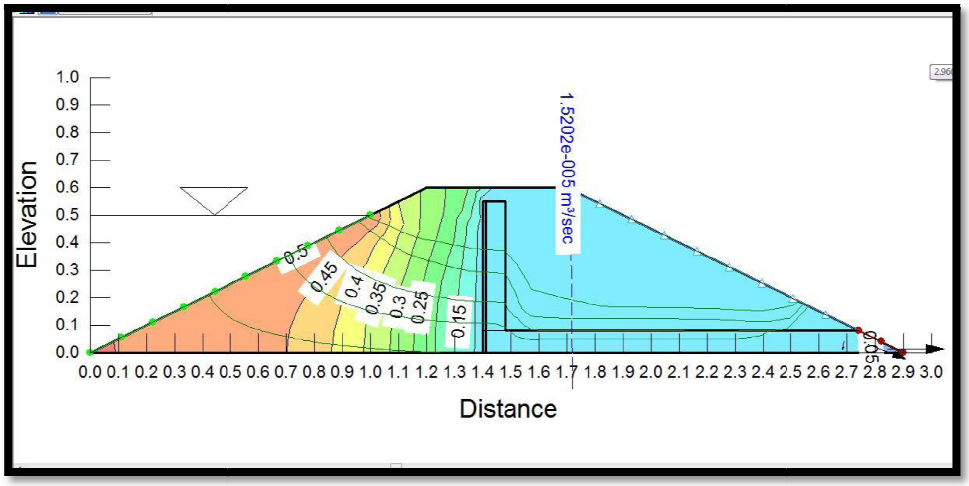

Fig. 11: Total Head Contours Obtained with Geotextile Filter case by using SEEP/W – Geo Studio 2007 software

The results of the tests are summarized in tabular form, and are presented in Table 3 in Para 5. It was observed that geotextile filter performed very effectively as a filter material, as it qualified with the required permeability of the filter material (Cedergren, 1977).

The results obtained from laboratory models were validated with the software SEEP/W also.

ANALYTICAL STUDY ON SEEP/W: WITHOUT ANY FILTER

Results of all the experimental model setups were also validated with the help of SEEP/W – GeoStudio 2007 software. SEEP/W is a numerical model that can mathematically simulate the real physical process of water flowing through a particulate medium. Numerical modeling is purely mathematical and in this sense is very different than scaled physical modeling in the laboratory or full-scaled field modeling. First of all, layout of the problem was drawn. Then various materials with their hydraulic properties were defined. After defining the material, these were assigned to respective regions. Then boundary conditions were defined and assigned to specific nodes, lines or regions. Then mesh properties were defined and finally the problem was solved using "solve analyses tool".

Firstly layout of the model was drawn for no filter case. Material property of the base soil i.e. fine sand was defined and then this material was assigned to the respective region drawn. Boundary conditions applied include:

- Total head at upstream side below the water level is constant

- At toe point pressure head is zero

- Downstream side is the potential seepage face

After defining the mesh properties, problem was solved and the total head contour and the total flux passing through the section was obtained. Thereafter problem definition and the total head contour for all the cases were drawn (Anamika, 2015). One representative such mesh is shown in Fig. 11 for geotextile filter.

RESULTS & COMPARATIVE STUDY

In each model test, flow rate was measured ,i.e. the particular quantity of water coming out of the filter material and the time taken for that. All the results are presented elsewhere (Anamika, 2015). The summary of a few test results is given in Table 3 below.

Table 3: Summary of Model and Analytical Test Results

Parameters	Without any filter	With Granular Filter	With Geotextile Filter
Time taken by water to appear at downstream slope (hrs)	3.5	2.5	2.75
Seepage rate per unit width (m^3/sec)	4.24×10^{-6}	15.87×10^{-6}	11.81×10^{-6}
Failure of downstream slope	Yes	No	No
Seepage rate per unit width obtained from SEEP/W analysis (m^3/sec)	4.43×10^{-6}	11.43×10^{-6}	11.42×10^{-6}

More results obtained in this research work are presented elsewhere (Anamika, 2015).

CONCLUSIONS

Conclusions drawn from this study are summarized as below:

1) Time taken by the water to seep through the dam model cross-section for various cases was observed in the following order,

No Filter > Geotextile Filter > Granular Filter

2) Seepage rate through the dam model cross-section for various cases was observed in the following order, Geotextile Filter ≈ Granular Filter > No Filter

3) Seepage rate through the dam model for various cases obtained by analytical analysis using SEEP/W – Geo Studio 2007 software was found to be comparable with the model test results obtained from the model tests conducted in the lab.

4) Geotextile filter design based upon above study forms a coherent criteria that allows safe design of geotextile filter. Since seepage rate for granular filter and geotextile filter was observed to be approximately same, these two can be used at site.

5) The sites, where granular material is not available in adequate quantity, geotextile filter can be adopted with the same efficiency.

6) Installation of geotextile filter involves less manual labour and there is no risk of segregation of material during placement as compared to pure granular filter.

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