DESIGN OF FLY ASH DYKE FOR SEEPAGE AND STABILITY ANALYSIS

THESIS IS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF TECHNOLOGY

IN

CIVIL ENGINEERING

By

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Gaurav Kumar

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National Institute of Technology Rourkela – 769008, India

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Under the guidance of

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CERTIFICATE

This is certify that the project entitled **DESIGN OF FLY ASH DYKE FOR SEEPAGE AND STABILITY ANALYSIS submitted** by **Mr. Saujanya Kumar Sahu (Roll No-108CE003)** and ***Mr. Gaurav Kumar (Roll No-108CE039***) in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Civil Engineering at NIT Rourkela is an authentic work carried out by them under my supervision and guidance.

DATE-09-05-12

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AKNOWLEDGEMENT

We would like to thank **NIT Rourkela** for giving us the oppurtunity to use their resources and work in such a chanllenging environment.

First and foremost we take this opportunity to express our deepest sense of gratitude to our guide **Prof. S.K. Das** for his able guidance during our project work. This project would not have been possible without his help and the valuable time that he has given us amidst his busy schedule. We would also like to extend our gratitude to ***Prof. N.ROY***, *Head, and Department of Civil Engineering*, who has always encouraged and supported doing our work.

We are also thankful to Mrs. Tapaswini Sahoo and Miss. Mamta, Research Scholar, Geotechnical Engineering and staff members of the Geotechnical Engineering Laboratory, for helping and guiding us during the experiments.

Last but not the least we would like to thank all the staff members of Department of Civil Engineering who have been very cooperative with us.

Saujanya Kumar Sahu

Gaurav Kumar

ABSTRACT

In India, due to progressively increase in number and capacity of coal based thermal power plant huge amount of fly ash is generated. In current scenario only 40-50% fly ash are used and rest of the fly ash is disposed of and restored in ash pond with dyke to reduce the land wastage. The failure rate of ash dykes are much higher than that of dams because seepage analysis is not taken into account while design of the former. So, construction of safe ash dyke becomes a top priority for engineers as its occasional failure creates havoc in safety of surrounding people. It causes economic losses as well as environmental and water pollution which is dangerous for both human and aquatic life. There is no well-defined design procedure and codal provision for design and maintenance of fly ash dam in India. This project describes about the design of ash dyke in various stages constructed in various methods with the help of finite element package PLAXIS considering various parameters representing varied environmental conditions. A laboratory model has been developed and it is found that the phreatic line is fairly matching with our numerical analysis result. Due to limited time, practical model variation could but made but numerical analysis are made for different heights of water at top of fill side, different rates of rapid drawdown, providing different width of vertical sand drains. The steady seepage analysis is done using PLAXFLOW module of PLAXIS and it is found that factor of safety is less compared to that of dry condition. Based on laboratory investigation it was observed that fly ash is dispersible. Further phreatic line does not remain within body of dyke when sand drains and toe filters are not provided, which may lead to its leakage. Then by using vertical sand filters of varying widths, dykes are analyzed and the one having minimum deformation is chosen.

CONTENTS

CHAPTER 5- RESULTS AND DISCUSSION

CHAPTER 6- CONCLUSION

List of Figures

List of Tables

CHAPTER -1

INTRODUCTION

1.1 INTRODUCTION

In India, in step with progressively increasing the capacity of coal-fired thermal power plants, the amount of fly ash generated is increasing very fast. Increase in number of coal based thermal power plant is also responsible for high amount of generation of flyash. The table given below shows data related to its generation and use in different year.

Table 1.1 Fly ash generation and use in India (Chatterjee 2011)

Year	Generation(Mt)	Use(Mt)	% Use of generation
1993-94	40	1.2	3
2004-05	112	42	38
2006-07	130	60	46
2011-12	170	170	100% use mandated
2031-32	600	-	Not yet planned; innovation essential

The utilization of fly ash in India varies between 40-50% and rests are disposed and are restored. Fly ash storage require huge amount of land area. So to reduce the land wastage it is stored using ash dam construction. Ash dam is an important structure, located few kilometers away from the hydraulic power stations for storing the coal ashes. Ash dam construction is continuous process and it is raised each step through dyke construction.

Ash dam should construction is a great challenge for civil engineers as the failure of ash dam has an adverse effect on surrounding environment as well as it can affect the smooth functioning of power stations. It also causes havoc among the surrounding people about safety of their life. It causes economic losses. It pollutes the surrounding river water which is dangerous for aquatic life as well as human being. So ash dam should be constructed with proper safety and precautions.

Fig.1.1 Breaching area due to failure of ash dam (Paul Robinson,Albuqurque,USA,)

1.2 CONSTRUCTION OF ASH DYKE:

The construction of fly ash dyke is classified into three broad categories as shown in Fig 1.2.

1.2.1 Upstream Construction Method

(a) This method is popularly used method as earth work required is minimum.However this method faces certain disadvantages:

(b)The entire weight of new construction when dyke raised is supported on deposited ash., There is possibility of finer ash particles deposited along the bund if ash deposition is not carefully done . This results inadequate bearing capacity for support of the new dyke.

(c) With increase in height of the pond the plan area of the pond reduces., It turnout to be uneconomical to raise the height further on this reason beyond a certain stage.

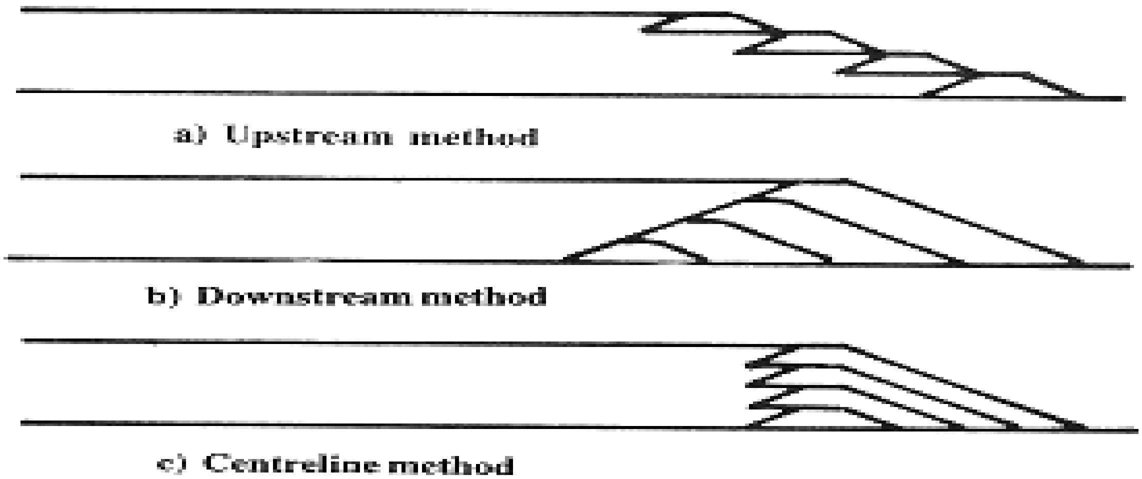

Fig 1.2 Methods of Raising Dyke Height

1.2.2 Downstream Construction Method

(a)When the pond gets filled upto the first stage of construction, the pond height is further increased by depositing the earth / fly ash on the d/s face of the ash dyke.

(b) There is possibility of raising the height of the pond even when the pond is operational However no reduction in the quantity of construction occurs which is same as the single stage construction

1.2.3 Centre Line Construction Method

(a)Here after the pond gets filled upto the first stage, material is placed for raising height of the dyke on either side of centre line of the dyke so that the center line of the dyke falls at the same location. This necessiates a part of the raw material to be placed on the deposited ash and part of the material on the down stream face of the existing ash dyke.

(b)The earth work required in centreline method is less compared to that of in down stream method.But as the material is required to be deposited on the settled fly ash, it is not convenient to carry out the construction when the pond is operational.

(c)This method is suitable only if the total area of ash pond is frsgmented into compartments.

CHAPTER -2

LITERATURE REVIEW

2.1 INTRODUCTION

Various works has been performed in the field of fly ash pond construction, inspection and maintenance. This chapter includes the brief review about the work performed in this field by different people across the world and the modification that took place with change of time.

Following are the summary of Fly ash pond document review.

Casagrande consultants (1976) prepared a document about investigation for proposed fly ash pond describing about Boring logs, compression analysis and stability analysis for construction of original fly ash pond structure.

IDNR (1975-77) prepared a document which describes about Approval for construction in a flood plain. It contains various engineer reports and conditions for construction.

Woodward-Clyde Consultants (1979) prepared a document about Final Report of Geotechnical Consultation and Inspection Services which consist of Report summarizing and documenting the construction of the original fly ash pond.

Barr Engineering and American Electric Power Company (BEAEPC,2002) prepared a document about Design drawings and construction specifications describing about Details of boring logs, seepage/stability analysis, design calculations, construction specifications and drawings to install a seepage collection drain in the south dike.

American Electric Power Company(AEPC) –ProServ and Barr Engineering (2002) prepared a document about Fly Ash Storage Pond Elevation 518' Raising Engineering Report describes about Geotechnical and stability analysis, toe drain design, hydraulic and hydrologic analysis, spillway structure design, and construction specifications.

Gandhi (2005) described the design and maintenance of ash pond for fly ash disposal. He explained the various method of raising the dyke describing its advantage and disadvantage. He suggested that ash dyke should be supervising regularly and necessary remedial measures should be taken. This is based on the observation and experience at different pond site.

APEC (2008) prepared a document about Annual Inspection Report describing about Annual inspection report documenting inspection completed by corporate engineering staff. It includes deformation/settlement data and analysis of new Upper Pond structure.

Indiana Michigan Power Company (IMPC, 2008) prepared a document about Site NPDES Permit describing about NPEDS Permit #IN0002160 detailing allowable discharge parameters from the Bottom Ash Complex (which receives water pumped from Fly Ash Pond).

Geo/Environmental Associates (GEA) and APEC (2009) prepared a document about Draft Emergency Action plan describing about Draft action plan for use in the event of a failure of the Fly Ash Pond embankments.

APEC (2009) prepared a document about deformation review describing about Summary of deformation related measurements collected since raising embankments to 518'.

GEA (2009) perform visual inspection of the fly ash pond and analyzed about the stability. The stability analysis describe about the potential high ratio of horizontal to vertical permeability. It describes about the improvement in construction of toe drain design and factor of safety after improvement design should be greater than 1.5.

IPMPE (2009) prepared a document about Fly Ash Pond Piezometer Static Water Levels describes about Records of static water levels monitoring of piezometers in the Upper Pond embankment.

IMPE (2009) prepared a document about Monthly inspection logs which describes about Recent monthly inspection checklists completed by Tanner's Creek personnel.

2.2 FAILURE OF ASH DYKE AND INVESTIGATION REPORT

The failure of ash dyke may be due to various factors. Different people have done different investigation in the field of ash dam failure. Failure of ash dyke may take place due to following reasons:

a) Seepage of water
b) Stability of dikes
c) Soil properties in starter dyke,
d) Method of compaction
e) Absence of drainage filter.

After investigation of ash dam failure different study were carried out.

i. Study of the detail drawings, prior inspection report, safety issue and gain an understanding of the original design and modifications of the facility.
ii. Perform site visit and visual inspection at regular interval of time.
iii. Evaluation of the structural stability, quality and adequacy of the management unit's inspection, maintenance and operation procedure.
iv. Identification of the critical structure in the surrounding environment.
v. Risk assessment.

Modification since original structure:

a) Ash pond was constructed by raising the dyke over the previously deposited fly ash. The upper pond was constructed by using bottom ash excavated from ash complex. Geogrid is provided to add stability for the new embankments. Toe drain system is installed.
b) Piezometers are installed to control seepage.
c) Downstream slopes were reinforced with the vegetation to provide integral stability.
d) Provision of emergency rectangular concrete spillway

CHAPTER -3

NUMERICAL ANALYSIS

3.1 INTRODUCTION

Limit equillibrium method is the most prominent method used for the analysis of ash dykes. Though Limit equillibrium is simple and easy to implement but it can not find out the stress strain values. Simillarly it is also difficult to take care of water pressure while using limit equillibrium method. In the present study finite element method has been used to study the stability analysis along with the flow analysis in the ash dyke. The finite lement analysis has been implemented using a commerical software PLAXIS(Pieter Vermier). A brief introduction about PLAXIS is presented below.

3.2 SOFTWARE USED FOR ANALYSIS:PLAXIS

PLAXIS is a finite element program designed for geotechnical applications in which soil models are used to simulate the soil behaviour. The initiation of this Finite Element Program was held at Delft University of Technology Netherland by Pieter Vermeer in 1974.(Burd,1999) . The name was derived from PLasticity AXISymmetry, a computer program developed by Pieter Vermeer and De borst to solve the cone pentrometer problem. Its commercial version was released in 1987. Earlier version of PLAXIS ran on DOS interface. For Wndows, PLAXIS V-7 was released with automated mesh generation.

Analysis using PLAXIS consists of three stages,viz, input stage, calculation stage and postprocessing (curves) stage. Input stage comprises of model design, assigning the material parameters, boundary conditions, loading and meshing. In the present analysis 15-node triangular element is considered for meshing which has 12 stress points. In PLAXIS, stresses and strains are calculated at individual Gaussian integration points rather than at individual nodes. The calculation stage requreis selection of analysis type such as Plastic, dynamic, consolidation and phi-c reduction. The loads assigned are activated here and analysed. In the post processing stage, plotting of curves between various calculated parameters such as load vs displacement is done. Input parameters like stiffness and poisson's ratio of the soil influence the displacement of the slope.

Phi-c reduction method is used to compute FOS for slope stability. In this approach the strength parameters (tanφ ,*c)* of the soil are successively reduced till failure of the system occurs. The total multiplier Σ*Msf* is utilized to define the value of the soil strength parameters at a given stage in the analysis.

$$\sum \text{Msf} = \frac{tan\Phi}{tan\Phi_r} = \frac{c}{c_r}$$

The safety factor is represented by the value of $\sum M_{sf}$ at failure, provided that at failure more or less constant value is obtained for a number of successive load steps.

3.3 OBJECTIVES OF PRESENT STUDY

The objectives of the present study are as follows:

- To design an optimum ash dyke for safety, by analyzing the dam section using finite element method (FEM). All the three methods shall be analyzed using FEM based software, PLAXIS, using the material properties to be determined from the laboratory investigation.
- To recommend the optimum design for the ash dyke by considering
  (a) Factor of safety and
  (b) Seepage analysis for the above methods.

The PLAXIS is well established software used for the analysis of slopes and embankments. Subramaniam (2011) observed that factor of safety obtained using PLAXIS is comparable with that of limit equilibrium method. However, the stress- strain information can be obtained unlike the limit equilibrium method.

3.4 COMPARISON OF THREE CONSTRUCTION METHODS BY PLAXIS

As a first step analysis was made to find out the factor of safety of ash dyke as per different methods of construction i.e. upstream, downstream and centerline method.

3.4.1 Material properties and model parameters used for PLAXIS analysis

Table 3.1 Properties of materials used in analysis of ash dyke

PARAMETERS	**COMPACTED FLY ASH USED IN DYKE**	**FLYASH FILL**
MATERIAL MODEL	MOHR-COULOMB	MOHR-COULOMB
MATERIAL TYPE	DRAINED	DRAINED
UNSATURATED UNIT WEIGHT(kN/m^3)	12	9.83
SATURATED UNIT WEIGHT (kN/m^3)	15	12
PERMEABILITY;K_X (m/day)	0.1	0.1
PERMEABILITY;K_Y (m/day)	0.1	0.1
E_{REF} (kN/m^2)	7500.000	1300.000
POISSON RATIO	0.3	0.28
C_{ref}(kN/m^2)	1.2	27.5
ANGLE OF INTERNAL FRICTION	30	20

3.4.2 MODELS OF THREE CONSTRUCTION METHODS

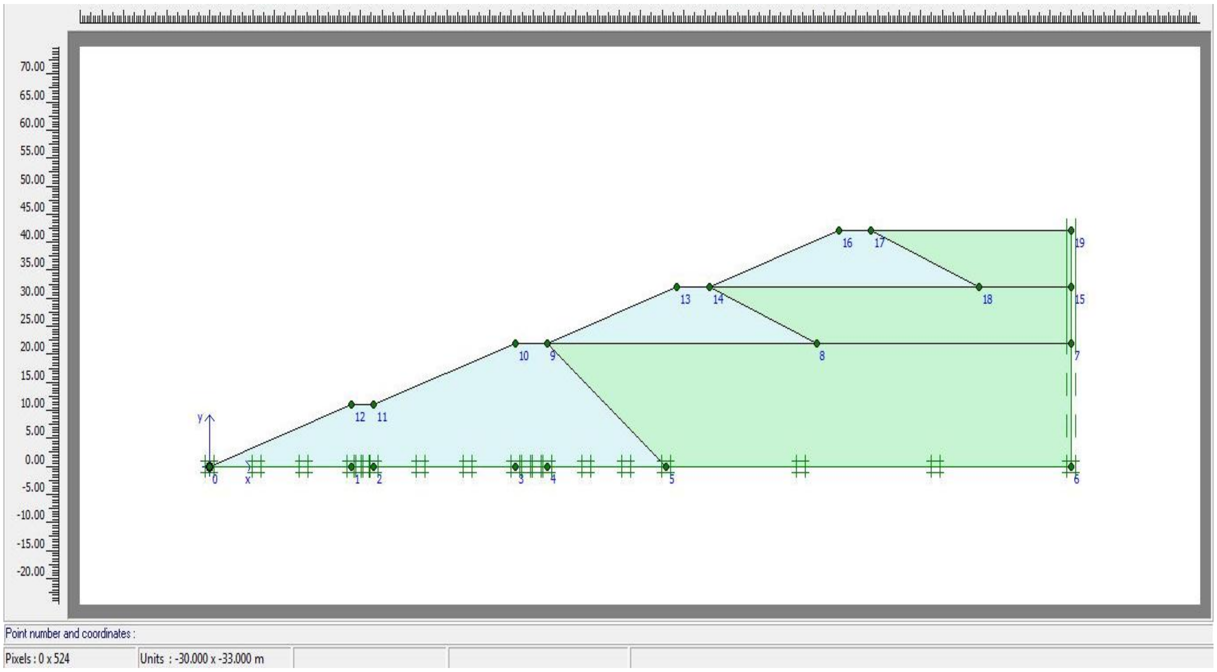

Fig 3.1 : Model for Upstream Construction Method

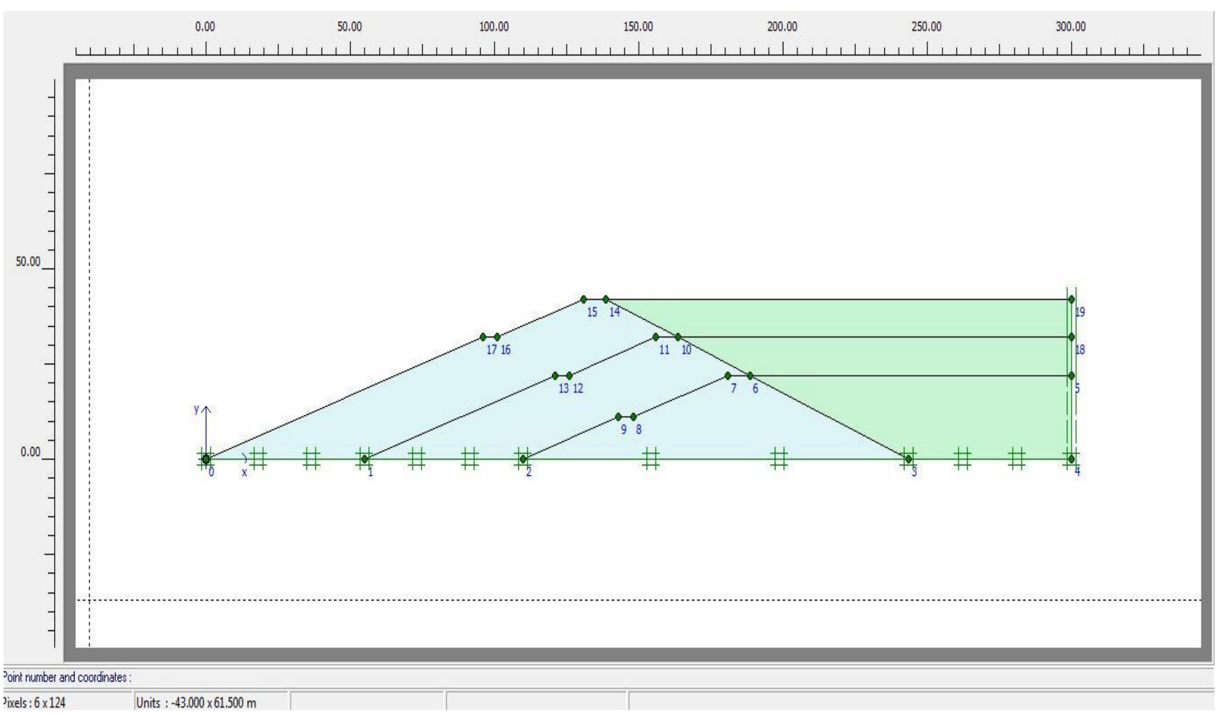

Fig 3.2 : Model for Downstream Construction Method

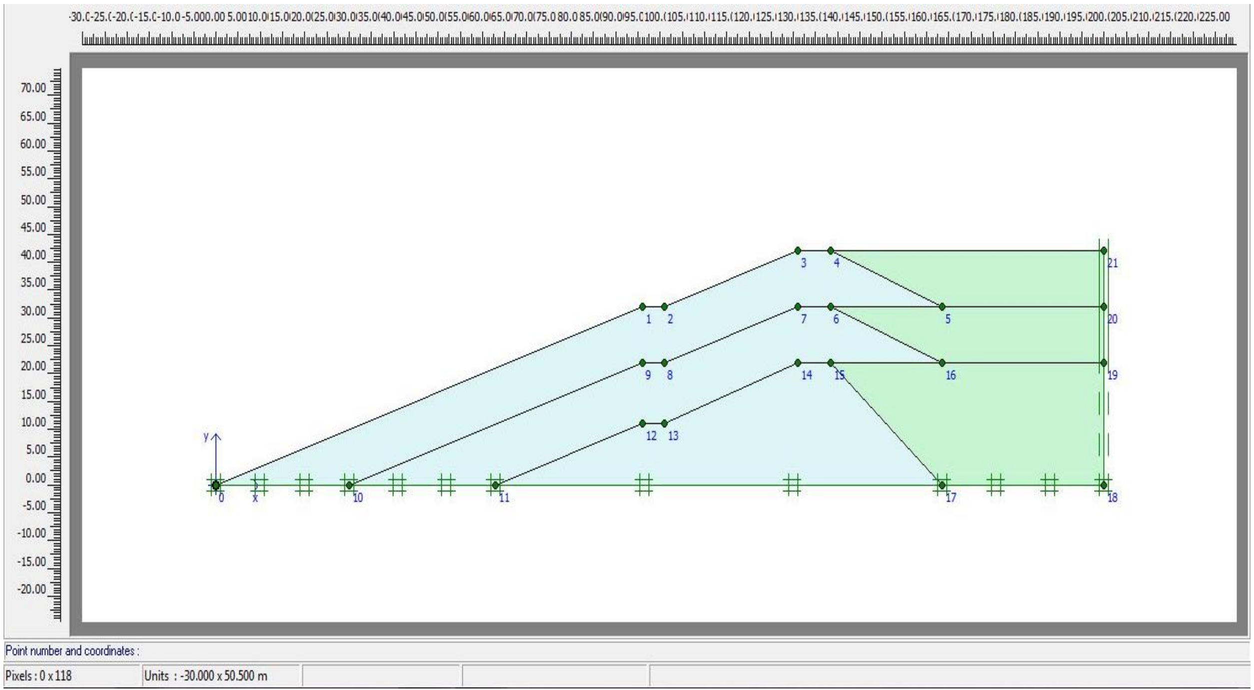

Fig 3.3 : Model for Centreline Construction Method

3.4.4 ANALYSIS UNDER VARIOUS CONDITIONS:

Analysis of the above three models are done for the following site conditions:

- Full dry condition.
- Completely submerged case.
  (Change in height of water table)
- Steady Seepage analysis.
- Rapid Drawdown
  (different rates of drawdown)

3.4.3.1 ANALYSIS IN DRY CONDITION:

Here phreatic level is kept at ground level. Relative shadings of effective mean stresses generated are shown below

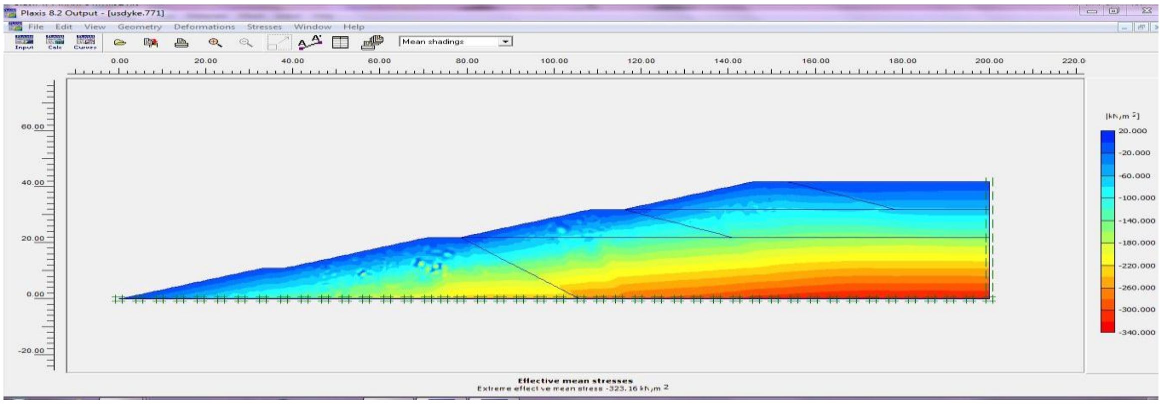

Fig3.4 Effective Mean Stress developed in dry state by Upstream Construction Method

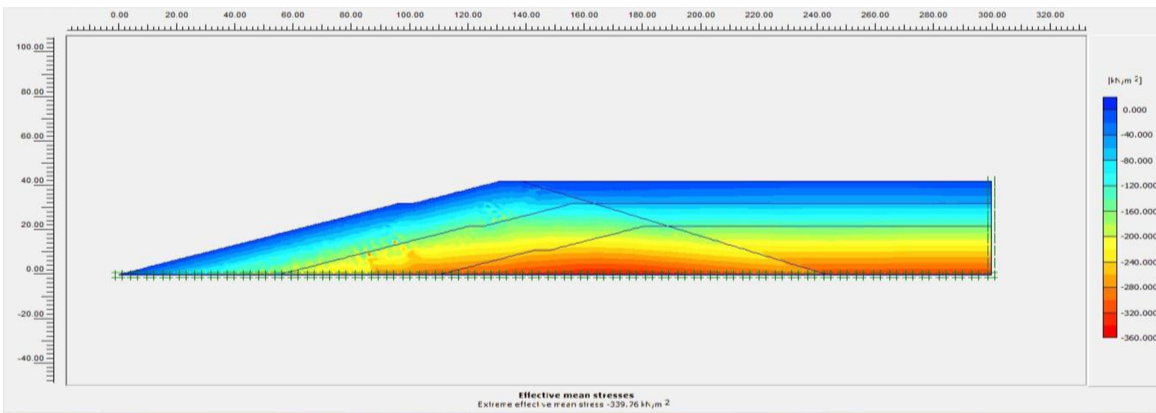

Fig3.5 Effective Mean Stress developed in dry state by Downstream Construction Method

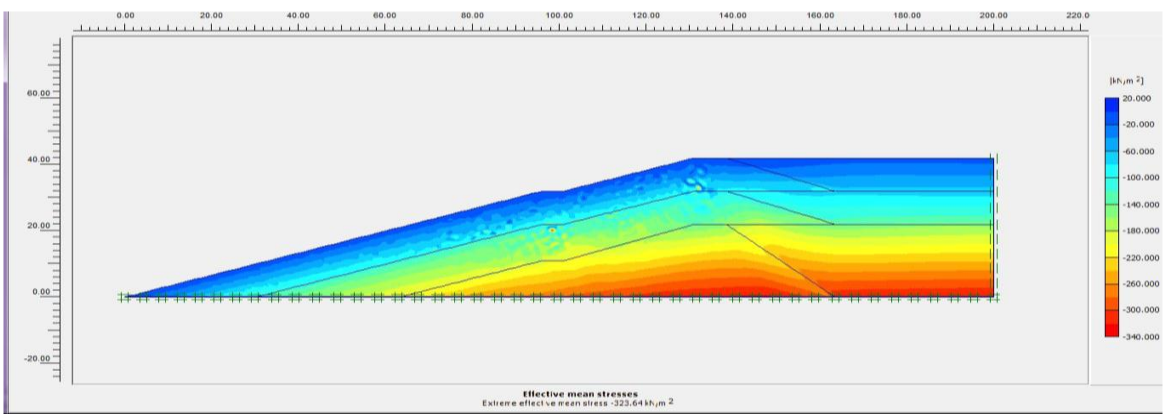

Fig3.6 Effective Mean Stress developed in dry state by Centreline Construction Method

FACTOR OF SAFETY IN VARIOUS METHODS:

Table3.2 Factor of Safety of different stages by three construction methods in dry state

CONSTRUCTION STAGE	FACTOR OF SAFETY		
	UPSTREAM METHOD	DOWNSTREAM METHOD	CENTRELINE METHOD
1ST STAGE	1.983	1.984	1.868
2ND STAGE	2.013	1.869	1.868
3RD STAGE	1.978	1.818	1.815

3.4.3.2 ANALYSIS BY CHANGE OF WATER TABLE:

Water level from ash fill side is varied for each of three stages and analysed for all the three construction methods.

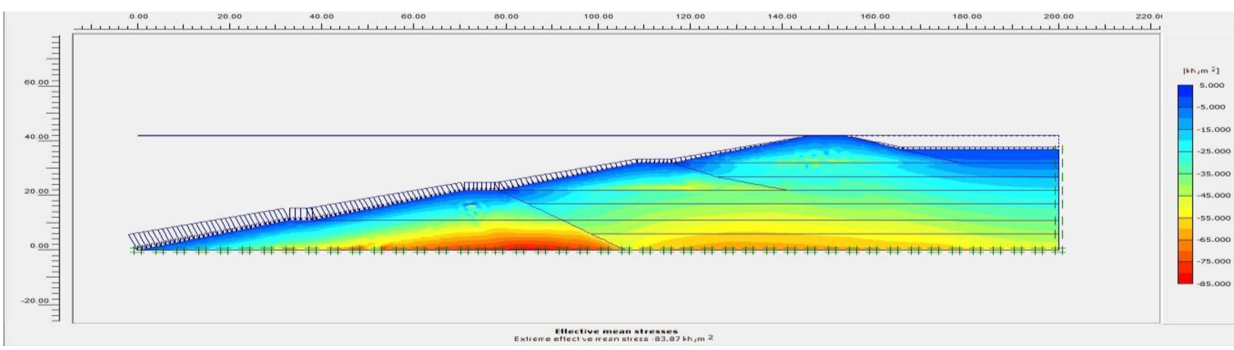

Fig3.7 Effective Mean Stress developed in final stage when water level varied for Upstream Construction Method

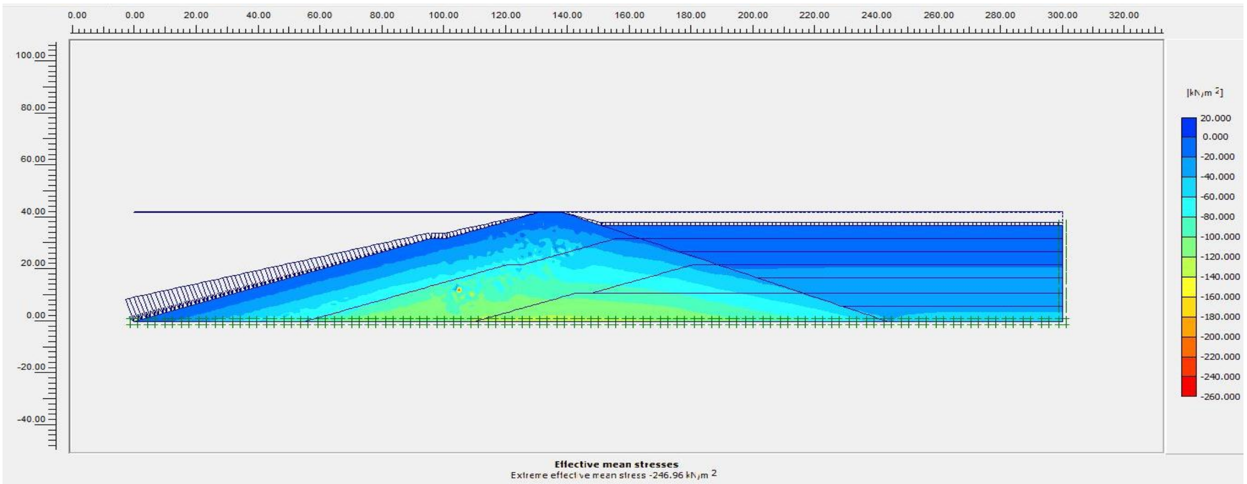

Fig3.8 Effective Mean Stress developed in final stage when water level varied for Downstream Construction Method

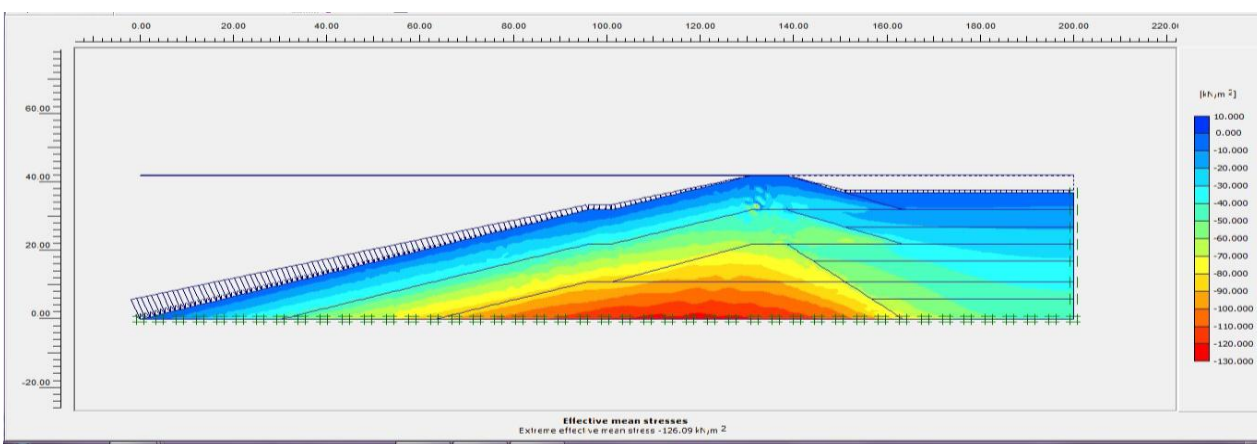

Fig3.9 Effective Mean Stress developed in final stage when water level varied for Centerline Construction Method

Table3.3 Factor of Safety of different stages by three construction methods in dry state

HEIGHT OF FLYASH FILL FROM BASE	HEIGHT OF WATER TABLE FROM BASE	FACTOR OF SAFETY		
		UPSTREAM METHOD	DOWNSTREAM METHOD	CENTRELINE METHOD
6m				
	8m	**1.069**	**1.727**	**1.101**
	10m	**1.231**	**2.031**	**1.246**
	11m	**1.398**	**2.158**	**1.477**
17m				
	19m	**1.000**	**2.209**	**1.078**
	21m	**1.191**	**2.198**	**1.231**
	22m	**1.406**	**1.972**	**1.447**
27m				
	29m	**1.371**	**1.766**	**1.585**
	31m	**1.623**	**1.766**	**1.973**
	32m	**1.923**	**1.974**	**1.975**
37m				
	39m	**1.605**	**1.769**	**1.603**
	41m	**1.905**	**1.917**	**1.886**
	42m	**2.16**	**_**	**1.885**

3.4.3.3 ANALYSIS UNDER STEADY SEEPAGE CONDITION:

The phreatic line is drawn by giving level points were (-1,10);(50;10);(150;40);(205;40). Analysis was done steady seepage(groundwater flow condition).

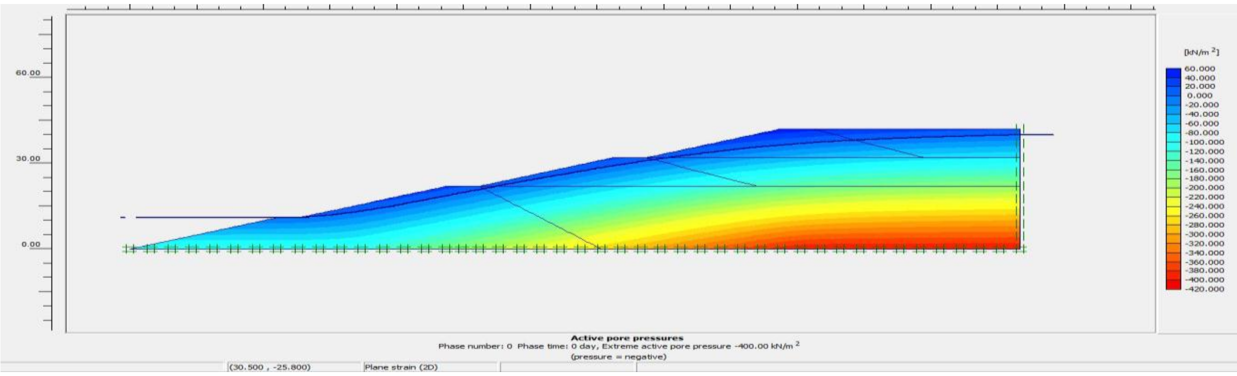

Fig3.10 Effective Mean Stress developed in steady seepage condition for Upstream Construction Method

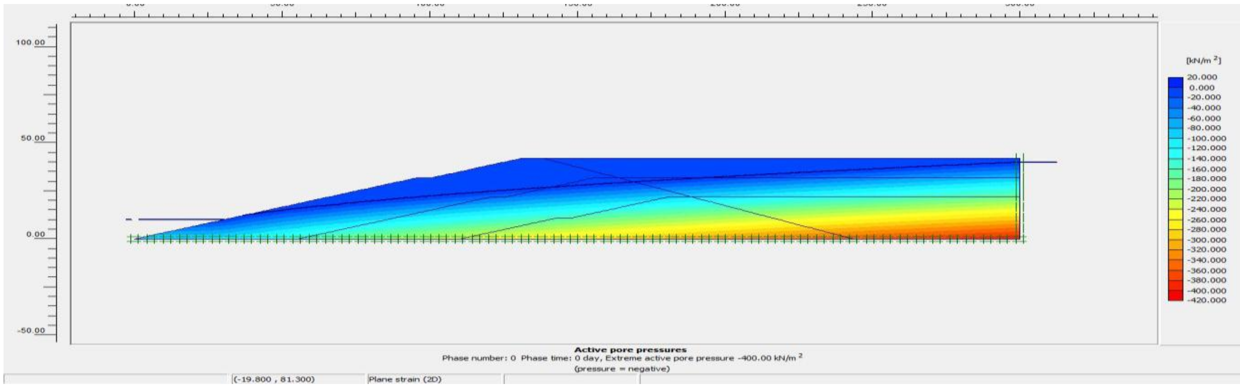

Fig3.11 Effective Mean Stress developed in final stage when water level varied for Downstream Construction Method

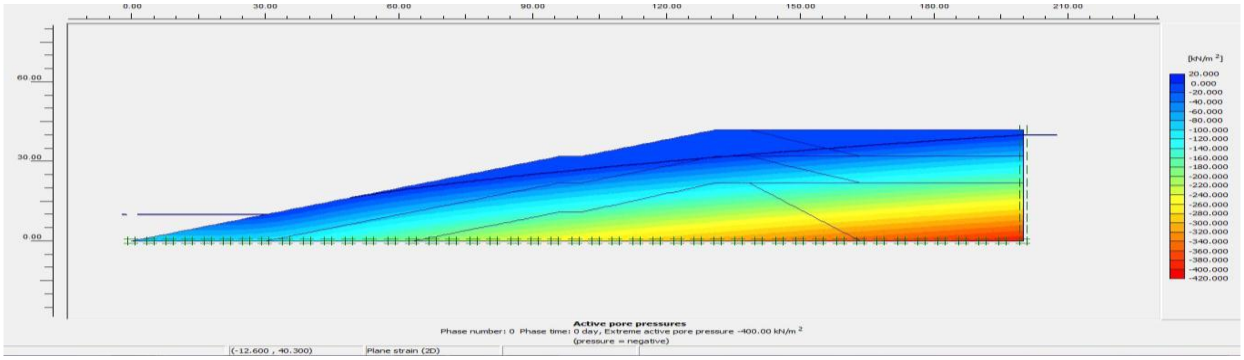

Fig3.12 Effective Mean Stress developed in final stage when water level varied for Centerline Construction Method

3.4.3.4ANALYSIS UNDER RAPID DRAWDOWN:

Here analysis was performed under 4 rates of rapid drawdown for upstream method which is the most popular one in India:

1) 5m water table drawdown in 1day, i.e. at rate of 5m/day.
2) 5m water table drawdown in 5 days, i.e. at rate of 1m/day.
3) 5m water table drawdown in 50 days, i.e. at rate of 0.1m/day.
4) 1m water table drawdown in 5 days, i.e. at rate of 0.2m/day.

In all the four cases the dyke collapsed at each of four stages.

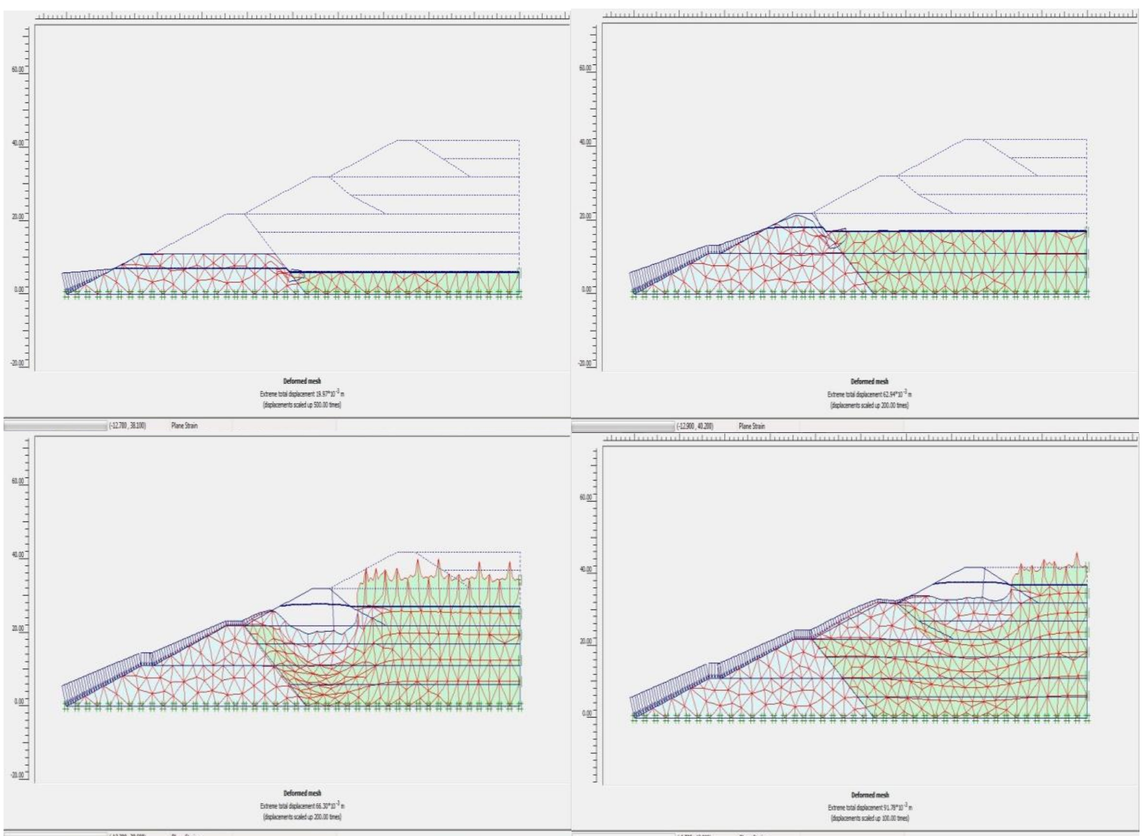

Fig 3.13 Deformed mesh of ash dyke under rapid drawdown for upstream construction method

CHAPTER -4

LABORATORY INVESTIGATIONS

&

MODEL STUDY

4.1 INTRODUCTION:

In india , ash dyke construction by upstream method is widely used. So a two stage dyke is built by upstream method and geotechnical properties of materials used in it are found in the laboratory to use the same for analysis in PLAXIS

4.2 LABORATORY INVESTIGATIONS

DETERMINATION OF GEOTECHNICAL PROPERTIES OF MATERIALS USED IN MODEL :

The geotechnical properties are found out by various tests done at Geotechnical Lab, NIT, Rourkela. These values are used in material sets of PLAXIS for simulation of model.

Following materials are investigated for their properties:

- FLY ASH
- CLAY
- SAND
- STONE CHIPS

4.2.1 FLY ASH :

PROCUREMENT: At first fly ash was to be brought from Jagda which comes from Rourkela Steel Plant .But it couldn’t be procured. Then material was brought from Jindal Steel Power Plant, Chhatishgarh. Following properties of fly ash used are found out:

- Grain size analysis
- Maximum dry density and optimum moisture content
- Angle of internal friction and cohesion value.
- Permeability
- Specific gravity test
- Dispersibility

4.2.1.1 GRAIN SIZE ANALYSIS:

It is done as per IS 2720: Part 4 :1985 specifications. Flyash upto 75 microns is done by sieve analysis and below it hydrometer analysis was done.

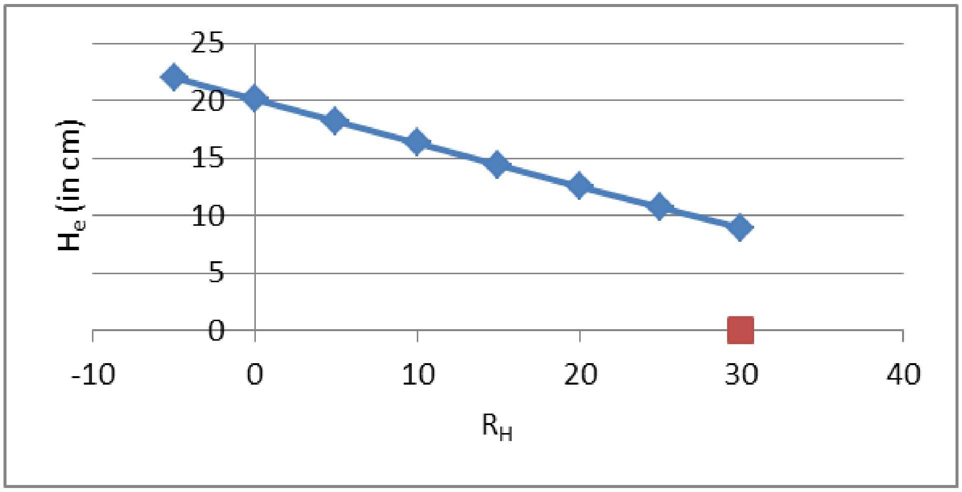

Fig. 4.1 Calibration Curve for Hydrometer used for wet analysis

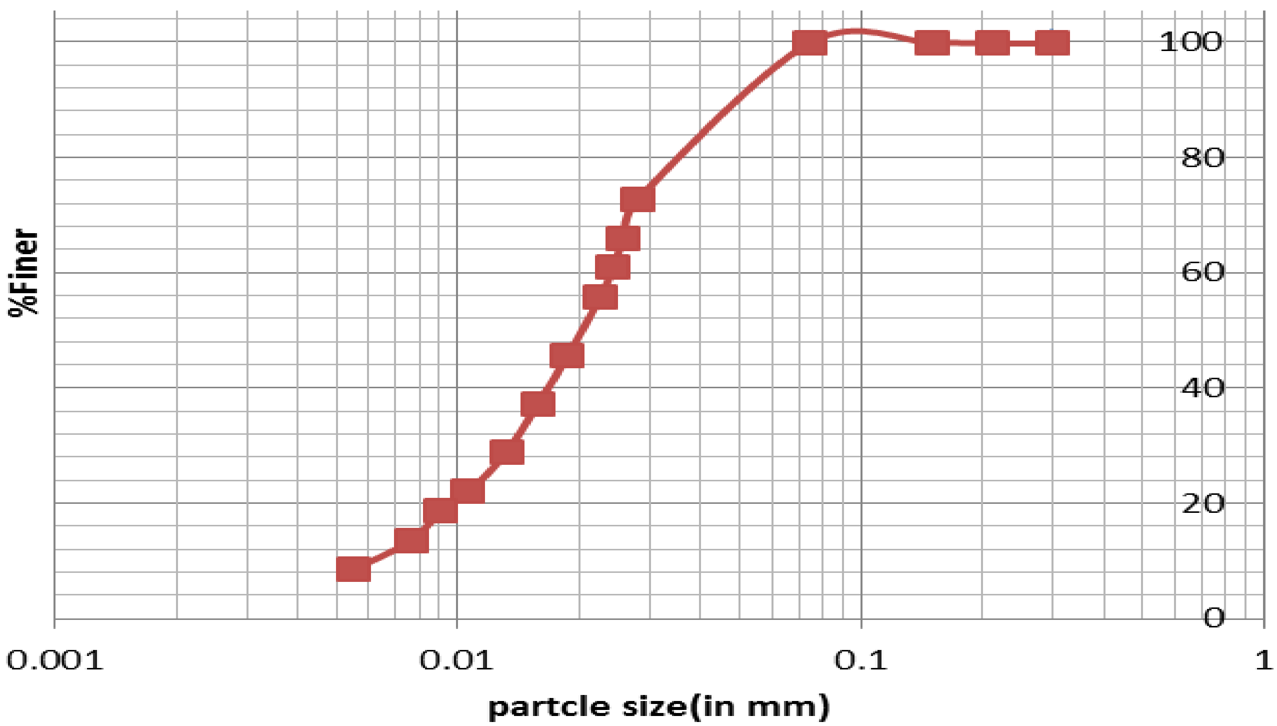

Fig. 4.2 Grain Size Distribution Of Fly Ash

4.2.1.2 STANDARD PROCTOR TEST:

It is done as per IS 2720 : Part 7 :1985 specifications

Table 4.1 Calculation of Dry Density And OMC by Standard Proctor Test

water **content**	dry **density**
(in *%)*	(in *g/cc)*
11.72	1.153
13.28	1.160
15.10	1.176
17.59	1.199
19.44	1.203
21.81	1.233
23.27	1.241

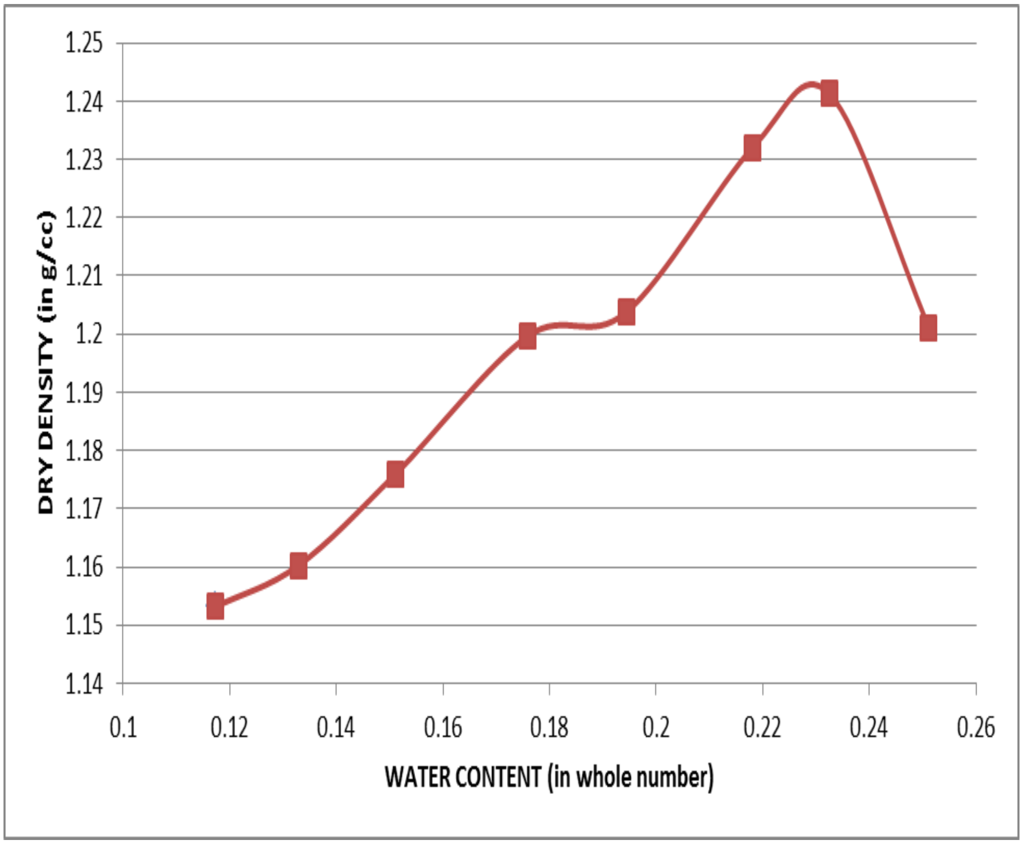

Fig. 4.3 Plot of Dry Density Vs Water content of fly ash

RESULT:

- ✓ MDD= 1.242 g/cc
- ✓ OMC=23.25%

4.2.1.3 DIRECT SHEAR TEST:

It is done as per IS 2720 : Part 13:1985 specifications

Table 4.2 Direct shear test For Fly ash

Normal stress *(in kN/m²)*	**shear stress** *(in kN/m²)*
50	41
100	61.389
150	81.111

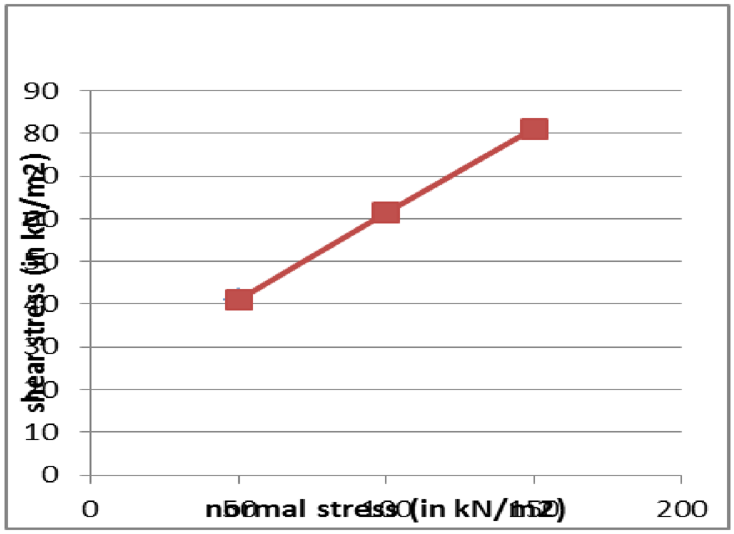

Fig.4.4 Plot of Shear stress vs Normal stress

<u>RESULT:</u>

- ✓ C=21 kN/m2
- ✓ Ø=22.13º

Fig. 4.5 Direct Shear Test Apparatus

4.2.1.4 UNCONFINED COMPRESSIVE STRENGTH OF FLY ASH:

It is done as per IS 2720 : Part 10:1991 specifications .Sample is taken from flyash slurry portion

- ✓ Area of proving ring =19.63 cm^2
- ✓ Value of each divison =3.397 N

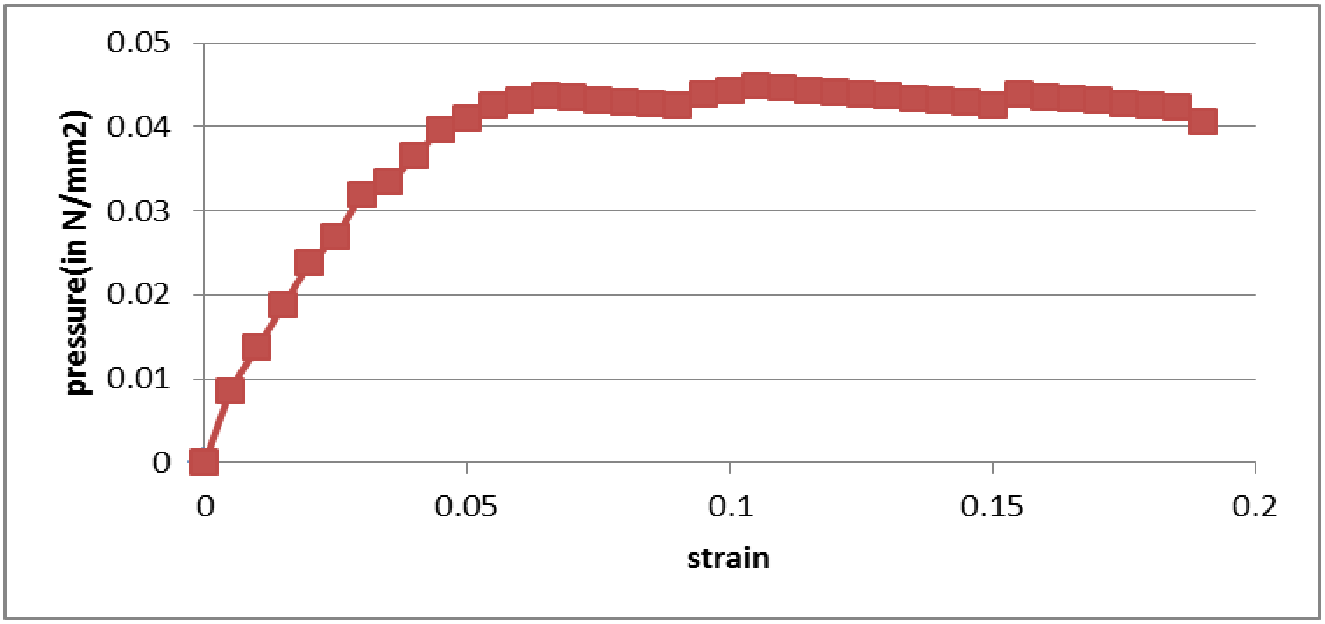

Fig. 4.6 Plot of Stress- Strain Curve

RESULTS:

MAXIMUM STRESS = qu =45 kN/m^2

Cohesion value = q_u /2 =22.5 kN/m^2

Fig. 4.7 Failure Of Fly Ash Specimen in unconsolidated compressive test

4.2.1.5 CONSOLIDATION TEST:

It is done as per IS 2720: Part 15:1986 specifications . From it permeability of fly ash is found out.

Specimen details:

- Initial height of specimen=20mm
- Dia. Of specimen=60mm
- Dry mass of specimen taken=79.9 gm
- Final height of specimen(Hs) =Md/(G*A*p_w)=12.93 mm

Fig. 4.8 Consolidation Test Apparatus

Table 4.3 Consolidation Test for Fly Ash

APPLIED PRESSURE	FINAL DIAL GAUGE READING	DIAL CHANGE	SPECIMEN HEIGHT	DRAINAGE PATH	Ht.OF VOIDS	VOID RATIO	FITTING TIME(t_{90})	Cv	a_v	k	
in kN/m^2	in mm	in mm	in mm	in mm	in mm		in min	cm^2/min	in m^2/kN	in cm/min	in m/day
0	18		20								
50	17.9	-0.1	19.9	9.975	6.97	0.539	480	0.176	0.003745	7.11E-05	0.001024
100	17.85	-0.05	19.85	9.9625	6.92	0.535	480	0.175	0.003772	7.05E-05	0.001016
200	17.6	-0.25	19.6	9.9	6.67	0.516	480	0.173	0.003913	3.47E-05	0.0005
400	17.11	-0.49	19.11	9.7775	6.18	0.478	480	0.169	0.004223	1.67E-05	0.00024
800	16.32	-0.79	18.32	9.58	5.39	0.417	930.25	0.084	0.004842	4.03E-06	5.8E-05

K(avg of first three values taken)= <u>0.000847 m/day</u>

4.2.1.6 PYCNOMETER TEST:

It is done as per IS 2720 : Part3:1980 specifications

Table 4.4 Specific Gravity Test for Fly ash

Sl. No.	Weight of Empty bottle (in g)	Weight of Bottle + dry soil (in g)	Weight of Bottle+soil+water (in g)	Weight of Bottle +water (in g)	Specific gravity
1	92.54	142.83	367.41	340.4	2.16
2	117.51	167.57	392.6	365.4	2.19
3	113.16	163.29	388.45	361	2.21

G(average) = 2.187

4.2.1.7 DISPERSIBILTY TEST:

(By CRUMB TEST)

Done as per ASTM D6572-06 specifications

- Dimensions of mould prepared
  = 1.5cm x 1.5 cm x 1.5 cm
- Weight of fly ash taken = 20 gm
- Time in which fly ash specimen dispersed
  in normal water = 5 min 38 sec
- Time in which fly ash specimen dispersed
  in distilled water = 14 min 26 sec
  (< 15 min)

Fig. 4.9 Crumb Test Of Fly Ash

4.2.2 CLAY

Following properties are found out:

- Maximum dry density and optimum moisture content
- Angle of internal friction and cohesion value.
- Permeability

4.2.2.1 STANDARD PROCTOR TEST:

It is done as per IS 2720: Part 7 :1985 specifications

Table 4.5 Standard Proctor Test

For Clay

water content	**dry density**
(in %)	*(in g/cc)*
09.94	1.737
12.59	1.815
14.74	1.831
16.06	1.771
18.34	1.725

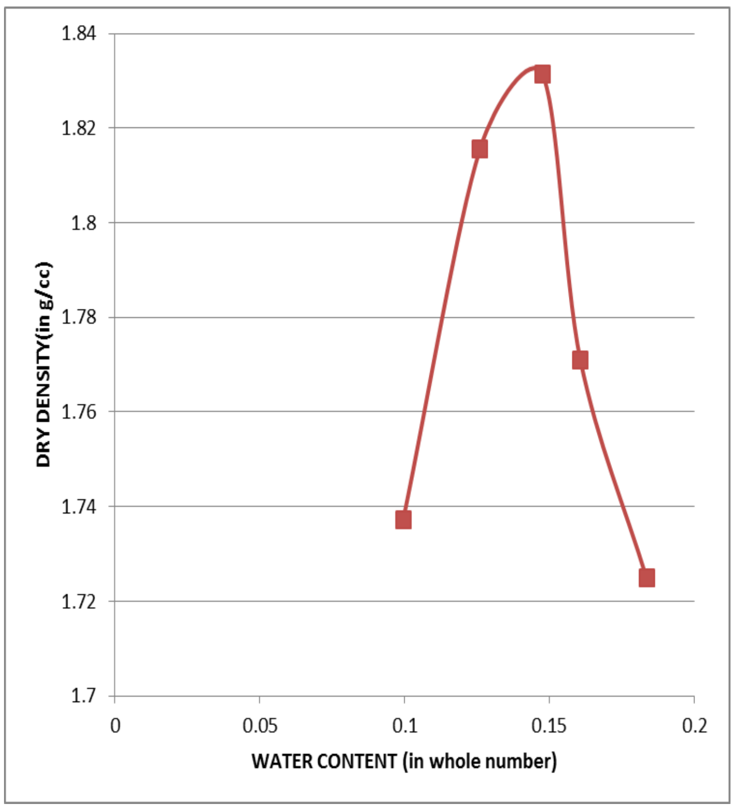

Fig. 4.10 Plot of Dry Density Vs Water content

<u>RESULTS:</u> MDD= 1.83 g/cc ; OMC=14.73%

4.2.2.2 DIRECT SHEAR TEST:

It is done as per IS 2720 : Part 13:1985 specifications

Table 4.6 Direct Shear Test

Of Clay

normal stress	**shear stress**
in kn/m2	*in kn/m2*
50	54.79
100	86.81
150	127.16

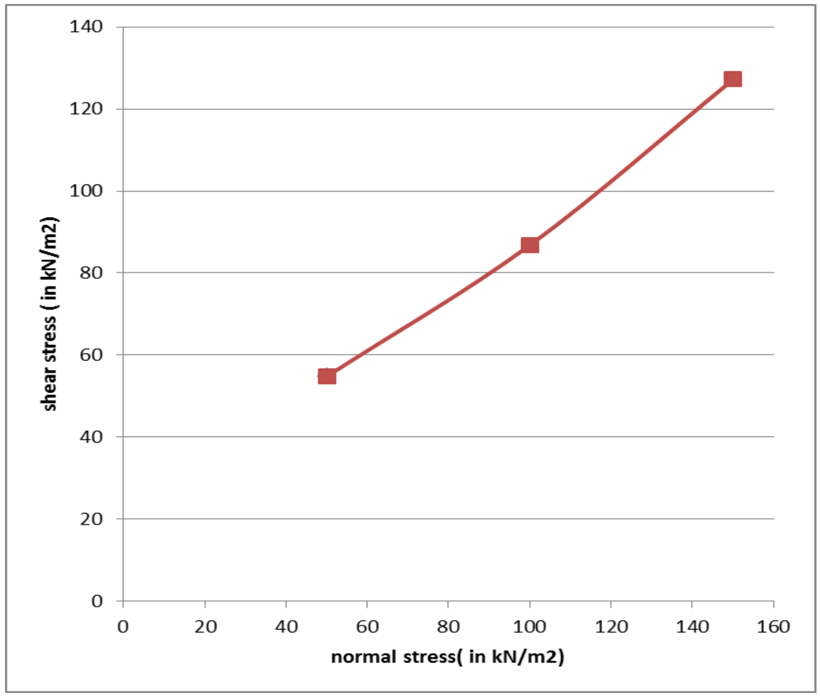

Fig.4.11 Plot of Shear Stress Vs Normal Stress of Clay

RESULTS:

C=22.8 kN/m2

Ø=32.62º

4.2.2.3 FALLING HEAD PERMEABILITY TEST:

It is done as per IS 2720: Part 17:1986 specifications

Experiment details:

- Dia of pipe= 2.4 cm
- Dia of soil specimen = 10 cm
- Length of soil specimen= 12.5cm

Table 4.7 Permeability Test Of Clay

HEAD (in cm)	Time elapsed (in sec)	K (in m/s)
91		
85	2503	1.965E-07
75	3809	2.372E-07
60	5285	3.032E-07
40	12007	2.433E-07
10	60578	1.647E-07
5	23531	2.124E-07

Fig.4.12 Permeability Test For Clay

RESULT : *K*(average) = 2.262E-07 m/s

4.2.3 SAND

Following properties of sand used are found out:

- Grain size analysis
- Maximum dry density and optimum moisture content
- Angle of internal friction and cohesion value.
- Permeability

4.2.3.1 GRAIN SIZE DISTRIBUTION:

It is done as per IS 2720 : Part 4 :1985 specifications .

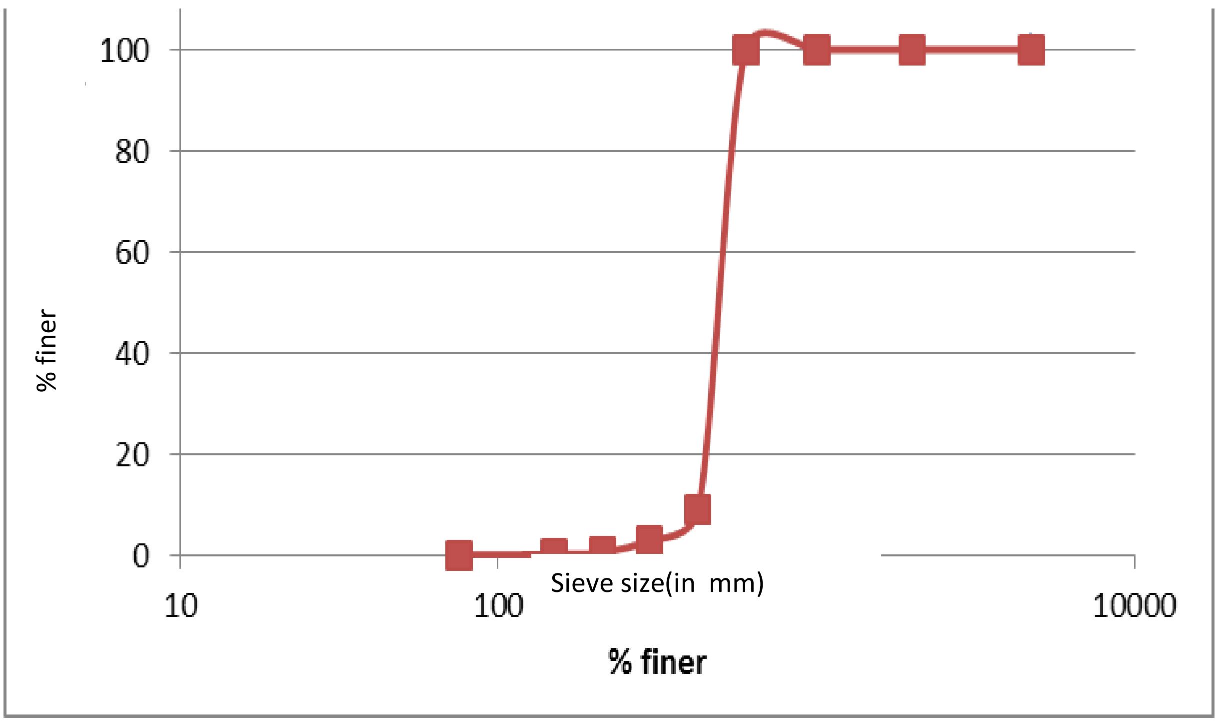

Fig. 4.13 Plot of Grain Size distribution of sand

4.2.3.2 STANDARD PROCTOR TEST:

It is done as per IS 2720 : Part 7 :1985 specifications

Table 4.8 Standard proctor Test for sand

water content	**dry density**
(in %)	*(in g/cc)*
02.15	1.447
03.70	1.459
005.64	1.454
07.31	1.465
08.58	1.481
12.78	1.517
17.56	1.540
19.84	1.447

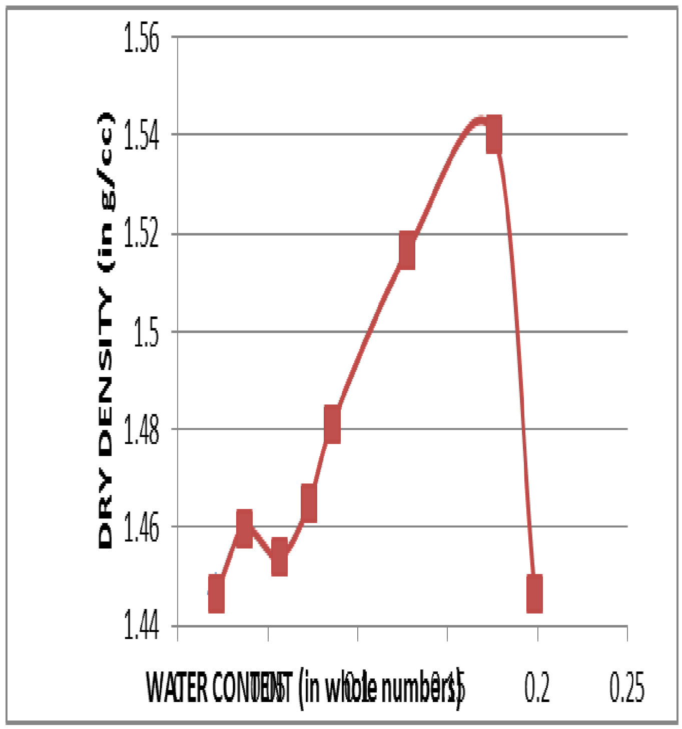

Fig. 4.14 Plot of Dry Density Vs water Content of sand

<u>*RESULT*</u>*:* MDD= 1.54 g/cc ; OMC=17.56%

4.2.3.3 DIRECT SHEAR TEST:

It is done as per IS 2720: Part 13:1985 specifications

Table 4.9 Direct shear Test Of Sand

normal stress	**shear stress**
in kn/m2	*in kn/m2*
50	48.464
100	94.767
150	140.382

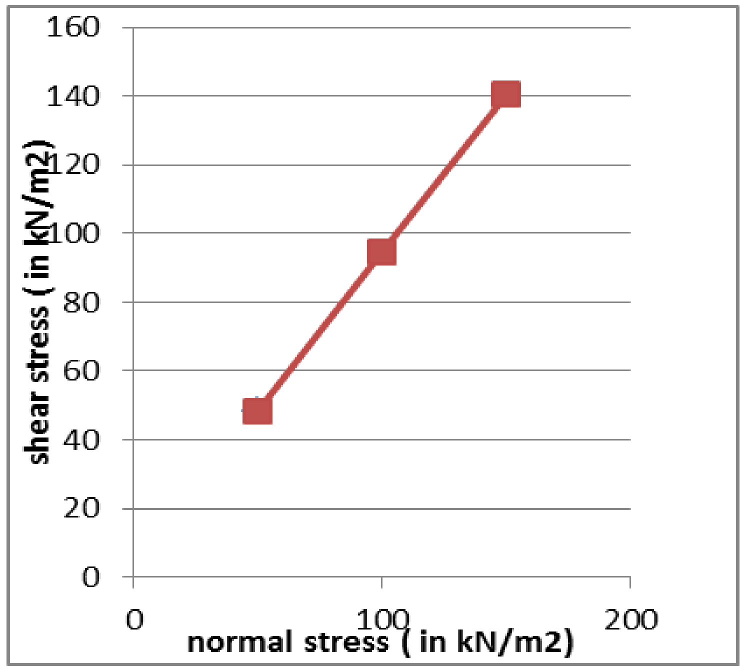

Fig.4.15 Plot of Shear stress Vs Normal stress of Sand

<u>RESULT:</u>

C=2.505 kN/m2

Ø=42.58º

4.2.3.4 CONSTANT HEAD PERMEABILITY TEST

It is done as per IS 2720: Part 17:1986 specifications

Experimental details:

- Dia of soil specimen = 10 cm
- Length of soil specimen= 12.5cm
- CONSTANT HEAD= 238cm

Table 4.10. Permeability Test for Sand

Time observed	Time elapsed (in sec)	Q collected (in ml)	K (in m/s)
10:15			
15:40	19500	25	8.57E-06
17:40	7200	9	8.36E-06

K (average) =8.465E-06 m/s

Fig.4.16 Falling Head Permeability Apparatus

4.2.4 STONE CHIPS:

4.2.4.1 G value found out = 2.67

4.2.4.2 **GRAIN SIZE DISTRIBUTION:**

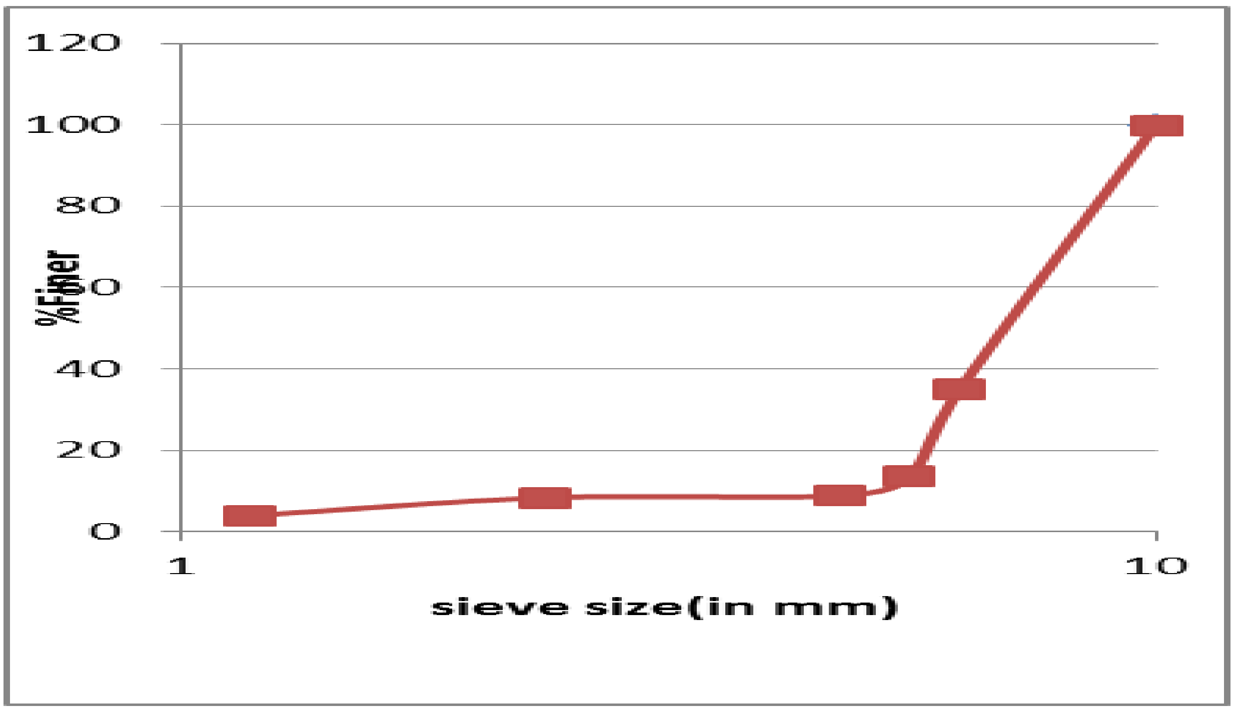

Fig.4.17 Grain Size Distribution of stone chips

4.3 MODEL STUDY:

PREPARATION OF TWO- STAGE DYKE BY UPSTREAM METHOD:

4.3.1 PURPOSE:

A model of dyke is prepared to find out whether tensile stresses develop below phreatic line .This will be helpful in analyzing failure of ash dyke as fly ash cannot take tension and that adversely affects the slope stability of the dyke.

4.3.2 SEQUENCE OF WORK

It consists of following stages:

- MODEL DIMENSIONING
- PROCUREMENT OF MATERIALS
- EXPERIMENTS TO DETERMINE GEOTECHNICAL PROPERTIES OF MATERIALS
- MAKING OF MODEL AND ADDING SLURRY.
- OBSERVING THE PHREATIC LINE AND FAILURE IF HAPPENS
- ANALYSING THE SAME WITH PLAXIS
- COMPARISON OF PHREATIC LINE DEVELOPED IN ACTUAL MODEL WITH THAT GENERATED IN PLAXIS

4.3.3 THE RECTANGULAR TANK :

- The model is to be constructed in a rectangular tank which is closed at 4 sides and bottom.
- It is open from top portion so that material can be added and compacted. \
- The tank is made up of transparent perplex sheet so that phreatic line can be observed.
- 4 openings were made on one side, i.e., towards toe of starter dyke.
- Dimensions of tank: 91cm (L) * 41cm(B) * 42cm(H).
- As length was limited to around 90cm three stage dyke was not possible to accommodate the required slope. Hence two-stage dyke is to be built with leaving space for slurry.

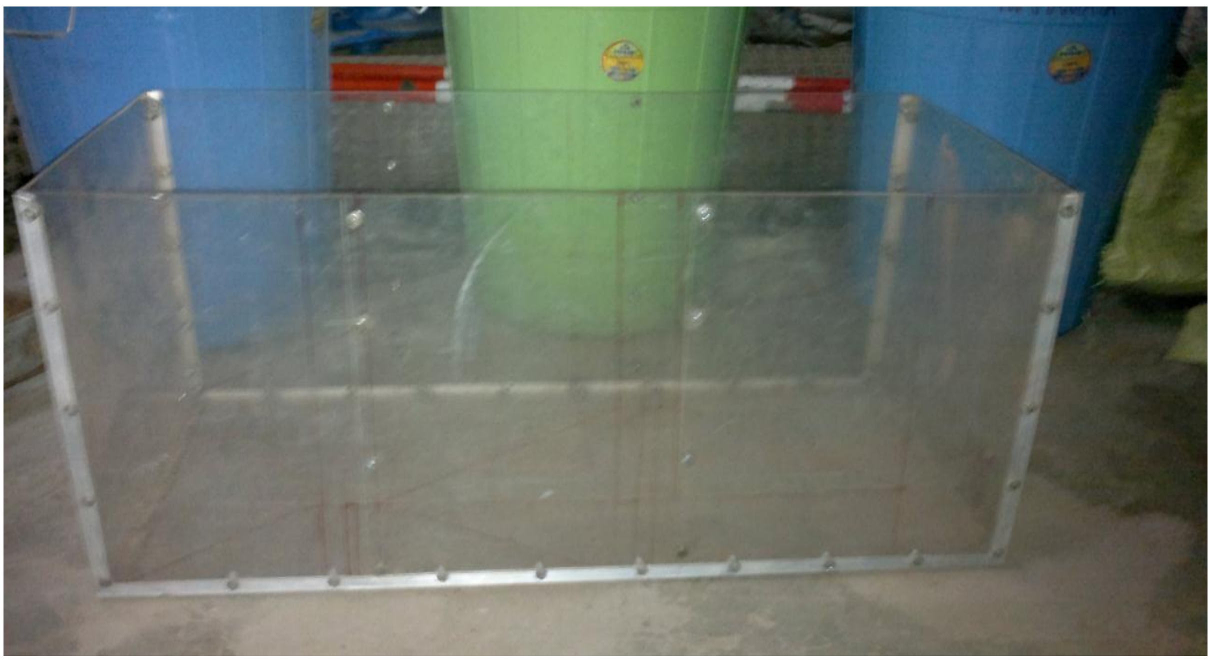

Fig: 4.18 Outline Marking for Maintaining proper slope

- 1st model:

  Here the side slope was kept 3:1 on dry side and 2.5:1 on fill side. Each dyke height was restricted to10 cm and width provided to each was 5cm.

- On consultation with Mr. Upendra Maharana ,engineer at NALCO the slope both on dry and fill side was kept 2.25:1 as per current practice .

- He suggested slurry in ratio of 1:9 by volumeof fly ash and water.

4.3.4 DIMENSIONING OF MODEL

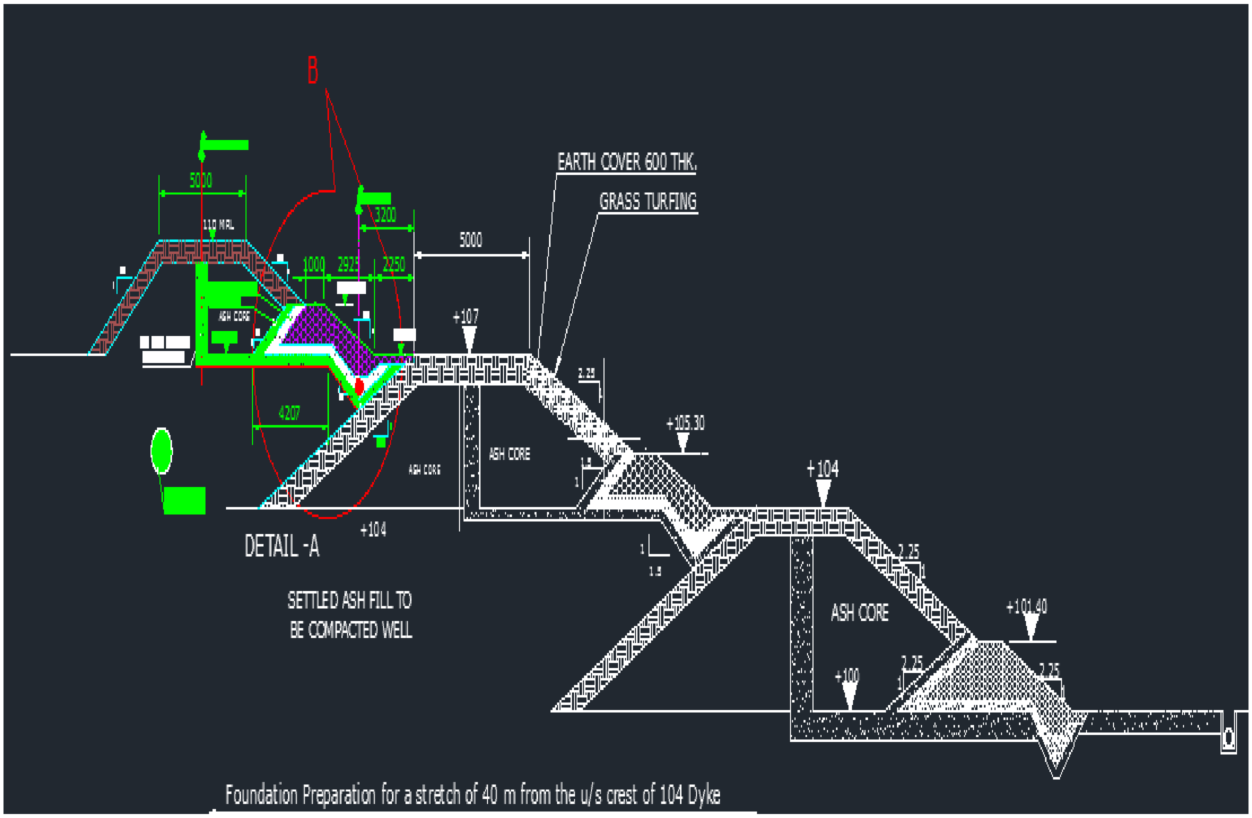

Fig.4.19. A Typical model used in current practice for the upstream method of ash dyke

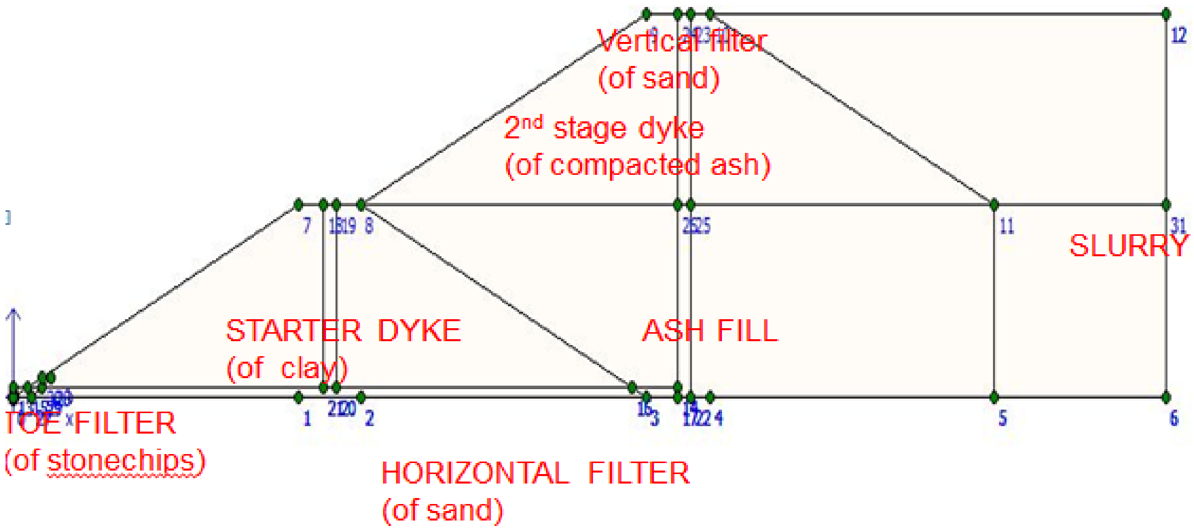

Fig.4.20. Dimensions Of The Model To Be Built

4.3.5 COMPUTATION OF VOLUME OF MATERIALS TO BE USED IN THE MODEL:

[1.] SAND (in filter)

Volume= [0.5 *(22.5+5+22.5+5) +1*9.5 +1*9.5]* 41 =2316.5 cm3 , around 2500cm3.

[2.] CLAY

Volume=9.5*(5+50-1)*41 = 20643.5 cm3 , around 21000cm3

[3.] compacted FLY ASH

Volume=10*(4+49)*41= 21730 cm3,around 22000 cm3

[4.] SLURRY ASH

Volume= [2*.5* 22.5*(9.5+10)+9.5*(5+22.5)+13.5*9.5)]= 33958.25cm3 around 35000cm3

Total slurry to be prepared = 0.35m3

4.3.6 MAKING OF THE MODEL:

It involves the the following stages:

- Provision of toe filter
- Provision of horizontal sand filter
- Making of starter dyke of clay with providing space for vertical sand drain
- Passing of slurry till ash settles upto height of starter dyke.
- Making of second stage dyke by compacting ash.
- Passing of slurry till ash settles upto height of second-stage dyke
- Observing the phreatic line

4.3.6.1 PROVISION OF TOE FILTER

Stone chips passing through 10mm IS sieve and retained on 2.36 mm IS sieve are used. The c/s of filter has a height of 1 cm and width of 1.5 cm.

Fig.4.21 Placing Of Toe Filter In The Model

4.3.6.2 PROVISION OF HORIZONTAL SAND FILTER

Sand is provided up to the centre of vertical sand drain of second stage dyke of thickness of 0.5 cm.

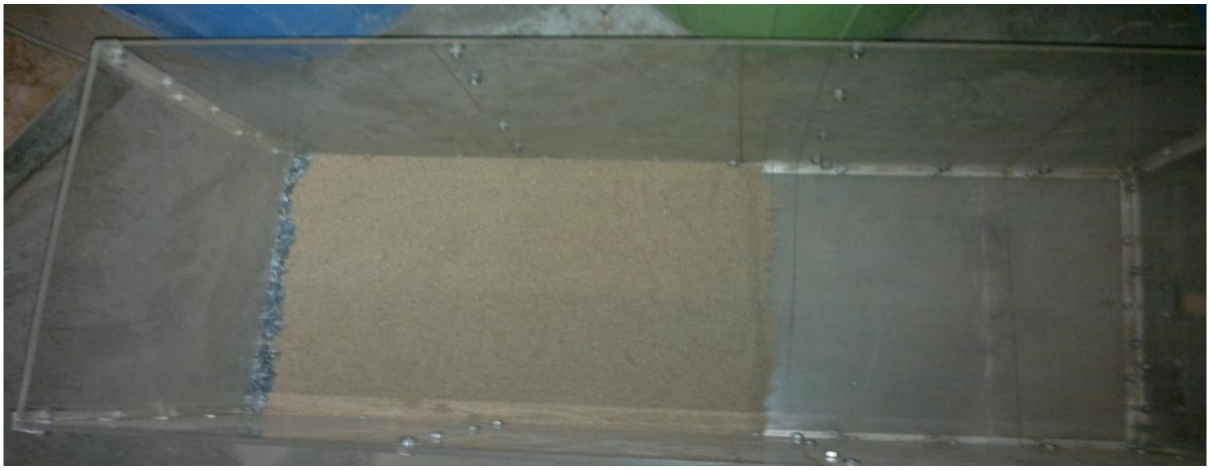

Fig.4.22 Placing Of Horizontal Filter In The Model

4.3.6.3 MAKING OF STARTER DYKE OF CLAY WITH PROVIDING SPACE FOR VERTICAL SAND DRAIN

Clay compacted slightly dry of OMC used to build the of first stage dyke.Two cardboards , one of thickness 6 mm and other of 4 mm are placed at centre It served the purpose of providing a vertical sand filter of 1 cm and restraining clay to occupy the space when it is compacted.

Fig.4.23 Making Of The Starter Dyke With Clay

4.3.6.4 COMPLETION OF FIRST STAGE DYKE WITH PROVISION OF VERTICAL SAND FILTER:

Fig.4.24 Placing Of Vertical Drain Filter In The Model

4.3.6.5 PASSING OF SLURRY:

Slurry was prepared by mixing fly ash and water in ratio of 1:9 by volume.Red ink dye is added so that phreatic line can be observed.

Fig.4.25 Passing of Slurry In The Model

4.3.6.6 SETTLEMENT OF FLY ASH IN SLURRY UPTO HEIGHT OF FIRST STAGE DYKE:

Fig.4.26 Compaction Of Slurry Up To Starter Dyke

4.3.6.7 MAKING OF SECOND STAGE DYKE:

After fly ash got deposited upto height of first stage dyke, a cut was made for providing drain. Then fly ash compacted of OMC is used to make the required dyke with providing cardboards for vertical drains.

Fig.4.27 Making Of The Second Stage Dyke

4.3.6.8 PASSING OF SLURRY MIXED WITH RED INK:

Fig.4.28 Passing of Slurry with Mixed colour Red Ink

4.3.7 PROBLEMS ENCOUNTERED WHILE MAKING OF THE MODEL:

Some problems were faced while making the practical model like:

- Difficulty in maintaining the exact slope of 1:2.25
- Difficulty in keeping sand drains perfectly vertical: The cardboard was getting tilted while compacting.
- Leakage of slurry at the fill: Due to high pressure slurry flowed out from angles used to join the perpex sheets of the box. M-seal was used to fix it.

Fig.4.29 Leakage Of Slurry

CHAPTER -5

RESULTS

&

DISCUSSIONS

5.1 INTRODUCTION:

The two-stage dyke was constructed by upstream method. On passing slurry the phreatic line developed was observed. Then a comparison was made by analysis of PLAXIS. For the input parameters of material sets in PLAXIS the geotechnical properties of materials used such as fly ash, clay in starter dyke, sand in horizontal & vertical drains and stone chips in toe filter are required. The same is found out from laboratory tests at Geotechnical lab , NIT, Rourkela . After that analysis is done in PLAXIS for steady seepage condition to get the phreatic line and compare with that of developed in practical model.

5.2ANALYSIS OF MODEL BY PLAXIS:

A two-stage dyke constructed by upstream method is taken. Analysis for steady seepage is done. The same model is constructed practically with scale ratio of 1:100. The phreatic lines in both cases are compared. The geotechnical properties of materials used in input of plaxis are found out by laboratory tests.

PROCEDURE:

5.2.1 CREATION OF MODEL:

Scale adopted: 1 cm(of model) = 1 m(of plaxis model)

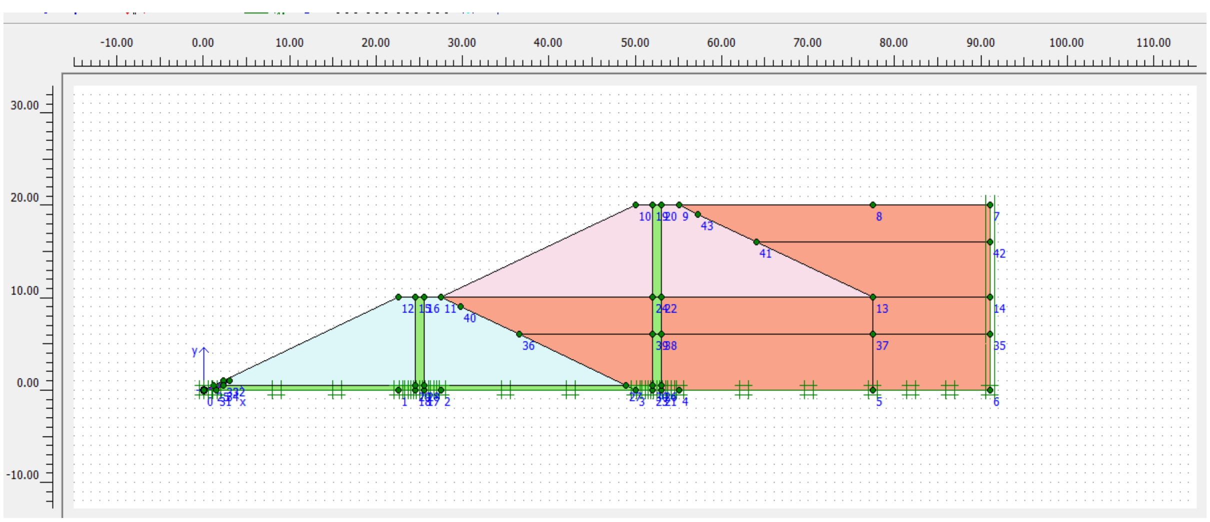

Fig 5.1 input model of 2-stage dyke in PLAXIS for phreatic line comparison

5.2.2 INPUT OF MATERIAL PROPERTIES

Table 5.1 Input parameters of material sets for 2-stage dyke

PARAMETERS	**COMPACTED FLY ASH** (*shown in light pink)*	**FLY ASH FILL** (*shown in dark red)*	**CLAY** (*shown in light blue)*	**SAND** (*shown in light green)*	**STONE CHIPS** (*shown in violet)*
MATERIAL MODEL	MOHR-COULOMB	MOHR-COULOMB	MOHR-COULOMB	MOHR-COULOMB	MOHR-COULOMB
MATERIAL TYPE	DRAINED	DRAINED	DRAINED	DRAINED	DRAINED
UNSATURATED UNIT WEIGHT(kN/m^3)	12.42	12.4	18.3	15.4	27
SATURATED UNIT WEIGHT (kN/m^3)	15.307	15.307	20.99	18.1	28.35
PERMEABILITY; K_X (m/day)	8.47E-04	8.47E-04	2E-04	0.739	800
PERMEABILITY; K_Y (m/day)	8.47E-04	8.47E-04	2E-04	0.739	800

E_{REF} (kN/m^2)	30000	30000	20000	50000	50000
POISSON RATIO	0.3	0.3	0.3	0.3	0.3
C_{ref}(kN/m^2)	21	21	22.8	2.505	.0001
ANGLE OF INTERNAL FRICTION	22.13	22.13	32.62	42.58	48
STRENGTH	RIGID	RIGID	RIGID	RIGID	RIGID

5.2.3 MESH GENERATION:

Very fine mesh is generated for each case.

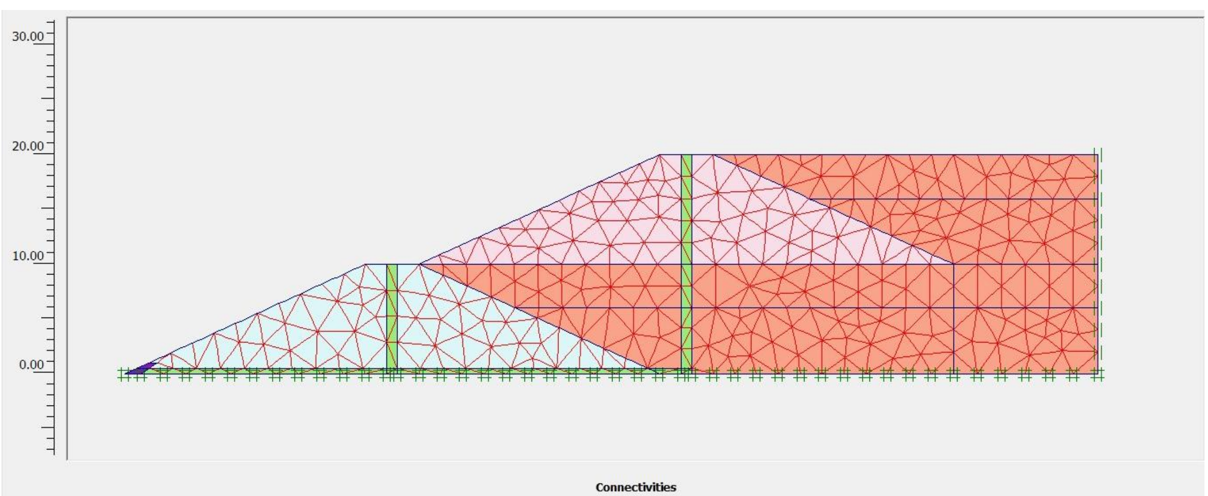

Fig 5.2 Mesh generation of 2-stage dyke in PLAXIS for phreatic line comparison

5.2.4. INITIAL PORE PRESSURE GENERATION:

Water pressure generated using ground water (steady state) condition.

5.2.5 CALCULATION

It is done in 2 stages.

STAGE 1:

Here only 1st stage dyke and flyash fill upto that height of 6 m is activated. Phreatic level is kept at 2m and at 3m height above flyash fill.

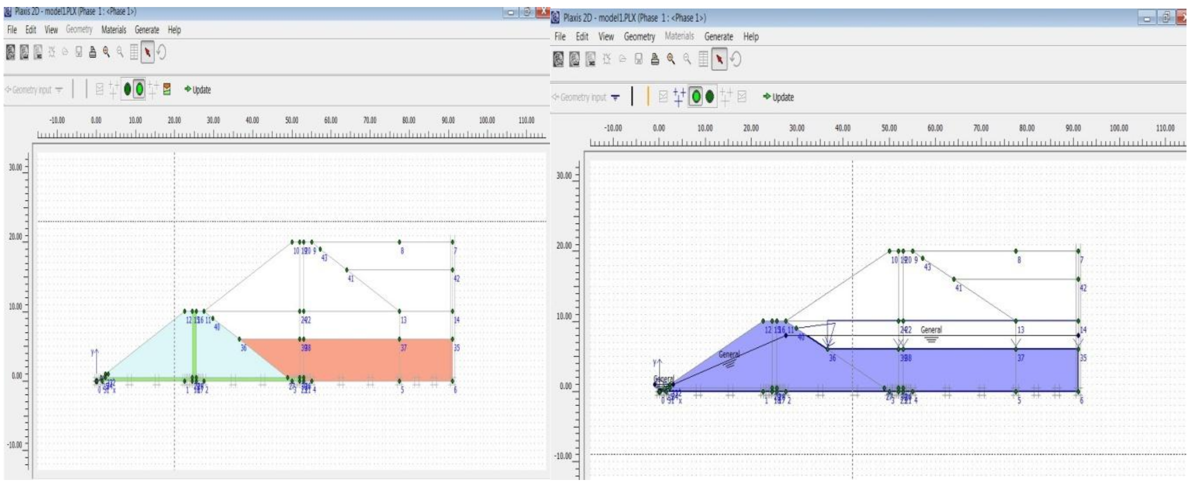

Fig 5.3 Phase 1 of calculation of 2-stage dyke in PLAXIS for phreatic line comparison

STAGE 2:

Here both stages of dyke and flyash fill upto that height of 16 m is activated. Phreatic level is kept at 2m and at 3m height above flyash fill.

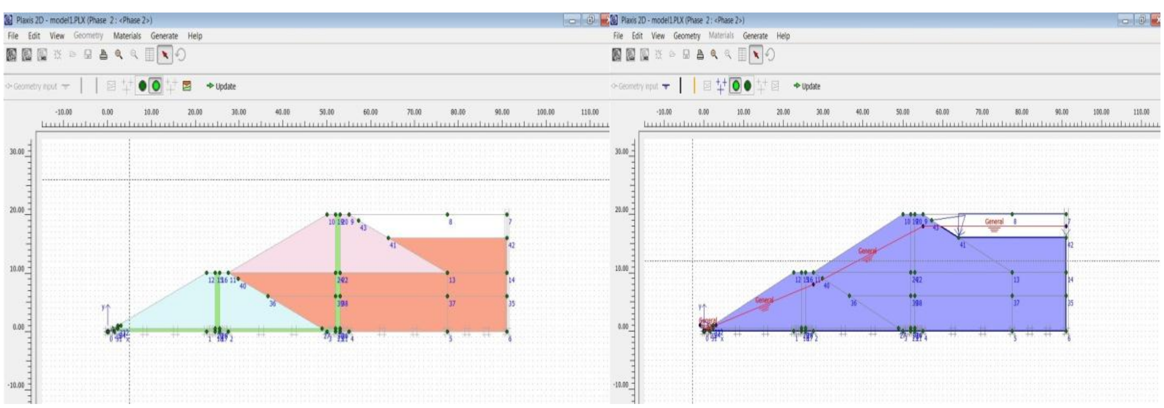

Fig 5.4 Phase 2 of calculation of 2-stage dyke in PLAXIS for phreatic line comparison

Then FOS for each stage was calculated by going for phi-c reduction method.

5.2.6 OUTPUT:

Relative shadings of effective mean stresses for various cases are studied to find if any positive pre pressure exists below phreatic line:

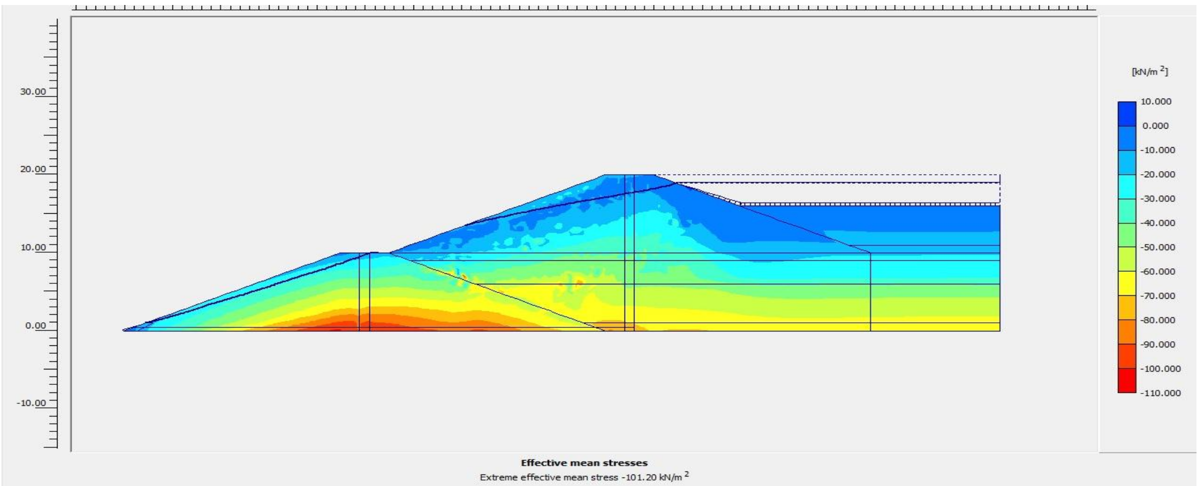

Fig 5.5 Effective mean stress of 2-stage dyke in PLAXIS for 3m height of water above fly ash fill without filters

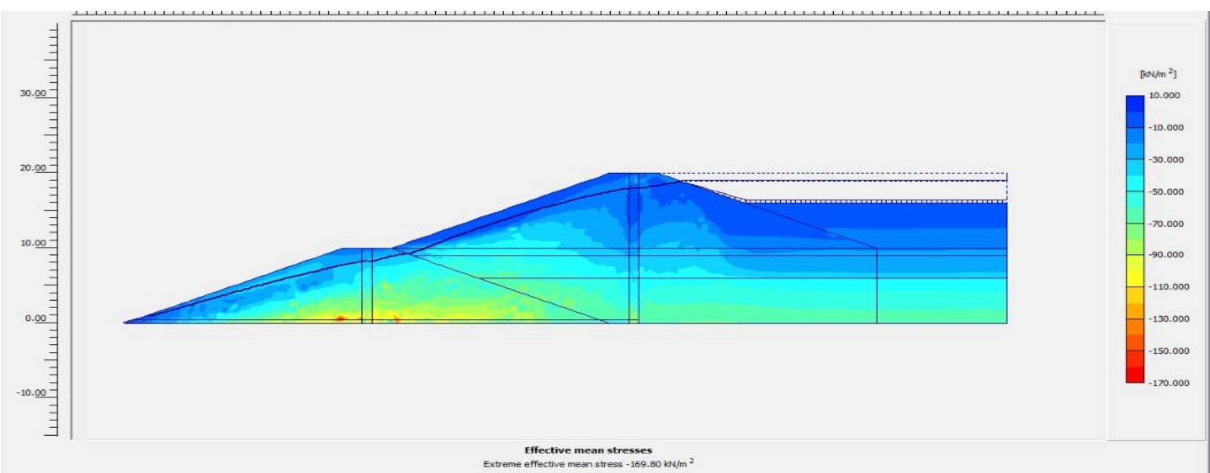

Fig 5.6 Effective mean stress of 2-stage dyke in PLAXIS for 3m height of water above fly ash fill with vertical filter of width of 1m

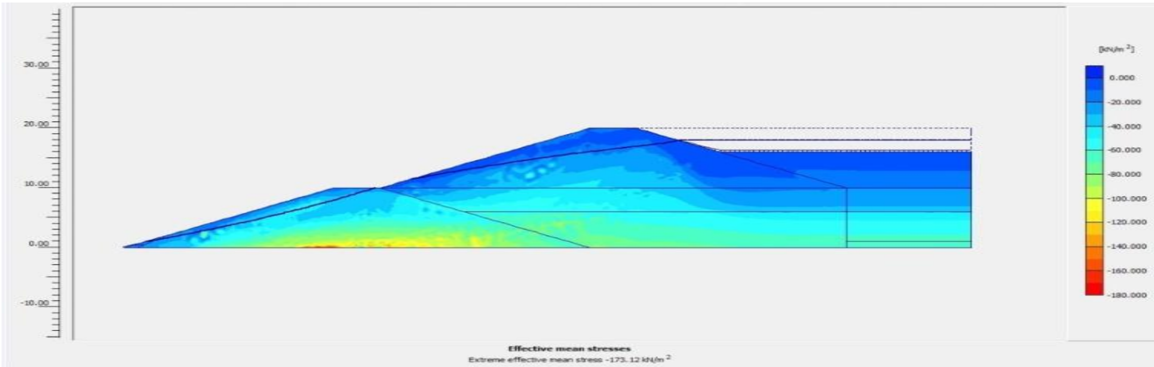

Fig 5.7 Effective mean stress of 2-stage dyke in PLAXIS for 2m height of water above fly ash fill without filters

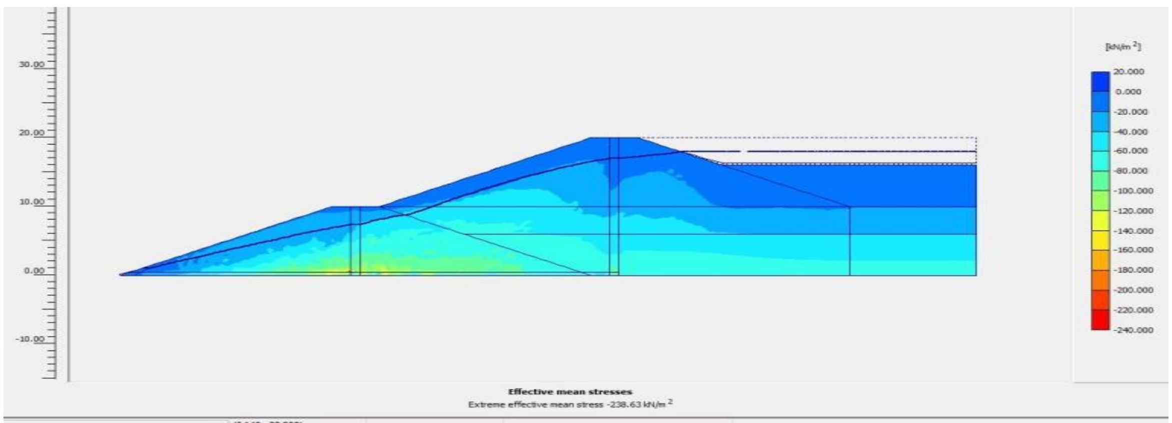

Fig 5.8 Effective mean stress of 2-stage dyke in PLAXIS for 2m height of water above fly ash fill with vertical filter of width of 1m

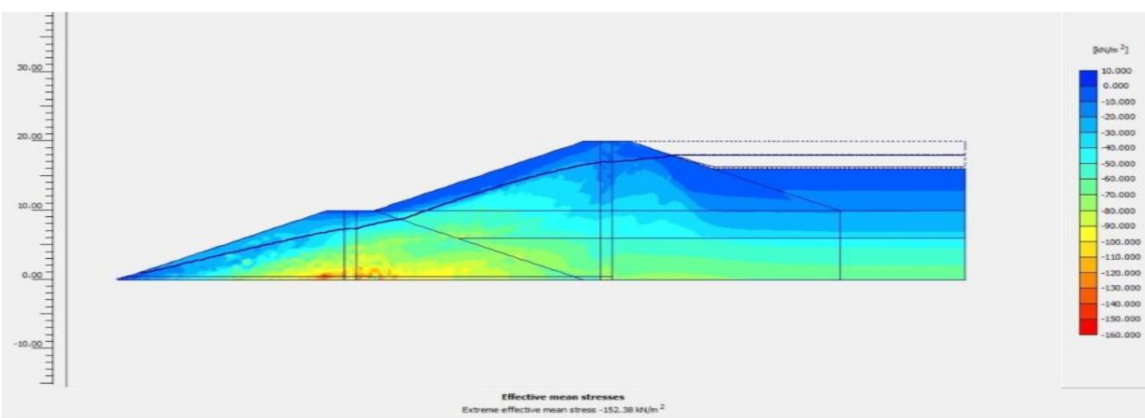

Fig 5.9 Effective mean stress of 2-stage dyke in PLAXIS for 2m height of water above fly ash fill with vertical filter of width of 1.25 m

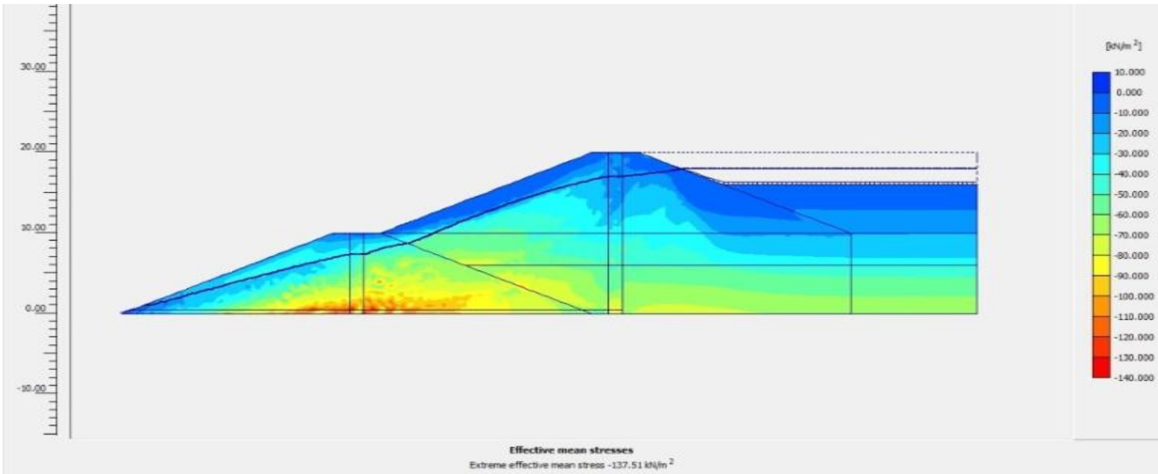

Fig 5.10 Effective mean stress of 2-stage dyke in PLAXIS for 2m height of water above fly ash fill with vertical filter of width of 1.5 m

5.2.7 DEFORMED MESH:

Table 5.2 Extreme displacements without and

with different widths of vertical sand drains

WIDTH OF FILTER APPLIED (in m)	EXTREME DISPACEMENT (in mm)
Not provided	2829.6
1	11.04
1.25	*8.28 (minimum)*
1.5	10.96

5.2.8 FACTOR OF SAFETY:

Table 5.3 FOS without and with different widths of vertical sand drains

WIDTH OF FILTER (in m)	FOR 1ST STAGE DYKE	FOR 2ND STAGE DYKE
For 2m height of water above fly ash fill		
Not applied	2.419	1.831
1	2.115	1.797
1.25	2.102	1.776
1.5	2.092	1.757
For 3m height of water above fly ash fill		
Not applied	2.248	1.615
1	1.974	1.639

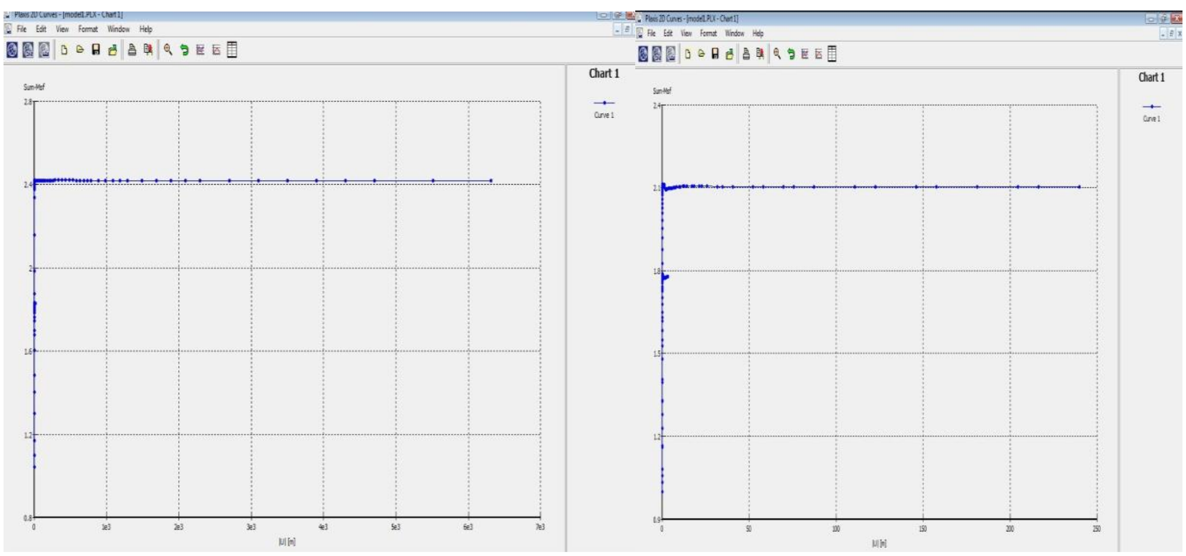

Fig 5.11 FOS curves for 2-stage dyke withou and with filter(of width 1.25m)

5.3 RESULT

5.3.1 SUITABILITY OF SAND AS FILTER USED IN DRAINS.

The grain size distribution of fly ash and that of sand was found to be nearly parallel. Hence this sand can be used as filter material in horizontal and vertical sand drains.

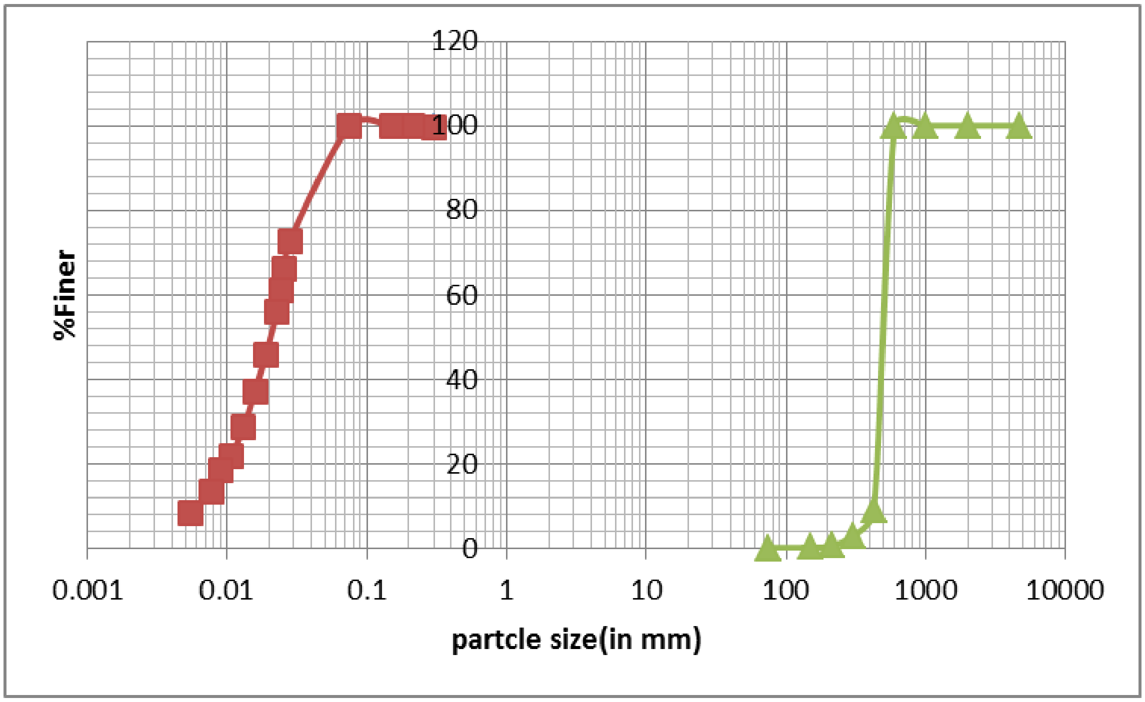

Fig:5.12 comparison of grain size distribution of fly ash and sand

For sand used :

D_5= 130 mm

D_{85}=710 mm

As D_{85} > $5D_5$ this sand can be used asfilter

The phreatic line is observed after passing slurry on completion of second stage dyke. The line is very faint and thereby marked by red pen marker .the phreatic line as generated by PLAXIS is found very similar to that one observed in laboratory model

5.3.2 COMPARISON OF PHREATIC LINE

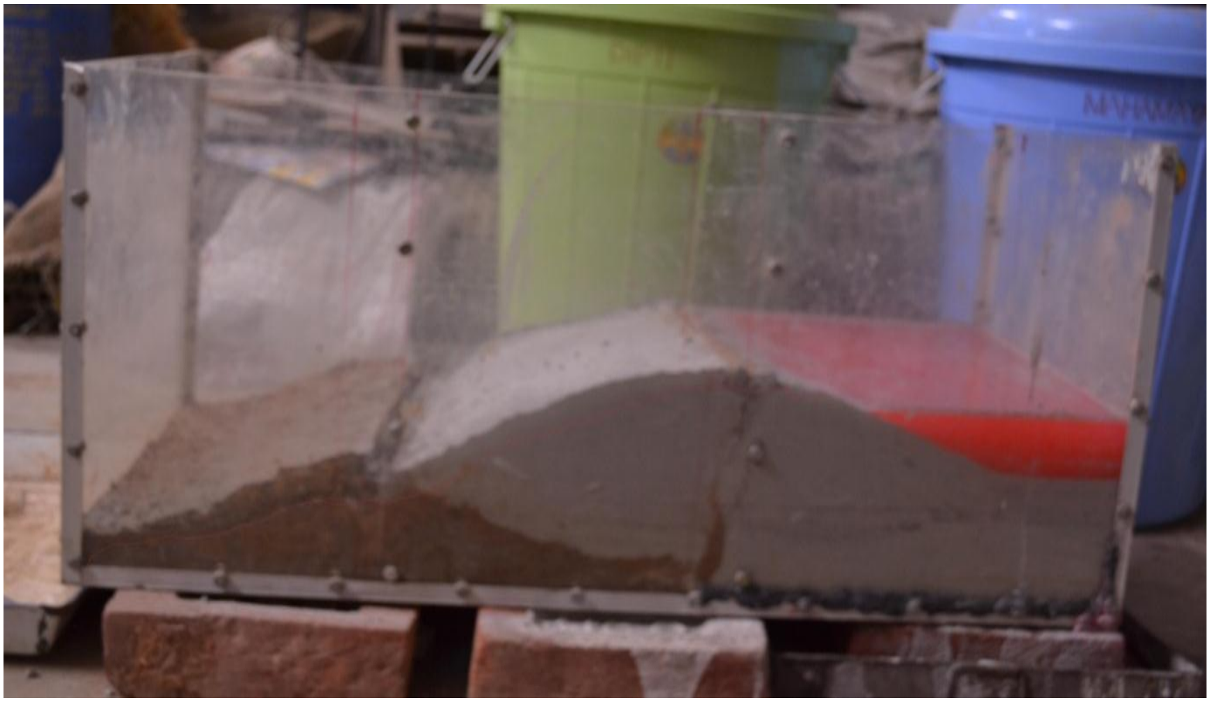

Fig.5.13. Observation of The Phreatic Line developed in Model

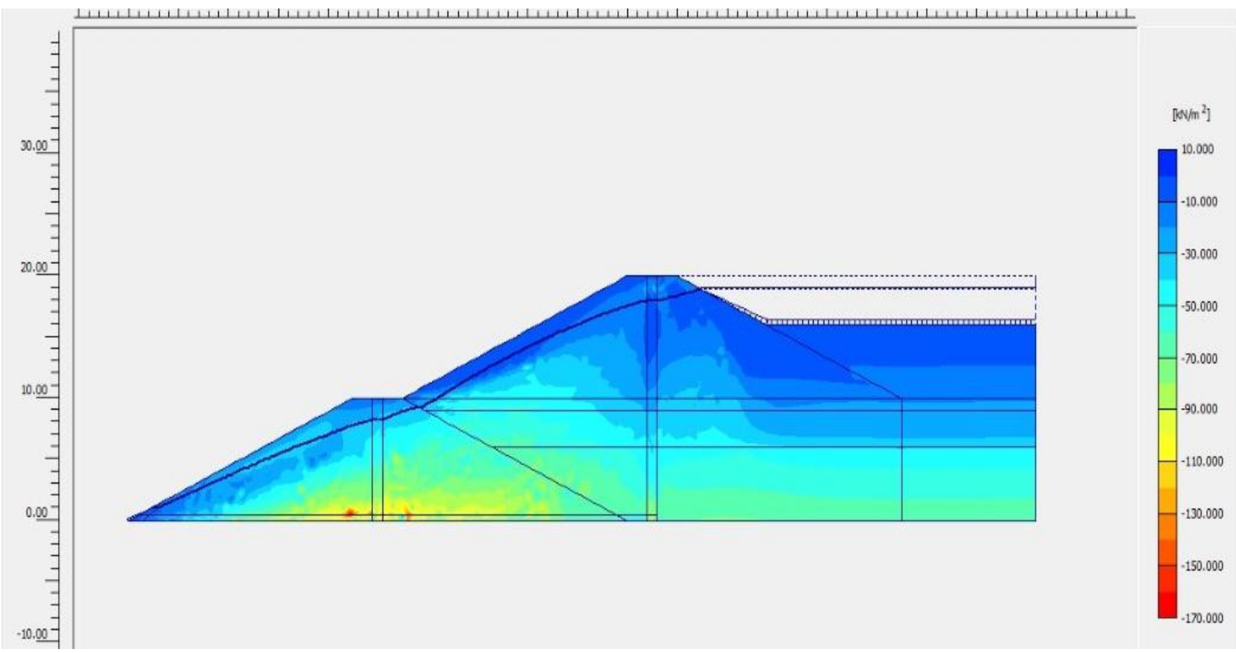

Fig5.14 Observation Of The Phreatic Line generated by PLAXIS

5.4 DISCUSSIONS

Analysis was done for stability of ash dykes by various methods under different conditions by finite element based software PLAXIS. In dry condition all the three methods give factor of safety above 1.8. Downstream method gives more FOS than other two. By changing pore water pressure done by changing position of water table FOS slightly decreases but remains well above 1.5 in all the three methods. Again in this case downstream method the most safe. In steady seepage analysis FOS lowers down. But in rapid drawdown condition ash dyke collapses whatever be rate of drawdown from 0.1m/day to 5m/day. Hence while designing and constructing ash dyke seepage analysis should be taken into account as it appears one of the most important reasons for failure of ash dykes.

In India, upstream method is popularly followed as earthwork required is minimum. A practical model of two-stage dyke by upstream method is constructed and fly ash slurry(in same proportion of water and fly ash as used in a Typical ash dyke is passed to observe the phreatic line and it matched very closely as that of generated in model analysed by PLAXIS. This illustrates PLAXIS can be very handy tool to predict stability of ash dykes in real site conditions and particularly useful in carrying out steady seepage analysis.

In two-stage dykes, phreatic level does not remain within body of dyke. This may lead to its failure due to piping. When toe filter, horizontal and vertical sand drains are provided the phreatic line is well within body of dyke contributing to its stability. Very narrow width of filter is ineffective in lowering the phreatic level and higher width reduces stability. So, in PLAXIS analysis is done by keeping toe filter dimensions and thickness of horizontal sand drain constant, width of vertical sand drain varied. The one which gave minimum displacement, in our case of width of 1.25m should be adopted.

CHAPTER -6

CONCLUSION

&

SCOPE FOR FURTHER STUDY

6.1 INTRODUCTION

Safe construction of ash dykes is very much essential in current scenario of management and mitigation of environmental hazards. Ash dykes are more prone to failure than gravity and earthen dams because seepage analysis is not taken into account in case of former. In this study an attempt has been made to analyze the leakage of the ash dyke which is an important issue of management of fly ash dykes. With help of commercial finite element package PLAXIS this lacunae of design was analyzed

6.2 CONCLUSIONS

Based on laboratory investigation, numerical analysis following conclusions can be made:

1. Three methods of construction of fly ash dyke are available namely upstream, downstream and centerline .The upstream method one is more popularly used because of land constraints.. Analysis in dry condition for all the three methods give factor of safety (FOS) above 1.8. FOS slightly decreased but remained well above 1.5 in all the three methods.when analysed by varying height of water level above ashfill. The FOS further lowered down in steady seepage case. The ash dyke collapsed in rapid drawdown condition whatever was the rate of drawdown (from 0.1m/day to 5m/day)

2. PLAXIS analysis shows the phreatic line does not remain within body of ash dyke when no filters are used. Provision of toe filters, horizontal and vertical sand drains lowers the phreatic line below the dyke body thus providing safety against piping. This has been confirmed by observing the pattern of phreatic line developed in the two stage ashdyke laboratory model , constructed by us using upstream method

3. Effect of sand drains on strength of dyke was analyzed with varying widths of vertical sand drains. Displacement of dyke initially decreased with increase in width of vertical sand drains and then increased with further increase in width.The one giving minimum displacement, 1.25m wide of vertical drain for 5m width of ash dyke was considered to be the most suitable.

6.3 SCOPE OF FUTURE STUDIES

- For steady seepage analysis using filters, our work is limited to upstream method. Analysis using varying widths of vertical sand filters in downstream and centerline methods should be done.

- Practically models with various widths of vertical sand filter should be constructed and also different slopes should be adopted to have a better idea on design of ash dykes

- Fly ash used is found to be dispersive. So clay coating is essential otherwise fly ash will flow down along with water. This may have effect on pattern of phreatic line developed. Hence, this aspect should be considered while doing steady seepage analysis by PLAXIS.

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