Section 4
Technology Effectiveness

This section discusses the two SITE demonstrations that were conducted to evaluate the effectiveness of the MatCon™ technology. This discussion addresses the construction of the MatCon™ covers, the measurements that were completed to determine conventional asphalt and MatCon,™ performance and the demonstration results and conclusions.

4.1 Description of the Installed Covers

The installation of the MatCon™ cover and the field tests at the DAFB and TCL sites are discussed below. The locations of these two sites are shown in Figure 2-1 (DAFB site) and in Figures 2-2 and 2-3 (TCL site).

4.1.1 DAFB Site

This section describes the cover at the DAFB site.

4.1.1.1 Cover Installation

WCC installed the MatCon™ cover system at DAFB in April 1999. The cap covers 124 by 220 feet (38.4 by 67.1 meters) (see Figure 4-1). The cover consists of three, hydraulically independent sections, as follows:

- Section I: 12-inch-thick (30.5-cm) MatCon™
- Section II: 4-inch-thick (10-cm) MatCon™
- Section III: 4-inch-thick (10-cm) conventional asphalt

A subsurface drainage collection (leak detection) system was constructed in Section I (Figure 4-2). The system consists of a 4-inch-thick channel of open-graded asphalt between two 4-inch-thick MatCon™ layers. The subsurface drainage system divides Section I into quadrants; the drainage layer beneath each quadrant flows into a separate 3-inch-diameter (7.6-cm) high density polyethylene (HDPE) pipe (Figure 4-3).

The area covered by the MatCon™ and conventional asphalt is small, so no cold joints were required. An elaborate design specification was not prepared for this site.

WCC contracted with a local asphalt contractor to construct the conventional asphalt and MatCon™ covers. The 6-inch-thick (15-cm) subgrade was prepared with crushed rock by DAFB personnel according to the requirements of WCC. However, for the 12-inch-thick (30-cm) MatCon™ section, no crushed rock was used in the subgrade. The soil was compacted to the grade specified by WCC, and the asphalt contractor placed the 12-inch-thick (30-cm) MatCon™ section using the material specified by WCC.

The installation was completed in about two days. WCC provided the special binder to the local hot mix plant, and the plant prepared the MatCon™ material according to the specifications provided by WCC. WCC prepared a video of the complete MatCon™ installation and submitted it to EPA.

4.1.1.2 Drainage System

A drainage ditch, a metering pit, and a lysimeter sump were installed during March 2000 to monitor runoff from the cover and infiltration into the lysimeter section of the cover. All hydrologic monitoring points were located on the down gradient side of Section I of the cover.

To monitor surface runoff, a lined ditch was constructed along the down gradient side of the cap, and berms were constructed on three sides to direct the runoff into the drainage ditch (Figure 4-4).

The ditch flows into a 4-ft by 4-ft by 4-ft deep (1.2- by 1.2- by 1.2-meter) metering pit (Figure 4-5). Flow into the metering pit was measured with a flow meter prior to surface discharge.

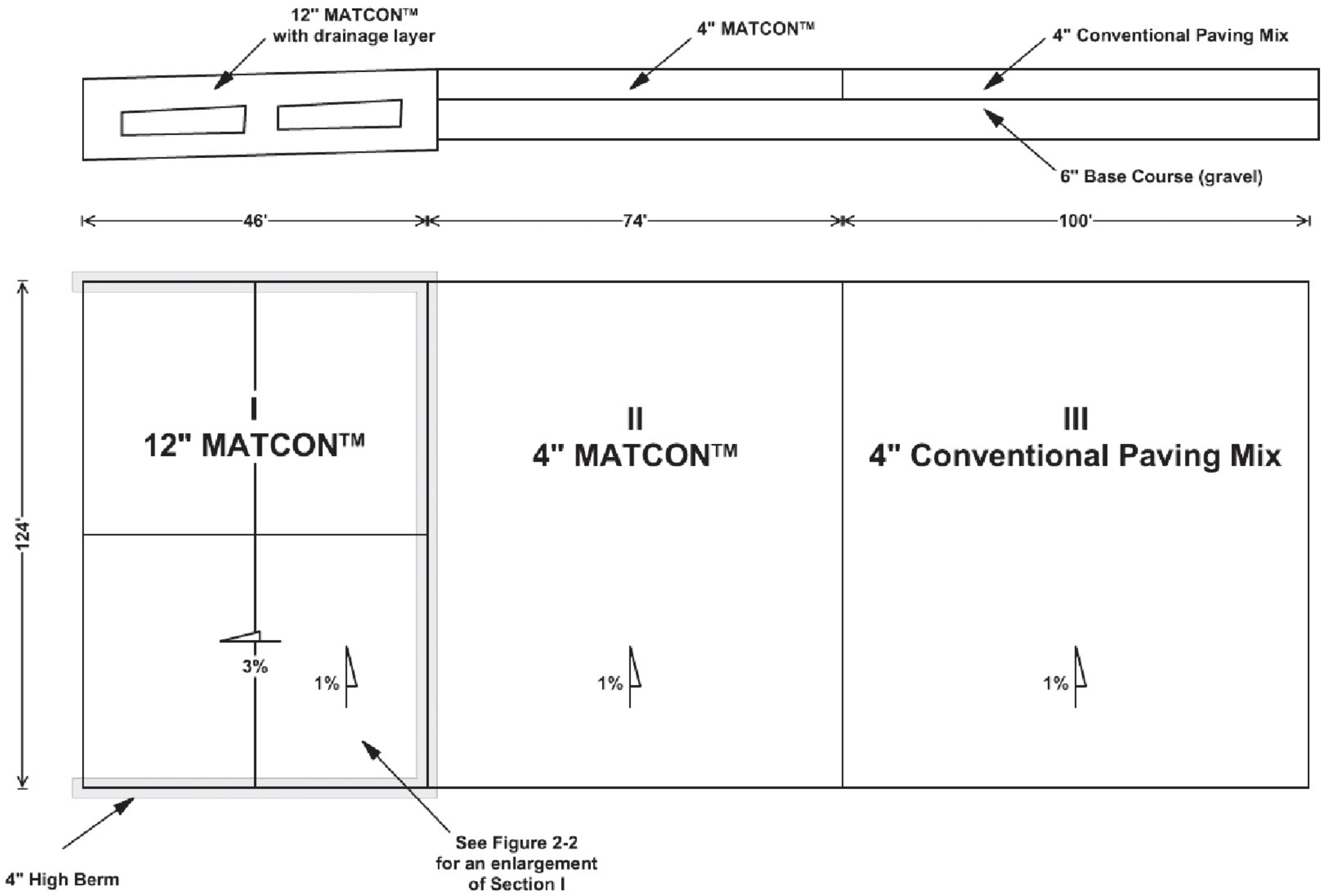

Figure 4-1. MatCon™ liner and cover system.

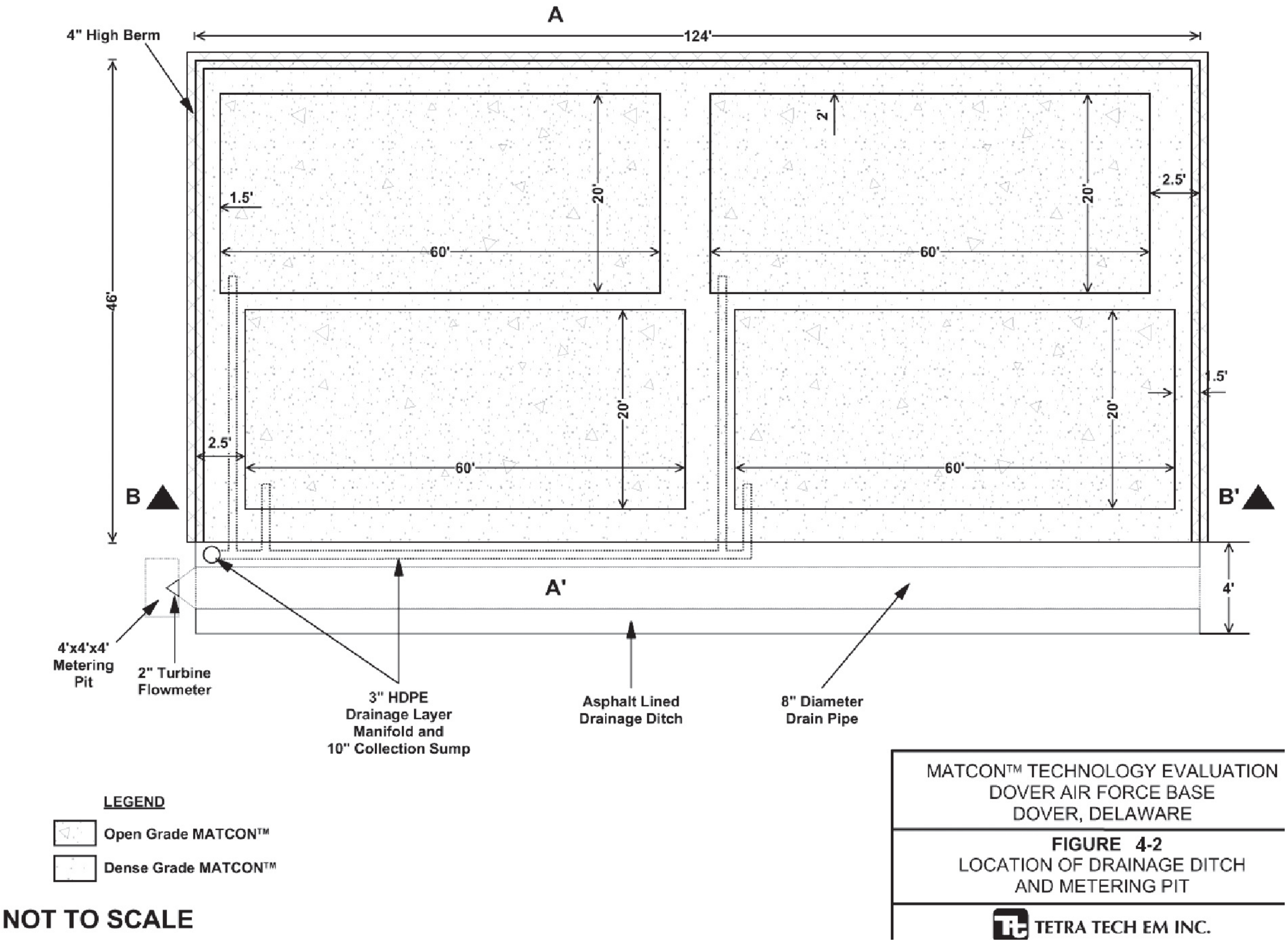

Figure 4-2. Location of drainage and metering pit.

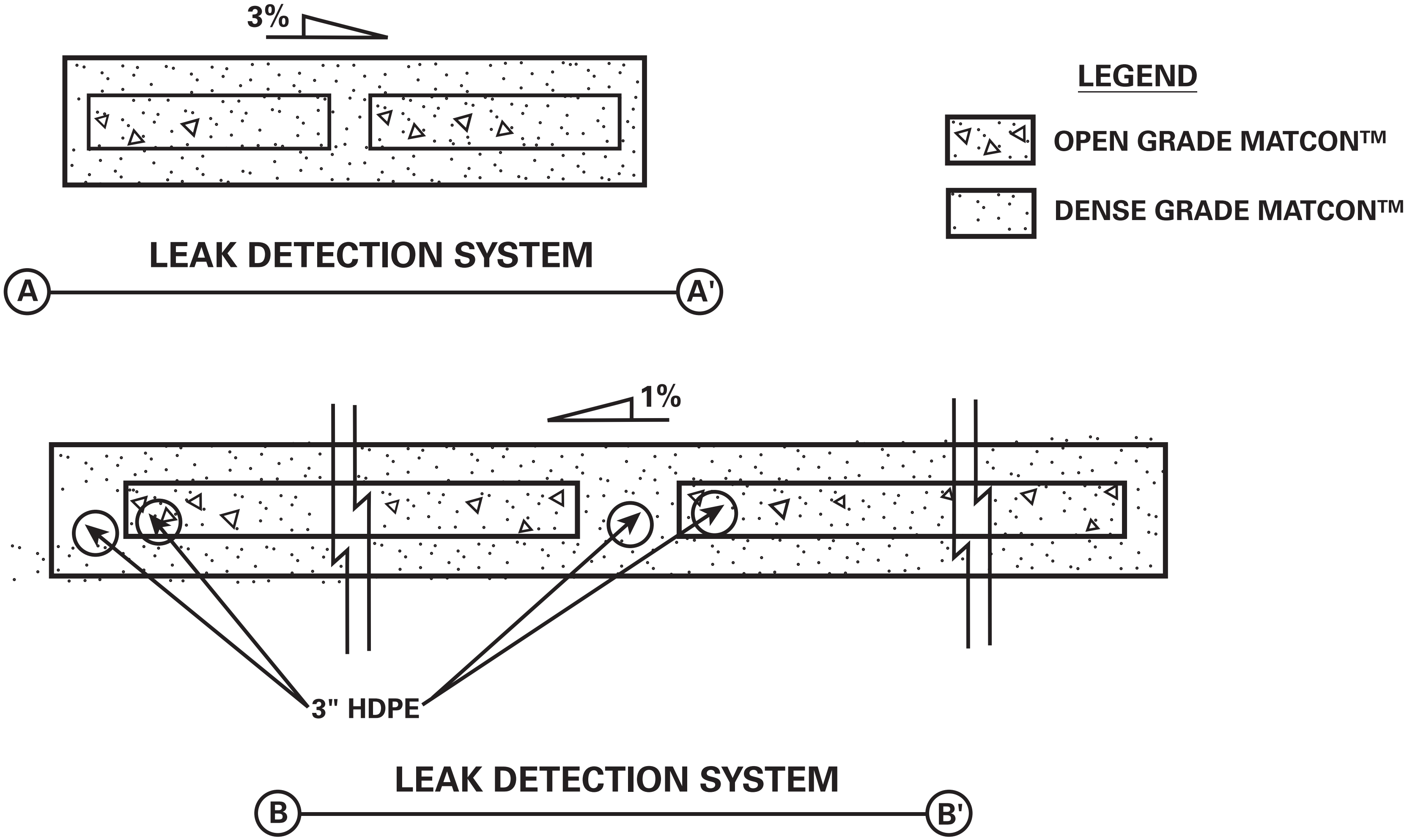

Figure 4-3. MatCon™ liner and cover cross-sections A-A' and B-B'.

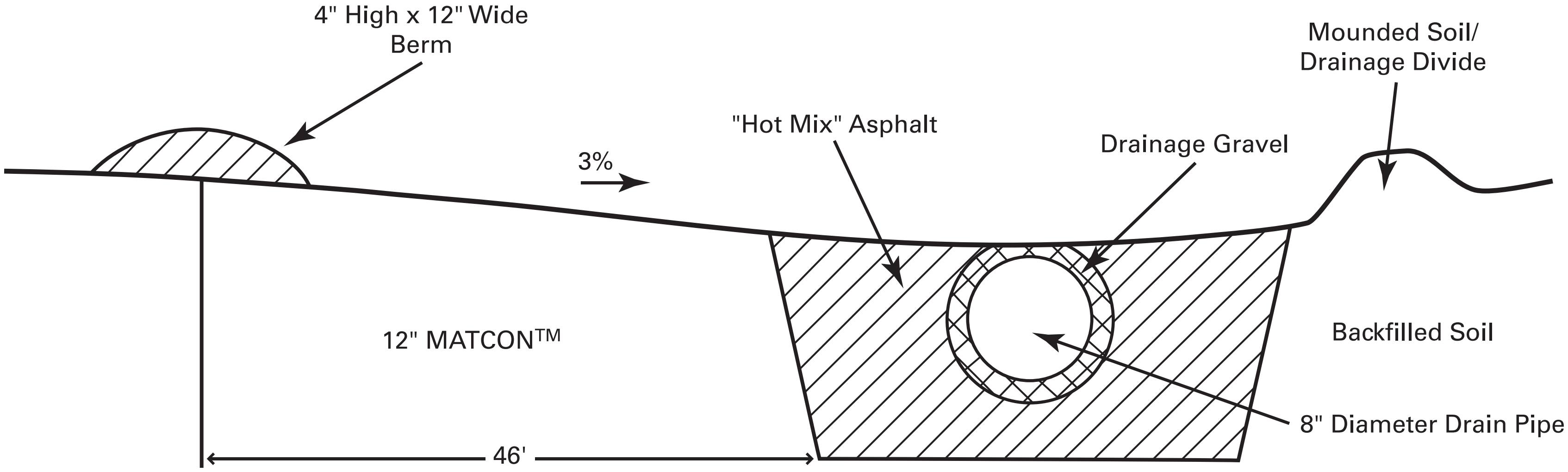

Figure 4-4. Ditch cross-section.

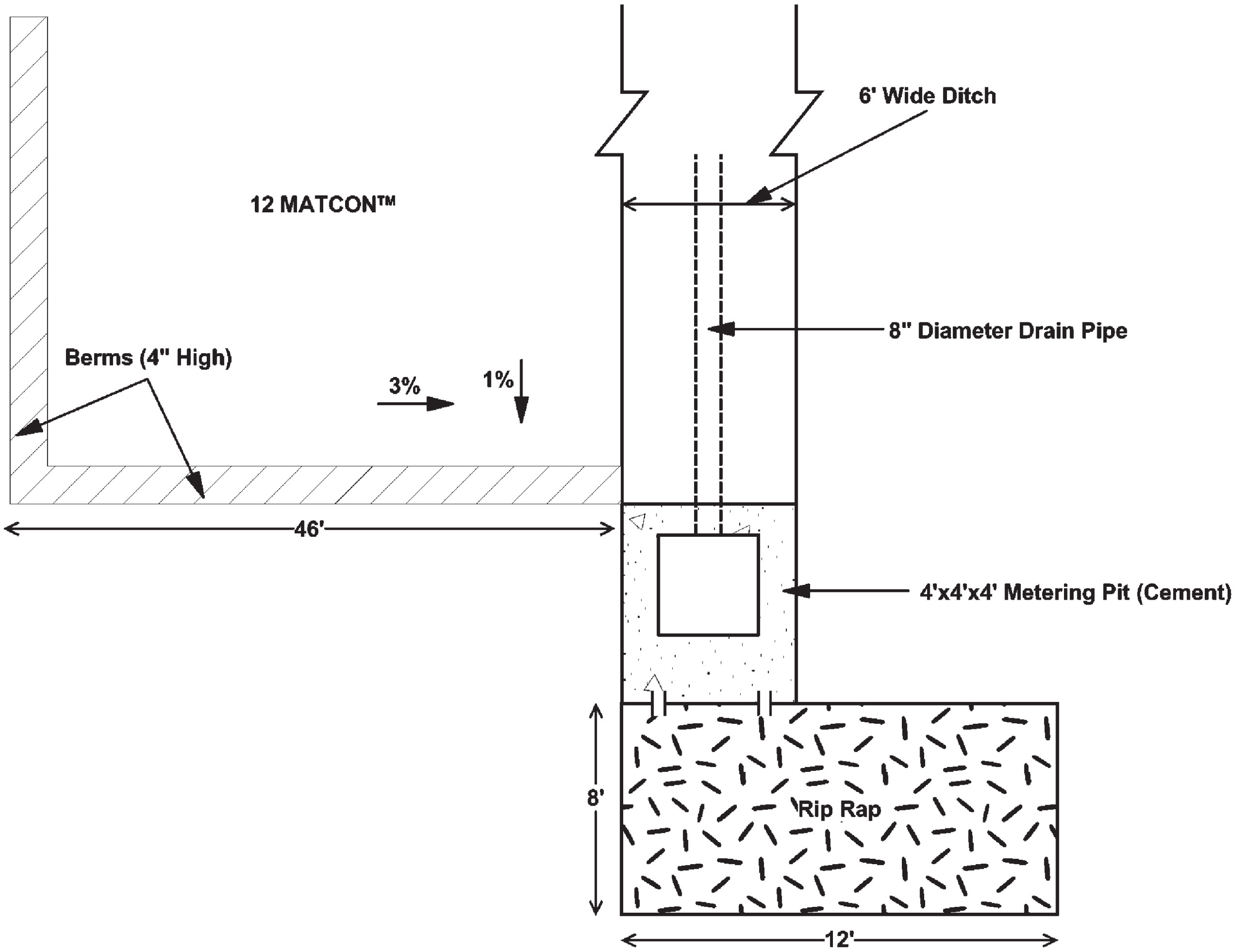

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Figure 4-5. Monitoring pit/french drain.

To monitor infiltration, the four 3-inch-diameter (7.5-cm) HDPE pipes leading from the drainage layer were connected to a 10-inch-diameter (25.4-cm) sump, as shown in Figure 4-6. Field installation of this sump utilized a single piece of HDPE pipe.

4.1.2 Tri-County Landfill

MatCon™ was installed at the TCL site in Elgin, Illinois, by WCC as a final cover system in November 1999. The project consisted of a 3.6-acre (16,092 m^2) site that had a subgrade previously prepared for WCC's final grading and subsequent MatCon™ installation. WCC prepared the final grade for paving, constructed the test section, and installed the MatCon™ cover over a 2-week period (Figure 4-7).

As part of the MatCon™ cap installation by WCC for the TCL site, the patented three-layer leak detection system was proposed. Review of the system design by the U.S. Army Corps of Engineers (COE) and their subsequent comments required the incorporation of several modifications for the lysimeter that was installed. Specific changes in the design included the use of a HDPE membrane liner as the underlying impermeable barrier. This was placed on top of a panel of conventional asphalt, over which a geotextile fabric was placed for protection and cushion purposes. The rounded drainage rock material was placed over the geotextile fabric as a replacement for the open-graded MatCon.™ The entire installation was then covered with the final MatCon™ panel (Figures 4-8 and 4-9). The lysimeter pipe and sump were installed by Waste Management, Inc. (WMI).

4.1.3 Installation Details

Installation of the MatCon™ covers at both the DAFB and the TCL sites was observed to document the construction details and construction quality.

4.1.3.1 Subgrade and Drainage Systems

At the TCL site, the underlying subgrade was firm and unyielding, and was compacted using conventional heavy load proof-rolling procedures. Surface grades of 1 to 3 percent were used to facilitate drainage of the final surface. The subgrade was inspected and accepted by WCC personnel. The surface was finish graded to within the tolerance of ± 0.5-inch (1.2-cm) measured using a 10-foot (3-meter) straight-edge level prior to paving.

At the TCL site, coarse aggregate placed as the drainage layer of the lysimeter facilitated the conveyance of water horizontally but could not be compacted to a firm and unyielding condition. This resulted in difficulties during the paving operation.

All retaining sidewalls, piping, and sump appurtenances were designed to be water tight. Sump design prevented intrusion from rain and snow (gasketed lid) and included protection from freezing temperatures, methods to adjust to barometric pressure changes and minimize condensation (adequate weatherproof venting), and measures for secure access (locking lid).

4.1.3.2 Cover Construction Quality

At the TCL site, a crack at a cold joint appeared after a prolonged period of cold weather in January 2000. The edge of the asphalt application is typically more difficult to compact because there is no lateral support for the roller. When the asphalt is hot, the edges weld together properly. However, an edge that is allowed to cool overnight is then very difficult to bond to the next day's first application of asphalt. In addition, it is especially difficult to increase density in the cold joint area. The result is a zone along the cold joint that may be poorly compacted. Raveling, or separation of aggregate particle fines from the surface or edges of the compacted asphalt, can occur in these zones. Although WCC has determined that poor quality workmanship was the cause, a better design has since been developed to overcome the raveling and reduce dependency on workmanship. A wedge-shaped cold joint panel (3-meters wide) proved to be a good design in terms of bonding and providing a good impermeable mat. The new design includes removal of some material and a heavy tack coating.

The crack that appeared at the cold joint at the TCL site was routed and sealed. The zone along the cold joint, about 3 feet wide (0.91 meter), was sealed with mastic to decrease the permeability by filling the surface voids.

4.2 Evaluation Procedures

Procedures used to evaluate the MatCon™ cover and compare it with conventional asphalt were described in the Technology Evaluation Plan/Quality Assurance Project Plan (TEP/QAPP) (Tetra Tech 2000). Field sampling of the slabs and cores at the DAFB site was completed in August 1999. Samples were obtained at the TCL site immediately after cover installation in November 1999, and then again in April 2000 to obtain samples in a portion of the

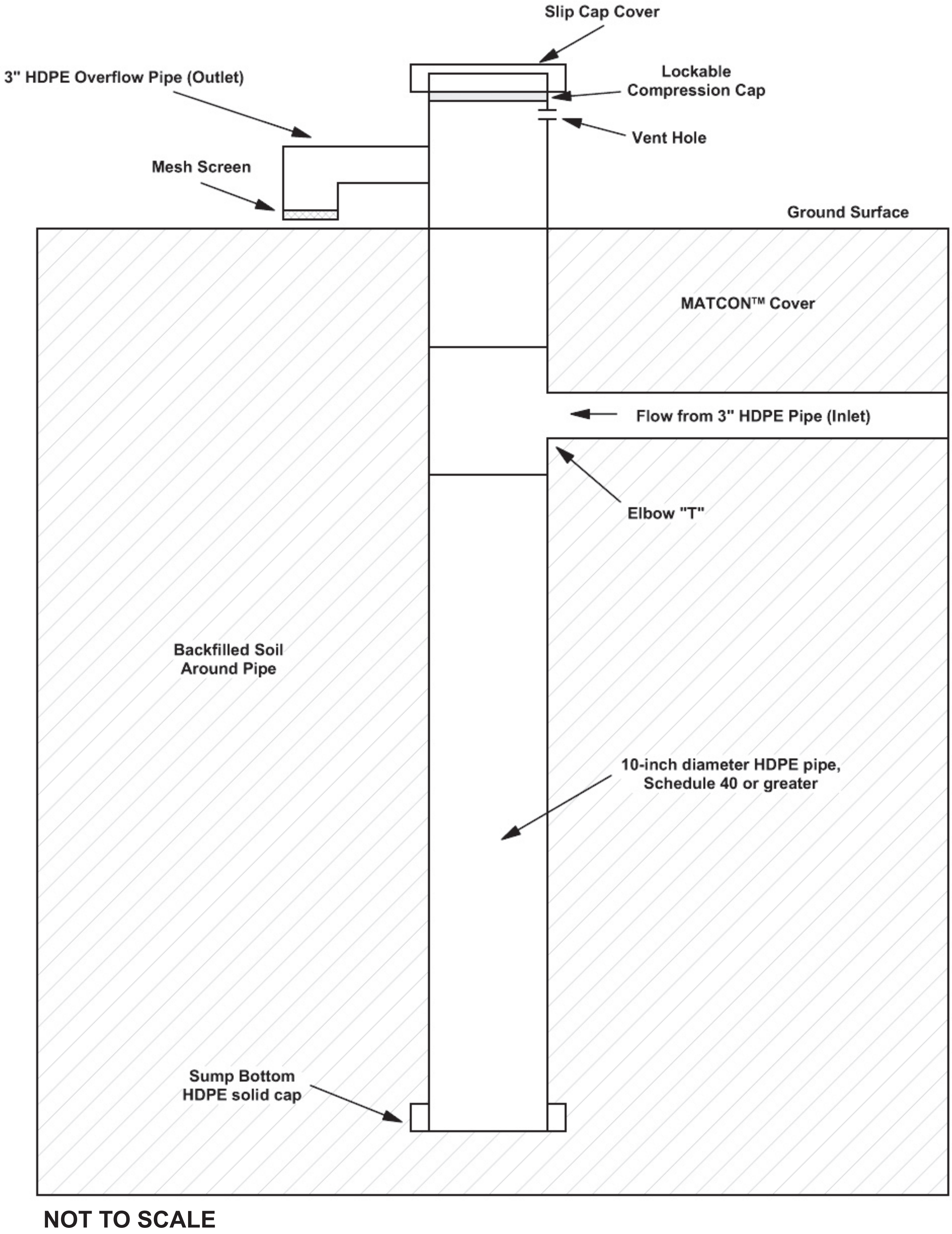

Figure 4-6. MatCon™ liner and cover system leak detection sump.

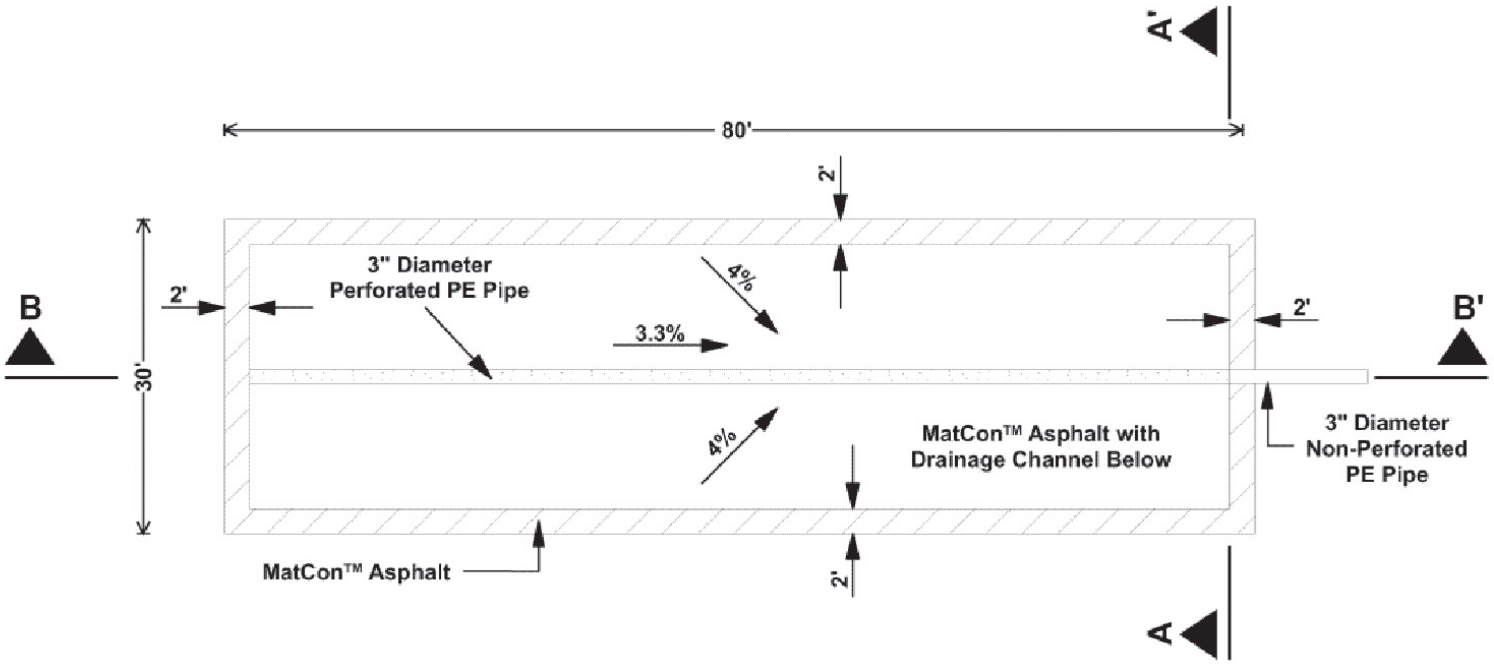

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Figure 4-7. Plan view of the MatCon™ cover.

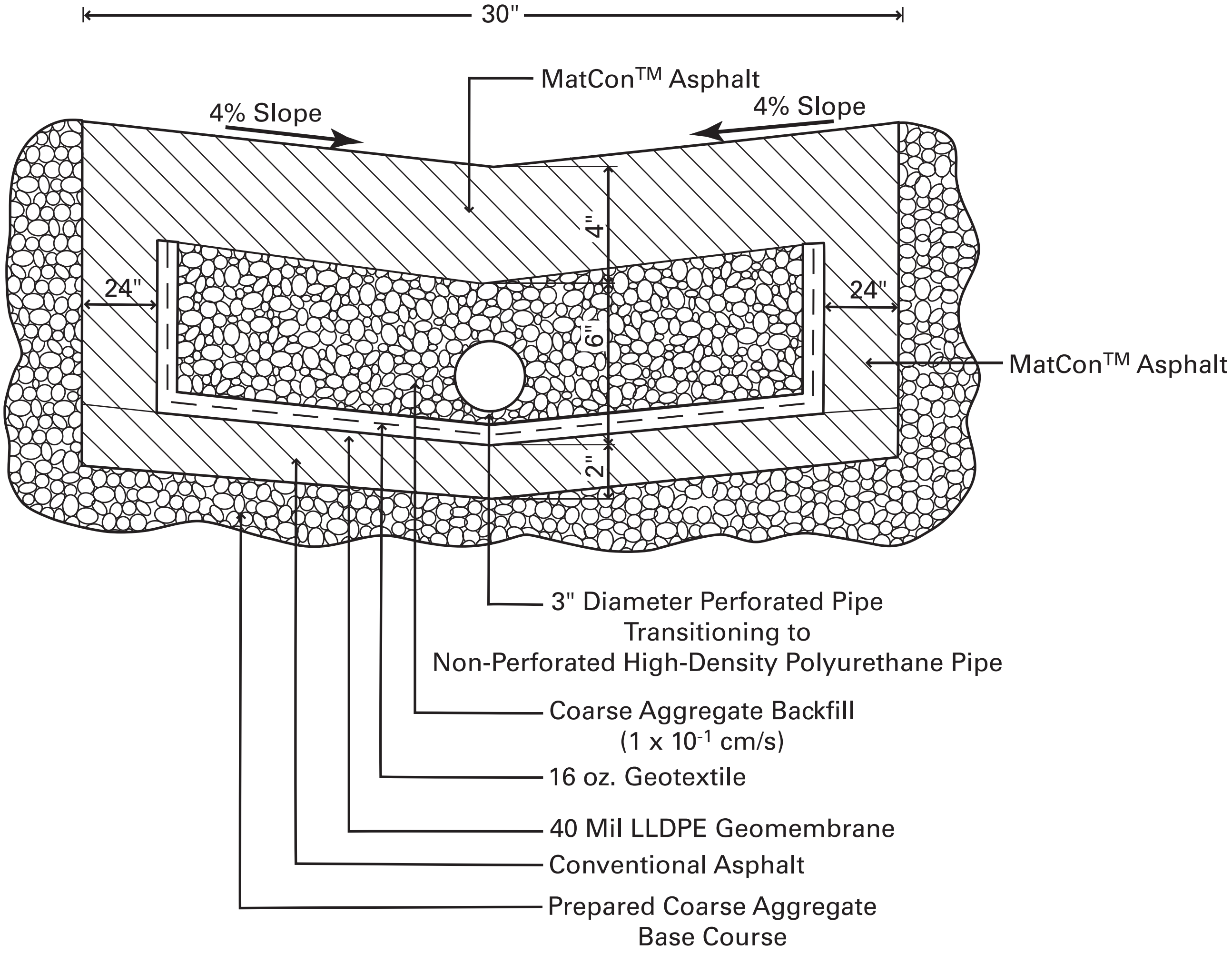

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Figure 4-8. Section A-A'

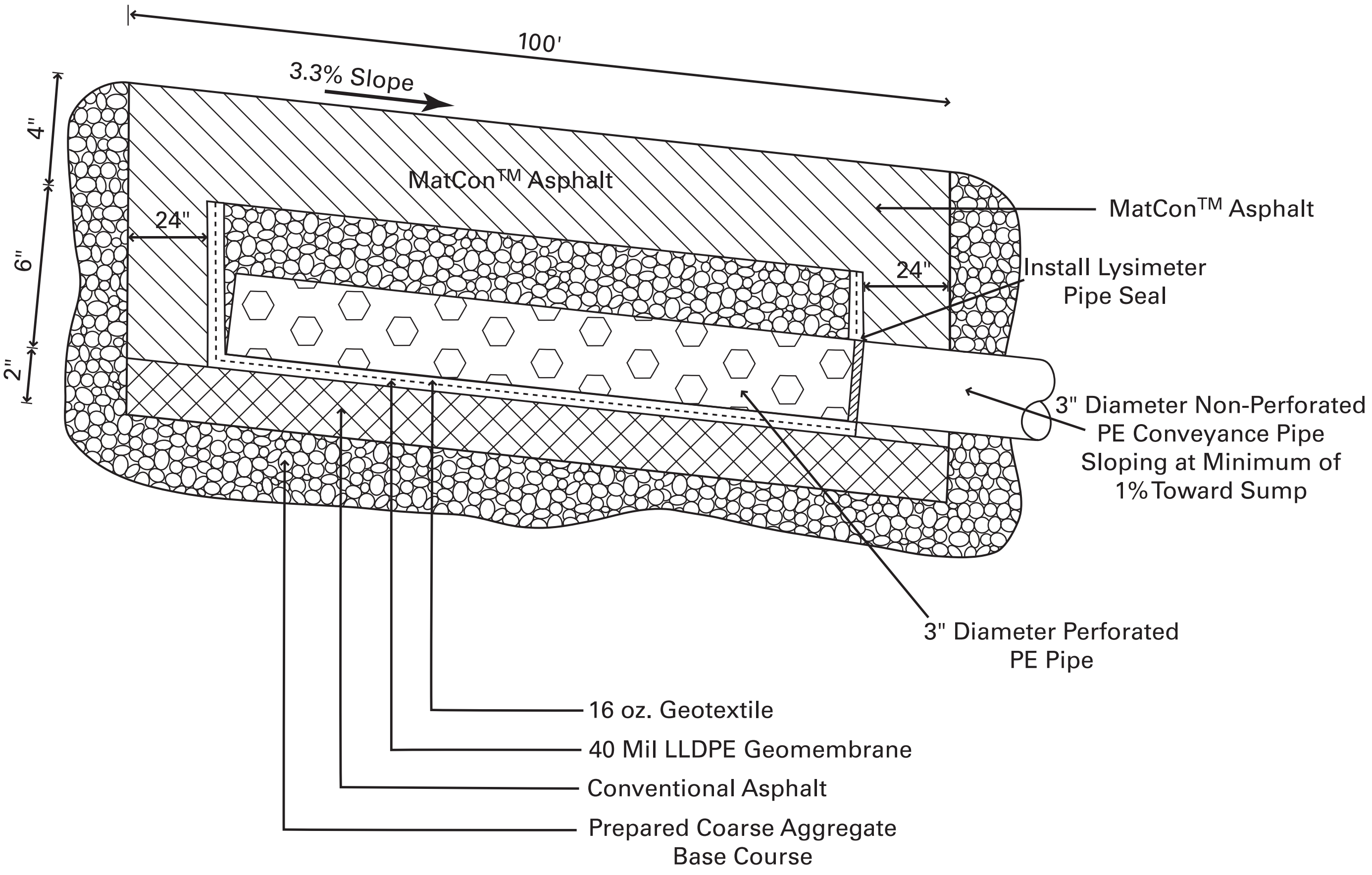

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Figure 4-9. Section B-B'.

MatCon™ cover where a crack was observed. Extensive testing of slab and core samples from the MatCon™ and conventional asphalt sections was performed for the DAFB site. However, only limited laboratory testing was performed on the TCL cores.

The sampling methods, field and laboratory tests, and the quality assurance procedures used for the field and laboratory testing are detailed in this section.

4.2.1 Field Testing

This section discusses field testing at DAFB and TCL.

4.2.1.1 Basis of Measurement of Field Permeability

Field permeability of the MatCon™ was calculated during periods of rainfall by measuring the drainage volume into the sump and using Darcy's Law. The permeability (k) was calculated using the following equation.

$$k = QL / A\,t\,h$$

where Q = flow into the sump
L = nominal thickness of the MatCon™ cover
A = area of the cover
t = duration of the test
h = hydraulic head (as described below)

The variable of hydraulic head (h) in the above equation was based on the reported USGS rainfall amount during each monitoring period. However, several assumptions were required, which caused uncertainties in the calculation (see Section 4.4.1). Therefore, constant-exposure ponding tests were established to better estimate the field permeability. For ponding test permeability calculations, hydraulic head (h) was equal to the thickness of the MatCon™ layer plus the height of the water ponded on the surface of the cover. Field measurements of water infiltration into the MatCon™ cover were completed at the DAFB site from April through July 2000. In addition, attempts were made to obtain a hydrologic balance for the DAFB site during April through June 2000 using a flow meter to measure runoff from the MatCon™ cover.

4.2.1.2 DAFB Site

Data for the volume of drainage layer infiltration and surface runoff were collected on a regular basis. These data were recorded in a field book, and Tetra Tech personnel performed hydrologic calculations. During each trip, the drainage layer sump (DLS) was inspected for integrity, and a water level measurement was taken. The sump was evacuated for the next measurement. A flow meter reading was obtained, and the monitoring pit was pumped out.

Data for the DLS were collected using a measuring tape. The depth of the water column accumulated in the sump was recorded in triplicate. The average depth measurement was then converted to a volume in gallons. This volume was then used to calculate a permeability value using Darcy's law, as described above.

Data from the surface drainage flow meter were more problematic. Consistent cumulative measurements were difficult to record due to the recurring heavy rainfall and subsequent flooding of the site. Therefore, reliable flow data could not be obtained.

A 6-hour ponding test was conducted that consisted of applying a head of approximately 2.5 inches (6.2 cm) of water over the MatCon™ Section I area while monitoring the flow in the DLS.

4.2.1.3 TCL Site

Monitoring trips were conducted to collect data for the volume drainage layer infiltration and surface runoff. Bi-weekly trips were made to the TCL site to measure the water level in the sump. The trip was planned after a rainfall event of 1 inch (2.5 cm) or more during the past 24 hours. After the measurement, the sump was bailed out for the next measurement. Using the sump water levels, , the drainage volume was determined, and the permeability of the MatCon™ cover was calculated using Darcy's law.

A 4-inch-high (10-cm) asphalt berm was constructed around the perimeter of the test section on top of the MatCon™ cover. In addition, berms were added between the edge berms, forming a series of terraces where water could be impounded. Water from both a tank truck and heavy rainfall filled the terraces to an average depth of about 2 to 2.5 inches (5.1 to 6.2 cm) and was maintained for almost 48 hours. During this period, the water inflow to the sump was monitored and used to calculate the permeability of the MatCon™ cover. A steady-state condition was reached in about 6 hours.

4.2.2 Sampling Methods

The objectives of the field sampling program were to obtain representative samples of the MatCon™ and conventional asphalt covers for subsequent laboratory testing. This section describes the sampling objectives, the sampling locations, and sampling procedures for the MatCon™ and conventional asphalt covers.

4.2.2.1 Sampling Objectives

The following general objectives were used for all sampling activities:

- Collect samples in a manner that ensures they will represent the medium being sampled
- Maintain proper chain-of-custody control of all samples, from collection to testing
- Follow QA/QC procedures appropriate for EPA National Risk Management Research Laboratory (NRMRL) Applied Research Projects

4.2.2.2 Sampling Locations and Procedures

The cover at the DAFB site was planned to be a long-term functioning cover, and was not constructed solely for demonstrations purposes. Therefore, the sampling strategy sought to minimize the amount of area impacted by sample coring, so that repairs to the cover could be implemented more effectively. It was decided that confining the sample cores to one subarea of the cover would still provide representative samples because the entire cover was installed in two days using the same work crew, materials, and procedures for all areas of the cover. Asphalt core and slab samples were collected from a 3-ft by 3-ft (0.91-by 0.91-meter) sampling area in Section I and from 6-ft by 8-ft (1.8- by 2.4-meter) sampling areas in Sections II and III, as shown in Figure 4-10. The number of samples taken in each of the three sections of the demonstration cover is listed in Table 4-1.

PRI collected samples from the locations shown on Figure 4-10 on August 26 and 27, 1999. A coring machine was used to obtain the 4-inch-diameter (10-cm) and 6-inch-diameter (15-cm) cores, and a diamond-toothed saw was used to obtain the slab samples. Areas where samples were collected were then patched with hot mix asphalt by WCC.

Samples at the TCL site were not obtained from the 30-ft by 80-ft (9.1-by 24.4-m) test section. They were obtained instead from an adjacent location where light poles were to be installed on the cover. Six cores were obtained initially, and five more cores were obtained in April 2000 at the location of a crack. The only testing that was done with these cores was aggregate properties, void space, and hydraulic permeability.

4.2.2.3 Sample Identification and Handling

Samples obtained by PRI Asphalt Technologies, Inc. (PRI) were identified by location and sample number, and were packed carefully in padded containers. Chain-of-custody forms were filled out by PRI to document the acquisition of the field samples. The containers were transported by PRI personnel in a van to PRI's laboratories in Tampa, Florida. The PRI personnel in the laboratory signed the chain-of-custody forms to document receipt of the samples. PRI had custody of the samples from field acquisition to receipt in the laboratory.

Laboratory tests run on the samples are listed in Table 4-2; a description of each of these tests is provided in the TER.

4.2.3 Laboratory Testing

The testing methods selected for the project are those standardized by the American Society of Testing and Materials (AS™) and the American Association of State Highway and Transportation Officials (AASHTO). Calibration of equipment used to perform the standardized tests (AS™ and AASHTO) was performed, when required, as recommended in the procedure (AS™ 1997).

For the flexural test that simulates the effect of differential settlement on the MatCon™ cover, no standardized test is available; however, Dr. Ronald Terrel of Terrel Research devised a test that was used for this demonstration. These laboratory testing methods are described in further detail in the Quality Assurance Project Plan (QAPP).

4.2.4 Quality Assurance and Quality Control Program

The overall objective for this evaluation was to produce well-documented data of known quality. Quality is measured by monitoring data precision and accuracy, completeness, representativeness, and comparability.

The evaluation was designed to ensure that a sufficient number of samples were collected to represent the cover material at each given site and that each sample was taken in a manner that ensures representativeness to the extent practical.

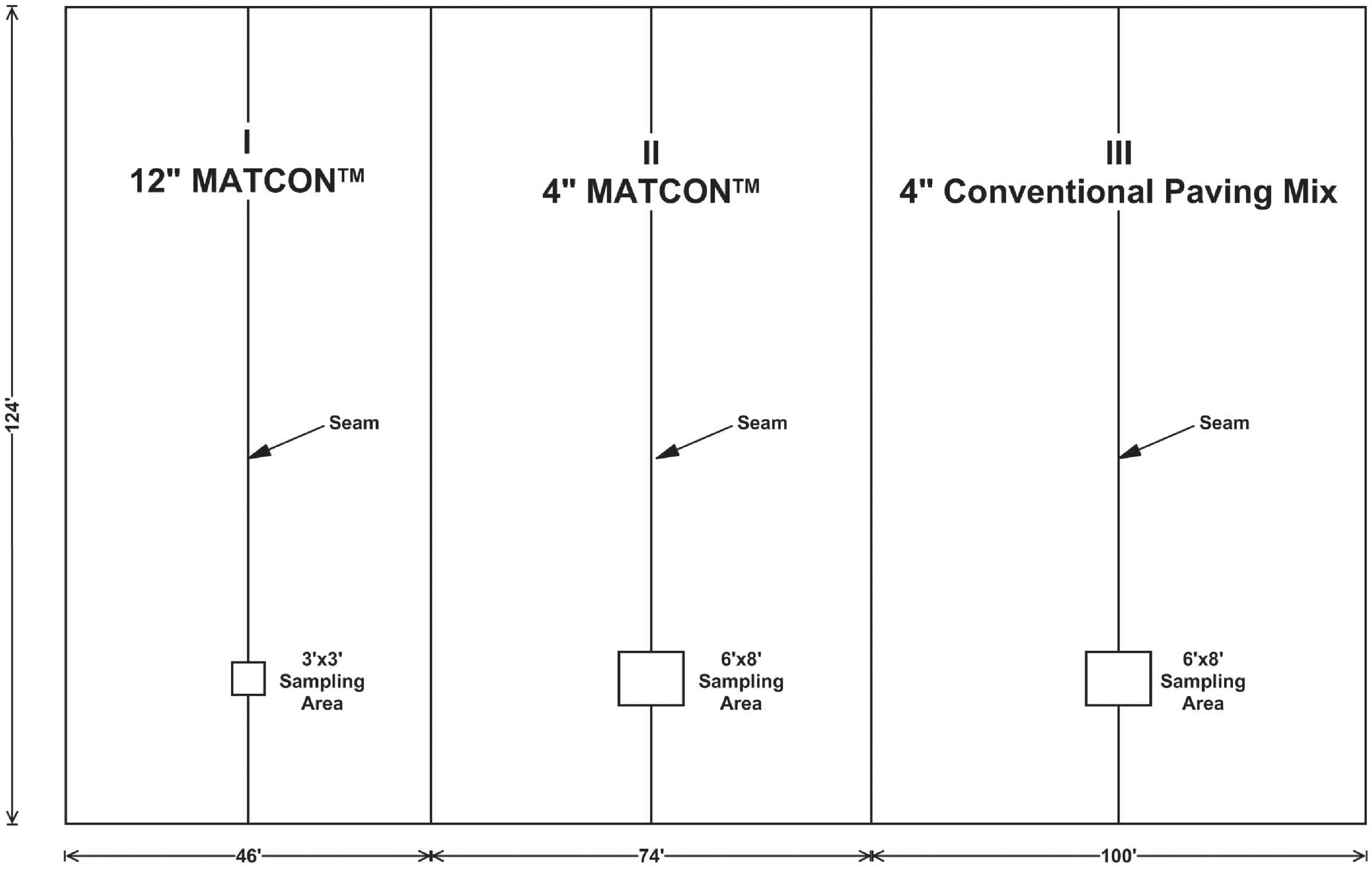

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Figure 4-10. Sampling area locations.

Table 4-1. Cover Sample Type, Numbers, and Labeling-DAFB Site

Sample Type	Approximate Size	Quantity	Location	Label
Core	4” (10 cm) diameter	5	Section III 4” (10 cm) Conventional Paving Mix	4-1 through 4-5
		5		5d-1 through 5d-5
		5		2a-1 through 2a-5
	6” (15 cm) diameter	12		7-1 through 7-12
		8		2b-1 through 2b-8
Slabs	14” x 40” (35 x 100 cm)	4		A, B, C, D
Core	4” (10 cm) diameter	5	Section II 4” (10 cm) MatCon™	4-1 through 4-5
		5		5d-1 through 5d-5
		5		2a-1 through 2a-5
		12		7-1 through 7-12
	6” (15 cm) diameter	8		2b-1 through 2b-8
Slabs	14” x 40” (35 x 100 cm)	4		A, B, C, D
Slabs	14” x 14” (35 x 35 cm)	4	Section I 12” (30 cm) MatCon™	A, B, C, D

Table 4-2. Characterization Testing on Asphalt Samples-DAFB Site

Parameter	Sampling Location Section			Proposed Test	Samples Used
	I	II	III		
Hydraulic Conductivity		X	X	ASTM D-5084 and AASHTO T-283	4” diameter cores, 3 replicates
Flexural Properties		X	X	Differential Settling Test at 25 °C (one month duration)	4” x 4” x 36” slab[2] 2 replicates
Load Capacity/ Deformation		X	X	Resilient Modulus at 25 °C ASTM D-4123	4” diameter cores, 3 replicates
Shear		X	X	Shear Test at 4, 20, and 40 and 60 °C AASHTO TP 7	6” diameter cores, 2 replicates per temperature per section
Joint Integrity (permeability)[3]		X	X	ASTM 5084	4” diameter cores, 3 replicates
Tensile Strength		X	X	AASHTO TP 9	4” x 4” x 10” slab[2], 3 replicates
Thermal Crack Resistance		X	X	AASHTO TP 10	4” x 4” x 10” slab[2], 3 replicates
Degradation and Accelerated Weathering Properties		X	X	ASTM D-5084 AASHTO TP 31	4” diameter cores Aged using water, ultra-violet light, and kerosene. Tested at initial, 1 week, 1 month, and 2 months, 2 replicates
Voids and Asphalt Binder Content		X	X	ASTM D-3203 and AASHTO TP 53	4” diameter cores, 3 replicates
Layer Thickness	X	X	X	Direct measurement with ruler	cores and slabs, 3 replicates
Aggregate Properties		X	X	ASTM C-136, C-131, C-127, D-2172	4” diameter cores, 3 replicates
Hydraulic Transmissivity (Drainage layer only)	X			Modified ASTM D-5084	12” x 12” x 12” slabs[2], 2 replicates

Notes:
1 Cores from the TCL site were analyzed for hydraulic conductivity only
2 Slabs were cut to size using a diamond-toothed saw
3 After cracking and prior to joint repair

The comparability of the data was maximized by using standard AS™ and AASHTO methods. Comparability was also maximized through the use of consistent sample collection techniques and field measurement methods throughout the evaluation.

4.2.4.1 Field Quality Control Program

Field quality control procedures consisted of a water-level meter precision check at the TLC site. This quality control check was not implemented at the DAFB site because a measuring tape was used to obtain the depth to water. After each field measurement event, the following precision-check procedure was executed. First, a graduated cylinder was fitted with a measuring scale divided into 0.10-inch (0.25-cm) increments. The vessel was then filled with water and the field water-level meter was used to obtain a measurement in the vessel. This measurement was taken three times. If the three measurements agreed within 0.1-inch (0.25-cm) of each other, the water-level meter was considered acceptable.

Each water-level measurement taken in the sump was taken three times to ensure precision. These three measurements were then used to calculate the relative percent difference (RPD). The measurements were accepted if they met the criteria of being less than a RPD of 2. If accepted, the three values were averaged and used to calculate the MatCon™ permeability.

The accuracy of the in-line volumetric flow meter was determined by field checking using a bucket and stopwatch method. The procedure required that flow occurred at the time of the field check, thus these checks had to be executed during rain events. The beginning flow rate registering on the flow meter was recorded to start. Then a 3-gallon (11.4-liter) bucket was filled at the outflow of the runoff discharge pipe while elapsed time was measured. The volume was then divided by the elapsed time to give a rate, which was compared to the rate read from the flow meter. Lastly, the rate was again read from the flow meter to ensure consistency in readings. If the difference between the flow meter and the bucket and stopwatch estimation was within 5 percent, the flow meter was considered accurate.

4.2.4.2 Laboratory Quality Control Program

PRI completed all the laboratory tests listed in Table 4-2 to characterize the cover materials at each site and to compare the MatCon™ cover with the conventional asphalt cover at the DAFB site. In conjunction with these physical testing procedures, PRI routinely performed a number of QC checks that are detailed in the QAPP (Tetra Tech 2000).

Calibration of the test equipment was performed, where required, and records maintained at PRI. For the air voids and binder property measurement, standard AASHTO specimens were used. Results obtained were within two standard deviations of the mean published by the Asphalt Materials Reference Library (AMRL) proficiency standard samples. The AMRL is maintained by the National Institute of Standards. Except for the shear test data, all other test data were within the acceptance criteria detailed in the QAPP. Due to equipment malfunction at the Auburn University laboratory (PRI's subcontractor), the shear test data were unacceptable.

Laboratory data were checked regularly for consistency with the expected result. For example, when the laboratory permeability results of the MatCon™ samples were significantly greater (greater than 1 x 10^{-6} cm/sec) than the expected value of 1 x 10^{-8} cm/sec, analyses of the air void percentage of the samples were found to be higher than the expected value of 3 percent. Air void percentage is a primary factor in the performance of the MatCon cover. In a real-world landfill cover application project, void percentages of greater than 3 percent would warrant the re-installation of the cover. Therefore, for the purposes of this demonstration, additional cores were obtained from the MatCon™ slab sample and analyzed for air void percentage. Based on these results, a re-analysis of permeability was conducted on core samples with 3 percent or less air void percentage. These results are presented in Section 3.0.

4.3 SITE Demonstration Results and Conclusions

The results of the evaluation are presented below in relation to the primary and secondary objectives established for the evaluation in the TEP/QAPP. Primary (P) objectives are considered critical for the technology evaluation, and secondary (S) objectives provide additional useful information.

P1--Determine if the MatCon™ cover exhibits a field permeability of less than the RCRA Subtitle C requirement of 10^{-7} centimeters per second (cm/sec).

To estimate the field permeability of the MatCon™ cover, the volume of infiltration during individual rainfall events was measured over the 6-month demonstration period at each of the two sites. Using Darcy's Law, the measured infiltration rates were converted into estimates of field permeability, and these estimates were compared to the regulatory requirement.

The in-field permeability calculated from measured infiltration for the MatCon™ covers at the DAFB and TCL sites is provided in Table 4-3. The table indicates that the in-field permeabilities are up to 3 orders of magnitude lower than the requirement for RCRA Subtitle C landfill covers.

P2--Compare the laboratory-measured permeability and flexural properties of the MatCon™ cover and the conventional asphalt cover at the DAFB site.

The vendor claims that the MatCon™ cover is both less permeable and has superior flexural properties when compared to conventional asphalt. To test these claims, laboratory tests that evaluate the two properties were conducted on both MatCon™ and conventional asphalt samples from the DAFB site. Results for each parameter were then compared using descriptive statistics to determine whether the MatCon™ cover appears to be superior to conventional asphalt for these two critical parameters.

Table 4-4 provides a summary of the laboratory properties of MatCon™ and conventional asphalt. As shown in this table, the average permeability of MatCon™ was about four orders of magnitude lower than that of conventional asphalt. The flexural tests of the MatCon™ cover samples indicate that a 36-inch-long (91.4-cm) beam can sustain 20.41 millimeters of deflection without cracking, whereas conventional asphalt cracked at 7 to 10 millimeters of deflection. Further, the MatCon™ cover sample had no cracks under 20 millimeter of deflection, whereas the conventional asphalt had 3-millimeter-wide, 2.5-cm-long cracks at about 25 millimeter of deflection.

S1--Measure other laboratory-measured physical properties of the MatCon™ cover and the conventional asphalt cover at the DAFB site

The vendor makes no specific claim for the superiority of MatCon™ to conventional asphalt with respect to physical parameters other than permeability and flexural properties. However, differences in other physical properties that can be measured in the laboratory may be of interest to potential users. Therefore, samples of both the MatCon™ cover and the conventional cover were taken

Table 4-3. Estimated In-Field Permeability of MatCon™ Cover During Rainfall Events*

Period Ending	Measured Leakage Volume (m^3)	Calculated Permeability (cm/sec)
Dover Air Force Base		
07-Apr-00	3.3E-02	4.5E-08
17-Apr-00	6.4E-03	1.3E-08
27-Apr-00	6.2E-02	1.3E-07
09-May-00	6.4E-03	2.6E-08
16-May-00	6.3E-02	1.3E-08
26-May-00	6.3E-02	8.5E-08
09-Jun-00	6.3E-02	8.5E-08
Tri-County Landfill		
20-May-00	2.8E-03	1.9E-09
02-Jun-00	5.9E-04	5.2E-10
7-Jul-00	2.7E-03	3.4E-09
21-Jul-00	9.4E-03	1.5E-08

* At each site, a ponding test was also conducted to measure in-field permeability.

Table 4-4. Statistical Summary of Laboratory Data.

Parameter	MatCon^{TM} Asphalt					Conventional Asphalt				
	No. of Samples	Mean	Std. Dev.	Min.	Max.	No. of Samples	Mean	Std. Dev.	Min.	Max
Tri County Landfill (TCL) Void Space, %	4	1.55	0.87	0.25	2.1	–	–	–	–	--
TCL Hydraulic Conductivity (cores) cm/sec	7	≤1.0 x 10^{-8}	0[2]	≤1.0 x 10^{-8}	≤1.0 x 10^{-8}	–	–	–	–	--
Dover Air Force Base (DAFB) Hydraulic Conductivity (cores)	4	≤1.0 x 10^{-8}	0[2]	≤1.0 x 10^{-8}	≤1.0 x 10^{-8}	3	1.04 x 10^{-4}	1.5 x 10^{-4}	1.8 x 10^{-5}	2.75 x 10^{-4}
Flexural Properties at Center, Deflection in mm	2	18.96	2.08	17.51	20.41	2	31.25	7.54	25.92	36.58
Joint Integrity cm/sec	3	5.47 x 10^{-5}	2.02 x 10^{-5}	4.3 x 10^{-5}	7.5 x 10^{-5}	3	1.04 x 10^{-4}	1.5 x 10^{-4}	1.8 x 10^{-5}	2.75 10^{-4}
Conductivity after Accelerated Weathering 30 days, cm/sec	3	7.35 x 10^{-9}	6.05 x 10^{-9}	1.65 x 10^{-9}	1.37 x 10^{-8}	3	2.96 x 10^{-4}	2.89 x 10^{-4}	2.65 x 10^{-4}	3.22 10^{-4}
Conductivity after Accelerated Weathering 60 days, cm/sec	3	2.2 x 10^{-6}	3.8 x 10^{-6}	3.9 x 10^{-9}	6.6 x 10^{-6}	3	3.15 x 10^{-4}	1.32 x 10^{-4}	1.77 x 10^{-4}	4.41 x 10^{-4}
Fuel Resistance (Kerosene) Depth of Penetration, cm	8	1.5	0	1.5	1.5	8	5.5	0.53	5	6

Table 4-4. Statistical Summary of Laboratory Data (continued).

Parameter	MatCon™ Asphalt					Conventional Asphalt				
	No. of Samples	Mean	Std. Dev.	Min.	Max	No. of Samples	Mean	Std. Dev.	Min.	Max.
DAFB Void Space, %	4	1.53	0.33	1.25	1.89	6	10.53	1.17	9.2	12.7
Coarse Aggregate Specific Gravity	3	2.74	0.01	2.73	2.75	3	2.75	0.03	2.72	2.78
Fine Aggregate Specific Gravity	3	2.72	0.01	2.71	2.72	3	2.74	0.01	2.73	2.74

from the DAFB site and analyzed for various parameters pertinent to the physical performance of asphalt paving and covers. Results for each parameter were then compared using descriptive statistics to determine if there are any significant differences between the two types of covers.

The physical properties measured to satisfy objective S1 are listed below:

- Joint integrity
- Load capacity and deformation
- Shear strength
- Tensile strength
- Thermal crack resistance
- Aging and degradation properties
- Void space
- Aggregate properties

S2--Determine whether extreme weather conditions or vehicle loads affect the field performance of the MatCon™ cover

To evaluate this objective, the MatCon™ covers at both sites were inspected periodically in the field, particularly following periods of extreme cold or other adverse weather conditions, to assess whether any cracks or surface deformities developed. These field inspections were used to evaluate the effects of extreme weather or vehicle loads since the previous inspection. General information on use of the covers for parking and on recent weather events was collected from the site owners and evaluated against any deformities noted in the field inspections. The TCL site in Elgin, Illinois, encountered much colder temperatures than the DAFB site in Dover, Delaware. As a result, data on the impacts of extreme cold were observed only at the TCL site.

At the TCL site, WMI parked their garbage trucks during the night and their waste recycling trucks traveled over the MatCon™ cover during the day. Further, the MatCon™ cover was subjected to extremely cold, sub-zero weather during January through March 2000. In late January, a crack was observed on the cover surface. This was investigated by taking core samples at the crack location and obtaining nuclear density measurements in the vicinity of the crack. Except for the core sample on the crack that had developed at a cold joint, all samples showed a permeability in the range of 10^{-7} cm/sec to 10^{-9} cm/sec. The sample on the crack had 8.2 percent air voids and a permeability of 3.56 x 10^{-5} cm/sec, indicating it was poorly compacted due to inadequate field quality control.

Based on the investigation, WCC improved the design and construction procedures for cold joint construction for MatCon™ covers. The crack was repaired by routing the joint, cleaning the joint using a hot air lance, and extruding it full of hot modified asphalt mastic joint sealer. Apart from the crack that developed at the cold joint, the rest of the MatCon™ cover performed well under extreme weather conditions and vehicle loads.

S3--Estimate a cumulative hydrologic balance for the MatCon™ cover over the period of the demonstration at the DAFB site

A hydrologic balance for the cover system was estimated at the DAFB site. The hydrologic balance was based on cumulative precipitation, totalized surface runoff, and subsurface drainage over the entire 6-month demonstration period. Although the hydrologic balance is approximate because of the length of time involved, it may provide additional insights into the performance of the MatCon™ cover.

Theoretically, the infiltration into the MatCon™ cover could be determined by using the equation
$I = P - ET - Qs$, where

I = Infiltration

P = Precipitation volume

ET = Evapotranspiration from the MatCon™ surface

Qs = Runoff

However, heavy precipitation events resulted in flooding and precluded accurate measurement of surface runoff. Therefore, a hydrologic balance for the DAFB site could not be obtained in this manner.

S4--Estimate the cost for constructing the MatCon™ cover and maintaining the cover for the duration of the demonstration

The capital and operating costs for the MatCon™ cover technology, as demonstrated at both the DAFB and TCL sites, were estimated based on cost information obtained from WCC and reviewed by Tetra Tech. The costs of the MatCon™ installation are detailed in Section 3.0 of this report.

4.4 Discussion of Results

A discussion of the field and laboratory measurements affecting MatCon™ performance is provided below.

4.4.1 Discussion of Field Data

The measured field permeability varied from a high value of 1.28 x 10^{-7} cm/sec to a low value of 5.15 x 10^{-10} cm/sec. The field permeability data calculations were based on several assumptions and Darcy's law. The uncertainties in the calculations included the following.

- The head was based on measured precipitation over the entire site; however, the MatCon™ surface was not subjected to the uniform head assumed for the precipitation event. Most of the precipitation did not remain on the surface, except for the two ponding tests.
- Infiltration measured as water volume in the sump does not account for changes in the water retained in the drainage layer.
- There was uncertainty at the DAFB site about the measurement of infiltration into the drainage layer. The high groundwater table at the site resulted in flooding, and there is a possibility that water infiltrated through the sidewalls of the sump.

To minimize uncertainties, a ponding test was then conducted at the TCL site during a 48-hour period. Oversight was provided by COE and EPA personnel. This resulted in a measured permeability value of 5 x 10^{-8} cm/sec. This value is higher than that obtained during rainfall events probably because during rainfall events a consistent hydraulic head is not maintained. The water head was maintained on the MatCon™ surface more consistently during the ponding test. The ponding test at the DAFB site yielded a result of 1.25 x 10^{-8} cm/sec.

4.4.2 Laboratory Data

The laboratory data presented in Table 4-4 and elaborated in this section provide a comparison of MatCon™ and conventional asphalt. As discussed in Sections 4.4.1 and 4.4.2, the primary physical properties that were studied included permeability and flexural properties, and the secondary physical properties that were measured included thermal crack resistance, load capacity and deformation, tensile strength, and aging and degradation properties. These properties are discussed below.

4.4.2.1 Permeability

Permeability is a critical parameter determining the performance of the MatCon™ cover. Table 4-4 indicates that the laboratory permeability of MatCon™ is about four orders of magnitude lower than conventional asphalt, and is less than 1 x 10^{-8} cm/sec. This is due to the lower void space and higher density of MatCon™ compared to conventional asphalt.

4.4.2.2 Flexural Properties

The ability of MatCon™ to settle over potential voids in the underlying materials isan important characteristic when considering caps over fills associated with waste materials. Most traditional tests for highway engineering do not consider flexural behavior that can occur with high strains in these settings. Consequently, a specialized test was used in this study to consider large strains.

Comparative data for MatCon™ and conventional asphalt are presented in Figure 4-11. This figure illustrates the total deflection versus time with notes indicating the onset of cracking. In all cases, the conventional material started cracking before the total deflection reached 15 millimeters, while the MatCon™ did not crack even at deflections as large as 20 millimeters. This increase in strain tolerance is attributed to the improved binder that is used in the MatCon™ system. The data collected demonstrate that MatCon™ is able to experience larger strains and deflections than conventional asphalt without cracking.

4.4.2.3 Load Capacity and Deformation

Introducing a loading stress, such as the weight of a vehicle, causes strains in the asphalt structure. These strains can lead to premature failure if the structure is not designed adequately. Two modes of failure are generally considered for the design of asphalt structures, which are dependent upon the resilient properties of the materials: (1) fatigue failure is dependent on resilient modulus/stiffness and fatigue properties of the materials and (2) permanent deformation, which is controlled by the aggregate interlock and high temperature properties of the binder.

Load capacity is determined by assessment of the resilient modulus over a range of conditions, and the permanent deformation behavior is measured with shear testing.

The resilient modulus was measured for temperatures ranging from -20 °C to +80 °C. The modulus of MatCon™ was 2048 MPa compared to 3200 MPa for the conventional asphalt. The reduced resilient modulus of the MatCon™ was due to the use of a modified binder that is more flexible at the lower temperatures applied in the resilient modulus test. However, at higher temperatures, the modulus of the MatCon™ exceeded that for conventional asphalt. This indicates that MatCon™ performs acceptably over a wider range of temperatures than conventional asphalt for distress modes such as cracking (at lower temperatures) and permanent deformation and rutting (at higher temperatures).

4.4.2.4 Tensile Strength

Tensile strength affects cracking due to thermal- or load-related effects. The tensile strength of asphalt materials varies with temperature, time of loading, and magnitude of strain. High stiffness materials are subjected to more stress at lower temperatures, and hence can be more susceptible to cracking.

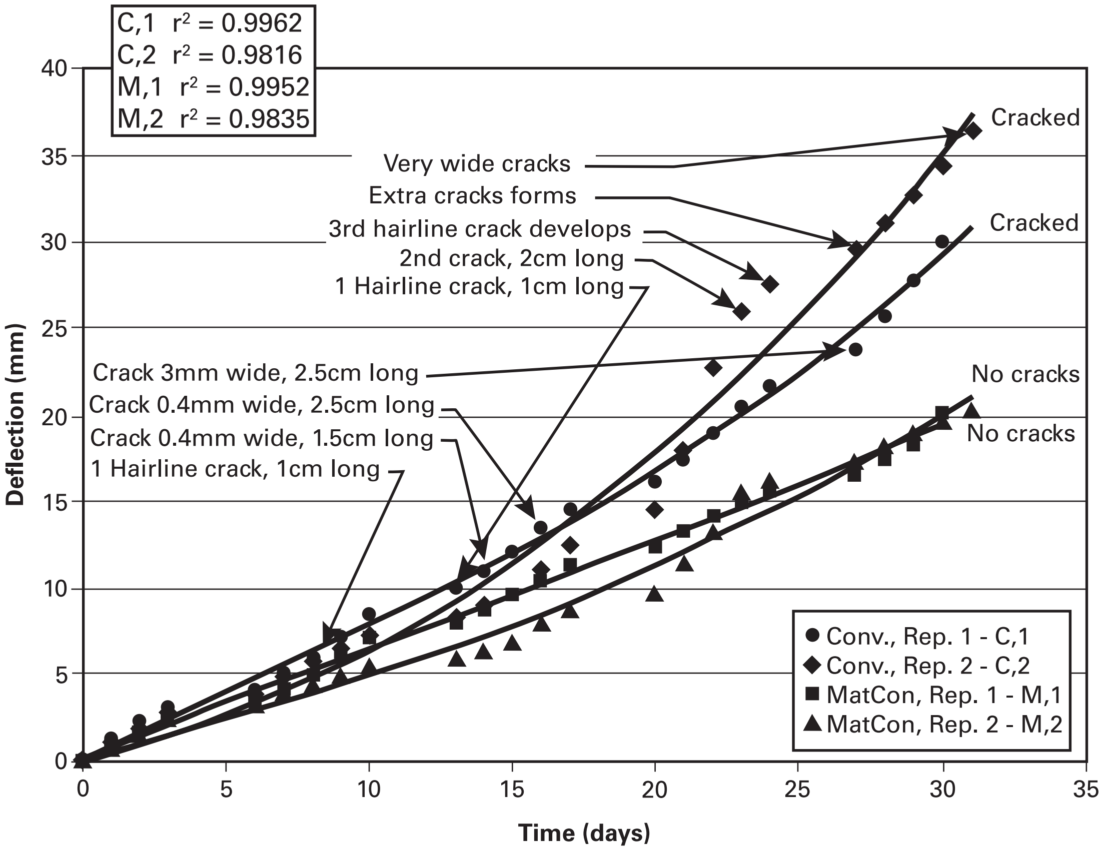
The low temperature tensile properties of MatCon™ and conventional asphalt are shown in Table 4-5. The data show that the tensile strength of the MatCon™ material is approximately 50 percent greater than for conventional asphalt, and that the expected cracking temperature is approximately 5 to 7 °C lower.

The tensile properties of MatCon™ indicate that it should be more resistant to the formation of cracks over the range of temperatures anticipated in a landfill surface cover. Of particular importance is the low-temperature tensile properties, since asphalt materials generally crack at these temperature extremes. At low temperatures, MatCon's™ tensile properties enable it to be used in significantly harsher climatic regions without the risk of cracking.

4.4.2.5 Thermal Crack Resistance

As asphalt materials cool, the natural tendency is for the material to attempt to contract as a function of the coefficient of thermal expansion. However, the contraction is effectively prevented by the structure; consequently, thermal stress builds in the asphaltic material as the temperature drops. The increase in thermal stress eventually results in fracture if the tensile strength of the material is exceeded.

The asphalt binder choice has the most significant impact on thermal crack resistance. Other factors, such as aggregate choice and subgrade type, affect the density and degree of cracking after cracks have started.



Source: PRI Asphalt Technologies, Inc. 2000.

Figure 4-11. Curves showing deflection versus time.

Table 4-5. Tensile Properties for Binder and Mixture at Cold Temperatures

	Tensile Properties Derived from Tests On:			
Property	Binder		Mixture	
	Conventional Asphalt	MatCon™	Conventional Asphalt	MatCon™
Tensile Strength (MPa)	1.86	2.97	2.579	3.551
Fracture Temperature (°C)	-18.8	-25.7	-25.4	-29.7

The results obtained are presented in Figure 4-12. The MatCon^{TM} samples had a higher fracture strength (by 37 percent) and a 4.3 °C lower fracture temperature than conventional asphalt. The test results indicate that MatCon^{TM} has improved low temperature behavior and will resist thermal cracking better than conventional asphalt. The degree of improvement in both fracture strength and temperature is attributed to the modified binder.

4.4.2.6 Aging and Degradation Properties

Aging of asphalt materials is caused by several chemical and physical processes, especially oxidation and volatilization. Volatilization is the loss of lighter molecular weight fractions through evaporation that begins with distillation of crude oil. Removal of lighter fuel oils leaves heavier residue, including asphalt. Further refining and processing results in a stable base asphalt cement that is then engineered for various uses, such as paving and roofing. The quality of asphalt is governed largely by the source of crude oil, and the only sources used for MatCon^{TM} are those in which long term stability and further volatilization are minimized. These properties are evaluated using standardized test protocols. The mass loss of volatile material in a standard laboratory test is almost immeasurable for high quality asphalt and is essentially nil over the multi-year life expectancy of pavements.

For very dense, low void MatCon^{TM} mixtures made with modified asphalt, the expectation is for longevity much greater than for conventional pavements. Several factors contribute to this expectation, including the use of base asphalt that was selected for superior aging characteristics, use of modifiers that chemically enhance resistance to degradation, and the low voids that prevent intrusion of air and water. The accelerated weathering tests used in this study were adapted from the roofing industry, in particular the International Conference of Building Officials (ICBO), which typically attempts to predict performance of asphalt roofing materials. However, any attempt to predict the actual service life of MatCon^{TM} based on this testing would be speculative because of the many variables and the heretofore unknown performance of MatCon.^{TM} The approach used in this study is to compare the behavior between MatCon^{TM} and conventional pavement on a relative basis, both in the laboratory and by monitoring field performance over several years.

The aging of asphalt materials is affected by a number of parameters such as binder quality, mixture type, and climate. However, if a system is made effectively impermeable, the supply of oxygen needed to age-harden the binder is effectively restricted. MatCon^{TM} materials are designed to achieve a low permeability and consequently, aging is anticipated to be low. For all conditions tested, the resilient modulus of the MatCon^{TM} does not exceed that of the conventional asphalt. The low void space and higher binder content in MatCon^{TM} results in the better aging properties observed for MatCon^{TM} compared to conventional asphalt.

Accelerated aging provides an insight into how MatCon^{TM} asphalt will perform over its expected life. The accelerated aging test method is used to determine changes in asphalt material and performance properties after 30 and 60 days of exposure to cycles of ultraviolet light and water sprays. In the accelerated aging study, the slab sections were placed in an accelerated weathering chamber and left exposed to cyclic ultraviolet light (20 hrs) and water sprays (3.5 hrs) with a surface temperature of approximately 160 °F. After 30 and 60 days, specimens were evaluated for changes in binder properties due to ultraviolet light and water exposure.

Results of binder property changes were reported as a PG rating, which is the performance window of the asphalt between a high and low temperature that the binder is expected to perform without cracking. The PG rating is the key component for long-term performance at the high service temperature for properties indicative of a susceptibility to deformation, such as rutting, and at the low service temperature for properties that forecast a susceptibility to fatigue and thermal cracking. A grading system for asphalt was developed by the highway industry and has been adapted by AS^{TM} (AS^{TM} D-6373).

The accelerated aging tests indicated that the MatCon^{TM} binder was essentially unaffected by exposure to ultraviolet light, maintaining the same performance grade, PG 82-22, after 60 days of aging, whereas the conventional asphalt binder lost both high and low temperature performance grades upon exposure, going from the initial PG 82-22 to PG 76-16 after 60 days of accelerated aging. The change in PG rating of the conventional binder indicates the binder has lost stiffness and elastic modulus at high temperatures and flexibility and pliability at low temperatures. The loss at low temperature is also indicative of a binder's aging rate.

Review of the binder properties after exposure to cyclic water sprays shows the MatCon^{TM} binder has a wider performance grade, PG 88-21 (109 °C), than

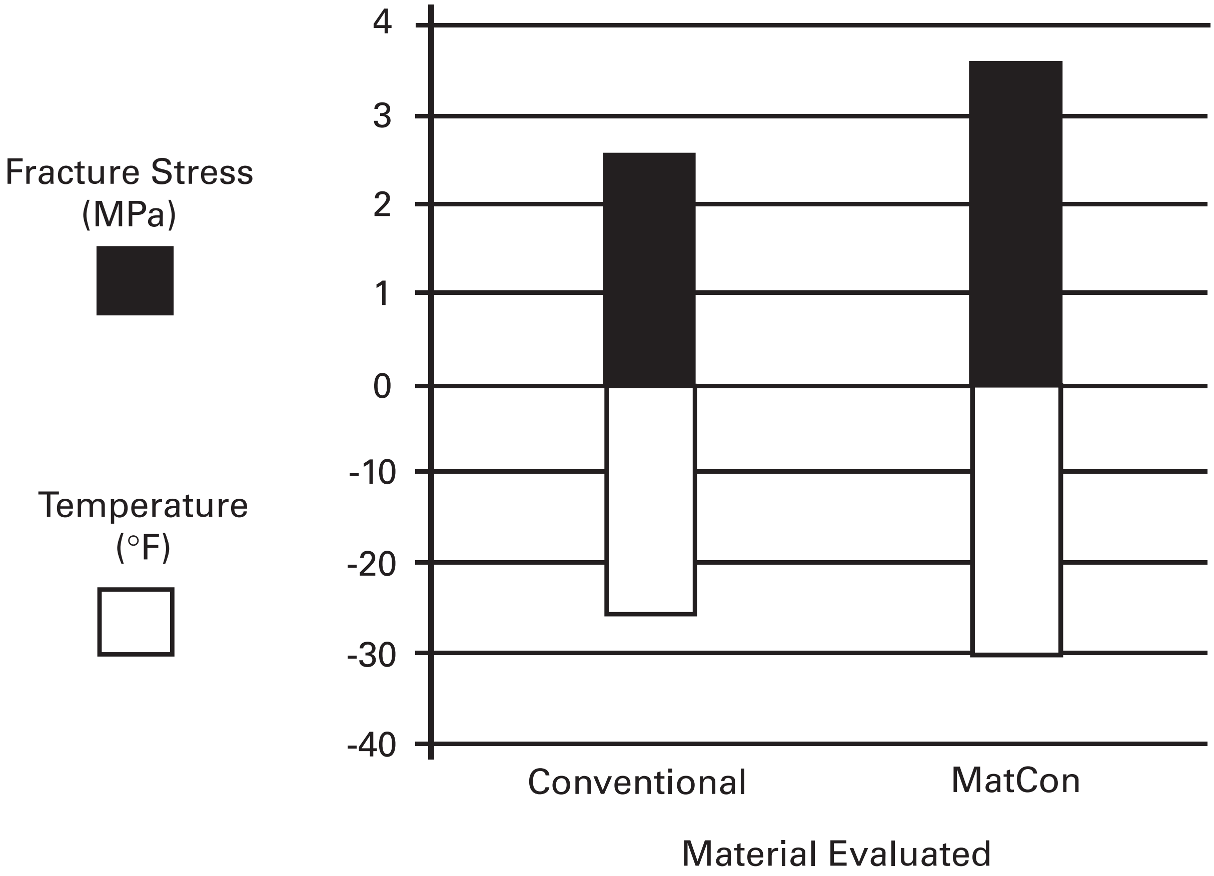


Figure 4-12. Fracture stress (MPa) and temperature (°C) for MatCon™ and conventional material.

the conventional binder, PG 82-19 (101 °C). The low temperature properties after aging also indicate that the MatCon^{TM} binder has an improved resistance to low temperature thermal cracking. A top to bottom profile comparison indicated that the exposure to water had minimal effect on the binder properties.

As seen from the data presented in Table 4-4, the permeability of the conventional cover remained generally unchanged after accelerated aging. The permeability of the MatCon^{TM} cover increased by an average of two orders of magnitude, but remained one to two orders of magnitude lower than that of the conventional cover. The degradation of the MatCon^{TM} after continued exposure to kerosene was 1.5 cm (out of a total 10-cm thickness). Under similar conditions, conventional asphalt degraded by an average of 5.5 cm (out of a total of 10-cm thickness).