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DESIGN, CONSTRUCTION AND OPERATIONAL ASPECTS OF SOLID WASTE LANDFILLS IN GERMANY

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ABSTRACT

Over the past two decades, owing to public awareness of environmental issues the need for waste containment systems is being increasingly felt, be it municipal waste or industrial waste. For municipal solid waste, landfills are being adopted world over in which wastes are placed for permanent disposal. This paper highlights the design, construction and operation aspects of solid waste landfills in Germany. Three landfills including Europe's largest and modern landfill design and operation details are reported.

INTRODUCTION

The municipal solid waste generation rate particularly in metropolitan cities is showing an increasing trend with an increase in population and migration of people to the cities. The waste disposal systems can be seen in the outskirts of a city usually in the form of open dumps, which can cause severe epidemic hazards to the inhabitants in the surrounding areas. Waste disposal methods like burning the waste are still in practice in developing countries, in particular in India. Though the waste disposal by burning reduces the quantum of waste, but pollutes the atmosphere with the huge amount of organic and inorganic gases. In addition due to on-going bio-degradation the leachate generates, which can contaminate the ground water resources. In the Indian context, the development of landfill concept is still in infant stage. Contrary to this, western countries recognised the dire necessity of landfills in the late eighties itself.

Figure 1 shows the schematic representation of unregulated and regulated waste disposal sites. As shown in Fig. 1a, there are many sites where wastes were disposed without any strict regulations. These sites may therefore be called as unregulated landfill sites or open waste dump sites. The open dumping of waste is being followed in India to a large extent except hospital waste which is being incinerated. Generally, leachate from these landfills and liquids from surface impoundment's may seep into the ground water and contaminate it. As shown in Fig. 1b, the waste can be disposed with the aim of producing a safe landfill, which is stable and whose containment elements should minimize emissions into air, soil and water over a long period of time. Figure 1b shows the typical cross-section of landfill with subsoil, basal lining and capping system respectively.

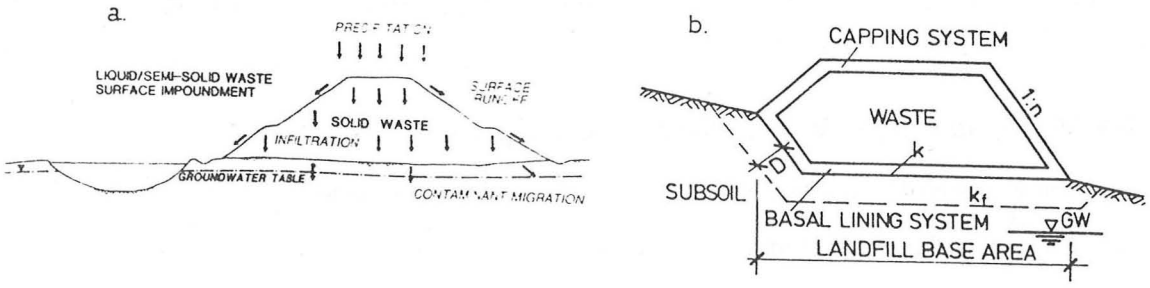


Fig. 1 a. Unregulated landfill and b. Regulated landfill

The landfill safety concept comprises of the following factors (I) the type, quantity and geotechnical parameters of the waste, (ii) the geology and hydrogeology of the site, (iii) the shape of the waste pile and (iv) design of lining systems **(4)**. The migration of contaminants to surrounding ground water (Fig. 1a) can be isolated by installing slurry cut-off walls.

Figure 2 gives the details of the possible components of landfill. These components are incorporated into the design with respect to the so called multi - barrier concept. The safety elements must be set out both in their independent functions and in their mutual influence and overall safety effects. As can be seen from Fig. 2, the waste is encapsulated by the basal lining system and the capping system. As per the German approach, it is the practice to combine a mineral sealing layer with a synthetic flexible membrane (Geomembrane) placed directly on top of it. The mineral sealing layer is one of the components of the lining system, which is generally made-up of compacted clay of low permeability characteristics. The drainage blanket that is positioned over the mineral sealing layer, which may be covered with a protective layer, is integrated in to the sealing system. The technical regulations adopted in Germany for the component sealing systems for basal lining and capping system **(5)** are as follows :

(a) Basal lining system:

- mineral sealing layer (low permeability soil layer) thickness 'd ' > 1.5 m; clay mineral content > 10%; permeability 'k' < 5×10^{-10} m/s, inclination > 3%.
- geomembrane thickness 't' > 2.5 mm, specified material.

(b) Capping system

- mineral sealing layer (low permeability soil layer) thickness 'd ' > 0.5 m; clay mineral content > 10%; permeability 'k' < 5×10^{-10} m/s, inclination > 5%.
- geomembrane thickness 't' > 2.5 mm, specified material.

The details of technical specifications and design details are not discussed in this paper. More details regarding geotechnics of landfill design and remedial works are contained in **(2, 4 and 6)**.

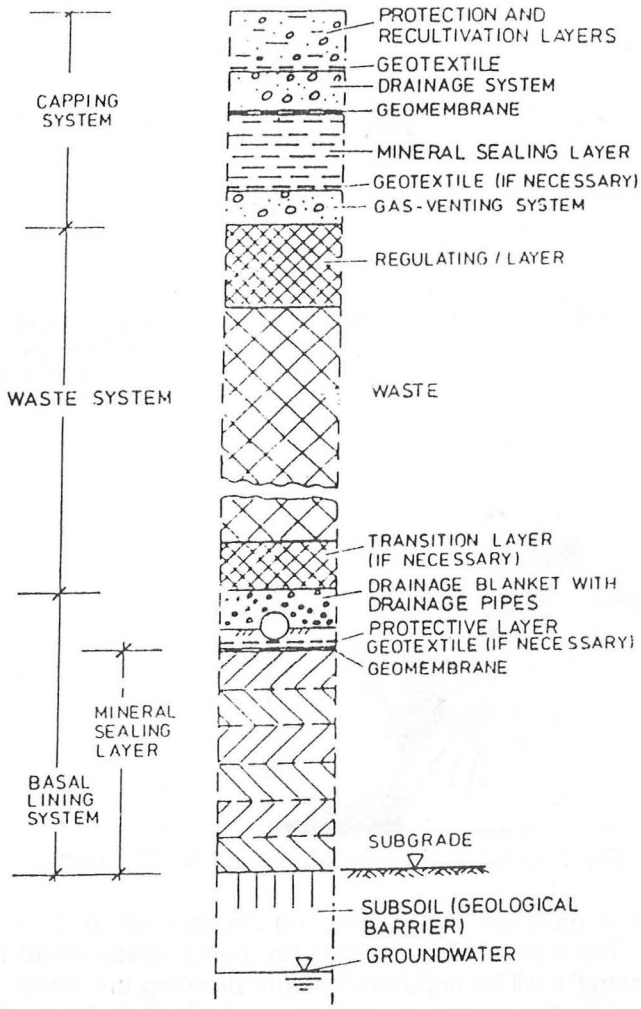


Fig. 2 Possible components of the landfill capping system

In this paper, the design, construction and operational aspects adopted at three landfill sites are discussed. The main intention of the authors is to bring the awareness of design, construction and operation aspects of landfill technology in the Indian context.

DORTMUND (N-E) LANDFILL

The Dortmund (N-E) landfill is one of the Europe's largest and modern landfill. The Dortmund (N - E) is located in between Dortmund-Derne and Dortmund-Lanstrop towns . The plan for having a landfill was initiated in 1984 and after getting the necessary approvals, the landfill construction was began in October, 1992. The design life period of the landfill is 25 years with a total landfill area of 141 hectares. Out of this approximately 6 hectares was devoted for transportation network within the landfill area. The construction period was about one and half years and the Dortmund landfill was opened for waste disposition in May 1994. In the backdrop to the Dortmund (N - E) landfill, there is an existing Grevel landfill and slopes of the coal mines add to landscape aesthetics. Figure 3 shows the location map of Dortmund (N -E) landfill along with access to German National Highway (GNH) A1. The planned transportation network for movement of loaded and unloaded trippers can be seen from Fig. 3. (represented with arrows). The traffic due to trippers is planned in such a way that the city network is not effected with the vehicles carrying waste.

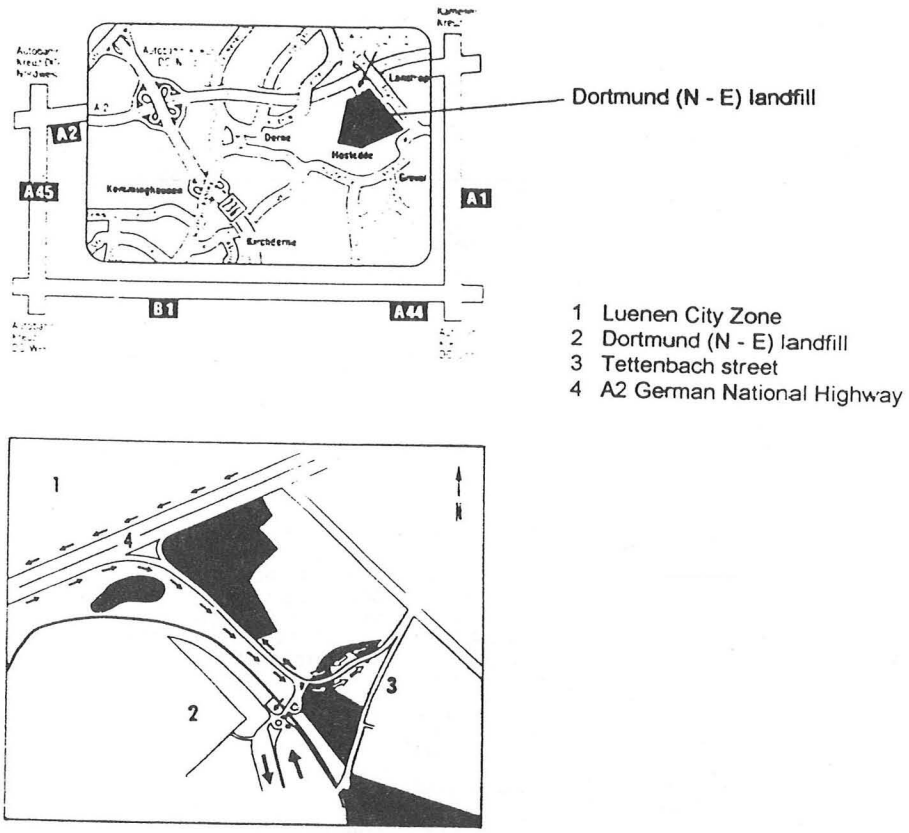


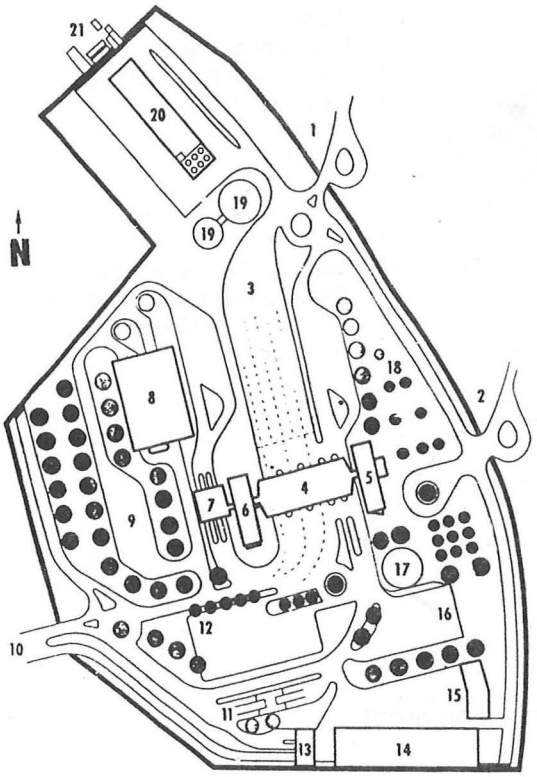
Fig. 3 Location map of Dortmund (N - E) landfill

The Dortmund landfill, in particular has a recycling concept with a main aim in reducing the quantity of the waste. The worth-while materials like paper, glass, white metals like tins etc., and other relevant materials will be separated before diverting the waste for deposition. The organic waste is reused after composting as a very useful fertilizer for agricultural applications. The residual organic waste is burned and diverted for deposition. One of the major state - of - art - technology adopted in the Dortmund (N -E) landfill is deposition of the waste depending upon its type and characteristics. The various design, construction and operational aspects are explained in the following sections **(1)**.

Entrance and clearance zone:

Figure 4 shows the layout of Dortmund (N - E) landfill infrastructure along with various operation systems. The solid waste collected from the city source points will be cleared, weighed and recorded at the entrance and clearance zone. Towards the identification purposes and checking purposes, the sampling will be done for laboratory analysis. The solid waste, which can not be admissible for deposition in landfill will be diverted temporarily to security area till the final decision of valid analysis arrives. After checking at the entrance, the trippers will be allowed to deposit the waste at respective zones. At the south - west end in Fig. 4, the entrance can be seen for landfill deposition. The empty trippers are needed to pass through tyre washing unit to avoid spoiling of national highways with waste. In the service building, the weight control personnel and other landfill administration are seated. The laboratory building is used for identification tests on waste and chemical analysis tests. The clearance zone between the service building and laboratory building also informs about weather conditions and the necessary protection measures. Towards the southern end of the clearance zone, the multi-purpose/equipment hall is located. Adjacent to equipment hall, a tank station is located to serve for the vehicles within the landfill zone. The water collected

from entrance and clearance zone will be diverted in four different drainage systems. The runoff water from roof areas and transport areas is allowed to flow through the underground drains. Towards the north end the buffer pools are located to collect the trickling water from the inorganic and organic waste respectively. The trickling water treatment unit and the gas utilization/energy station is a complete major infrastructure for a landfill.



1 Exit BAB
2 Tettenbach Street - Emergency exit
3 Collection zone
4 Entrance and Clearance / Weighing zone
5 Service building
6 Laboratory building
7 Sampling
8 Security area
9 Park area
10 Landfill
11 Tyre washing unit
12 Container
13 Tank station
14 Multi-purpose/equipment hall
15 Tripper yard
16 Free area for problematic waste / sandwich layer
17 Zisterne
18 Parking place
19 Trickling water buffer pool
20 Trickling water treatment
21 Gas utilization/Energy station

Fig. 4 Layout plan of various units of Dortmund (N - E) landfill

Deposition areas:

The deposition of waste in Dortmund (N -E) landfill is sorted in terms of inert, inorganic and organic waste. This was adopted to have better control on the state or condition of the waste after closure of landfill (Prior to this in other landfills in Germany, mixed deposition is allowed. The mixed deposition is one wherein no separation of waste is carried out before deposition). Figure 5 shows the layout of the Dortmund (N - E) landfill with waste deposition areas. At the northern end, the inorganic waste is deposited with the main constituents like slag, ashes and similar materials. The inert waste consisting of primarily soil and construction waste is deposited at the southern end. In the central portion, organic waste is deposited. Each zone is provided with separation dams to prevent contamination within the landfill. Out of the above, the inert waste relatively produces less emissions and the settlement behaviour is more or less like soil. A large amount of settlements are anticipated in the organic waste deposition zone due to the on-going biological decomposition. The landfill gases and leachate, which are produced are collected at the trickling water treatment plant/energy station (Fig. 5).

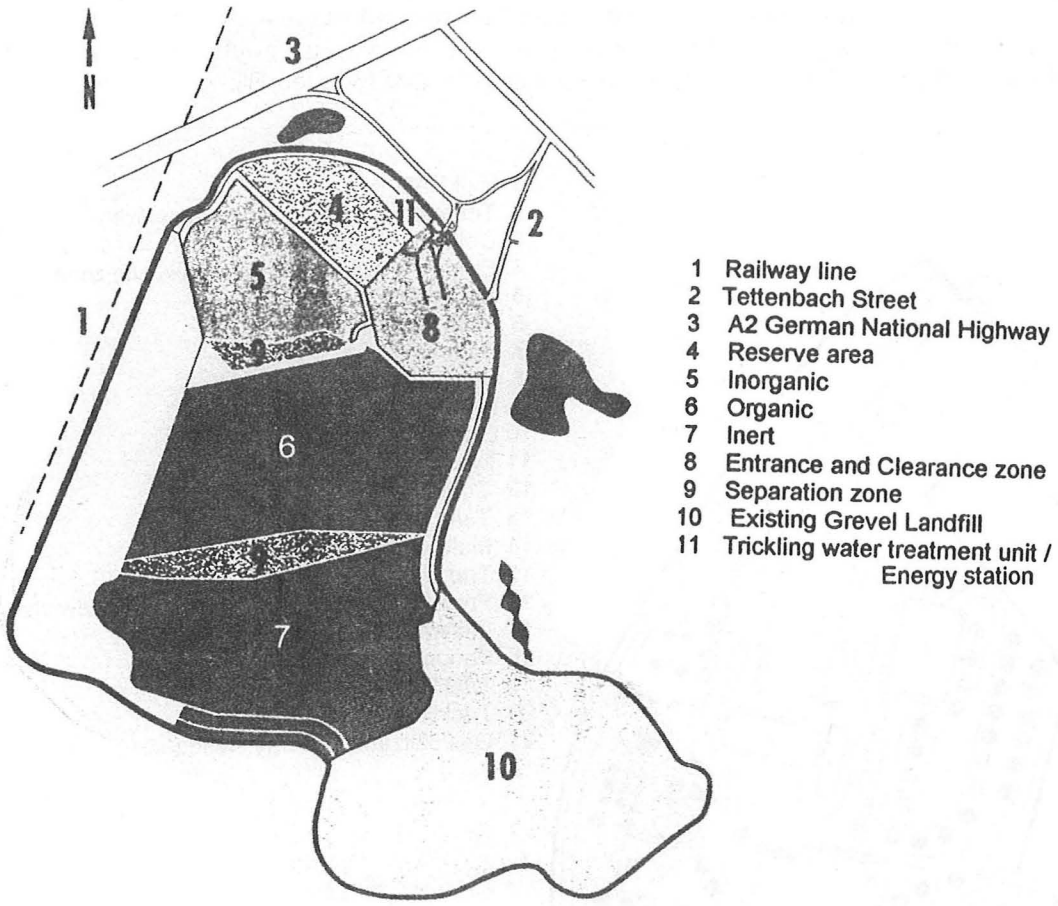


Fig. 5 Landfill deposition areas

Multi - barrier system:

The safe disposal of waste is successfully achieved by ensuring the impermeability of the total landfill system. Therefore the properly compacted waste itself may act as barrier. Typical cross - section of landfill, along with basal lining system and capping system is presented in Fig. 6. The runoff water migrating through waste along with soluble pollutants collects in the surface drainage system provided with gravel in the basal lining system. Besides this, during the construction and post - closure period, a controlled gas retrieval system is planned in the organic waste deposition zone. After achieving the desired height of landfill, a surface capping system (as shown in Fig. 2) is provided to encompass the waste deposited in the landfill area (Fig. 6).

In organic and inorganic zone, the basal lining system was constructed by adopting composite lining system. The cross-section of the existing basal lining system is given in Fig. 7. The basal lining system mainly consists of (i) One meter thick mineral sealing layer (made up with clay), (ii) 2.5 mm thick geomembrane layer and non-woven geotextile for protection, (iii) 15 cm sand protection layer and (iv) 50 cm drainage layer (Gravel). The relatively low-permeable clay is compacted in four lifts, with each lift of 25 cm. The geomembrane delivered by the manufacturer in 5 metre width rolls was installed above the surface of the clay layer.

The long-term observations of landfill behaviour will be controlled and recorded. This includes, the settlement behaviour of landfill, generation potential of leachate and gas generation. The above observations will help in assessing the in-visible state or condition of the solid waste.

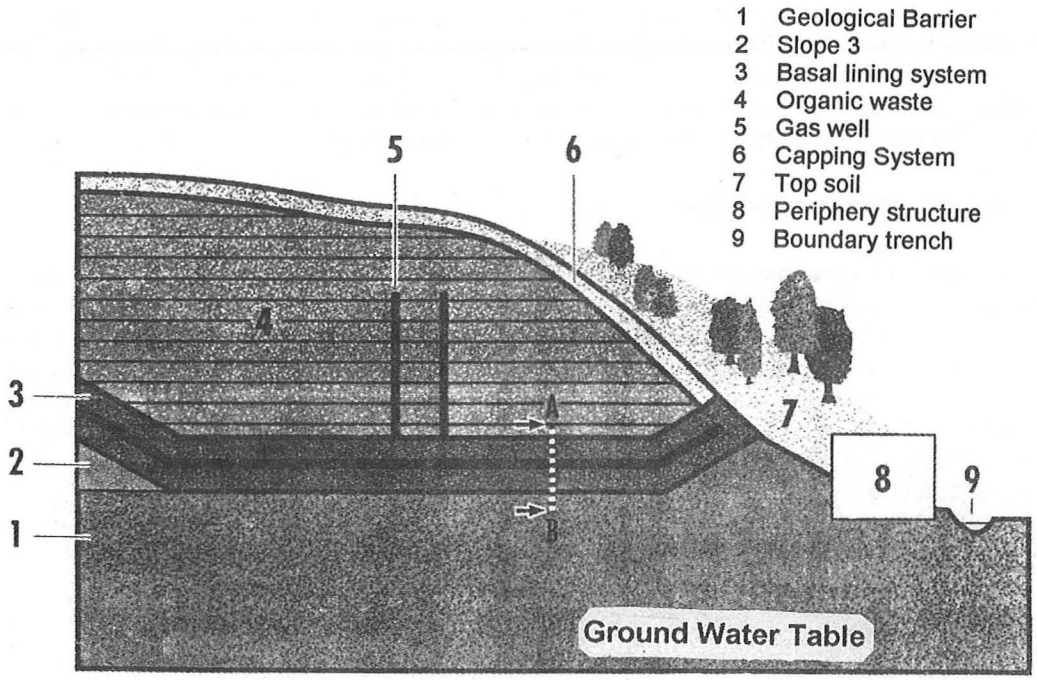
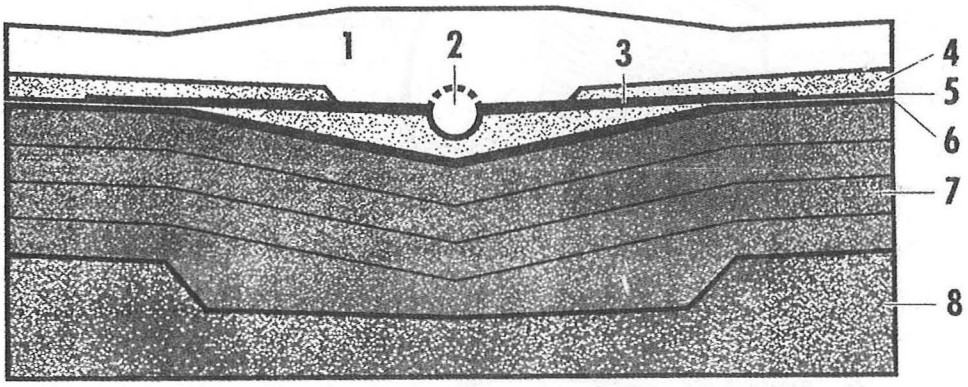


Fig. 6 Cross - section of Dortmund (N - E) landfill



1 Drainage layer 16/32 mm
2 Trickling water collector through PE-HD, PN 16, dia. 400 mm
3 Bentonite mattress, (thickness 't' = 10 mm)
4 Protection layer, Sand, Grain size 0/8 mm
5 Non-woven geotextile for protection (1200 gsm)
6 Geomembrane (PE-HD, t = 2.5 mm)
7 Mineral Sealing layer (Clay) in four lifts, each lift 25 cm
8 Geological barrier

Fig. 7 Typical cross - section of basal lining system

Landfill drainage:

The trickling water with pollutants, which will get generated from the waste body will be collected in the drainage system provided in the basal lining system. In order to prevent any clogging, the surface drainage system is provided with good permeability characteristics. Figure 8 shows the total landfill drainage system adopted in the Dortmund (N-E) landfill. The trickling water generated from the respective organic, inorganic, and inert waste is diverted through drainage collection pipes is transported to the treatment plant via organic/inorganic buffer pool. The trickling water flow network is represented through arrows in Fig. 8.

Control and maintenance works:

In order to ensure the prevention of clogging of drainage pipes, a control and maintenance during construction and the post-closure period is essential. A view of Dortmund (N-E) landfill is presented in Photo 1. By considering its significance and potential, an indigenous methodology is being adopted at Dortmund (N - E) landfill. Figure 9 shows the checking and maintenance of the trickling water collection pipes. In the first step, the pipe is jetted with highly pressurized water. After cleansing the pipe, condition of the pipe is observed by introducing camera (Fig. 9). The camera observations and the measurements will be helpful in indirectly in predicting the landfill behaviour with higher safety standards. The pictorial view of the camera observation chamber along the edge of the landfill can be seen from Photo 1. In the backdrop, the waste dump in the landfill can also be observed.

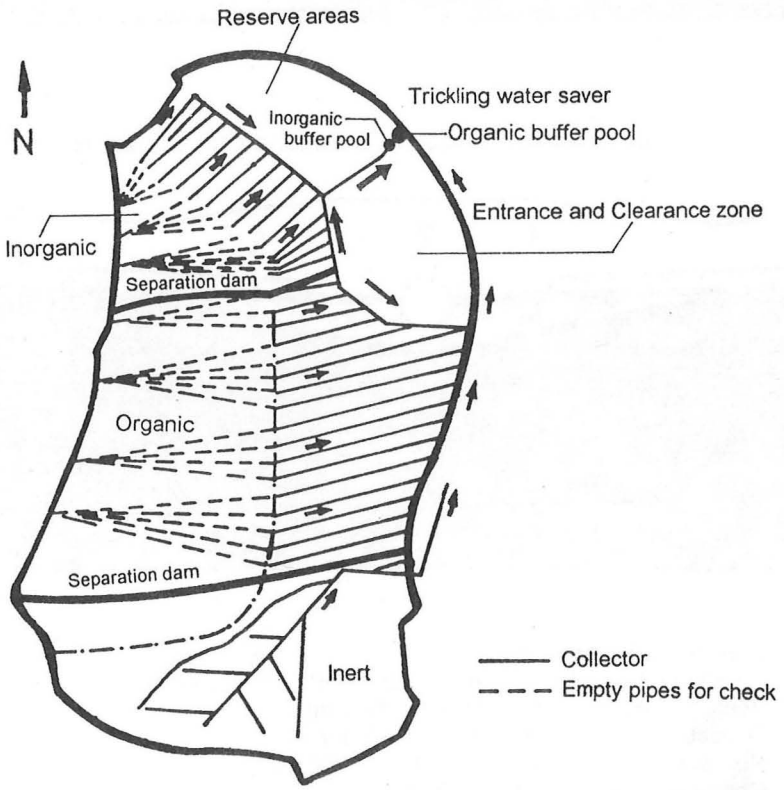
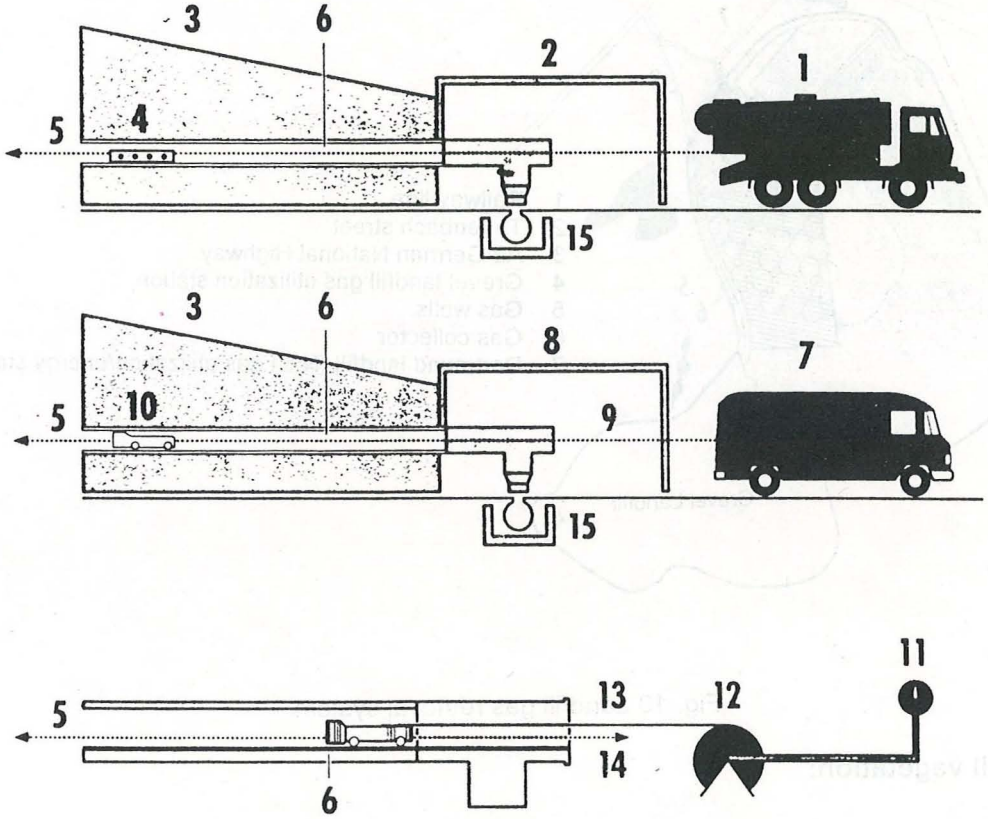


Fig. 8 Landfill drainage system

Photo 1 Dortmund (N - E) landfill along with camera observation chamber



1 Cleaning vehicle; 2 Control room1; 3 Landfill - boundary dam
4 Cleaning spear; 5 Tensioned cable; 6 Trickling water collector
7 Vehicle mounted with Camera; 8 Control room2
9 Cable and tensioned reaction cable; 10 Camera
11 Pressure gauge; 12 Tube roll; 13 Tube
14 Tensioned reaction cable; 15 Collection unit

Fig. 9 Checking and maintenance of trickling water collection pipes

Controlled gas retrieval system:

When organic material decomposes the gas generation will take place. Such type of gases mainly generate due to the presence of putricible matter or household waste. The landfill gas mainly consists of CH_4 and CO_2 . The landfill system without any technical measures could lead to uncontrollable build-up of gas along the surface capping system. The pollutants in the gas will carry over to the surroundings causing environmental pollution. Figure 10 shows the landfill gas retrieving system adopted along the base of the landfill. The retrieval system consists of gas wells and gas collection pipes. The gas retrieval system for the organic deposition zone is presented in Fig. 10. The generated gas will be sucked with pressure through landfill wells. The generated methane is reused for generating electrical/thermal energy for the functioning of the various systems in the landfill area with self-dependency.

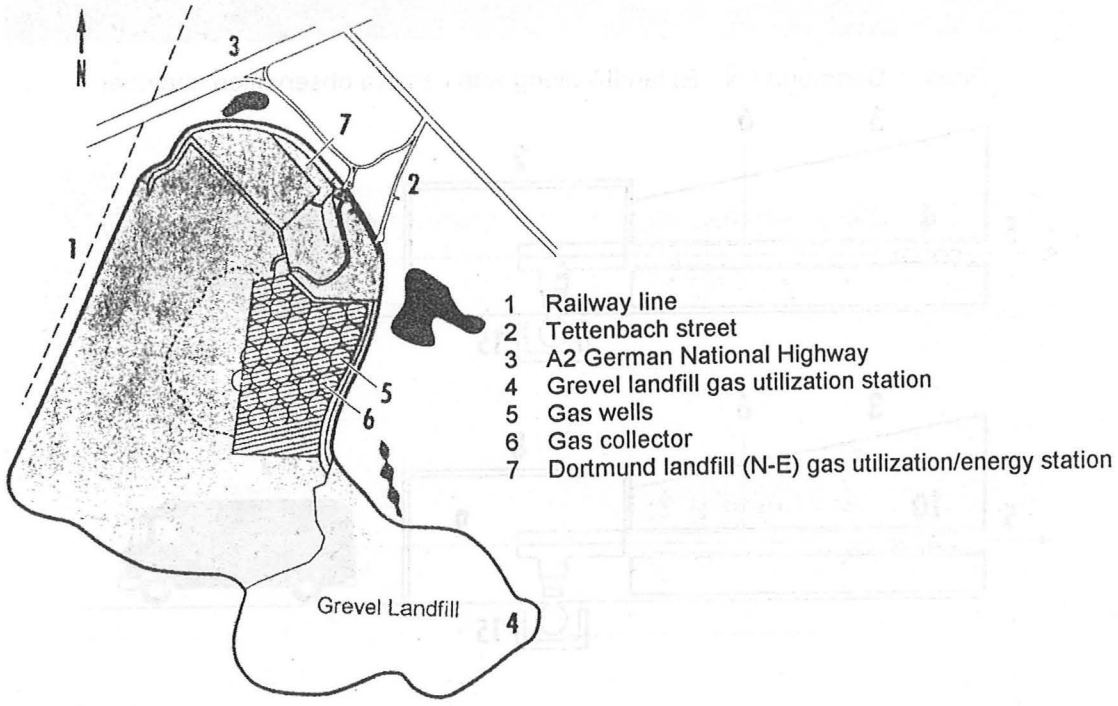


Fig. 10 Landfill gas retrieval system

Landfill vegetation:

The landfill vegetation is an equally important aspect for the landfill maintenance and operation. In order to vegetate the landfill, normally one meter thick cover soil is provided above the drainage layer of the capping system. While vegetating the landfill, a precautionary measure is to see that the roots will not penetrate through the mineral sealing layer of the capping system. Otherwise, this could damage the integrity of the liner systems. Finally, a green landfill is an acceptable landfill both from environmental and aesthetic point of view.

FRIESLAND/WITTMUND LANDFILL

The Friesland/Wittmund landfill is located in the northern part of Germany. Due to an increase in amount of the solid waste from the city zone, it was planned to enlarge the existing landfilling facility. Photo 2 presents the view of old existing landfill in the backdrop along with drainage blanket. The old landfill is closed and sealed with lining systems. The area is opened for dumping the waste. The waste collected by the trippers from the different collection points from the city zones is allowed to dump after preliminary processing. The typical cross-section of the Friesland/Wittmund landfill along with the lining systems for the new landfill is presented in Fig. 11. The slope of the existing landfill is covered with the restoration profile in the from of sand. It is overlaid by gas drainage layer of 50 mm thickness. A mineral sealing layer of 85 mm thickness is laid over the drainage layer. Over the mineral sealing layer till the toe of the slope, a layer of cover soil consists of mainly cohesive nature is placed (50 mm thick). Over the restoration layer, a mineral sealing layer of identical thickness is continued (85 mm). Along the slope and overlying sand protection layer at the bottom of a surface drainage layer was placed.

Photo 2 View of the existing landfill along with the drainage measures

Non - woven geotextiles for separation and protection are used along the interface of the mineral sealing layer and drainage layer. The geotextile used is with strengthening fibers. The specifications like mass per unit area are presented in Fig. 11. A 2.5 mm thick geomembrane was placed on the top of the mineral sealing layer to increase impermeability of the system and to prevent leakage of leachate etc. The geotextile fabric was used for tension reinforcement at the top of the slope. The fabric is anchored at the top within the cover soil. Photo 3 presents the view of the non-woven geotextile laid on top of the drainage layer.

The basal lining system is an important component of the landfill. The main purpose is to divert landfill drainage and to prevent the leakage of leachate generated due to on-going biological decomposition with the help of mineral sealing layer overlaid by geomembrane layer. To protect the geomembrane from damage and rupture, a layer of non-woven geotextile is placed. The mineral sealing layer is made-up of low permeability soil and compacted in small lifts. Figure 12 shows the typical cross-section of the basal lining system provided in Friesland/Wittmund landfill. At the central portion, a drainage pipe (porous) is laid to collect the trickling water. The surface drainage layer of the basal lining system spread over the new landfill is shown in Photo 2. It is also seen from this photo that the deposition area is divided into number of compartments.

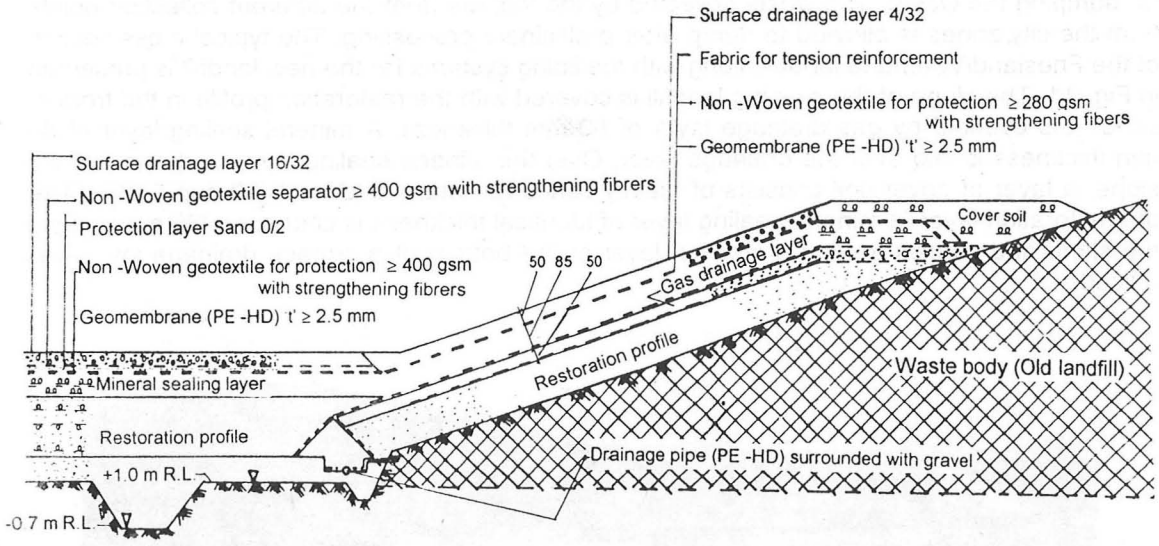


Fig. 11 Typical cross - section of Friesland/Wittmund landfill

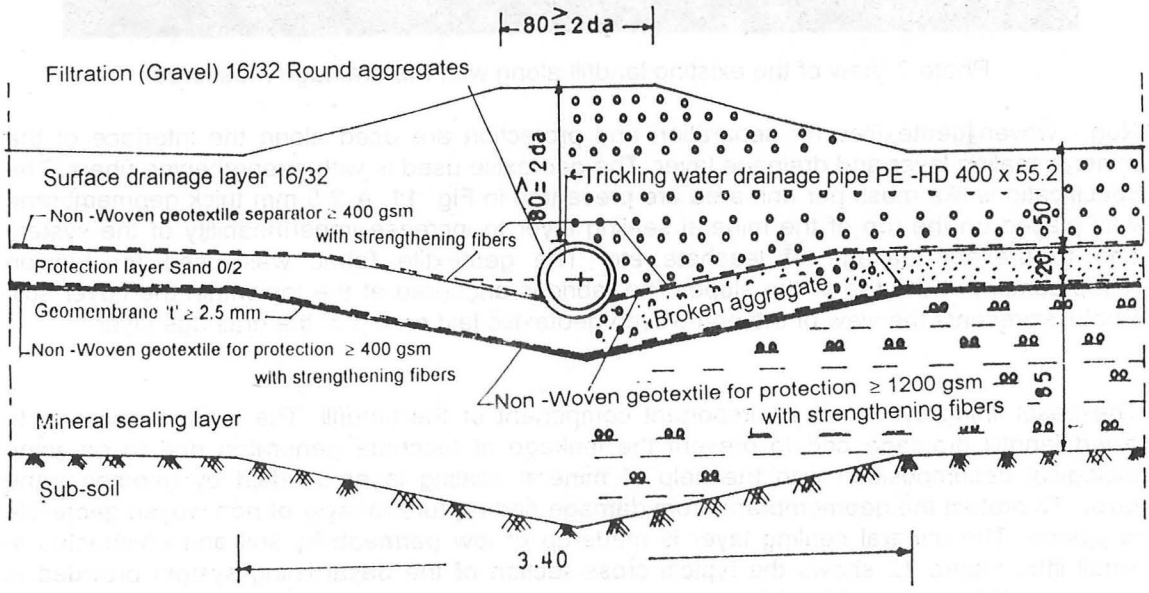


Fig. 12 Typical cross - section of the basal lining system at Friesland/Wittmund landfill

Photo 3 View showing drainage layer overlaid by non-woven geotextile

Once the landfill deposition area is cleared from all aspects the waste which arises from the city source points is allowed for dumping. The deposited waste is compacted by using sheep foot roller cum dumper. To avoid light weight constituents from flying, area is surrounded with fence protection. The daily waste deposited in one of the compartments in the new landfill is shown in Photo 4.

Photo 4 Waste deposition in Friesland/Wittmund landfill

Photo 5 presents the view of completed slope portion of the earth fill. Leachate collection control point can been seen from Photo 5. In the backdrop, it is also seen from this photo a plant for treating the leachate collected due to on-going decomposition of the waste.

Photo 5 View showing leachate collection control point and treatment plant

BOCHUM LANDFILL

All industrialised countries have problems with the contaminated land and abandoned landfills. A new remediation concept adopted for one of such sites developed by Jessberger & Partners, Bochum, Germany is reported here with a particular emphasis on providing containment. A former sand pit located in the outskirts of Bochum city, Germany was used for dumping municipal waste, industrial waste and construction debris. The site covers an area of 2700 Sq. m with a depth of 10m with some 10, 000 m^3 of contaminated material. The contaminants include heavy metals, such as mercury, lead and arsenic together with organic compounds. The ground water level is about 20 m below the ground level. The surrounding uncontaminated soil is found to be sand to silty sand. In spite of replacing the huge amount of contaminated material a remediation concept was recommended at Bochum landfill.

The remediation concept aimed at providing containment comprises the following sequential steps **(3)**. (i) Excavation of the upper 1 to 2 m of contaminated soil, (ii) Decontamination of organic compounds in an incineration plant, (iii) Installation of capping system, (iv) Suction and treatment of the soil - air and (v) Surface water collection. An overall view of the site is presented in Fig. 14 and Fig. 15 shows the details of the capping system adopted in remediating the landfill.

The capping system consists of primarily surface drainage layer, geocomposite, geomembrane (2 mm thk.), regulation layer etc. The remidiation concept is acceptable if the waste or the contaminated soil is not in direct contact with the ground water. If the contaminants are transported by infiltrating through surface water, the capping system cuts off this potential pollutant migration. The soil - air collection and treatment system together with the capping system prevent uncontrolled gas emission and results in a continuously decreasing concentration of organic compounds in the soil - air. The encapsulation of the abandoned landfill by a capping system incorporating active gas venting proved to be an appropriate and economical solution at this site.

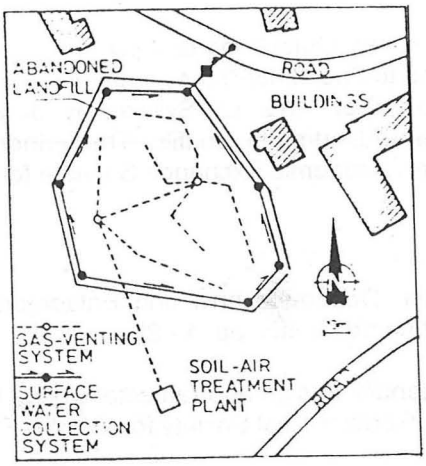


Fig. 14 Site plan of an abandoned landfill in Bochum
(After Jessberger, 1993)

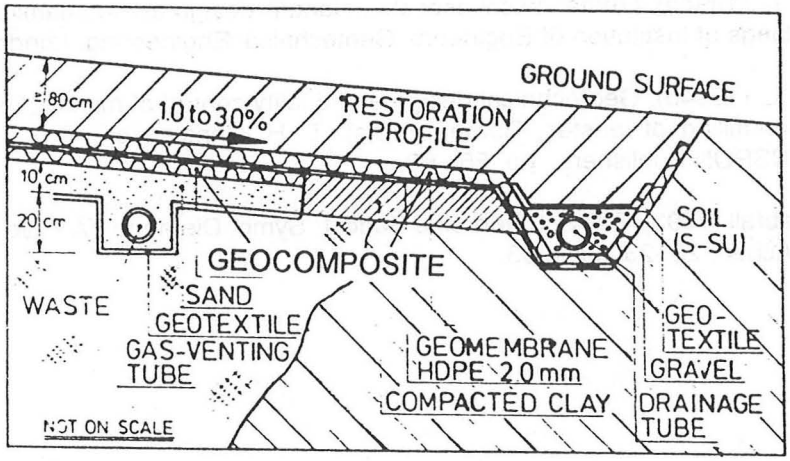


Fig. 15 Details of the capping system
(After Jessberger, 1993)

CONCLUDING REMARKS

Based on the descriptions of the landfills presented in this paper, the following observations may be made:

- A total well controlled, designed and monitored landfill is necessary for the safe disposal of the solid waste.

- The waste deposition depending upon its type and characteristics could be a viable alternative for proper assessment of the state/condition of the waste.

- The landfilling system does not end up by mere provision of liner systems for sealing the waste. It shall include the various units like landfill drainage systems, landfill gas retrieval systems and trickling water treatment plant/Energy station. This should serve as an example of development of landfilling systems in India.

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