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DESIGNING OF DOUBLE LINED IMPOUNDMENTS—LESSONS LEARNED
ARCHITECTURE DE RESERVOIRS A DOUBLE PAROIES — LECONS APPRISES
KONSTRUKTION VON SPEICHERBECKEN MIT DOPPELTER DICHTUNG — PRAKTISCHE ERFAHRUNGEN

A case history on the use of geosynthetics in rehabilitating two adjoining surface impoundments is described. The rebuilt impoundments represent a new breed of impoundments being constructed in the United States, primarily in response to strict governmental regulations for mitigating adverse environmental impact from waste management facilities. The impoundments each have two synthetic liners and one clay liner, two leak detection and collection systems, and two gas venting systems. Geomembranes, drainage nets, and geotextiles were used for several of these components. The use of readily available technical publications and manufacturers' literature on geosynthetics expedited the design and preparation of construction documents. A comparison is made between key design features and minimum technology requirements recently proposed by the U.S. Environmental Protection Agency (EPA).

Im vorliegendem Artikel wird der Einsatz von Geosynthetics bei der Sanierung von Schadstoffreservoiren mit doppelter Dichtung beschrieben. Dieses Verfahren ist neu und bezieht sich auf die kürzlich veröffentlichten strengen U.S.-Bedingungen über Grundwasserschutz bei Mülldeponien. Die Becken haben 2 synthetische Dichtungen, eine Lehmdichtung, 2 Drainagesysteme und 2 Gastransportsysteme. Für diese Komponenten wurden Geomembranen, Geotextilien und spezielle Drainagematten verwendet. Mit Hilfe vorhandener technischer Publikationen und Herstellerschriften konnten die Konstruktionsunterlagen rasch erstellt werden. Die ausgeführte Konstruktion wird mit den kürzlich veröffentlichten Mindestansprüchen der amerikanischen Umweltschutzbehörde (EPA) verglichen.

BACKGROUND

Owners of industrial plants want the assurance of cost-effective and predictable facilities, and are disappointed when a particular facility does not perform as expected. Such was the case with a pair of liquid waste impoundments at a chemical manufacturing plant. Over a period of several years, the initial basins experienced several problems, including: loss of synthetic liner integrity, primarily due to failure of about one-half of the cemented seams; soil slumping under the liner on sideslopes at about the normal operating waste level; methane gas accumulation in 1- to 3-m (2.7- to 8.2-ft) diameter pockets under the liner; partial plugging of the leak detection system; and deterioration of the backup clay liner. Although the basins continued to be serviceable, the Owner determined that a major upgrade was necessary.

Concurrent with the technical need to rehabilitate the basins, the regulatory status of the basin system was also changing. Regulations issued by EPA under the Resource Conservation and Recovery Act (RCRA) required the plant to apply for hazardous waste permits or permit exemptions for its waste facilities by a date that roughly coincided with the design studies. The outcome of a request to exempt the facilities from RCRA regulations was not anticipated to be known until after designs were completed. Additionally, EPA's requirements for the design of surface impoundments were also evolving, and design criteria for impoundments such as the ones being rehabilitated had not yet been finalized.

Preliminary planning by the Owner indicated that the most cost-effective solution to deterioration of the basins and the one most expedient from a regulatory standpoint was to rebuild the basins in place. It was intended that the two basins would be individually removed from service for a period of about 2 months, during which time the existing liners and softened soils would be removed, the basin sideslopes and bottoms rebuilt, and new liner systems installed. Work would be scheduled to rebuild one basin in each of two summer construction seasons. The Owner's stated objective for the project was to extend the service life of the reconstructed basins for a minimum of 20 years, without incurring major maintenance costs. It was also determined early in the project that the basins would be reconstructed to meet present and reasonably forseeable requirements for surface impoundments under RCRA, to minimize the possibility of future basin upgrades as a result of regulation changes over their service life.

EPA's regulations at the time of the design stage required one or two liners, depending on plans for groundwater protection at the waste management facility. Exemption from groundwater monitoring requirements necessitated the use of a double-liner design with a leak detection system between the liners. Liners could be constructed either with synthetics or compacted soil, depending on closure plans for the impoundments. For example, impoundments closed with wastes left in place were required to have liners that prevented the migration of wastes into the liner (synthetics). Impoundments from which wastes would be removed at closure could be designed with compacted clay, provided that migration of wastes to the soil or groundwater below the impoundment was prevented during its active life. Based on EPA regulations and guidelines available at the start of the design stage, the Owner accepted Dames & Moore's recommendation that each basin was to have two synthetic liners, each with a leak detection system, and a backup clay liner.

The Owner's experience with the initial basins had shown that selection of suitable synthetic materials for the liners and geotextiles was a key element in the design process. A liner consultant, engaged prior to Dames & Moore's design work, conducted several months of onsite, full-scale testing of prospective liner materials. Liner samples, including seams, were mounted on large frames suspended on inside slopes of the existing basins. By using large frames that extended over about 6 m (20 ft) of the slope, samples were exposed to all field conditions from air exposure to full immersion. Following a year of testing, high-density polyethylene (HDPE) was determined to be the most suitable liner material. Knowledge gained during the liner testing also facilitated the selection of geotextiles compatible with the waste liquid.

FACILITY DESCRIPTION

The wastewater impoundment system at the plant consists of two contiguous basins that equalize and/or store plant effluent for eventual discharge to an industrial wastewater treatment plant. The larger of the two basins is about 43 m (140 ft) by 100 m (330 feet) in plan, and has a working capacity of 17,000 m^3 (4.5 x 10^6 gallons). It is used for equalizing and mixing day-to-day plant effluents prior to discharge. The adjacent, smaller basin is 26 m (84 ft) by 100 m (330 ft) in plan, with a capacity of 11,300 m^3 (3.0 x 10^6 gallons). Effluents with higher waste concentrations and spills are diverted to the smaller basin, stored, and later metered slowly into the discharge pipeline.

The site of the impoundment system was formerly occupied by a fly ash (fine residue from the combustion of coal in the generation of electricity and steam) settling basin; the basin was closed when coal burning was discontinued at the plant. Both fly ash and local sandy clay soil were used to construct the basins. The enclosing embankments were about 3.4 m (11 ft) high, with interior sideslopes of 3 horizontal to 1 vertical (3:1), and exterior sideslopes of 2:1. The bottoms of the basins were level, and the entire interior of each basin was lined with an EPDM liner placed over a prepared base of sandy clay soil. Vitrified clay drain tiles connected to a sump external to the basins were installed in the sandy clay soil beneath the liner.

In operation, plant effluents were directed to either basin via a 450-mm (18-in.) diameter stainless steel pipeline, and entered the basins through vertical inlet risers penetrating the basin floors. The larger, equalizing basin had a decant structure at the opposite end and a 450-mm (18-in.) diameter discharge pipe. The smaller diversion basin used a 300 mm (12-in.) diameter discharge pipe, without a decant structure. The basin outlet pipes joined at a mixing chamber and measuring flume, before joining the pipeline to the industrial treatment facility.

DESIGN CRITERIA

Meetings between the design team and the Owner were held early in the project to define the key elements of the then present operating difficulties, and the design criteria and constraints for the basins' rehabilitation. The resulting criteria pertinent to this paper include the following:

- The basins would be redesigned to meet current or forseeable RCRA standards for hazardous waste impoundments.
- Design would be for a minimum 20-year life, with emphasis on preventing leaks, leak detection, and preventing gas accumulation.
- Recommendations of the liner consultant would govern materials selection.
- The reconstructed basins were to contain no less than their present capacity, therefore a thin liner system cross-section was preferred.
- Slumping of basin interior sideslopes was to be prevented.

DESIGN APPROACH

The key element of this project was the design of an integrated liner system for the containment of liquids, the detection and collection of leaks, and the venting of gases. Our design approach started with a review of technical literature and regulatory requirements for both the liner system and its individual components. Major manufacturers and/or installers of geosynthetics were contacted for additional design data and/or installation experience associated with double synthetically lined impoundments. Although a considerable amount of technical literature useful in designing the basins was readily available, our search was unable to identify similar completed projects. A few similar projects were scheduled for construction at about the same time as the subject basins.

The technical literature addressed many of the problems experienced by the basins, as previously described, and contained data useful in preparing and/or evaluating concepts. Proceedings of previous conferences on geotextiles and/or geomembranes, as well as publications of trade associations, testing and materials societies, and regulatory agencies were instrumental in our ability to cost effectively design and specify geosynthetic components of the basins. Several of the publications found to be particularly useful on this project are listed as references (1, 2, 3, 4, 5).

In lieu of specific technical requirements, the liner system for this project was designed to meet EPA's principal objective for waste management facilities, which is to minimize adverse effects on public health and the environment. An EPA document (6) describing minimum technology requirements for the design and construction of hazardous waste surface impoundments was released following the liner system design for this project. The first draft of this document was made available for public review in December 1984, after the first impoundment had been rehabilitated. A revised second draft was released in May 1985, after the start of construction on the second impoundment. We believe that the project design meets or exceeds the intent of EPA's minimum design requirements described in the second draft (6). In fact, the project design is surprisingly similar to EPA's preferred design alternate, which consists of a leachate collection system sandwiched between an upper geomembrane and a lower composite liner (geomembrane overlying a recompacted clay layer). The liner system selected for this project and comparisons between it and EPA's preferred design are described in the following section.

LINER SYSTEM DESCRIPTION

Geomembranes

The upper (primary) synthetic liner is a 1.5-mm (60-mil) thick HDPE geomembrane, which is twice as thick as the minimum EPA requirement for covered liners and 33 percent thicker than EPA's requirement for geomembranes exposed longer than 3 months. Table 1 contains minimum

Table 1 - Minimum Geomembrane Specification

Test	Name	Value
Base Resin		
ASTM D 792	Density	>0.935 g/cm^3
ASTM D 1238	Melt Index	<1.1 g/10 min
ASTM D 1693	Environmental Stress Cracking Resistance	>750 hours
ASTM D 746	Low Temperature Brittleness	-40^{o}F no break
Sheet		
Average thickness		As specified
ASTM D 638	Tensile Strength (Yield)	>2,000 psi
ASTM D 638	Tensile Strength (Break)	>3,500 psi
ASTM D 638	Elongation (Break)	>650 percent

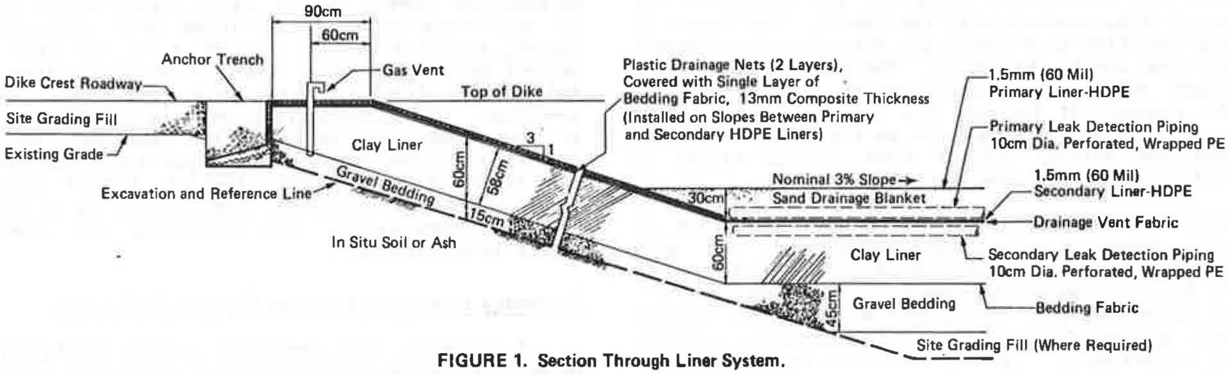

FIGURE 1. Section Through Liner System.

specifications required of the geomembrane sheet and base resin for this project. Figure 1 represents a detailed section of the liner system.

Because the risk of liner damage from normal basin operations is low (the basins are not used for solids disposal, and sludge clean-out is very infrequent), a protective cover over the liner was not specified since HDPE is sunlight resistant. The lower (secondary) synthetic liner also consists of an HDPE geomembrane, 1.0 mm (40 mil) and 1.5 mm (60 mil) thick for the equalization and diversion basins, respectively. The thickness of the secondary liner for the diversion basin was increased for extra conservatism at the Owner's request. A minimum thickness of 1.0 mm is specified by EPA for protected secondary liners. The secondary liner, like the primary liner, must allow no more than de minimis infiltration of liquids into the liner itself. De minimis leakage can occur as a result of vapor passing through the liner or through very small imperfections in the liner or seams. EPA believes that properly designed and installed geomembranes, with an effective leakage rate of 1×10^{-11} cm/sec or less, achieve this requirement.

The 1.5- and 1.0-mm thick primary and secondary liner combination was recommended by the liner consultant. Our observations suggest that the benefits gained as a result of specifying one liner thickness (simplification of construction documents, installation process, etc.) outweigh the increase in cost for the added liner thickness on similar size projects.

Project specifications required that geomembrane field seams be welded and tested in accordance with specifications of the geomembrane manufacturer. The contractor responsible for furnishing and installing the geomembrane was required to submit detailed descriptions and test data of his proposed materials and installation process for approval by the Owner. In addition, the contractor was required to provide a written guarantee stating that the geomembrane and workmanship specifically provided or performed under this project shall be free from any significant defects for a minimum period of 20 years. The guarantee applies to normal use and service and requires the total and complete repair or replacement of the defect or defective area of the geomembrane, upon written notification from the Owner of specific nonconformance with the project specifications.

Contractor acceptance of the terms and conditions of this warranty and guarantee was facilitated by the fact that the successful liner contractor was to have total control over the furnishing of geomembranes and installation of the liner system. The responsibilities of each contractor during installation of the liner system were determined in consultation with the Owner's representative, who would be supervising the work, and were fully described in the project specifications. The general contractor, under the direct supervision of the liner contractor, was required to provide the necessary equipment and personnel for earthwork associated with the liner system, such as the excavation of drain pipe trenches below the secondary liner and placement of the sand drainage blanket between the secondary and primary liners. We note that, though a 20-year warranty and guarantee were obtainable for this project, such an agreement may not be readily available if the time period is extended significantly to cover hazardous waste management facilities regulated under RCRA through the post closure period (30 years following closure).

Primary Leak Detection

The primary leak detection/collection system for this project is located between the geomembranes. This system is referred to as the secondary leachate collection system by EPA since its primary system is constructed on top of the upper liner in the case of landfills, which is not inappropriate for surface impoundments like the ones described herein. Along side-slopes, the system consists of two layers of medium density polyethylene drainage nets, each approximately 6.4 mm (0.25 in) thick, covered by a 1.5-mm (60-mil) thick nonwoven polypropylene, or polyester geotextile. A 30-cm (12-in.) thick sand layer and leak detection piping replaced these geosynthetics along the basin bottoms. The Owner felt that the extra protection (from accidental punctures due to dropped objects) afforded to the secondary liner by the greater separation distance between liners was desirable. The poor stability of sand on sideslopes (particularly between liners in a double-lined impoundment) and the associated increase in construction difficulty resulted in use of the geosynthetic composite at these locations. Use of a geosynthetic over the drainage nets was carefully evaluated due to concern regarding the potential for clogging of flow channels with the fabric. Two layers of net were specified to minimize any potential interference with drainage due to the fabric. The fabric was provided to prevent significant penetration of sludge or fines into the channels of the net if a leak occurred. A side benefit of using the drainage net on the basin sideslopes was that the thinner overall liner section helped to preserve basin storage capacity.

Other synthetic drainage media such as waffle or egg-crate shaped plastics were considered, but were eliminated from further consideration in part due to concern for crushing by equipment loads during construction or basin cleanout. Also, most manufacturers did not routinely produce these media in polyethylene, polypropylene, or polyester (mostly available on the shelf in polystyrene), which are the polymers of choice for chemical compatibility with the waste. Higher unit costs and long delivery times for special orders were also factors affecting the selection of the drainage nets.

A perforated and fabric-wrapped polyethylene drain pipe 100 mm (4 in.) in diameter was specified for the leachate collection pipes embedded in the sand drainage layer. Lateral pipes spaced at 12.2-m (40 ft) intervals were connected to a trunk line located along the longitudinal centerline of the basins. The base of each basin was pitched 2 and 3 percent in the longitudinal and lateral directions, respectively, to facilitate leachate flow and early leak detection following their occurrence. The trunk pipe terminated in the base of the concrete structure used to support the walkway extending over each

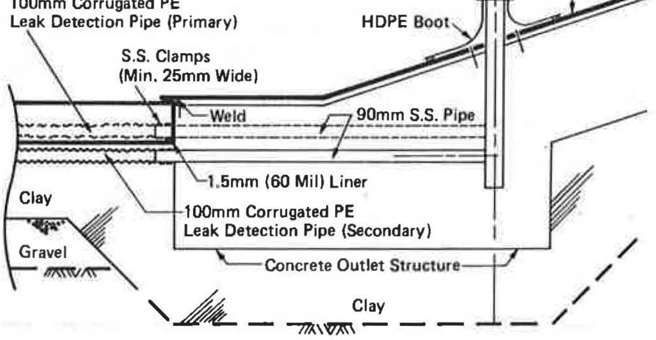

FIGURE 2. Leakage Collection Structure and Walkway Support.

basin. Since the system was designed to detect and collect only small amounts of leakage, a large sump such as would be required for leachate collection in a landfill was not provided. Any leachate is directly conveyed to a stainless steel vertical riser capable of accommodating a submersible pump. If a leak develops and it is desirable to keep the primary leak detection system drained, the submersible pumps can be automatically operated to pump leachate back into the basin. This design simplified the pond reconstruction since extension of the leachate detection pipes to an external location was avoided. Figure 2 illustrates this detail as designed for the diversion pond.

The primary leak detection design also satisfies the EPA bedding requirements below the primary liner and above the secondary liner, since EPA requires a minimum of 30-cm (12-in.) sand bedding, or equivalent protection, between the liners. Filter sand, classified as SP or SW in accordance with the Unified Soil Classification System, having a maximum size of 1 in. and less than 5 percent by weight greater than 4.7 mm (U.S. Sieve No. 4) and smaller than 0.074 mm (U.S. Sieve No. 200) was specified. The geosynthetic composite between the liners on sideslopes is believed to represent protection equivalent to the sand bedding layer since puncturing of the liners from the geosynthetics is not considered likely, and some degree of liner cushioning is achieved. Also, as noted earlier, the problem of sand slumping on slopes is eliminated.

Secondary Leak Detection and Back-up Soil Liner

A secondary leak detection system consisting of a network of 100-mm (4-in.)-diameter perforated and fabric-wrapped polyethylene drain pipes, configured similar to the primary leak detection pipes, but installed in a 60-cm (2-ft) thick recompacted soil layer beneath the secondary liner, was provided in each basin. EPA does not currently require such a leachate detection/collection system as part of its minimum technology guidance for surface impoundment design, but does indicate the need for a back-up soil liner. EPA's second draft of the minimum technology guidance document, previously referenced, requires a 90-cm (36-in.) thick back-up soil liner. The initial draft required a 60-cm (24-in.) thick liner.

The drain pipes are installed in 20-cm (8-in.) wide by 20-cm (8-in.) deep trenches and bedded in rounded gravel (GP). The gravel is surrounded by a nonwoven geotextile to prevent infiltration of fines from the surrounding soil or waste, if leaks occur. The trunk line also extends into the concrete base housing the primary leak detection riser pipe. A separate collection system and riser are provided, however, consisting of the same design described previously for the primary leak detection system.

A 3.75-mm nonwoven geotextile is placed over the back-up soil liner and drain pipes to accomplish several functions, as follows: drainage media providing a flow path from all areas to the collection pipes; bedding below the secondary liner; and transmission of gas (to vents located around the basin periphery) potentially generated by the active ingredients in the leachate. Therefore, the compression seal required in EPA's design between the secondary liner and the back-up soil liner is not provided. The principal objective of EPA's requirement, however, is believed to have been met--if not exceeded--by the project design. This objective is to minimize the volume of contaminants potentially entering the environment. The main function of the back-up liner is to contain leaks for a finite duration while remedial plans can be formulated. Since the project design provides direct data as to the integrity of the secondary liner, it facilitates the planning of corrective measures based on observed leachate flow rates, which precludes waste migration through the back-up liner.

The soil liner was specified to consist of recompacted clay or silt (CL, ML, CH, MH), capable of achieving an in-place saturated hydraulic conductivity of not more than 1 x 10^{-7} cm/sec at the specified placement density. Its functions are to retard the downward migration of leachate entering the secondary leak detection sytem, minimize the upward migration of gas into the liner system, and provide a stable, uniform base for the overlying liner system.

Gas Ventilation

EPA does not specify minimum requirements for gas ventilation systems in designing surface imoundments. As previously indicated, the nature of the waste composition, as well as subsurface conditions existing below the depth of construction, necessitated the provision of such systems. The 3.75-mm (150-mil) thick geotextile described previously represents the secondary gas ventilation system.

A 3 percent slope of the basin bottom was selected to facilitate gas migration in the geotextile toward the sideslopes. The suitability of this slope for its intended purpose was established by others, as described in reference 7.

The primary gas ventilation system consists of a gravel (GP) layer that is 45 cm (1.5 ft) thick along the impoundment bottom and 15 cm (6 in.) thick along sideslopes. The gravel layer is separated from the overlying clay liner and underlying soil or site grading fill by a nonwoven geotextile also used in the liner system. The gravel layer served to further stabilize the impoundment base. General site grading fill instead of gravel was used to replace deeper areas of soft fly ash for economic reasons. The gravel bedding also served to stabilize and drain the fly ash contained in embankments during construction, since replacement of the embankments was not cost effective. Final embankment sideslopes of 3:1 were maintained during the reconstruction for stability reasons and to minimize the amount of cut or fill.

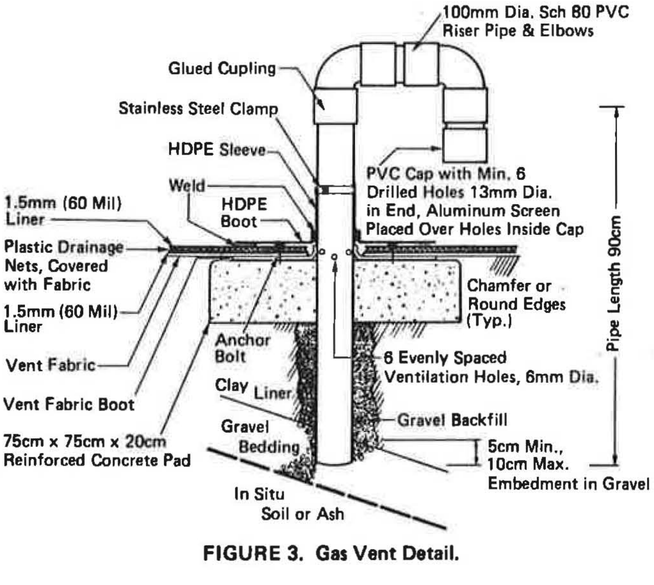

FIGURE 3. Gas Vent Detail.

Venting of gases collected in either the primary or secondary system is accomplished as shown in Figure 3. This detail also illustrates the precautions taken to preclude leakage around liner penetrations. In general, concrete slabs were specified to provide a smooth transition and firm anchorage for the geomembranes at such discontinuities. Submerged penetrations were designed using seepage collars embedded in the concrete slabs and a neoprene adhesive sealant between the geomembrane boot and the protruding element.

Anchor Trench

A minimum 60-cm (2-ft) wide by 60-cm (2-ft) deep anchor trench was specified to secure the various geosynthetics of the liner system. Use of a wide, deep trench was important due to the number of components to be secured, and the expected high forces from thermal expansion and contraction. A minimum 180-cm (3-ft) setback of the trench from the slope crest was specified to minimize the potential of disrupting the prepared grade due to the weight of the anchored geosynthetics.

To reduce the potential for caving of the anchor trench, the clay liner was extended beyond the slope crest to the far edge of the anchor trench. The anchor trench proved to be suitable in achieving its intended purpose.

Miscellaneous Details

Several details were incorporated into the design to maximize the duration of low maintenance impoundment operation and to improve system operation. The major details include the following:

- Provision of an auxiliary inlet pipe to facilitate the disposition of tanked wastes in the diversion pond without the need for truck access on the dike crest.
- Provision of splash pads around the main and auxiliary inlets consisting of sacrificial strips of geomembrane to minimize primary liner degradation from impinging liquids.
- Reconfiguration of the main inlet from a single riser to a multiported manifold to improve basin mixing.

PRINCIPAL COST COMPONENTS

Each impoundment project, such as the one described in this paper, is constructed under a unique set of circumstances. New impoundments constructed on virgin ground will generally cost less per cubic volume of effluent stored than rehabilitation projects. For this project, however, a new location was not available, and the costs for closure of the old site would have been incurred regardless. Overall, rehabilitation of the two basins and related work at this site cost the Owner about \$2,200,000, excluding indirect costs. The project cost included such items as the excavation and removal of sludge and contaminated soil and disposal in a landfill (about 20 percent of project total); earthwork for reconfiguring the basins (20 percent); and modifications and upgrades to piping, valves, valve pits, instrumentation, electrical, etc. (25 percent). An accelerated construction schedule was used to minimize out-of-service time for this critical facility; overtime costs for contractors, plant guards, etc., were estimated to be nearly 10 percent of total project costs.

The liner system--two geomembranes, a clay backup liner, gravel bedding, geotextiles, and the leak detection system--was estimated to be about 25 percent of total project costs, or about \$43 (U.S.) per square meter of lined area (\$36 (U.S.) per square yard). Of this cost, the clay and geomembranes were about two-thirds, geotextiles and drainage net about one-quarter, and other materials constitute the remainder.

The above numbers are presented to provide an indication of the primary cost components associated with a project of this type. Although the liner system was the principal reason for the project being undertaken, its installed cost was much less than the cost of the other repairs and upgrades that were conducted. Of the components of the liner system, the cost of liner materials is the principal expense. While the cost per installed square area of geosynthetics is relatively predictable, costs for impermeable clay vary widely with location. The availability and cost of clay should be investigated early in the design of an impoundment. The double leak detection system was also found to be a significant cost item.

In addition to the 34,000 m^2 (41,000 yd^2) of HDPE liner, over 79,000 m^2 (95,000 yd^2) of other geosynthetics was used on the project, including two types of geotextiles and an extruded drainage net. The geomembranes and other geosynthetics were furnished and installed at a cost of approximately \$5.80 (U.S.) per square meter (\$4.85 per square yard) and \$1.45 (U.S.) per square meter (\$1.20 (U.S.) per square yard), respectively. Each application was reviewed carefully during the design phase. Geosynthetics were found to be competitive with other alternatives considered.

CONCLUSIONS

The liner system design prepared for the subject project is believed to meet or exceed the objectives of EPA's minimum technology guidance provided for hazardous waste surface impoundments. The use of geosynthetics greatly facilitated the cost-effective rehabilitation of the impoundments, and in two applications (drainage nets on basin sideslopes and use of geotextiles for gas venting) was found to be technically superior to other solutions considered.

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