

Ohio Stormwater Conference 2019

Pervious Pavement – Lessons Learned During Construction



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Lessons Learned During Construction

- Erosion Control
- Materials
- Construction
- Structural Design
- Cost Estimates



Erosion Control?



Sod in Lieu of Seeding

Leaf Litter



Loss of Chips / Grass Growing in Gaps



Outlets & Underdrains



All Proposed Perforated Underdrain (PUD) shall be per ASTM F758 PVC SDR 26 with 4 holes, 3/8" perforations, every 3" at 90° and 160°, holes to be facing down.



Stormtech DC-780

GeoFabrics

Tencate Mirafi RS-380i

- Reinforcement in weak soils
- High Infiltration Rate



Fabric	Permitivity	Grab Strength	Tear/Tensile Strength
ODOT Type D	0.05 sec ⁻¹	800 N	70 lbs
Mirafi RS-380i	0.9 sec ⁻¹	1500 N	180 lbs



A large pile of recycled concrete rubble, consisting of various sized grey and light-colored stones and chunks, is spread across a dirt area. In the background, a paved road is visible with several parked cars, including a white pickup truck, a white van, a dark pickup truck, a white sedan, and a pink car. A yellow caution tape is strung across the road. A concrete curb separates the road from the construction area. A blue metal crowd control barrier is positioned along the curb, with an orange and white striped traffic cone placed next to it. To the right, a pile of broken concrete blocks and a large grey pipe are visible.

Recycled
Concrete



Recycled
Concrete



No. 8's on top of
recycled
concrete dust



Easton video

<https://youtu.be/2Kbk6-47WVo>

LA Abrasion Test

- The standard LA abrasion test subjects a coarse aggregate sample to abrasion, impact, and grinding in a rotating steel drum containing a specified number of steel spheres
- LA abrasion of 40 means 40% of the original sample passed through the No. 12 sieve (1.70 mm)



No. 2, 3, or 4 Stone

- Testing Requirements
 - LA Abrasion Test <40 as per ASTM C-131
 - Angular particles >90% (no rounded river gravel)
 - Less than 2% passing No. 200 sieve
 - CBR >80%
- Recycled Concrete Typically Can't pass the LA abrasion test





Tech South

-Soft rock or
contaminated material?




09/24/2013

GeoWeb – Increases Strength



Doubles Layer Coefficient of
the Stone Layer it Confines

The GEOWEB® Cell Dimensions

Relative Size ¹				
Name	GW20V (small cell)	GW30V (mid cell)		GW40V (large cell)
		For All Other Applications	For Earth Retention ⁴	
Nominal Length x Width ²	8.8 x 10.2 in (224 x 259 mm)	11.3 x 12.6 in (287x 320 mm)	10.5 x 13.0 in (267 x 330 mm)	18.7 x 20.0 in (475 x 508 mm)
Nominal Area ³	44.8 in ² (289 cm ²)	71.3 in ² (460 cm ²)	68.3 in ² (440 cm ²)	187.0 in ² (1206 cm ²)
Cells per yd ² (m ²)	28.9 (34.6)	18.2 (21.7)	N/A	6.9 (8.3)

1 All details and dimensions are nominal and subject to manufacturing tolerances.

2 Cell length and width will vary approximately ±10% through the recommended expansion range.

3 Cell area will vary only ±1% through the recommended section expansion range.

4 Cell dimensions for Earth Retention sections are fixed and NOT variable or nominal.



Construction Sequencing Suggestions

- Do as much utility work as you can before closing road
- If going with phased construction, don't let contractor mill off all phases at one time
- Try to find streets with alley access for residents
- Don't close road during colder months



Contractor didn't want to spend money on utility backfill that would be removed later



Tailings had to be brought in to maintain drivable surface

Weather

- No work that impacts vehicular driveway access between Thanksgiving and Easter
- Wet subgrade, use of stronger fabric allows project to keep moving



A construction site in a residential area. A yellow roller is compacting a dark brown geofabric layer in a trench. Workers in safety vests are visible. A stack of green pipes is on the left. A blue text box is overlaid on the bottom left.

Subgrade Compaction & Proof Roll

GeoFabric Layers

- Bottom and sides of trench



No. 57 Stone

- Testing Requirements
 - LA Abrasion <40
 - Angular particles >90% (no rounded river gravel)
 - Less than 2% passing No. 200 sieve
 - CBR >80%



No. 57 Layer

Compaction Equipment



10-12 Ton Roller

Compaction of Stone Layers

- Roll (2) Vibratory Mode
- Roll (2) Static Mode
- Test w/Light Weight Deflectometer
 - 1.0 mm for No. 2, 3, or 4 stone
 - 0.5 or less for No. 57 stone
- Fail Test, re-roll until it passes
- Cannot test for density



Deflectometer Testing

Procedure

1. (3) Drops to Seat plate
2. (3) More Drops record readings
3. Take average of last (3) readings

Material	Maximum Deflection
No. 2, 3, or 4 Stone	1 mm
No. 57 Stone	0.5 mm

Note

1. First lift of base stone may have high readings because the native subgrade will deflect and elevate the readings
2. Can only test to a depth equal to plate diameter = 12"



Light Weight Deflectometer

- Purchased by CTL
 - \$6000
- Easy to use
- Good form of QA/QC between contractor and inspector
- Most tests passed, few small areas had to be re-rolled





No. 8 Setting Bed

- Testing requirements
 - LA Abrasion Test <40 as per ASTM C-131
 - Angular particles >90% (no rounded river gravel)
 - Less than 2% passing No. 200 sieve
 - CBR >80%

Poor Stone Compaction





Lift Thickness

- 12" or less

09/24/2013

Poor Stone Compaction?





Poor Stone Compaction



Pavement Rutting Too Much Traffic/Trucks?



Displaced Pavers





Structural Design – AASHTO Flexible Pavement Design

1. Obtain Subgrade CBR value (typically 2-7)
2. Calculate Traffic Load
3. Calculate Structural Number
4. Design Subbase Stone Thickness Based on Layer Coefficients

City of Columbus No credit for:

- Geoweb
- Geogrid
- Geofabrics

Traffic Loads – Maximum 1,000,000 ESAL's

Table 3-1. Road Classification, Description and Traffic (after BIA 2003)

Road Class	Description	Design ESALs*	Design TI**	Design Range for PICP on Non-stabilized, Open-Graded Aggregate Bases	***Potential Design Range for PICP with Stabilized Bases
Arterial	Through traffic with access to high-density, regional, commercial and office developments or downtown streets. General traffic mix.	9,000,000	11.5		
Major Collector	Traffic with access to low-density, local, commercial and office development or high density, residential sub-divisions. General traffic mix.	3,000,000	10		
Minor Collector	Through traffic with access to low-density, neighborhood, commercial development or low-density, residential sub-divisions. General traffic mix.	1,000,000	9		
Bus Passenger Drop-off	Public transport centralized facility for buses to pick up passengers from other modes of transport, or for parking of city or school buses.	500,000	8.5		
Local Commercial	Commercial and limited through traffic with access to commercial premises and multi-family and single-family residential roads. Used by automobiles, service vehicles and heavy delivery trucks. This category includes large parking lots at commercial retail facilities.	330,000	8		
Residential	No through traffic with access to multi-family and single-family residential properties. Used by automobiles, service vehicles and light delivery trucks, including limited construction traffic.	110,000	7		
Facility Parking and Alleys	Parking areas for automobiles at large facilities with access for emergency vehicles and occasional use by service vehicles or heavy delivery trucks.	90,000	7		
Commercial Parking	Restricted parking and drop-off areas associated with business premises, mostly used by automobiles and occasional light delivery trucks. No construction traffic over finished surfaces.	30,000	6		
Commercial Plaza	Predominantly pedestrian traffic, but with access for occasional heavy maintenance and emergency vehicles. No construction traffic over finished surfaces.	10,000	5		

*ESAL = 18,000 lb (80 kN) equivalent single axle load

**TI = Caltrans Traffic Index $TI = 9 \times (ESALs/1,000,000)^{0.119}$

***Consult a pavement engineer

AASHTO Flexible Pavement Design

Columbus Residential Design Policy

Typical short one to two block long loop street with no future extensions

- 1,500 cars/day
- 5% trucks
- 30 Year Design Life
- Directional Distribution = 50%
- Design Lane Distribution Factor = 100%
- B/C Ratio – Other Urban (Use 0.725)

Total ESALs: 299,962

Traffic Factors	202-1
	July 2016 Reference Section 202

RATIO OF B:C COMMERCIAL VEHICLES		
Functional Classification	B:C Ratio	
	Urban*	Rural*
Interstate (01)	4:1	7:1
Other Freeway or Expressway (02)	3:1	
Principal Arterial (03)	2:1	5:1
All Other (04, 05, 06, 07)	1:1	2:1

ESAL CONVERSION FACTORS				
Functional Classification	Rigid		Flexible	
	B	C	B	C
Interstate (01), rural*	1.53	0.37	0.98	0.29
Principal Arterial (03), rural*	1.67	0.44	1.06	0.33
All Other (04, 05, 06, 07), rural*	1.26	0.76	0.79	0.48
Interstate (01), urban*	1.46	0.46	0.93	0.34
Expressway & Freeway (02), urban*	1.38	0.72	0.90	0.47
All Other (03, 04, 05, 06, 07), urban*	1.64	0.53	1.04	0.41

* The designer must determine if the location is urban or rural in character. The 2003 Highway Functional Classification System Concepts, Procedures and Instructions document available from the Office of Program Management should be used as a guide.



Structural Thickness Design No. 1

CBR = 3.0

Total Flexible ESALs = 299,962

Resulting Structural No. = 3.55

Material	Layer Coefficient	Thickness (in)	Total
No. 2, 3, or 4 Stone	0.06	30	1.80
No. 57 Stone	0.09	4	0.36
Pavers & Setting Bed	0.30	4.625	1.39
		Total	3.55



Structural Thickness Design No. 2

CBR = 5.0

Total Flexible ESALs = 299,962

Resulting Structural No. = 2.95

Material	Layer Coefficient	Thickness (in)	Total
No. 2, 3, or 4 Stone	0.06	20	1.39
No. 57 Stone	0.09	4	0.36
Pavers & Setting Bed	0.30	4.625	1.39
		Total	2.95

UC Davis Research Study



UC Davis Design Tables

Table 9.1: Design Table for PICP (Metric) (continued)

Number of Days in a Year When the Subbase has Standing Water (Wet Days)		50				90				120			
Resilient Modulus of Subgrade (MPa)	Dry	40	60	80	100	40	60	80	100	40	60	80	100
	Wet	24	36	48	60	24	36	48	60	24	36	48	60
Cohesion (kPa), Internal Friction Angle of Subgrade (°) ¹	Dry	10, 20	15, 25	20, 30	25, 35	10, 20	15, 25	20, 30	25, 35	10, 20	15, 25	20, 30	25, 35
	Wet	6, 12	9, 15	12, 22	15, 25	6, 12	9, 15	12, 22	15, 25	6, 12	9, 15	12, 22	15, 25
Lifetime ESALs (Traffic Index)		Minimum Subbase Thickness in mm ASTM #2 for 25 mm Allowable Rut Depth (All designs have 80 mm Paver, 50 mm ASTM #8 Bedding Layer, & 100 mm ASTM #57 Base Layer)											
50,000 (6.3)		175	150	150	150	210	150	150	150	230	150	150	150
100,000 (6.8)		285	180	150	150	325	215	150	150	340	235	150	150
200,000 (7.4)		395	285	185	150	430	320	215	150	450	335	235	155
300,000 (7.8)		455	340	240	160	495	375	275	195	515	395	290	215
400,000 (8.1)		500	380	280	200	535	415	310	235	555	435	330	250
500,000 (8.3)		530	410	305	230	570	445	340	260	590	465	355	275
600,000 (8.5)		555	435	330	250	595	470	360	280	615	490	380	300
700,000 (8.6)		580	455	350	270	620	490	380	300	640	510	400	315
800,000 (8.8)		600	470	365	285	640	505	395	315	660	525	415	335
900,000 (8.9)		615	485	380	295	655	525	410	330	675	540	430	345
1,000,000 (9.0)		630	500	390	310	670	535	425	340	690	555	440	360

¹ Default values based on testing cited in the literature (10,12)

Annual Number of Days with Rainfall (46 years of record)

Greater Than	
0.1"	71
0.25"	44
0.5"	24
1"	9
1.5"	3
2"	2

$$\text{MPa} = 17.61 \times \text{CBR}^{0.64} \quad (\text{CBR of 3} = \text{MPa 36})$$



UC Davis Sample Problem

CBR = 3.0 (soaked)

MPa = 36

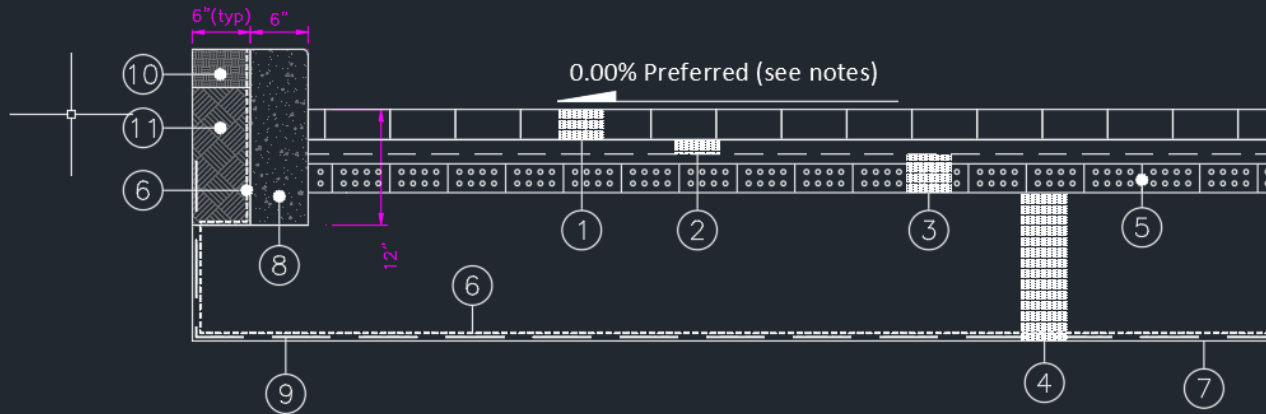
ESALs = 300,000

No. of Days with Wet Subgrade = 71 (use 90)

No. 2 Stone Layer Thickness = 375 mm = 15"

Total Thickness = 15" + 4" + 3 1/8" = 22 1/8"

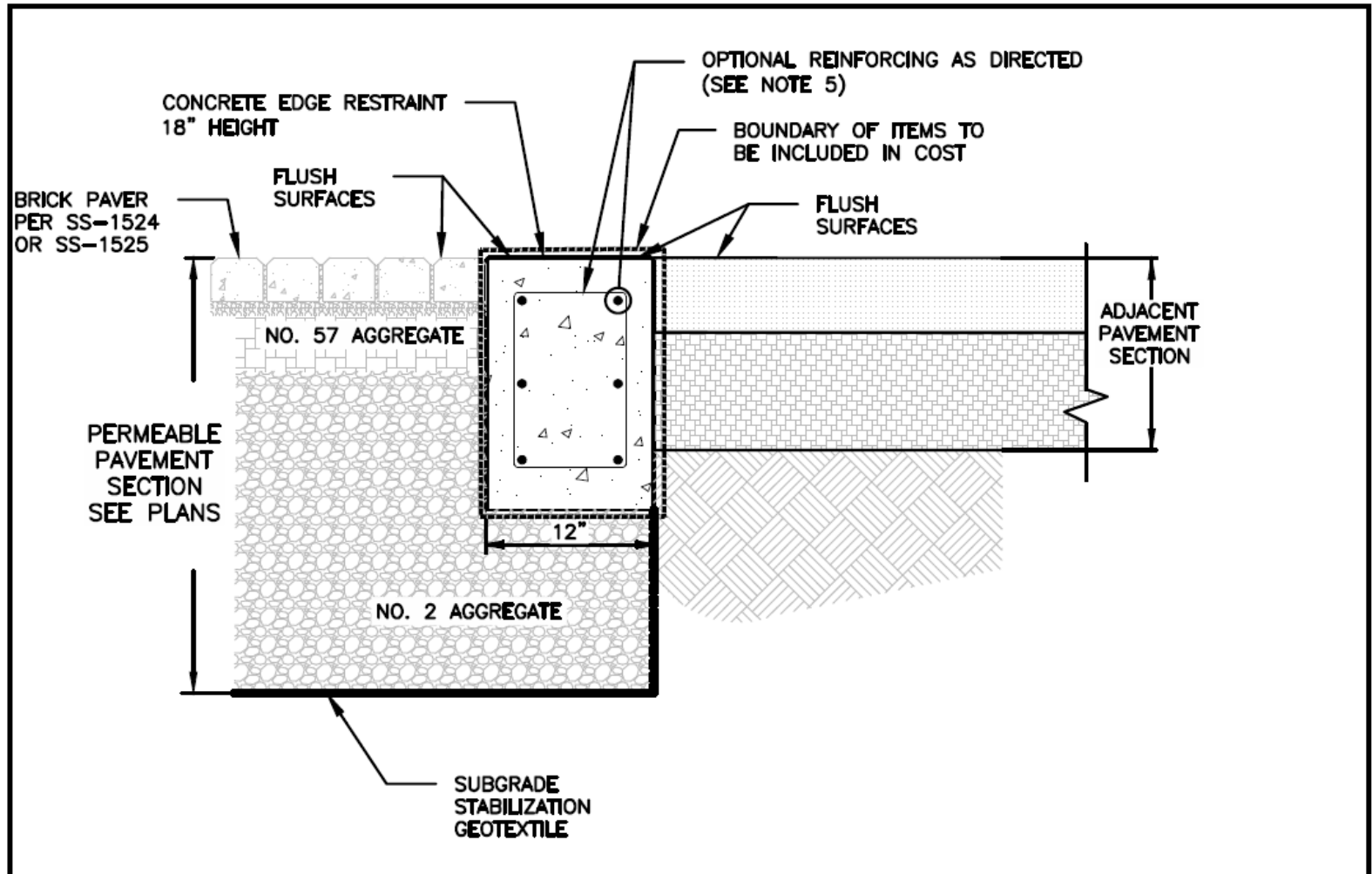
Columbus Typical Section



- ① ITEM 1525 - PERMEABLE PAVERS (T=___") (INCLUDE WITH PERMEABLE PAVER ROADWAY FOR PAYMENT)
- ② ITEM 1525 - AGGREGATE SETTING BED, NO. 8 STONE (T=1 1/2") (INCLUDE WITH PERMEABLE PAVER ROADWAY FOR PAYMENT)
- ③ ITEM 1525 - AGGREGATE BASE, NO. 57 STONE (T=4")
- ④ ITEM 1525 - AGGREGATE SUB-BASE, NO. 2 OR 4 STONE (T=___")
- ⑤ ITEM 1525 - CELLULAR CONFINEMENT SYSTEM (T=3")
- ⑥ ITEM 1525 - SUBGRADE STABILIZATION GEOTEXTILE
- ⑦ ITEM 204 - SUBGRADE COMPACTION
- ⑧ ITEM 609 - CURB, STRAIGHT 18"
- ⑨ ITEM 1525 - GEOMEMBRANE PVC LINER (OPTIONAL)
- ⑩ ITEM 653 - TOPSOIL FURNISHED AND PLACED (4" MIN)
- ⑪ ITEM 203 - EMBANKMENT

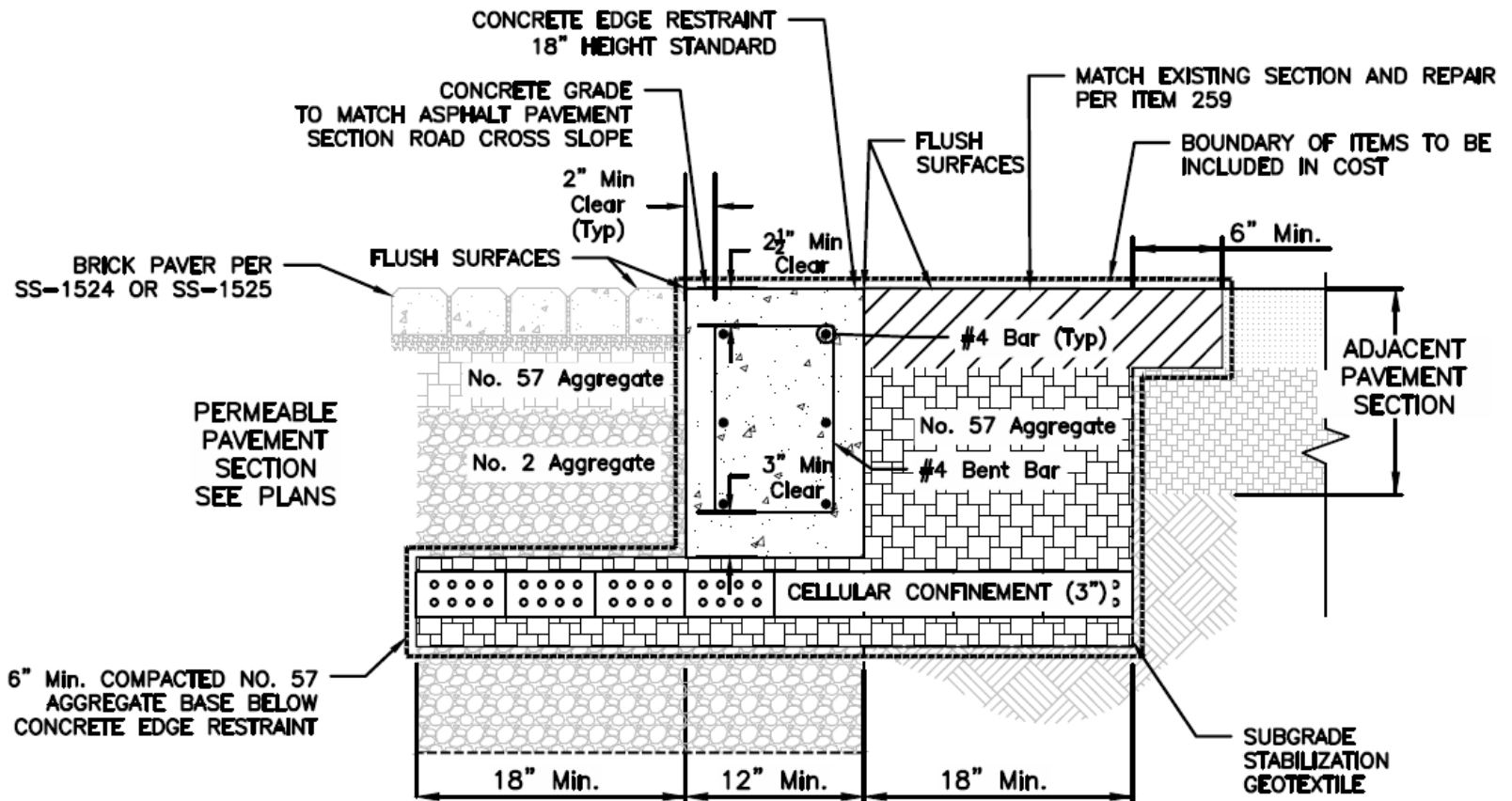
Edge Restraints – Columbus Detail

Parallel to Traffic



Edge Restraints – Columbus Detail

Perpendicular to Traffic

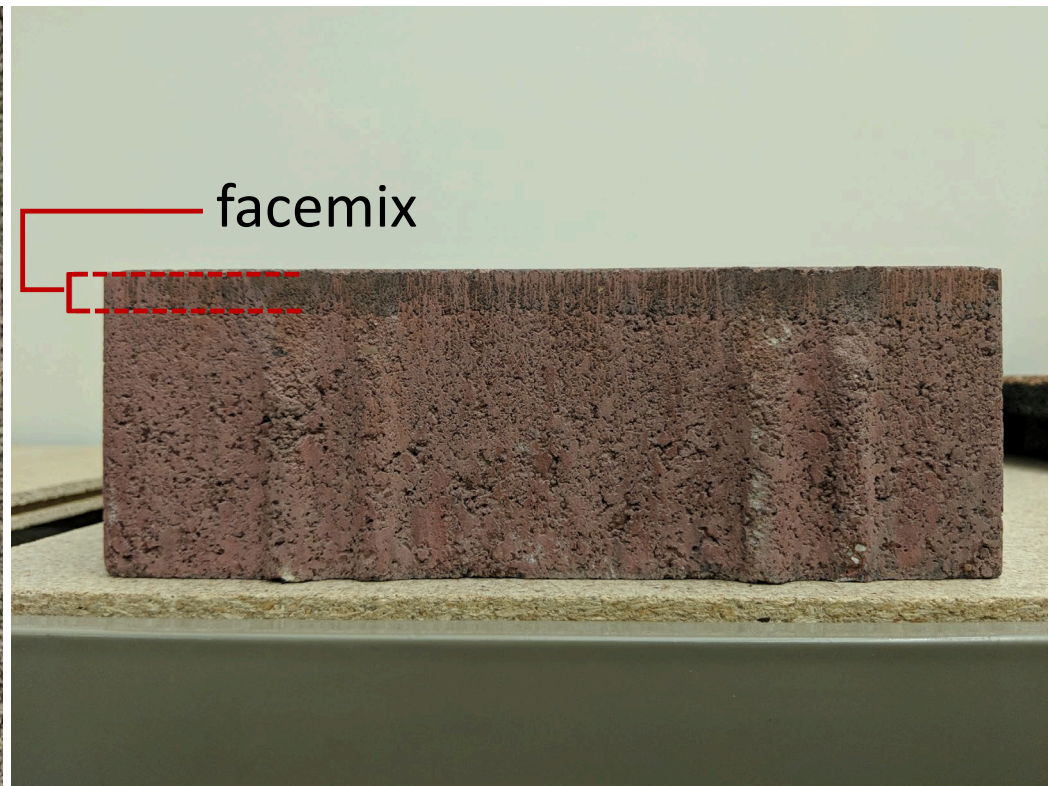


Concrete bands



- 18"x6" straight curb
- 12"x12" flush band

Concrete Pavers – Unilock EnduraColor



Eco-Priora vs. Eco-Optilok



Unilock Standard Finish – Tech South



Third Street New Albany
Pine Hall Brick – Iron Spot (2 ¾")



Third Street, New Albany, OH



Paver Material & Install Prices

Unilock Endura Color: \$4.50/SF delivered

Unilock Standard Color: \$2.60/SF delivered

Pine Hall Clay: \$4.50/SF delivered

Machine Install Price: \$2.00/SF (includes setting bed & chips)

Hand Install Price: \$5.00/SF (includes setting bed & chips)



Clay Paver Parking Stall Installation

To Small of an
area for
concrete
machine
installation, use
hand setting
prices



Bid Item Costs

Item No.	Description	Total	Unit	Low Bid	Total Cost	Contractor Suggested Change	New Bid Cost	
203	EXCAVATION	11,411	CY	\$ 20.00	\$228,220.00	\$5.00	\$25.00	hard to work in existing streets
605	6" PVC PIPE UNDERDRAIN PERFORATED, AS PER PLAN	2925	LF	\$15.00	\$43,875.00			
660	SODDING, UNSTAKED	1,912	SY	\$ 12.00	\$22,944.00			
SPEC	PRESTO GEOWEB GW20V (3-inch), OR EQUAL	7,888	SY	\$8.00	\$63,104.00			
SPEC	PERVIOUS CONCRETE PAVERS (T=3 1/8")	70,794	SF	\$7.50	\$530,955.00			
SPEC	AGGREGATE BASE, AS PER PLAN NO. 57 STONE (T=4")	1,033	CY	\$51.00	\$52,683.00	\$5.00	\$56.00	more work to get to grade than anticipated
SPEC	AGGREGATE BASE, AS PER PLAN (NO. 2, 3, OR 4 STONE)	9,529	CY	\$39.00	\$371,631.00			
SPEC	WOVEN GEOSYNTHETIC Mifafi RS380i or EQUIVALENT	9,801	SY	\$5.30	\$51,945.30			

Bid Prices (70,794 SF pervious pavement)

Contractor	Bid
George Igel	\$3.6 million
Shelly & Sands	\$3.8 million
Conie Construction	\$4.1 million
Facemeyer	\$4.2 million
Estimate	\$4.6 million

Includes

20% Force Account

\$405,000 street sweeper

\$129,000 contingency items

Cost Per SF

Low bid (w/o force account, contingency, and sweeper) = \$34.60/SF



Paver Installation Contractor

- Most Knowledgeable
- Minimum Responsibilities
 - No. 8 Setting Bed
 - Set Pavers
 - Sweep in Chips
 - Plate Compact Finished Pavers
 - Replace Cracked or Chipped Bricks
 - Re-joint with Aggregate as needed until end of 2-year Warranty Period
- Laying patterns
 - Soldier Course
 - Herringbone
 - Stagger lines
 - Swap pavers
 - Special Patterns

Paving contractor

- Screed machine
 - Much slower if done by hand
- Saw cutting is very loud
- Pavers will look dirty for awhile with all the concrete dust & chip dust





Soldier Course Prep



Plate Compactor

- Use in areas not reachable by roller
- Minimum Force of 13,500 lbf for Stone
- Minimum Force of 5,000 lbf for Pavers



Swap ½ Pieces to
Break Up Lines



Provide Laying
Details Around
Catch Basins and
Manholes – Low
Volume Streets

**Provide Laying
Details Around
Catch Basins and
Manholes – Higher
Volume Streets**





Warranty and As-Built Tolerances

Warranty Covers

- Creep
- Cracked pavers
- Loss of Joint material

Warranty Does not Cover

- Sediment removal

As-built Tolerances

- Final elevations not deviate more than $3/8''$ over 10-feet
- Lippage shall be no greater than $1/8''$ between pavers
- Bond lines shall be $\pm 1/2''$ over a 50-ft string line
- Top of pavers may be $1/8''$ to $1/4''$ above adjacent structures for possible minor settling



Construction Observations

- General contractor
 - Doesn't like to roll stone
 - Doesn't like shallow lift depths
 - Doesn't like sod
 - Doesn't like multiple mobilizations for pavement planning
 - Doesn't like to use plate compactor to compact stone at edges
 - Doesn't like phased construction
 - Tree removal
 - Curb
 - Only wants subcontractors there once
- General contractor is typically least knowledgeable of the bunch
- Paver Installer is most knowledgeable
- Inspectors have never seen a project like this before
 - Deflectometer helps them quantify inspection



Design Engineer

- Construction Observation Contract with City
- Answers a lot of Questions in Field
 - Contractor
 - Inspector
 - Residents
- Light Weight Deflectometer Training
- Attended Monthly Project Meetings



References

- City of Columbus
 - Supplement Spec 1525 – Permeable Pavement
 - Standard Details
 - Typical Section
 - Concrete Band Detail
 - Castings Detail
 - Laying Patterns
 - Green Infrastructure Design Manual Update
- Interlocking Concrete Pavement Institute

East Dominion Before



East Dominion After





QUESTIONS?