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Pervious Concrete Bicycle Lanes – Roadway Stormwater Mitigation within the Right-of-Way

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Abstract

The City of Olympia has completed a roadway reconstruction project using innovative techniques to mitigate the project's stormwater requirements within the existing right-of-way.

The reconstructed RW Johnson Boulevard incorporates two pervious concrete bicycle lanes adjacent to two asphalt vehicle lanes. The bicycle lanes treat and infiltrate the stormwater runoff generated by the vehicle travel lanes. The roadway project also includes pervious concrete sidewalks along the length of the roadway. The planter strip between sidewalk and roadway is amended with compost to enhance its infiltration capability. The use of these techniques allows the project to meet its stormwater requirements within the roadway right-of-way.

The pervious concrete used for this project is a new material with a surface texture very similar to regular concrete. The concrete has a high fines content (75%) resulting in a smooth finish for the bicycle lanes and sidewalks. This paper details our experience with the design, construction, and costs of pervious concrete bicycle lanes and sidewalks.

Introduction

Increasing land costs, increasing stormwater requirements, and the need to improve our roadways is leading design engineers to look for more creative ways to manage stormwater runoff. Traditional stormwater management requires the purchase of land for building stormwater ponds; often this land is not available or prohibitively expensive. This trend is especially apparent in roadway reconstruction projects.

Traditional stormwater management addresses the rate of runoff or discharge from a site through the use of sometimes large stormwater ponds. Conversely, Low Impact Development (LID) design must match predevelopment runoff rates and volumes, preferably with as much water as possible infiltrated close to the point of creation. Pervious concrete bicycle lanes are one example of a LID roadway design that can help a project meet its stormwater requirements within the roadway right-of-way, thereby avoiding high land costs.

The RW Johnson Boulevard was a good place to try pervious concrete bicycle lanes for a variety of reasons:

- Olympia City Council has long supported staff's use of permeable pavement in sidewalk applications and encouraged the use of permeable pavement in low risk roadway projects,
- RW Johnson Boulevard is adjacent to an extensive City-owned stormwater facility. Underperformance of the permeable pavement system could be mitigated in the existing stormwater facility.
- The project site has a lack of readily available land for construction of traditional stormwater management resulting in potential high costs.
- RW Johnson is an industrial major collector with considerable truck traffic. High loading from traffic challenges the potential use of permeable asphalt or other completely permeable roadway section. Durability and life cycle cost concerns are significant in high truck traffic areas. Concrete was chosen for the permeable surface rather than asphalt.
- The underlying soils provide a reasonably high expected infiltration rate. This enables the area under the 5-foot bicycle lanes to effectively manage the site's stormwater.
- Olympia has past experience and success constructing pervious concrete sidewalks.

Design Considerations

The RW Johnson Boulevard pervious bike lane design goes against one of the assumed rules of permeable pavement design. In theory, permeable design should reduce or eliminate runoff from other surfaces flowing onto the permeable surface. The additional runoff increases the need for high rates of infiltration and brings additional sediment and debris to the pavement potentially accelerating clogging.

To counter the risks associated with accelerated debris and sediment loading to the pavement we used PercoCrete pervious concrete for the bicycle lane. PercoCrete is a high fines pervious concrete with very small pores and a surface texture similar to regular concrete. These traits enable the pavement to be effectively cleaned with conventional sweeping and vacuum machines. The City has had problems with sediment deposition in large-void pervious concrete. Cleaning these materials using conventional machinery is difficult. Pressure washing can clean large voids, but it is time consuming and expensive.

Loading and strength of the pervious concrete is a primary concern in roadway designs. Olympia's experience with PercoCrete pervious concrete had shown us that the material is strong enough to support truck traffic; however, the pavement edges are susceptible to tension failure. To address this concern, the pervious concrete bicycle lane was constructed with an at-grade curb between the conventional asphalt roadway and the pervious concrete bicycle lane. The at-grade curb has several other benefits. Functionally, the curb held the drainage rock layers below the permeable pavement in place while the rest of the roadway section was constructed. Potential movement or voids in the drainage layer can result in cracks and breaks in pervious material. The curb also helps delineate the edge of the vehicle and bicycle travel lanes, and provides a structural transition for vehicle loads.

In all but the most porous subgrades, the permeability of the roadway drainage rock is much greater than the permeability of the subgrade soil. Slope in the subgrade will result in the infiltrated precipitation flowing into the downhill drainage layer faster than it can be infiltrated. Concentration of water in the low point in the drainage layer can result in water exfiltrating from the permeable pavement. Effective permeable pavement systems need to infiltrate water under the entire pavement area. Check dams, or barriers, were installed to force the infiltration of water and prevent subsurface lateral flows. Check dams create cells so that water fills up a cell before overflow to the next downstream infiltration cell. In this way, the infiltration capacity of each cell is maximized.

The pervious bicycle lanes are designed to manage the rainfall from a 50-year storm event. Even with this relatively high level of service, failure of the drainage system should be expected during extreme storms. The permeable pavement could clog or the infiltration capacity of the underlying soils could be exceeded. Accommodating the potential failure of the pavement should be incorporated in the roadway design. In the case of RW Johnson Boulevard, the bicycle lane was designed with a gutter slope, and a system of overflow catch basins was installed to remove standing water from the roadway surface and direct it into the adjacent stormwater facility.

Design Details of RW Johnson Pervious Bicycle Lanes

<u>Infiltration Rate</u>

The site soils are identified by the Soil Conservation Service Soil Survey of Thurston County, Washington, as *Everett Very Gravelly Sand*. The City of Olympia's Stormwater Manual uses Massman's grain size permeability equation to estimate soil infiltration rates. The soil analysis generates an infiltration rate of 2 inches per hour.

<u>Reservoir Layer</u>

Permeable pavements need a water reservoir layer between the pavement and the underlying soils. The reservoir layer provides structure support for the pavement and stores the captured rainfall until it can be infiltrated. The reservoir layer's size should be evaluated for these two different functions and the thickest needed depth used for the design. In soils with a low infiltration rate such as the City's project, the storage of rainfall provides the larger reservoir layer thickness.

Reservoir layers should be sized for both long-duration and short-duration storm events. In Western Washington, a continuous simulation HSPF model is used to size stormwater facilities. Western Washington has fairly low rainfall intensities with half-inch per hour being typical. The impressive thing about Western Washington rainfall is not the rate, but the fact that it seems to never stop. Using these low rainfall rates with the HSPF model's 1-hour time step can suggest that reservoir storage is not necessary. Often the soil infiltration rate exceeds the rainfall rate, so according to the model, water will not pond. However, short duration storms must also be considered in the design of the reservoir layer.

For the RW Johnson bicycle lane, we examined the volume of reservoir needed for the 50-year short duration storm as described by the Olympia rainfall intensity duration frequency curve. For each 15-minute time step, the volume of rainfall, runoff, and amount infiltrated was calculated. By accounting for the quantity of runoff that was not infiltrated, we determined that the peak storage need was 19 inches of reservoir rock. The calculations for this analysis are provided in Table 1 below:

Table 1: Reservoir Rock Sizing for Short Duration

Time (T)	Rainfall x Intensity (I)	Cumulative Rainfall Depth (Qc)	Half Road x Width (Wr)	Storm x Runoff (Qr)	Gallery x Width (Wg)	Infiltration x Volume (Qi)	*Detention x Volume (V)*	Rock Gallery x Volume (Vg)	Rock Gallery x Depth (D)
(min)	(In/hr)	(In)	(FT)	(CF)	(FT)	(CF)	*(CF)*	(CF)	(Inch)
15	2.03	0.507	25	1.06	3.3	0.14	*0.92*	**3.1**	7.4
30	1.46	0.728	25	1.52	3.3	0.28	*1.24*	**4.1**	9.9
40	1.27	0.846	25	1.76	3.3	0.37	*1.40*	**4.7**	11.2
50	1.14	0.95	25	1.98	3.3	0.46	*1.52*	**5.1**	12.2
60	1.05	1.045	25	2.18	3.3	0.55	*1.63*	**5.4**	13.0
70	0.97	1.133	25	2.36	3.3	0.64	*1.72*	**5.7**	13.8
80	0.91	1.215	25	2.53	3.3	0.73	*1.80*	**6.0**	14.4
90	0.86	1.292	25	2.69	3.3	0.83	*1.87*	**6.2**	14.9
120	0.75	1.501	25	3.13	3.3	1.10	*2.03*	**6.8**	16.2
150	0.67	1.687	25	3.51	3.3	1.38	*2.14*	**7.1**	17.1
180	0.62	1.855	25	3.86	3.3	1.65	*2.21*	**7.4**	17.7
210	0.57	2.01	25	4.19	3.3	1.93	*2.26*	**7.5**	18.1
240	0.54	2.156	25	4.49	3.3	2.20	*2.29*	**7.6**	18.3
270	0.5	2.314	25	4.82	3.3	2.48	*2.35*	**7.8**	***18.8***
300	0.48	2.422	25	5.05	3.3	2.75	*2.30*	**7.7**	18.4

Storm Runoff Qr = (Qc x Wr)/12
Infiltration Flow Qi = (T/60) x Wg x 1 x (2"/12) @ infiltration rate = x 2"/hr
Detention Volume V = Qr - Qi
Rock Gallery Volume Vg = x V/30%
Rock Gallery Depth D = Vg/Wg x
* Use Olympia 50-year Storm Event

Using the same procedure, the pervious concrete sidewalks are design with 6 inches of reservoir rock.

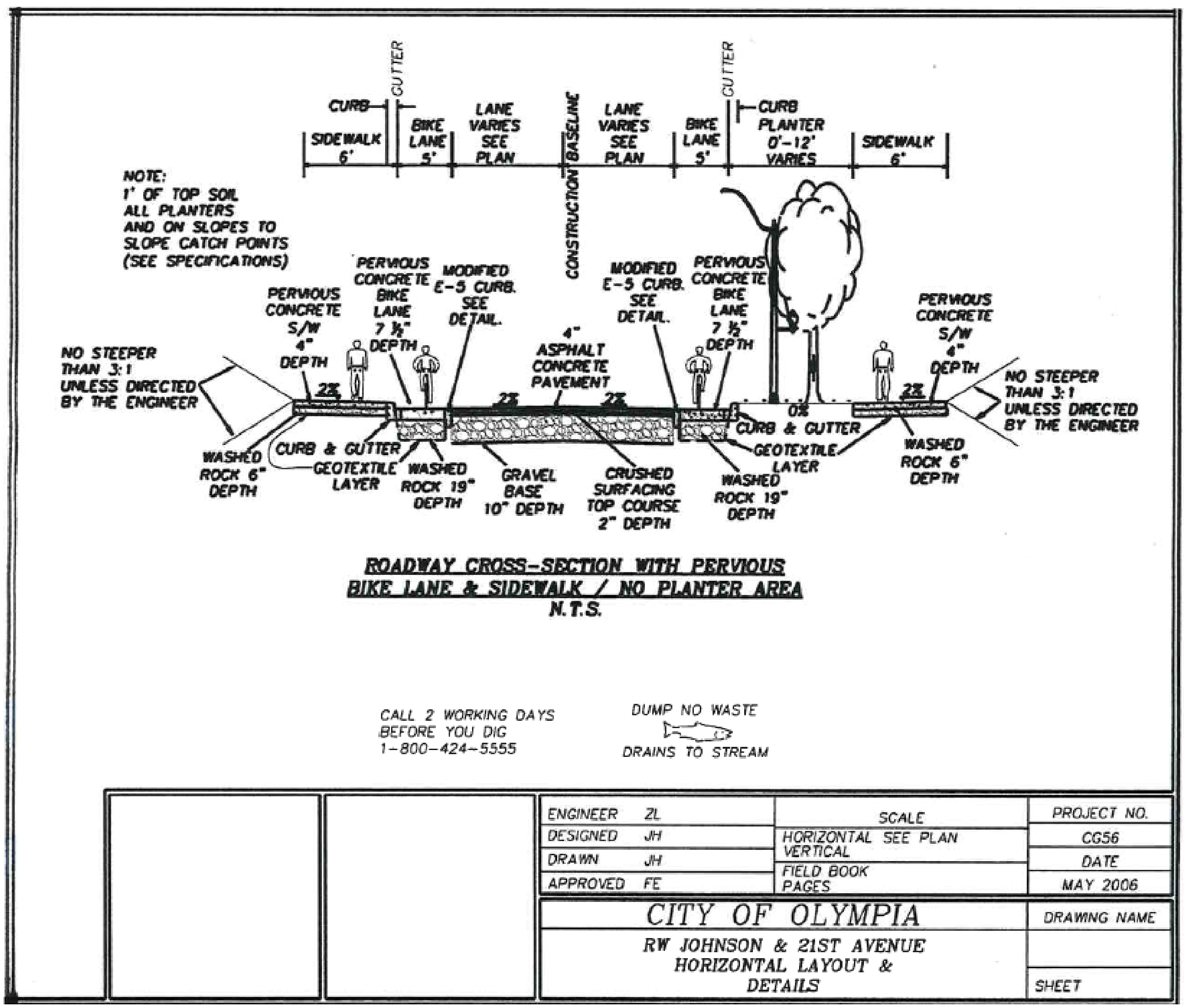
Pavement Section

The concrete pavement section for the bicycle lane was determined using procedures recommended by the American Concrete Pavement Association and presented in their information paper, *Design of Concrete Pavement for City Streets*. In order to fully understand the pavement design, we created several test beam samples of the pervious concrete material. A materials lab tested the samples and determined the concrete's flexural strength to range from 300 to 750 pounds per square inch (psi) with an average of 550 psi.

The pavement design required an estimate of likely pavement loading for the bicycle lane. Vehicle lane loadings produced an extremely conservative estimate. On the other hand, some incidental vehicle loading must be anticipated. In the end, we decided on an ADTT of 300 to 800 trips. The pavement was designed for a 30-year life with a subgrade strength of 150 to 200 psi. As a result, we required a 7.5 inch concrete pavement section.

Given that pedestrian loading is light, sidewalks are not designed for structural strength. Both traditional and permeable sidewalks use 4 inches of concrete. Roadway design cross sections are provided in Figure 1.

Figure 1. Cross Section of RW Johnson – Pervious Bike Lane Section



Costs of Pervious Bike Lanes and Sidewalks

The RW Johnson Boulevard project was constructed in 2006. Table 2 presents a summary of the construction bid prices for pervious concrete-related items. It is important to remember that the costs of permeable pavement need to be compared to the cost of traditional stormwater management techniques in urban settings. The pavement incorporates the stormwater systems. In the case of RW Johnson, the cost of the bike lane includes the cost of the stormwater mitigation for the roadway as well. Since potential land costs were not evaluated, a direct cost comparison with traditional stormwater mitigation was not made for this project. However, land costs often drive stormwater management costs in roadway reconstruction projects.

Table 2. Pervious Concrete-related Bid Items in RW Johnson Project

Unit	Quantity, SY	Range, $	Average, Cost $
Pervious Concrete Bike Lane	2,004	135 - 150	140
Pervious Concrete Sidewalk	2,610	87.75 - 99.00	92.25
Pervious Concrete Bike Lane Testing	2,004	2.25 - 10.00	5.42
Pervious Concrete Sidewalk Testing	2,610	2.25 - 10.00	5.42
Pervious Concrete Underdrain System	1,320	43.00 - 80.00	63.50

Note: Prices from Project CG56 RW Johnson Bid 6-15-2006

Construction

In general, pervious concrete is difficult to batch and correctly install. Placing pervious concrete in the project was preceded by several pre-pour meetings with the batch plant and applicator in addition to a series of test panels of the pervious concrete material. PercoCrete pervious concrete proved to be more difficult to install than regular pervious concrete. However, the finished product is excellent.

Since the pervious concrete needed to be 7.5 inches thick, two lifts of concrete where required. One lift would not have resulted in sufficient consolidation or compaction of the concrete at the bottom of the section. The concrete applicator elected to place both lifts in one pour. The first lift was compacted and immediately followed by the second lift. This process resulted in good work flow and enabled the pervious concrete to be placed once and left to cure undisturbed.

Even with the best care and quality control at the time of concrete placement, we experienced some structural failures. Some sections failed due to lack of strength, others failed to infiltrate. The failures could be tied to individual truck loads of concrete. This link suggests that faulty batching is the dominant cause of the failures. The PercoCrete concrete material may be more sensitive to moisture-cement ratio than batch plants can easily control. Regardless, failures of some sections of pervious concrete should be anticipated with construction. About 3% of the pervious pavement on the RW Johnson project had to be replaced.

Failure of pervious concrete after placing was not a surprise. It is something to be anticipated, tested for, and replaced as necessary. We have found that pressure washing is the best way to tests for failures. Washing at 3000 psi water pressure with a flow rate of 1 gallon per minute and the nozzle held 3 inches above the surface is sufficient to identify weaknesses. Water will accelerate the deterioration of weakly cemented pavement. Infiltration failure will also be evident. Failures should be replaced while the contractor is still working the project.

Lessons Learned and Concerns about the Future of Permeable Pavement

The RW Johnson pavement design appears to be a good compromise between risky permeable roadways and traditional methods. The City considers the RW Johnson project a success and a significant step forward in our incorporation of permeable pavements into our roadway designs. However, the project is not without unexpected outcomes. For example, the surface of the pervious concrete bike lanes is not as smooth and uniform as anticipated. The bike lane concrete was placed between a fixed curb and gutter so grade control was adequate. Most likely, the grade undulations are the results of the compaction of the concrete surface by a plate compactor after placement. The flow of pervious concrete under the plate compactor results in minor undulations in the surface. We have not resolved the problem, but it is important to know and understand. Bicycles are sometimes seen traveling in the vehicle lanes in order to avoid a rough ride.

The design also is more sensitive to clogging of the surface pores than traditional permeable pavement designs. The flow of runoff from the rest of the roadway surface onto the pervious bike lane transports fines and sediment. Even with regular sweeping and cleaning it is difficult to keep the pervious pavement clean. However, the pavement is still effective due to use of the high fines PercoCrete pervious concrete. This material is significantly easier to clean and is less prone to clogging than other materials.

Long-term durability and permeability are major concerns with the RW Johnson project. The pervious concrete bike lanes appear to be successful after 2 years of operation. Until long-term projects and trials can provide data, uncertainty is a factor in permeable pavement projects. Design professionals should recognize this reality and manage the projects accordingly.