Meeting the Challenges of Environmental Pavement Cap Systems

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ABSTRACT

Asphalt- and Portland cement-concrete pavements have been used to cover and isolate contaminants at cleanup sites for decades. These structures—referred to as "caps"—are typically employed where concentrations of contaminants are relatively low, and where other remedial technologies, such as excavation and removal, may be cost prohibitive. This paper looks at the range of functional expectations that drive cap designs, and the implications of designs for long-term cap maintenance. This document also explores how the Port of Tacoma and Port of Seattle (Ports) have successfully applied caps at their redeveloped harbor facilities, and includes lessons learned regarding inspection methods and maintenance approaches. The authors draw upon more than 30 years of experience in cap design, inspection, and construction oversight to provide useful tips for maximizing remediation effectiveness and compatibility with site uses, while minimizing long-term operation and maintenance costs.

INTRODUCTION

Capping is a type of environmental remediation technology often referred to as an "engineered control," and can span a broad range of designs, applications, construction materials, and placement/installation methods. Upland caps (i.e., vs. in-water) can consist of multi-layer systems (such as those used for landfills), building foundations, utility pads, roadways, or soil covers. This paper focuses on pavement caps applied at active outdoor industrial facilities, such as port cargo terminals, where legacy contamination has been addressed as part of a previous site cleanup under the federal Comprehensive Environmental Response, Compensation, and Liability Act (i.e., Superfund) or similar state-level regulations.

Pavement caps typically consist of one or more layers (referred to as lifts) of either cement- or asphaltic concrete of various thicknesses, underlain by a base course of gravel or other suitable material. Caps often serve the dual purposes of isolating underlying contaminants while functioning as a working surface (parking lot or container terminal) or as a foundation for buildings or utility installations; as a result, caps must meet several sets of performance requirements. For example, at a container terminal, the pavement must be able to withstand certain loading conditions, while simultaneously preventing the erosion and infiltration of water to underlying soil or wastes. Depending on site conditions, caps may also be used to prevent or control vapor migration to the overlying airspace. Additional pavement cap design elements typically include stormwater drainage features, utility penetrations, and integrated surface structures (e.g., building, barricades, and fences). Other structural components to consider include transitions from capped to non-capped areas, and painted surface markings.

Historically, environmental pavement caps were introduced as a remediation technology to address soil contamination and, indirectly, groundwater contamination, through the reduction of water infiltration, contaminant leaching, and lateral transport. Other technologies, such as *in situ* treatment or excavation and removal of contaminated soil or wastes, are often preferred by regulatory agencies as a means of destroying or removing the contaminant sources. However, at some sites, these options have been deemed impractical or too expensive relative to the net reduction in risk and large amount of material involved, so "containment-in-place" (i.e., capping) has often been the selected option. Capping is often viewed as a solution for multi-acre commercial/industrial sites with relatively low-level contaminant concentrations that would be paved anyway (e.g., parking lots and shipping terminals).

While capping can have relatively low initial capital costs compared to waste excavation or other more intrusive remedial actions, agency approval for an environmental cap is typically accompanied by requirements for long-term inspections and maintenance. These additional requirements can translate into significant recurring costs in the future. All pavements should be periodically inspected and maintained, and environmental pavement caps typically have additional inspection and maintenance protocol requirements. These requirements can include specific criteria that trigger repair, more intensive repair measures, the preparation and submittal of written inspection reports to oversight agencies (e.g., Washington State Department of Ecology [Ecology] or US Environmental Protection Agency [EPA]), and long-term performance monitoring. Complying with these protocols is particularly challenging at terminals, where inspections and repair work need to be carefully scheduled and coordinated with cargo loading and storage operations.

There are typically two general environmental performance goals for pavement caps: 1) isolate and prevent the erosion of or direct contact with underlying contaminated materials, and 2) prevent or reduce surface water infiltration, contaminant leaching, and transport via groundwater. Depending on the specific site conditions and history, infiltration may not be a concern, so a cap may only be needed to physically isolate underlying material. However, at most locations in the Pacific Northwest—where groundwater is typically located at shallow depth and may discharge to nearby surface water—control of infiltration is often a design and maintenance priority.

Pavement caps are not static—they change over time, but they must continue to meet their performance objectives. Over the long term, a cap can be subjected to the same aging processes that affect conventional roadway pavements. Settling, damage, and mechanical wear can all result in the need for periodic patching, or even repaving or replacement of entire cap sections. At cargo terminals, heavy loading, prolonged container storage, and repetitive traffic patterns can exacerbate and accelerate these processes. The nature of localized subsurface materials beneath caps is not always precisely known, and pockets of softer fills, such as sawdust and bark, or rigid items, such as buried concrete and piles, can result in uneven settling over the life of the cap.

Blending Environmental and Conventional Cap Pavement Design Objectives

Conventional pavement design objectives include the need for strength and resistance to wear. Prevention of water infiltration, which can cause damage during freezing conditions, is also a factor; seal coats are often applied to asphaltic pavements to address this potential issue. Industrial pavements need to have sufficient load-carrying capacity; for intermodal container terminals, some pavements may need to be thicker in the cargo handling/storage areas and thinner in the rail yard portions.

The design of pavement caps typically needs to consider additional objectives. For example, to further prevent water infiltration, cement-concrete pavements may be designed to have fewer contraction joints. However, because one purpose of these joints is to prevent uncontrolled cracking, a design including fewer joints can be counterproductive. Pavement contraction joints and joints where the pavement abuts non-cap structures can be installed with sealed construction joints (Figure 1), but these can be expensive and must be installed properly. Crack sealants may be used for this purpose, as well as for sealing around utility penetrations. The development of cracks in pavements is to be expected, especially in rigid pavements, so proper subbase preparation is imperative.

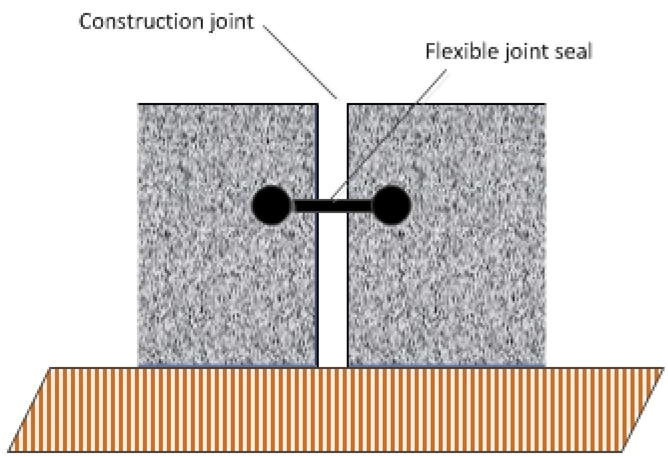


Figure 1. Flexible seal installed in concrete pavement construction joint to prevent water intrusion

For concrete pavement caps, it is possible to specify mixes that have a lower water-to-cement ratio and reduced porosity, and special sealant coats can be applied to pavement surfaces, although these can be expensive and difficult to maintain. In addition to sealant coats, specialized low-permeability paving fabrics and asphalt-aggregate mixes may be used to construct asphaltic pavement systems. Geotextile fabric can also be installed beneath the cap and clean base course/fill to mark the boundary with underlying contaminated soil. Such a marker is helpful when planning and conducting utility excavations in capped areas.

While sealant coats can significantly extend the life of pavements (especially asphaltic pavements), special attention should be given to the selection of sealants and coatings, since they will eventually wear off and may pose a risk of environmental contamination (Mahler et al. 2012). Many jurisdictions—including Washington State; Minnesota; the District of Columbia; Austin, Texas; and others (MPCA 2016; Needleman 2015)—have banned the use of coal-tar-based sealant coat products, and many products now indicate that they are coal-tar free. While epoxy/polyurethane or penetrating sealants can also be applied to concrete pavements, these are not commonly used on large outdoor caps, where freeze/thaw cycles are not a major concern and concrete alone is likely to provide sufficient impermeability. The effectiveness, cost, and added maintenance requirements of sealants should be considered on a project-specific basis.

Where volatile contaminants are present, pavement caps may also be designed to prevent emanating vapors from migrating into the overlying air, and to assist in vapor collection using buried vapor collection systems. Cap systems are often augmented with an underlying geomembrane or similar design element to enhance resistance to upward vapor migration. Specially designed vaults may be required for access to vapor control system valves and for in-line or *in situ* vapor monitoring.

Specifications for pavement cap systems typically include requirements pertaining to the pavement mix and thickness, as well as base course composition and compaction. Asphaltic pavements installed in lifts will typically be required to meet a minimum thickness for each lift, a prerequisite that can be achieved by careful construction monitoring and verified by obtaining post-construction cores. Adequate compaction is critical, especially where caps are placed on existing fill; sometimes, it may first be necessary to remove structurally unsuitable material (e.g., sawdust or wood waste) and replace it with sufficiently compacted fill.

Cap designers or oversight agencies sometimes specify a numeric limit on hydraulic permeability and requirements for post-construction permeability testing. They can further require pavements that do not meet the limit to be removed and replaced, and the replacement to be tested. In practice, the permeability of multi-layer pavement systems may be difficult to measure using field or laboratory-based methods, and results for multiple samples from the same pavement can vary significantly, creating an “acceptance” issue for the project owner and contractors. One solution is to use cap system designs and specifications that have already been proven to meet the specified limits, and that do not need to be retested after each installation. This approach can be proposed in the basis-of-design report prepared for oversight agency review and approval prior to construction.

Finally, it is important to consider the design life of caps relative to conventional pavements. Typical container terminal surfaces are often designed with a minimum 20-year life expectancy. Life expectancies for pavement caps are typically expected to be longer; an assumed life of 30 years is typical for life cycle costing purposes for environmental remediation technologies including caps (EPA 2000).

GROUNDWATER MONITORING FOR LONG-TERM CAP PERFORMANCE

Some type of groundwater monitoring program is often required to confirm that the cap is effectively blocking contaminant mobilization and transport. The designs and details of these programs—the scopes of which are typically negotiated with the oversight agency—are widely varied and beyond the scope of a detailed discussion herein. However, the following general concepts should be considered when integrating a groundwater monitoring program with a pavement cap system:

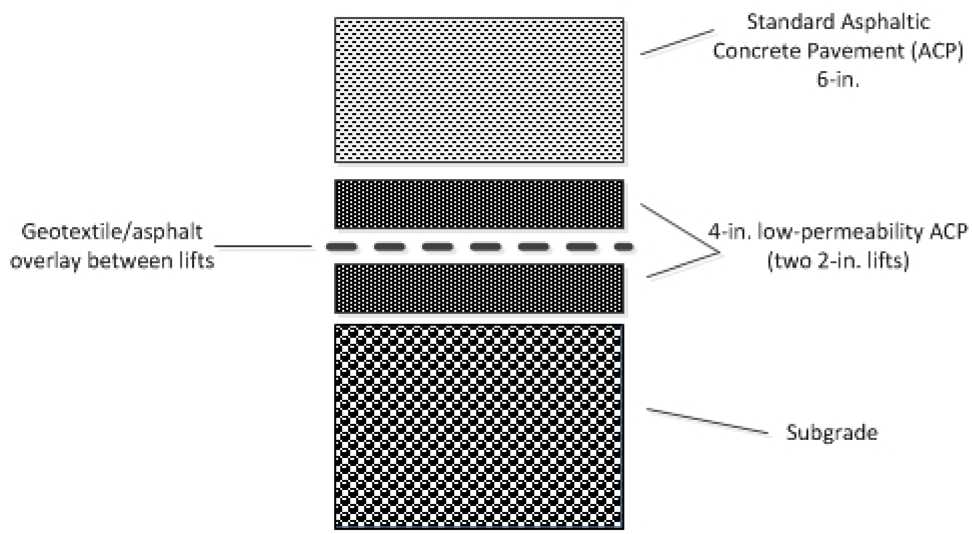
- Groundwater hydrology may not respond immediately to a newly installed low-permeability cap. It may be prudent to evaluate long-term changes in groundwater flow and piezometric conditions before implementing a full groundwater monitoring effort. Sometimes this equilibration can take several years.
- Monitoring wells installed within the cap may be useful for monitoring certain parameters, such as water levels or redox, but chemical analyses may be indicative of the quality of water in direct contact with capped source material. Downgradient monitoring may give a better indication of long-term cap performance.
- Capping may have long-term impacts on subsurface geochemistry due to changes in hydrology, oxygen levels, or redox.
- Monitoring wells placed in industrial settings need to be relatively “bomb proof.” Specially designed flush-mounted well monuments that can withstand impacts from heavy equipment and cargo are commonly used.
- Safety and accessibility are important considerations when selecting well locations.

SPECIAL CONSIDERATIONS FOR CAP DRAINAGE

Effective conveyance of runoff from pavement cap surfaces helps ensure a problem-free work surface, while also removing rainwater that might otherwise collect on the surface and infiltrate the cap. Proper grading of pavement surfaces toward catch basins and trench drains is a design necessity, and proper compaction helps prevent subsidence that can result in excessive ponding and pavement cracking. Consideration should be given to drainage structures that can be inspected and cleaned easily. For terminal properties at the Ports, drainage inspection and maintenance programs already exist as part of their stormwater compliance programs.

EXAMPLES OF CAP DESIGNS

The various caps presently in place at the Ports’ facilities show how diverse designs can be effective for both long-term containment and control of infiltration. A cross section of the pavement profile for the cap at the former Murray Pacific No. 2 Log Sort Yard (Murray Pacific), a Port of Tacoma property, is shown in Figure 2. This area was used as a log sort yard from the 1970s through the early 1990s. To stabilize the soils to cope with the heavy loads associated with log yard operations, approximately 68,000 tons of smelter slag, along with rock and gravel, were placed at the facility. In 1983 and 1984, Ecology collected stormwater runoff samples from the site in which elevated levels of arsenic, copper, lead, and zinc were found to be present. Ecology concluded that the smelter slag was likely the source of the elevated metals concentrations. A remedial investigation/feasibility study (RI/FS) was completed in 1993 and in 1994, Ecology and the Port of Tacoma entered into a consent decree in order to implement the remedy selected based on the findings of the FS. The selected remedy included excavation, installation of an asphaltic concrete cap, use of stormwater controls, groundwater monitoring, and use of institutional controls. Remedial actions were completed from 1995 to 1998.

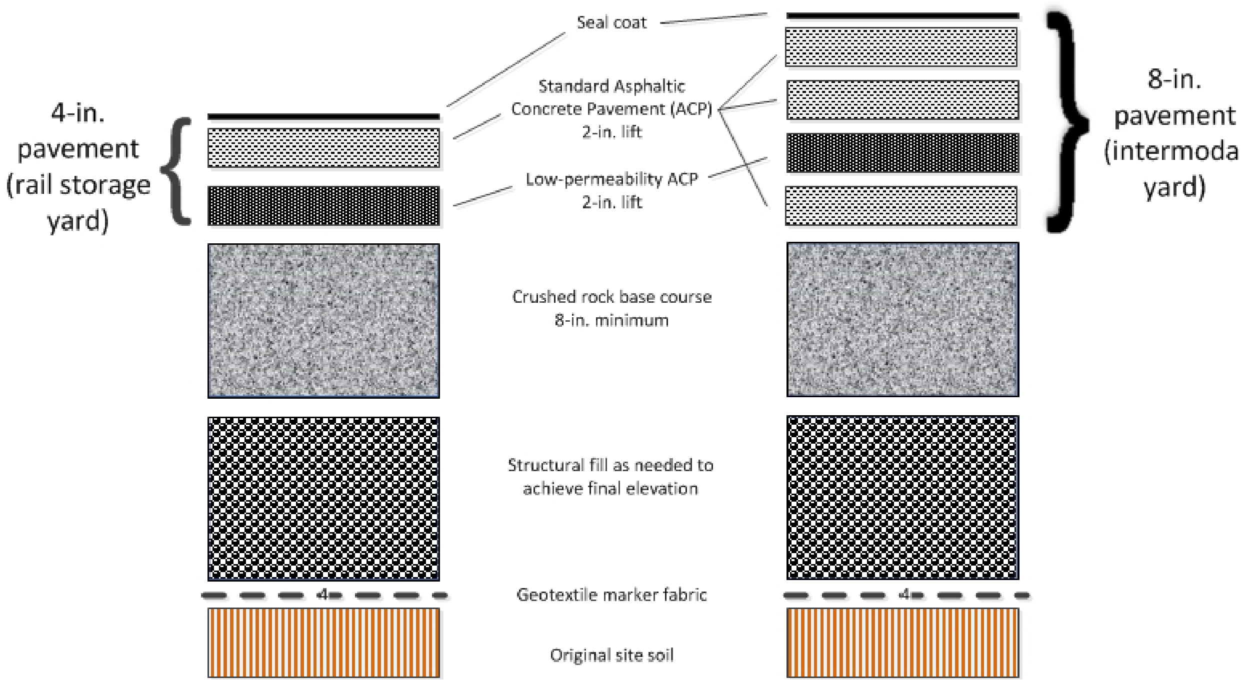


Adapted from HLA (1997)

Figure 2. Cross section of the low-permeability asphaltic concrete cap for the former Murray Pacific No. 2 Log Sort Yard

Murray Pacific is one of five Port of Tacoma-owned former log sorting yards where Asarco slag was used to build stable ground for running heavy machinery. The five sites are nearly identical in former site use (i.e., former log yards), source of metals contamination (Asarco slag), and RI and cleanup. Cleanup actions were similarly comparable, consisting of removing some contaminated material and installing impermeable caps, stormwater infrastructure, and a perimeter monitoring well network. The Port of Tacoma is now required by the consent decree to maintain the structural integrity and functionality of the remedial caps and drainage systems.

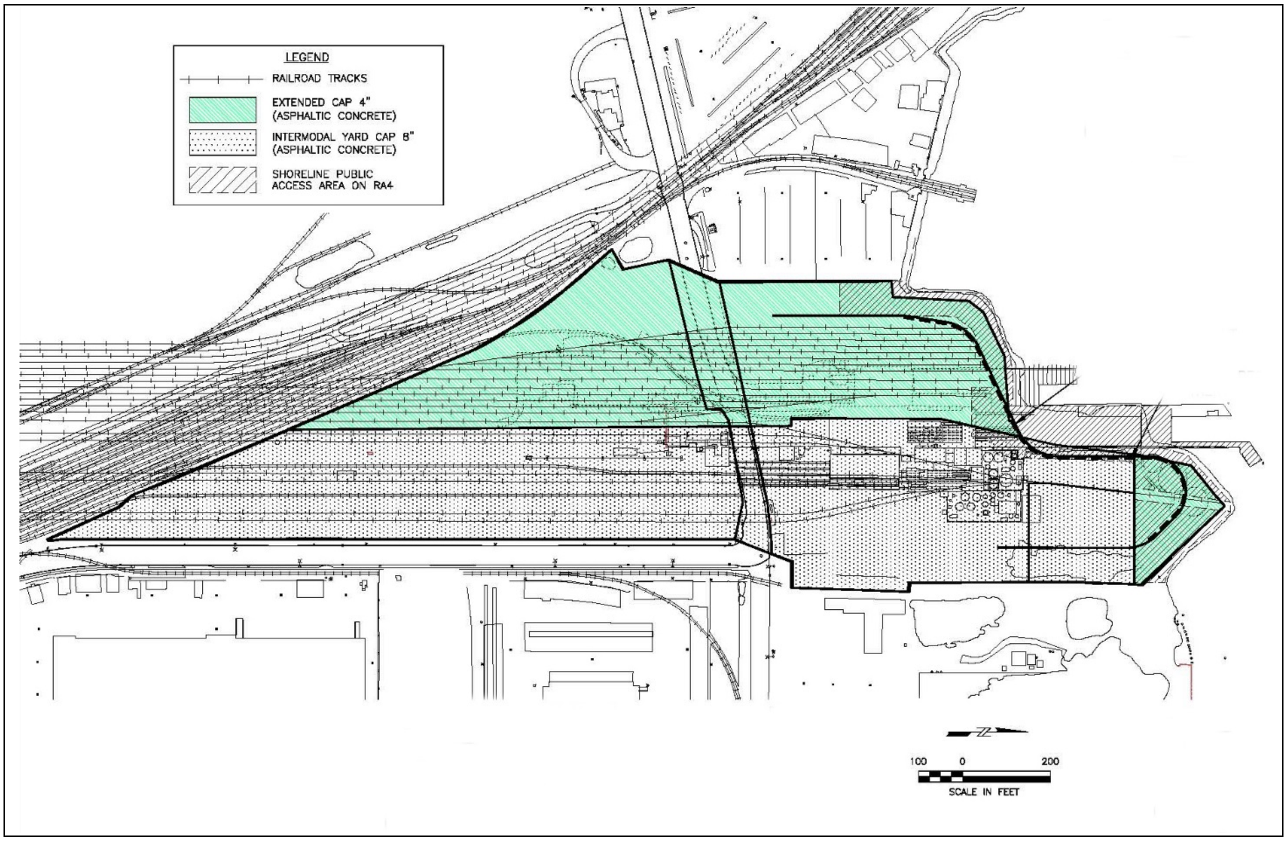
The two types of caps shown in Figure 3 were designed for portions of the north end of Terminal 5 at the Port of Seattle. The area, known as the Pacific Sound Resources (PSR) Superfund site, was formerly a wood-treating (creosoting) facility, and was remediated and redeveloped under an agreed order on consent (AOC) with EPA.



Adapted from RETEC (2004)

Figure 3. Example asphaltic concrete cap sections design with a low-permeability lift

Two different cap thicknesses were used for a rail storage yard and an intermodal yard (Figure 4), based on the yards' different uses and anticipated loadings. For both, a standard mix (class A gradation) asphaltic concrete was used. The top lift serves as a replaceable wear layer, and there is an underlying low-permeability lift consisting of a slightly higher percent of asphalt and a slightly lower percent of voids. In the intermodal yard, additional lifts exist both above and below the low-permeability lift to provide additional strength. The use of a top wear layer on the multi-lift pavement has allowed deeper sections to remain in place during resurfacing. Some localized areas on the cap have experienced settlement exceeding 3 in., a criterion that requires replacement of the entire impacted pavement section (Table 1).



Adapted from RETEC (2004)

Figure 4. Application of two cap types depending on yard use and activities

Table 1. Repair/maintenance measures based on cap inspection criteria

Inspection Item	Cap Condition	Maintenance Required
Asphaltic Concrete Pavement		
Pavement surface	alligator cracks over 5-ft^2 area	Seal crack.
	parallel traverse or longitudinal cracks > 24 in. long	Seal crack.
	cracks > 4 in. long and < 1/2 in. wide	Seal crack (without routing).
	cracks > 1/2 in. wide	Seal crack (with routing).
	cracks at construction joints	Seal crack.
	surface settlement < 3 in. deep	Patch surface
	surface settlement > 3 in. deep	Repair by removing and replacing asphaltic concrete and subgrade.
Along structures	gap between pavement and structure interface > 1 in.	Seal crack.
	gap between pavement and railroad track interface	Monitor gap for 1 year.

Inspection Item	Cap Condition	Maintenance Required
Other Cap Components		
Storm drainage system	standing water	Inspect adjacent catch basins and/or nearby surface drains and clean out as necessary. If settlement causes ponding, refer to cap condition surface settlement, above.
Cap boundary markings (striping/painting)	not visible/removed	Restripe/repaint when performing general yard restriping/ repainting.
Other		
Notification by tenant of cap damage	damaged area to be inspected within 5 working days of receiving tenant notification	Repair/maintain as necessary.

Table source: Pacific Sound Resources Superfund Site *Inspection and Maintenance Plan for the Asphalt Cap and Associated Stormwater System* (RETEC 2004)

DESIGNING WITH MAINTENANCE IN MIND

The Ports are well into their third and fourth decades of cap inspection and maintenance efforts for their capped facilities. The following points are provided in the hope that they will inform future cap design efforts:

- Consider including permanent survey marks (with an accurate survey and as-built design) to designate cap boundaries (and inspection points) as needed. Painted surface markings can wear away and become illegible.
- Keep in mind that pavement caps can cover a range of materials, including sawdust or wood waste. Different degrees of settlement may occur as organic materials break down, resulting in drainage and structural issues with the cap.
- Consider more durable pavements and infrastructure where access may be difficult. Evaluating necessary repairs and completing them at an operating terminal may be impossible or very difficult due to operational constraints.
- Container chassis landing gear concentrate the load on asphaltic concrete cap surfaces, resulting in depressions (also referred to as divots or dimples) that can lead to further pavement degradation. Portland cement-based concrete slabs are expensive to install, but some cap designers elect to install long, narrow concrete slabs to support container chassis landing gear (Figure 5).
- Use of proper bedding and sufficient compaction of fill and sub-base materials around utility vaults and manholes is a perquisite to preventing settlement and cracking of pavement around these structures (a common maintenance issue).

Figure 5. Concrete apron installed to support container chassis landing gear

Cap Inspections and Documentation

As mentioned, periodic inspections are often required by oversight environmental agencies as a condition of installing an environmental pavement cap system. Inspection frequency for the Ports' caps ranges from 6 to 30 months, and cap inspection reports are periodically evaluated by the agencies during their multi-year site reviews. A written inspection and maintenance plan should be available to guide the inspection process. These plans are prepared as part of the original cap design and are often one of the required deliverables for agency review.

Inspection frequency is often determined by original agreements with the oversight agency. Full inspections may be impossible due to operational constraints at container terminals. Some inspections involve examining representative portions of the cap and cap boundaries, with the assumption that other, similar areas are undergoing similar effects of wear and aging. This assumption can be confirmed, if necessary, by less-frequent cap-wide inspections. Either way, every drainage structure should be inspected.

Scheduling with facility tenants and operators is helpful in order to gain safe access. Facility operators can help with train schedules where it is necessary to inspect a cap area within rail alignments, and they can sometimes relocate cargo to provide access. Cap inspections can also be done during yard downtimes or at night. Coordination between owner and tenant is very important and should be done well in advance of the planned inspection/maintenance work.

Inspections help track pavement conditions over time, often bring to light potential maintenance items in a timely manner, and help ensure that the performance goals of the cap system continue to be met. Problems with surface damage and wear, potholes, subsidence, and ponding are not only indicative of potential cap degradation, but are also often an operational concern for facility tenants and operators. Part of the inspection process includes communicating with tenants and operators, who may be aware of pavement-related problems. This communication also provides an opportunity to remind tenants about operational constraints, including load limits and unauthorized penetrations into the cap surface.

Some surface wear and pavement aging are expected and do not necessarily indicate a cap performance issue or immediate need for repair. There are useful pavement inspection guides (USACE 2009a, b) that can be adapted and used as a means of describing the nature and extent of pre-maintenance pavement conditions. While asphalt weathering, surface markings wear, and shallow alligator cracks may not require immediate repair, these conditions can be readily observed and tracked over time. This information is useful in anticipating future problem areas and evaluating when cap resurfacing or repair may be needed, facts that can be important for longer-term budgeting and planning.

If possible, inspections should be done during or after rain events, as the resultant water is helpful in identifying areas of ponding, drainage problems/patterns, etc. Inspection for cracks or gaps in pavements should be done during cool weather or early in the day, when the air is cool and thermal expansion is at a minimum.

Agencies often require the submittal of environmental cap inspection reports, which may necessitate the preparation of a list of specific repair needs that are prioritized and justified relative to the established repair criteria. Even if the agency does not require it, the preparation of a list of observations and necessary repairs can be helpful in conveying and tracking maintenance needs. The operation and maintenance manual for the cap can include a list of specific repairs for each type of wear/damage that may arise (similar to those shown in Table 1). This can help streamline the process of putting together a catalog of repairs after each inspection.

Inspections should include checking previously repaired items and items noted during previous inspections. For some items, the underlying cause of damage may still exist, and follow-up repairs may be needed. It is important to include the date and nature of repairs so that the status of a specific observation can be tracked over time. Bid documents, project descriptions, completion reports, and other pertinent information related to larger repair projects (e.g., repaving or cap-wide crack repairs) should be included as attachments to inspection reports.

CONCLUSION

The use of pavement caps at port cargo facilities makes sense for areas that will be paved anyway to provide a functional work surface for port tenants. However, as “engineered controls,” environmental caps go hand-in-hand with a long-term commitment to inspect and maintain the structure. One does not just build a cap and walk away. For some facilities that already have caps, the structures were installed at a time when disposal requirements or redevelopment schedules made removal too expensive or infeasible. The costs and regulations associated with managing waste removal to an off-site location are always subject to change, so an up-to-date evaluation of the long-term trade-offs between capping in place vs. treatment or removal should always be part of the planning process. This is especially true for any pavement system that is reaching the end of its useful life and will be expensive to replace. In such a situation, removal of some or all of the capped material could be a sensible alternative. In addition, large cap repair or repaving projects can present an opportunity for improvements and upgrades designed to reduce future maintenance demands.

REFERENCES

EPA. 2000. A guide to developing and documenting cost estimates during the feasibility study. EPA 540-R-00-002. US Environmental Protection Agency, Washington, DC.

HLA. 1997. Operation and maintenance plan, Murray Pacific log yard remediation project, Port of Tacoma, Tacoma, Washington. Harding Lawson Associates, Bellevue, WA.

Mahler BJ, van Metre PC, Crane JL, Watts AW, Scoggins M, Williams ES. 2012. Coal-tar-based pavement sealcoat and PAHs: implications for the environment, human health, and stormwater management. Environ Sci Tech 46:3039-3045.

MPCA. 2016. Actions to restrict or discontinue the use of coal tar based sealants in the United States. Current as of July 12, 2016. Minnesota Pollution Control Agency.

Needleman H. 2015. The use, impact, and ban of coal tar-based sealants. Virginia Coastal Policy Center at the College of William & Mary Law School, Williamsburg, VA.

RETEC. 2004. Inspection and maintenance plan for the asphalt cap and associated stormwater system. Revision 1. Pacific Sound Resources Superfund Site, remediation area 4, Southwest Harbor Cleanup and Redevelopment Project. Prepared for the Port of Seattle. The RETEC Group, Inc., Seattle, WA.

USACE. 2009a. Asphalt surfaced roads & parking lots. Paver™ distress identification manual. US Army Corps of Engineers.

USACE. 2009b. Concrete surfaced roads & parking lots. Paver™ distress identification manual. US Army Corps of Engineers.