"DESIGN AND SLOPE STABILITY ANALYSIS OF A PROPOSED ASH POND FOR WASTE TO ENERGY PLANT IN SHIMLA"

A Thesis

Submitted in partial fulfillment of the requirements for the award of the degree of

MASTER OF TECHNOLOGY

IN

CIVIL ENGINEERING

With specialization in

Environmental engineering

Under the supervision of

Mr. Niraj Singh Parihar
(ASSISTANT PROFESSOR)

&

Mr. Saurabh Rawat

(ASSISTANT PROFESSOR)

By

Shaman Chauhan
(152758) to

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

WAKNAGHAT, SOLAN – 173234

HIMACHAL PRADESH, INDIA

May-2017

CERTIFICATE

This is to certify that the work which is being presented in the thesis titled **"DESIGN AND SLOPE STABILITY ANALYSIS OF A PROPOSED ASH POND FOR WASTE TO ENERGY PLANT IN SHIMLA"** for partial fulfillment of the requirements for the award of the degree of Master of Technology in "**ENVIRONMENTAL ENGINEERING"** and submitted to the Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out By **Shaman Chauhan** (Enrolment No. 152758) during a period from July 2016 to May 2017 under the supervision of **Mr. Niraj Singh Parihar** Assistant Professor and **Mr. Saurabh Rawat** Assistant Professor, Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

The above statement made is correct to the best of our knowledge.

Date: - ………………………

Dr. Ashok Kumar Gupta	**Mr. Niraj Singh Parihar**	**Mr. Saurabh Rawat**	**External Examiner**
Professor and Head of Department Department of Civil Engineering JUIT Waknaghat	Assistant Professor Department of Civil Engineering JUIT Waknaghat	Assistant Professor Department of Civil Engineering JUIT Waknaghat	

ACKNOWLEDGEMENT

In performing my research, I had to take the help and guideline of some respected persons, who deserve my greatest gratitude. First of all, I would like to express my deep gratitude to my project guide **Mr.Niraj Kumar Parihar,** *(Assistant Professor, Department of Civil Engineering)* for providing me an opportunity to work under his supervision and guidance. He has always been my motivation for carrying out the project. I also sincerely thank **Mr. Saurabh Rawat** *(Assistant Professor, Department of Civil Engineering)* for his generous support, coaching, constant encouragement and for sharing his expertise with me generously at every step during my work.

I express my deep appreciation and sincere thanks to **Dr. Ashok Kumar Gupta**, Head of the Civil Engineering Department for providing all kinds of possible help and encouragement during my project work.

I am thankful to the faculty of Department of Civil Engineering, Jaypee University of Information Technology for providing me all facilities required for the experimental work.

I would like to thank my parents for their continuous support and motivation. Finally I would like to thank to all who directly or indirectly helped us in completing this project.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The thesis work presented here deals with the proposal for ash disposal from a waste to energy plant 2MW capacity located in Shimla (H.P.).The ash would be disposed in an ash pond, the thesis work shows the volume calculations of ash production and design of the ash dykes used in the construction of the pond using an upstream method. Ash would be used as a construction material for raising the dykes further, suitable drainage methods have also been proposed. The study includes the geotechnical aspects of the soil being used as a base for the ash pond, samples were taken from a depth of 3m and the tests were carried out. The soil samples were firstly determined for their nature and type and were then subjected to direct shear test to find out cohesion and angle of internal resistance.

Slope stability analysis have been performed for the proposed design using the software GEO5.The minimum factor of safety for a slope of (1H: 2.5V) was calculated using the software for different water conditions (seepage conditions), the designed upstream slopes were found to be stable and were suitable for practical application of construction of ash pond. All the design details along with the geotechnical investigations and software output results have been explained in thesis using descriptive diagrams and graphs where needed.

CHAPTER 1

INTRODUCTION

1.1 GENERAL

1.1.1 ASH GENERATION

With tons of waste generation every day in the last few decades has led to numerous waste management alternatives, but the disposal of fly ash from thermal power plants and various wastes to energy facilities still remain one big issue that poses a potent threat to the environment. One of the techniques for disposal of ash is the use of ash pond. But the biggest challenge for a big country like India lies in the fact that, the ash has crossed the annual generation of 100 million tonnes whereas the utilization of fly ash is still not satisfactory in comparison to its generation which is causing imbalance.

YEAR	GENERATION	USER(MT)	% USE OF GENERATION
1993-1994	40	1.2	3
2004-2005	112	42	38
2006-2007	130	60	46
2011-2012	170	170	100% USE MANDATED
2031-2032	600	-	NOT YET PLANNED

Table.1.1 Shows the current scenario of ash generation and use in India.(Chatterjee 2011)

40-50% of ash utilisation takes place in India and rest of it gets disposed off. Since the ash storage requires a huge expanse of land area it is a critical issue to deal with. Ash which is surplus and needs to be disposed is dumped in the ash ponds or impoundments. Mine tailings and coal ash are the categories of ashes which have a particle grain size in the range of silt and sand sized grains and are transported in the form of a slurry. Large quantities of ash generated are disposed off by pumping into ponds or impoundments on land adjacent to the mines or the power plant. The present thesis hence deals with this upcoming problem of ash disposal. The thesis work takes into consideration a mini waste to energy plant in Shimla district of Himachal Pradesh India. The plant has an installed capacity of 2MW and will have a significant quantity of ash generation, for this ash generation a ash pond has been designed and analysed for its slope stability. Provisions have been proposed for timely excavation of the ash fill by mechanical excavators for companies that need a bulk supply of fly ash, thereby increasing the capacity of the designed ash pond.

1.1.2 ASH POND OR IMPOUNDMENT

To reduce the land wastage it is stored using ash pond construction. Ash pond is an important structure, located few kilometers away from the energy power stations for storing the coal ashes. Ash dam or pond construction is continuous process and it is raised each step through dyke construction. Ash pond should construction is a great challenge for civil engineers as the failure of ash pond has an adverse effect on surrounding environment as well as it can affect the smooth functioning of energy stations. It also causes havoc among the surrounding people about safety of their life and pose a threat to environment. 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.

The thesis work here deals with the detailing of the ash pond which is proposed in the nearby vicinity of the waste to energy facility at Bhariyal in Shimla. The proposed ash pond will have a 100m length and two chambers of 30m wide section. Analysis for the slope stability thereby analysing the designed dykes for different ponding levels has also been considered in the report.

1.2STUDY AREA PROFILE

1.2.1 SHIMLA AREA

Shimla is located in the Central Himalayas at $31^0$4’ to $31^0$10' north latitude and $77^0$5' to $77^0$15' east longitude. Discovered in 1819 by the British, Shimla has evolved from a small hill establishment to one of the popular tourist destinations of India. Part of Himachal Pradesh was carved out of erstwhile Punjab state in the year 1966 and Shimla became the capital of newly formed state of Himachal Pradesh in 1971. The topography of Shimla is characterized mainly by rugged mountains, steep slopes and deep valleys. Shimla is located at an altitude of 2130 meters above mean sea level. It experiences cold winters during December – February, with temperatures ranging from 0-13^{0}C. Shimla receives snowfall around in the last week of December. The summers (May – June) are mild with temperatures varying from 20- 30^{0}C. The monsoon period extends from the month of June September and records moderate rainfall. The average rainfall recorded in the last 25 years (1980 – 2005) in Shimla is 1437 mm. As per Census (2011), Shimla is the only Class I City in the State of Himachal Pradesh with total population of 1,69,758 persons. The total area coming under the jurisdiction of MC Shimla also has increased after merger of New Shimla, Totu (including some parts of Jutog) and Dhalli areas to 35.00 sq km. Presently, Municipal Corporation of Shimla (MCS) is divided into 25 wards covering urban core and urban fringes or ends.The problems associated with solid waste in hilly regions are numerous. Urban forest within the city is most vulnerable as the growth of the samplings is severely hampered. The natural and manmade stromwater drainage and natural water resources are clogged due to indiscriminate dumping of waste leading to unmanageable situation especially during monsoon season. Piled heaps of garbage disturb the aesthetic view, surroundings and create scavenging problems. Various studies have reported the human-monkey conflict in Shimla city (Chauhan & Pirta, 2010 and UNDP, 2012). The dog and monkey menace problem can be limited to great extent by effective waste management. The tourism industry growth is also intangibly linked to the aesthetic beauty of the city.

Figure1.1. Limits of the Shimla municipal Area

1.2.2 WASTE DISPOSAL FACILITY AND PROPOSED LOCATION

The sanitary landfill area is located at Bhariyal, along Taradevi-Totu bypass road, Maujja. Shimla having coordinates of $31^0$05'06" N and $77^0$7'44" E. The site has an area of 9.77 Ha. The annual average rain is 1,089 mm and average daily evaporation is approximately 4 mm. The landfill site is a natural valley of a depth of approx. 80 m below the bypass road. The nearest residential area is more than 500 m away from the downstream end of the site. The landfill site is shown in Figure 1.2.

The proposed ash pond site is shown in Figure 1.3.It is a rocky terrain with no access road for vehicle traffic.The proposed ash pond facility is within 800m range of the plant on the downhill slope section pedestrian tracks are visible at the site as can be seen in pictures below. There is a need to notify the buffer zone on the periphery as a 'No Development Zone' under the H.P. Town & Country Planning Act, 1977.

Figure 1.2 Existing Landfill site and waste to energy plant site at Bhariyal Shimla

Figure1.3. Proposed ash pond site

1.3 OBJECTIVE OF STUDY

The present work has the following objectives related with the ash generation from the waste to energy plant in Shimla district:

- To design and propose a suitable ash pond for a 79 m^3 volume of ash generation in 2017 and for a capacity of 2273m^3 ash in the year 2047 from the 2MW capacity WTE (waste to energy) facility in Shimla.
- To analyze the slope stability of the proposed ash pond using the slope stability analysis software GEO 5, which would analyse weather the proposed slope is stable or not.

1.4 NEED OF STUDY

The growing production rates of ash in the power generation sector calls for a demand of places like ash ponds which would restrict these facilities from irresponsibly dumping the ash causing serious environmental impacts. Proper Designing methods for the ash dyke raising hence would not only prove as a storage facility for the ash but also would help in avoiding any hazards caused by the ash dykes. Improper designing of the ash dykes and ash pond in the recent past has resulted in the failure of the impoundments due to seepage and ponding factors. Also proper stability analysis is a must for avoiding the failure under different water conditions.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

Out of the various alternatives available for disposal of fly ash, use of ash pond in which ash slurry is discharged is most widely used by thermal power plants and waste to energy plants. Fly ash and bottom ash from the power plants is mixed with water in a ratio varying from 1 part ash and 4 to 10 parts of water by volume. The slurry is then pumped till the ash ponds which are located within few kilometers distance from the power plant. Depending on the distance and elevation difference of the location, energy required for pumping is very high and often requires booster pumps at intermediate locations.

2.2 ASH POND LAYOUT

Following points shall be considered while selecting the location and layout of the ash pond:

1. The area shall be as close as possible to the power plant facility to reduce the pumping cost.
2. Provisions shall be made for vertical and horizontal expansion of the ash pond depending on estimated life of the plant facility.
3. To the extent possible, the area shall be away from natural water bodies such as river, lake, etc. to prevent pollution of the water body due to the seepage of water from ash slurry and causing contamination.
4. In coastal area were ground water is already saline, areas with pervious soils are preferable to effectively drain the water through the bottom of the ash pond. Such ash pond can have good drainage water gets drained faster and have better stability.
5. In the interiors, even if they are away from water bodies, it is preferable to have a fairly impervious stratum to prevent migration of ash water into the ground water. As per Pollution Control Board norms, an impervious membrane should be provided to prevent pollution of the ground water.
6. In a hilly terrain if it is within reasonable distance, a suitable valley can be identified for forming the ash pond. In such case, the hill slopes will serve as ash dyke and the length of the dyke to be built will get considerably reduced (eg.

Vijaywada and Mettur Power Plants). In most of the ash ponds, the total area available is divided into two or more compartments so that anyone of the compartment can be in operation while other compartments where ash has already been deposited is allowed to dry and there after the height of the pond is further increased. If the area comprises of a single pond, it would not be possible to increase the height while the pond is in operation. Each compartment is required to have certain minimum area to ensure that there is adequate time available for settlement of ash particles while this slurry travels from the discharge point to the outlet point. This distance should be minimum 100m to 200m to ensure that only clear water accumulates near the outlet or it can vary with the terrain conditions.

2.3DESIGN OF DYKES.

Unlike water reservoir, the ash pond is constructed in stages. Each stage has an incremental height of 3 5m. The advantage of constructing the ash pond in stages is that their initial cost is very low. It also saves the overall cost compare to a single stage construction. Following methods are commonly adopted for stage wise construction as shown in Fig.1:

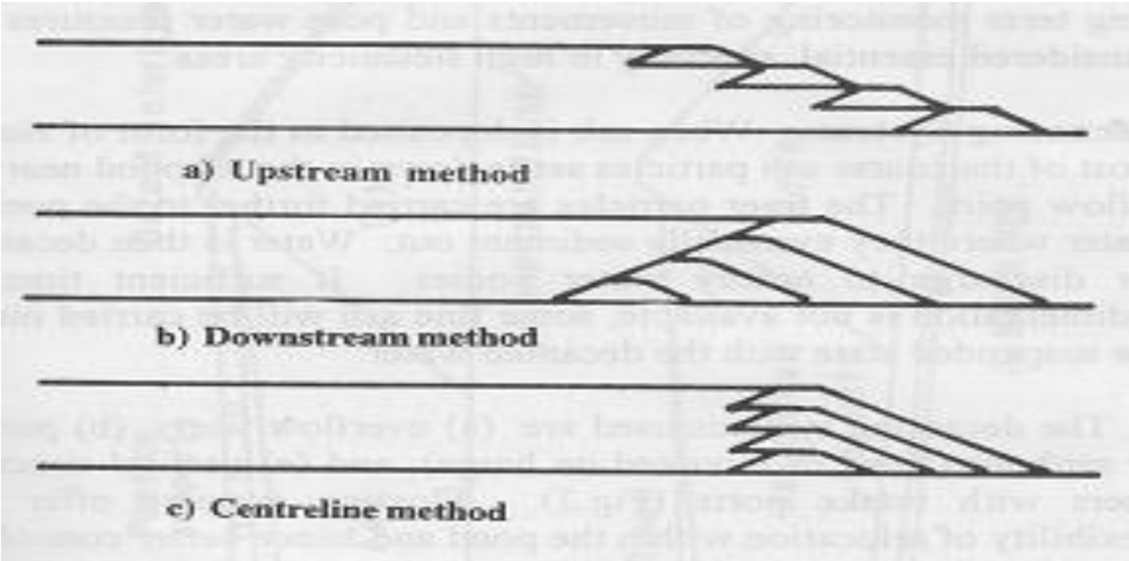

Figure2.1. Methods of raising ash dyke[7].

a) **Upstream Construction Method**

This is most referred design as the earthwork quantity required is minimum. However this has following disadvantages:

- The entire weight of new construction for raising the dyke is supported on deposited ash. Unless ash deposition is carefully done, there can be finer ash particles deposited along the bund and may not have adequate baring capacity to support the new dyke.
- As the height of the pond increases, the plan area of the pond goes on reducing. Beyond certain stage, it becomes uneconomical to raise the height further on this account.
- The drain provided on the upstream face needs to be suitably connected to the drain of the earlier segment. If this is not carried out properly, the drainage can be ineffective resulting in rising of phreatic line and reducing the stability of slope.
- Since the entire segment of new construction is supported on deposited ash, liquefaction analysis of the deposited ash is very important. If the deposit is not safe against liquefaction, suitable remedial measures need to be adopted before raising dyke.
- While raising the height of the dyke, it is not possible to operate the pond as it needs to be dried, particularly along the periphery to initiate the construction.

  Out of the above 3 alternative methods, the upstream method is mostly chosen due to its minimum cost. The aspects to be taken care are adequacy of the deposited particles to support the additional weight. Apart from the stability of the dyke, following features shall be included in the design:
- The entire upstream face of the dyke shall be provided with stone pitching or brick lining or precast tile lining to prevent erosion of the slope by wave action during heavy wind.
- The entire downstream slope shall be provided with grass turfing to prevent erosion of the downstream side during rains.
- A rock toe and toe drain shall be provided for safe exit of seepage water into a natural drain without any inundation of the downstream area and thereby softening of the natural strata.

- Adequate transverse and longitudinal drains shall be provided on the downstream face. Wherever the height of the dyke is exceeding 5m, berms shall be provided at ever 3m vertical intervals with a longitudinal drain to prevent erosion.
- The material for the dyke shall be adequate resistance to erosion. The erodibility of the chosen material shall be checked by a peak hole test (Sherard).
- Decanting system shall be provided to ensure that free water inside the ash pond does not pile up to a large head. After decantation, the clear water shall be drained off ensuring minimum height of water above the ash deposition at the outlet such that the suspended particles are within the permissible limit of 100ppn.
- If natural valley is utilized for ash pond, the surface runoff from natural hill slopes outside the pond area shall not be allowed to enter the ash pond area.
- Instead it should be suitably diverted to the surrounding area by constructing catch drains so that the load on decanting system does not increase during monsoon. Also a spillway shall be provided for the unforeseen circumstance of very heavy rain and blocking of the decanting system. If such spillway is not provided, slurry and rain water can reduce the minimum free board required and can result in serious failure of the dyke.

b) Downstream Construction Method

After the pond gets filled upto the first stage of construction, the pond height is increased by depositing the earth / fly ash on the downstream face of the dyke ash shown in the figure. In this case it is possible to raise the height of the pond even when the pond is in operation. However there is no reduction in the quantity of construction which is same as a single stage construction.

c) Centre Line Construction Method

In this method, 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 such that the centre line of the dyke remains at the same location. This requires 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 dyke. The earth work required in this case is less compared to the construction while downstream method. However, as the material is required to be deposited on the settled fly ash, it is not possible to carry out the construction when the pond is in operation. This method can be adopted only if the total area of ash pond is divided into compartments.

2.4 DIFFERENCE BETWEEN ASH POND AND WATER RESERVOIR.

There is a basic difference between an ash pond and a water reservoir. The major differences are highlighted below:

- Only the ash particles settle close to the bund and the water after decantation travel away from the bund forming a sloping beech in the case of ash pond.
- The bund is not subjected to hydrostatic pressure over the full height of the bund as the water travels away from the bund in ash ponds. Due to provision for good drainage all along the bund, the phreatic line is maintained at very low level to ensure that the bund section and the deposited ash particles closer to the bund are in dry condition most of the time.
- The water, after decantation is not allowed to accumulate in the pond but it is removed from the pond to ensure that the phreatic line is maintained at lower level.

The ash pond can be designed economically utilizing the advantage of low phreatic line as mentioned above.

This paper describes important issues related to design, operation and maintenance of ash pond. It is noticed that in many places, some of the important requirements have not been met with which results in unsatisfactory performance of the ash pond.

2.5 FAILURE CAUSES OF ASH DYKES AN INVESTIGATION

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) Instability of dykes.
c) Unsuitable soil properties in starter dyke.
d) Improper methods of compaction.
e) Absence of drainage filters.

After investigations of ash pond failure different studies were carried out.

i. Study of the detailed drawings, prior inspection of the report, safety issue and gaining an understanding of the original design and modifications of the facility.
ii. Performing of site visits 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.

2.6 LITERATURE GENERAL OVERVIEW

The data source available for the design and analysis of the Ash pond were the various research documents and some books which dealt with the geo environmental aspects of ash pond construction. The material available for the design was scarce as the ash pond construction is not based on some construction manual or code. A readily available material for the ash pond construction would facilitate in the detailed designing with clarity. The following are the research papers and documents reviewed for the thesis study.

2.7 Effective solid waste management a case study of shimla, Omesh bharti Amarjeet singh D.P.Singh Vibhor Sood(2014)[1].

This paper deals with the stringent enforcements of the solid waste management and Handling Rules, 2000 through systematic planning process and emphasizes the need to take holistic view of state towards municipal solid waste management. Management and Disposal of municipal solid waste is an obligatory function of the urban bodies but even today these urban local bodies are budget deficit, lac technical staff and understanding to execute this job perfectly. Attempts have been made to access the existing solid waste management systems, environmental concerns and the future inventions with respect to environment and social well being. Study of the Shimla urban local body, a civil society organization and increasing private sector participation in waste management arena highlights the issues of effectiveness, weaknesses and relevant planning.

2.8 Raising of Dykes using slurry ash pond – A case study. S.K.Singh Manoj data(2010)[2].

The present paper deals with designing of dykes for ash pond by upstream method using ash as construction material with suitable protection and drainage measures for a Thermal Power Plant in Punjab (India). Site investigations were carried out at the pond and dyke area through SPT and undisturbed sampling and results were calculated. Stability analyses were also carried out using a software geo slope/w. Minimum factor of safety for the existing dyke (2.5 H : 1 V) without any consideration of seepage is observed to be 1.5 and in the case of ponding of water (seepage condition) FOS drops down below 1.0. All the design details including remedial measures are presented in the paper. In the existing ash pond no slurry decantation arrangement was provided and F.O.S of the starter dyke falls below 1 in case of seepage occurs through dyke. Therefore, necessary arrangement for safe exit of slurry water has been recommended and proposed from stability point of view. Results from the stability analysis indicate that seepage of water through the existing dyke under condition of prolonged ponding can affect the stability of the dyke. At present such a condition has not been observed at the site taken into consideration. However, as the height of dyke is raised, the head of water increases and the possibility of seepage also increase. Hence monitoring of phreatic line inside the existing starter dyke is recommended by using piezometers. Open stand pipe piezometers, up to a depth of 10m from the crest of the existing embankment may be used or installed at a spacing of 250m along the dyke. If seepage is detected by the development of phreatic line, remedial measures in the form of a suitable berm and an internal drain on the downstream side of the existing dyke is recommended

2.9 Fly Ash Characteristics from Waste-to-Energy Facilities and Processes For Ash Stabilization, E.Kalogriou, N. Themelis, P.Samaras, A.Karagiannidis, St. Kontogianni(2009)[3].

The objective of the work were the implementation of an inventory study regarding processes used for management of Waste to energy solid by-products, with emphasis on techniques applied for the utilization of fly-ash residues and an evaluation of existing practices for the stabilization of combustion residues. The work also included ashes qualitative analysis and their potential relation relation to the specific condition (feed, type of furnace etc). Also the existing methods are evaluated for production of cleaner and stabilized materials that can be directly re-used, thereby reducing the requirements of landfills for hazardous residues. Despite increased efforts to prevent, reduce, reuse and recycle the appropriate management of municipal waste remains an issue of concern. Today waste-to-enrgy plants produce clean renewable energy by applying state of the art technology which helps in the pollution control. Countries like Germany France Japan Switzerland Denmark Sweden are examples of nations where 50% or more of the un-recycled waste is incinerated and turned into energy also these countries have passed into legistlation which prohibits the future landfilling of combustible waste.

2.10 Emergency procedures for embankment failure,Geo/Environmental Associates (GEA) and APEC (2009)[4]

Prepared a document about Draft Emergency Action plan in case of ash pond or embankment failure.

2.11 Discharge parameters from an energy plant, Indiana Michigan Power Company (IMPC, 2008)[5]

Presented a draft 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).

2.12 Settlement analysis of new pond structure, APEC (2008)[6]

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.

2.13 Design and maintenance of ash pond for fly ash disposal, Gandhi S.R.(2005)[7]

This was the parent paper for the thesis as this paper included entire synopsis needed for a basic design for the ash pond. The research deals with the fly ash and ash being a waste product companies don't pay much heed to the disposal of the ash, plus the maintenance of the ash pond is a must as there have been failures of many ash ponds in the later past. This paper deals with the various issues of construction maintenance and operation of ash ponds,most of the observations are based on the study from the various ash pond sites.

2.14 Ash pond storage at an elevation, American Electric Power Company(AEPC) –ProServ and Barr Engineering (2002)[8]

Prepared a draft 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.

2.15 Barr Engineering and American Electric Power Company (BEAEPC,2002)[9]

Proposed a report 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 dyke.

2.16 Design, construction and monitoring as ash dykes implemented by department of civil engineering IIT Kanpur(2000)[10].

Although the beneficial uses of ash have been found in concrete, brick making, soil stabilization treatment and other application have been found, very small quantity of ash produced in India is used in such applications. Most of the ash produced from the plants is disposed off in the vicinity covering several hectares of valuable land. The fly ash mission initiated by the department of science and technology is run by IIT Kanpur along with the active support of NTPC.The design details have been prepared for starter dyke and the next dyke raising. The phenomenon of liquefaction and dynamic analysis of ash dyke raising has been proposed and procedures have been outlined for evaluating the liquefaction potential of ash pond facility. The study includes the construction procedure and guidelines and technical specifications of the key elements of the ash dyke construction. The lateral movement of the dykes is measured by digital inclinometers and the plate load tests were carried out to assess the strengths of the in situ strength of the settled ash.

2.17 Constructions of the ash pond design, Woodward-Clyde Consultants (1979)[11]

Published 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.

2.18 Construction of ash dykes in a flood plain area, IDNR (1975-77)[12]

Prepared a document which describes about approval for construction in a flood plain area. It contains various engineered reports and conditions for construction of ash dykes.

2.19 Construction analysis and stability analysis of ash pond, Casagrande consultants (1976)[13]

Proposed a document about investigations for proposed fly ash pond describing about Boring logs, compression analysis and stability analysis for construction of original fly ash pond structure has been provided in this document.

2.20 CONCLUSIONS FROM LITRATURE REVIEWS

The intensive study of the above mentioned studies resulted in certain observations. Like flyash is an important component produced from an energy plant and can be used in various fields of construction as it has high values of silica (Si) sulfur trioxide (SO_3). Also it was observed from the previous researches that a proper decant system has to be provided for the removal of water from the ash pond, as the ponding conditions force the phreatic more towards the downstream slope side and more closer the phreatic line towards the downstream face more unstable is the slope . Likewise it is observed that upstream construction method is more economical as compared to the centerline and downstream construction techniques as the upstream method uses the ash for the construction of dykes. Also it was observed from the research studies of Shimla municipal area that the population is increasing and the waste generation is projected to increase to 210MT in 2047 from 85MT in the year 2017. Certain geotechnical properties were also taken into consideration for the comparison with the laboratory investigations carried in the thesis later on, of both the base grade soil used as bed material and ash samples.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 INTRODUCTION

The prime objective of the research work is to design an ash pond for the waste to energy 2MW plant being setup at bhariyal shimla municipal area. For the design process there are no specified codal provisions as stated earlier but there are certain standard values mentioned within which the geotechnical properties of the soil and ash sand mix, must lie. For this very purpose a site was selected after close inspection of the area. Shimla being a hilly region the terrain to setup an ash pond was unlikely to be found as it requires a plain large stretches of area. So a bund increase height method would be followed and for that purpose a site 800m SW of the operational WTE plant was finalized. Geotechnical properties of the soil had to be determined of that selected area. The area marked was rectangular in shape 100m in length and 60m in breadth, two sections have been proposed of 30m width and 100m length accordingly 5 sample points were marked. As the terrain was similar in nature so the number of sampling point were reduced to five. The five points were taken and the samples were collected from depth of 3m at each hole. Undisturbed samples could not be collected as the strata were rocky and the sampler was not able to penetrate in the rocky strata. Collection of samples in undisturbed state was a major problem in this research. SPT (standard penetration test) apparatus was unable to operate due to presence of rocks and no ‘N’ value could be determined, moreover undisturbed samples could not be collected because the split spoon sampler could not collect samples due to presence of rock strata in the hilly terrain. So the angle of internal friction and direct shear values were determined in the laboratory. Similarly the ash and soil present at the site were mixed and tested for the different parameters that were required in the GEO5 software input.

In India , ash dyke construction by upstream method is widely used. So a two stage dyke is proposed by upstream method and geotechnical properties of materials used in it are found in the laboratory to use the same for analysis in GEO5. The geotechnical properties are found out by various tests done at Geotechnical Lab.

3.2 SITE INVESTIGATION

A geotechnical site investigation will include surface exploration and subsurface exploration of a site. Subsurface exploration usually involves soil sampling and laboratory tests of the soil samples retrieved. Whereas surface exploration can include geologic mapping, geophysical methods, and photo-grammetry, or it can be as simple as a geotechnical professional walking around on the site to observe the physical conditions at the site. To obtain information about the soil conditions below the surface, some form of subsurface exploration is required. Methods of observing the soils below the surface, obtaining samples, and determining physical properties of the soils and rocks include test pits, boring, and in situ tests.

In our design procedure geotechnical attributes required were for the purpose of starter dyke construction and for the dykes above it ash samples were analyzed. The geotechnical findings are listed later in this section with the detailed laboratory procedures.

3.3 COLLECTION OF SAMPLES

Sample collection for the proposed ash pond site was done by manual boring. 5 pit holes were made in form of a circle from a site of approximately 60mx100m dimension on the. One pit hole was made in the centre of the rectangular area of the site. Samples were collected from depths 3m from all test points. Five samples were collected in different packets from the site and were directly transferred to laboratory where the geotechnical tests were conducted. Figure3.1 shows the collected soil samples.

Similarly ash was collected from a RDF plant in Chandigarh operated by Jaypee, as the production of ash samples from the WTE plant was not initiated yet, the tests and design were proceeded on the premise that the ash samples produce in shimla would be of similar nature as the RDF plant also processes municipal solid waste of Chandigarh city. Further samples were collected and were tested in the laboratory. Figure3.2 shows the collected ash samples from the furnace.

Figure3.1 Collected soil samples

Figure 3.2 Collected ash samples

3.4 SIEVE ANALYSIS

3.4.1 INTRODUCTION

A sieve analysis (or gradation test) is a practice or procedure used (commonly used in civil engineering) to assess the particle size distribution (also called gradation) of a granular material of any size. The size distribution is often of critical importance to the way the material performs in any use. A sieve analysis can be performed on any type of non-organic or organic granular materials including sands, ash, crushed rock, clays, granite, feldspars, coal, soil, a wide range of manufactured powders, grain and seeds, down to a minimum size depending on the exact method. Being such a simple technique of particle sizing, it is probably the most common method for determining the particle size.

In this research sieve analysis is used to determine the soil particle size distribution of the collected samples also the particle size determination is necessary of ash particles for settling time and particle velocity purposes. Procedures are described as under.

3.4.2 APPARATUS REQUIRED

- Drying oven
- Mechanical sieve shaker.
- Balance
- Standard U.S. sieves (2.36mm, 1.18mm, 600 micron, 425 micron, 300 micron,75 micron)
- Pans

3.4.3 PROCEDURE

- Take a representative oven dried sample (dried for 24 hours) of soil that weighs 500 g
- Determine the mass of the sample correctly.
- Prepare a stack of sieves such that sieves having larger openings (i.e. lower numbers) are places above the sieves having smaller openings (i.e. higher number) i.e. in order 2.36mm, 1.18mm, 600 micron, 425 micron, 300 micron,75 micron, pan.
- Make sure sieves are clean if any soils particles are stuck in the openings try to poke them out using brush.
- Pour the measured soil or ash into the stack of sieves from the top and place the cover, put the stack in the sieve shaker and fix the clamps, adjust the time on 10 to 15 minutes and get the shaker going.
- Stop the sieve shaker and measure the mass of retained soil or ash in each sieve.

3.4.4 RESULTS

Following results were obtained by grain size analysis these values have been depicted in the form of graphs and the tables of the readings is included in the annexure. Five soil samples from sampling points A1,B1.C1,D1.E1 were observed for their particle size and ash sample was named as M1. Following plots were obtained for the particle size analysis.

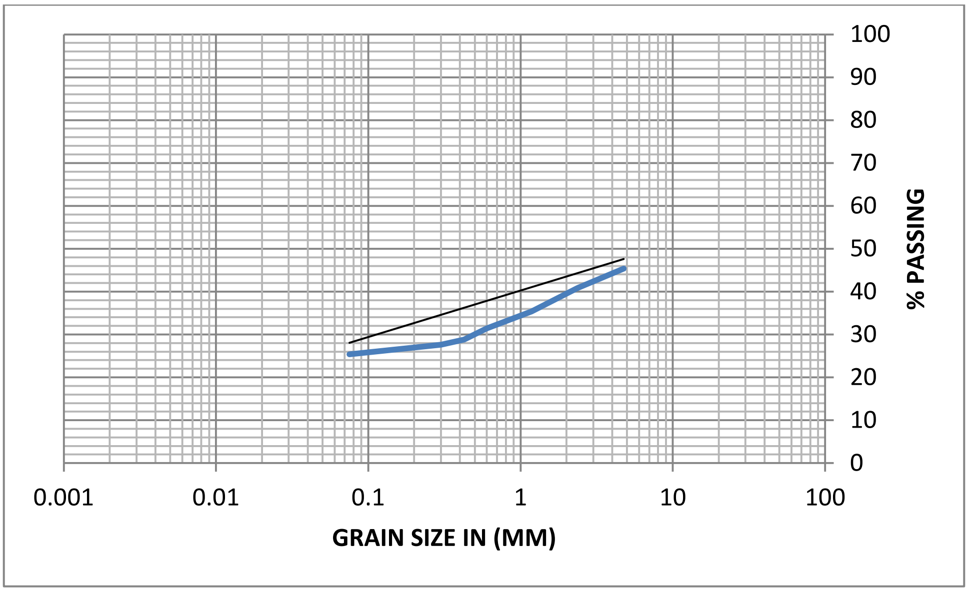

Figure 3.3 Grain size distribution for A1 soil sample

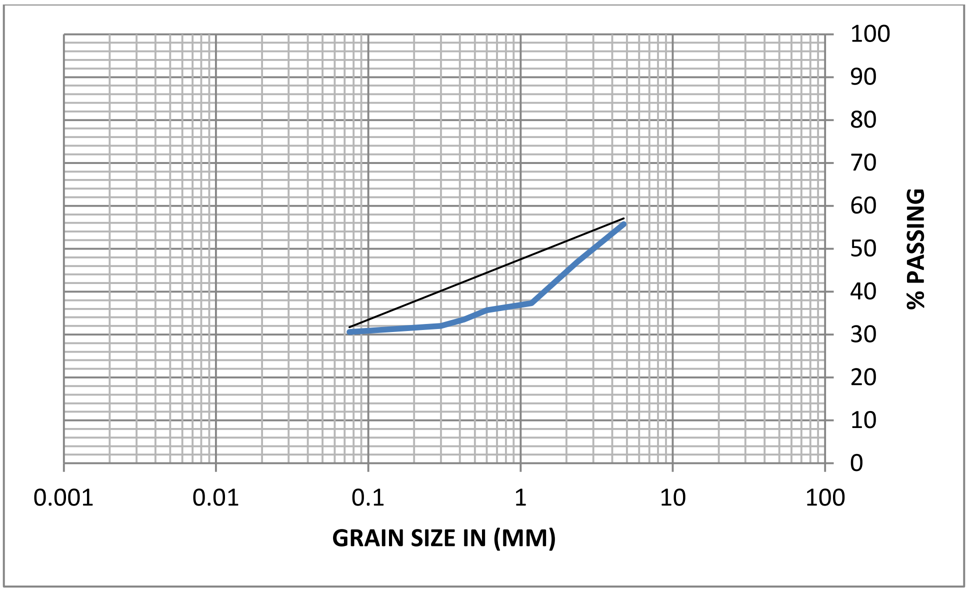

Figure 3.4 Grain size distribution for B1 soil sample

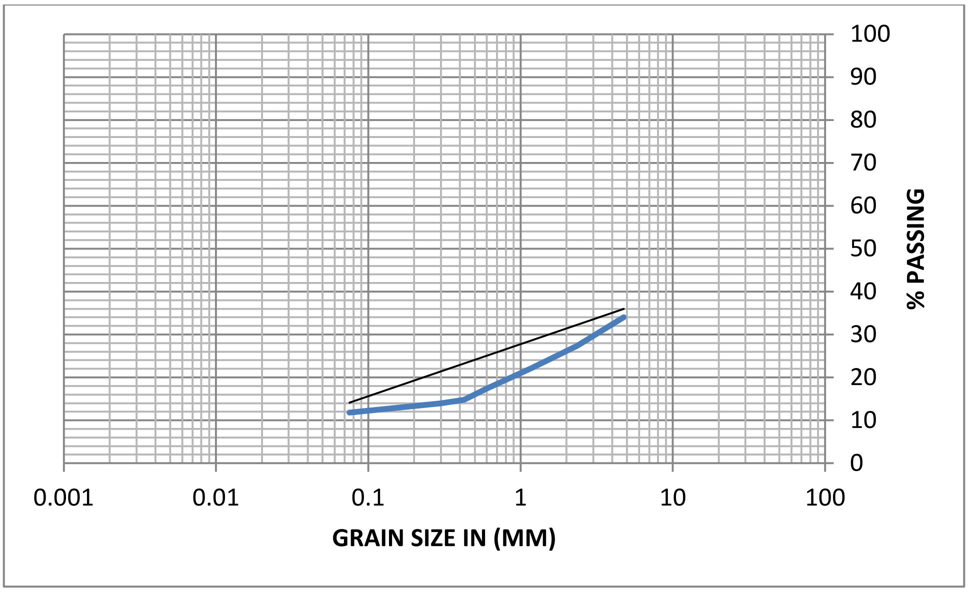

Figure 3.5 Grain size distribution for C1 soil sample

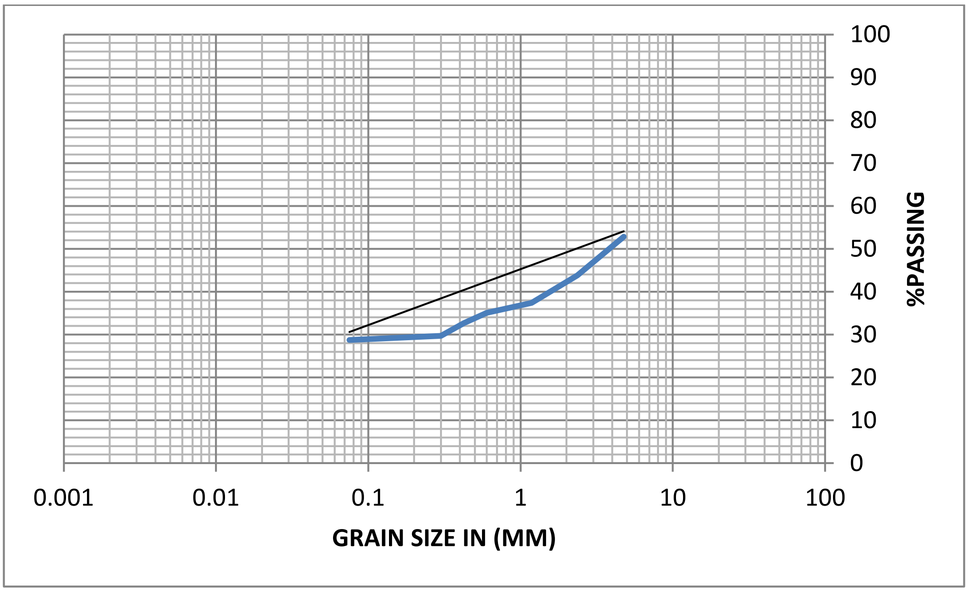

Figure 3.6 Grain size distribution for D1 soil sample

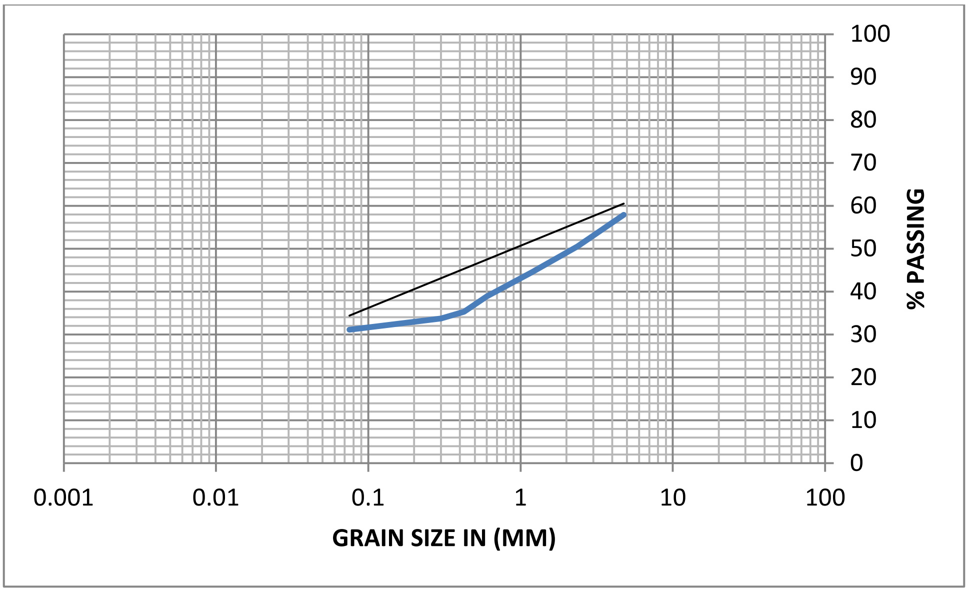

Figure 3.7 Grain size distribution for E1 soil sample

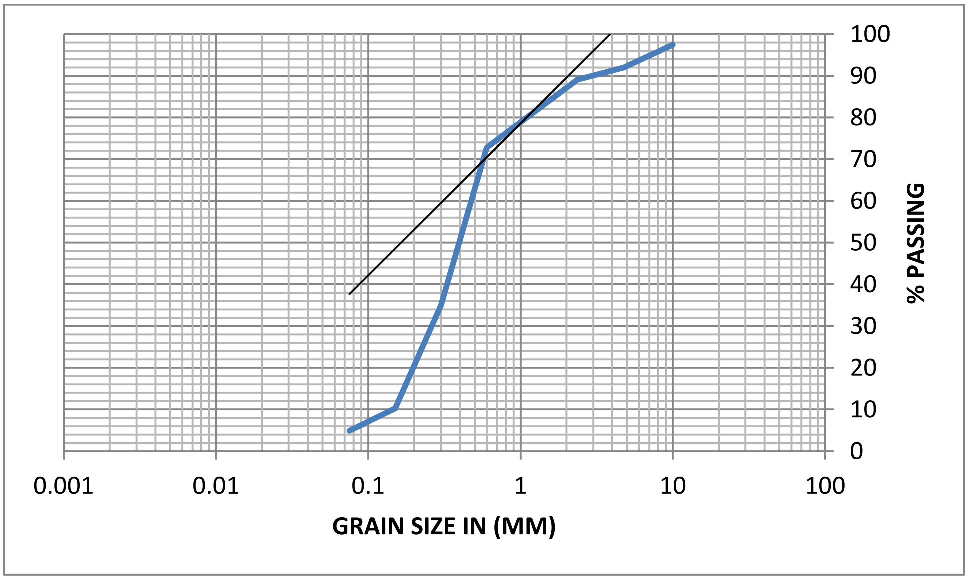

Figure 3.8 Grain size distribution for M1 soil sample

3.5 MOISTURE CONTENT TEST

3.5.1 INTRODUCTION

This method covers the laboratory determination of the moisture content of a soil as a percentage of its oven-dried weight. The method may be applied to fine, medium and coarse grained soils; for particle sizes from 2 mm to >10 mm

The method is based on removing soil moisture by oven-drying a soil sample until the weight remains constant. The moisture content (%) is calculated from the sample weight before and after drying**.**

Here 5 soil samples were tested for the moisture content value[16].

3.5.2 APPARATUS REQUIRED

- A thermostatically controlled oven preferably of the forced-draught type, capable of maintaining a temperature between 105 °C and 110 °C.
- A balance readable and accurate to 0.01 g.
- Suitable corrosion-resistant container.
- A scoop.

3.5.3 PROCEDURE

- Clean and dry the container and weigh the empty container, this is W1
- Fill the container with wet or moist soil and weigh again, mark this weight as W2
- Place the container containing moist soil in an oven maintaining temperature 105 °C and 110 °C.
- After the soil sample is completely dried measure its weight as W3.
- Calculate the moisture content using empirical relation.

3.5.4 RESULTS

Following results were obtained for the moisture content values of 5 soil samples and one ash sample. The soil samples were tested several times to obtain following moisture content values.

W1(gm)	40
W2(gm)	300
W3(gm)	286

Table-3.1 Moisture content values for sample A1

$$MC = \frac{W2 - W3}{W3 - W1} * 100$$

MC=5.69%

W1(gm)	40
W2(gm)	250
W3(gm)	243

Table-3.2 Moisture content values for sample B1

$$MC = \frac{W2 - W3}{W3 - W1} * 100$$

MC=3.44%

W1(gm)	40
W2(gm)	280
W3(gm)	275

Table-3.3 Moisture content values for sample C1

$$MC = \frac{W2 - W3}{W3 - W1} * 100$$

MC=2.12%

W1(gm)	40
W2(gm)	290
W3(gm)	283

Table-3.4 Moisture content values for sample D1

$$MC = \frac{W2 - W3}{W3 - W1} * 100$$

MC=3.0%

W1(gm)	40
W2(gm)	300
W3(gm)	290

Table-3.5 Moisture content values for sample E1

$$MC = \frac{W2 - W3}{W3 - W1} * 100$$

MC=4.0%

3.6 Optimum moisture content

One sample of ash and soil mix was tested also the maximum dry density was calculated by Proctor Method .

Required Compaction = Min. 98%

A	Mould + Wet soil weight (gm)	3843	3915	3988	4046	4113
B	Mould empty weight (gm)	2308	2308	2308	2308	2308
C	Volume of mould (cc)	1000	1000	1000	1000	1000
D	Only wet soil weight	1535	1607	1680	1738	1805
E	Wet Density of soil gm/cc	1.535	1.607	1.680	1.738	1.805
F	Max. Dry Density of soil gm/cc	1.39	1.44	1.48	1.50	1.54
	Can No.	**2**	**3**	**4**	**5**	**6**
1	Can empty weight	33.5	36.5	30.5	30.5	34.0
2	Can + Wet soil weight	115.0	108.5	120.5	130.5	139.0
3	Can + Dry soil weight	107.5	101.0	110.0	117.0	123.5
4	Water weight in (gm)	7.5	7.5	10.5	13.5	15.5
5	Only Dry soil weight	74	64.5	79.5	86.5	89.5

Table-3.6 Moisture content values for sample M1

MDD = 1.54gm/cc OMC = 17.3 %

3.7 SPECIFIC GRAVITY TEST

3.7.1 INTRODUCTION

Specific gravity is the ratio of the density of a substance to the density of a reference substance; equivalently, it is the ratio of the mass of a substance to the mass of a reference substance for the same given volume. The reference substance is nearly always water at its densest (4°C) for liquids; for gases it is air at room temperature (21°C). Specific gravity G is defined as the ratio of the unit weight (or density) of soil solids to unit weight (or density) of water. The knowledge of specific gravity is required in calculation of soil properties like void ratio, degree of saturation and also weight-volume relationship.We have calculated the specific gravity values for the five soil samples and one value for the ash samples.

3.7.2 APPARATUS REQUIRED

- Pycnometer
- Sieve(4.75 mm)
- Oven
- Weighing balance
- Glass rod.

Figure3.9 Picnometer apparatus setup

3.7.3 PROCEDURE

- Dry the soil sample in an oven at a temperature of 105 to 115^{0}C for a period of 16 to 24 hours.
- Dry the pycnometer and weight it with its cap (W_1).
- Take about 200 g to 300 g of oven dried soil passing through 4.75mm sieve into the pycnometer and weigh again (W_2).
- Add water to cover the soil and screw on the cap.
- Shake the pycnometer well to remove entrapped air for about 10 to 20 minutes.

- After the air has been removed, fill the pycnometer with water and weigh it (W_3).
- Clean the pycnometer by washing thoroughly.
- Fill the cleaned pycnometer completely with water up to its top with cap screw on.
- Weigh the pycnometer after drying it on the outside thoroughly (W_4).

3.7.4 RESULTS

The specific gravity of the soil samples was determined using pycnometer method.by using the following formula

$$\frac{(W2 - W1)}{(W2 - W1) - (W3 - W4)}$$

Where;

W_1=Empty weight of pycnometer

W_2=Weight of pycnometer + oven dry soil/ash

W_3=Weight of pycnometer + oven dry soil/ash + water

W_4=Weight of pycnometer + water full

SR. NO.	SAMPLE NO.	SPECIFIC GRAVITY
1	A1	2.62
2	B1	2.48
3	C1	2.57
4	D1	2.52
5	E1	2.68
6	M1	2.13

Table 3.7 Specific gravity values for soil and ash samples

3.8 DIRECT SHEAR TEST

3.8.1 INTRODUCTION

The concept of direct shear is simple and mostly recommended for granular soils, sometimes on soils containing some cohesive soil content. The cohesive soils have issues regarding controlling the strain rates to drained or un-drained loading. In granular soils, loading can always assumed to be drained. A schematic diagram of shear box shows that soil sample is placed in a square box which is split into upper and lower halves. Lower section is fixed and upper section is pushed or pulled horizontally relative to other section; thus forcing the soil sample to shear/fail along the horizontal plane separating two halves. Under a specific Normal force, the Shear force is increased from zero until the sample is fully sheared. The relationship of Normal stress and Shear stress at failure gives the failure envelope of the soil and provide the shear strength parameters (cohesion and internal friction angle). The value internal friction angle and cohesion of the soil are required for design of many engineering problems such as foundations, retaining walls, bridges, sheet piling. Direct shear test can predict these parameters quickly. We have calculated the values of cohesion and values for internal angle of friction by plotting the graphs of shear stress versus total stress. The plots have been shown in this section but the detailed tables have been included in the annexure.

3.8.2 APPARATUS REQUIRED

- Direct shear box apparatus, and Loading frame.
- Dial gauge, Proving ring, Balance to weigh up to 200 g.
- Tamper, Straight edge, Aluminum container, Spatula

Strain controlled direct shear machine consists of shear box, soil container, loading unit, proving ring, dial gauge to measure shear deformation and volume changes. A two piece square shear box is one type of soil container used. A proving ring is used to indicate the shear load taken by the soil initiated in the shearing plane.

3.8.3 PROCEDURE

- Check the inner dimension of the soil container, and put the parts of the soil container together
- Calculate the volume of the container. Weigh the container
- Place the soil in smooth layers (approximately 10 mm thick). If a dense sample is desired tamp the soil
- Weigh the soil container, and find the weight of soil
- Plane the top surface of soil, and put the upper plate and loading block on top of soil
- Apply the desired normal load and Remove the shear pin.
- Record the initial reading of the dial gauge and calibration values.
- Start the motor. Take the reading of the shear force and volume change till failure
- Add corresponding normal stress and continue the experiment till failure
- Record carefully all the readings. Set the dial gauges zero, before starting the experiment.

3.8.4 RESULTS

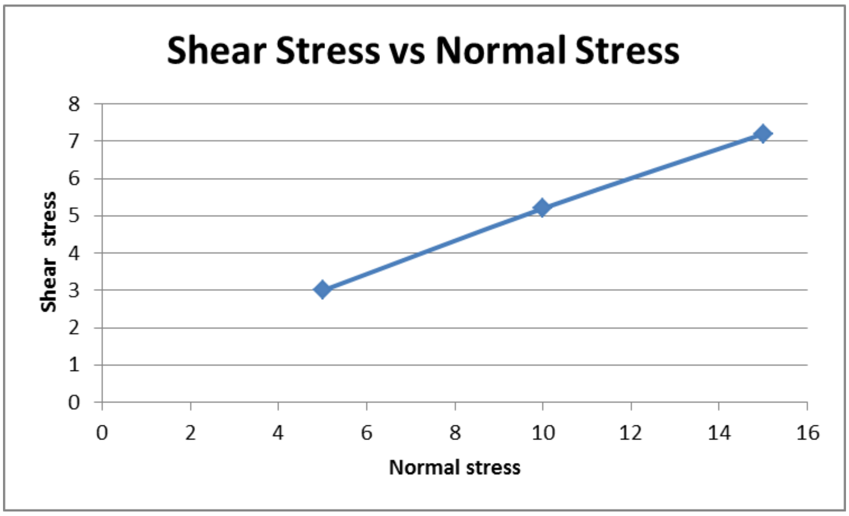

Figure 3.10 Plot of ash sample M1 between shear stress and total stress.

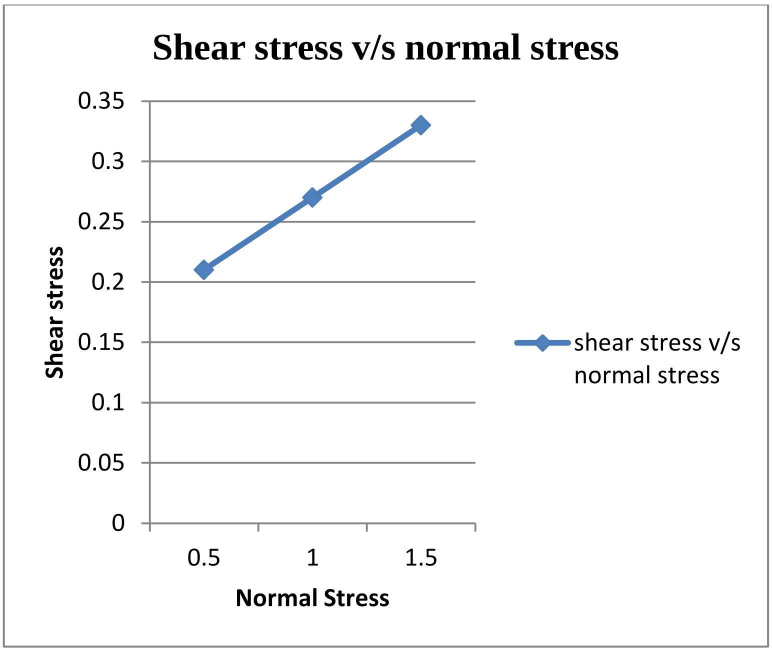

Figure 3.11 Plot of soil sample A1 between shear stress and normal stress.

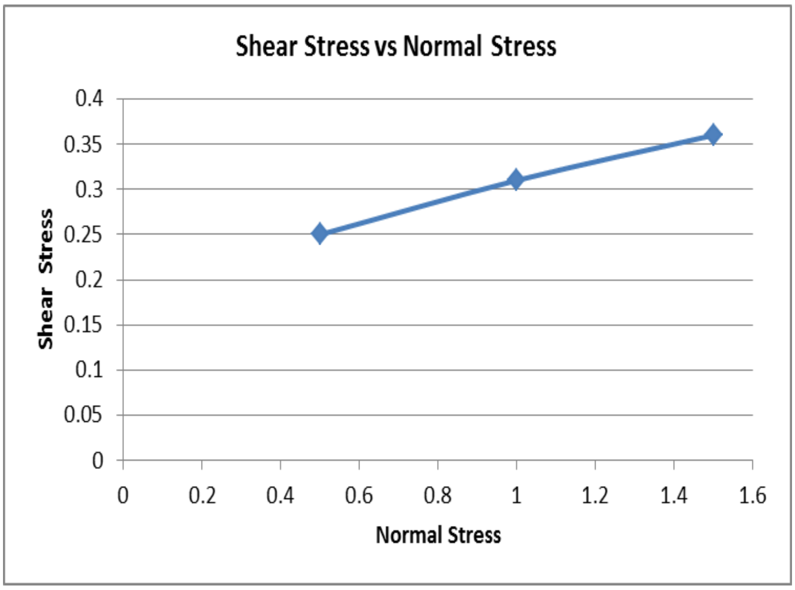

Figure 3.12 Plot of soil sample B1 between shear stress and normal stress

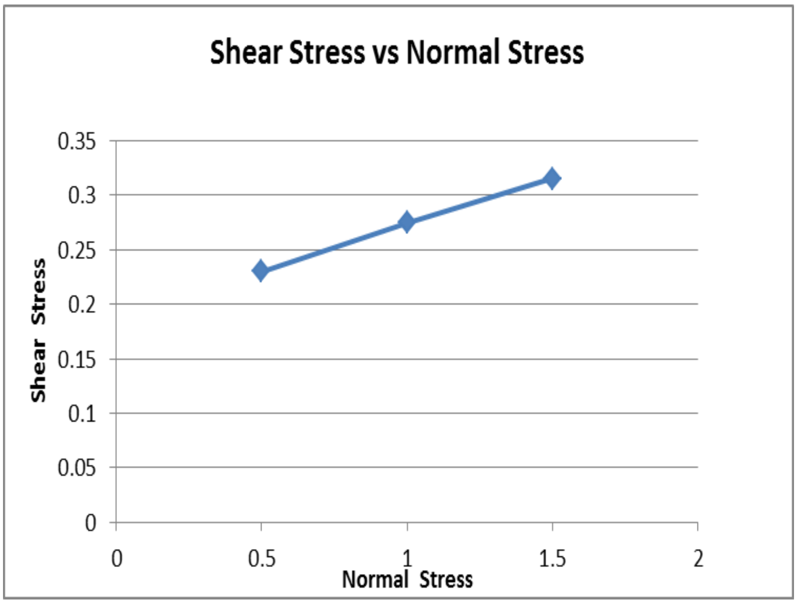

Figure 3.13 Plot of soil sample C1 between shear stress and normal stress

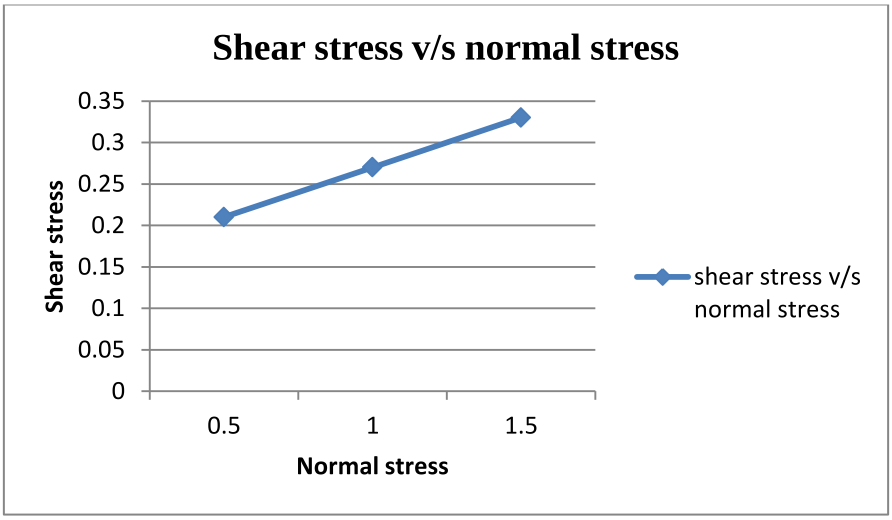

Figure 3.14 Plot of sample D1 between shear stress and normal stress.

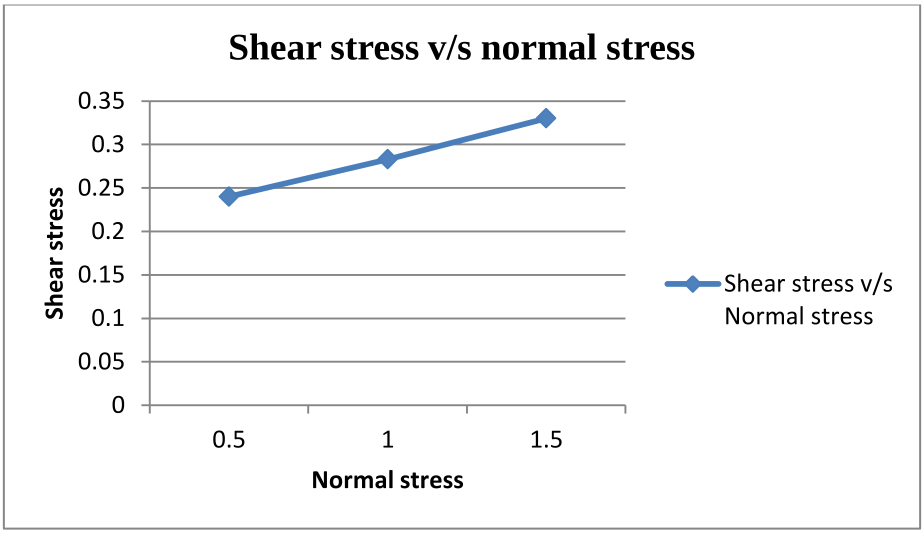

Figure 3.15 Plot for sample E1between shear stress and normal stress

3.9 Design and numerical analysis

A certain set of calculations were carried out as under for the design of ash dykes and the design of the dewatering systems. Further the piping system was designed using the under mentioned set of calculations and the set of factor of safeties (FOS) were also calculated. Partial Data used here is provided by the Municipal Corporation of Shimla city and certain geotechnical values have been calculated in the laboratories.

3.9.1 Area :

Area of the ash pond was calculated using the proposed area dimensions as under:

Length of the proposed ash pond (L)	=100m
Width of each proposed section of ash pond	=30m
(Proposed two sections of equal width)	
Total width of ash pond (W)	=60m
Therefore total area of pond (A)	= (100x60) m^2
	= 600m^2

3.9.2 Volume :

The most important set of calculations are the volume calculations as they take into consideration the volume of slurry input in the pond, according to which the volume of the ash pond would be designed. The volume of the ash pond on the other hand would be changing with the increase in the dyke height, thereby accommodating more ash slurry. The data used for volume calculations was provided my MC Shimla. The calculations are for maximum inflow values.

Waste generated in Shimla in 2017 (per day) =86MT

Waste collection for Energy production =70-75MT

*Design is proposed for the maximum input i.e. =75MT

Amount of total Ash generated from a WTE facility =10-15% of input waste.

*Design is proposed for maximum ash production i.e. 15%

Ash pond is designed for proposed time =30 years

% of waste reaching processing (2017) =87% of generation.

% of waste reaching processing (2047) =92% of generation.

Waste generated in Shimla in 2047 (per day) =210MT

Waste in plant to be processed per day (2047) =92% of 210MT

=193.2MT

Amount of ash generated (2047) = 15% of 193.2 MT

=29MT

Volume of ash is calculated using the following formulation:

Volume of ash $= \frac{\text{Mass of Ash}}{\text{Density of ash}}$

Mass of ash in (2047) $= \frac{\text{Weight}}{\text{Accelaeration due to gravity}}$

$= \frac{29 \times 1000 \times 1000}{9.81}$

= 2,956,167.17Kg

Density as calculated above of the ash sample = 1300kg/m^3

Therefore Volume of ash generation in 2047 $= \frac{2956167.1}{1300}$

= 2274m^3

Volume of water required for slurry formation is 6 to 10 times the volume of ash we have considered 8 times water [7]

Volume of ash slurry generated in (2047) = 2274 + (2274x8)

=20,466m^3

Similarly,

Amount of ash generated (2017)	= 15% of 75MT
	=11.25MT
Mass of ash in 2017	$= \frac{11.25 \times 1000 \times 1000}{9.81}$
	= 102,700Kg
Volume of ash in 2017	$= \frac{102{,}700}{1300}$
	$=79m^3$
Volume of slurry ash reaching the pond in 2017	= 79+ (8x79)
	$=711m^3$

3.9.3 Base ash height.

The base ash calculations deal with the height of the ash being deposited at the bed of the ash pond after the full settlement of the finest particle has taken place. The settlement calculations are based on an assumption that the slurry will spread evenly over the bed area of the ash pond section. As the sections proposed are identical we have designed the settlement depth and the time the ash will take to fill the entire dyke only for one section. Likewise the result would be same for the other half as the inflow slurry volume and the volume of the pond are the same. Here the slurry is calculated for 7 days on the basis of settlement calculations done later on,which shows that minimum time for settlement of the smallest particle of ash is 4 days but we consider 7 days taking 3 days as a factor of safety.

Volume of slurry reaching the pond	$= 711m^3$
Volume of ash in this slurry per day	$=79m^3$
Volume of ash in the slurry in 7 days	=79x7
	$=553m^3$
Bed Area covered by the a	$=300m^2$

Therefore the height of this deposited ash is calculated as under:

(Length of the bed)x(Breadth of the bed)x(Height of the deposited ash)=Volume of ash

100x30xheight =553m^3

Height of the 7 day slurry deposit at the bottom =.18m

Hence, we have to calculate the time ash will take to completely fill the 3m proposed dyke section. This time calculation is a must because we are dealing with pond conditions of water wherein the water table will rise with the rise in the bed ash base, resulting in the different water pressures at the dyke. These different water pressures are later taken into considerations for measuring the slope stability using the software in the later sections.

.18m of ah gets deposited in the base in the period of seven days

3m of ash will get deposited in = (7/.18) x 3

=117 Approx 120days

3.9.4 Particle settling time.

The ash particles are very fine in nature and hence need quite some time to settle when in the suspended form. In the present case where we have a slurry form of ash suspensions we will calculate the settling time for the smallest particle of ash which is under 0.075mm. Based on this calculation we will be able to design a decant system wherein we will draw the clear water from the pond i.e. without any ash particles.

Smallest particle to settle in the ash slurry=0.075mm

Using Stokes law,

$$V_t = \frac{g\left(\rho_p - \rho_w\right)d^2}{18\mu}$$

ρ_p = Density of the particle

ρ_w = Density of water

g = Acceleration due to gravity

d = Diameter of the particle

µ = Viscosity of fluid i.e. water

$$V_t = \frac{[9.81(1300-1000)\text{Kg/m}^3]x[0.075x10-4]2\text{m}^2}{18x1.002x10^{-3}\text{N.S/m}^2}$$

V_t = $9.17x10^{-6}$ m/s

Time = $\frac{\text{Distance}}{\text{Velocity}}$

$= \frac{3}{9.17x10^{-6}}$

Time = 90hrs

= 4days

Hence it can be inferred from the above calculation that the smallest particle of the ash will take 4 days to settle at the bed of the ash pond. Taking a factor of safety of 3 days we have designed the ash pond keeping the slurry undisturbed for 7 days and then only we will remove the water through the decant system.

3.9.5 Design of ash Dykes

The design procedure of the ash dyke is the most critical part of the ash pond design as it serves many purposes, like impounding the slurry, water removal through chimney drains, and further the dykes serve as a base for accessibility for the further dykes that have been created above the starter dyke. The starter dyke is that part of the pond up till which we will construct our ash pond in the first face. Providing provisions for removal of deposited as will increase the capacity of the ash pond as 3m height would be filled and removed with the passage of time. Once the starter dyke height is filled further provisions have also been designed with detailed drawings for the increase in height of the dykes.

The only constraint faced while designing the starter dyke and the 3m height dykes was lac of codal provisions there is no proposed code to be followed as mentioned above, still the design is in accordance with the design parameters mention in the references[21][15]

The design slopes proposed here along with the material strengths provided were later on analyzed on the slope stability software GEO5 for different phreatic water heights and was found to be stable.

Dyke design for a 3m height

Figures 3.14 and 3.15 show a detailed cross sectional view of how the construction would be done. Where figure 3.16 and figure 3.17 deals with rock toe detailing and Figure 3.17 deals with the drainage system detailing. Following are the key elements of design:

- Crest width of the dyke :3m
- Height of the dyke :3.5m
- Slope angle for both upstream and downstream faces (2.5:1.0) i.e. 21°.
- Main construction material at the centre: compacted ash.
- Final top cover: 0.5m thick cover made of locally available soil, will support vegetation.
- Internal drains (chimney and blanket) : will consist of sand having less than 5% finer particles shown in figure3.1
- Rock toe for raised dyke: as per the details shown in the figure 3.3.
- Toe drain, Cross drain pipes are designed as shown in figure 1 for the raised dyke.
- Contrary slopes (1in500) will be provided at a 50m interval for longitudinal alignment of the toe drain.
- Rock toe and toe drain along the starter dyke are the remedial measures for the starter dyke and are shown in figure 3.4
- Erosion Protection: Vegetative cover (local grass which is self sustaining) will be provided on the upstream and the downstream slope. Suitable lining would be provided or riprap lining would be provided if corrosion due to wave action is observed on the upstream side.
- Free board provision: 0.3m

Dyke design for 6m height.

Figure 3.15 through 3.16 show the detail components of ash dyke designed for raising the height by 6m using upstream construction method. Most of the features remain same as of the starter dyke but the key elements are listed as under:

- Crest width : 3.0m
- Height of the dyke :6.5m
- Outer slopes on both sides (downstream and upstream): 2.5:1.0.
- Main material used: compacted ash.
- Cover same as was provided in 3m rising.
- Internal drainage system same as provided in 3m raising chimney drains and Blanket.
- Rock toe for 6m rising: same as proposed for 3m height.
- Toe drain and cross pipe drain same as proposed for 3m rising.
- Erosion protection: same as proposed for the 3m height starter dyke.
- Freeboard :1m

Central dyke design for pipeline

The central dyke shown in the figure 3.17 shows all the components of the dyke along with the placement of pipes as a central (partition) dyke. Following are the key components of the dyke:

- Crest width :3m
- Height of the dyke :3.0m
- Outer slopes both upstream and downstream : 2.5:1.0
- Main material used (hearting) : Compacted ash
- Cover same as in the case of 3m rising
- Internal drains(chimney and blanket) consisting of sand having lesser than 5% finer particles shown in the figure 5
- Rock toe same as provided in the 3m rising
- Erosion protection same as provided 3m rising

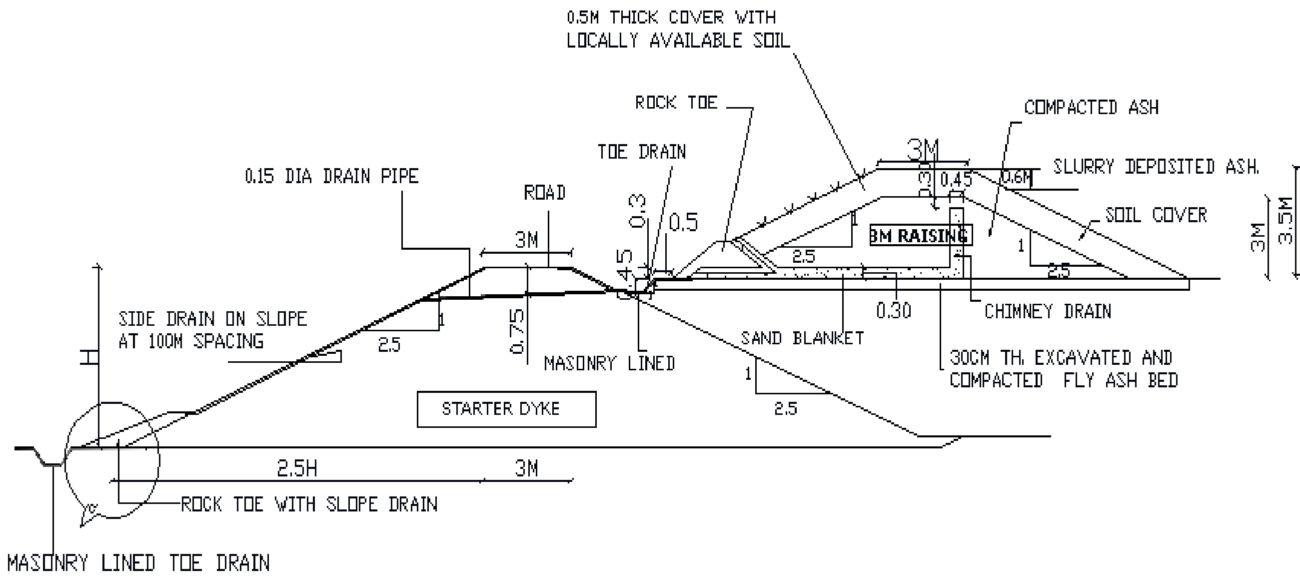

Figure3.16. Raising of Dyke by 3m.

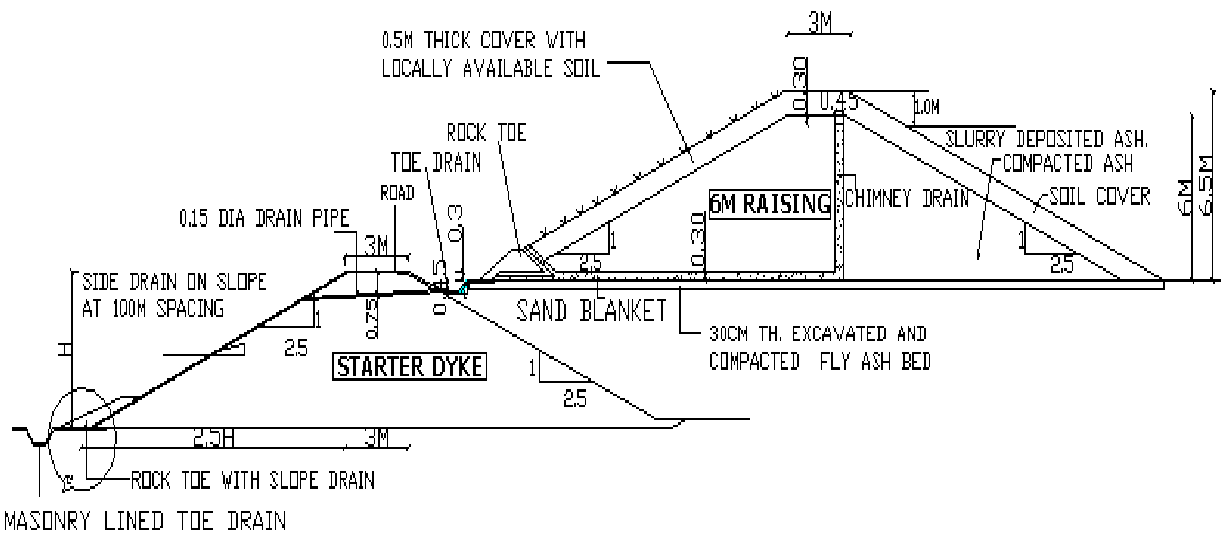

Figure3.17. Raising of Dyke by 6.0m

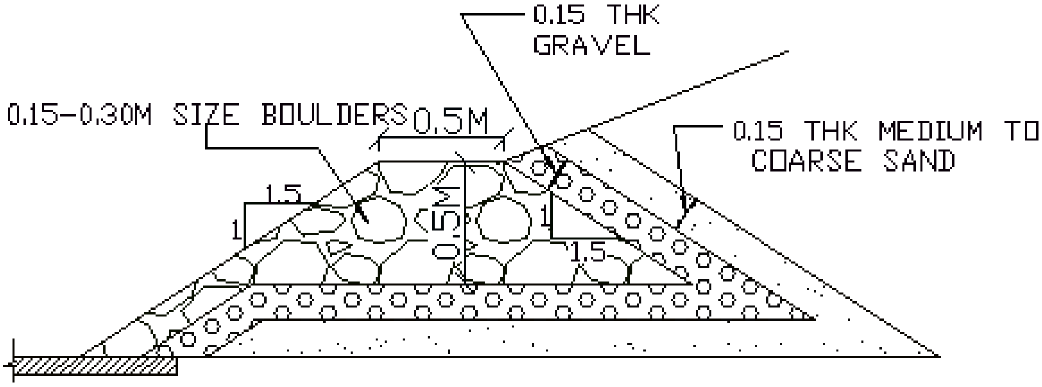

Figure3.18. Details of rock toe of raised dyke.

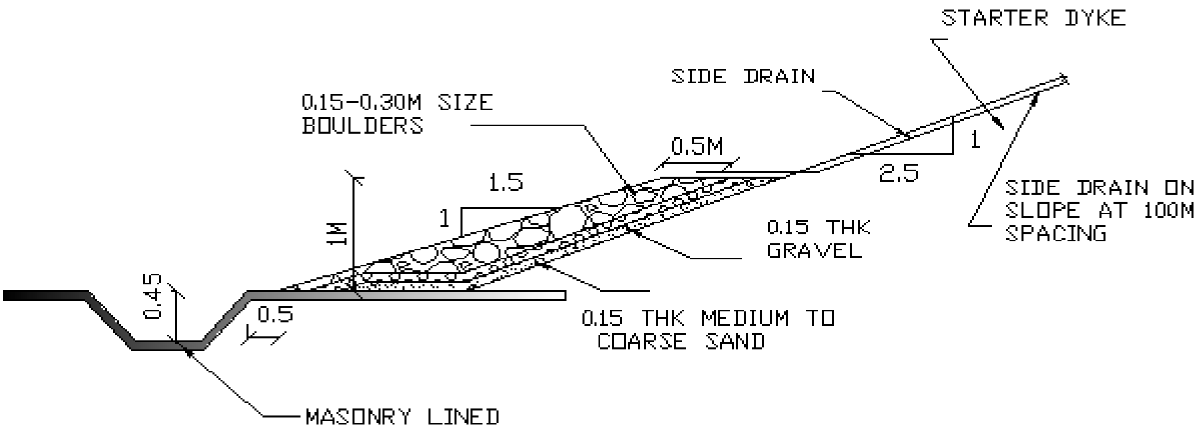

Figure3.19. Details of toe drain and rock toe for starter dyke.

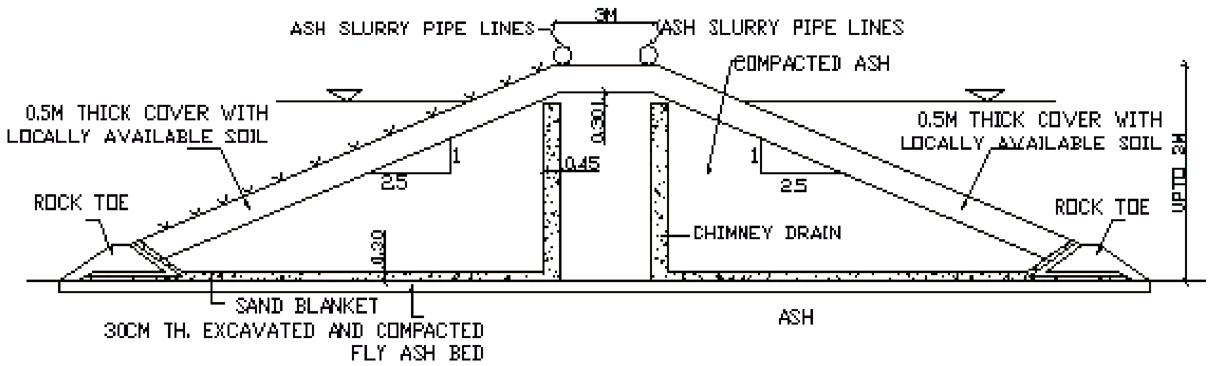

Figure3.20 Cross section of Central Dyke.

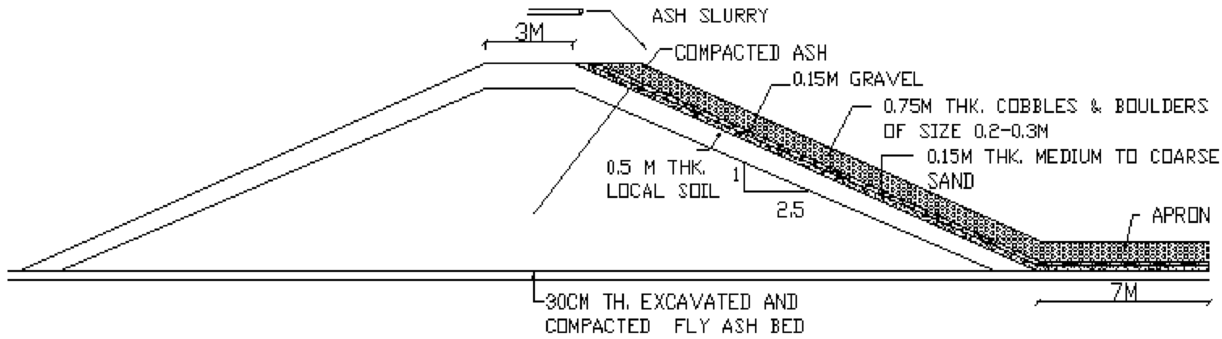

Figure3.21. Protection details of central Dyke at Inflow Points.

Construction Details of Dykes

- Construction of the starter dyke would be done after excavation .5m base from the periphery of the ash pond.
- Only when the ash pond is full on both the sections further ash dykes would be constructed.
- Construction would be done on the dry ash, if the area has been ponded in the recent past the area would be allowed to dry for a period of 30 days minimum.
- The top 0.3m of the ash at the surface of the pond would be removed/excavated and then compacted in the same manner as the dyke.
- Ash for the dyke would be compacted at an OMC in the layers of 350mm thickness using vibratory smooth steel-drum rollers.
- The roller speed and number of passes will be determined from the field trial embankment and minimum 95% of proctor maximum dry density would be achieved, then only the construction would proceed for heights greater than 3m.

- A standard quality control program would be followed for the checking of the compaction of the ash layers as well as for the earth works.
- Dust emissions would be avoided by providing a vegetative cover on the top layer of 0.3m of soil. The soil used would be locally available.
- Materials used in the filters and drains would meet the filtration criterion.
- Local horticulture officer would be consulted for the type of vegetative cover that would be suitable according to the geographic conditions.

3.9.6 Piping system layout and calculations.

The decant towers or pipes would be provided at the far end of the pond for removal of the stored. Based on the above calculations we will operate the decant system every seventh day and likewise the inflow pipes will carry the slurry. The inflow pipes have perforations called spigots having 50mm diameter which are carried by 200mm diameter pipes which run on the periphery of the ash pond and the central ash dyke[21].

Decant pipes

The outflow arrangement usually consists of a decant tower. The decant tower usually has pluggable openings at various heights for drainage of accumulated water in the pond. Once the ash becomes deposited around a particular portion of the decant tower the opening in that portion would be plugged up. Sometimes floating barrages with pumps are used to remove water from ash pond.

A network of slotted piping is places to collect and drain water towards collection points. Shown in Figure 3.22.A careful selection of the type size and spacing of the pipes should be proposed. The type of the pipe selected for both inflow and outflow is based on several factors, including the outflow compatibility, durability, physical properties, ease of installation and cost. Due to outflow and slurry compatibility and perforation spigots required flexible thermoplastic pipes are generally used. Commonly, slotted high-density poly ethylene (HDPE) pipes with inside diameter between 4 and 8 in is used .i.e. 100 to 1800mm diameter pipes can be used we in the design process have proposed 900mm diameter pipes. The study of the pipes here later serves the purpose of spacing and structural analysis to ensure that the estimated flow can be accommodated and stability under loads (construction loads and waste loads) can be ensured

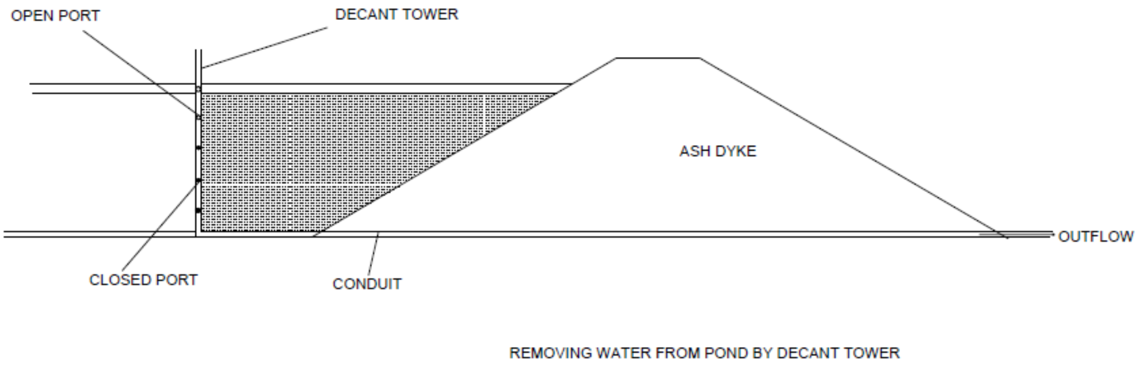

Figure 3.22 Decant tower system.

1. **Pipe spacing**.

The pipe spacing may be determined by the mound model. The slope of the ground surface between the pipes is in Mound Model the maximum height of fluid between two parallel perforated drainage pipes is equal to (U.S. EPA,1989) The following formula can help to obtain line spacing (L), (Moore, 1980)[14];

$$h_{max} = \frac{1}{2}\frac{L}{c}\left[\frac{\tan^2\alpha}{c} + 1 - \frac{\tan\alpha}{c}\sqrt{\tan^2\alpha + c}\right]$$

Material of pipe	= 0.95g/cc
Distance between the pipes(L)	= 30m
Slope of ground surface between the pipes (α)	$=5^0$
The spacing of pipe (h_{max})	=6.06m

2 **Factor of safety for flow capacity**

The factor of safety of flow capacity (Q) can be calculated using [14]

$$FOS = \frac{Q}{Q_L}$$

Q_L = Expected flow rate of the ponded water.

Q_L = (Volume of water accumulated in 1 day) x (Number of storage days)

= ($632m^3$) x (7)

$= 4424 m^3$

Likewise,

Pipe capacity Q is given by (Simon and korom, 1997):

$$Q = CA\,(2Gh)^{1/2}$$

C is about 0.6

Cross- sectional area (C) = 30x100

$= 3000 m^2$

Water head above the pipe (H) =3m

$$Q = (0.6 \times 30 \times 100) \times (2 \times 9.81 \times 3)^{1/2}$$

$= 13810 m^3$

Therefore FOS = $\frac{Q}{Q_L}$

Factor of safety for flow capacity =$[\frac{13810}{4424}]$

=3.12

Structural analysis

High-density polyethylene (HDPE) pipes are currently the most commonly used pipes for decant system applications, due to their strength characteristics and chemical resistance to many constituents. Since HDPE pipe is a flexible pipe with ability to transfer load to surrounding soils. F is taken as the lag factor (usually equal to 1.0), K the bedding constant=0.085, P the pressure (which includes the pressure due to cover layer also).

The three pipe parameters typically found to be most critical in the performance analysis of buried flexible pipes are deflection, wall crushing, and wall buckling (dirscope,1988)[14] .

- **DEFLECTION**

The vertical pipe deflection is given by

$$\frac{\Delta}{D} = FKP(1.1)\frac{2E}{3(SDR-1)^3} + 0.061E'$$

Elastic modulus of pipe in psi (E) = 130,000psi

Soil modulus in lb/in^2 (E')=120MPa

Standard dimension ratios. SDR(pipe diameter/pipe thickness) =(900/43)mm

$$\frac{\Delta}{D} = 1 \times 0.085 \times \left(\frac{1250}{3}\right) \times (1.1) \times 2\frac{130{,}000}{3\left(\frac{900}{43}-1\right)^3} + 0.061 \times 120$$

Δ =.898 mm

Hence the deflectin of the considered piping system with the assumed diameter of 990mm was calculated keeping in mind the above pressure which gave an optimum deflection of .898m which is reasonably acceptable.

- **WALL CRUSHING**

To check the potential for wall crushing following formula can be used

$$P_W = \frac{(SDR-1)P}{2}$$

$$P_W = \frac{(\frac{900}{43}-1)}{2}\ 1250 \times 3$$

Where,

P_W is the pipe wall stress =37,369

P pressure in lb/in^2 =2,46,073

Then comparing P_W to the allowable material stress in terms of factor of safety:

$$FOS = \frac{P_W\ Allowable}{P_W Calculated}$$

$$= \frac{246073}{37369}$$

$$= 6.58$$

- **PIPE BUCKLING**

Finally, to check the potential of pipe buckling, calculate the critical buckling pressure without surrounding soil using the following equation

$$P_{cr} = \frac{2.32E}{(SDR)^3}$$

$$= \frac{2.32 \times 17404}{(\frac{900}{43})^3}$$

$$= 5.04$$

With soil surrounding the pipe, the critical buckling pressure is calculated by the following equation:

$$P_b = 1.15(E'P_{cr})^{1/2}$$

$$=1.15(130{,}000x5.04)^{1/2}$$

$$=930psi$$

Then factor of safety against pipe buckling is given as under

$$FOS = \frac{P_{b\ allowable}}{P_{b\ calculated}}$$

$$=2.39$$

3.10 SLOPE STABILITY ANALYSIS USING GEO5

The Slope stability analysis was carried out for the above proposed ash pond design using the software Geo 5. The software has variety of applications in the field of civil engineering which include settlement analysis stability analysis deep foundation excavation design etc. We used this software to check the slope stability of the ash dyke slopes for different water levels in the pond. It was here where the values calculated above were incorporated in the software to analyze the stability of the slope.

The analysis was carried out under 3 water level conditions, this was carried for one section only. It has been proposed in the thesis that there would be a time to time excavation of the ash from the pond as one section gets filled, hence seeing that no need for raising the dyke would arise in the near future slope stability for a height of 3m was analyzed.

Following are the three conditions under which the slope stability has been analyzed

3.10.1 WATER LEVEL AT A HEIGHT OF 1m FROM BASE

The slope stability was analyzed of the starter dyke under 1m height of water pressure following were the geotechnical soil parameters considered in the software analysis of the ash samples and the soil samples. Likewise a slip surface was projected by the software and the analysis result was carried out under the optimization condition, Morgenstern-Price method was followed for the slope stability as it takes into consideration both the moment and shear failure whereas methods like bishop’s method of analysis takes into account just the wedge failure of the slopes.

The parameters considered are as follows:

Sandy clay (CS), consistency firm

Unit weight: $\gamma_{effective}$ = 18.50KN/m^3

Stress-state: effective

Angle of internal friction: $\phi_{effective}$` = 24.50^0

Cohesion of soil: $C_{effective}$ = 14kPa

Saturated unit weight: γ_{sat} = 20KN/m^3

Clayey gravel (GC)

Unit weight: $\gamma_{effective}$ = 19.50KN/m^3

Stress-state:	effective	
Angle of internal friction:	$\phi_{effective}$`	$= 30.00^0$
Cohesion of soil:	$C_{effective}$	= 6.0kPa
Saturated unit weight:	γ_{sat}	$= 23KN/m^3$

Ash

Unit weight:	$\gamma_{effective}$	$= 13KN/m^3$
Stress-state:	effective	
Angle of internal friction:	$\phi_{effective}$`	$= 28^0$
Cohesion of soil:	$C_{effective}$	= 5kPa
Saturated unit weight:	γ_{sat}	$= 19.5KN/m^3$

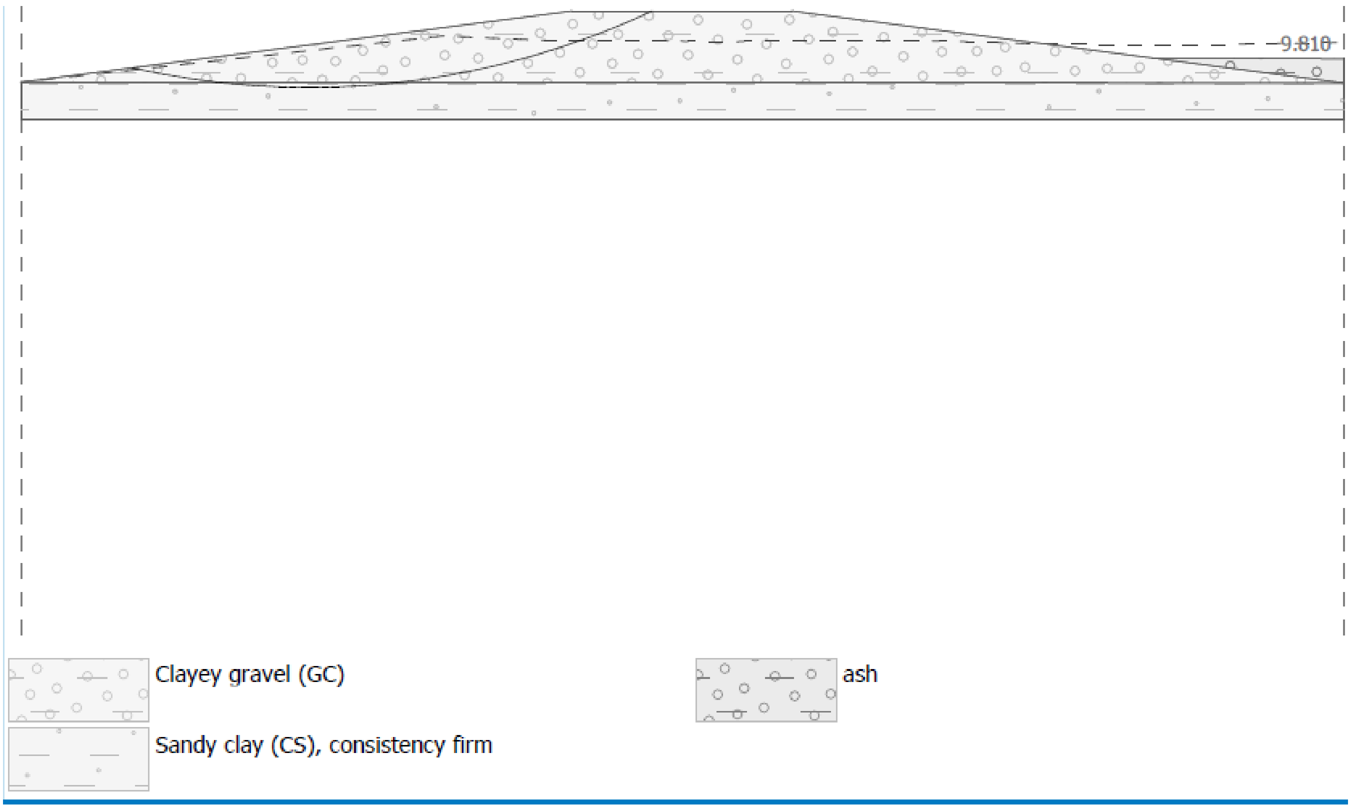

Figure 3.23 Slip surface for 1m height water level.

As can be seen from the above figure a suitable slip surface was analyzed by the software by the Morgenstern-Price method and the factor of safety was found to be 8.09>1.50 which indicates a safe slip surface.

3.10.2 WATER LEVEL AT A HEIGHT OF 2m FROM BASE

The 2nd water condition that has been considered here in the software is the 2m water level rise from the base of the ash pond. Here as shown in the figure 3.10the phreatic water line that should be maintained away from the downstream side has come closer to the downstream slope therby reducing the factor of safety.

Following were the parameters considered for the software analysis:

Sandy clay (CS), consistency firm

Unit weight:	$\gamma_{effective}$	= 18.50KN/m^3
Stress-state:	effective	
Angle of internal friction:	$\phi_{effective}$`	= 24.50^0
Cohesion of soil:	$C_{effective}$	= 14kPa
Saturated unit weight:	γ_{sat}	= 20KN/m^3

Clayey gravel (GC)

Unit weight:	$\gamma_{effective}$	= 19.50KN/m^3
Stress-state:	effective	
Angle of internal friction:	$\phi_{effective}$`	= 30.00^0
Cohesion of soil:	$C_{effective}$	= 6.0kPa
Saturated unit weight:	γ_{sat}	= 23KN/m^3

Ash

Unit weight:	$\gamma_{effective}$	= 13KN/m^3
Stress-state:	effective	
Angle of internal friction:	$\phi_{effective}$`	= 28^0
Cohesion of soil:	$C_{effective}$	= 5kPa
Saturated unit weight:	γ_{sat}	= 19.5KN/m^3

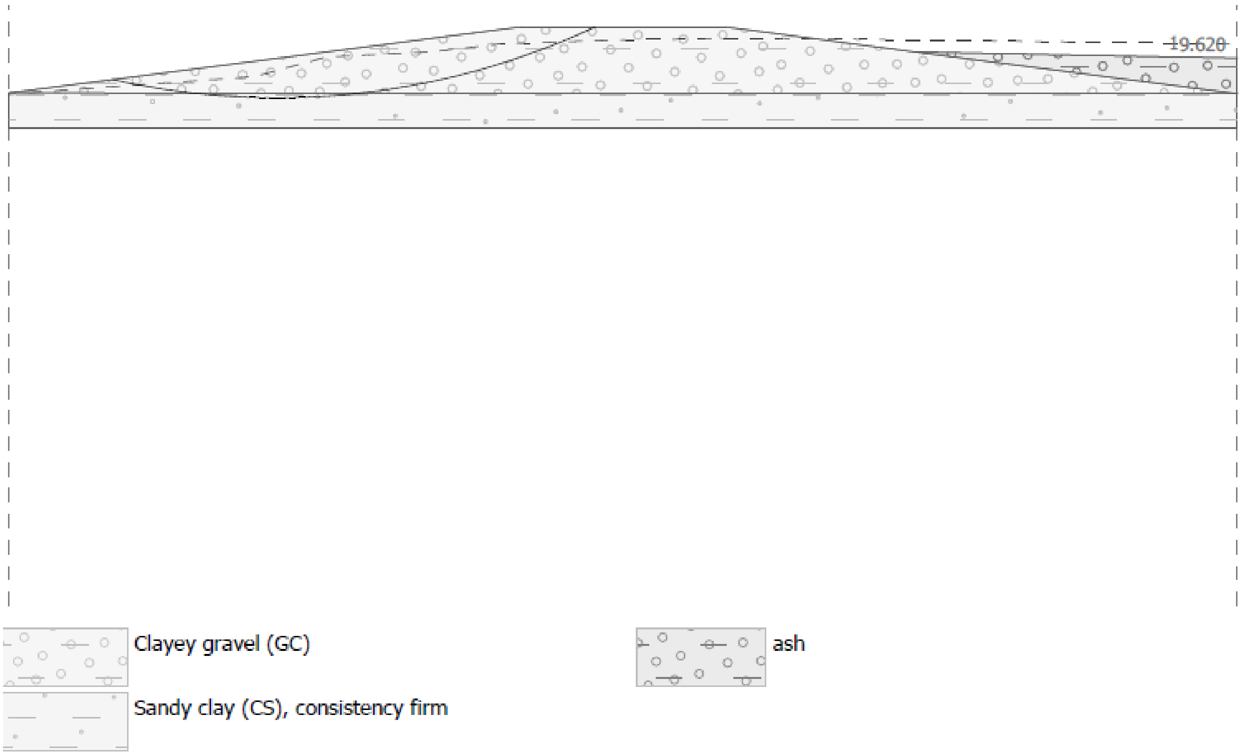

Figure 3.24 Slip surface for 2m height water level.

As can be seen from the above figure a suitable slip surface was analyzed by the software by the Morgenstern-Price method and the factor of safety was found to be 7.00>1.50 which indicates a safe slip surface.As the water level rises there is a reduction in the factor of safeties.

3.10.3 WATER LEVEL AT A HEIGHT OF 3m FROM BASE

The final water ponding level is the maximum water level that the pond will witness it's the 3m height water level or the condition of total submergence the slip surface obtained of the analysis along with the soil parameters considered are mentioned as under, along with the value of the factor of safety obtained**.**

Following were the parameters considered for the software analysis:

Sandy clay (CS), consistency firm

Unit weight:	$\gamma_{effective}$	= 18.50KN/m^3
Stress-state:	effective	
Angle of internal friction:	$\phi_{effective}$`	= 24.50^0
Cohesion of soil:	$C_{effective}$	= 14kPa
Saturated unit weight:	γ_{sat}	= 20KN/m^3

Clayey gravel (GC)

Unit weight:	$\gamma_{effective}$	$= 19.50KN/m^3$
Stress-state:	effective	
Angle of internal friction:	$\phi_{effective}$`	$= 30.00^0$
Cohesion of soil:	$C_{effective}$	$= 6.0kPa$
Saturated unit weight:	γ_{sat}	$= 23KN/m^3$

Ash

Unit weight:	$\gamma_{effective}$	$= 13KN/m^3$
Stress-state:	effective	
Angle of internal friction:	$\phi_{effective}$`	$= 28^0$
Cohesion of soil:	$C_{effective}$	$= 5kPa$
Saturated unit weight:	γ_{sat}	$= 19.5KN/m^3$

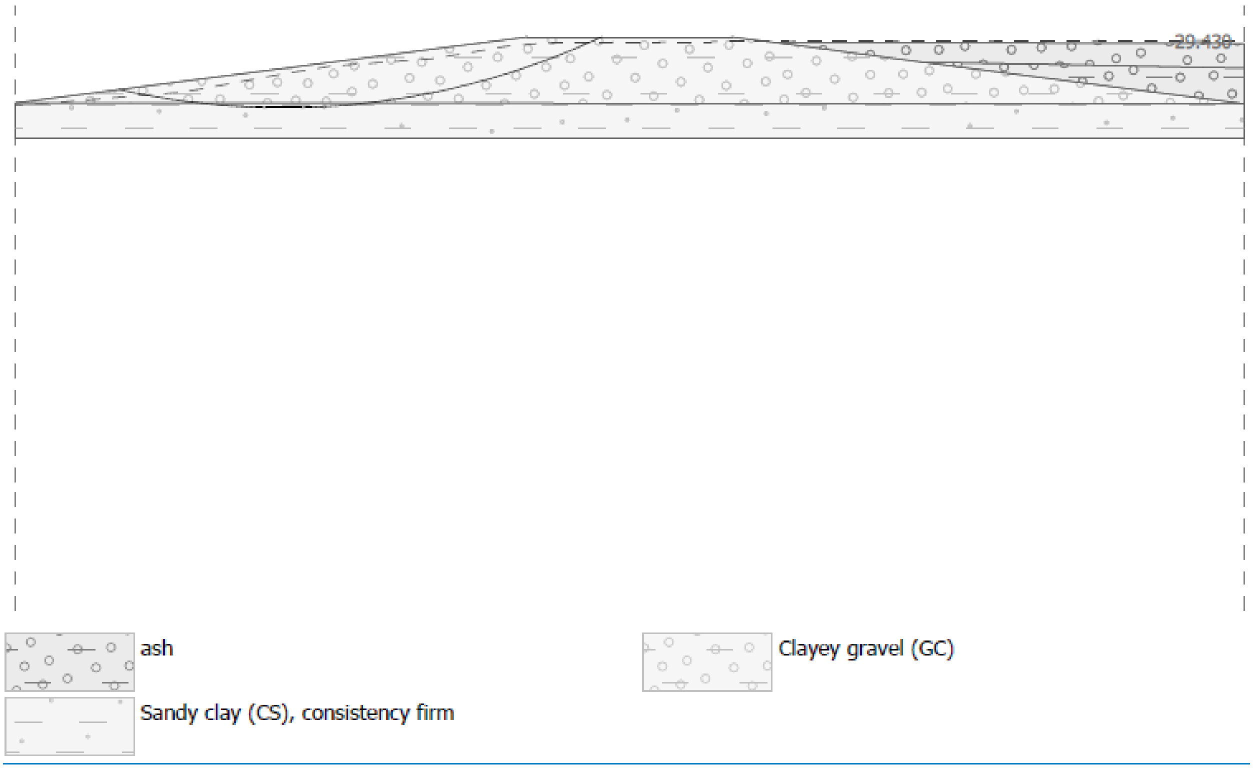

Figure 3.25 Slip surface for 3m height water level.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 General

After the detailed testing analysis and designing processes certain set of result values were obtained. These set of values or the results were taken as feeder values for the designing process and the software analysis. Further the slope stability results were obtained in the terms of factor of safety and are represented in a tabular form in this section.

4.2 SIEVE ANALYSIS.

The plots have been obtained for the particle size distribution in the chapter 3 of the thesis. Here the results have been listed in a tabulated form of both the soil as well as ash samples.

Sieve analysis tests provide us with following results:

SR. NO.	SAMPLE NO.	GRAVEL (%) 4.75mm Retained	SAND (%) Fraction - 4.75mm to 0.075mm	SILT (%) Passing 75 micron
1	A1	54.6	20.1	25.3
2	B1	44.3	25.1	30.6
3	C1	66.0	22.2	11.8
4	D1	47.2	24.1	28.7
5	E1	42.1	26.8	31.1
6	M1	8.00	87.1	4.9

Table 4.1 % of particle size passing through different size sieves

As concluded from the particle size analysis the geotechnical aspects were mostly gravel in nature and the ash was found out to have a very fine texture as the nature of the ash sample resembles that of fine grained clay here in combination with soil.

4.3 MOISTURE CONTENT.

The determination of water content of soil is one of the prime engineering activity that is undertaken before constructing a structure. Water is a major driving component that governs the engineering properties of any soil sample. Water in is simplest form can be found in the oceans, seas, rivers, lakes etc. But apart from that the presence of water in the soil capillaries and pores is another form of water. The presence of water in the soil capillaries is the one that affects the engineering properties of soil. This is because soil is the ultimate factor upon which the stability, strength, durability, resistance to undue effects of nature and man-made activities of a building or structure depends. The thesis work deals with the determination of the moisture content of the soil samples and the ash samples, procedures have been described in details above.

Following are the results of moisture content in % obtained by oven dry method using following equation.

$$MC = \frac{W2 - W3}{W3 - W1} \times 100$$

SR. NO.	SAMPLE NO.	MOISTURE CONTENT (%)
1	A1	5.69
2	B1	3.44
3	C1	2.12
4	D1	3.0
5	E1	4.0

Table 4.2 Different moisture content values for soil samples.

The moisture content test result shows that the moisture content of soil samples is very low hence the soil is dry in nature..

4.4 OPTIMUM MOISTURE CONTENT

Sr. NO.	Sample No.	Optimum moisture content (%)
1	M1	17.3

Table 4.3 Optimum moisture content value for ash sample

The optimum moisture content value for the ash sample was calculated as 17.3% using a required compaction of 98% maximum dry density was also calculated 1.54gm/cc

4.5 SPECIFIC GRAVITY TEST RESULTS

The specific gravity of the soil samples was determined using pycnometer method.

Using the following formula

$$\frac{(W2 - W1)}{(W2 - W1) - (W3 - W4)}$$

SR. NO.	SAMPLE NO.	SPECIFIC GRAVITY
1	A1	2.62
2	B1	2.48
3	C1	2.57
4	D1	2.52
5	E1	2.68
6	M1	2.13

Table 4.4 Specific gravity values for different samples.

4.6 DIRECT SHEAR TEST

To calculate values of C (cohesion) and ϕ(angle of internal resistance) a graph between normal stress and shear stress needed to be plotted. Values of shear stress are obtained by following equation.

$$\frac{\left[\frac{\{D_H * 1000\}}{9.81}\right]}{\left[36\left(1 - D_G \frac{reading}{3}\right)\right]}$$

The values of C(cohesion) and ϕ(angle of internal resistance) were required for the slope stability software analysis Following are the values of these parameters in the tabulated form whereas they have been graphically represented in the chapter 3 . The detailed set of values of a shear stress and normal stress, based on which c Φ were calculated can be found in Annexure A.

SR. NO.	SAMPLE NO.	C (Kpa)	Φ (^{0})
1	A1	16.66	30
2	B1	17.64	24.50
3	C1	18.63	23
4	D1	19.61	28
5	E1	20.58	29
6	M1	5	28

Table 4.5 Values showing Cohesion and angle of internal resistance..

4.7 AREA OF THE ASH POND

Area of the proposed ash pond was calculated in the chapter 4 which was 600m$^{2.}$

4.8 VOLUME

Volume of one of the section was calculated as the other section is identical volume of the pond was calculated as 9000m^3 in the initial working stage. Likewise volume of ash production and slurry production was calculated for the year 2017 which were 73m^3 and 711m^3 respectively. Easily accommodates the ash slurry production in the designed volume of the ash pond.

4.9 BASE ASH HEIGHT

The height of the ash getting deposited at the base of ash pond was necessary to calculate the time in which one section would fill with ash. This thickness came out to be .18m per seven days which implies that .18m of ash would deposit at the base in a period of seven days slurry inflow. Also the time taken to fill the pond would be 120 days with the dry ash then the next section would be proposed for the use, meanwhile the first chamber would be evacuated.

4.10 PARTICLE SETTLING TIME

The time taken by the smallest particle of ash to settle so that clear water remains on the top is calculated as 4 days. Here we have taken a factor of safety of 3 days to ensure full settlement of the particles before operating the decant system.

4.11 DESIGN OF THE ASH DYKES

The slope angle was found to be 21^0 for both the upward and downward slopes. Likewise the crest width was calculated as three meters and the base width of the starter dyke was calculated as 18m.

4.12 PIPING SYSTEM LAYOUT

The piping system was designed using pipes of 900mm inner diameter and 43mm thickness for withdrawing water from the pond the slope angle was calculated as 5^0 slope towards the decant tower . Likewise the spacing was calculated as 6.06m the pipes used were of HDPE in nature.

4.13 FACTOR OF SAFETY FOR PIPINGS

S.No.	BEHAVIOUR	FACTOR OF SAFETY	DEFLECTION(mm)
1	Wall crushing	6.58	-
2	Pipe buckling	2.39	-
3	Deflection	-	0.898

Table 4.6 Different values of FOS for pipe wall behaviours

4.14 FACTOR OF SAFETY USING GEO5 SOFTWARE

S.No.	Water height(m)	Pore pressure (kpa)	Factor of safety >1.5	Method of analysis
1	1	9.81	8.09	Morgenstern-Price
2	2	19.62	7	Morgenstern-Price
3	3	29.43	6.87	Morgenstern-Price

Table 4.7 Different values of FOS for different water levels

The Factor of safety indicates that the slope is stable for the proposed slopes using Morgenstern-price method of analysis. The analysis is taking into consideration all the factors including the geotechnical aspects and the slope proposal aspects also.

CHAPTER 5

CONCLUSION

5.1 Conclusion

Safe construction of ash pond and ash dykes is very much essential in the present scenario of management and mitigation of environmental hazards. In a place like Shimla where the nature has not been much compromised by the polluting activities yet it falls upon us to design safe structures whose failures can result in environmental hazards.

The present study was found to be suitable for accommodating a small amount of Ash generation in the form of slurry and later would serve as bulk supply of fly ash for companies in need for the fly ash.

Based on the laboratory investigations and numerical analysis following conclusions can be made:

1. Out of the three construction methods available for the ash pond construction upstream method downstream method and centerline method, upstream method was applied and analyzed. Upstream construction method is more economical than the two other methods and was suitable to include the slurry in flow values.
2. The decant system proposed was found suitable to carry the water outside the pond. The crushing buckling deflection values were all in the acceptable range of design. Hence overall design can be proposed for the ash pond construction in Shimla city.
3. GEO5 software was useful in determining the stability of our slope proposed for the dykes using different geotechnical values of ash and soil. The method of analysis used in the software was Morgenstern-Price method which takes into account the shear and the moment failure unlike the Bishop’s methods etc. which are not that accurate as they take into account the wedge failure only. The slip surface that was taken into consideration here was a circular section other option available for analysis was polygonal method of slip surface generation.
4. The software was used for the optimization values. The factor of safeties obtained thereof were in decreasing order with the increasing order of the rise of the water table but were way above 1.5 proving the slopes were stable. The phreatic line falls below the dyke body due to the provisions of toe filters and horizontal and vertical drains.

CHAPTER 6

SCOPE OF FUTURE STUDIES

The work undertaken in the thesis was carried out by sticking to one of the few designing techniques in the field of ash pond and analysis of slope stability was done but the other aspects to be considered for the future studies are mentioned as under:

1. Designing method followed here was by the upstream method of construction of ash dyke considering the economic feasibility. The designing could be done using the downstream and centre line methods. The results obtained would be different and the analysis patterns would be different to study with different capacity of the pond and different dyke behaviour.

2. GEO 5 software analysis can be extended to analyse the stability of the dykes of height greater than 3m. Here in the thesis provision was provided of evacuation of the ash hence the need of raising of the dyke was not seen as a mandate in the near years. But analysis of dykes of greater height can be done as further study.

3. Seepage analysis is calculated using softwares like PLAXIS and was not included in the present design of the ash pond. Hence designing can be done using seepage parameters also.

REFRENCES

[1] Bharti, O. Singh,D.P. Sood,V.(2014) "*Effective solid waste management a case study of Shimla.*"

[2] Singh,S.K. Data, M.(2010) *"Raising of Dykes using slurry ash pond – A case study"*

[3] Kalogriou,E. Themelis,N. P.Samaras, A.Karagiannidis, St Kontogianni(2009) *"Fly Ash Characteristics from Waste-to-Energy Facilities and Processes For Ash Stabilization*.**"**

[4] Geo/Environmental Associates (GEA) and APEC (2009) "*Emergency procedures for embankment failure."*

[5] Indiana Michigan Power Company (IMPC, 2008) "*Discharge parameters from an energy plant."*

[6] APEC (2008) *"Settlement analysis of new pond structure."*

[7] Gandhi, S.R.(2005) "*Design and maintenance of ash pond for fly ash disposal*."

[8] Paul.R, (2004) *"Partizansk Coal Ash Dam Break and Spill* - *Observations*",.

[9] American Electric Power Company (AEPC) –ProServ and Barr Engineering (2002). "*Ash pond storage at an elevation*."

[10] Barr Engineering and American Electric Power Company (BEAEPC,2002) "*About Design drawings and construction specifications describing about Details of boring logs, seepage/stability analysis"*

[11] IIT Kanpur(2000) *"Design, construction and monitoring as ash dykes implemented by department of civil engineering***"**

[12] Woodward-Clyde Consultants (1979) *"Constructions of the ash pond design"*

[13] IDNR (1975-77) *"Construction of ash dykes in a flood plain area"*

[14] Casagrande consultants (1976) *"Construction analysis and stability analysis of ash pond"*

[15] Sharma, H.D. Reddy, R. "Geoenvironmental engineering" John Wiley & Sons

[16] IS 2720 : Part VII : 1980 **"***Methods of Test for Soils - Part VII"* : Determination of Water Content-Dry Density Relation Using Light Compaction ,Bureau of Indian Standards, New Delhi.

[17] IS 2720 : Part 8 : 1983 *"Methods of Test for Soils - Part 8"* : Determination of Water Content-Dry Density Relation Using Heavy Compaction. ,Bureau of Indian Standards, New Delhi.

[18] IS 2720 : Part 13 : 1986 *"Methods of Test for Soils - Part 13"* : Direct Shear Test. ,Bureau of Indian Standards, New Delhi.

[19] IS 2720 : part 4 :1985 *"Method of Test for Soils – Part 4"* : Grain size analysis,Bureau of Indian Standards, New Delhi.

[20] IS 2720 : PART 3 : 1980 *"Method for Test for soils- Part 3"* :Specific Gravity Test. Bureu of Indian Standard, New Delhi.

[21] Dutta M and Gulati S K" *Geoenvironmental engineering*" Tata Mgraw Hill Page no.647

ANNEXURE-A

SR. NO.	SAMPLE NO.	NORMAL STRESS(kg/cm2)	SHEAR STRESS (kg/cm2)
1	A1	0.5	0.21
2	A1	1.0	0.27
3	A1	1.5	0.33
4	B1	0.5	0.25
5	B1	1.0	0.31
6	B1	1.5	0.36
7	C1	0.5	0.23
8	C1	1.0	0.275
9	C1	1.5	0.315
10	D1	0.5	0.25
11	D1	1.0	0.31
12	D1	1.5	0.36
13	E1	0.5	0.24
14	E1	1.0	0.283
15	E1	1.5	0.33
16	M1	5	3.0
17	M1	10	5.2
18	M1	15	7.2