APPLICABILITY OF LOCAL SOILS AS BASE LINER MATERIALS TO CONSTRUCT SANITARY LANDFILL

by

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A thesis submitted in partial fulfillment of the requirements for the degree of
Master of Science in Civil Engineering

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Declaration

This is to certify that the thesis work entitled as "Applicability of Local Soils as Base Liner Materials to Construct Sanitary Landfill" has been carried out by Md. Rezaul Islam in the Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh. The above research work or any part of this work has not been submitted anywhere for the award of any degree or diploma.

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This is to certify that the thesis work submitted by Md. Rezaul Islam entitled as "Applicability of Local Soils as Base Liner Materials to Construct Sanitary Landfill'' has been approved by the board of examiners for the partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh in June 2010.

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-Md. Rezaul Islam, June 2010

DEDICATION

To

my parents who taught me morality

and

my wife

ABSTRACT

This thesis represents the findings of application of local soils as base liner materials in the construction of Pilot Scale Sanitary Landfill (PSSL) at Rajbandh, Khulna, the ultimate disposal site (UDS) of Khulna City Corporation (KCC). The base liner of pilot scale sanitary landfill has been studied in situ condition during and post construction phases. The sub-soil investigation was carried out at the PSSL site to identify the soil strata, physical and engineering properties. Boring to a depth of 17m revealed that the gray clay minerals with organic forms to a depth of 1.5m followed by silty clay having clay minerals content ranges from 23 to 30% and hydraulic conductivity varies from 2.45×10^{-6} to 2.5×10^{-8} cm/sec at different molding water content. Swelling clay minerals are present in varying the amount of 0 to 11% of the composition. The characterization shows that local soils at UDS of Rajbandh are suitable as a compacted clay liner for the construction of sanitary landfill, which has been verified in this study in field conditions.

This study describes the process employed for the construction of PSSL. A very simple but technically compatible design is considered here to use local building materials and to avoid any imported or expensive materials such as any kind of geosynthetics. The available indigenous approach mostly manual labor intensive was employed to complete the construction of landfill. This field experience described in the study, which will help in establishing the sanitary landfill construction standard for Bangladesh based on the local conditions, socio-economic settings and technological capabilities. The mineralogical of the top clay layer also indented through standard laboratory test to see the potentiality as clay barrier to be used in the PSSL. A team consisting Asian and European design the PSSL based on local conditions, availability of natural barrier and construction materials, technical needs and the expert's experience. In the construction phases, emphasis was given on the best use of local building material, huge potential of manual labor force and the technical requirements.

The performance of base liner has been measured by collecting the percolating water on areas from 2500 m^2 of compacted clay liner. The performance of compacted clay liners, however, decreased severely within one year due to desiccation and shrinkage. The maximum percolation rates have increased from 36×10^{-3} to 46.6×10^{-3} m^3/day. 400mm of compacted clay liner (CCL) has been tested for one year. The CCL desiccated during the first dry summer of the study. High percolation rates through the CCL were measured during the monsoon. Wetting of the CCL did not significantly reduce the percolation rates. The laboratory test result of leachate from detection & collection system shows that the base liner has protected the migration of contaminant significantly. It also prevents the percolation of leachate as the major portion of generated leachate has been received through the collection system. The water tested in ground water monitoring well indicates that CCL works appreciably to prevent the migration of leachate from the landfill cell. Finally, it can be concluded that the CCL is constructed in the base liner using local clay and the construction techniques works with high degree of satisfaction.

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ABBREVIATIONS

BOD	:	Biochemical Oxygen Demand
CCL	:	Compacted Clay Liner
CBO	:	Community Based Organization
CEC	:	Cation Exchange Capacity
CDIA	:	City Development Initiatives for Asia
CDM	:	Clean Development Mechanism
COD	:	Chemical Oxygen Demand
DCC	:	Dhaka City Corporation
DGHS	:	Directorate General of Health Services
DoE	:	Department of Environment
DtD	:	Door to Door
GoB	:	Government of Bangladesh
JICA	:	Japan International Cooperative Agency
KCC	:	Khulna City Corporation
KCPA	:	Khulna City Project Area
KDA	:	Khulna Development Authority
KMP	:	Khulna Master Plan
KUET	:	Khulna University of Engineering and Technology
LCS	:	Leachate Collection System
LDACs	:	Least Developed Asian Countries
LDCs	:	Least Developed Countries
NEMAP	:	National Environmental Management Action Plan
MoEF	:	Ministry of Environment and Forest
MSW	:	Municipal Solid Waste
MSWM	:	Municipal Solid Waste Management
NGO	:	Non-Governmental Organization
PSSL	:	Pilot Scale Sanitary Landfill
RP	:	Roy Para
RPM	:	Respirable Particulate Matter
SDS	:	Secondary Disposal Site
UDS	:	Ultimate Disposal Site
UFC	:	Unified Facilities Criteria

CHAPTER ONE

INTRODUCTION

1.1 General

Solid waste is a useless, unwanted and discarded materials causing from production and consumption. It is produced at all levels of human activity. Its sources include residential areas, business and industrial facilities, construction and demolition, treatment plants and agricultural activities. An integrated management approach for municipal solid waste has to address the overall flow of material through the various waste management activities, such as collection, transport, separation, reuse, recycling, composting, treatment and final disposal. Disposal of solid waste is one of the most important functional elements of Integrated Solid Waste Management.

As the amount of waste produced in the country increases, new methods of disposal are needed to replace the old ones. Now a day, waste is often placed in open dumps, where waste is left open to the atmosphere and free to blow around. This results in bad smells and frequent fires that would burn uncontrollably, releasing pollutants into the atmosphere. In addition, verminous creatures such as roaches, flies, mosquitoes, rats, etc. would live in the dump increasing the chance for the spread of disease. A large quantity of organic waste is also fed to hogs. This led to the spread of trichinosis and more stringent regulations on the treatment of waste before it could be fed to the hogs. Other waste was dumped in the low laying areas like pond. These dumps are illegal, and hog-feeding is impractical. As a result, the most common disposal method for municipal solid waste is the sanitary landfill. Incinerators are also used in some localities, but are now being phased out due to air pollution problems and public pressure.

The sanitary landfill of today is designed to minimize pollution problems. To prevent water from moving through the landfill and into groundwater, a runoff system is installed to collect drainage and keep the landfill as dry as possible. When water does move through the landfill picking up pollutants, it is referred to as leachate. If it picks up heavy metals or some toxic organic chemicals, it can contaminate nearby groundwater sources. To prevent the movement of leachate, clay liners are installed at the base of the landfill before the solid waste is put in. To prevent trash from blowing around and to reduce smells and the spread of disease, the solid waste is covered with clean fill material throughout the day. Finally, a gas collection system is installed. Once the landfill is filled, it is monitored and maintained for another 30 years by law. This includes methane removal and constant monitoring of water quality in the surrounding area. These areas are usually converted into parks or golf courses because they settle unevenly making them unsuitable for structures.

1.2 Background of this Study

Khulna, the 3rd largest city of Bangladesh is located at the south-west side of the country beside the river Rupsha, near the world largest mangrove forest "Sundarban". With a population of about 1.5 million the city is estimated to generate about 550 tons of municipal solid waste (MSW) every day of which 320 ton of MSW has been estimated to open dump in nature.

To address one of these most striking environmental and social issues in the urban areas of LDACs i.e. MSW management, a 12 months feasibility study project entitled *as "Integrated management and safe disposal of municipal solid waste in LDACs - WasteSafe*", was conducted by the Department of Civil Engineering, Khulna University of Engineering & Technology (KUET), Bangladesh during the period of 2004 to 2005, co-financed by Asia Pro Eco Programme of the European Commission. The project proposed a system named as *'WasteSafe Approach'* with some specific guidelines to address the MSW issues in an integrated and sustainable way. An appropriate method of MSW management can be established for any specific location/region of LDACs considering local conditions with the analysis and evaluation of practical application of this approach. To develop a safe and sustainable management of MSW in Bangladesh through the practical application of *WasteSafe Approach* with required reality check and evaluation of the implemented parts, a three years (2007 to 2009) partnership project entitled as "*Safe and Sustainable Management of MSW in Bangladesh through the Practical Application of WasteSafe Proposal – WasteSafe II*" had conducted since January 01, 2007 co-financed through a grant received from EU-Asia Pro Eco II Programme of the European Commission. One of the key activities of this research project is to establish the landfill construction technologies suitable for Bangladesh conditions as realized from field level experience through a pilot scale sanitary landfill (WasteSafe II 2007). To this endeavour, the landfill cell of the dimension of 50x50x6m, which is 3m below and 3m above the existing ground surface, has been constructed with the necessary components, at Rajbandh, Khulna, at the ultimate disposal site of MSW of Khulna City Corporation (KCC) (Alamgir et al. 2009).

1.3 Purpose of this Study

This research establishes the minimum liner design requirements for sanitary landfills, provides engineering criteria for construction, and lists recommended practices for planning and feasibility studies to best use of local materials, under tropical hydrogeological conditions based on Pilot Scale Sanitary Landfill experience in the LDACs like Bangladesh.

1.4 Objective of This Study

- Selection of local soils and construction of base liner of a Pilot Scale Sanitary Landfill using Khulna clay.
- To investigate the potentiality of local soils as a base liner used in the Pilot Scale Sanitary Landfill.
- To build up specification and construction procedure of Base Liner for the construction Sanitary Landfill in Khulna region using local clay.

1.5 Research Framework

Figure 1.1 diagrams the research design and method of research used in the study. It is a logical explanation of steps that can be followed to replicate the same kind of research in the future at elsewhere. It explains in a nutshell possible method of designing the base liner towards and willingness to build a sanitary landfill for waste management programme. The major steps are to (i) define the aim of the study; (ii) define ways how to achieve the objectives; (iii) describe the data required to achieve the aim of the study and analysis of data for conceptual design; (iv) provide information about sanitary landfill construction and monitoring; (v) Performance analysis to results that describe the design; and (vi) conclusions and assess the successfulness of the research.

Aim:
Investigate the applicability of local soils as baseliner material to construct a sanitary landfill in Khulna.

Objectives:
Facilitate environmental improvement through safe initiatives and technology propagation with a focus on significant appraisal of existing system of MSW management in KCC.

(Chapter 1)

Literature review:
Details about SWM system in Bangladesh and Khulna, characteristics of MSW, sanitary landfill, , evaluation of sanitary landfill, different component of landfill and purpose of landfill disposal are described in this chapter. Brief reviews of relevant literatures are also discussed here.

Data Analysis & Design:
Feasibility study, site characteristics, topography, sub soil investigation, mineralogy and Meteorological Conditions are analyzed in this chapter for conceptual design of base liner of landfill.

(Chapter 3)

Construction and Monitoring:
Construction of base liner in the field using locally available material and technical support for Khulna soils are examined here through proper monitoring system to establish suitable economical construction procedure of a sanitary landfill.

(Chapter 4)

Results and Discussion:
The field performance of base liner is discussed here to that 400mm thick which is examined by measuring the quantity of leakage rate per unit area in liters per day and comparing the physical and chemical properties of leakage water with leachate and ground water monitoring well.

(Chapters 5)

Summary and conclusions:
Assess the achievement of objectives; draw conclusions of the findings and provide summary to improve the design of sanitary landfill in this region.

(Chapter 6)

Figure 1.1 Research design for the practical approach.

CHAPTER TWO

LITERATURE REVIEW

2.1 General

The problems associated with MSW management have acquired an alarming dimension in the developing countries during the last few decades. High population growth rate and increase of economic activities in the urban areas of developing countries combined with a lack of infrastructures, appropriate system and associated training, awareness and commitment in modern solid waste management practices complicate the efforts to improve the solid waste service. Compared to developed countries, the urban residents of developing countries produce less per-capita solid waste, but the capacity of the developing countries to collect, process dispose or reuse it in a cost effective way is limited.

2.2 History of Solid Waste Disposal

Before World War II, the Army disposed of refuse on land (open dumps) in remote areas of the installation and burned the combustible materials periodically. The Army did not adopt sanitary landfilling as a solid waste disposal practice until 1942, when published instructions recommended that refuse be compacted into trenches and covered daily with soil. In 1946, the Army published TM 5634, which provided specific guidance. At that time, the primary emphasis of waste disposal was to reduce garbage odors and blowing litter and to control insects and rodents.

The 1958 version of TM 5-634 was the first Army guidance to address landfill site selection. Although site selection criteria dealt mainly with distance to refuse sources and access to the site, the manual did indicate that landfill sites should not have surface or subsurface drainage that might pollute a water supply.

These practices were undoubtedly considered "state of the art" and environmentally safe at the time. This view prevailed, even though it was common practice to codispose waste engine oil, spent solvents, industrial sludges, and municipal type wastes together in the landfill. Furthermore, no one considered that these liquids might escape from a landfill and seriously contaminate surface waters or subsurface aquifers or otherwise harm the natural environment. In the 1960*s and 1970*s engineers started designing sanitary landfills that relied on the depth to ground-water, and biological, chemical, and physical mechanisms of the soil to protect the ground-water. However, more recent findings have proven that these natural mechanisms do not fully protect the environment from methane gas, a by-product of decaying organic matter, or from leachate. Because of these past practices, many of these old "sanitary landfills" are now found to be "hazardous waste sites" (UFC, 2004).

2.3 Solid Waste Management in Bangladesh

Solid waste management has so far been ignored and least studied environmental issues in Bangladesh, like in most developing countries, but recently the concerned stakeholders have begun to consider this area to be an inseparable component to protect human and nature. In Bangladesh, urban population have been increasing at a very steep rate, about 6% and concentrated mostly in six major cities, where nearly 13% of total population and 55 to 60% of total urban population are living. In the cities, the city authority generally manages MSW; however, recently, some NGOs, CBOs and Private organization are working with city authority's initiatives.

2.3.1 Source storage to disposal

Residential wastes are the main sources of MSW in Bangladesh. Householders those cooperating existing management system, store wastes in a plastic or metal container of different size and shape and keep it inside the house or premises, mostly in kitchen and/or corridor .Solid wastes are collected from generation sources by NGOs, CBOs and city authority by door to-door collection systems, and most of the cases owner by himself disposes it to the nearest community bins or secondary disposal sites.

There is no transfer station and handover point in Bangladesh in true sense. Secondary disposal sites are considered as the facilities where large amount of wastes are accumulated and finally transferred to the desired sites by large vehicles such as open or closed Trucks, Demountable haul container truck, etc. City authority collects wastes from SDS and transfers them to ultimate disposal sites. Only motorized vehicles are used for collection of MSW from Secondary disposal sites. The safe and reliable long-term disposal of solid wastes is an important component of integrated waste management. There is a sanitary landfill at Matuail, Dahka, in which waste is disposed by semi anaerobic process. Figure 2.1 shows the flow path of MSW from source to ultimate disposal site, a typical way to handle MSW in Bangladesh.

2.3.2 Sources of Solid Wastes in Bangladesh

The sources and types of MSW with the data of composition and generation are the basic parameters in the design and operation of the functional elements associated with the management of solid waste (Tchobanoglous and Kreith, 2002). Sources of waste in a community are usually related to land use and zoning. In general, sources of MSW are categorized as: (1) Residential, (2) Commercial, (3) Institutional, and (4) street sweepings (Chan, 1993).

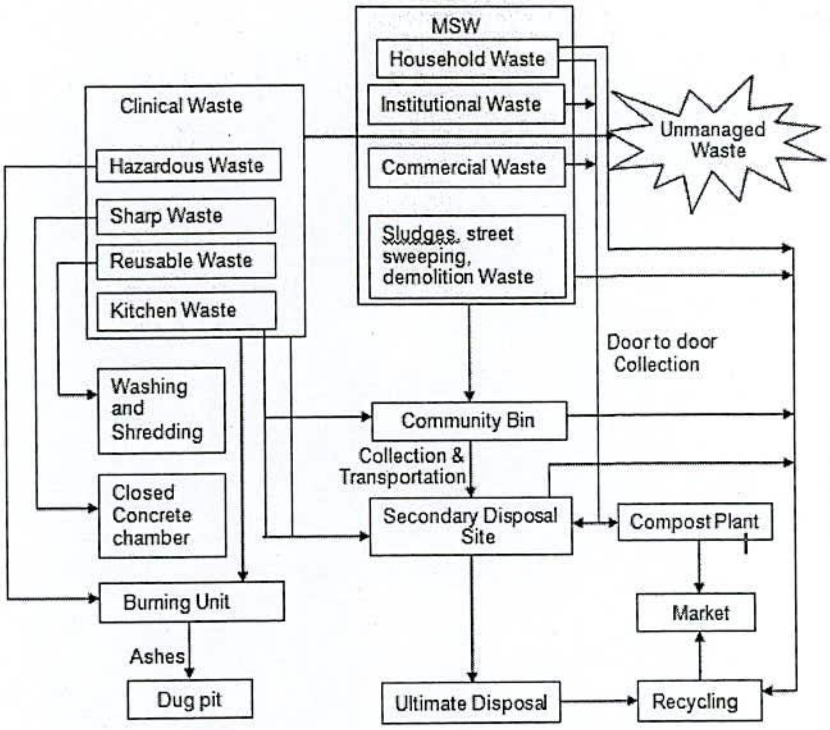


Figure 2.1 Flow path of MSW from source to ultimate disposal site in Bangladesh (alamgir et. al 2005)

Residential Sources: Residential wastes are the main sources of MSW in Bangladesh. Major portion are generated due to household activities. The types of dwellings are single family, multifamily, low, medium and high-rise apartments. These wastes include food wastes, rubbish ashes and others.

Commercial Sources: Solid wastes in commercial sources are generated from stores, restaurants, markets, hotels, service station and others. These wastes include papers, plastics packaging materials and others.

Institutional Sources: The sources of these wastes are mainly universities, schools, hospitals clinics, pathological laboratories, prisons, government and private centers/offices/institutions these wastes include mainly paper, plastics, office articles and medical waste.

Street Sweepings: These wastes are mostly generated in open areas such as streets, alleys, parks, highways, vacant lots, playgrounds, beaches, terminals, recreational areas, etc. Street sweepings include dust, rubbish and others.

2.3.3 Generation of Solid Waste

The term generator means any person, by site or location whose act or process, produces solid waste or first causes it to become regulated. The locations of generators of MSW according to different sources are given in Table 2.1.

Table 2.1 Sources and locations of waste generation (Alamgir et al.2005)

Sources	Locations where wastes are being generated
Residential	Single family & multifamily, low medium & high rise apartment, typical town houses, slum etc.
Commercial	Stores, restaurants, markets, hotel, motel, garage etc.
Institutional	Schools, hospitals, prisons, medical facilities, governmental and private offices/centers/institutions, etc.
Industrial	Small and large industries, rice mill, bakery & biscuit, poultry firm, seed processing, cold storage, etc.
Municipal Services	Street sweeping, drain cleaning, park, landscaping, beach, other recreational areas, etc.
Treatment plant sites	Sludges from water treatment plant.
Public facilities	Bus terminal, launch terminal, rail station, bus stoppage, air port, inside the vehicles such as bus, train, launch, airplane, cinema hall, theatre, recreational areas, etc.
Agricultural	Paddy land, vegetable field, nursery of plants, etc.

2.3.4 MSW generation in major six cities of Bangladesh

Bangladesh, like most of the developing countries, is facing a serious environmental problem due to huge amount of municipal solid waste (MSW) generation and its management. The generation rate is very close in each major city. Overall, the generation varies from house to house depending on the economic status, food habit, age and gender of household members and seasons. Contribution of different sources in total generation of MSW in the six major cities is given in Table 2.2. The generation of MSW in six major cities of Bangladesh is given in Table 2.3.

Table 2.2 Contribution of different sources in total generation of MSW in six major cities of Bangladesh (Alamgir et al. 2005)

Sources	MSW generated daily from different sources (%)					
	Dhaka	Chittagong	Khulna	Rajshahi	Barisal	Sylhet
Residential	75.86	83.83	85.87	77.18	79.55	78.04
Commercial	22.07	13.92	11.60	18.59	15.52	18.48
Institutional	1.17	1.14	1.02	1.22	1.46	1.29
Municipal Services	.53	.51	.55	1.24	1.15	.80
Others	.37	.60	.96	1.77	2.32	1.40
Total	100	100	100	100	100	100

Municipal solid wastes are the heterogeneous composition of wastes, organic and inorganic, rapidly and slowly biodegradable, fresh and putrescible, hazardous and non-hazardous, generated in various sources due to human activities. The various types of waste generated in various sources are shown in Table 2.3

Table 2.3 Generation of MSW in six major cities of Bangladesh (Alamgir et al. 2005).

MSW Generation	Dhaka	Chittagong	Khulna	Rajshahi	Barisal	Sylhet
Population(Millions)	11	3.65	1.5	0.45	0.40	0.50
MSW generation(tons/day)	5340	1315	520	170	130	215
MSW generation rate (kg/capita/ day)	0.485	0.360	0.346	0.378	0.325	0.430

2.3.5 Characteristics of solid wastes in Bangladesh

A total of 7690 tons of municipal solid waste generated daily at the six major cities of Bangladesh, namely, Dhaka, Chittagong, Khulna, Rajshahi, Barisal and Sylhet, as estimated in 2005. The composition of the entire waste stream was about 74.4% organic matter, 9.1% paper, 3.5% plastic, 1.9% textile and wood, 0.8% leather and rubber, 1.5% metal, 0.8% glass and 8% other waste. The per capita generation of municipal solid waste was ranged from 0.325 to 0.485 kg/cap/day while the average rate was 0.387 kg/cap/day as measured in the six major cities. The potential for waste recovery and reduction based on the waste characteristics are evaluated and it is predicted that 21.64 million US$/yr can be earned from recycling and composting of municipal solid waste (alamgir et al.,2007).

Physical characteristics

The important physical characteristics of MSW are pH, moisture content, volatile solid content and ash residue; bulk density and particle size distribution. Table 2.4 shows the average value of some important physical characteristics representing six city corporation areas of Bangladesh. Moisture content and volatile solids data differ seasonally and generally has very high value in rainy season. The experimental results show that the moisture content ranges from 56 to 70% for six major cities of Bangladesh as shown in Table 2.4. Bulk densities were determined in 3 states of compactness as described earlier. In loose state, bulk density ranges from 549 to 669 kg/m3, while in medium state, it ranges from 764 to 951 kg/m3 and for compacted state 875 to 1127 kg/m3 (Table 6) as evaluated by laboratory experiments. However, it ranges from 578 to 621 kg/m3 as obtained through field test in loose state. Although source reduction, reuse, recycling and composting can divert large portions of MSW from disposal, some waste still must be placed in landfills. Bulk density in loose and compact state indicates that the volume can be reduced 50% by normal compaction.

Chemical characteristics of MSW

The nutrient contents in organic component of MSW were carbon (C), nitrogen (N), phosphorous (P) and potassium (K), signify here as chemical characteristics were determined by chemical analysis in the laboratory and the results are shown in Table 2.5. The test shows that the highest C/N ratio was 17.22 while the lowest value was 10.17 as obtained in Chittagong and Dhaka city, respectively. The concentration of phosphorous and Potassium were ranged from 0.23 to 0.41% and 0.42 to 1.37% (Table 7) as measured for organic waste of MSW.

Table 2.4 Physical characteristics of MSW in six major cities of Bangladesh (Alamgir et al., 2007)

Physical characteristics	DCC	CCC	KCC	RCC	BCC	SCC	Weighted average
pH	8.69	8.23	7.76	7.72	7.70	7.71	8.50
H2O (% FM)	70.00	62.00	68.00	56.00	57.00	69.00	68.00
Volatile solid (% DM)	71.00	54.00	56.00	48.00	43.00	65.00	66.00
Ash residue (% DM)	29.00	46.00	44.00	52.00	57.00	35.00	34.00
BD[a] (loose) (kg/m3 FM)	578.00	605.00	610.00	588.00	621.00	609.00	587.00
BD[b] (loose) (kg/m3 FM)	621.00	549.00	556.00	568.00	577.00	669.00	604.00
BD[b] (medium) (kg/m3 FM)	951.00	865.00	764.00	921.00	926.00	899.00	921.00
BD[b] (compact) (kg/m3 FM)	1127.00	994.00	875.00	1052.00	1048.00	1037.00	1082.00

Note: DCC=Dhaka city corporation. CCC=Chittagong city corporation. KCC=Khulna city corporation. RCC=Rajshahicity corporation. BCC=Barisal city corporation. SCC=Sylhet city corporation.
FM = Fresh matter. DM = Dry matter. BD = Bulk density.
[a] By field test. [b] By laboratory test.

Table 2.5. Chemical characteristics of organic component of MSW in six major cities of Bangladesh (Alamgir et al., 2007)

	Chemical characteristics			
City	C/N	N_{total} (% DM)	P (% DM)	K (% DM)
Dhaka	10.17	0.89	0.31	0.62
Chittagong	17.22	0.17	0.23	0.57
Khulna	16.08	1.62	0.41	1.37
Rajshahi	12.15	0.56	0.31	0.38
Barisal	12.44	1.23	0.40	1.18
Sylhet	11.96	0.90	0.32	0.42
Weighted average	11.91	0.82	0.30	0.66

Note: DM = Dry matter. % P as P_2O_5 = % P × 2.29. % K as K_2O = % K × 1.20.

2.3.6 Ultimate Disposal Practices of Solid Wastes in Bangladesh

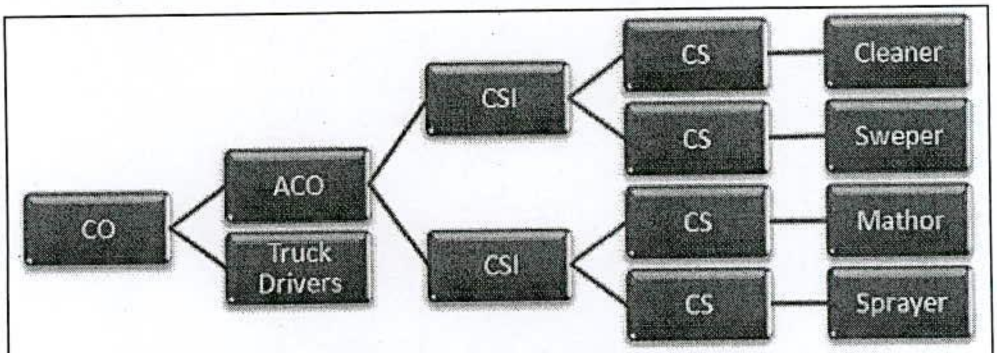
World Bank has categorized some countries as Least Developed Countries (LDCs) in terms of the following criteria: low-income, human resource weakness, and economic vulnerability. At present, 50 countries are designated as LDCs, out of which 8 countries are from Asia - Afghanistan, Bangladesh, Bhutan, Cambodia, Laos PDR, Maldives, Myanmar & Nepal. These countries have a number of priority issues pertaining to the country's development. Among those, management of municipal solid waste is one of the priority urban issues. Common problems for MSW management in LDACs include institutional deficiencies, inadequate legislation and resource constraints. Long and short term plans are inadequate due to capital and human resource limitations. There is a need for financing equipment for MSW management, training specialists and capacity building. The governments have formulated policies for environmental protection, but they were only implemented in the national capital cities. In most urban areas, open dumping is still considered the most popular method of solid waste disposal. Only Dhaka City Corporation has converted the Matuail dump site into an engineered sanitary landfill. The Dhaka City Corporation is set to inaugurate its first-ever sanitary landfill site at Matuail with an aim to reduce the risks of health and environmental hazards.

The landfill site had been constructed as per the master plan on solid waste management, formulated in 2005 with the technical assistance from the Japan International Cooperation Agency aiming at making the city clean by 2015. Generally, significant amount of the solid waste generated in urban centers are uncollected and either burned in the streets or end up in rivers, creeks, marshy areas and empty lots. Waste that is collected is mainly disposed off in open dump-sites, many of which are not properly operated and maintained, thereby posing a serious threat to public health. The collection rate varies from city to city and collection facilities are either inadequate or inefficient in almost all of the cities (Alamgir et al. 2005).

Heavy rainfall during the monsoon is very conducive to the generation of leachate at the dumping sites. Leachate has the potential of slowly moving downwards and eventually reaching the aquifer used for the city water supply, thus contaminating this precious resource. Other problems related to un-organized waste dumping are the spread of waste by wind, run-off and flood waters, and the easy accessibility by persons to potentially hazardous or infectious materials. While waste reduction and reuse efforts may diminish the per capita quantity of waste generated in industrialized nations, there is no doubt that landfills will remain an important method for the safe disposal of municipal solid wastes for the foreseeable future due to their simplicity and cost-effectiveness (wastesafe 2007).

2.3.7 Institutional Arrangement for Solid Waste Management

Presently, the solid waste management system in Bangladesh in not well organized. However, efforts are under way to improve the organizational structure for solid waste management in different cities/towns. For instance, Dhaka City Corporation has recently established a Solid Waste Management Department to improve the waste management services in the city. In most of the city corporations and municipalities there is no separate department for solid waste management. Solid waste management is organized and run by conservancy section of the urban local bodies, whose prime responsibility is maintenance of the sanitation system. The organizational structure of conservancy section is shown in Figure- 1.2. (Only in City Corporations)



Elaboration: CO= Conservancy Officer; ACO=Assistant Conservancy Officer; CSI=Conservancy Supervising Inspector; CS= Conservancy Supervisor

Figure 2.2 Organizational Structure of Conservancy Section in Urban Local Bodies in Bangladesh.

The number of staff for conservancy varies from city to town depending upon the size of the city and the workload. Some of the cleaners and sweepers are hired on temporary basis. Although, the organizational structure presented in Figure 2.2 deals with the collection and storage of waste as well as street sweeping, separate department in the city corporations and municipalities does transportation of waste. The chief conservancy officer or the conservancy officer in the pourasahavs has to coordinate with the transport department to get the waste transferred from collection points to designated waste disposal sites. Generally in most of the urban local bodies have insufficient number of staff involved in waste management activities. In addition to the shortage of personnel, the staffs are handicapped with relatively small amount of resources available to them for management of solid waste in their particular area of operation.

2.3.8 Laws and Regulations

There is no independent law in Bangladesh to address the problems of solid waste. In Bangladesh, solid waste management is entrusted with the local government bodies. The responsibility of removing MSW and disposing of it lies with the City Corporation. The Dhaka City Corporation Ordinance 1983 is the only local law that gives some idea on disposal of municipal waste. Dhaka Municipal Ordinance 1983 has a provision for the removal of refuse from all public streets, public latrines, urinal drains, and dustbins and for collection and disposal of such refuse. Moreover, due to shortage of funding, due to almost no direct user charges as well as insufficient subsidies, and other institutional constraints, the local government has not been able to effectively collect and dispose off the waste properly Most of the waste is visible on the streets and in the drains and Only DCC converted the Matuail open dumping site to a engineered sanitary landfill with the help of JICA (source, http://kitakyushu.iges.or.jp/docs/demo/dhaka_bangladesh).

The government is going to impose strict regulations on the healthcare facilities for safe disposal and proper management of medical waste. The Ministry of Health and Family Welfare is formulating the Medical Waste Management Regulations, which is now in the final stage, under The Bangladesh Environment Conservation Act, 1995. Sources at the Directorate General of Health Services (DGHS) said the draft of the regulations has been prepared and it is currently with the Ministry of environment and Forest for suggestions. Finally it will be sent to the law ministry for vetting.
(Source, http://www.thedailystar.net/pf_story.php?nid=24105)

Since there is no separate policy or handling rules for solid waste management in Bangladesh. Ministry of Environment and Forest is currently preparing a comprehensive solid waste anagement handling rules for the country. The existing legal aspects relating to solid waste management can be classified into two groups, which are given below (www.icmab.org.bd):

a) National Level Framework

Environment Conservation Act, 1995 requires that before establishment of industrial enterprise as well as undertaking of projects environmental aspects must be given due consideration and prior environmental clearance is obtained. As such, for the purpose of environmental clearance, the Environment Conservation Rules 1997 made under the Act. Apart from Environment Conservation Rules 1997, to improve the waste disposal system the Government has recently formulated some policies and plans, which are as:

(i) National Environmental Management Action Plan (NEMAP) has been prepared for a 10-year period (1995-2005), by the Ministry of Environment and Forest (MoEF) of the Government of Bangladesh in consultation with people from all walks of life (GoB, 1995).

(ii) Urban Management Policy Statement, 1998, prepared by the Government of Bangladesh has clearly recommended the municipalities for privatization of services as well as giving priority to facilities for slum dwellers including provision of water supply, sanitation and solid waste disposal (GoB, 1998a).

(iii) National Policy for Water Supply and Sanitation 1998 prepared by the Local Government Division of the Ministry of Local Government Rural Development & Cooperatives gives special emphasis on participation of private sector and NGOs in water supply and sanitation in urban areas through proper collection of wastes, use and recycling.

(iv)National Clean Development Mechanism (CDM) Strategy 2004 prepared by the Ministry of Environment and Forest (MoEF) has identified waste sector as one of the potential sectors for attracting CDM finance in the country. The waste sector options for Bangladesh can be landfill gas recovery, composting, poultry waste, and human excreta management using eco-sanitation and wastewater treatment.

b) Local Level Legal Framework

In Bangladesh, solid waste management is entrusted with urban local government bodies. The responsibility of removal and disposal of municipal solid waste lies with the City Corporations and municipalities. The six City Corporation Ordinances and Pourshava Ordinance 1977 are the only local law that gives some idea about disposal of municipal waste. These ordinances contain identical provisions relating to solid waste management, which are as follows:

- The pourshava or city corporation shall be responsible for sanitation of the municipality/city corporation area and for the control of environmental pollution.
- A pourashava or city corporation shall make adequate arrangements for removal of refuse from all public streets, public latrines, urinals, drains, and all buildings and land vested in the pourshava or city corporation and for collection and proper disposal of such waste.
- Subject to the general control and supervision of the pourashava/city corporation, the occupiers of all other buildings and land shall be responsible for removal of refuse from such buildings and lands.
- The poursahava/city corporation may, and if so required by the governments shall provide public bins or other receptacles at suitable places and by public notice, require that all refuse accumulating in any premise or land shall be deposited by the owner or occupier of such premises or land in designated bins or receptacles.
- All refuse removed and collected by staff of pourashava/city corporation or under their control and supervision and all refuse deposited in the bins and other receptacles provided by the poursahava/city corporation shall be the property of the pourashava/city corporation.
- A pourashava/city corporation shall provide adequate public drains in the municipality/city area and all such drains shall be constructed, maintained, kept cleared, and emptied with due regard to health and convenience of the public.

2.3.9 Current Practice of SWM in Khulna

Khulna City Corporation (KCC) is responsible for the operation and maintenance of municipal services, including solid waste management. The City Corporation is headed by an elected Mayor and operates through 41 elected Ward Commissioners one for each of the 31 Wards with an additional 10 women Ward Commissioners. It is made up of eight functional departments and the conservancy department is responsible for solid waste management, street sweeping, public latrines and urinals, cleaning of drains, etc. The solid waste management service organizes waste collection from approximately 1,200 City Corporation masonry bins, located on roadsides throughout the city. Households are expected to dispose of their waste in the masonry bins. The waste is then transported to its final disposal site (approximately 8 km from the city) by City Corporation trucks. Heaps of waste remains uncollected in many parts of the city; KCC trucks only pick up waste from the roadside bins while waste is frequently disposed in open drains, free land and around the waste bin sites (http://ekh.unep.org). It is estimated that of the 520 tons of waste generated daily, between a third and a half remains uncollected. Uncollected waste blocks drains, causes water logging and spills over on to roads, often resulting in increased traffic congestion. These problems are acute during the rainy season especially in poor neighborhoods which are frequently located in relatively low lying areas and have narrow alleys through which municipal trucks cannot pass. The problem of solid waste management is too extensive for the City Corporation to manage and they are heavily dependant on grants from the central government. The conservancy tax (4% of holding tax) is insufficient to fund the current level of service. In 2008-2009 financial year income from the tax was only Taka 256.52 million (1 US$ = Taka 70) while expenditure by the conservancy department was Taka 65.5 million.

The Current SWM System in Khulna is discussed below (CDIA 2009):

- SWM in Khulna, and in many other Bangladeshi cities, is hampered by the absence of adequate national or local legislation relating to municipal SWM and the treatment and disposal of hazardous waste. In particular, there are no mandatory regulations or performance standards for city corporations (e.g. KCC) to establish and manage an effective SWM system; nor are there any sanctions to prevent littering and indiscriminate dumping.

- As a result SWM in Khulna has developed in a piecemeal and unintegrated manner with NGOs, CBOs, informal recyclers and private enterprises being involved along with KCC. Apart from one ward where KCC operates Door to Door (DtD) collection, its main responsibilities are the transport of waste from 130 Secondary Disposal Sites (SDS) and 1,200 roadside Dustbin Points (DBP) to a landfill site at Rajband about 8km to the west of the city, which it operates. NGOs and CBOs, along with a KCC contracted private company, collect household waste door to door on a daily basis, using rickshaw vans, in parts of several wards and then transport it to the SDS (Figure 2.3). These are considered to be effective operations, although only a minority of city dwellers receives this service. For the most part, householders take the waste to the SDS themselves or dispose of it indiscriminately.

- Informal recyclers collect and dispose of the great majority of recyclable materials (e.g. plastics, glass and paper) but this waste only constitutes a minority (around 20% by weight) of the total daily generated household waste. The great majority of household waste is bio-waste. Although there are some composting initiatives, their total output is negligible, 20-25 tons per month when compared to the average daily household waste generation of just under 300 tons for the KCC area.

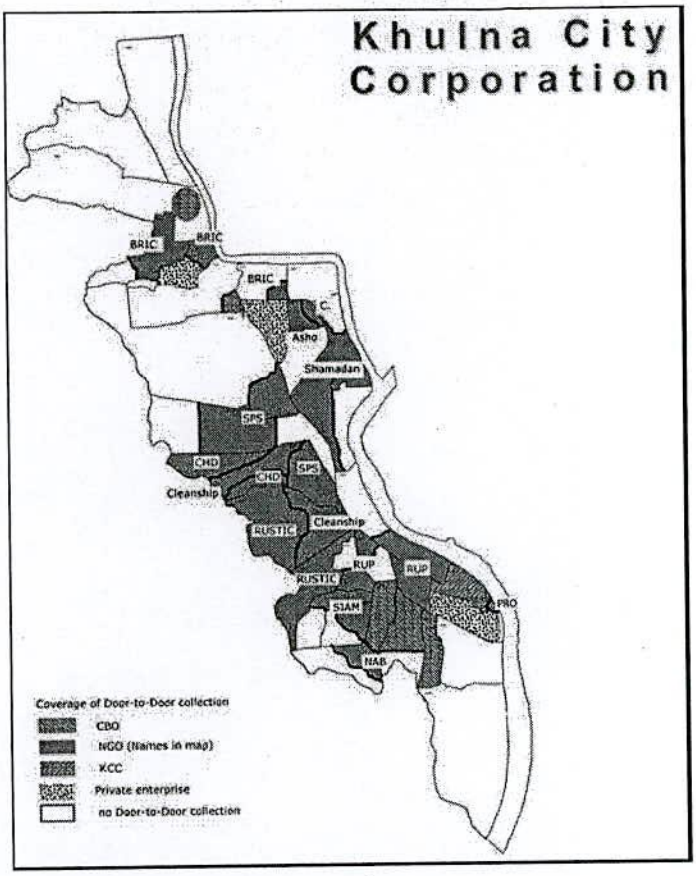


Figure 2.3 Coverage of Wards by Door to Door Refuse Collection(CDIA 2009)

- In 2000, it was estimated that under 30% of KCC households had access to waste disposal facilities. While this situation has improved due to the increased involvement of NGOs and the private sector, currently only 50-60% of household waste is collected with most of the remainder being disposed of indiscriminately in drains, at roadsides and into vacant areas. A substantial proportion is also used for land reclamation, sometimes through the diversion of KCC trucks going to the landfill site.
- Commercial wastes amount to 65-70 tons daily, all of which is disposed of by the enterprises themselves. Hospital wastes amount to under 1 ton per day, around 86% of which is non-hazardous. Despite attempts by NGOs to establish an incineration plant for hazardous waste, this is no longer functioning and there is now no mechanism for hazardous waste disposal. NGO Prodipan does however

operate a system of collecting separated hazardous waste from around 1/3rd of Khulna's health facilities.

- The general operational inadequacy of the system is exacerbated by the inadequate management and maintenance of the SDS by KCC, the poor maintenance of KCC trucks (up to 40% are off the road at any one time), indiscriminate dumping, scavenging at SDS and DBPs which results in waste being dispersed around these sites, and the absence of engineered sanitary land fill cells and associated lack of emissions control at Rajband.
- The major reasons for Khulna's poor SWM system are 1) The low managerial, technical and financial resources available to KCC to operate an effective SWM system and 2) The lack of public awareness and commitment by a large proportion of the population which leads to indiscriminate dumping of waste exacerbated by a resistance to NGO operated DtD services for which payments additional to the conservancy charges levied by KCC need to be made.

- Quite apart from the negative impacts on health and the urban environment in general, the failure to operate an effective SMW system exacerbates the flooding that occur during the rainy season (see preceding section). The poor SWM system therefore also contributes to the adverse economic, environmental and social impacts arising from frequent flooding.

2.4 Sanitary Landfill

Landfill is a term used to describe the physical facilities for disposal of solid wastes and Solid waste residuals in the surface soil of the earth. Landfill may be classified into three categories-

Class I: Hazardous waste Landfill

Class II: Designated waste Landfill

Class III: Municipal Solid waste (MSW) Landfill

Based on the physical infrastructures and other associated facilities landfill is classified as-

i) Sanitary landfill
ii) Monofills
iii) Secure landfills
iv) Uncontrolled land disposal sites

2.4.1 Definition of Sanitary Landfill

- Wastes those are susceptible to contaminate air, ground water and surface water are needed to contain in an engineered safe containment system, known as engineered or sanitary landfill.
- Sanitary landfill may be defined as the operation in which wastes to be disposed of are compacted in layers and covered with a layer of earth at the end of each day's operation.
- In a word Sanitary landfills are sites where waste is isolated from the environment until it is safe. A real sanitary landfill is shown in Figure 2.4

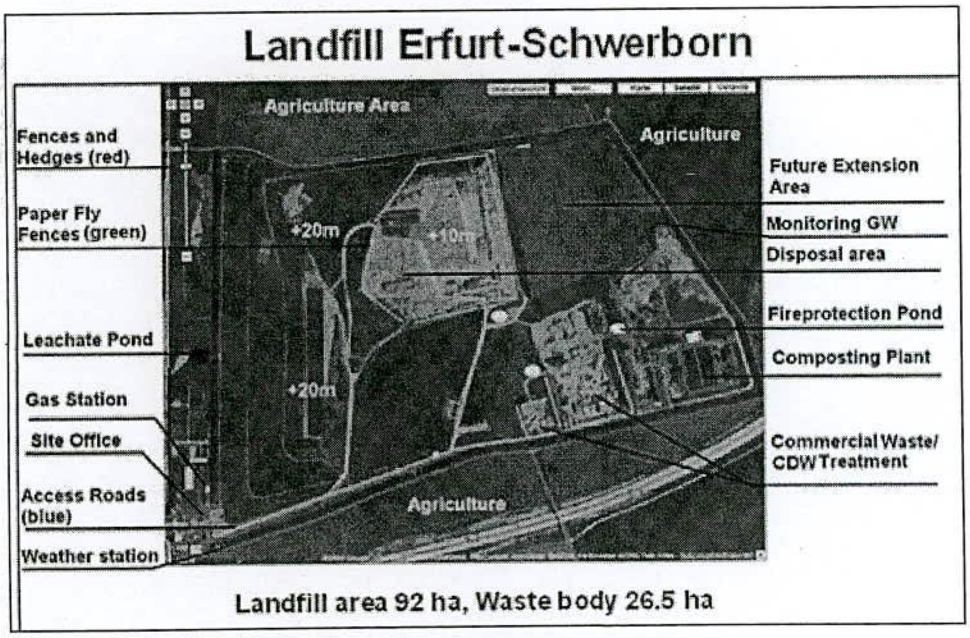


Figure 2.4 Top view of a real sanitary landfill in Germany

2.4.2 Purpose of Landfill Disposal

The purpose of landfill disposal is to stabilize the solid waste and to make it hygienic through proper storage of waste and use of natural metabolic function. Sanitary landfilling is generally preferred over other alternatives, because there is less handling and processing of materials. However, a landfill may not be the most economical or environmentally preferred method. The rapid filling of available sites, and outdated containment systems of existing landfills have forced authorities to consider alternative disposal methods. A combination of the options may be the best solution, but may depend on several factors at the installation, including: the type of refuse, availability of land for site selection, incinerator accessibility, economic feasibility for recycling usable materials, suitable locations for large quantity composting, and possible contractual arrangements that would combine several of these methods. The main advantage of a sanitary landfill is that handling and processing of refuse is kept to a minimum. Handling is limited to the pickup and transport of the waste, the spreading of refuse, and covering with a suitable cover material. Composting requires more handling before it is stored to decompose, and may only be suitable for disposing of organic matter such as yard waste. Therefore, composting may not be a viable alternative for a majority of the situations. Recycling requires that only specific materials be processed, and requires more handling than most other methods, but can reduce solid wastes in a landfill by as much as 30% (UFC 2004).. After the material is collected, it may go through various changes and processes, at a substantial expenditure of energy, before it results in a reusable form. Recyclable materials include paper, plastics, glass, metals, batteries, and automobile tires. Incineration with energy recovery has been used for some time, but has come under increased scrutiny because of new laws and regulations aimed at reducing air pollution and the resulting products of incineration may be even more dangerous than originally thought. Clean air laws, and negative public sentiment may require additional expense and waste treatment that can make incineration the least favored alternative. Ash residue and bulky refuse which are not burned during incineration will still require disposal. The main advantage of incineration is the capability to reduce landfill use by 70-80% (UFC 2004).. The critical factors which must be considered include: the possibility of surface and ground water contamination, explosions from gases generated by waste decomposition, airborne ash from incineration, odors from the composting process, and the lack of suitable sites with the capacity for long term use are critical factors which must be considered. Design authorities must make decisions which are critical to the areas surrounding the proposed sanitary landfill. Selecting a method for proper and complete disposal can be a very intricate process (UFC 2004).

2.4.3 Solid Waste Stabilization in a Sanitary Landfill (UFC 2004)

Alternatives:

While past designs required that landfills receive extended maintenance after closure, increasingly stringent regulations and the shrinking availability of suitable sites for landfills may force the designer to consider some of the new technologies that can speed up solid waste stabilization. Stabilization is achieved by the degradation of the deposited refuse, mainly through decomposition, which reduces the pile volume and can lead to surface subsidence. Landfill designs offer two options: dry or sealed landfills; and wet landfills.

Dry Landfills:

Dry landfills are designed to seal off the solid waste in hopes of reducing leachate production, therefore decreasing the possibility of leachate leakage outside of the landfill system. Unfortunately, studies show that solid waste stabilization is limited with the "dry" system. Archaeological investigations have found 20 years old refuse in existing landfills which was preserved from the elements. Because the waste was sealed off, it was protected from the rotting influences of air and moisture. While this method may require low maintenance, it could possibly require maintenance for several decades, with little actual stabilization or decomposition of the solid waste.

Wet landfills:

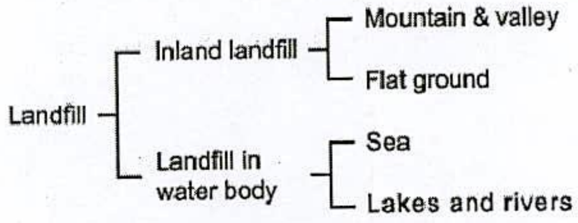
(1) Biodegradation: Current studies have shown that wet systems, or landfills that use leachate recirculation, are becoming the favored option when considering solid waste stabilization as a priority for the landfill. Since most biodegradation results from complex interactions of microbial bacteria, these "wet landfills" may also require the addition of air along with the recirculation of leachate. Lined landfills that have been properly designed and constructed provide leachate containment with a low risk of leakage.

(2) Gas Generation: Methane gas generation is considered to be a problem at some landfills. Therefore, the production of methane and other gases should be considered in the design. The economics of extracting methane gas as an energy source makes accelerated methane gas production a benefit of wet landfill designs. This may require that containing and recovering the methane gas be made part of the landfill design.

(3) Stabilization Time: The main advantage of a wet landfill is the increased rate of stabilization of the solid waste in the landfill. Studies show that the process of leachate recirculation can speed up the rate of waste decomposition, by an active biological process

in a landfill from 50 or more years for a dry landfill, to just 5 or 10 years for a wet landfill. Long term financial savings through eliminated or reduced maintenance and long term monitoring may outweigh the initial start-up costs and requirements for leachate recirculation, and should be considered in the design of the sanitary landfill.

2.4.5 Classification of Landfill Site



2.4.6 Classification of Landfill Structure

Landfill sites are classified into 5 types according to structure as shown in Table 2.6. In terms of quality of leachate and gases generated from landfill site, either semi-aerobic or aerobic landfill method is desirous.

Table 2.6 Classification of Landfill Structure(www.menlh.go.id)

Anaerobic landfill	Solid wastes are filled; in digged area of plane field or valley. Wastes are filled with water and in anaerobic condition
Anaerobic sanitary landfill	Anaerobic landfill with cover like sandwich shape. Condition in solid waste is same as anaerobic landfill.
Improved anaerobic sanitary landfill (Improved sanitary landfill)	This has leachate collection system in the bottom of the landfill site. Others are same as anaerobic sanitary landifll. The conditions is still anaerobic and moisture content is much less than anaerobic sanitary landfill.
Semi-aerobic landfill	Leachate collection duct is bigger than the one of improved sanitary landfill. The opening of the duct is surrounded by air and the duct is covered with small crushed stones. Moisture content in solid waste is small. Oxygen is supplied to solid waste from leachate collection duct.
Aerobic landfill	In addition to the leachate collection pipe, air supply pipes are attached and air is enforced to enter the solid waste of which condition becomes more aerobic than semi-aerobic landfill.

2.4.7 Evolution of Sanitary Landfills

Since the turn of the last century, the use of landfills, in one form or another, has been the most economical and environmentally acceptable method for the disposal of solid wastes throughout the world. Landfills, in various forms, have been used for many years. The first recorded regulations to controls municipal solid waste are implemented during the Minoan civilization, which flourished in Crete (Greece). From 3000 to 1000 B.C.E. Solid wastes from the capital, Knossos, were placed in large pits and covered with layers of earth at intervals (Tammemagi, 1999). This basic method land filling has remained relatively unchanged right.Up to the present day, the summary of the evolution of municipal landfills is given in the Table 2.7.

Table 2.7 Summary of municipal landfill evolution (after Bouzza et al., 2002)

Period	Development	Problems	Improvements
1970s	Sanitary landfills	Health/nuisance i.e. odor, fires, litter	Daily cover, better compaction, engineered approach to containment
Late 1970- early 1990s	Engineered landfills recycling	Ground and ground water contamination	Engineered liners, covers, leachate and gas collection system, increasing [illegible]
Late 1980s- early 1990s	Improved sitting and containment, waste diversion and re-use	Stability, gas migration	Incorporation of technical, socio-political factors into sifting process, development of new lining materials, new cover concepts, increased post-closure use
2000s	Improved waste treatment		Increasing emphasis on mechanical and biological waste pretreatment, leachate recirculation and

A Timeline of Trash (http://www.bfi-salinas.com/kids_trash_timeline-printer.cfm) is shown below

Date	Location	Notes
6,500 BC	North America	Archeological studies shows a clan of Native Americans in what is now Colorado produced an average of 5.3 pounds of waste a day.
500 BC	Athens Greece	First municipal dump in western world organized. Regulations required waste to be dumped at least a mile from the city limits.
New Testament of Bible	Jerusalem Palestine	The Valley of Gehenna also called Sheoal in the New Testament of the Bible "Though I descent into Sheol, thou art there." Sheoal was apparently a dump outside of the city of that periodically burned. It became synonymous with "hell."
1388	England	English Parliament bars waste dispersal in public waterways and ditches.
1400	Paris France	Garbage piles so high outside of Paris gates that it interferes with city defense.
1690	Philadelphia	Rittenhouse Mill, Philadelphia makes paper from recycled fibers (waste paper and rags).
1842	England	A report links disease to filthy environmental conditions - "age of sanitation" begins.
1874	Nottingham England	A new technology called "the Destructor" provided the first systematic incineration of refuse in Nottingham, England. Until this time, much of the burning was accidental, a result of methane production.
1885	Governor's Island NY	The first garbage incinerator was built in USA (on Governor's Island in NY)

A Timeline of Trash (http://www.bfi-salinas.com/kids_trash_timeline-printer.cfm) is shown below

Date	Location	Notes
1889	Washington DC	Washington DC reported that we were running out of appropriate places for refuse (sound familiar?).
1896	United States	Waste reduction plants arrive in US. (for compressing organic wastes). Later closed because of noxious emissions.
1898	New York	NY has first rubbish sorting plant for recycling (are we reinventing the wheel?).
Turn of Century		By the turn of the century the garbage problem was seen as one of the greatest problems for local authorities.
1900		"Piggeries" were developed to eat fresh or cooked garbage (In the mid-50's an outbreak of vesicluar exenthama resulted in the destruction of 1,000s of pigs that had eaten raw garbage. Law passed requiring that garbage had to be cooked before it could be fed to swine).
1911	New York City	NYC citizens were producing 4.6 pounds of refuse a day (remember the Native Americans from 6500 BC mentioned above?).
1914	United States	there were about 300 incinerators in the US for burning trash.
1920's		Landfills were becoming a popular way of reclaiming swamp land while getting rid of trash.
1954	Olympia Washington	Olympia Washington pays for return of aluminum cans.
1965	United States	The first federal solid waste management laws were enacted.
1968		By 1968 companies began buy back recycling of containers.
1970	United	The first Earth Day was celebrated, the Environmental

A Timeline of Trash (http://www.bfi-salinas.com/kids_trash_timeline-printer.cfm) is shown below

Date	Location	Notes
	States	Protection Agency EPA created and the Resource Recovery Act enacted.
1976	United States	In 1976 Resource Conservation and Recovery Act (RCRA) was created emphasizing recycling and HW management. This was the result of two major events: the oil embargo and the discovery (or recognition) of Love Canal.
1979	United States	The EPA issued criteria prohibiting open dumping.
Today		The list goes on and on.

2.4.8 Elements of a Sanitary Landfill

Sanitary landfill are consists of some elements that are essential to prevent any environmental hazard. These elements are provided at different steps of construction and daily operation. Various elements of a sanitary landfill are described as below:

Cell: The term cell is used to describe the volume of material placed in a landfill during one operating period, usually 1 day.

Daily cover: Daily cover usually consists of 6 to 12 in of native soil or alternative materials such as compost, foundry sand, or auto shredder fluff that are applied to the working faces of the landfill at the end of each operating period.

Lift: A lift is a complete layer of cells over the active area of the landfill.

Bench: A bench is typically used where the height of the landfill will exceed 50 to 75 ft. Benches are used to maintain the slope stability of the landfill, for the placement of surface water drainage channels, and for the location of landfill gas recovery piping.

Landfill liners: Landfill liners are materials that are used to line the bottom area and bellow grade sides of a landfill.

Landfill Cover: The final landfill cover layer is applied over the entire landfill surface after all land filling operations are complete.

Monitoring wells: It is designed and placed to define groundwater flow and water quality below the surface of a solid waste facility. Properly designed and placed wells will also ensure that groundwater samples and water level measurements are representative of the groundwater below the site. Placed individually or as clusters, each individual well is installed in its own boring. The above elements are shown in Figure 2.5.

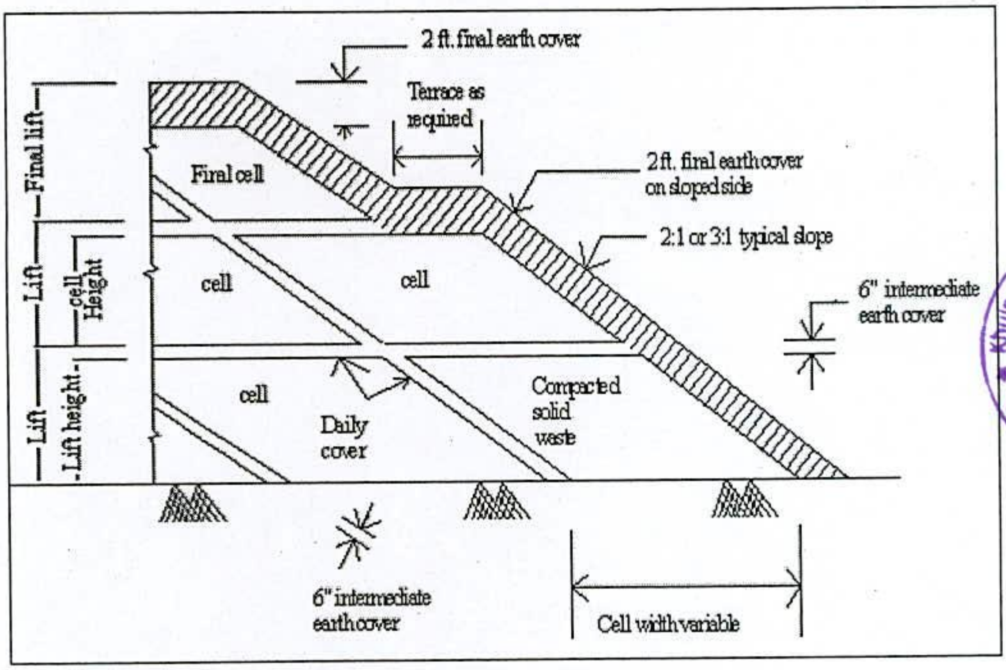


Figure 2.5 Typical sectional view of a sanitary landfill (G.Tchobanoglous, H. Theiswn, & S. Vigil, 1993)

2.5 Sanitary Landfill in Bangladesh

Despite a Pilot Scale Sanitary Landfill (PSSL), this is the second experience in Bangladesh after the Matuail's one (Ahmed 2008), where the Dhaka City Corporation has been developing an engineered landfill in semi aerobic method by converting the existing open dumping site as shown in figure 2.6. A semi-aerobic landfill system has been adopted to reduce the polluting load on the environment and speed up the stabilization of the disposed waste. A perforated pipe network for leachate collection and gas venting arrangement are installed for proper collection of the leachate and provision of air supply system. Periodical monitoring of the environmental parameters of the ground and surface water, leachate quality and landfill gas is introduced as part of the operational measure of the sanitary landfill. Under this semi-aerobic system, the lifetime of the landfill is estimated to be 20 years at the present rate of incoming waste of around 1,700 tons/day (www.citynet-ap.org).

KUET and KCC jointly have been constructing the PSSL in Rajbandh, Khulna to establish appropriate construction technology for Bangladesh conditions using local building materials, technical capabilities and the available technology. The pilot scale sanitary landfill is designed and constructed during the first-half of 2008. In the design and construction, very simple approach relevant to the condition of LDACs is considered; the details are discussed in the following chapter.

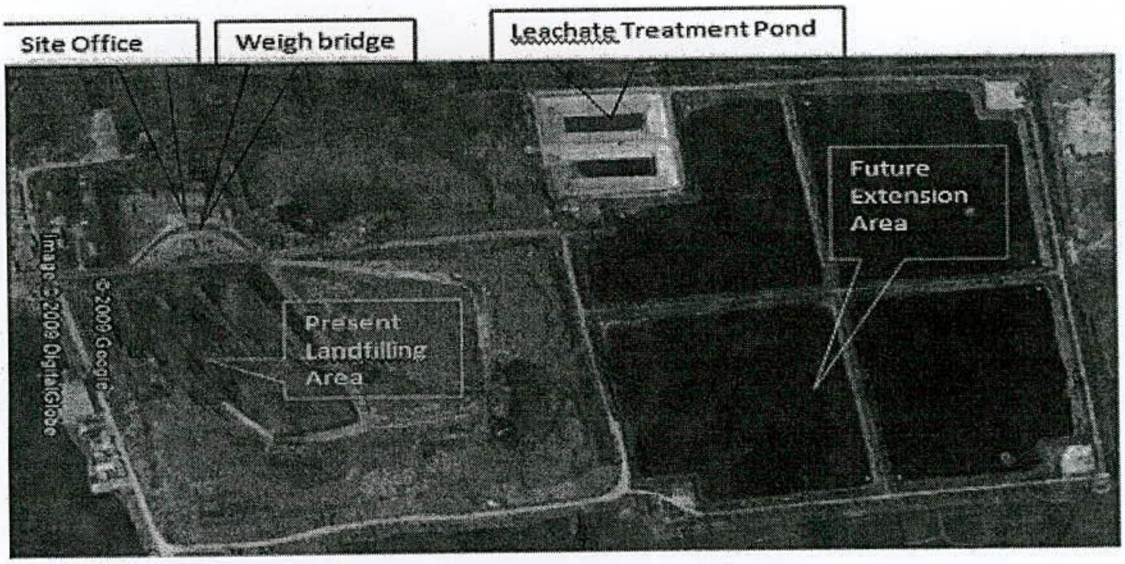


Figure 2.6 Matuail Sanitary Landfill of DCC, Bangladesh (www.google earth.com)

2.6 Landfill Liners

Once a contaminant has escaped into the ground, it flows from pore to pore through the soil, sometimes traveling several kilometers. The manner and rate of transport depend on many factors including:

- Whether the soil is saturated or unsaturated
- The type of soil
- The type of material flowing through the soil, especially its solubility in water and its specific gravity
- The velocity and direction of natural ground water flow
- The rate of infiltration from the source.

For all except the most toxic wastes, it was felt that leachate should be allowed to disperse into surrounding soils where its toxicity would be naturally reduced (attenuated) through physico-chemical and microbiological mechanisms. In general, the extend of this action depends on the characteristics of the soil, especially clay content.

Almost invariably, new landfills are now required to incorporate some form of impermeable lining material *(liner)* entirely covering the floor and sides of the excavated area. The purpose of the liner is to prevent the migration of gas or leachate from the landfill into the surrounding environment, and to prevent the migration of groundwater into the landfill. The liner may be constructed from compacted clay soil *(mineral liner)*, or from synthetic plastic sheeting (*geomembrane*), or from a combination of the two (*composite liner*).

2.6.1 Liner Components

Landfill liners are so designed and constructed as to create a barrier between the waste and the environment and to drain the leachate to collection and treatment facilities. Barriers are intended to limit and control contaminants escaping from the landfills. Now a day's barrier include one or more of the components:

- Natural clayey soil and /or re-compacted clayey soil liners
- Natural bedrock
- Cut-off walls
- Artificial liners

Liner Components are as follows:

Clay : To protect the ground water from landfill contaminants, clay liners are constructed as a simple liner that is two- to five-feet thick. In composite and double liners, the compacted clay layers are usually between two- and five-feet thick, depending on the characteristics of the underlying geology and the type of liner to be installed. It is required that the clay used can only allow water to penetrate at a rate of less than 1.2 inches per year. The effectiveness of clay liners can be reduced by fractures induced by freeze-thaw cycles, drying out, and the presence of some chemicals.

In theory, one foot of clay is enough to contain the leachate. The reason for the additional clay is to safeguard the environment in the event of some loss of effectiveness in part of the clay layer. The efficiency of clay liners can be maximized by laying the clay down in four- to six-inch layers and then compacting each layer with a heavy roller.

The efficiency of clay liners is impaired if they are allowed to dry out during placement. Desiccation of the clay during construction results in cracks that reduce the liner efficiency. In addition, clays compacted at low moisture contents are less effective barriers to contaminants than clays compacted at higher moisture contents. Liners that are made of a single type of clay perform better than liners constructed using several different types.

Geomembranes: Geomembranes are also called flexible membrane liners (FML). These liners are constructed from various plastic materials, including polyvinyl chloride (PVC) and high-density polyethylene (HDPE). The preferred material for use in MSW and secure landfills is HDPE. This material is strong, resistant to most chemicals, and is considered to be impermeable to water. Therefore, HDPE minimizes the transfer of leachate from the landfill to the environment.

Geotextiles: In landfill liners, geotextiles are used to prevent the movement of small soil and refuse particles into the leachate collection layers and to protect geomembranes from punctures. These materials allow the movement of water but trap particles to reduce clogging in the leachate collection system.

Geosynthetic Clay Liner (GCL): Geosynthetic clay liners are becoming more common in landfill liner designs. These liners consist of a thin clay layer (4-6 mm) between two layers of a geotextile. These liners can be installed more quickly than traditional compacted clay liners, and the efficiency of these liners is impacted less by freeze-thaw cycles.

Geonet: A geonet is a plastic net-like drainage blanket which may be used in landfill liners in place of sand or gravel for the leachate collection layer. Sand and gravel are usually used due to cost considerations, and because geonets are more susceptible to clogging by small particles. This clogging would impair the performance of the leachate collection system. Geonets do, however, convey liquid more rapidly than sand and gravel.

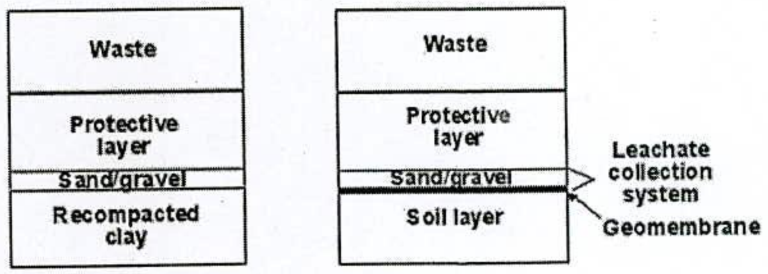
2.6.2 Liner system

Different type of liner system is required for different categories of Landfills depending on the potential threat of the waste in consideration. There are single, composite, or double liners.

Single-Liner Systems

Single liners consist of a clay liner, a geosynthetic clay liner, or a geomembrane. Single liners are sometimes used in landfills designed to hold construction and demolition debris results from building and demolition activities and includes concrete, asphalt, shingles, wood, bricks, and glass. These landfills are not constructed to contain paint, liquid tar, municipal garbage, or treated lumber; consequently, single-liner systems are usually adequate to protect the environment.

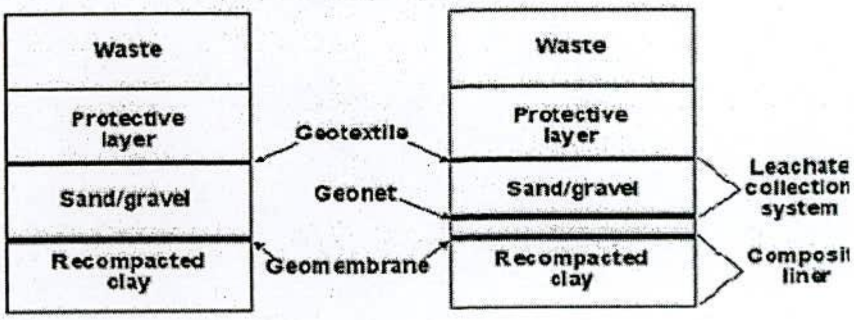
Single liner system



Composite-Liner Systems

A composite liner consists of a geomembrane in combination with a clay liner. Composite-liner systems are more effective at limiting leachate migration into the subsoil than either a clay liner or a single geomembrane layer. Composite liners are required in municipal solid waste (MSW) landfills.

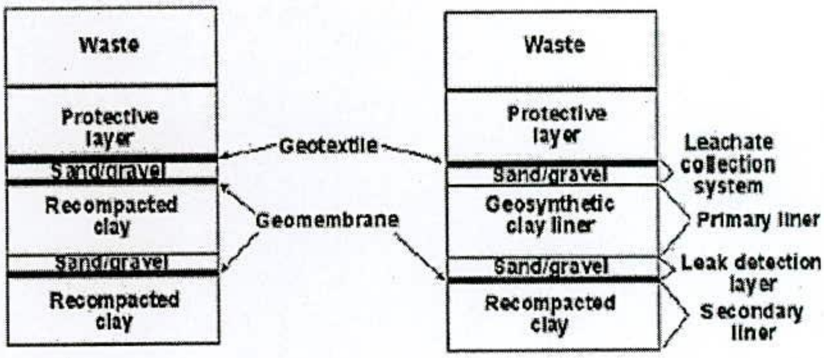
Composite liner system



Double-Liner Systems

A double liner consists of either two single liners, two composite liners, or a single and a composite liner. The upper (primary) liner usually functions to collect the leachate, while the lower (secondary) liner acts as a leak-detection system and backup to the primary liner. Double-liner systems are used in some municipal solid waste landfills and in all hazardous waste landfills.

Double liner system



2.6.3 Basic Liner Specifications

Natural soil liner are relatively impervious geologic formations such as aquitards or aquicludes. An aquitard is a geologic formation that transmit water at a very slow rate relative to aquifer whereas an aquicludes is a geologic formation which is so impervious that it completely obstruct the flow of ground water. Natural soil liner, made of native soil are having some common criteria:

1. $K = 10^{-9}$ m/s or less
2. Clay (< 20^{-60} m) content > 15 -20 %
3. Plasticity Index I_p (PI) > 7%
4. Minimum CEC of 10 meq (milliequivalants) / 100 gr.Soil
5. Leachate compatibility (no k- value increase)
6. Minimum thickness for MSW : 1.0 m, 0.6 m with geomembrane
7. Minimum thickness for industrial /toxic waste 3-4 m (15 m), alternatively Multiple Composite Liner Systems.

Table 2.8 Basic Characteristics of Liner Soils (Akter, 2007)

Type of soils	**Dry strength**	**Dilatancy**	**Plastiicity**	**Toughness**	**Remarks**
Silt	None to low	Slow to rapid	None to low	Low or thread can not be formed	Lean clay is only slightly plastic, whereas fat clay is highly plastic. Dilatancy is increased in volume when soil is compressed
Lean clay	Medium to high	None to slow	Low to medium	Medium	
Elastic silt	Low to medium	None to slow	Medium	Low to medium	
Fat clay	High to very high	None	High	High	

2.7 Engineering Parameters of Clay Lining Materials

The use of clay as lining materials is the preferential method of reducing or eliminating of percolation of leachate from landfills for its ability to adsorb and retain many of the chemical constituents and resistance to flow. If suitable earthen material is available near the site of construction, or is in-situ, a lining of compacted earth is an inexpensive and efficient means of controlling seepage. This type of lining, especially a thick compacted lining, has proved better than other types of earthen linings and has been used extensively.

2.7.1 Hydraulic Conductivity

A critical parameter of a landfill liner to isolate leachate from the subsurface environment is hydraulic conductivity. Of all the landfill liner parameters investigated by researchers, hydraulic conductivity has been received the most attention when designing and analyzing the performance of a landfill (Yanful et al. 1990, Fernandez and Quigley 1985 and Quigley et al. 1987). The hydraulic conductivity of soil generally decreases with an increasing amount of he fine grained soil. Lambe (1958) suggested that the soil with a flocculated structure (i.e. at dry of optimum moisture content) exhibits greater hydraulic conductivity than soil having an equal density and moisture content but a dispersed structure (i.e. at wet of optimum moisture content).

2.7.2 Moisture Content & Plasticity

Natural moisture content and plasticity should be carefully established as these are two key parameters in governing the ability of a soil to produce a well engineered and impermeable liner. For a given soil sample there is a unique compactive effort at which the density ceases to increase. The higher the moisture content, the lower the compactive effort beyond which no further increase in density occurs. A minimum Plasticity Index of 10% is normally required / stipulated as soils with a lower plasticity index are unlikely to achieve a sufficiently low permeability.

2.7.3 Plasticity Characteristics

Plasticity characteristics describe a material's ability to behave as a plastic or moldable material. Soils containing clay are generally categorized as plastic. Soils that do not contain clay are non-plastic and typically considered unsuitable materials for compacted clay liners, unless soil amendments such as bentonite clay are introduced. Plasticity characteristics are quantified by three parameters: liquid limit, plastic limit, and plasticity index. The liquid limit is defined as the minimum moisture content (in percent of oven-dried weight) at which a soil-water mixture can flow. The plastic limit is the minimum moisture content at which a soil can be molded. The plasticity index is defined as the liquid limit minus the plastic limit and defines the range of moisture content over which a soil exhibits plastic behavior. When soils with high plastic limits are too dry during placement, they tend to form clods, or hardened clumps, that are difficult to break down during compaction. As a result, preferential pathways can form around these clumps allowing leachate to flow through the material at a higher rate. Soil plasticity indices typically range from 10 percent to 30 percent. Soils with a plasticity index greater than 30 percent are cohesive, sticky, and difficult to work with in the field. Common testing methods for plasticity characteristics include the methods specified in ASTM D-4318, also known as Atterberg limits tests.

2.7.4 Percent Fines and Percent Gravel

Typical soil liner materials contain at least 30 percent fines and can contain up to 50 percent gravel, by weight. Common testing methods for percent fines and percent gravel are specified in ASTM D-422, also referred to as grain size distribution tests.5 Fines refer to silt and clay sized particles. Soils with less than 30 percent fines can be worked to obtain hydraulic conductivities below 1 x 10-7 cm/sec (4 x 10-8 in./sec), but use of these soils requires more careful construction practices. Gravel is defined as particles unable to pass through the openings of a Number 4 sieve, which has an opening size equal to 4.76 mm (0.2 in.). Although gravel itself has a high hydraulic conductivity, relatively large amounts of gravel, up to 50 percent by weight, can be uniformly mixed with clay materials without significantly increasing the hydraulic conductivity of the material. Clay materials fill voids created between gravel particles, thereby creating a gravel-clay mixture with a low hydraulic conductivity.

As long as the percent gravel in compacted clay mixture remains below 50 percent, creating a uniform mixture of clay and gravel, where clay can fill in gaps, is more critical than the actual gravel content of the mixture. Similar to gravel, soil particles or rock fragments also can create preferential flow paths. To help prevent the development of preferential pathways and an increased hydraulic conductivity, it is best to use soil liner materials where the soil particles and rock fragments are typically small (e.g., ¾ inches in diameter).

Table 2.9: Typical Soil Properties (Akter, 2007)

Soil Type	*Hydraulic Conductivity K (cm/s)*	*Total Porosity n (%)*	*Effective Porosity n_e (%)*	*Bulk Density d (g/cm³)*
Clayey	10^{-9} - 10^{-6}	40-60	0-5	1.2-1.8
Silty	10^{-7} - 10^{-3}	35-50	3-20	1.1-1.8
Sandy	10^{-5} - 10^{-1}	20-50	10-35	1.3-1.9
Gravelly	10^{-1} - 10^{2}	25-40	12-30	1.6-2.1

Where a compacted clay liner functions as a bottom layer to a geosynthetic, gravel can cause puncturing in geosynthetic materials. Controlling the maximum particle size and angularity of the gravel should help prevent puncturing, as well as prevent gravel from creating preferential flow paths.

2.8 Conclusion

Waste materials in landfills are so designed to make the waste isolated from surrounding environment by providing liners. Liners control or restrict the migration of pollutant from the landfill into the environment. From the above discussion it is clear the provision of bottom liner is an invariable part of modern landfills. The use of clay as a barrier or liner in order to retard the leachate has become very popular throughout the World in recent years. The low hydraulic conductivity of compacted clayey soils combined with their availability and relatively low cost makes them potential materials to use as liners in landfills for environmental protection. It is difficult to identify or categorize the contribution made by each process of contaminant transport. The well-known factors to be considered in contaminant risk assessment are the source, pathway, and receptor or target.

CHAPTER THREE

DESIGN OF BASE LINER IN A PILOT SCALE SANITARY LANDFILL

3.1 General

Proper design is vital to the successful operation of a landfill disposal facility in even the most suitable location. All technological alternatives which meet requirements of the proposed landfill should be reviewed prior to incorporation into the design. The design should produce a landfill capable of accepting given solid waste materials for disposal. To serve as a basis for design, the types and quantities of all refuse expected to be disposed of at the landfill should be determined by survey and analysis.

3.2 PotentialStudy of the Site

The feasibility study of PSSL site is summarized the findings from an investigation of several factors are discussed herein including advantages and costs.

i) Ownership/Acquisition: The present ownership of the property is KCC which is the Local Government Authority as a single owner, rather than multiple.

ii) Zoning: The site is within an area that is currently zoned by the local government for this type of land use.

iii) Road Access: It is easily accessible from a main highway and has an access road that is presently maintained year-round.

iv) Topography: The topography of the site is suitable for the efficiency of the cut and fill operations as well as equipment movement at the landfill.

v) Site Capacity: The capacity of PSSL is estimated for one year based on the site's size, shape, and topography.

vi) Soils: Deep deposits of clay soils are ideal for a landfill site.

vii) Depth to Groundwater: As the depth to groundwater is increased, the probability that the groundwater quality will be contaminated by leachate will be decreased.

viii) Proximity to Wells: The landfill site is over 500 meters up gradient of water supply wells.

ix) Surface Water: The site is more than 300 meters away from a stream, but allows closer distances with engineering measures.

x) Flood Hazard: The site is located outside of a 100-year floodplain.

xi) Airport Safety: The landfill site will must not pose a bird hazard to aircraft.

xii) Holocene Fault: The landfill site is located more than 100 meters from a fault that has experienced displacement during the present Holocene Epoch.

xiii) Seismic Impact Zone: The siting of a landfill will not occur in a seismic impact zone.

xiv) Site Stability: The stability of site is considered in the site evaluation. It has no slope stability problems, no expansive soils, or no subsurface instabilities.

xv) Run-on/Run-off Controls: Both run-on and run-off will be controlled.

xvi) Landfill Gas Control: The potential for landfill gas to migrate off the site and the impacts of the gas migration is considered.

xvii) Land Use: The site will located at Rajbandh where residential, industrial, or recreational land uses are improbable.

xviii) Agricultural Land: The site has with little agricultural value that will be viewed more favorably.

xix) Habitat Value: The site is ideal because landfill development will have little or no impact on wildlife or plant habitat.

xx) Visual Impacts: It is preferable that landfill operations will be kept out of view from present or future residences near the site.

xxi) Downwind Impacts: The impact to residences downwind will be minimized by siting the landfill further upwind of residences.

3.3 Site Characteristics

3.3.1 Location and Site Selection

It was decided by the WasteSafe II Team member to select a site in the ultimate disposal site (UDS) of KCC at Rajbandh for the construction of PSSL. In the Rajbandh, there are two sites used as UDS by KCC as crude open dumping of solid waste generated in the Khulna city, one is known as 'Old Rajbandh' and the other is 'New Rajbandh'. The Old Rajbandh having an area of 20 acres is located about 8km far from the city centre i.e. 'Royal-Castle Salam Square' of Khulna city and situated along the North-side of Khulna-Satkhira highway as shown in Figure 3.1. The New Rajbandh the second UDS site of MSW of KCC, having an area of 5 acres is just 700m west from the Old Rajbandh. KCC started to dump waste in Old Rajbandh in 1977. Later, KCC acquire this land for UDS and later converted to Children Park.

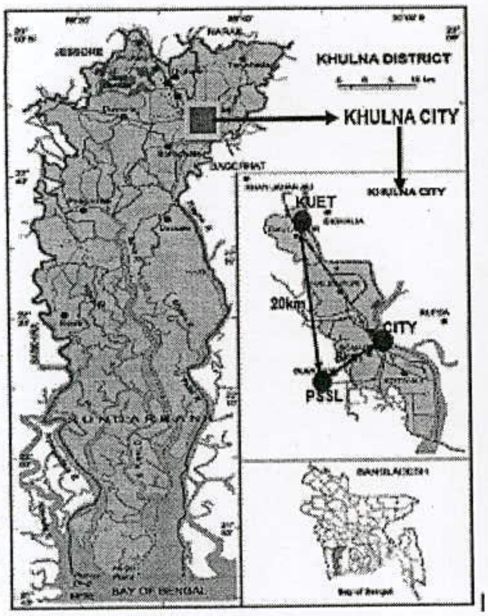


Figure 3.1 Location of PSSL with respect of Khulna city map.

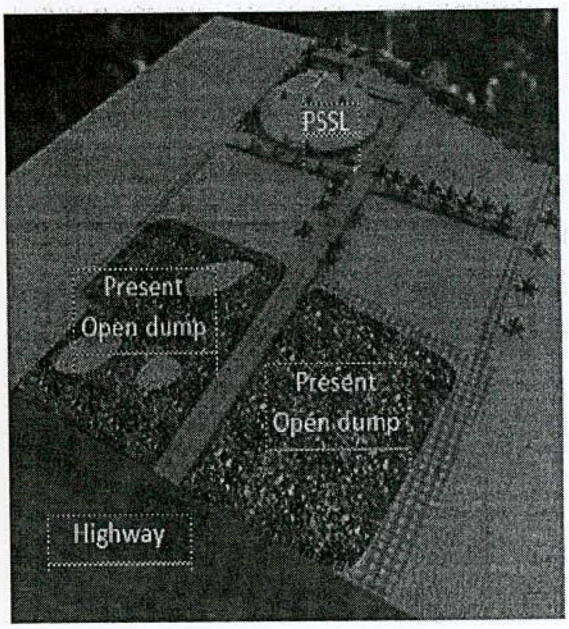


Figure 3.2 Layout of the PSSL at new Rajbandh.

The New Rajbandh consists of 5 cells (shallow depth pond) surrounded by earthen embankment, where paddy plantation and fish cultivation were continued till the waste deposition started. However, still it has significant capacity to accommodate the solid waste. Despite the Old Rajbandh filled-up partially with solid wastes, KCC started to dump wastes in the New Rajbandh since January 2007 and first two cell cells along the

Khulna-Satkhira Highway were started to fill as shown in Figure 3.2. The site of the PSSL is located at the north-west corner with an area of 1.1acres. This location for PSSL was selected based on the series of site visit and the discussion with KCC team members. Since, the wastes deposition as open dumping was already started in the first two cells (Shallow ponds), the last corner was selected to avoid all the possible interferences due to open dumping. The corner pond is surrounded by earthen embankment and located at distance of 122m from the Khulna-Satkhira Road. The ground surface of the site 1m below the top of the surrounding earthen embankment and site has the dimension of 52x64x85x55m.There is a public natural stream in the North side and private paddy land in the west.

3.3.2 Topography of the Site

The site is not a deep valley with a gentle slope. A small stream channel of about 8 m wide, flows beside the site from east to west and joins Dumuria River at about 1.5 km in the down stream. The valley, with undulating terrain present depths of 10 to 15 m (appx.) respectively, at two different locations. It is evident that the performance of all the Geo-environmental structures such as landfill liners, covers, impoundments of vertical barriers, settlement and side stability depends mainly on the sub-soil conditions and the basic characteristics of the soils. The geotechnical characteristics of the sub-soils were determined in the laboratory using conventional test methods after collecting the soil samples through a sub-soil exploration by wash boring method up to a depth of 15m. The three boreholes were executed and the values of soil parameters were evaluated. The existing ground surface exists at a depth of 1m from the road level, while the ground water table is encountered at a depth of 2m as shown in the sub-soil strata presented in Figure 3.3.

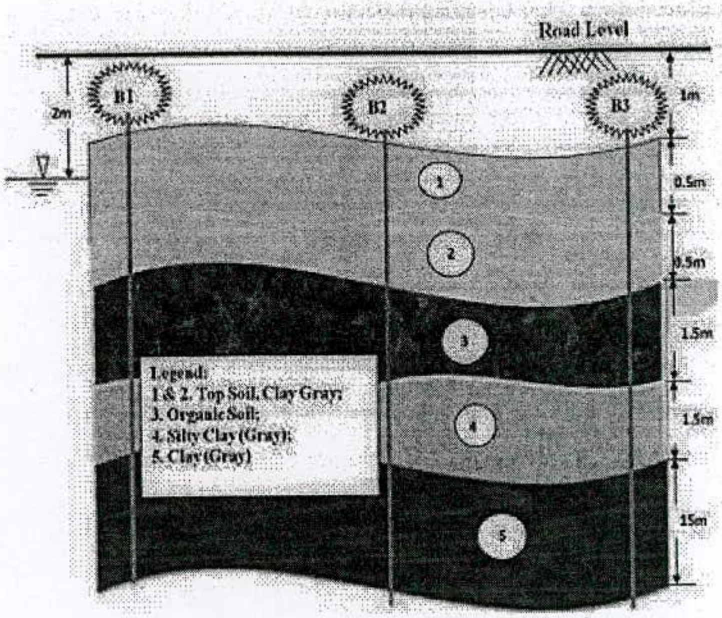


Figure 3.3 Sub-soil strata of the site of PSSL at Rajbandh, Khulna

3.3.3 Subsoil Investigation

The sub-soil investigation was carried out at the Pilot Scale Sanitary Landfill site to identify the soil strata, physical and engineering properties. Boring to a depth of 17m revealed that the gray clay minerals with organic forms to a depth of 1.5m followed by silty clay having clay minerals content ranges from 23 to 30% and hydraulic conductivity varies from 2.45×10^{-6} to 2.5×10^{-8} cm/sec at different molding water content. Swelling clay minerals are present in varying the amount of 0 to 11% of the composition. The soil quality analysis at the proposed site shows that the soil is acidic with pH ranging from 4.42 to 5.50 and the soil density ranges from 1.1 to 1.4 gm / cc. The geotechnical properties of the Rajbandh landfill site is shown in Table 3.1.

Table 3.1 Geotechnical properties of the landfill site (Akhter, 2007)

Depth (m)	Liquid limit W_L (%)	Plastic limit PL (%)	Plasticity index IP (%)	Hydraulic conductivity ($x10^{-5}$ cm/s)	Void ratio e_0	Porosity n (%)	Specific Gravity ,Gs	Dry Density (kN/m^3)
0-1	51.20	31.80	19.40	0.217	1.026	50.64	2.72	16.9
1-2	55.06	48.09	6.97	0.481	1.303	56.58	2.72	14.93
2-3	54.43	29.29	25.14	0.252	2.229	69.03	2.72	10.68
3-4	88.23	31.46	56.77	0.728	5.464	84.53	2.25	4.4
4-5	53.21	31.78	21.43	1.34	0.901	47.40	2.15	14.3
5-6	112.88	70.49	42.39	1.01	3.804	79.20	2.15	5.66
6-7	47.05	31.31	15.73	0.622	1.079	51.90	2.74	16.66
8-9	25.40	13.90	66.40	0.20	1.091	52.18	2.73	16.5
9-10	41.40	24.39	17.01	0.994	0.939	48.43	2.70	17.6
10-11	41.81	32.63	8.77	0.8	--	--	--	--

3.3.4 Mineralogical Composition of Clay

The mineralogical composition of clay which to be used as CCL is one of the most deciding factors. The mineralogical composition of clay collected from the depth of 0 to 0.6m (Sample I) and 1.2 to 2.0m (Sample II) are shown in Table 3.2 as measured in the laboratory of the department of Applied Geology, Karlsruhe University, Germany (Roehl, 2007). The samples collected from the site was shifted to Germany and their mineralogical composition was analyzed using the X-ray Diffraction Equipment. From the result, it is observed that the clay minerals account for more than two-thirds of the mineralogical composition. The amount of swelling clay minerals is as high as 20% dominated by highly-swelling smectite. In the non-swelling clay minerals, the amount of illite is very high and found as 50%, while kaolinite is around 10% with insignificant amount of chlorite. In general, fine-grained sediments in Bangladesh appear to constitute a valuable material for geological and technical barrier for landfill. The mineralogical findings of the clay collected from New Rajbandh site have proved such postulation.

Table 3.2 The mineralogical composition of the PSSL site (Roehl 2007)

Major type	*Name of the Minerals*	*Minerals (by % of weight)*	
		Sample I (0 to 0.6m)	*Sample II (1.2 to 2.0m)*
Non-clay minerals	Quartz	19	17
	Feldspars	< 1	< 1
	Carbonates	< 1	< 1
Non-Swelling clay minerals	Illite	~50	~50
	Kaolinite	~10	~10
	Chlorite	1	1-1
Swelling clay minerals	Smectite	20	19

3.4 Environmental Parameters

3.4.1 Meteorological Conditions

Bangladesh is called the land of six seasons. It has a tropical climate because of its geological location. The Bangla calendar year is traditionally divided into six seasons. Each season on average two months lasting, some seasons merge into another seasons, while others are short. More broadly, Bangladesh has three distinct seasons such as the hot and dry pre-monsoon season, from March to May; the rainy season, from June to October, the cool and dry winterseason, from November to February.Rainfall which takes place during this time accounts for 10 to 25% of the annual total. This rainfall is caused by thunderstorms. This rainy season coincides with the summer monsoon. Rainfall of thisseason accounts for 70 to 85% of the annual total.The maximum rainfall is recorded in July and August as shown in Table3.3. There is a hydrograph shape of rainfall in Khulan region which start fromApril to November as shown in Figure 3.4. This is caused by the tropical depression that enters the country from the Bay of Bengal.In regard to the study of meteorological condition of the PSSL siteTable 3.3shows for five years precipitation data from 2004 to 2008 and up to August in 2009.The seasons of Bangladesh regulate its economy, communications, trade and commerce, art and culture and, in fact, the entire lifestyle of the people. The influence of the tropical monsoon climate is clearly evident in Bangladesh during the rainyseason. April& Mayare usually the hottest month in the country caries low humidity as shown in Table 3.4.

Wind direction changes from time to time in this season, especially during its early part. January is the coldest month in Bangladesh. However, the cold winter air that moves into the country from the northwestern part of India loses much of its intensity by the time it reaches the northwestern corner of the country.

Table 3.3 Monthly Average Precipitation from 2004 to 2009 in Khulna

(Khulna Weather Station, 2009)

Month	Precipitation (mm) in Year					
	2004	2005	2006	2007	2008	2009
January	000	015	000	000	067	001
February	000	000	000	054	036	006
March	007	148	005	014	048	010
April	085	047	019	092	036	023
May	180	215	246	119	151	137
June	383	103	262	392	187	233
July	253	435	522	591	301	347
August	266	194	371	160	203	570
September	621	363	603	397	379	
October	182	420	105	198	187	
November	000	000	004	113	000	
December	000	000	000	000	000	
Total	1977	1940	**2137**	2130	1595	
Average	165	162	178	177.5	132.91	

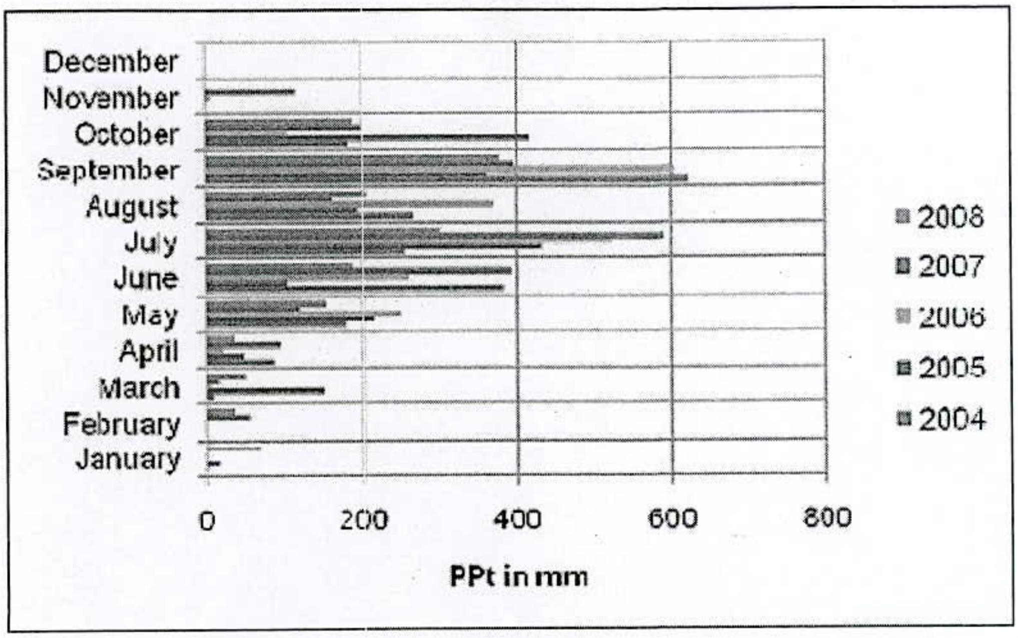


Figure 3.4 Distribution of precipitation over the year (2004 to 2008)

Average temperature in January varies from 13 to 25^{0}C in this region of the country. The minimum temperature in the Khulna City in late December and early January can be as low as 12^{0}C to 14^{0}C as shown in Table 3.5.As the winter season progresses into the pre-monsoon hot season, temperatures rise, reaching the maximum in April, which is the middle of the pre-monsoon hot season. Average temperatures in April vary from about 25^{0}C to 35^{0}C. After April, the temperature decreases slightly during the summer months, which coincides with the rainy season. Average temperatures in July vary from about 26^{0}C 6 to 32^{0}C (Weather Station, Khulna 2008).

Table 3.4 Monthly mean humidity from 2006 to 2008 (all units are in %)(Khulna Weather Station, 2008)

Year	January	February	March	April	May	June	July	August	September	October	November	December
2006	77	74	69	71	77	84	87	87	86	84	80	79
2007	78	77	70	75	78	82	87	84	91	89	86	80
2008	80	74	77	74	75	81	89	86	86	84	79	85

Table 3.5 Monthly Temperature data from 2004 to 2008(Khulna Weather Station, 2008)

Year	2004		2005		2006		2007		2008		Average	
Month	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max**	**Min**
January	23.8	13.2	25.2	13.5	25.9	12.8	24.9	12.3	25.1	13.8	25	13.1
February	27.8	14.8	30	17.3	31.8	18.8	27.6	16.9	26.8	15.3	28.8	16.6
March	33	21.9	32.6	22.1	33.3	21.1	30.2	19.9	32.3	22.4	32.3	21.5
April	33.9	25	34.9	25.2	35	24.9	34.1	25.5	35	24.5	34.6	25
May	35.8	26.2	35.1	25.3	34.5	25.7	34.8	26.2	35.9	25.3	35.2	25.7
June	33.2	26.2	34.9	27.3	33.6	26.9	33.6	26.2	32.7	26.2	33.6	26.6
July	32.1	26.4	31.5	26.3	32.4	26.4	30.9	26.7	31.5	26.3	31.7	26.4
August	32.6	26.3	32.4	26.9	32.2	26	32.2	27.1	32.4	26.6	32.4	26.6
September	31.9	26.6	32.7	26.3	32.4	26.1	31.4	26.6	32.8	26.2	32.2	26.4
October	30.8	24.2	30.8	24.6	32.4	24.9	31	24.4	31.8	23.8	31.4	24.4
November	29.8	18.4	29	18.9	29.6	20.1	29.1	20.5	29.6	19.6	29.4	19.5
December	27.2	15.8	26.8	15.1	26.9	15	25.7	14.4	26.1	16.4	26.5	15.3

3.4.2 Air and Surface Water Quality

There is natural air in the site and the other pollutants like Respirable Particulate Matter (RPM), SO_2 andNO_2 are well within the permissible limits. A small channel of 8 m width originates beside the proposed landfill site and tangent through the site beforejoining the nearby River Kya flowing at about 3 km in the down stream. The residents ofvillage and other people utilize the stream water for domestic uses, fishing and cattlewashing.Critical parameters such as total dissolved solids (1560 mg/l), BOD (20 mg/l), COD (335mg/l), Total Coliforms (>600 per 100 ml), Lead (0.001 mg/l) and Cadmium (0.01 mg/l)were all found to be above the permissible limits.Further in the down stream, the quality of water in the River at the point ofconfluence of the stream indicates no significant levels of pollution. However, Coliformswere found in the samples, which indicate organic pollution in the river body.

3.4.3 Ground Water Hydrology and Quality

The geology of the proposed site is characterized as tropical weathered and organic aquifer and the depth of water table ranges from 2 m to 3 m. The quality of ground water in the project area (based on sample analysis beside the proposed site) indicates the presence of iron, chloride and traces ofheavy metals. The downstream ground water is however acidic in nature (pH of about 6.3).

3.4.4 Ecological Environment

Coconut plantations are the predominant types of vegetation found at the proposed landfill site. The ecological inventory of the site indicated no endangered species at the proposed site. There are approximately various species of vascular plants belonging to the botanical families, of which about major species represent Angiosperms and some species represent Pteridophytes. Poaceae, Leguminosae, Asteraceae, Moraceae, Euphorbiaceae, Rubiaceae, Amaranthaceae, Apocynaceae, Malvaceae, Arecaceae, Labiatae, and Verbenaceae are the top 10 families in the order of dominance. With regards to fauna, four species of amphibians, ten species of reptiles, seven species of mammals, ten species of birds and many species of insects can be found at the site and its influence area.

3.5 Health and Safety

The design has produced a pilot scale sanitary landfill which does not threaten the health and safety of nearby inhabitants and which in general precludes the following:

a. Pollution of surface and ground-waters from landfill generated leachate.

b. Air pollution from dust or smoke.

c. Infestation by rats, flies or other vermin.

d. Other nuisance factors such as odors and noise.

e. Fires and combustion of refuse materials.

f. Explosive hazards from methane gas generated within the landfill.

3.6 Volume Minimization

Reducing the need for a landfill should be a priority for all installations. The type and extent of compaction should be considered in design to reduce landfill volume. Recycling and other methods of reducing landfill volume are discussed elsewhere in this report.

3.7 Conceptual Designs of Landfill Components

In the cities of Least Developed Asian Countries (LDACs), city authorities have been facing the challenges to run a sustainable integrated management of municipal solid waste (MSW). The challenges have become unattainable despite the huge demand from the city dwellers due to poor governmental policy and response, lack of political will, inadequate economic and human resources, weak local institutions and the absence of appropriate management system. As a result the generated MSW remains unmanaged and unsafe and poised serious threat to human health and nature. In a consequence, the environmental sustainability in most of the cities of LDACs could not be achieved. Due to very high population density in the cities of Bangladesh and huge gap between the existing and the appropriate systems of MSW management, in the recent time waste management becomes one of the most striking environmental issues which need to address properly.

In the existing MSW management of Bangladesh, no engineering approach is followed for the ultimate disposal of waste. Crude open dumping of all types of solid waste in low-lying areas is the common practiced. However, recently the relevant stakeholders including city authority have realized the need of the construction of engineered landfill to replace the open dump. In Bangladesh, except Matuail Engineered Landfill at Dhaka in which the open dumping was converted engineered landfill with help of JICA (Japan International Cooperation Agency), there is no experience of the construction, daily operation and performance evaluation of sanitary landfill. In the footsteps, a pilot scale sanitary landfill have been constructing in Khulna Bangladesh as part of research project, WasteSafe II, at Khulna University of engineering & technology, Bangladesh co-financed by EU-Asia Pro Eco II Programme of the European Commission. In the main aim of this field research work is to establish the landfill standard for Bangladesh condition.

To this endeavor, a Pilot Scale Sanitary Landfill (PSSL) was designed and hence constructed at New Rajbandh, Khulna (Alamgir et al. 2008, Alamgir and Islam 2009). A simple version of sanitary landfill was design ensuring minimum basic technical requirements. In the design emphasis has been given to use the locally available construction techniques, equipments and building materials. In earth excavation, construction of various components of the landfill such as approach road, site office, base liner and leachate collection system, leachate holding tank, leachate treatment pond etc. the above principle was fully accomplished (WasteSafe II 2007 and 2008). Moreover, in every phase of PSSL construction such as material processing, maintaining of slope, placement, remolding and compaction work of earth, manual labors were used where female participant was viewed a focus because 70% of labors were female. In every steps of construction, closing monitoring was given to ensure the quality control of the works. During the daily operation, composition and quatity of MSW, the amount and quality of leachate generated from MSW have been recorded. A small scale leachate treatment system has also been cintroduced in the site to identify the suitable technique. It is expected that the PSSL will be closed at the middle of 2009 and the post closure monitoring will be conducted accordingly.

Despite a PSSL, this is the second experience in Bangladesh after the Matuail's one (Ahmed 2008), where the Dhaka City Corporation has been developing an engineered landfill in semi aerobic method by converting the existing open dumping site. In case of PSSL, it is observed that using of locally available construction materials, methods and manual labor intensively, the landfill can be constructed successfully with major necessary components such as base liner, leachate detection and collection system, ground water monitoring well and the small scale leachate treatment installation. Experiments have also been conducting to see the performance of CCL used in base liner and the small scale leachate treatment facilities. The field experience acquired in the construction of this PSSL depict that sanitary landfill in full scale can be constructed using local building materials and present technological capabilities by satisfying the first hand technical requirements. Moreover, this attempt will build the confidence among the local consultants, engineers and authorities to go ahead with full scale replication of the employed technique to build a sanitary landfill with accomplishment of necessary modification.

3.7.1 Capacity of PSSL

The land available at the Rajbandh site for development of the landfill is approximately 5 acres and one acre of land is accepted for PSSL site. The foot print of the site is shown in figure 3.5.With 40 ton of trash to fill daily, the life of the landfill has been estimated at 6 months. The landfill area has been divided into 3 parts as indicated figure 3.6 below:

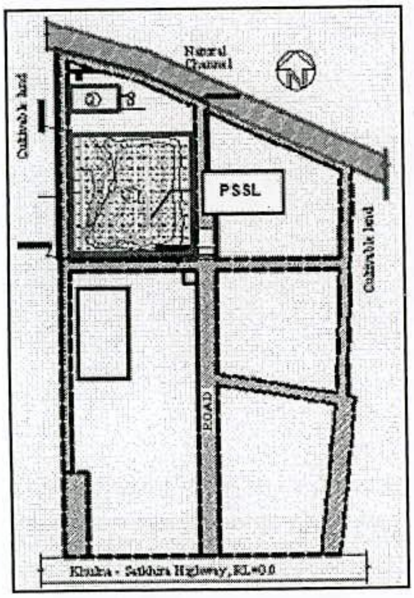


Figure 3.5 Foot print of the site

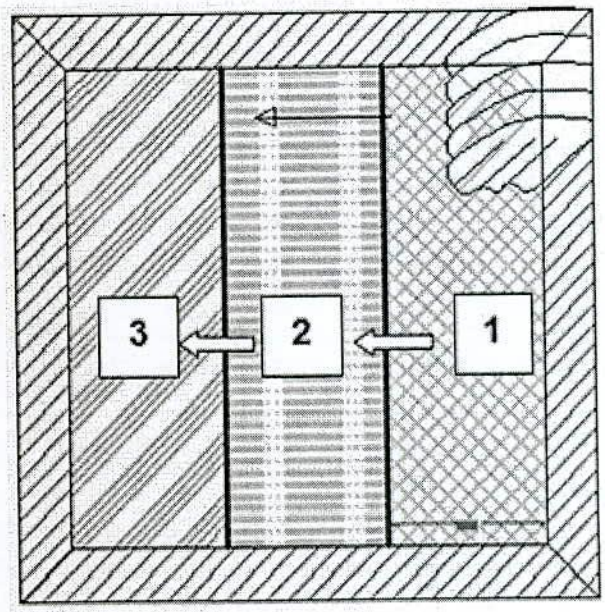


Figure 3.6 Parts of landfill

3.7.2 Design of CCL

Subsurface disposal of waste materials has long been a key element in waste management. In modern solid waste management, many countries still consider landfilling as the preferred means of disposing waste materials because it is generally the cheapest way of eliminating refuse compared with other methods such as incineration and composting (Lemaet. Al. 1988). The critical issue pertaining to waste containment facilities (i.e., landfills) is usually groundwater pollution and emission of Green House Gases. The use of some type of liner on the bottom and sides of landfills that contain solid wastes has been considered necessary in many countries since the late 1970s. This necessity is created by the liquids in the landfilled materials, augmented by rainfall and snowmelt, interacting with the waste and forming liquid called "leachate" (Daniel &Keorner 2007). Use of Compacted Clay Liner (CCL) is the most important element of a liner of a sanitary landfill. The main requirements of liners are the minimization of pollutant migration, high adsorption capacity and retardation of pollutants, resistance to chemicals and low swelling and shrinkage potential (Brandl 1992). Clay and clay minerals play an important role in increasing containment removal capacity as well as in reducing hydraulic conductivity of soil because of their large specific surface area and high Cation Exchange Capacity (CEC) (Oweis&Khera 1998; Czurda& Cranston 1991).

Low-permeability compacted soil liners, also referred to as CCLs are the historic engineered component used in landfills. Clay-rich soil is placed in layers and compacted with heavy equipment to form a barrier of movement of liquids and gases. The soil liner is typically designed to have a hydraulic conductivity ≤lx10-7 cm/s. The origin of this design criterion is unclear; 1x10-7 cm/s was evidently selected on the assumption that this was an achievable value that would result in negligibly small seepage through the liner (Daniel &Keorner 2007). The low hydraulic conductivity of clay minerals makes them potential materials to use as CCLs in sanitary landfill for environmental protection. The attenuation positively charged chemical species in leachate through a clay liner is a function of CEC of the liner material. Higher CEC of a clay liner material will result in greater amount of cationic containments being removed from the leachate (Kayabali 1997);Rowe et. al.(1995) recommended that soils with a minimum CEC of about 10 meq/100g of soil might be specified for clay liner. Soils classified as inorganic clay with high plasticity (CH) is considered as the suitable material for landfill liner (Oweis&Khera 1998). If natural available clay or clayey soil is not suitable for liner, kaolinite or commercially available high swelling clay (Bentonite) can be mixed with local soils or sand. In Bangladesh these materials are not locally available and would have to be imported from elsewhere and could significantly increase the cost of construction (Alamgir et. al. 2005a).

There is no controlled/engineered /sanitary landfill in Bangladesh. Only the Dhaka city has a partial landfill to dispose the waste with the help of JICA. The ultimate waste disposal sites are situated in and around the city areas of low-laying open spaces, unclaimed land, riverbanks and roadsides (Alamgir et. al. 2005b). This research aims to study the relevant properties of Khulna clay, for potential use as a CCL for the construction of sanitary landfill sites. Typical tests that are generally used to investigate soil minerals proposed as CCL such as Atterberg limits, hydraulic conductivity at different water content as shown in figure 3.8, standard proctor test were conducted on samples of Khulna clay collected from an active ultimate disposal sites of MSW, namely, Rajbandh at Khulna city. The test results reveal that the subsoil properties, which should be considered as a potentially suitable material for the compacted clay liner of sanitary landfill.

Materials and Method

The material used for this study is Khulna clay soil obtained from the vicinity of Rajbandh ultimate disposal site, about 8km far from the city center. Wash boring method was executed upto a depth of 17m to collect the required soil samples. The soil samples were transported to the geotechnical laboratory of Khulna University of Engineering & Technology, Bangladesh to conduct the necessary tests.

The basic tests such as specific gravity, particle size distribution and Atterberg limits of the soil were performed according to British Standard (BS 1377:1990). The data of these index properties were used to classify the soil in the Unified Soil Classification System. The hydraulic conductivity of collected soil samples were measured using rigid wall permeameter under falling head condition.The tap water was used as permanent liquid and permeation was conducted on the samples until steady condition were achieved. Standard

Proctor compaction test was performed of the soil samples at different molding water content and then the hydraulic conductivity of that samples were observed simultaneously. The compaction test is used to determine for Khulna clay to see that (1) whether the soil was at the proper water content for compaction and (2) whether the soil has received adequate compactive effort.

Determination of Compaction Behaviors

The behavior of studied soils compaction was established in the laboratory by preparing several batches of soil at different molding water contents and then compacting the materials from each of the batches into the molds of known volume. Hence, Standard Proctor Test was used. Total unit weight of each compacted specimen by weighing the compacted specimen and dividing the total weight by total volume. The water content (w) of each compacted specimen is determined by oven drying the specimen. To prepare a compaction curve, maximum dry density points for the samples prepared over a range of water contents are plotted and a smooth curve is drawn between the points. Great care was taken to follow the procedures for soil preparation outlined in the relevant test method.

The maximum dry density or dry unit weight occurs at optimum water content. The main reason for developing a compaction curve is to determine the optimum water content, maximum dry density and compaction procedure for Khulna clay. Compaction test also help the quality control assurance personnel to determine (1) whether the soil is in the state of proper water content for compaction and (2) whether the soil has received adequate compactive effort. The zero air void line was drawn for Khulna clay also that relates dry unit weight to water content for a saturated soil that contains no air. If the specific gravity of soils change, zero-air-void line also changes. For the designated Khulna clay it is observed that no points lie above the zero air void line.

Physical Properties

The performance of all the Geo-environmental structures such as landfill liners, covers, impoundments of vertical barriers depends mainly on the basic characteristics of the soils. To this endeavor, the plasticity characteristics of the studied soils were determined in the laboratory using conventional test methods. The evaluated index properties of the designated Khulna soils are listed in Table 3.6.

Table 3.6: Index Properties of Khulna soils

Depth (m)	Liquid limit (%)	Plastic limit (%)	Plasticity Index (%)
0-2	53	33	20
2-4	71	30	41
4-6	61	37	24
6-8	36	22	14
8-10	41	28	13

The plasticity of a soil refers to its capability to behave as a plastic and moldable material. Soils that contain clay are usually behave as plastic materials. Based on the above data, the Khulna clay soil is classified as plastic soil from 1.5 to 10m. Plastic clay is a typical suitable material for sanitary landfill liner. Soils with high liquid limit generally have low hydraulic conductivity. The soil with plasticity index as low as approximately 10% can be compacted to achieve a hydraulic conductivity≤1x10-7 cm/s (Daniel &Koerner 2007). Binson et al. (1994) recommended that the liquid limit of the liner material be at least 20%.Literatures suggest that the plasticity index must be more than 7% (Daniel 1993;Benson et al. 1994;Rowe et al. 1995).

The plasticity index is an important phenomenon for the selection of soil of CCL because it is the key property in achieving low hydraulic conductivity. Soil with high plasticity index (>30%) tend to form hard clods when dried and sticky clods when wet (Daniel &Koerner 2007). Very high plastic soil becomes sticky when wet results difficult to work in the field. Also high plastic soil forms hard lumps when they are dried and difficult to break down during compaction and preprocessing work. For plasticity index value greater than 35, excessive shrinkage can be expected (Daniel 1991). The grain size distribution curve of CCLas shown in figure 3.7 reveal the fact that the soil is almost silt and clay.

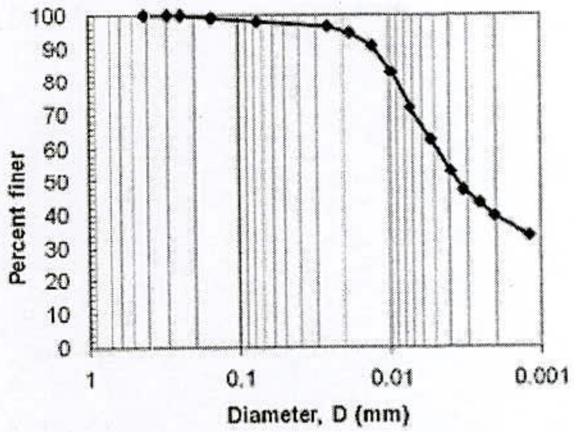


Figure 3.7 Grain size distribution curve of CCL

Hydraulic Conductivity at Different Molding Water Content

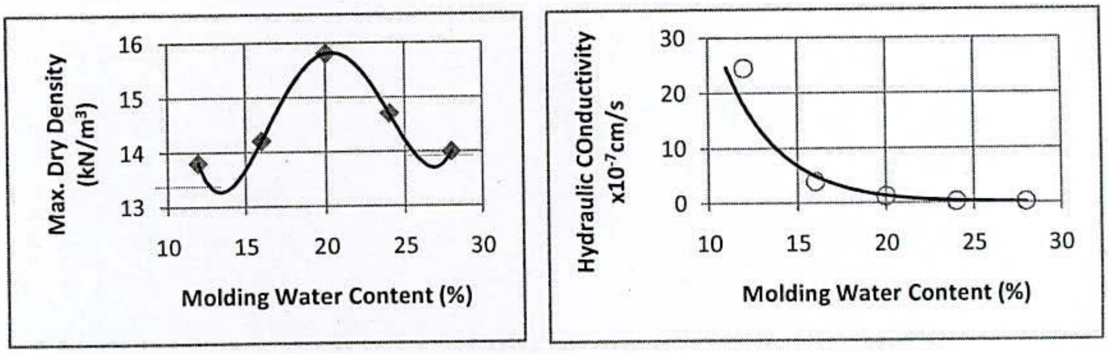


Figure 3.8 Effect of molding water content on hydraulic conductivity for Khulna clay.

Hydraulic conductivity is very much related with molding water content. For natural soils, the water content of the clay liner material at the time of compaction is perhaps the singly most important variable that controls the engineering properties of the compacted material. Soil compacted at water contents less than optimum tend to have relatively high hydraulic conductivity; soil compacted at water contents greater than optimum tend to have a low hydraulic conductivity and low strength. In general, if the water content is greater than the plastic limit, the soil is in a plastic state and should be capable of being remolded into a low hydraulic conductivity material. Soils with water contents dry of the plastic limit will exhibit little plasticity and may be difficult to compact into a low hydraulic conductivity mass without delivering enormous compactive energy to the soil (Daniel &Koerner 2007). Hydraulic conductivity is a main indicator of CCL for the construction of landfill. Liner soil should have at least 30% fines and 15% clay to achieve hydraulic conductivity in the range of 1x10-7cm/s (Daniel 1993b; Benson et al.1994). Hence Khulna clay can be used for natural barrier to achieve a hydraulic conductivity in the range of 1x10-7 cm/s, as it possesses suitable amount of clay and fine fractions. But the soil must not be placed at too high water content, it results low shear strength and may be great risk of desiccation cracks forming if the soil dries, and ruts may form when construction vehicles pass over the liner. The hydraulic conductivity for different molding water contents that are obtained in the present study is shown in Table 3.7.

Table 3.7 Hydraulic conductivity and Molding Water Content of Khulna clay

Molding Water content (%)	Hydraulic conductivity(k) x 10-7 cm/s
12	24.5
16	3.9
20	1.3
24	0.25
28	0.15

The water content of CCL material at the time of compaction is the most important variable that controls the engineering properties of the compacted material. The typical relationship between hydraulic conductivity and molding water content is shown in figure 3.8. For Khulna soils, it is shown that soils compacted at water content less than optimum tend to have a relatively high hydraulic conductivity: soils compacted at water contents greater than optimum tend to have a low hydraulic conductivity.

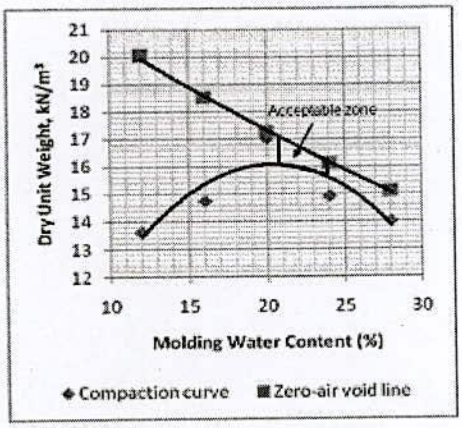


Figure 3.9 Water Content-Dry Unit Weight Specification for Khulna clay.

Identification of Acceptable Zone

Determination of water content and dry unit weight of the soil liner immediately after compaction is one of the most important aspects in case of quality control assurance for design engineer. Design engineer often require that soil liners be compacted within a specified range of water content and to a minimum dry unit weight. The acceptable zone shown in Figure 3.9 represents the zone of acceptable water content-dry unit weight combinations for Khulna clay.

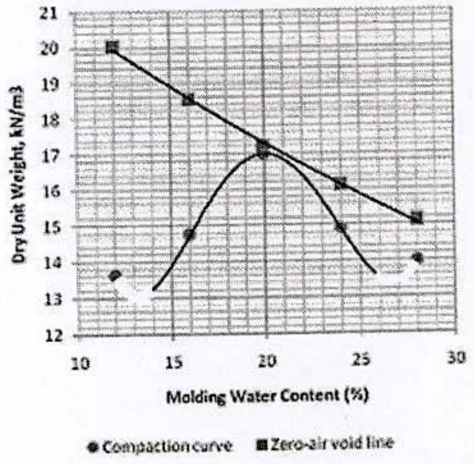


Figure 3.10(a) Development of compaction curve.

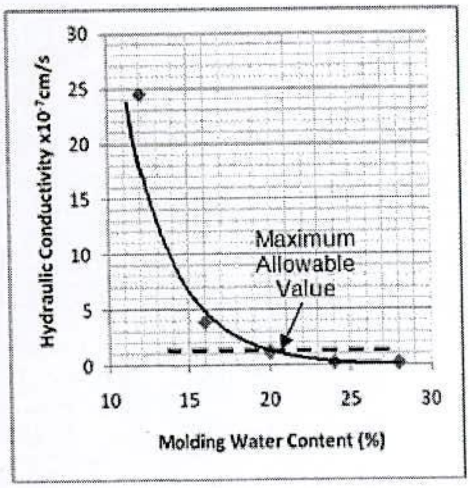


Figure 3.10(b) Hydraulic Conductivity with a function of Molding Water Content.

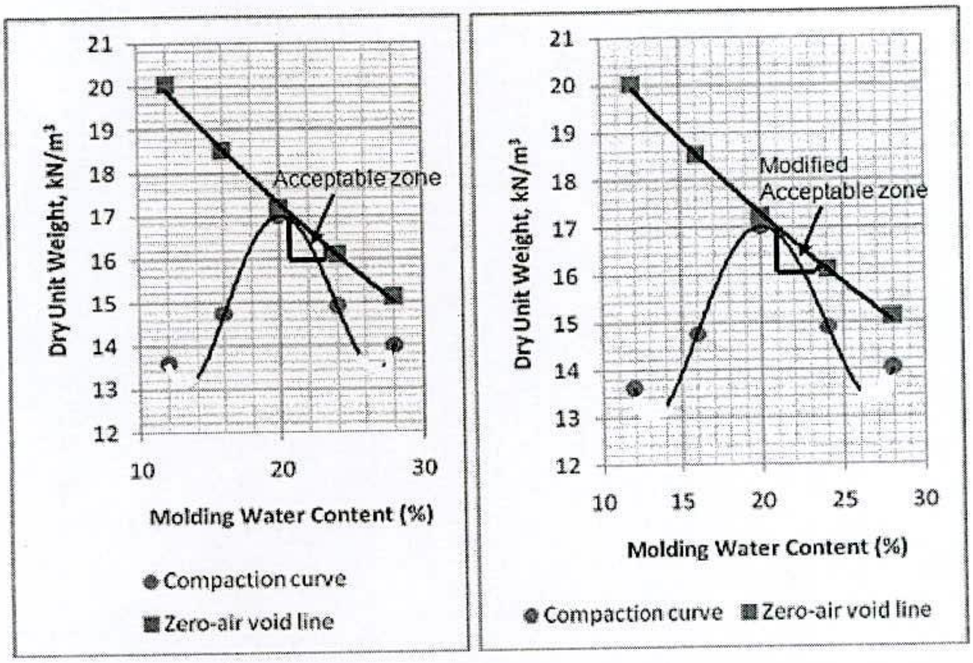


Figure 3.10(c) Acceptable Zone Zone

Figure 3.10(d) Modified Acceptable

Figure 3.10Determination of Acceptable Zone of Water Content-Dry Unit Weight Values Based on Hydraulic Conductivity Consideration for Khulna Clay.

The shape of acceptable zone as shown in Figure 3.9 empirically from construction practices applied to roadway bases, structural fills, embankments and earthen dams. As discussed by Mundell and Bailey (1985), Boutwell and Hedges (1989), and Daniel and Besson (1990), this method of specifying water content and dry unit weight is not necessarily the best method for compacted soil liners.

The recommended approach is intended to ensure that the soil liner will be compacted to a water content and dry unit weight that will lead to low hydraulic conductivity and adequate engineering performance with respect to other consideration such as shear strength. Modified Proctor effort represents a reasonable upper limit on the compactive effort likely to be delivered to the soil in the field. Standard Proctor compaction effort represents a medium compactive effort. The recommended approach for Khulna clay for medium effort is as follows:

Developing the compaction curves as shown in figure 3.10(a) by preparing and compacting soil in the laboratory over a range of water content with modified, standard and reduce compaction procedures.

The measured hydraulic conductivity is then plotted with a function of molding water content as shown in figure 3.10(b).

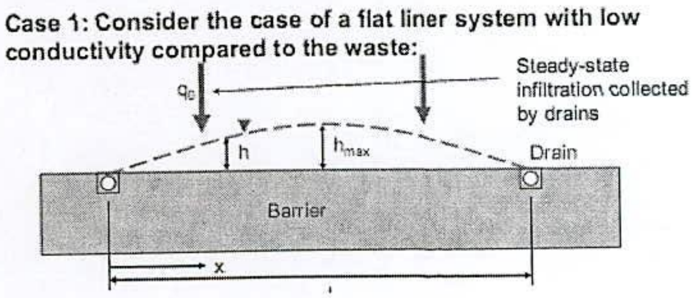
As shown in Figure 3.10(c), the dry unit weight-water content points should be repotted to represent compacted specimens that had hydraulic conductivities greater than the maximum acceptable value and specimens with hydraulic conductivities less than of equal to the maximum acceptable value. An acceptable zone is drawn to encompass the data points representing test results meeting or exceeding the design criteria.

The acceptable zone is modified based on other consideration such as shear strength that satisfies hydraulic conductivity is shown in Figure 3.10(d).

3.7.3 Design of Leachate Collection Layer

Leachate Collection System (LCL) is a typical component of most modern landfills. These system commonly comprises perforated leachate leachate collection pipe at regular spacing in a continuous blanket of granular material. The primary function of leachate collection system is to control the leachate head acting on the liner system. This involves the collection of leachate. Controlling of leachate head minimizes the advective transport of contaminants through the liner system and also controls side slope leachate breakouts.

Leachate Mounding



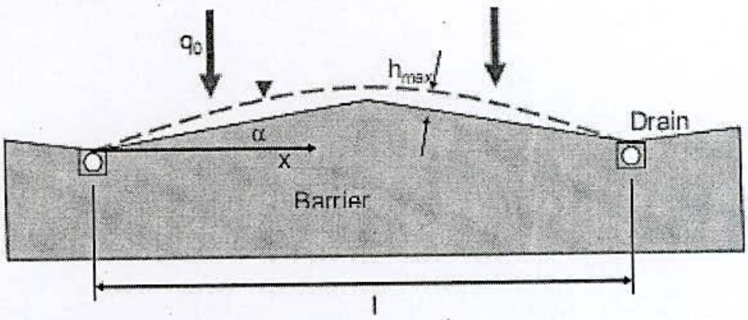
Following Harr (1962) the leachate height h can be calculated as:

$$h = \Omega^{\frac{1}{2}}\left[(l-x)x\right]^{\frac{1}{2}} \quad \text{where } \Omega = \frac{q}{k_w} \text{ and for } x = \frac{l}{2}$$

Maximum height of leachate can be calculated as:

$$h_{max} = 0.5l\Omega^{\frac{1}{2}} \qquad \bar{h} = 0.785h_{max}$$

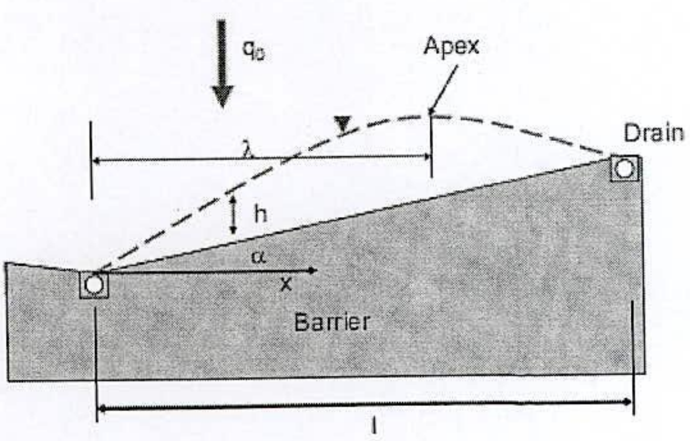
Case 2: Consider the case of a liner system with sloping geometry and a low conductivity compared to the waste:



The maximum height of of mounding above the barriers is given as:

$$h_{max} = 0.5l\left[\left(\Omega + s^2\right)^{\frac{1}{2}} - s\right] \quad \text{where} \quad \Omega = \frac{q}{k_w} \text{ and } s = \tan\alpha$$

Case 3: Practical questionable case.



All above ca: :aulic conductivity compared to · : equations are not valid and it becomes necessary to estimate the entire flow regime using numerical techniques

Design Considerations:

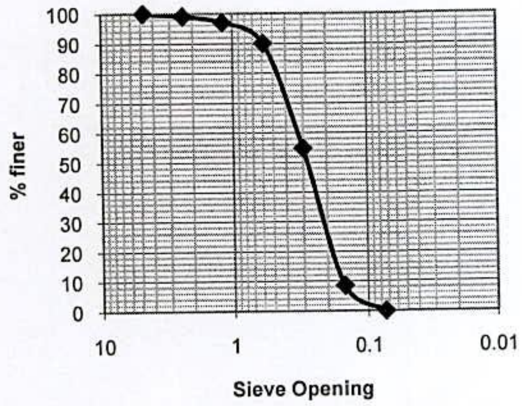


Figure 3.11 Grain size distribution curve of LCL

Based on grain size distribution curve of LCL as shown in Figure 3.11 there is sufficient knowledge on quantities of leachate production available to estimate q. One must not expect that q is varying in orders of magnitude.However, the hydraulic conductivity of the waste must be also estimated and there is a limited number of field measurements available. In practice it is considered to be in the order of 10^{-6} m/s. Due to the nature of waste (heterogeneous, anisotropic) conductivity is expected to vary. Design must consider this uncertainty.

Example:

Consider the case with $\alpha = 0$, $l = 25$, $k_w = 10^{-6}$ m/s and $q = 0.20$ m/a.

This lead to a mounding of leachate of 1.00 m. Doubling the leachate production in the landfill, which is conservative, results in a leachate mounding of 1.40 m, i.e. an increase of 40%.

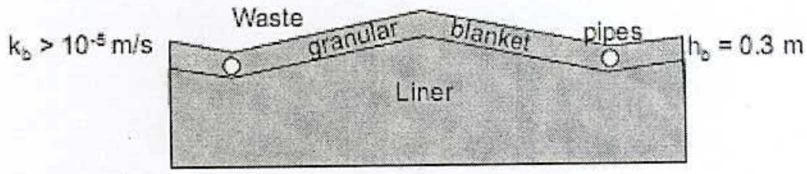
For the same basic case, but taking the hydraulic conductivity as 10^{-7} m/s, which is in a realistic order, leads to a maximum height of leachate of 3.15m, i.e. an increase of more than 200%.

It is evident, that substantial mounds of leachate can develop. To reduce these mounds and hence head on liner, spacing of pipes can be decreased or increasing the slopes between drains

In our case for $k_w = 10^{-6}$ m/s spacing of 7.5 m is required to achieve a reasonable, nominal leachate height of 0.3 m.

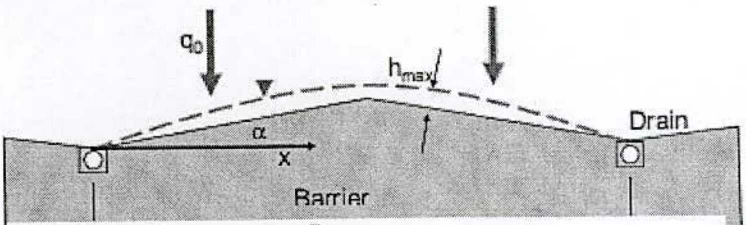
To allow a hydraulic conductivity of $k_w = 10^{-7}$ m/s a spacing of less than 2.4 m is required. Using the same example, but increasing the slope between the drains, requires slopes of 0.12 for $k_w = 10^{-6}$ m/s, and 1.27 (52 degrees) for $k_w = 10^{-7}$ m/s. These results clearly indicate that both options are not realistic.

A granular (sand) blanket is introduced, which significantly increases the hydraulic conductivity above the barrier:



Recall: Consider the case of a liner system with sloping geometry and a low conductivity compared to the waste:

The maximum h



$$h_{max} = 0.5l\left[\left(\Omega + s^2\right)^{\frac{1}{2}} - s\right] \text{ where } \Omega = \frac{q}{k_w} \text{ and } s = \tan\alpha$$

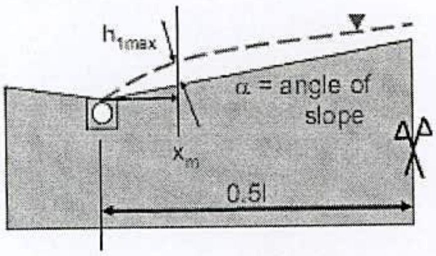
This is valid for very small slope angles and for $\Omega < 0.01$.
q = infiltration rate collected by drains.

k_w = conductivity of waste (or filter material)

Primary Leachate Collection System Design

The amount of liquid in a LCS at a certain time can be expressed by the thickness of liquid on the liner or head on liner.

The thickness h is used because it can already be compared to the (required) thickness of the LCS, since we assume $k_w = k_{LCS}$. At a certain distance x_m the maximum height of leachate h_{1max} occurs.



The value of x_m depends on a parameter λ, which is defined as: $\lambda = \frac{q}{k_{LCS1} \tan^2 \alpha}$

$x_m/0.5l < 0.2$, i.e. the maximum head on liner occurs close to the drain (for $\lambda < 0.15$, which is frequent)

3.8 Base Liner of Pilot Scale Landfill

The two most important components of the PSSL are the baseliner and top cover. Analysis and Design of the PSSL was completed by WasteSafe Team members by December 2007 guided by field experiences, local condition and project provision while fixing up the dimensions and materials specification of the various components of the landfill. The waste streams and the materials availability were considered. Emphasis was also given to ensure the use of locally available building materials. It is decided to follow the standard landfill operation system with local perspectives will be followed during the construction, waste deposition and operation, and monitoring phases. Post closure monitoring will be conducted till the end of the project, which will be continued by KUET till the active period of the landfill.

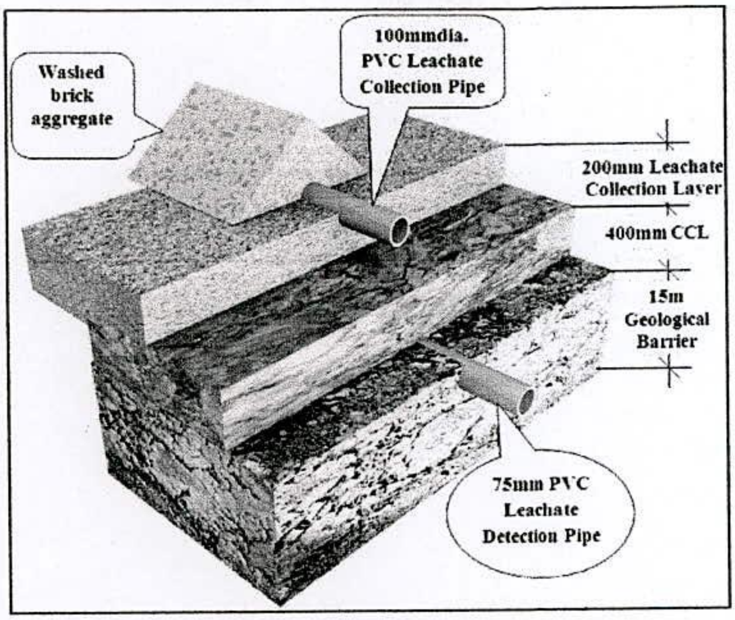


Figure 3.12 Base liner system of PSSL.

In this PSSL, the base liner includes a leak detection sump system, 15m geological barrier of clayey soil, compacted clay liner (CCL), leachate collection pipe system with a leachate collection layer. It is designed considering hydrological data of the site, the size of landfill, suitability of construction and locally available of material as shown in Figure 3.12. The CCL is 400mm thick just above the geological barrier, over which 200mm thick sand layer as drainage layer. Leachate collection pipe is placed in the drainage layer.

3.9 Cross Section of Pilot Scale Landfill

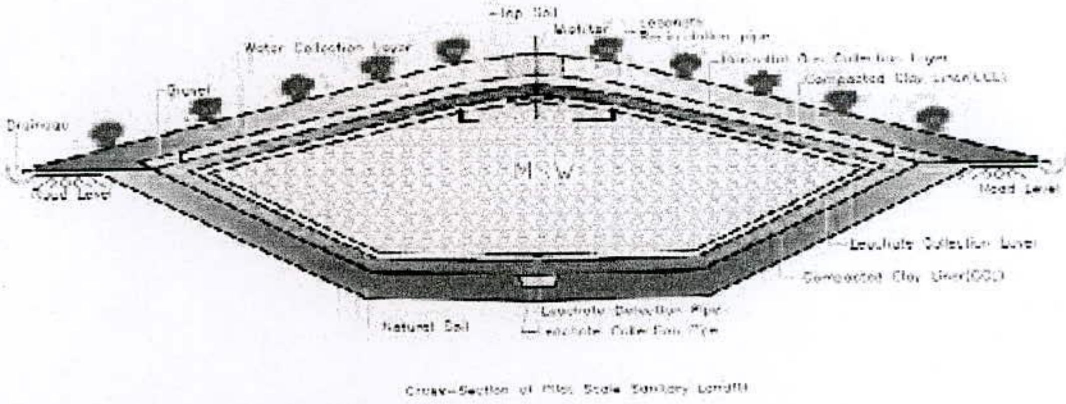


Figure 3.13 Schematic diagram of the containment of pilot scale sanitary landfill

In the experimental study, the size of containment is control by several physical and technical factors. The factors can be listed as: (i) land availability, (ii) time frame of the study, (iii) fund, (iv) technical capacity, (v) daily waste streams, etc. Considering the above mentioned aspect, the team decided to construct a waste containment is 50x50x6m, which is 3m below and 3m above the ground surface with a side slope of 26°, which gently maintained a horizontal distance of 4.25m and following a mild slope till the middle of the cell. The schematic diagram is presented in Figure 3.13. In the top cover, to control possible soil erosion, two slopes are introduced, at the edge a slope of 15° from the edge to the half of the top.

CHAPTER FOUR

CONSTRUCTION AND MONITORING OF BASE LINER

4.1 Introduction

The Pilot Scale Sanitary Landfill has constructed and being operated to establish landfill construction technology in Bangladesh. Locally available construction techniques, equipments and building materials were used for the excavation of earth, construction of various components of the landfill such as approach road, site office, base liner and leachate collection system, leachate holding tank, leachate treatment tank etc. In every phase of PSSL construction such as material processing, maintaining slope, placement, remolding and compaction work manual labors are used where female participant was viewed a focus because 70% of labors were female. The deposition of waste has been monitoring and other necessary aspects have been controlling to ensure the quality management of daily operation. In spite of a pilot scale sanitary landfill, this is the second experience of the construction of sanitary landfill in Bangladesh. It is observed that using locally available construction materials and methods using manual labor intensively, the sanitary landfill can be constructed successfully with necessary components such as compacted clay liner, leachate detection and collection system. This small scale but real experience using indigenous method will provide confidence to the city authority and the concerned stakeholders about landfill technology in the contrast of presently practicing crude open dumping.

This PSSL is the first of this kind of construction in Bangladesh. The construction works have been conducted based on the design ensuring close monitoring by the project engineer. Another important aspect is that the locally available construction techniques, equipments and building materials were used for the earth excavation, construction of various components of

Figure 4.1 Layout and preparation of site to start construction

4.4 Earth Excavation

The main volume of works is the excavation of earth for the construction of landfill cell till the required depth. The ground surface was existed at the depth of 1m from the road level. Firstly, it was decided that the excavation will be conducted mechanically using the excavator, however, the non-availability of the machine, the alternate option came into mind. Moreover, due to the existence of very soft soil and the size of the land, it was decided to conduct the excavation works using manual labour and traditional digging tools as shown in the Figure 4.2. Daily about 50 to 100 people works at the site and nearly 70% of the work force were female. The excavation of earth was completed successfully maintaining proper slope of the cell as per the design and specification. Very close monitoring was conducted by the project engineer for the proper execution of the works. During the execution of the earth excavation, the soil from the top 2m, which seems to be suitable for the preparation of CCL, were collected with care and deposited in the middle of cell as well as on the bank, those were used later. During excavation, soils were also placed properly in the north side and south-west corner for the construction of the earth embankment surrounding the cell. Initially, it was thought that manual work might not be suitable for such sophisticated works, however, finally it was proved that, this kind of work at small scale can be done properly within reasonable timeframe if proper level of monitoring can be ensured. However, such works will not be suitable in the monsoon season.

Figure 4.2 Manual excavation of earth using traditional digging tools

4.5 Reservation technique of Compacted Clay Liner Material

Figure 4.3 Stock pile of appropriate and its spreading to prepare CCL

The low hydraulic conductivity of clay minerals makes them potential materials to use as CCLs in sanitary landfill for environmental protection. The attenuation positively charged chemical species in leachate through a clay liner is a function of CEC of the liner material. Higher CEC of a clay liner material will result in greater amount of cationic containments being removed from the leachate (Kayabali 1997); Rowe et. al. (1995) recommended that soils with a minimum CEC of about 10 meq/100g of soil might be specified for clay liner. Soils classified as inorganic clay with high plasticity (CH) is considered as the suitable material for landfill liner (Oweis & Khera 1998). The clay liner is typically designed to have a hydraulic conductivity $\leq 1x10^{-7}$cm/s. The origin of this design criterion is unclear; $1x10^{-7}$cm/s was evidently selected on the assumption that this was an achievable value that would result in negligibly small seepage through the liner. In the PSSL, the clayey soils collected from the depth of 0 to 2m of the site, were used for the construction of CCL as the test results revealed the suitability of the clay. The stock pile of clay used to construct CCL and later its spreading over the bed for compaction are shown in Figure 4.3.

4.6 Compacted Clay Liner (CCL)

Compacted Clay Liner is a hydraulic barrier for water retention and waste containment facilities. It contains a single compacted clay layer of 400mm thickness. The properties of CCL in the pilot scale sanitary landfill as shown in Table 4.1

Table 4.1 Properties of clay liner of the pilot scale landfill

Characteristic	Compacted Clay Liner(CCL)
Materials	Natural mineral materials, native soils
Construction	Constructed in the field
Thickness	400mm
Hydraulic conductivity	$< 10^{-7}$ cm/s
Water content at the time of construction	Nearly saturated so that can desiccate and produce consolidation water.

4.6.1 Quality Control Assurance

- To ensure that the liner materials are suitable.
- To ensure that the liner materials are properly placed and compacted.
- To ensure that the completed liner is properly protected.

4.6.2 Liner Requirements

- The sub grade on which the CCL is placed should be properly prepared.
- The materials used in constructing the CCL should be suitable and should confirm to the plans and specifications for the project.
- The liner materials should be preprocessed to adjust the water content, to remove oversized particles, to break down clods of soil, or to add amendments such as bentonite.
- The soil should be placed in lifts of appropriate thickness and then properly remolded and compacted.
- The completed CCL should be protected from damage caused by desiccation or freezing temperatures.
- The final surface of the CCL should be properly prepared to support the next layer that is placed on top of the soil liner.

4.6.3 Sub-Grade Preparation

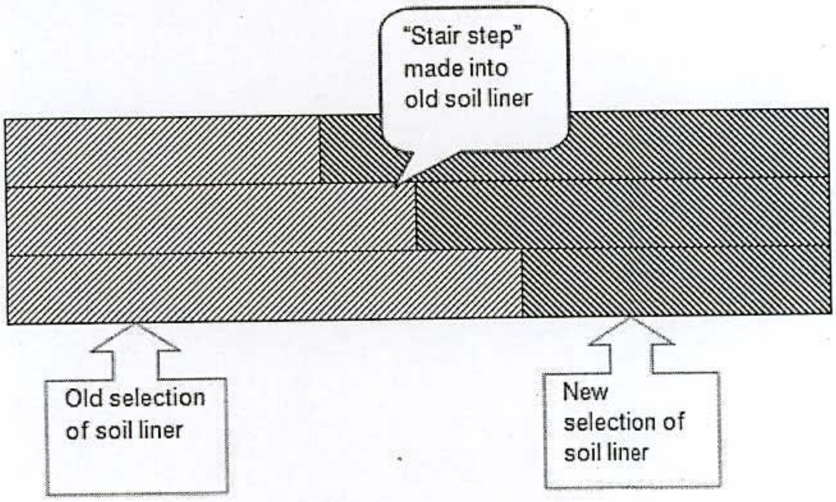


Figure 4.4 Tie-In of new soil liner to existing soil liner

The sub-grade on which a clay liner is placed should be properly prepared, that is, it should have adequate support for compaction and be free from mass movements. The CCL will be placed on a natural material which is the lowest component of the liner system, native soil is compacted to eliminate soft spots. Water should be added or removed as necessary to produce a suitably firm subgrade per specification requirements.

Sometimes it is necessary to "tie in" a new section of soil liner to an old one (e.g., even a landfill is being expanded laterally). In such cases, a lateral excavation should be made about 2 to 5 m into the existing section of CCL and the existing CCL should be stair-stepped as shown in Figure 4.4 below. The surface of each of the steps in the old liner should be scarified (roughened) to maximize bonding between the new and old sections.

4.6.4 Material Selection

Clay liner materials ate selected so that a low hydraulic conductivity will be produced after the soil is remolded and compacted. The process of selecting construction materials and verifying the suitability of materials are follows:

A potential borrow source (if needed) is located and explored to determine the vertical and lateral extent of the source and to obtain representative samples, which are tested for properties such as liquid limit, plastic limit, and percent fines. The borrow source should also be checked for the presence of deleterious materials such as roots, organic matter and debris.

Once construction begins, additional quality control assurance observation and tests may be performed in the borrow pit to confirm the suitability of materials being removed.

After a lift of soil has been placed CQA tests should be performed for final verification of the suitability of the materials.

4.6.5 Preprocessing of Material

Some soil liner materials require processing before use. Preprocessing steps that may be required include drying of soil that is too wet, wetting of soil that is too dry, removal of oversized particles, pulverization of clods of soil, homogenization of soil and addition of bentonite. The degree of processing can affect the performance of the CCL. The more extensive the soil processing and the longer the period of time allowed for the wetted soil to hydrate, the lower the hydraulic conductivity.

Placement, Remolding and Compaction

The soil liner material should first be placed in a loose lift of appropriate thickness. If a loose lift is too thick, adequate compactive energy may not be delivered to the bottom of a lift. The specifications should state the maximum thickness of a loose lift, compacted lift or both. The type and weight of compaction equipment can have an important influence on the hydraulic conductivity of the constructed liner.

4.6.6 Protection

The completed CCL should be protected from damage caused by desiccation of freezing temperatures. Each completed lift of the soul liner as well as the completed liner, should be protected.

4.6.7 Final Surface Preparation

The surface of the liner should be properly compacted and smoothed to serve as a foundation for an overlying component of a liner or cover system. Verification of final surface preparation is an important part of the CQA process.

4.7 Preparation of Compacted Clay Liner

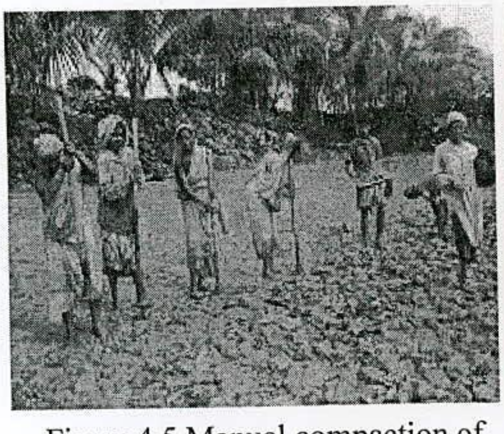


Figure 4.5 Manual compaction of clay to prepare CCL of the PSSL

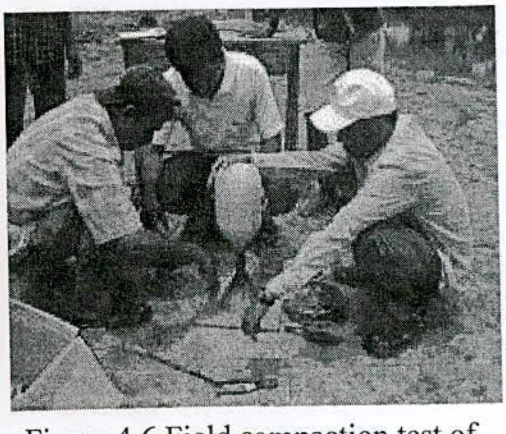


Figure 4.6 Field compaction test of the prepared CCL of the PSSL

The compaction of soil was done manually in three layers by using locally manufactured hammer made of cast iron connected with timber handle. The clay were placed uniformly over the bed and then compacted by adding required amount of water as shown in Figure 4.5. To ensure uniformity of compaction, a locally practiced technique is maintained while applying the hammer drop by a group of female worker. The thickness of the layer was maintained in such a way that the resultant thickness of the CCL reached as 400mm. The degree of compaction of the CCL was checked in the field by sand cone test method as shown in Figure 4.6, usually used as field compaction test. Initially, it was planned to prepare the CCL by using Sheep foot or smooth wheeled roller, however, due to the soften nature of soils; later compaction was done using manual intensive practice and equipments. However, finally a very impressive CCL was constructed with locally available technology and equipments without heavy machineries and skilled people as shown in Figure 4.7.

4.8 Leachate Detection Pipe System

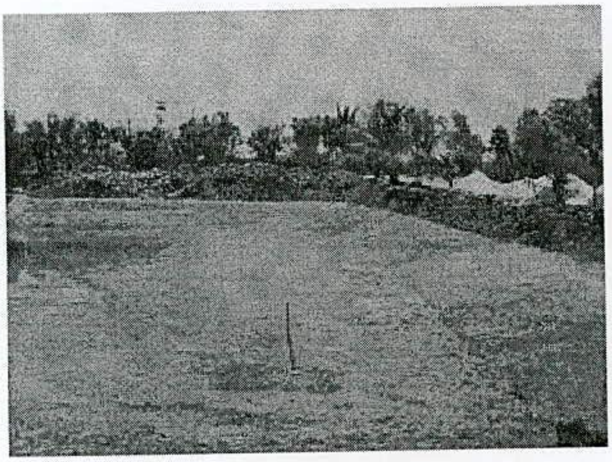


Figure 4.7 Complete bed of CCL

Figure 4.8 construction of leachate detection pipe system

To depict the applicability of simple liner system and the functionality of CCL, leachate was collected through a leachate detection pipe placed just below the CCL. A long trench of 0.75mx0.75m starting from the center point of the cell till the leachate storage tank was dug in the bed of natural soil barrier of the landfill site to accommodate the pipe. A No. 10 perforated

PVC filter pipe of 38mm in diameter used as leachate detection pipe system was placed in the trench which was surrounded by 150mm thick layer of granular soil to ensure free drainage of detected leachate. To ensure the gravity flow of the collected leachate, 1% slope towards the sump was maintained as shown in Figure 4.8. A vertical pipe having larger diameter is connected with the outlet end of the pipe, which is just at the inner surface of the tank, so that the leachate can be collected and the flow can be measured by removing leachate from the top. In all these works, local materials and traditional techniques were used and the performance so far is found quiet satisfactory.

4.9 Leachate Collection System

Figure 4.9 jointing of leachate collection pipe in the field

Figure 4.10 Preparation of bed to place leachate collection pipe

Leachate Collection System (LCS) is considered as one of the most important components of sanitary landfill. The system commonly comprises perforated pipe at regular spacing in a continuous blanket of granular material to collect leachate. The primary function of leachate collection system is to control the leachate head acting on the liner system. Controlling of leachate head minimizes the advective transport of contaminants and also controls side slope leachate breakouts. Lowering height of leachate mounding, leachate seeps can be minimized. Leachate pressure head on liner gets reduced, hence gradient through liner gets reduced resulting flow reduction through liner. Finally, removing contaminants from the landfill reduces the available amount contaminants for transport.

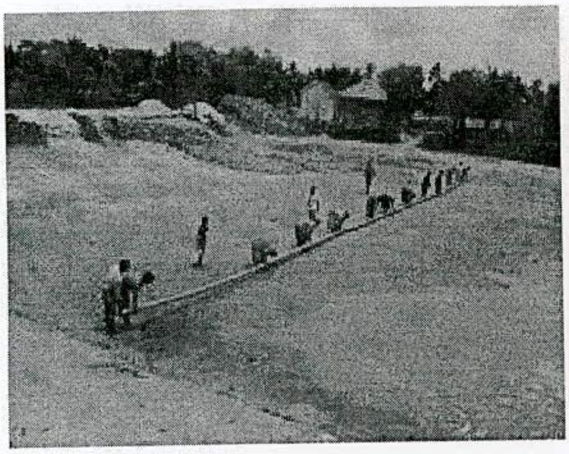


Figure 4.11 Placement of leachate collection pipe at bed

Figure 4.12 Leachate collection pipe with brick aggregates as filter media

To collect the leachate through gravity the bed was constructed maintaining a 3° slope and the leachate collection pipe is placed at the middle of the cell. The leachate collection layer of 200mm thick was construction to accommodate a perforated leachate collection pipe with 100mm dia. and surrounded by washed brick aggregates as shown in the Figures 4.9-4.12. The collection was laid maintaining a slope of 3° towards the leachate holding tank to ensure the easy movement of leachate through gravity flow as mounded on the leachate collection pipe. A Leachate holding tank of 2x2x4m size was constructed with brick masonry and properly connected with both the leachate collection and detection pipes.

4.10 Ground Water Monitoring Well

Three monitoring wells are designed as shown in Figure 4.13 and placed to define groundwater flow and water quality below the surface of pilot scale sanitary landfill. Locking protective steel net is placed over the well and secured in a concrete surface seal to protect the well. A distinctive, readily visible marker is attached to the well for easy location. A vent hole is located near the top of the protective casing to prevent explosive gas buildup and to allow water levels to respond naturally to barometric pressure changes. The well cap is also vented by loose fitting. A drain hole is drilled at the base of the protective casing to prevent water buildup. The protective casing is filled with gravel. The concrete surface seal is extended below the existing ground level, at least three feet across and sloped to drain water away from the borehole of the well.

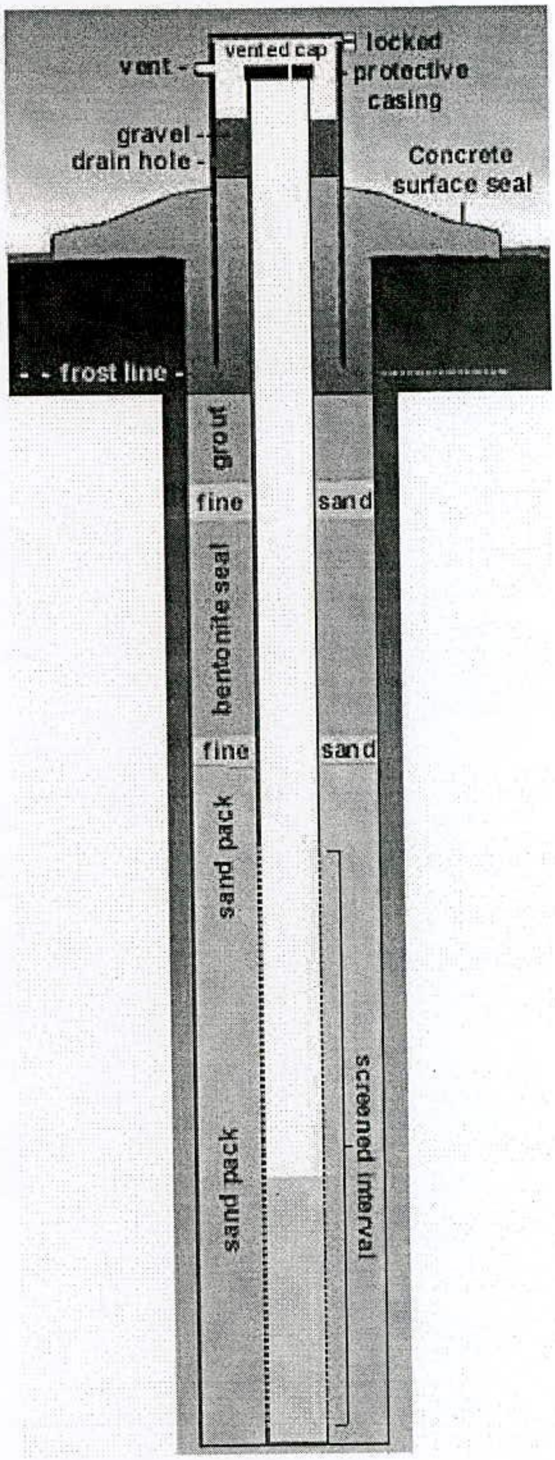


Figure 4.13 Cross-section of monitoring well (not in scale)

Well screens are slotted plastic pipes and the slot size of the screen was smaller than the surrounding sand pack. The sand pack acts as a filter. The screen length is dependent on the horizon to be monitored, but is less than 20 feet. The sand pack surrounding the well screen was clean, inert, siliceous material. The grain size is based on the grain size of the material the wells is drilled into and minimizes the amount of fine materials entering the well without inhibiting the inflow of groundwater. The sand pack was placed in the annular space around the well screen and extended two feet (or 20 percent of the screen length whichever is greater) above the top, and six inches below the bottom, of the screen. A finer grained sand pack material six inches thick was placed at the top of the sand pack between the sand and the concrete seal. Concrete was placed above the sand pack to form a seal at least three feet thick and a six to 12 inch fine grained sand pack was placed above the concrete seal to minimize grout infiltration. Grout of cement (low permeability material) completely fills the remaining annular space to the surface seal. The Figure 4.14 shows the construction of monitoring well in the pilot scale sanitary landfill.

Figure 4.14 Construction of monitoring well in the pilot scale sanitary landfill

4.11 Construction Costs

Details of construction costs are given in Annex D.

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Introduction

Base liner for landfills and contaminated sites has a variety of tasks. Usually they prevent the direct uptake of contaminants by organisms, control gas fluxes and reduce the infiltration of rainfall and snowmelt. The design of liner depends on several factors such as the climatic conditions of the site, the geotechnical properties and the environmental risks of the contaminated area, the planned use of the site, and costs. Sites to be used for industrial purposes are sealed by the layers of asphaltic concrete. The service life of a liner usually is long compared to most other engineered constructions. It varies from several decades to hundreds of years. Though there is a lot of practical experience with the design and construction of base liners, little is known of their practical performance. Unlike base liners of landfills, covers are exposed to a variety of environmental stresses (e.g. erosion, heat, frost, desiccation, biological turbation, transport and precipitation of colloids, hydroxides, carbonates) in addition to the impact of the waste body (gas and gas condensate, contaminated liquids, subsidence). Therefore it is hard to predict the long-term performance of a base liner on the basis of theoretical considerations and laboratory data. For this reason a team of researchers and technicians has set up and operated several in situ test facilities during the last one years to study and monitor the performance of CCL. This study gives a brief overview of the most important results. The field performance of CCL is found satisfactory to that 400mm thick which is examined by measuring the quantity of leakage rate per unit area in liters per day and comparing the physical and chemical properties of leakage water with leachate.

5.2 Overview of Pilot Scale Sanitary Landfill

A suitable location for the construct of PSSL has been selected. The overview of the site, location, sub-soil conditions and the nature of solid waste to be deposited in the PSSL are discussed here in the following sections. It was decided by the WasteSafe II Team member to select a site in the ultimate disposal site (UDS) of KCC at Rajbandh for the construction of PSSL. In the Rajbandh, there are two sites used as UDS by KCC as crude open dumping of solid waste generated in the Khulna city, one is known as 'Old Rajbandh' and the other is 'New Rajbandh'. The Old Rajbandh having an area of 20 acres is located about 8km far from the city centre i.e. 'Royal-Castle Salam Square' of Khulna city and situated along

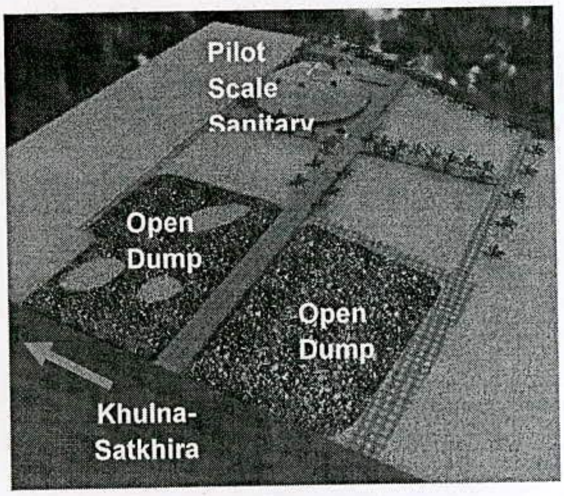


Figure 5.1. Layout of PSSL at New Rajbandh

the North-side of Khulna-Satkhira highway. The New Rajbandh the second UDS site of MSW of KCC, having an area of 5 acres is just 700m west from the Old Rajbandh. KCC started to dump waste in Old Rajbandh in 1977. Later, KCC acquire this land for UDS and later converted to Children Park.

The New Rajbandh consists of 5 cells (shallow depth pond) surrounded by earthen embankment, where paddy plantation and fish cultivation were continued till the waste deposition started. However, still it has significant capacity to accommodate the solid waste. Despite the Old Rajbandh filled-up partially with solid wastes, KCC started to dump wastes in the New Rajbandh since January 2007 and first two cell cells along the Khulna-Satkhira Highway were started to fill as shown in Figure 5.1. The site of the PSSL is located at the north-west corner with an area of 1.1acres. This location for PSSL was selected based on the series of site visit and the discussion with KCC team members. Since, the wastes deposition as open dumping was already started in the first two cells (Shallow ponds), the last corner was selected to avoid all the possible interferences due to open dumping. The corner pond is surrounded by earthen embankment and located at distance of 122m from the Khulna-Satkhira Road. The ground surface of the site 1m below the top of the surrounding earthen embankment and site has the dimension of 52x64x85x55m. There is a public natural stream in the North side and private paddy land in the west (Islam and Alamgir et. al.,2009).

5.2.1 Design Criteria

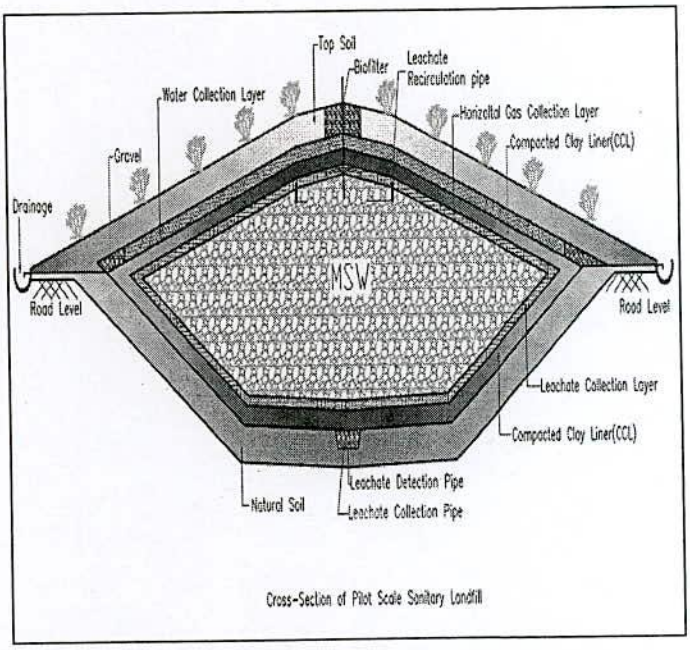


Figure 5.2 Schematic diagram of the pilot scale sanitary landfill

To establish an appropriate construction technology of landfill for Bangladesh conditions using local building materials and available technological capabilities and facilities, the pilot scale sanitary landfill has designed at New Rajbandh, Khulna. Analysis and design of PSSL was completed by WasteSafe II Team members within December, 2007 (WasteSafe II, 2008). Despite a pilot scale sanitary landfill cell, the WasteSafe II Team decided to consider all the relevant aspects of a standard sanitary landfill while designing the cell and the components. Emphasis is also given for the best use of locally available building materials and construction techniques. However, scientific an technical considerations, guided by field experiences, are given while fixing up the dimensions and materials specification of the various components of the landfill. The PSSL consists of the main components of a standard landfill such as (i) Waste deposition cell, (ii) Compacted clay liner on a geological barrier with a drainage layer on top (iii) Top Cover with compacted clay liner, drainage layer, top soil as vegetation cover, surface run-off and percolated water collection system, (iv) Gas measurement and management facility, (v) Leachate detection and collection system with leachate holding tank, (vi) Leachate pond with leachate treatment facility, (vii) Vehicle inspection and washing facility, (viii) Access Road and Site office, (ix) On-going and post closure monitoring facilities.

Analysis and Design of the PSSL was completed by WasteSafe Team members by December 2007 guided by field experiences, local condition and project provision while fixing up the dimensions and materials specification of the various components of the landfill. The MSW collected from Khulna city was deposited in shortest possible time with moderate compaction efforts. It was decided to follow the standard landfill operation system with local perspectives that was followed during the construction, waste deposition and operation, and monitoring phases. Post closure monitoring was conducted till the end of the project, which is continuing by KUET till the active period of the landfill.

The size of the waste containment is 50x50x6m, which is 3m below and 3m above the ground surface with a side slope of 26° the schematic diagram is presented in Figure 5.2. The base liner, the most important component, includes a leak detection sump system, compacted clay liner, leachate collection pipe system with a leachate collection layer. It is designed considering hydrological data of the site, the size of landfill, suitability of construction and locally available of material. The base liner has a 400mm thick of CCL just above the geological barrier of 15m clay deposits, over which 200mm thick sand layer as drainage layer. Leachate collection pipe is placed in the drainage layer, while the leachate detection pipe is placed just below the CCL. The generated leachate will be stored in leachate holding tank of 2x2x4m and later transfer to the leachate treatment pond of 10x20x3.5m. The system is designed in such a way so that the leachate can be collected and thus stored in the tank through gravity flow. The leachate detection pipe is also designed and connected in the leachate holding tank by ensuring gravity flow. From tank the leachate will be transferred to the pond using pump.

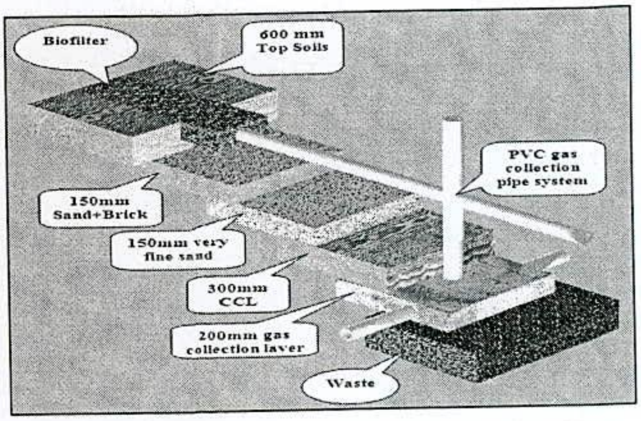


Figure 5.3 Schematic diagram of the Top Cover

The final cover of PSSL as shown in Figure 5.3, consists of top soils, percolation water collection layer, compacted clay liner and gas collection pipe system with gas collection layer. The inclusion of biofilter for methane oxidation is kept as possible inclusion in the top cover. The top has gas collection layer at the top of 200mm thick just over the waste, then 300mm CCL, 150mm fine sand and 150mm sand plus brick aggregates as percolation and drainage layer which is followed by 600mm top soil. The combination of fine sand layer and then sand and brick aggregates is given to ensure capillary rise of water for the keeping CCL wet as much as possible to prevent possible desiccation and cracking. Top soil layer of 600mm thick will help to support and maintain the growth of vegetation by retaining moisture and providing nutrients. There is a Leachate Recirculation System that will maintain moisture and enhance degradation of waste. To control possible soil erosion, mild slope is maintained at the top cover, which is 15° at the edge to middle and then 7° from middle to top (Alamgir et. al., 2009).

5.2.2 Construction Process

The construction works have been conducted based on the design and the locally available construction techniques, equipments and building materials. The earth excavation, construction of various components of the landfill such as approach road, inspection point, site office, base liner, leachate collection and detection systems, leachate holding tank, leachate pond and the small scale leachate treatment option are discussed in the paper Islam et. al., 2008. The construction process of base liner is shown in figure 5.4.

Figure 5.4 Construction process of base liner in the field of PSSL.

5.2.3 Waste Deposition

MSW generated in KCC areas has been deposited in the PSSL. The incoming waste carrying vehicles are being counted, volume of waste measured roughly, weighted indirectly, inspected and hence recorded properly. Initially, deposited wastes were spread manually, latter KCC's vehicle such as Back-wheeled Compactor cum Excavator and Chain-dozer, were employed for the spreading of wastes. Up to date (August, 2009) 11700ton of MSW is filled in the PSSL of which 90% is rapidly biodegradable waste through fourteen months of operation. The detail of waste deposition is discussed in a companion paper by Rahman et. al. (2009).

5.3 Compacted Clay Liner

The base liner consists of properly compacted clay liner of 400mm in thickness. A Leachate collection and removal system in combination with Leachate and leakage detection system has been developed which intending to receive the entire surface run off and leachate. This may flow across the landfill floor to a sump through waste into a drainage media and on to the sump. The downward percolation of water is prevented by the CCL. The landfill with leak detection sump system intending to collect that water which pass or leaks through the first CCL only. Both collection and sumps are perforated at definite elevations and both sumps rest in a concrete basin. The CCL was prepared applying Hand Compaction in three layers at the wet side of proctor curve to achieve the optimum hydraulic conductivity,1x10-7cm/sec.

5.3.1 Properties of CCL

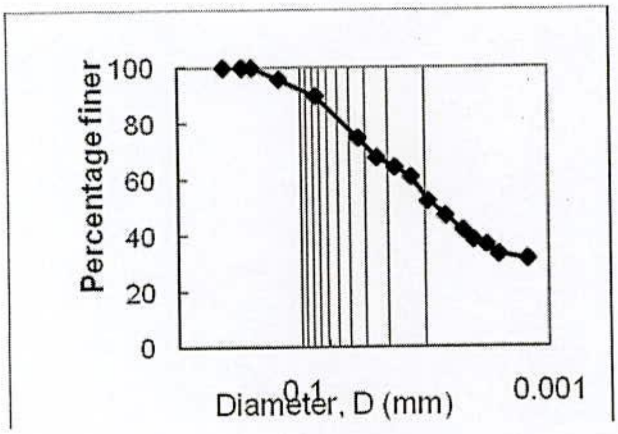


Figure 5.5 Grain size distribution curve of compacted clay

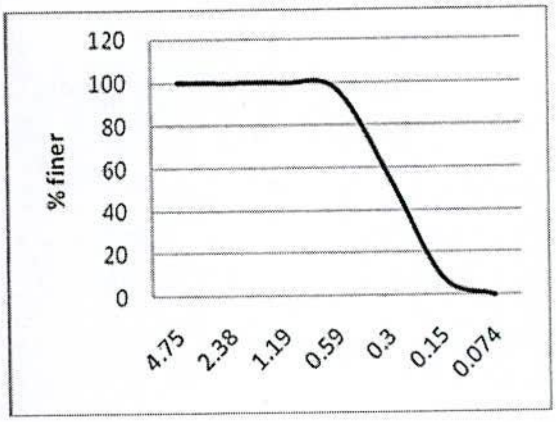


Figure 5.6 Grain size distribution curve of leachate collection layer

The sub-soil investigation shows that 15m of clay-gray existed beneath the Landfill will act as Natural soil Barrier to prevent spreading of contaminant. The mineralogical composition of CCL material are find out which illustrates that the non clay minerals such as Quartzs are 19% and Feldspar and Carbonates both are less than 1%. The non-swelling cay minerals such as Illite are around 50%, Kaolinite is around 10% and Chlorites are less than 1%. The swelling clay mineral such as Smectite is 20%.

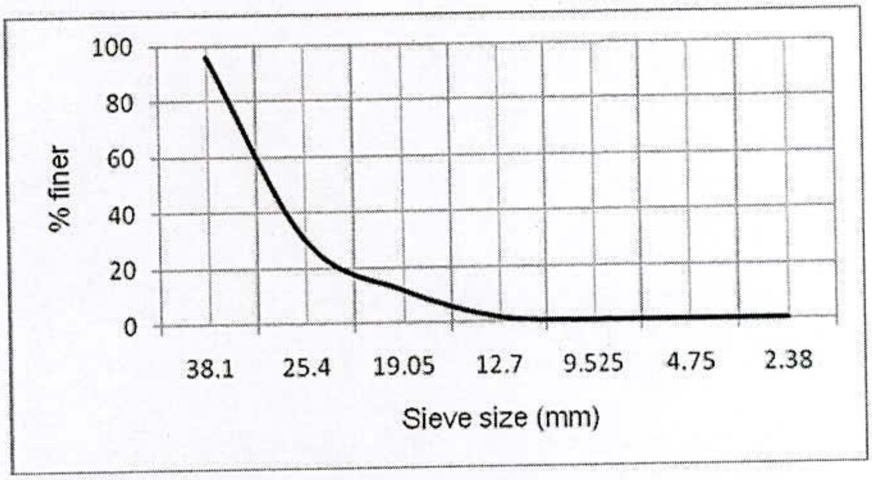


Figure 5.7 Grain size distribution curve of washed brick aggregate

The soil liner is typically designed to have a hydraulic conductivity $\leq 1x10^{-7}$ cm/s. The origin of this design criterion is unclear; $1x10^{-7}$ cm/s was evidently selected on the assumption that this was an achievable value that would result in negligibly small seepage through the liner (Daniel & Keorner 2007).CCL and drainage layers are uniform on all fields, the CCL (0.4 m) being plasticity index >20% and compacted at the wet side of proctor curve, the leachate collection layer (0.20 m) being a sand (56% < 2 mm, 38% from 2 mm to 6.3.mm) with CaCO3. The figure 5.5, 5.6 and 5.7 shows the grain size distribution curve of CCL, leachate collection layer and washed brick aggregate.

5.3.2 Construction of Compacted Clay Liner

Low-permeability compacted soil liners, also referred to as CCLs are the historic engineered component used in landfills. Clay-rich soil is placed in layers and compacted with heavy equipment to form a barrier of movement of liquids and gases. The soil liner is typically designed to have a hydraulic conductivity $\leq 1x10^{-7}$ cm/s. The origin of this design criterion is unclear; $1x10^{-7}$cm/s was evidently selected on the assumption that this was an achievable value that would result in negligibly small seepage through the liner. The low hydraulic conductivity of clay minerals makes them potential materials to use as CCLs in sanitary landfill for environmental protection. Soils classified as inorganic clay with high plasticity is considered as the suitable material for landfill liner.

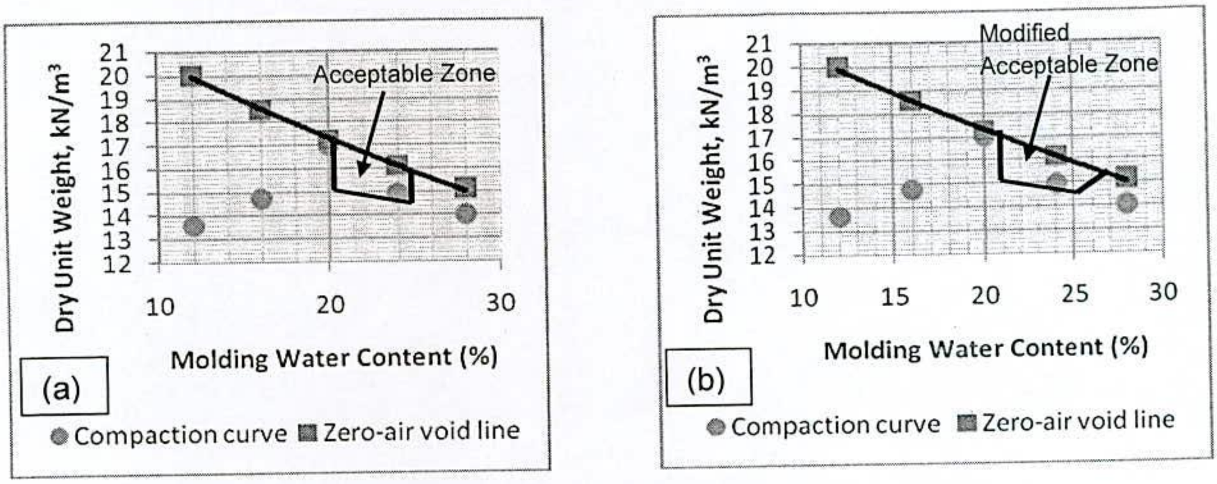


Figure 5.8. Determination of Acceptable Zone of Water Content-Dry Unit Weight Values Based on Hydraulic Conductivity for Clay in PSSL.

If natural available clay or clayey soil is not suitable for liner, kaolinite or commercially available high swelling clay (Bentonite) can be mixed with local soils or sand. In Bangladesh these materials are not locally available and would have to be imported from elsewhere and could significantly increase the cost of construction (Alamgir et. al. 2005). For Khulna soils, it is shown earlier that soils compacted at water content less than optimum is tended to have a relatively high hydraulic conductivity and soils compacted at water contents greater than optimum is tended to have a low hydraulic conductivity. Figure 5.8 shows the acceptable zone based on the hydraulic conductivity of the clay.

5.3.3 Construction Method

In the PSSL, the clayey soils collected from the depth of 0 to 2m of the site, were used for the construction of CCL as the test results revealed the suitability of the clay. The stock pile of clay used to construct CCL and later spreading over the bed for compaction. The compaction of soil was done manually in three layers by using locally manufactured hammer made of cast iron connected with timber handle. The clay were placed uniformly over the bed and then compacted by adding required amount of water as shown in Figure 5.9. To ensure uniformity of compaction, a locally practiced technique is maintained while applying the hammer drop by a group of female worker. The thickness of the layer was maintained in such a way that the resultant thickness of the CCL reached as 400mm.

Figure 5.9 Compaction method of clay for CCL

Figure 5.10 Field density test of the CCL

sand cone test method as shown in Figure 5.10, usually used as field compaction test. Initially, it was planned to prepare the CCL by using Sheep foot or smooth wheeled roller, however, due to the soften nature of soils; later compaction was done using manual intensive practice and equipments. However, finally a very impressive CCL was constructed with locally available technology and equipments without heavy machineries and skilled people.

5.3.4 Leachate collection system

Leachate Collection System (LCS) is a typical component of most modern landfills. These system commonly comprises of perforated leachate collection pipe at regular spacing in a continuous blanket of granular material. The primary function of leachate collection system is to control the leachate head acting on the liner system. The construction of 200mm leachate collection layer of sand with 100mm dia. of perforated leachate collection pipe surrounded by washed brick aggregate. LCS is considered as one of the most important components of sanitary landfill. The system commonly comprises perforated pipe at regular spacing in a continuous blanket of granular material to collect leachate. The primary function of leachate collection system is to control the leachate head acting on the liner system. Controlling of leachate head minimizes the advective transport of contaminants and also controls side slope leachate breakouts. Lowering height of leachate mounding, leachate seeps can be minimized. Leachate pressure head on liner gets reduced, hence gradient through liner gets reduced resulting flow reduction through liner. Finally, removing contaminants from the landfill reduces the available amount contaminants for transport.

To collect the leachate through gravity the bed was constructed maintaining a 3° slope and the leachate collection pipe is placed at the middle of the cell. The leachate collection layer of 200mm thick was construction to accommodate a perforated leachate collection pipe with 100mm dia. and surrounded by washed brick aggregates as shown in the Figure 5.11. The collection was laid maintaining a slope of 3° towards the leachate holding tank to ensure the easy movement of leachate through gravity flow as mounded on the leachate collection pipe (Islam et. al., 2009).

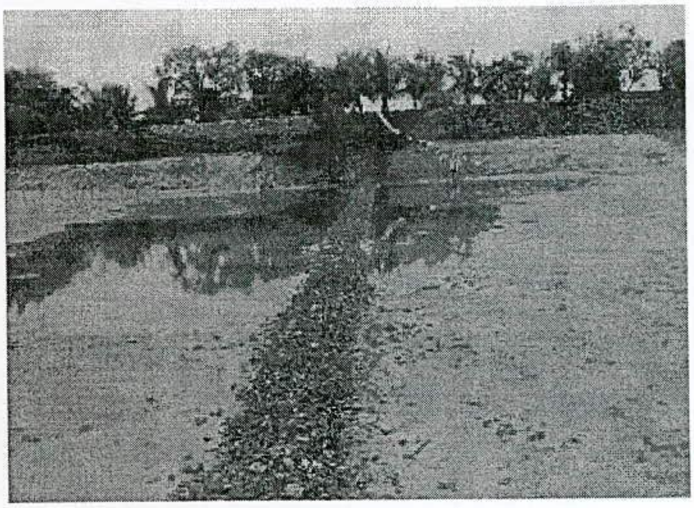


Figure 5.11 Leachate collection pipe with brick aggregates as filter media

5.4 Water Balance Data

The water balance data are listed in Table 1. Evapotranspiration and lateral drainage above the liners are the dominant parameters in the water balance. Significant detection runoff occurred during the first year. Later on it is very low and almost independent of inclination. During the fourteen months of measurements, however, there have been unusually some thunderstorms with high rainfall intensities and no snowmelt events compared to the this short-term average.

Lateral drainage within the collection layer (inter-flow) only occurred under steep slope conditions and even then contributed only a few liters to the water balance (maximum flow rates vary from 36.0 L/d or 46.6 L/d). There is some variation in the drainage and evapotranspiration data over the years and between the individual fields. In general, the amount of drainage discharge per year is independent of inclination. The short-term flow rates however are higher on the steep fields than on the flat fields. The annual evapotranspiration is higher on the flat fields than on the steep fields due to a higher input of solar radiation in winter, spring and monsoon. In consequence the annual drainage rates are lower on the flat fields. The landfill has been closed since October, 2009. After the detection of high concentrations of leachate a small scale treatment action program is started in July, 2008. The temperature within the landfill is 48°C.The vegetation will formed by grasses and perennial weeds later. The climate of Khulna is humid and tropical, influenced by the Bay of Bengal. The average precipitation is 1982 mm/a, distributed almost inconsistently over the year. Rainfall intensity usually is high, maximum intensities being around 6 mm/10 min and rarely above 20 mm/h. The long-term average air temperature is 26°C with average values of 18°C in January and 31.1°C in April. An average of 60 days per year (d/a) show a maximum temperature above 25°C, 60 d/a have a maximum temperature below 15.5°C. The potential evapotranspiration is above 700 mm/a. The Liner design is shown in Figure 5.4. The Landfill is 'flat' with an inclination of 3%, the leachate collection pipe have a slope of 2%. All fields were constructed with the aim of Bangladesh local technology, materials and quality control as used during the construction of the liner of the whole landfill. No artificial materials cut through the liners at the boundary of the test fields to avoid the formation of preferenial flow paths (details in Melchior and Miehlich 1989; Melhior 1993). Meteorological data, soil hydrological parameters of the site as well as the leakage through the liners are measured directly.

5.5 Performance of Clay Liner

Compacted clay liner has been monitored in the PSSL fields. On field soils have been compacted to a total thickness of 0.4 m after compaction. It has the following average properties: 33% clay, 57% silt and 10% fine sand (Rafizul et. al., 2009); no organic matter; 50% of the clay minerals are illite, 20% smectite, 1% chlorite and 10% kaolinite; liquid limit, 53.0%; plasticity index, 20; bulk density, 1.950 gm/cm3; water content >25%; Proctor density, 17 kN/m^3; compacted >90%; Proctor density on wet side of optimum water content; pore volume, 27.0%; degree of saturation, 0.87; geometric mean of saturated hydraulic conductivity in the laboratory, $\leq 1.0 \times 10^{-9}$ m/s. Due to its graded particle size distribution, its high silt content, and the dominance of relatively inactive clay minerals, it shows a low potential for shrinkage compared to other 'clay liners'.

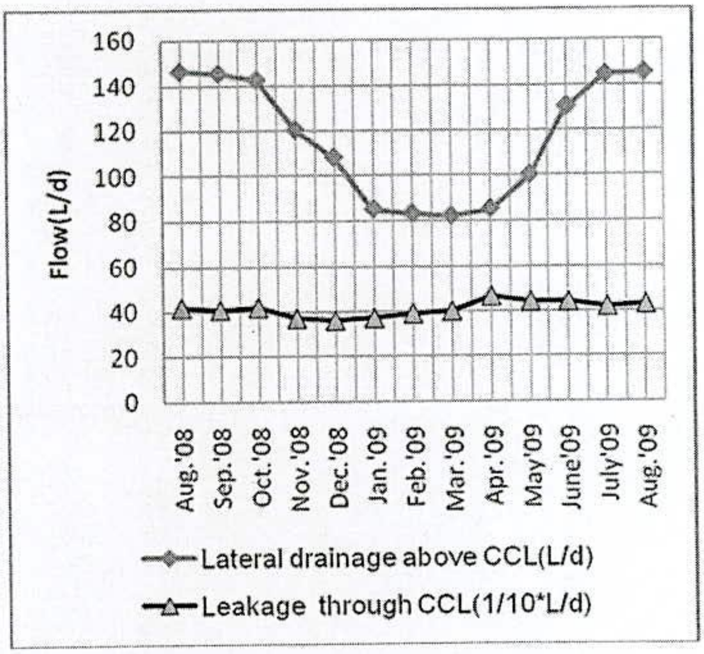


Figure 5.12 The discharges in the drainage layer above the CCL and the CCL leakage.

Figure 5.12 shows the discharges in the drainage layer above the liner and the liner leakage. The drainage discharge above the liner is high during winter, monsoon and spring, whereas little happens during the summer. The measured soil hydrological data (water content and matric potential) clearly show that upward directed water transport into the dry drainage layer and topsoil has caused a desiccation of the liner and consequently the formation of cracks (details in Melchior 1993 and Melchior et al. 1994). The variation of leak detection through CCL is compared with ppt. and temperature is shown in table 5.1.

Table 5.1 Variation of leak detection with ppt. and temperature

Compacted clay liner														
	July' 08	Aug '08	Sep.' 08	Oct.' 08	Nov.' 08	Dec.' 08	Jan.' 09	Feb.' 09	Mar.' 09	Apr.' 09	May' 09	June' 09	July' 09	Aug.' 09
ppt (mm)	301	203	379	187	00	00	01	06	10	23	137	233	347	570
Drainage above CCL(L/d)		146	145	142	120	108	85	83	82	85	100	130	144	145
Leakage through CCL(L/d)		42	41	42	37	36	37	39	40	46.6	44.2	44	42	43
Max. avg. temp. (°C)	31.5	32.4	32.8	31.8	29.6	26.1	26.2	29.8	33.2	36.6	35.6	34.8	32.3	32.6

5.5.1 Composition of Leachate and leak detection through CCL

Under normal conditions, leachate is found in the bottom of landfills. From there, its movement is through the underlying strata, although some lateral movement may also occur, depending on the characteristics of the surrounding material. As leachate percolates through the underlying strata, many of the chemical and biological constituents originally contained in it will be removed by the filtering and adsorptive action of the material composing the strata. In general, the extent of this action depends on the characteristics of the soil, especially the clay content. Because of the potential risk involved in allowing leachate to percolate to the groundwater, best practice calls for its elimination or containment. Landfill liners ate now commonly used to limit the movement of leachate from the landfill site. The use of clay as a liner material has been the favored method of reducing or eliminating the seepage of leachate form landfills. Clay is favored for its ability to adsorb and retain many of the chemical constitutes found in leachate and for its resistance to the flow of leachate (G. Tchobanoglous and F. Kreith, 2002).In PSSL 400mm of locally available clay is used as CCL and its performance is explored. Table 5.2 shows the difference in composition of landfill leachate and leak detection through the CCL.

Table 5.2 composition of leachate and leak detection through CCL in the PSSL

Mean value, mg/L*		
	Leachate above CCL	Leakage detection through CCL
pH	7.6	7.43
Chloride	1672.0	975.0
Iron	321.0	6.04
Alkalinity	8936	2975
Hardness	1869	1727
TDS	12349	6835
BOD_5	5816	3.7
COD	21858	40.0
Lead	0.39	0.001
Nickel	0.18	0.001
Cadmium	0.02	0.001

* Except pH, this is unit less.

5.5.2 Observation of monitoring well

The observation of monitoring well is listed in Table 5.3 shows that it removes iron, salinity, TDS, COD and hardness with satisfactory.

Table 5.3 Composition of Channel water, Monitoring well water and landfill leachate in the PSSL

S.L No	TEST PARAMETER	Channel water	Monitoring Well	Landfill Leachate
01	PH	6.32	6.8	7.6
02	Iron (mg/l)	0.1	1.2	321.0
03	Salinity (mg/l)	125	1300	1672.0
04	DO-1(mg/l)	4.90	0.98	0.90
	DO-5(mg/l)	2.56	0.48	0.45
05	TDS (mg/l)	820	305	2310
08	Alkalinity (mg/l)	200	900	8936
09	Hardness (mg/l)	277.8	1018.6	6694.5
10	COD (mg/l)	1440.0	35.0	21858

CHAPTER SIX

SUMMARY AND CONCLUSION

6.1 Summary

Uncontrolled dumping of solid waste around the world becomes one of the major striking social and environmental issues. The majority of these are located in the developing countries, which generate the solid waste with high rapidly biodegradable fraction. In Bangladesh, like other Least Developed Asian Countries (LDACs), ultimate disposal sites of Municipal Solid Waste (MSW) are situated in and around the city areas at low-lying open spaces, unclaimed land, riverbanks and roadsides. Even in some city authorities do not have any specific place for ultimate disposal. Such disposal sites do not have minimum infrastructure requirements and environmental protections, as a result, present open dumping practices pose to high threat to health and environment. There are no controlled/engineered/sanitary landfills in Bangladesh; however, recently Dhaka City Corporation has taken an initiative to convert 'Matuail Open Dumping Site' into the Engineered Landfill. Due to severe financial constraints and the priorities to other sectors such as food, shelter, health and education, central and local governments are not able to address this social and environmental issue despite the realization that the only affordable disposal solution in Bangladesh for the foreseeable future – is to establish engineered landfills. So, Bangladesh needs develop as appropriate method of landfill construction considering local conditions. To this endeavor, a pilot scale sanitary (PSSL) landfill at Rajbandh, Khulna has been constructed using local clay as a base liner material. This study illustrates the design, construction and performance of this compacted clay liner. In design of the PSSL all the relevant aspects of a standard sanitary landfill is considered. Emphasis is also given for the best use of locally available building materials and construction techniques. However, scientific and technical considerations, guided by field experiences, are given while fixing up the dimensions and materials specification of the various components of the landfill. The PSSL consists of the main components of a standard landfill such as (i) Waste deposition cell, (ii) CCL on a geological barrier with a drainage layer on top (iii) Top Cover with CCL, drainage layer, top soil as vegetation cover, surface run-off and percolated water collection system, (iv) Gas measurement and management facility, (v) Leachate detection and collection system with leachate holding tank, (vi) Leachate pond with leachate treatment facility, (vii) Vehicle inspection and washing facility, (viii) Access Road and Site office, (ix) On-going and post closure monitoring facilities.

The site of the PSSL is located at the north-west corner with an area of 1.1acres. The ground surface of the site 1m below the top of the surrounding earthen embankment and site has the dimension of 52x64x85x55m. There is a public natural stream in the North side and private paddy land in the west. The sub-soil investigation was revealed that the gray clay minerals with organic forms to a depth of 1.5m followed by silty clay having clay minerals content ranges from 23 to 30% and hydraulic conductivity varies from 2.45×10^{-6} to 2.5×10^{-8} cm/sec at different molding water content. Swelling clay minerals are present in varying the amount of 0 to 11% of the composition.

The total surface area of the landfill base including side slope is $2683 m^2$. The base liner consists of properly compacted clay liner of 400mm in thickness. A Leachate collection and removal system in combination with Leachate and leakage detection system has been developed intending to receive the entire surface run off and leachate. This may flow across the landfill floor to a sump through waste into a drainage media and on to the sump. The downward percolation of water is prevented by the CCL. The landfill with leak detection sump system is intending to collect water which passes or leaks through the CCL only. Both collection and sumps are perforated at definite elevations and both sumps rest in a concrete basin. The CCL was prepared applying hand compaction by locally fabricated hammer of weight 5kg in three layers and at the wet side of proctor curve to achieve the optimum hydraulic conductivity, 1×10^{-9}m/sec. The generated leachate will be stored in leachate holding tank of 2x2x4m through gravity flow and later transfer to the leachate treatment pond of 10x20x3.5m. The leachate detection pipe is also designed and connected in the leachate holding tank by ensuring gravity flow. A leachate collection layer of 20 cm and a leachate collection pipe are placed above.

During 18 months landfill operation, required amount of MSW wastes was deposited in the landfill. During the deposition period huge amount of leachate generated due to inherent wastes nature and the typical monsoon season of Bangladesh and it has created an adverse condition to landfill. The amount of leachate obtained the leachate collection system and the detection systems were measured and hence monitored. It is observed that the leachate collection and detection system have worked well as no clogging was reported. To examine the performance of the CCL, the leachate collected through both the collection and detection pipes have been characterized in the laboratory through necessary routine tests. The quality of the surface water and ground water in and around the landfill cell, have been tested collecting water samples both from the constructed ground water monitoring well and the adjacent natural streams. After the completion of PSSL on last December 2009, the cover system was constructed and the post closure monitoring have been conducting by other researchers of the Department of Civil Engineering, KUET.

6.2 Conclusion

An appropriate technical set-up is required and time is needed to collect and interpret valuable data to examine the performance of constructed CCL used as the base liner. The most important conclusions after one year of field studies on base liner can be concluded as the followings:

1. The local soil of Khulna is highly plastic. Generally this type of soil possesses desirable characteristics to minimize hydraulic conductivity and frequently can be use as compacted clay liner materials. The index properties of the soil satisfy the basic requirements to use as a CCL material. At a molding water content of 24% or more,

the hydraulic conductivity of soil satisfies the value of $1x10^{-7}$cm/s. Thus, the characteristic of Khulna clay is suitable to use as a CCL material for the construction of sanitary landfill.

2. The construction technique used here for the preparation of base liner using CCL, such as earth excavation, placement of clay compaction and monitoring is found quite satisfactory.

3. The laboratory test results of leachate as obtained from the leachate detection & collection system shows that the base liner has protected the migration of contaminant significantly. It also prevents the percolation of leachate with high degree of satisfaction as the major portion of generated leachate has been received through the collection system.

4. The test results of water samples collected from the ground water monitoring well and the surface of adjacent natural streams indicate that the CCL works perfectly to prevent the migration of leachate from the landfill cell. So, it can be concluded that the CCL constructed in the base liner using local clay and the locally available manual labor intensive construction techniques work perfectly.

5. Khulna City Corporation as like as Bangladesh needs to convert the existing ultimate open disposal sites of MSW into sanitary landfill through the development of sustainable landfill technology based on her prevailing socio-economic settings, technological capabilities and the local conditions. The specification and construction procedure of pilot scale sanitary landfill using base liner has been designed and hence constructed successfully by means of mostly indigenous techniques with close field monitoring. The success history of the studied PSSL achieved so far from the performance study, will bring a positive change in the attitude of the local authority to switch from existing practice of crude opening dumping to sanitary landfill. Finally, it can also be concluded that this filed study will help to build the specification and construction procedure of base liner for Bangladesh conditions, which can be replicable to other Least Developed Asian Countries with required refinement.

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FIELD NOTE

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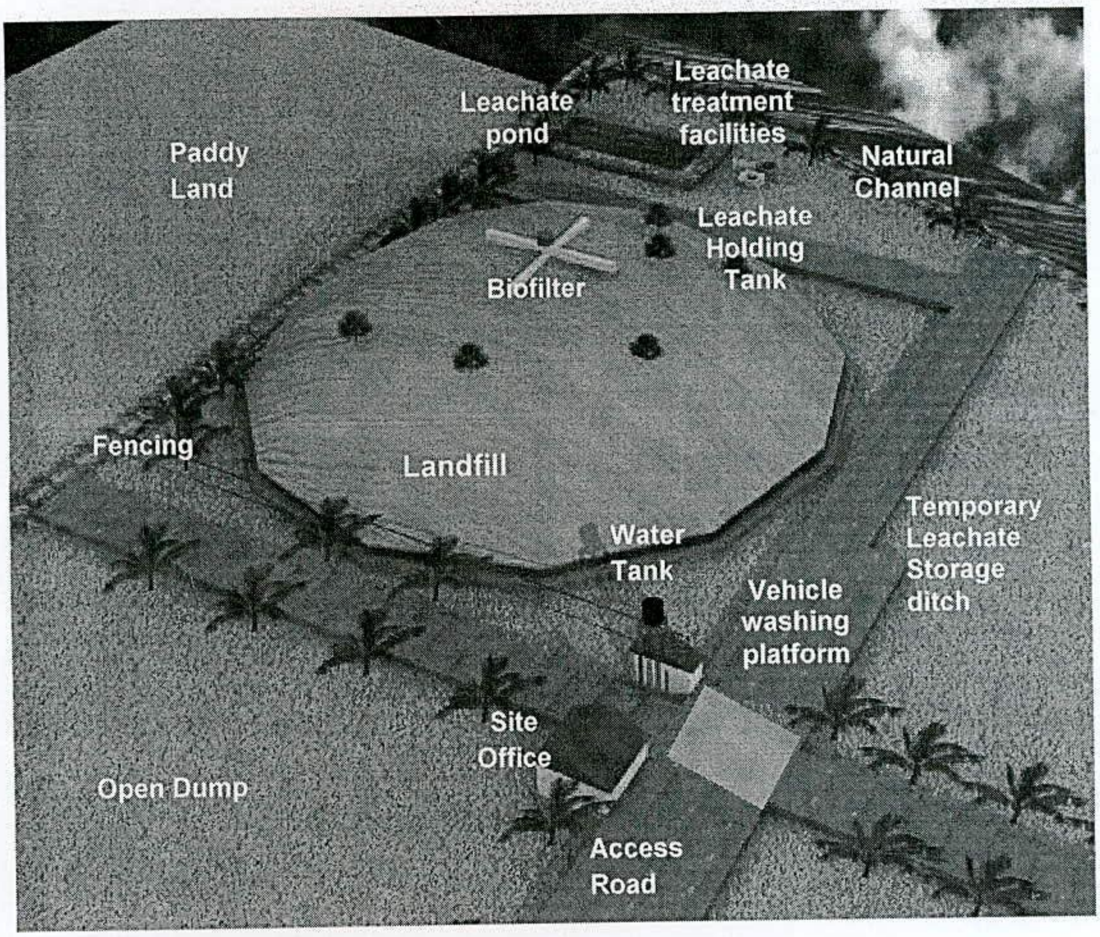
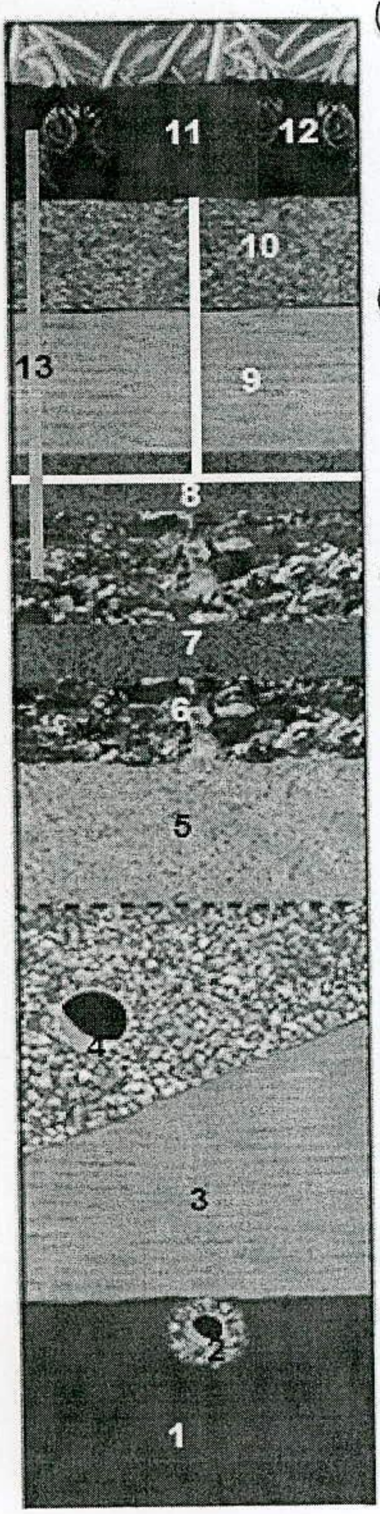
ANNEX A



Perspective view of Pilot Scale Sanitary Landfill at the design level

ANNEX B

Anatomy of Pilot Scale Sanitary Landfill (At design Phase)



13 Leachate Recirculation System: It will Maintain moistuer and Enhance degradation of waste.

10 Drainage Layer: A layer of sand and gravel drains excess precipitation from the protective cover soil to enhance stability and help prevent infiltration of water through the landfill cap system.

8 Gas Collection Layer: Waste produces gas and that gas will be colledted by perforated pipe system sourunded by a layer of sand and gravel to check its characteristics.

6 Waste: As waste arrives, it is compacted in layers within a small area to reduce the volume consumed within the landfill. This practice also helps to reduce odors, keeps litter from scattering and deters scavengers.

4 Leachate Collection Pipe System: Perforated pipes, surrounded by a bed of gravel, transport collected leachate to specially designed low points called sumps. Pumps, located within the sumps, automatically remove the leachate from the landfilland transport it to the leachate management facilities.

2 Leachate Detection System: 38mmφPVC filter pipe surrounded by 150mm of course sand & 1% slope to the sump will detect the leachate that leave from CCL

12 Top Soil: Helps to support and maintain the growth of vegetation by retaining moisture and providing nutrients.

11 Biofilter: It will oxidize CH_4 in to CO_2 to protect environment

9 Compacted Clay: It is placed to form a cap when the landfill reaches the permitted height. This layer prevents excess precipitation from entering the landfill and forming leachate and helps to prevent the escape of landfill gas, thereby reducing odors.

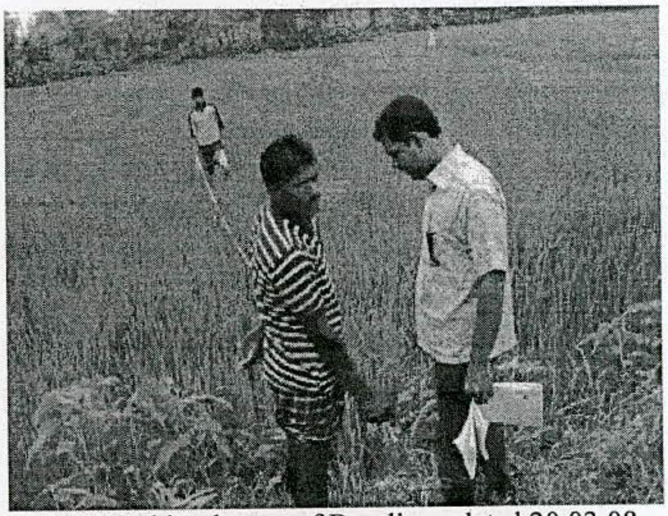
7 Daily Cover: At the end of each working period, waste is covered with 150mm of compost or other approved material. Daily cover reduces odors, keeps litter from scattering and helps deter scavengers.

5 Leachate Collection Layer: A layer of sand or gravel collects leachate and allows it to drain by gravity to the leachate collection pipe system.

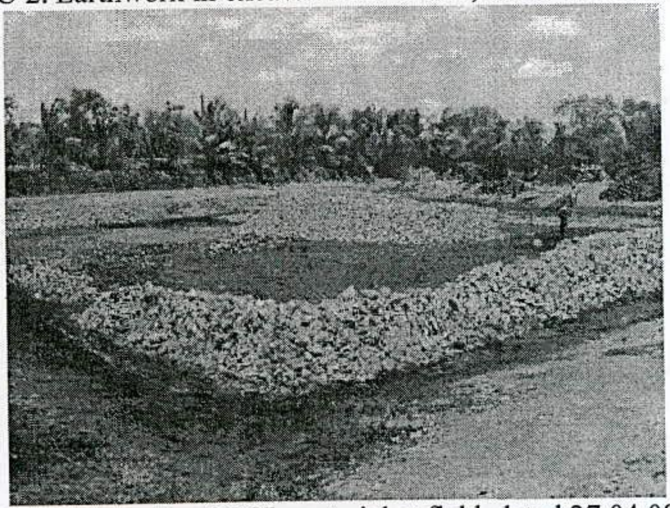
3 Compacted Clay: Is located directly below the Leachate Collection Layer and forms an additional barrier to prevent leachate from leaving the landfill and entering the environment. This layer also helps to prevent the escape of landfill gas.

1 About 15m of clay-gray benath the Landfill will be act as Natural soil Barrier to prevent spreading of cotaminant

ANNEX C


C-1. Working layout of Baseliner, dated 20.03.08

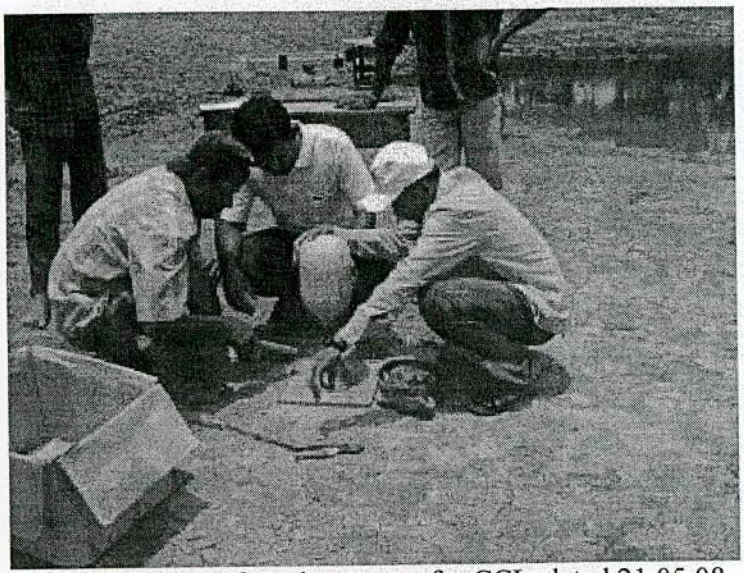

C-2. Earthwork in excavation of PSSL, dated 17.04.08


C-3. Stock pile of CCL material at field, dated 27.04.08

C- 4. Supervision of Leachate Detection System, dated 07.05.08

C- 5. Compaction of CCL at field, dated 12.05.08

C- 6. Placing of Leachate Collection Pipe, date 26.06.08



C-7. Execution of sand cone test for CCL, dated 21.05.08

C- 8. Visit of 1st secretary of EC Delegation, dated 20.05.08

C-9. Visit of completed Base Liner by external expert, date 11.07.08

Annex D

Construction costs of Base Liner

Area=50mx50m=2500sqm

Item No	Items	Unit	rate	Quantity	Amount(Tk)
1	Earth work in excavation	cum	25.00	6557.814	163945.35
2	Earth filling in the CCL bed	cum	45.00	4666.093	209974.19
3	Compaction of CCL	cum	25.72	1271.655	32706.97
4	Supplying of local sand	cum	210.00	484.54	101753.40
5	Supplying & fitting of 100mm PVC LCL pipe	m	299.24	61.00	18253.64
6	Supplying and spreading of washed brick aggregates	cum	1237.00	375.67	464703.79
7	construction of leachate holding tank	LS			50000.00
8	Fencing the boundary	LS			39003.00
9	Bailing out of water	LS			20000.00
	Total				1100340.33
				Say	**1100340.00**

(In word: Tk. Eleven Lac Three Hundred Forty only.)

Annex E

Operation Record of Landfill

all unit in ton

Days	July,08	Aug,08	Sep,08	Oct,08	Nov,08	Dec,08
1	0.0	34.8	27.3	40.2	0.0	45.5
2	0.0	17.2	0.0	0.0	0.0	22.5
3	0.0	55.2	0.0	19.6	0.0	58.3
4	0.0	17.3	0.0	28.2	0.0	42.5
5	0.0	40.8	0.0	0.0	0.0	24.7
6	0.0	63.2	0.0	0.0	0.0	28.9
7	0.0	62.7	43.3	0.0	0.0	20.3
8	0.0	35.8	51.9	0.0	0.0	59.2
9	0.0	57.9	30.3	0.0	0.0	0.0
10	0.0	46.0	46.2	0.0	0.0	23.4
11	20.1	7.8	18.2	0.0	0.0	24.3
12	15.7	0.0	0.0	0.0	0.0	13.0
13	41.9	10.2	11.7	0.0	0.0	12.4
14	37.8	9.5	49.2	0.0	0.0	3.1
15	47.2	0.0	32.8	0.0	0.0	22.0
16	40.2	0.0	0.0	0.0	0.0	0.0
17	46.5	0.0	0.0	0.0	0.0	22.3
18	21.1	62.1	0.0	0.0	0.0	8.6
19	26.8	53.6	0.0	0.0	0.0	0.0
20	57.5	34.4	11.9	0.0	0.0	0.0
21	54.4	35.2	16.5	0.0	0.0	0.0
22	36.2	0.0	29.9	0.0	0.0	25.7
23	45.9	0.0	52.4	0.0	0.0	48.8
24	43.9	28.7	31.5	0.0	0.0	40.6
25	21.3	0.0	56.1	0.0	27.6	30.7
26	34.0	11.3	41.7	0.0	43.9	27.5
27	22.6	26.4	39.5	0.0	33.9	41.1
28	0.0	54.9	0.0	0.0	14.4	36.7
29	0.0	30.1	0.0	0.0	30.7	0.0
30	22.9	38.3	24.2	0.0	55.0	29.1
31	44.1	33.9		0.0		24.9
Total	**680.0**	**867.2**	**614.5**	**88.0**	**205.4**	**736.2**

all unit in ton

Days	Jan,09	Feb,09	Mar,09	Apr,09	May,09	June,09	July,09	Aug,09	Sep,09
1	32.9	47.9	41.4	47.4	0.0	86.2	44.2	0.0	200.0
2	27.1	25.6	34.1	39.1	31.0	51.5	40.4	0.0	200.0
3	13.7	13.9	17.2	19.7	26.4	88.8	18.3	0.0	200.0
4	41.2	21.6	51.8	59.4	54.5	68.8	11.6	0.0	200.0
5	26.9	34.3	33.7	38.7	33.8	48.6	52.7	0.0	200.0
6	31.3	6.6	39.3	45.1	30.8	57.7	54.2	0.0	200.0
7	28.1	18.3	35.3	40.4	38.9	78.4	56.2	0.0	200.0
8	29.5	29.9	37.0	42.4	13.9	79.6	31.0	0.0	200.0
9	21.9	39.1	27.6	31.6	26.4	51.9	0.0	26.2	200.0
10	24.5	30.8	30.8	35.3	27.9	52.7	0.0	0.0	200.0
11	37.7	21.2	47.3	54.2	39.2	0.0	0.0	39.6	200.0
12	24.9	30.8	31.3	35.8	41.9	0.0	0.0	34.6	100.0
13	49.8	15.2	62.5	71.7	44.8	60.3	0.0	21.6	100.0
14	40.1	27.2	50.4	57.8	53.1	71.7	0.0	0.0	100.0
15	34.3	22.5	43.1	49.4	59.9	48.1	0.0	0.0	100.0
16	35.6	33.9	44.8	51.3	35.7	79.1	0.0	19.0	100.0
17	26.3	41.4	33.0	37.8	51.7	44.0	21.2	51.5	100.0
18	28.1	42.6	35.3	40.5	64.3	76.2	13.5	55.5	100.0
19	59.7	38.8	74.9	85.9	81.7	34.5	0.0	41.8	100.0
20	51.6	14.2	64.8	74.3	70.0	40.8	0.0	0.0	100.0
21	52.9	52.9	66.4	76.1	71.2	43.3	0.0	0.0	33.0
22	44.8	44.5	56.2	64.4	46.6	54.5	0.0	0.0	
23	25.3	26.5	31.7	36.3	77.2	63.5	0.0	0.0	
24	54.5	37.7	68.4	78.4	80.4	55.9	0.0	11.0	
25	54.5	34.3	68.5	78.5	45.9	46.2	0.0	56.4	
26	53.4	22.2	67.1	76.9	0.0	43.9	0.0	38.5	
27	44.0	31.8	55.3	63.4	0.0	24.6	0.0	13.1	
28	45.5	31.1	57.1	65.5	21.6	0.0	0.0	11.3	
29	48.1		60.3	69.2	26.4	7.7	0.0	6.6	
30	21.5		27.0	31.0	63.1	48.5	0.0	0.0	
31	32.4		40.7	46.7	83.6		0.0		
Total	**1142.0**	**837.0**	**1434.1**	**1644.1**	**1342.0**	**1507.2**	**343.3**	**426.5**	**3133.0**

Grand total=15000ton

Annex F

Test Results of Ground Water and Leachate

Test No- 01 Date:-29/08/08

S.L No-	Test Parameter	unit	Cannel Water	Dumping Site Water
01	P^H		7.54	7.75
02	Iron	mg/l	0.1	0.9
03	Salinity	mg/l	270.0	240.0
04	DO-1	mg/l	5.31	6.87
	DO-5	mg/l	4.84	4.1
05	TDS	mg/l	1750.0	2410.0
06	Alkalinity	mg/l	100.0	435.0
07	Hardness	mg/l	424.0	370.5
08	COD	mg/l	1600.0	640.0

Test No- 02 Date:-25/08/08

S.L No-	Test Parameter	Unit	Cannel Water	Landfill water	Leachate
01	P^H		8.29	7.75	7.82
02	Iron	mg/l	0.06	6.6	7.2
03	Salinity	mg/l	157.5	372.5	602.5
04	DO-1	mg/l	4.69	0.31	0.32
	DO-5	mg/l	3.18	0.27	0.28
05	TDS	mg/l	870.0	3090.0	3540.0
06	Alkalinity	mg/l	115.0	330.0	840.0
07	Hardness	mg/l	1833.48	750.0	916
08	COD	mg/l	1120.0	4800.0	6400.0

Test No- 03 Date:-5/08/08

S.L No-	Test Parameter	unit	Cannel Water	Dumping Site water
01	P^H		7.17	7.75
02	Iron	mg/l	0.0	6.02.1
03	Salinity	mg/l	487.5	812.5
04	DO-1	mg/l	1.54	3.55
	DO-5	mg/l	0.86	1.7
05	TDS	mg/l	3750.0	2730.0
06	Alkalinity	mg/l	1170.0	445.0
07	Hardness	mg/l	1083.42	1685.32
08	COD	mg/l	736.0	1800.0

Test No- 04 Date:-14/09/08

S.L No-	Test Parameter	unit	Cannel	Dumping	Leachate
01	P^H		8.03	8.32	6.93
02	Iron	mg/l	0.06	0.33	0.45
03	Salinity	mg/l	105.0	500.0	350.0
04	DO-1	mg/l	1.16	1.07	1.06
	DO-5	mg/l	0.85	0.63	0.92
05	TDS	mg/l	200.0	1290.0	1460.0
06	Alkalinity	mg/l	160.0	300.0	150.0
07	Hardness	mg/l	138.9	648.2	1018.6
08	COD	mg/l	288.0	1408.0	256.0

Test No- 04 Date:-14/09/08

S.L No-	Test Parameter	unit	Cannel	Holding Tank	Landfill
01	P^H		6.32	6.8	7.5
02	Iron	mg/l	0.1	1.2	0.8
03	Salinity	mg/l	125	1300	425
04	DO-1	mg/l	4.90	0.98	0.90
	DO-5	mg/l	2.56	0.48	0.45
05	TDS	mg/l	820	3050	2310
06	Alkalinity	mg/l	200	900	750
07	Hardness	mg/l	277.8	1018.6	6694.5

Test No- 11 Date:-21/10/08

S.L No-	Test Parameter	unit	Treatment Pond	Cannel	Landfill
01	P^H		7.89	7.58	7.18
02	Iron	mg/l	6.0	1.77	0.0
03	Salinity	mg/l	375.0	426.0	225.0
04	DO-1	mg/l	4.68	3.35	2.38
	DO-5	mg/l	1.56	1.08	0.46
05	TDS	mg/l	1160.0	520.0	2340.0
06	Alkalinity	mg/l	800.0	300.0	1250.0
07	Hardness	mg/l	463.0	324.1	926.0
08	COD	mg/l	2080.0	1440.0	2240.0