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CONSTRUCTION OF ENGINEERED LANDFILL FACILITY FOR PHARMACEUTICAL WASTE – A CASE STUDY

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ABSTRACT

Rapid growth in industrial and pharmaceutical sectors has enormously increased hazardous wastes in the recent years. Engineered landfills facilitate safe disposal of the hazardous waste without affecting the environment, subsoil and ground water. The engineered landfill system for hazardous waste consists of bund, double base lining system, side lining system and a capping layer at top. The outer bund slopes are to be stable and the inner slope shall facilitate laying of side lining system. The geosynthetic materials used in landfill construction, namely Non-woven Geotextile, Geomembranes and Geosynthetic Clay Liner (GCL) in base and side lining systems are to be tested for assessing their suitability and compliance with Central Pollution Control Board (CPCB) norms. Also, suitability of clay intended for use as liner in base lining system is to be assessed for permeability and swelling properties. The degree of compaction of compacted clay liner system shall be evaluated. During execution of landfill construction, jointing of geomembranes shall be evaluated for imperviousness by conducting air pressure and vacuum tests. The seam strength of jointed geomembranes shall be evaluated from Peel and Shear tests. In the present work, various quality control issues related to landfill construction are described pertaining to hazardous landfill construction at Jawaharlal Nehru Pharmacity, Parawada, Visakhapatnam.

1. INTRODUCTION

Industrial societies produce increasingly large volumes of waste, including wastes of potentially toxic nature. Historically, hazardous waste disposed took place in regular landfills. This resulted in unfavourable seepage of hazardous materials into natural hydrologic systems (Chaudhary and Rachana, 2006). Disposing of hazardous waste using this method possess threat to natural resources (Fatta et al, 1999). Hence hazardous wastes are to be disposed in safe containment systems.

Modern landfills, also known as engineered landfills, are highly engineered containment systems, designed to minimize the impact of solid waste on the environment and human health. In modern landfills, the waste is contained by a liner system (Venkatappa Rao and Sasidhar, 2009). The primary purpose of the liner system is to isolate the landfill contents from the environment and, therefore, to protect the soil and ground water from pollution. Landfill liners are designed and constructed to create a barrier between the waste and the environment and to drain the leachate to collection and treatment facilities. These liner systems include combined use of geosynthetics (Giroud & Cazzuffi, 1989, Koerner, 1990, Cancelli & Cazzuffi, 1994, Gourc, 1994, Rowe et al., 1995, Manassero et al., 1998, Rowe, 1998, Bouazza et al., 2002) and earthen materials. Also the stability of engineered landfill primarily depends on bund and hence it is considered as the vital component in engineered landfill. Bund is to be constructed with steep stable slopes to cut down the required material of construction and also to minimize the space (Satyanarayana Reddy, 2011). The materials used in lining system and bund require quality checks for effective construction of engineered landfill. Hence the present study highlights various quality control issues in construction of engineered landfill of hazardous waste at Jawaharlal Nehru Pharmacity, Parawada.

2. DETAILS OF LANDFILL

The engineered landfill cell for containment of pharmaceutical waste under construction, with a capacity of 80000 tons at Jawaharlal Nehru Pharma City is selected for the study. It is proposed to dump waste to a height of 14 m. A 4 m high bund with 5 m top width, 1V:3H inner bund slope and 1V:1.2H outer slope is used to contain the waste material. The bund is constructed using subsoil available from landfill area.

3. PROPERTIES OF PHARMACEUTICAL WASTE

Laboratory investigations are carried out to determine the engineering properties of pharmaceutical waste material dumped at the landfill area and the results are tabulated in Table 1(a). The concentrations of various contaminants present in the waste are presented in Table 1(b). As the contaminants are toxic in nature, the waste is considered as hazardous.

Table 1: (a) Engineering properties of Pharmaceutical waste at landfill site

Engineering Property	**Value**
In-situ density (kN/m^3)	20
Water content (%)	27.78
Shear parameters (a) Cohesion (kN/m^2) (b) Angle of internal friction	 2 21^0

Table 1: (b) Concentration of contaminants in waste dump at landfill site

Contaminant`	**Concentration**
pH	8.64
Total phenols (mg/l)	74
Arsenic (mg/l)	0.82
Lead (mg/l)	1.26
Cadmium (mg/l)	0.14
Chromium-VI (mg/l)	0.37
Copper (mg/l)	4
Nickel (mg/l)	2.18
Mercury (mg/l)	0.06
Zinc (mg/l)	7.48
Fluoride (mg/l)	32
Ammonia (mg/l)	853
Cyanide (mg/l)	1.12
Nitrate (mg/l)	23
Adsorbable organic bound chlorine (mg/l)	2.64
Water soluble compounds except salts (%)	7.36
Calorific value (Kcal/kg)	2356

Based on the above properties, the pharmaceutical waste is hazardous in nature and double base lining system is considered for the landfill. The cross section of adopted landfill is shown in Figure 1.

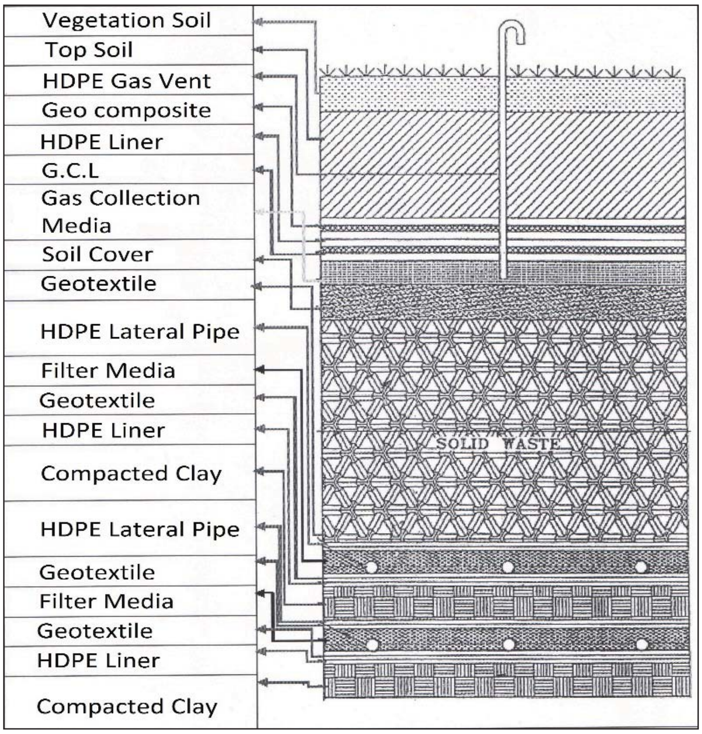

Fig. 1: Section of hazardous waste engineered landfill

4. COMPONENTS OF ENGINEERED LANDFILL

Deposition of waste directly into the landfill site creates pollution to the surrounding environment. Hence securing of landfill before dumping waste is essential in environment point of view.

4.1 Bund

Bund encases the area where the waste is to be dumped. The volume of encased area can be increased by increasing the height of bund, so that more amount of waste can be dumped in it.

4.2 Basal Lining System

Basal lining system protects the subgrade from leachate which invariably generates from waste. This liner is permitted to accept contaminants into it but not allowed to migrate the contaminants through it. There is a protective layer over geomembrane layer comprising geotextile which helps in redistribution of concentrated stresses over the geomembrane which may be due to the angular aggregates of the drainage blanket.

4.3 Side Lining System

The components of side lining system are similar to the components of basal lining system. Geocomposite clay liner is used in second layer instead of clay liner to overcome difficulty in placement over sloping surface of the bund.

4.4 Surface Lining or Top Capping

The covering of landfills requires an ideal liner system which will provide the dual functions of containing the waste materials while inhibiting the infiltration of precipitation and the ingress of vegetative and animal life (Gartung, 1996). The compacted soil liners are subjected to desiccation and shrinkage, geosynthetic lining system is preferred. Also, the substitution of the earthen layers with multilayer geosynthetic liners results in beneficial extra storage.

5. ENGINEERING PROPERTIES OF SUBSOIL

Extensive laboratory investigations are carried out to determine the engineering properties of subsoil and the results are presented in Table 2. Optimum moisture content and maximum dry density are determined by conducting IS heavy compaction test. The shear parameters are determined by testing specimens prepared at OMC-MDD with and without saturation.

Table 2: Engineering properties of sub-soil at landfill site

Engineering Property	Value
Grain size analysis	
a) Gravel (%)	25
b) Sand (%)	62
c) Fines (%)	13
Atterberg's limits	
a) Liquid limit (%)	23
b) Plastic limit (%)	18
c) Shrinkage limit (%)	17
IS classification	SC-SM
Compaction characteristics (IS heavy compaction)	
a) Optimum moisture content (%)	11.4
b) Maximum dry density (g/cc)	2.1
Shear parameters	
1) OMC-MDD condition	
a) Cohesion (kN/m^2)	2
b) Angle of internal friction	39^0
2) Full saturation condition	
a) Cohesion (kN/m^2)	12
b) Angle of internal friction	35^0

6. PROPERTIES OF GEOSYNTHETICS

Laboratory tests are carried out to evaluate the properties of Non-Woven Geotextile, Geomembrane and Geosynthetic Clay Liner used in the construction of landfill and the properties of the materials are presented in Table 3 to 5. The properties of Bentonite of GCL are presented in Table 6.

Table 3: Properties of non-woven geotextile

Property	Value
Mass per unit area (g/m^2)	400
Thickness (mm)	2.19
Compressibility (mm/kPa)	1.01
Grab tensile test a) Tensile Strength (kN) b) Elongation (mm) c) Strain (%)	 1.0 10.52 10.52
Coefficient of permeability (cm/s) a) In plane b) Cross plane	 3.5 x 10^{-4} 1.2 x 10^{-3}

Table 4: Properties of geomembrane

Property	Value
Mass per unit area (g/m^2)	2000
Thickness (mm)	2.0

Table 5: Properties of geosynthetic clay liner

Property	Value
Mass per unit area (g/m^2)	1200
Thickness (mm)	3.9
Compressibility (mm/kPa)	2.06
Coefficient of permeability (cm/s)	9.2 x 10^{-11}

Table 6: Properties of bentonite in GCL

Property	Value
Grain size analysis Gravel (%) Sand (%) Fines (%)	 0 3 97
Liquid Limit (%)	350
pH value	9
Loss on drying (%)	5.4
Free swell index (%)	425

7. PROPERTIES OF CLAY LINER

The clay used in lining system of landfill is procured from borrow area located at Lankelapalem. The properties of clay are determined from laboratory investigations and the results are tabulated in Table 7.

Table 7: Engineering properties of clay proposed for use in lining system

Engineering Property	Value
Grain size analysis a) Gravel (%) b) Sand (%) c) Fines (%)	 0 22 78
Atterberg's limits a) Liquid limit (%) b) Plastic limit (%) c) Plasticity index (%)	 45 25 20
IS classification symbol	CI
Compaction characteristics (IS light compaction test) a) Optimum moisture content (%) b) Maximum dry density (g/cc)	 16.4 1.74
Differential free swell index (%)	30
Coefficient of permeability (cm/s)	3.8×10^{-8}

8. MONITORING OF LANDFILL CONSTRUCTION QUALITY

Monitoring of landfill construction quality involved checking the stability slopes of bund, adequacy of cross section, properties of different materials used in construction whether they meet the required standards or not.

8.1 Quality of Compacted Clay Liner

A 450 mm thick layer of clay of intermediate compressibility with coefficient of permeability of 3.8 x 10^{-8} cm/s and differential free swell (DFS) of 30 % is used as compacted clay liner over the subsoil. As DFS of clay is less than 50 % and permeability is less than 10^{-7} cm/s, the clay is suitable for serving as impervious clay liner. Clay liner is formed by compacting with sheep foot roller. In-situ density of compacted clay liner is determined using core cutter. The results of compaction evaluation based on core cutter tests are presented in Table 8. As the degree of compaction achieved is more than 95 percent, the quality of compaction is satisfactory.

Table 8: Results of core cutter tests on compacted clay liner in first and second layers

Layer	First	First	First	Second	Second	Second
OMC (%)	16.4	16.4	16.4	16.4	16.4	16.4
MDD (%)	1.74	1.74	1.74	1.74	1.74	1.74
Compacted density (g/cc)	1.95	1.96	1.95	1.93	1.96	1.94
Field moisture content (%)	14.6	16.1	14.4	14.2	16.3	15.4
Compacted dry density (g/cc)	1.70	1.68	1.70	1.70	1.69	1.68
Degree of compaction (%)	97.7	96.5	97.7	97.7	97.1	96.5

8.2. Quality of Bund Construction

The bund of landfill is constructed using excavated soil from landfill area by compacting at OMC with 10t vibratory roller. Core cutter and sand replacement tests are conducted on compacted layers of bund to evaluate the compaction. Some of the results of core cutter tests from bund construction are presented in Table 9. As the degree of compaction is above 95 percent, the quality of compaction of bund is found to be satisfactory.

Table 9: Results of core cutter tests conducted during bund construction

Layer	First	Second	Third	Fourth
OMC (%)	11.4	11.4	11.4	11.4
MDD (g/cc)	2.1	2.1	2.1	2.1
Compacted density (g/cc)	2.27	2.24	2.26	2.27
Field moisture content (%)	10.3	11.2	10.8	11.1
Compacted dry density (g/cc)	2.06	2.02	2.04	2.05
Degree of compaction (%)	98.3	96.5	97.2	98

8.3. Quality of Geomembrane Joints

HDPE liner of 2 mm thickness is provided over the clay liner. As width of HDPE liner used is 7 m, number of liners are provided to cover entire width of cell and joined along length of liner with overlap joint. This overlap joint is made by wedge welding. Various tests are conducted on geomembrane joints to assess the integrity of jointing as detailed below.

8.3.1 *Tensile Test*

Tensile test is carried out on pieces cut from the joints to determine peel and shear strengths of geomembrane joints as per ASTM D 6392 and the results obtained are presented in Table 10.

Table 10: Results of tensile strength test in joints of geomembrane

Stitching Temp. (^{0}C)	Speed of Jointing (m/min)	Load (N)	Peel (N)	Shear (N)
360	1.10	1000	840	960
360	1.10	1000	750	780
360	1.10	1000	615	996
360	1.10	1000	664	853
360	1.10	1000	704	864
360	1.10	1000	761	962

8.1.2 *Air Pressure Test*

Air pressure test is carried out for a duration of 5 minutes in which 2 bar pressure is made to withstand in joints without any leakage (ASTM D5820-95). The results are tabulate in Table 11. As the pressure is sustained for 5 minutes, the jointing of geomembranes has passed the air pressure test and is considered to be satisfactory.

Table 11: Results of air pressure test

Pressure (bar)		Time HH:MM		Duration (minutes)
Initial	Final	Start	End	
2.1	2.1	16:20	16:25	5
2.1	2.1	16:30	16:35	5
2.1	2.1	11:45	11:50	5
2.1	2.1	11:55	12:00	5

8.1.3 *Vacuum Test*

Vacuum test is conducted at places of patch work done on HDPE liner. This test utilizes a pressure of 100 mm of Hg of water for a duration of 10 seconds (ASTM D5641-94). Results of air pressure test presented in Table 12 shows that the patches on the HDPE liner withstood the pressure and hence the test results are satisfactory as per CPCB norms.

Table 12: Results of vacuum test

Pressure (bar)		**Time HH:MM:SS**		**Duration (Seconds)**
Initial	**Final**	**Start**	**End**	
100 mm Hg of water		10:01:00	10:01:10	10
		10:15:00	10:15:10	10
		10:18:00	10:18:10	10
		10:25:00	10:25:10	10

9. DISCUSSION

9.1 Properties of Materials of Landfill

Engineering properties of Sub soil presented in Table 1 indicate that the sub-soil is granular material with good frictional characteristics ($\text{Ø}=39^0$) and has a maximum dry density of 2.1 g/cc. Hence, it is suitable for use in construction of landfill embankment with stable slopes. The Atterberg's Limits infer that sub-soil is stable and is low compressible in character.

Engineering properties of waste dump presented in Table 2(a) show that it has cohesion of 2 kN/m^2 and angle of internal friction of 21^0.

The properties of Non-Woven geotextile presented in Table 3 indicate that it has thickness of 2.19 mm, weight of 400 g/m^2 and in-plane permeability of 3.5×10^{-4} cm/s. Hence it is suitable as drain. The geomembrane proposed for use in landfill system is found to have a thickness of 2.0 mm which is essential for use in hazardous landfill with fill heights up to 15 m.

The properties of bentonite used in GCL, reported in Table 6 reveal that the quality is good as it has liquid limit value more than 300 % and DFS more than 400 %. The GCL is found to have permeability of $9.2\text{x}10^{-11}$ cm/s, which is considered fair for its usage in side lining system of landfills as per CPCB norms.

Engineering properties of clay sample, from borrow area located at Lankelapalem, presented in Table 7 reveal that it is clay of intermediate compressibility. The differential free swell value of clay (30 percent) is less than 35 percent, and hence has moderate swell potential. Further, it has low permeability (k = $3.8\text{x}10^{-8}$ cm/s). Hence, it is suitable to form impervious lining system at base of the landfill.

9.2 Stability of Slopes and Adequacy of Cross Section of Bund

Stability analysis using Taylor's stability numbers yielded safe slope as 1V:0.65H for 4 m high slope of bund corresponding to a factor of safety of 1.5 in sliding. However, much flatter slope, i.e 1V:3H is adopted for inner slope of embankment to facilitate laying of side lining system. The adequacy of bund section is checked for safety against sliding, overturning, bearing failure and no tension condition against the lateral thrust from pharmaceutical waste dump. As the outer slope of embankment (1V: 0.65H) from slope stability analysis is found to be inadequate for stability against sliding, the outer slope requirement is revised to ensure a factor of safety of 1.5 in sliding as 1V : 1.2 H. Hence, the adopted outer slope of bund of 1V : 2H is adequate to contain the waste.

9.3 Quality Control Assessment of Landfill Construction

The results of compaction evaluated from core cutter tests on clay liners and bund revealed that degree of compaction achieved is more than 95 percent and hence the quality of compaction is satisfactory.

The Air Pressure tests conducted on joints of geomembranes under a pressure of 2 bar, conducted for 5 minutes indicated that pressure is maintained without any drop for a duration of 5 minutes. Hence, the jointing of HDPE liner sheets is found to be satisfactory. Results of vacuum tests revealed that the patches on the HDPE liner withstood the pressure of 100 mm of Hg for a period of 10 s and hence the test results are satisfactory as per CPCB norms.

Joints of HDPE liner should have a minimum peel value of 590 N and minimum shear value of 735 N. Tensile strength test results of samples collected from the joints are observed to be more than that of minimum values and hence jointing of liners is satisfactory as per CPCB norms. Tests performed on geotextile collected from the site during construction at random indicated that the properties are as per the specifications.

10. CONCLUSIONS

The following conclusions are drawn from the quality control carried out in the study.

- The site of landfill for containing Pharmaceutical (hazardous) waste under study is ideally suited as water table is present at deep depth and the subsoil consists of gravelly soil which has high bearing capacity.
- The proposed Bund Section is safe to withstand the thrust from pharmaceutical waste dump and slopes adopted on outer and inner sides are stable.
- The excavated soil from the site for forming drains and base lining of landfill is used in construction of bund as it is suitable being gravelly soil and thus reduced cost of construction of bund.
- As pharmaceutical waste is hazardous, the landfill construction involved usage of double base lining system.
- Materials of basal and side lining systems tested in the study passed the quality control tests and are suitable for the construction of engineered landfill as per ASTM and CPCB standards.
- Jointed Geomembranes of landfill are observed to be airtight and possess tensile strengths more than the minimum prescribed values and hence, quality of jointing is satisfactory.

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