PERMEABLE PAVEMENTS FOR ROADWAY SHOULDERS

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ABSTRACT

With an increased interest in low impact design and green infrastructure incentives, permeable pavements are becoming increasingly popular as an alternative pavement solution to minimize stormwater runoff and to improve water quality. Traditional shoulders are designed to provide a safety zone for emergency pull offs, provide a traffic lane during rehabilitation and maintenance operations, provide lateral support for the mainline pavement as well as providing a travel lane for other modes of transportation including buses, bicycles, etc. A permeable pavement shoulder system would provide all of these features as well as stormwater management benefits. The system would be designed such that surface water would flow across the pavement into the permeable shoulder into a stone reservoir. This stone reservoir would then temporarily store and treat the runoff. The stored water would then either infiltrate into the subgrade soils or be discharged to other stormwater outlet systems. Highway shoulder applications provide a unique set of design considerations that need to be evaluated and properly designed for prior to constructing permeable shoulders. The design of permeable pavement shoulders requires a balance between providing a structurally sufficient pavement to withstand traffic loading as well as achieving the stormwater management/ hydrologic design goals. Construction techniques and proper maintenance of the permeable shoulders are critical to the success and the longevity of the permeable pavement shoulders. Permeable pavements are not suitable for every shoulder application, however, with the proper design, construction and maintenance, they provide a low impact and green alternative that may be considered.

INTRODUCTION

With the recent 2013 flooding in Calgary and Toronto and municipal interest in green infrastructure solutions for stormwater quantity and quality management, interest in the use of permeable pavements has been rapidly increasing. Cities such as Vancouver, Calgary, Toronto and numerous private sector developers have been designing and building permeable pavements. Traditional pavement surfaces are virtually impermeable. For permeable pavements precipitation is channelized along the surface towards stormwater management facilities through ditches and storm drains. In contrast, permeable pavements allow precipitation to infiltrate and flow through the pavement surface. The water can be stored and slowly returned into the local groundwater system or other conveyance systems. The primary benefits of permeable pavements are to reduce peak flows, reduce surface ponding, decrease downstream erosion, filter and clean contaminants and promotes groundwater recharge.

Departments of Transportation (DOTs) and other municipal organizations have expressed interest in permeable shoulders to assist in the overall management of stormwater. Water from the surface of the roadway would flow into the permeable shoulder into a stone reservoir to temporarily store and treat runoff before infiltration into the roadway subgrade soils and/or discharge to other stormwater conveyance and treatment systems. Potential challenges for success of permeable shoulders include: reduced structural capacity compared to conventional pavements, possible moisture weakening of adjacent roadway lanes (and shoulders themselves), potential maintenance issues, durability, and perceived safety concerns.

This paper summarizes the findings of an investigation into the suitability for permeable pavements for use for roadway and highway shoulders for the National Cooperative Highway Research Program (NCHRP) technical report (Published October 2013). This research focuses specifically on the application of permeable pavements for highway shoulder applications.

PERMEABLE SHOULDER FEASIBILITY DECISION CRITERIA

The primary purpose of highway shoulders are to provide a safety zone for emergency pull-off from the main highway lanes. Shoulders may be used to carry mainline traffic during rehabilitation and maintenance operations and be used by other modes of transportation. Shoulders also provide lateral support to the pavement and drainage of surface water away from the travelled portion of the roadway.

While the use of permeable shoulders may have significant benefits in terms of stormwater management, their application is not suitable for all situations. To determine the suitability, the key factors specific to the project should be considered. Based on their importance in overall decision making, these factors can be divided into primary, secondary, and other considerations which may impact the decision to use permeable pavements. Each of these criteria is discussed in more detail in Table 1.

Table 1. Suitability decision considerations

Importance Level	Description
Primary Considerations	
Availability of funding	Initial construction cost is typically higher than for conventional pavement. Overall long term life-cycle costs can be very competitive if consideration is given to stormwater quality and quantity benefits.
Environmental approval status	In some jurisdictions, may not be permitted or may require additional environmental approvals.
Safety	Ability to accommodate safety features such as rumble strips, etc.
Significant longitudinal grades	Grades > 5 percent may pose significant design challenges. May require relatively costly design features (regular cut-off walls or below grade shallow slopes with step-downs) to provide needed level of infiltration.
Depth of water table	Should not be used in areas where the water table is within 0.6 m of the top of the subgrade.
Geotechnical risks	Geotechnical risks may introduce added design complexity and may necessitate the use of an underdrain and/or impermeable liner.
Groundwater contamination risk	Factors including: soil characteristics, depth to groundwater, existing soil contamination, and application of salt for deicing may influence the potential for stormwater sources to contaminate groundwater.
Secondary Considerations	
Stringent receiving water quality standards	For special cases of protected watersheds, cold water streams, the level of treatment provided may not provide adequate protection from stormwater quality impacts.
Winter maintenance	Winter sand may clog the systems resulting in reduced permeability.
Low soil infiltration rates	May need to be supplemented with an underdrain to provide adequate drainage, which tends to reduce performance and increase costs.
Target design volumes and runoff rates	Due to geometric factors, storage volume may be limited. Supplementary drainage features may be required.
Complexity of geometric conditions	Geometric constraints such as horizontal or vertical grades, presence of bridge structures, curbs, retaining walls, guiderails, etc.
Risk of flooding	Frequent flooding areas may require supplemental drainage features.
Mandates for stormwater quality control	May contribute substantially to water quality improvement. Where regulations require stormwater quality management, this may significantly incentivize the use of permeable pavement.

Importance Level	Description
Mandates for drainage and peak flow control	Permeable pavements provide stormwater management alternatives to more costly practices to provide drainage and peak flow control.
Maintenance protocols	Require mandatory non-traditional maintenance practices i.e. (vacuum sweeping), which may influence their applicability and desirability.
Shoulder utilization	Some shoulders are used as driving lanes. Design for moderate to heavy traffic use would require additional considerations and additional costs.
Other Considerations	
Presence of utilities	The design and construction may be problematic or require additional design features in areas where utilities are present.
Impact of unknown site conditions	Variability of soil conditions, presence of organics, potential for frost heave, etc. may impact pavement performance.
Risk of accidental chemical spill	While spills are relatively uncommon and tend to occur at low volumes they can typically be retained in the permeable pavement.

PERMEABLE SHOULDER FEASIBILITY DECISION MATRIX

To assist in evaluating the suitability of projects for the use of permeable shoulders, a project suitability matrix (template) was developed (Table 2) which could be tailored for individual user needs. The matrix includes the considerations outlined above with appropriate weighting factors for each group. Within each group, the individual consideration items also are given weighting factors. Each factor should be assessed using specific criteria of the owner's needs and expectations for the project. Once the factor is rated, the total scores are summed on a scale of 0 to 100. A suggested total score evaluation metric includes if the score totals less than 65; the project is not considered a good candidate for permeable shoulders. Between 65 and 75, the project can be considered for permeable shoulders. Scores over 75 indicate that the project is well suited for permeable shoulders. This scoring evaluation should be vetted and adjusted as necessary for their own conditions.

In the example shown in Table 2, the primary considerations have been given a category weighting of 60 points; the secondary considerations are weighted at 30, and other considerations are weighted at 10. When considering the primary factors, there was a preference for selecting projects where funding was available, where there are minimal environmental issues and where there is sufficient depth to the water table to provide adequate drainage. In terms of secondary factors, there is a clear mandate for stormwater quality and quantity improvements with minimal maintenance and operational concerns, favoring the use of permeable pavements. The "other considerations" category provides only a minimal contribution to the decision weighting. These weighting factors can be adjusted to better reflect specific goals and objectives.

STRUCTURAL AND HYDROLOGICAL DESIGN OF PERMEABLE PAVEMENTS

The design of permeable pavements requires the consideration of both structural and hydrological components. The structural design of the pavement determines the thickness of the various pavement components that are necessary to support the intended design traffic while protecting the subgrade from permanent deformation. The hydrological design determines the key design elements necessary to infiltrate rainwater and surface runoff into the pavement and store and filter the water to achieve the stormwater management objectives. An optimal pavement design is one that is just strong enough to

Table 2. Permeable shoulder feasibility decision matrix (with example scores)

1. Primary Considerations Part 1 Weighting: 60

Consideration	Project Score	Weighting	Weighted Score	A	B	C
				Project Scoring Guidelines		
				Favorable for Permeable Shoulders	<<====================>>	Not Favorable for Permeable Shoulders
Availbility of Capital Funding	B	20.0	12.0	Project funded; requirement to implement	Need to justify funding	No specific funding available; no requirement to implement
Status of Environmental Approval	B	20.0	12.0	Approved	Approval pending	Application required
Safety	A	10.0	10.0	Minimal safety issues	Safety issues can be addressed	Significant safety issues
Significant Longitidinal Grades	B	10.0	6.0	Grades < 1 percent	Grades of 1 to 3 percent	Grades > 3 percent
Depth of Water Table	B	20.0	12.0	Water table > 1.5 m below subgrade	Water table 0.6-1.5 m below subgrade	Water table < 0.6 m below subgrade
Geotechnical Risks	B	10.0	6.0	Low complexity	Medium complexity	High complexity
Groundwater Contamination Risk	A	10.0	10.0	Low risk	Elevated Risk	High risk
Total		**100.0**	**68.0**			
	Weighted Total Score:		**40.8**			

2. Secondary Considerations Part 2 Weighting: 30

Consideration	Project Score	Weighting	Weighted Score	A	B	C
				Project Scoring Guidelines		
				Favorable for Permeable Shoulders	<<====================>>	Not Favorable for Permeable Shoulders
Stringent Water Quality Standards	B	10.0	6.0	Regulations in place	Limited restriction	No restrictions
Sand use for Winter Maintenance	B	10.0	6.0	Used < 1 month/year	Used 1 to 4 months/year	Used for > 4 months
Low Soil Infiltration Rates	A	10.0	10.0	Infiltration < 12 mm/hr	Infiltration >12mm/hr < 40 mm/hr	Infiltration > 40 mm/hr
Target Design Volumes and Runoff	A	10.0	10.0	Frequent/non-intense storm	Moderate frequency/intensity	Intense storms
Complexity of Geometric Conditions	A	10.0	10.0	Minimal geometric restrictions	Some geometric challenges	Significant geometric restrictions
Risk of Flooding	A	10.0	10.0	None	Occasional	Frequent
Mandates for Water Quality	B	10.0	6.0	Water quality concerns	Some water quality issues	No concerns
Mandates for Stormwater Management	A	10.0	10.0	Stormwater management concerns	Some stormwater management issues	No concerns
Maintenance Protocols	C	10.0	2.0	Proactive maintenance	Reactive maintenance	Minimal maintenance
Shoulder Utilization	B	10.0	6.0	Use for emergency stopping only	Occassional use for traffic	Regular use by traffic
Total		**100.0**	**76.0**			
	Weighted Total Score:		**22.8**			

3. Other Considerations Part 3 Weighting: 10

Consideration	Project Score	Weighting	Weighted Score	A	B	C
				Project Scoring Guidelines		
				Favorable for Permeable Shoulders	<<====================>>	Not Favorable for Permeable Shoulders
Interest in Innovation	B	20.0	12.0	Regular innovation implementation	Innovation encouraged	Minimal interest
Presence of Utilities	B	20.0	12.0	None	Non-critical utilities	Critical utilities
Impact of Unknown Site Conditions	B	20.0	12.0	Site conditions well known	Some site information available	No site specific information available
Risk of Accidental Chemical Spill	A	20.0	20.0	Limited exposure	Elevated risk of spills or elevated risk of grou	Elevated risk of spills and elevated risk of groundwater contamination
Owner Experience and Resources	C	20.0	4.0	Significant owner experience	Limited owner experience	No owner experience
Total		**100.0**	**60.0**			
	Weighted Total Score:		**6.0**			

Sub Totals

	Weighting	Weighted Score
1. Primary Considerations	60	40.8
2. Secondary Considerations	30	22.8
3. Other Considerations	10	6.0
Grand Total Project Score	**100**	**69.6**
Decision		**Can Consider**

Decision Range		
From	**To**	**Implement Alternative**
0	65	No
65	75	Can Consider
75	100	Yes

accommodate the design traffic and has the minimum hydrological features to provide water quantity and quality management.

The most common structural analysis procedure for porous asphalt and permeable interlocking concrete pavement follows the requirements of the American Association of State Highway and Transportation Officials (AASHTO) Guide for the Design of Pavement Structures [1]. Pervious concrete structural design is based on the StreetPave system as modified by the American Concrete Paving Association (ACPA) [2].

For the AASHTO design procedure, the higher the selected reliability and standard deviation, the higher the design ESALs used in the design and the thicker the pavement design for a specified loading. Critical facilities are typically assigned reliability factors of 95 percent or higher. Low traffic volume roadways and less critical facilities may be assigned reliability values of 75 percent or less. For permeable shoulder pavements, a reliability factor in the order of 80 percent (Z_R=-0.841) would be considered appropriate. This represents a low to medium level of reliability.

The characterization of subgrade soils is one of the most challenging parts of pavement design. Subgrade soil consists of native soil left after the removal of the existing overlaying material, as well as soils used as earth borrow to construct embankment fills or to replace existing unsuitable soils. The objective of the subgrade construction is to provide a uniform foundation for the pavement structure. The ability of subgrade soil to support a pavement structure is characterized by its laboratory-determined

M_R. The design modulus used in the AASHTO design is based on the support capability determined after the subgrade material has been 'soaked' for 96 hours, i.e. saturated. The AASHTO design equation is very sensitive to this input. The common approach in providing guidance in the selection of resilient modulus is to group soil types into common categories and assign typical M_R values to each category. The selection of an appropriate design value for M_R depends on a number of factors and a suitability qualified geotechnical engineer should be consulted for its determination. In general, coarse grained soils such as sands and gravels have higher M_R values than fine grained soils such as silts and clays. As such, the required pavement thickness for a given traffic level is higher for fine grained soils.

The characterization of the subgrade is not only for structural design purposes. It is also important if one of the goals of the permeable pavement design is to infiltrate water into the subgrade. It is important to establish the relationship between soil permeability and insitu soil density achieved during construction. This is important to establish a relationship between subgrade infiltration capability and the structural capacity necessary to support the design traffic. For example, a resilient modulus determined at a soil compaction level of 95 percent of the standard Proctor maximum dry will have lower infiltration capacity and higher structural capacity than a resilient modulus determined at a soil compaction level of 90 percent. Further, in the event that the field density is less than the design density, it may be necessary to decrease the design resilient modulus, which decreases the structural capacity especially when the soil is saturated, requiring a thicker pavement structure.

It should be noted that some of the current permeable pavement design documents require that the subgrade not be compacted to promote infiltration. This would be very difficult to achieve in a highway construction environment as a uniform subgrade cross-section is desirable to provide lateral drainage and it would be very difficult to control the movement of construction equipment which would tend to compact the subgrade during construction operations.

The application of permeable pavements on shoulders presents a special case, where travel lanes are constructed of traditional pavement that drain to shoulders that receive inflow via sheet flow runoff from the travel lanes as well as direct precipitation. Conventional roadway pavements are designed to remove water from the pavement surface and within the structure as quickly as possible. Water remaining on the pavement surface may pose safety issues, including hydroplaning and spray of water. Water within the pavement structure may reduce the strength of the pavement layer and subgrade thereby reducing the overall structural capacity of the pavement and increasing the potential for frost heaving. Permeable pavements, in general, are intended to remove water from the pavement surface by infiltrating it through the surface layer and channel it into the underlying stone reservoir where it can be stored and slowly released to either the underlying soils or the underdrain system. The application of permeable pavements on shoulders of roadways presents a special case of permeable pavement application, where travel lanes are constructed of traditional pavement that drain to shoulders that receive inflow via sheet flow runoff from the travel lanes as well as direct precipitation.

The hydrological design for permeable shoulders involves several components:

- Infiltrate water into the pavement structure, including sheet flow runoff from travel lanes and impermeable sections of shoulder, plus direct rainfall over shoulder and potential inflows from upstream areas of permeable shoulders.
- Provide temporary storage capacity for water in the stone reservoir.
- Filter contaminants in the water as it flows through a filtering course and/or the permeable stone reservoir.
- Infiltrate water into the subgrade (where possible).

- Convey excess water to an appropriate discharge points.
- Provide flow control for water leaving stone reservoir.

The approach used for hydrologic design of permeable shoulders depends on the hydrologic design goals of the project. Hydrologic design goals may take a number of forms, including:

- Capture and infiltrate or treat runoff from a specified water quality design storm to address pollutant loads; water quality design storms specified in regulations are typically a smaller storm representative of more frequent events that result in the bulk of cumulative runoff volume.
- Capture and infiltrate or treat a specified fraction of long term average runoff volume to address pollutant loads; common percent capture goals specified in regulations range from about 80 and 90 percent capture of long term runoff volume. Water quality design storms are frequently set to meet the 80 to 90 percent capture goal.
- Capture and detain runoff to provide flow duration control to match pre-development peak runoff flow rates and durations over a specified range of flows; flow ranges of interest typically span from less than the 2 year flow rate to the 10 year or greater flow rate to provide protection against channel erosion.
- Capture and detain and/or infiltrate runoff to match pre- vs. post-project peak flow rates and/or volumes for a specified design storm to meet water quality, channel protection, and/or flood control goals; events of interest may range from smaller, more frequent storms (less than 1 year recurrence interval) to infrequent, extreme events (greater than 25 year recurrence interval).
- Opportunistic implementation, intended to achieve the maximum feasible pollutant load and/or peak flow and/or volume reduction given the constraints of the site.
- Reduction of pollutants to help meet total maximum daily loads (TMDLs).
- A combination of multiple goals.

BALANCING STRUCTURAL AND HYDROLOGICAL DESIGNS

Subgrade strength and permeability will impact the thickness design for permeable pavements. If the hydrological design results in a stone reservoir thickness that is sufficient to accommodate the vehicular traffic loading, then the design is feasible. If the stone reservoir thickness required for hydrological design is significantly thicker than required for structural capacity and would therefore be cost-prohibitive, the designer may modify some of the design parameters to make the design more cost-effective. The depth of the granular layers for the pavement shoulder would likely have to match or exceed that of the pavement structure to maintain transverse subgrade cross slope. This may in fact govern the overall thickness of the permeable shoulder. If the stone reservoir thickness required for structural design is significantly thicker than required for hydrological design, the designer must improve the structural capacity of the pavement or accept a lower design life. The permeable pavement is designed to maximize the thickness of the stone reservoir layer as these materials are the least expensive.

PERMEABLE SHOULDER USE AND CONFIGURATIONS

There are many different configurations of permeable shoulders that could be considered for roadway pavements. There are several conditions that may influence the type and configuration of the permeable system. These may include:

- Urban versus suburban versus rural.
- Location (median or outside shoulder pavement).

- Subgrade strength and permeability.
- New construction versus retrofit of existing pavement.

In an urban environment, conventional roadway shoulders act as an emergency pull-off area and access for maintenance and emergency vehicles. They typically are constructed adjacent to an urban section designed with curbs, catchbasins and underground piping to capture and transmit stormwater away from the pavement. In rural areas, shoulders may or may not be paved with stormwater draining from the pavement, over the shoulder to either ditches or onto the surrounding natural grades.

For urban area permeable shoulder design, the conventional shoulder surface, base and subbase can be replaced with the permeable pavement system. Catchbasins may be completely eliminated in some situations or at least reduced in terms of frequency. Underground stormwater pipes could be eliminated or their use limited to specific high water volume locations. In rural areas, permeable shoulders could assist in channeling stormwater to assist in mitigating localized washouts, capturing stormwater, reducing peak runoff volumes and promoting water filtration. In the cases above, the reduced infrastructure may result in overall reduced project costs.

In addition, a complete permeable shoulder design would need to include design details for the locations and spacing of stormwater discharge points. The water flow within the stone reservoir could also be controlled through the use of flow barriers placed transversely to the water flow to delay and treat stormwater.

Permeable shoulder systems may offer a good solution for highway median drainage. Current urban highway configurations typically consist of an inside shoulder varying in width with a median barrier system (e.g. Jersey barrier, cable and post or metal guiderail) between traffic directions. Depending on the width of the median and number of traffic lanes draining towards the median, the inside shoulder could be replaced with a permeable shoulder system. Water draining towards the median would drain into the system and then either be infiltrated into the subgrade, where possible, or to conventional drainage outlets. While permeable shoulders could also be used in the rural environment, most inside median areas are relatively narrow and typically not paved and therefore, a permeable pavement section may not be practical.

Subgrade strength and permeability will impact the thickness design for permeable pavements. Low strength and low permeability subgrade may require a thicker granular stone reservoir layer to support the design traffic and stormwater management. High strength, high permeability subgrade would typically require much thinner stone reservoir layers; however, most pavements are designed to ensure lateral drainage across the pavement section by providing shoulder granular depths that exceed that required for the roadway lanes. As such, the thickness of the stone reservoir will likely exceed that required for both structural and hydrological design.

Permeable shoulder construction for new pavements is relatively straight forward. Given that the current focus in North America is on pavement maintenance and rehabilitation, there is more opportunity for the retrofit of existing shoulders using permeable systems. For example, in urban areas where existing stormwater systems are aging or are undersized for current storm events, permeable shoulders may offer the opportunity to reduce and/or supplement existing drainage systems thereby mitigating the needs for expensive excavation and traffic disruption during construction and could result in overall reduced project costs.

CONCEPTUAL DESIGNS

There are many potential configurations for permeable shoulder systems. The designs need to consider many features such as local or rural environment, design traffic, storm intensity, subgrade type, geometric restrictions, stormwater management objectives, etc. A few generic/conceptual designs are provided in Figures 1 through 3. The cross-sections shown are for a rural design. For urban designs, the granular rounding may be reduced in width and hard surfaced. Curb and gutter, gutter, barrier walls, safety barriers may also be present beyond the permeable shoulder.

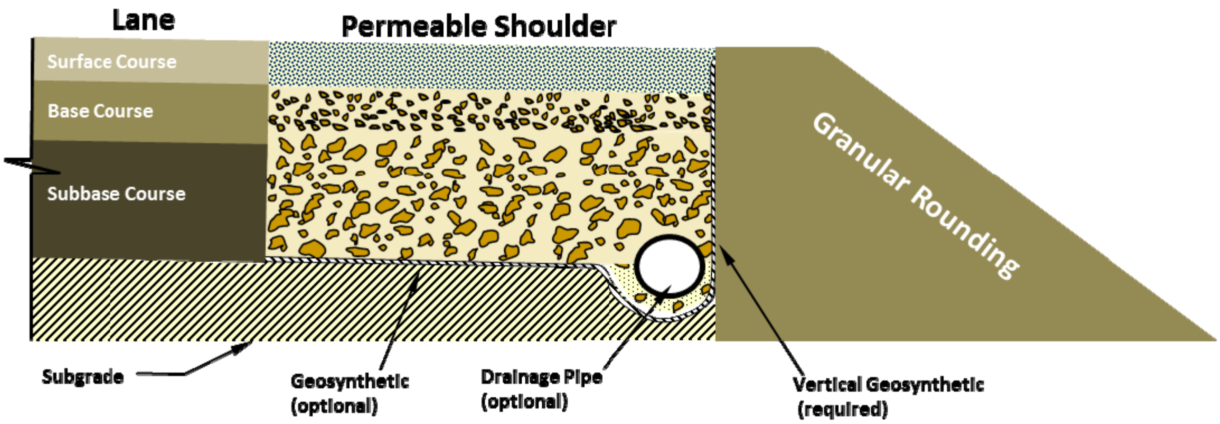

Figure 1. Basic permeable shoulder configuration.

The above configuration could be modified to accommodate various driving lane surfaces. For example, in some areas, open grade friction course (OGFC) is used as a surface for the driving lanes. The thickness of this layer is typically 25 to 30 mm. The OGFC layer could be placed over the dense graded asphalt driving lane and then daylighted at the edge of the driving lane, distributing surface runoff into the permeable shoulder. Alternatively, the OGFC layer could be placed as the surface course of both the driving and shoulder lanes.

Should additional strength be required for the permeable shoulder, an asphalt stabilized base or a perforated dense graded asphalt concrete layer could be placed directly beneath the permeable surfacing.

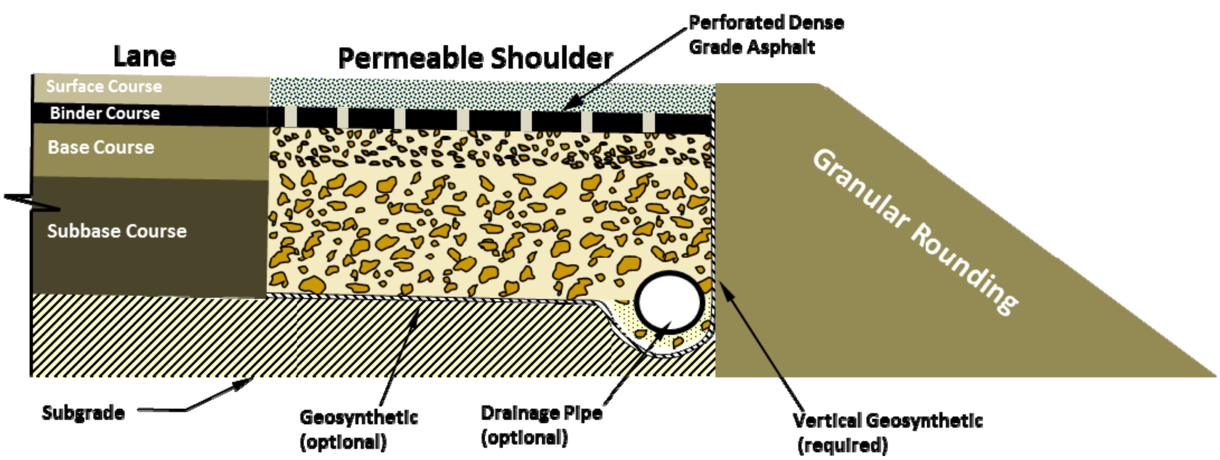

Figure 2. Conceptual strengthened permeable shoulder.

This configuration has been used successfully in the United Kingdom [Interpave 2010]. The conventional and permeable pavements are constructed up to the upper binder course level. The dense graded binder course would be extended across the whole width of the pavement including the shoulder. Upon completion of the remainder of the roadwork, holes are drilled into the shoulder binder course at a frequency dependent on the design rainfall intensities for the system. The holes are filled with open graded aggregate and then the permeable surface is placed. While this may result in a reduction in surface permeability, a significant increase in strength for the pavement is possible. In another variation, the dense graded perforated asphalt concrete on the shoulder could be replaced with an asphalt treated permeable base or cement stabilized layer such as cement stabilized open graded drainage layer or pervious concrete.

A channeled permeable shoulder design would possibly be used for urban roadways, permeable shoulder retrofit applications or to provide edge support to prevent damage to the outside edge of the shoulder under heavy vehicular traffic. An example of this configuration is shown in Figure 3.

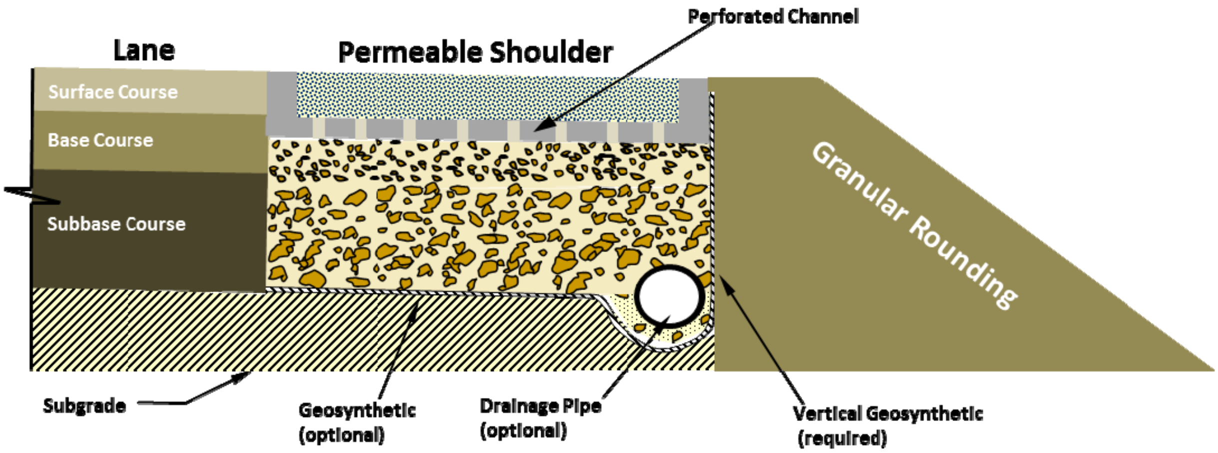

Figure 3. Conceptual channeled permeable shoulder.

The perforated channel could consist of a wide variety of products including cast in-place concrete, precast concrete, recycled plastic wood, etc. The channel provides strength for the shoulder pavement, lateral support for the permeable shoulder material and support for the granular rounding, which would force stormwater to enter the permeable shoulder and prevent scouring of the surface of the adjacent granular shoulder. The channel also provides a ‘clean’ edge with the adjacent travel lane edge. If desired, the top of the channel adjacent to the travel lane could be constructed wide enough to accommodate rumble strips.

DETAILED DESIGN ELEMENT GUIDANCE AND DISCUSSION

This section provides some detailed guidance on various design aspects for permeable shoulder pavements.

Highway Geometrics. In most situations, two or possibly three lanes of roadway would drain at a cross-slope in the order of 2 percent to the shoulder. For superelevated sections, or multi-lane highways (> 3 lanes), a standard width permeable shoulder pavement may not be able to accommodate the total stormwater volume from significant storms.

Impact on Mainline Pavement. If water cannot enter into the surface of the shoulder, it will either pond on the surface and potentially back up onto the travelled portion of the roadway or overrun the shoulder edge. Careful consideration must be given to the duration that water is retained in the stone reservoir. While pavement bases and subbases are typically dense graded and have low permeability, water remaining in the stone reservoir may infiltrate the mainline pavement structure and subgrade. If the site subgrade materiel is coarse grained, the impact will likely be minimal. If the subgrade is fine grained, water may weaken the subgrade and reduce the structural capacity of the mainline pavement.

Surface Layers. A porous asphalt layer is typically 75 to 125 mm thick. Durability may be improved through mix design modifications. Pervious concrete is typically placed 75 to 200 mm thick. Durability can be improved by ensuring uniform density and compaction during construction and through mix design modifications. Standard permeable pavers come in 6, 8 and 10 cm thicknesses. Pavers require lateral support to ensure that the units act as a system to transfer loading.

Aggregate Layers. Stone reservoir aggregates should be hard, durable, clean, be low in fines content and graded for maximum porosity. They typically have a maximum size in the order of 75 mm.

Shoulder Erosion Protection. Potential overflow onto the shoulder rounding can cause erosion and undermining of the pavement. The erodibility of the shoulder material and/or adjacent native soils should be assessed. Increased erosion protection may be required. Depending on the type of shoulder material and its construction, water may try to exit laterally through the shoulder/rounding. The use of an impermeable liner may be placed vertically between the reservoir and the rounding. The stability of may be improved through the use of sealing materials.

Expansive soils. Silt and fine sands tend to hold water which expands when frozen potentially resulting in differential frost heaving. High plasticity clays can also expand if subjected to changes in moisture content. In general, permeable pavements are not recommended for these soil conditions; however, for these conditions, subgrade infiltration should be minimized by ensuring rapid drainage of water from the stone reservoir and through the use of an impermeable liner.

Geosynthetics. Impermeable liners may be used to prevent shoulder rounding washout as well as frost heaving or expansive of moisture sensitive subgrade soils. For infiltration and partial infiltration designs, an impermeable liner should not be placed horizontally between the bottom of the stone reservoir layer and subgrade; however, it would still be prudent to include an impermeable liner between the vertical edge of the stone reservoir and shoulder rounding. If there is concern for water infiltrating from the stone reservoir back into the mainline pavement, consideration may be given to using an impermeable liner vertically between the stone reservoir and the mainline pavement; however, it should be recognized that the liner would prevent water in the mainline pavement from draining horizontally away from the pavement and additional design features may be required to drain the pavement.

It should be noted that the use of an impermeable liner can also affect the water filtration capacity of the system. When a liner is not used, contaminants will be deposited on the subgrade. If a liner is present, contaminants that deposit on top of the liner may be “washed” from the surface by fast moving stormwater thus reducing the effectiveness of water quality treatment measures.

Subdrains. It is considered best practice to install subdrains for all permeable shoulder applications and connect to a positive outlet away from the pavement structure. Longitudinal subdrains should be placed below the bottom of the stone reservoir elevation.

SHOULDER CONSTRUCTION

To ensure the success of the permeable shoulder system care must be taken during construction of permeable shoulders to prevent damage and contamination of the system and ensure that there is positive sub-surface drainage away from the main line pavement. Up-gradient surfaces that may contribute run-on to the permeable pavement during construction should be stabilized or the permeable shoulder pavement protected by using silt fences. Shoulders are not generally supported at the outside of the shoulder surface (unless supported by an end slope or retaining wall). Control of construction operations and sequencing are important and may differ from that of construction for a traditional permeable parking area. Compaction of the subgrade is necessary to support the design traffic and it would not be practical to limit compaction of the subgrade directly below the permeable shoulder while specifying high compaction under main line travel lanes immediately adjacent to the shoulder. Protecting the shoulder materials from contamination is critical as contamination could potentially result in subsequent migration of contaminants to surface water and/or groundwater. Construction equipment travelling across the permeable shoulder should be avoided. Care must be taken to ensure that all placed pavement materials are adequately supported during each construction step. This is of particular importance for rural cross sections with granular shoulder rounding. For retrofit construction, care must be taken to avoid undermining of the travel lanes of the existing pavement.

INSTALLATION AND MATERIALS

The construction and materials for permeable shoulders are similar to conventional shoulder pavement construction, with several key differences. For highway and municipal roadway applications, compaction of the subgrade under the roadway is necessary to provide support for traffic. It is not considered practical to treat shoulder pavement differently. As a result subgrade infiltration will be reduced which may need to be accounted for in the reservoir thickness design.

Geosynthetics including geotextiles and geomembranes may be used to separate different material types and prevent the movement of fine materials from one layer to another and to resist the passage of water between layers respectively.

In cases where the storage volume in the stone reservoir cannot be infiltrated in a reasonable time, supplemental drainage features including: underdrains, catch basins/control structures, observation wells, drainage gaps for rural sections, and/or curb cutouts for urban roadways, etc. may be used.

Compaction of the open graded aggregate is required for shoulder applications. This will provide a stable platform for the placement of the surface course, provide structural capacity for traffic and the prevention of settlement. A dual or single smooth 10 ton (min) vibratory drum roller or a 60 kN (13,500 lb centrifugal force) reversible vibratory plate compactor which provides maximum compaction effort without crushing the drainage layer aggregate should be used to compact the stone reservoir aggregates.

Porous asphalt is manufactured at the asphalt plant similar to dense graded asphalt. Conventional placement and compaction equipment is used such as static steel wheel rollers are used to achieve compaction. A Rubber tire roller is not recommended. Due to its open texture, porous asphalt may cool more rapidly and should therefore be compacted as soon as possible using the appropriate compaction rollers. Pervious concrete may be placed using forms and roller screeds, asphalt pavers, concrete floor finishers or conventional concrete paving equipment. Pervious concrete cannot be pumped. Special curing practices are required to ensure that the cement hydrates and uniform strength is achieved. Conventional surface finishing practices are not recommended as they can reduce the permeability of the surface. Permeable interlocking concrete pavements utilize the same concrete mixes as conventional pavers except the pavers themselves have spacers that create a larger joint opening. The joints are filled with open graded aggregate to provide access for water to enter the pavement structure. A bedding layer is required between the stone reservoir and the concrete pavers. All interlocking concrete block paving surfaces require adequate edge restraints to ensure the interlock of the system.

All permeable surfaces should have some form of edge restraint to prevent lateral movement of the surface both during construction and under traffic. This could consist of concrete curbs, adjacent pavement surfaces, granular base, landscape architectural features, etc. This is particularly important for permeable shoulder applications for vehicles traversing on the shoulder to the travelled lanes. Vehicle wheel loading near an unsupported edge may damage the permeable pavement.

Water moving within the pavement structure may erode the aggregate base/subbase and/or subgrade and adjacent support features such shoulder rounding, curbs and embankments. The permeable pavement design should account for possible water flow erosion. The joint between the travelled lanes and the permeable shoulder must provide support for the installation of the permeable shoulder surface.

SHOULDER MAINTENANCE

Proper and timely maintenance is considered extremely critical for permeable pavement systems. The surface should be properly monitored and maintained to provide a durable and safe driving surface. Maintenance practices can greatly affect the ability of the permeable pavement system to effectively infiltrate water. Additionally, winter maintenance for permeable and impermeable pavements has important differences that need to be understood [3]. The ability of the permeable pavement system to effectively infiltrate water can be affected by pavement use and maintenance practices. For example, extensive use of winter sanding, biomass loading from surrounding vegetation (trees, grass, weeds, etc.) can substantially reduce system infiltration. Preventive maintenance activities include:

- Visually inspect for clogging and durability as well as monitor permeable pavement. Permeability checks should be completed using standard infiltration tests. Inspect after major rain events to ensure pavement structural integrity and surface infiltration.
- Vacuum sweep at regular intervals in high risk areas (high sources of sediment/organic debris).
- Properly maintain upstream landscaping to minimize run-on of sediment and debris.
- Maintain drainage pathways from upstream areas to minimize potential for run-on to pavement.
- Inspect and clean all outlet structures to ensure positive water flow from the permeable pavement.
- Provide inspection ports and regularly monitor drainage rates to identify if clogging of underlying soils or outlet structures has occurred.

WINTER MAINTENANCE CONSIDERATIONS

Properly designed permeable surfaces can be resistant to freeze-thaw related damage [4]. Due to the higher porosity of the surface material, use of winter deicing chemicals are rarely required [5]. Sanding operations should be avoided as the sand can lead to increased clogging. Deicing chemicals should be used moderately. In cold weather climates snow plows may cause abrasion of the surface. Snow plow damage may be reduced by using wide blades, and minimizing back-blading [6].

PERMEABILITY RESTORATION AND STRUCTURAL REHABILITATION

Typically, restoration of pavement permeability can be achieved through restorative vacuum sweeping using specialized, vacuum street cleaning equipment. If permeability cannot be effectively restored and/or the pavement surface is damaged, more substantial rehabilitation may be required. Surface damage may be addressed by partial or full-depth patching for porous asphalt or pervious concrete or removal and replacement of damaged paver units for PICP installations. For rural roadways, it is important to maintain lateral support. Restoration of granular edge support and rounding should be completed for localized scouring and undermining of the pavement.

MAINTENANCE FOR WATER QUALITY AND HYDROLOGIC PERFORMANCE

There are several items that should be considered to maintain water quality and hydrologic performance of permeable pavements. Contamination spills may require complete removal and replacement of the permeable pavement to prevent washout. Full depth excavation, removal of sediment, and scarification of the underlying surface may eventually be required to mitigate clogging due to long term migration of sediment fines into the subgrade. Clogging of underdrain pipes should be remediated via traditional drain cleaning methods. Outlet structure configuration may need to be adapted to changing subsurface conditions. Reservoir materials can be saturated by accumulation of metals, phosphorus, and/or other constituents with resulting decline in water quality treatment performance. In this situation, granular filter material may need to be replaced to restore treatment performance.

CONCLUSIONS

Traditional shoulders are designed to provide a safety zone for emergency pull offs, provide a traffic lane during rehabilitation and maintenance operations, provide lateral support for the mainline pavement as well as providing a travel lane for other modes of transportation. A permeable pavement shoulder system would provide all of these features as well as stormwater management benefits. Highway shoulder applications provide a unique set of design considerations that need to be evaluated and properly designed for prior to constructing permeable shoulders. The design of permeable pavement shoulders requires a balance between providing a structurally sufficient pavement to withstand traffic loading as well as achieving the stormwater management/ hydrologic design goals. Construction techniques and proper maintenance of the permeable shoulders are critical to the success and the longevity of the permeable pavement shoulders.

Key design features include a careful assessment of the permeable pavement site and its surrounding land use to ensure that the pavement surface does not become contaminated with sand/dust or vegetative matter. A hydrological design taking into account rain water landing on the pavement and water shed from the surrounding area can be accommodated into the permeable pavement and then properly treated for water quality improvements and permitted to exit the pavement either through infiltration into the subgrade or controlled through underdrains. Construction processes and techniques should consider the protection of the pavement from contaminants during construction and to ensure that the pavement is able to accommodate both vehicle loading and water infiltration and exfiltration in accordance with the pavement design. Finally, maintenance practices should including vacuum sweeping to ensure the longevity of the permeable surface with repairs completed to address any localized deficiencies such as settlement and ravelling etc.

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