Pennoni
PENNONI ASSOCIATES INC.
CONSULTING ENGINEERS

November 19, 2014

PVDR 1401.00

Mr. Doug Buch
PaveDrain, LCC
4880 W. Abbott Avenue
Greenfield, WI 53220

RE: PAVEDRAIN CONCRETE BLOCK STRUCTURAL ANALYSIS FOR HS-25 AASHTO TRUCK LOADING

Dear Mr. Buch:

We have completed our structural analysis of the PaveDrain concrete blocks and find them capable of supporting AASHTO HS-25 truck loading.

We analyzed the the blocks as unreinforced concrete arches supporting a uniform truck tire load with impact per AASHTO standards. The arches were reviewed considering both a fixed end condition and a pinned end condition. We used the ASTM D 6684-04 specified minimum compressive strength of 4000 psi for the concrete. The actual tested strength of the PaveDrain units averages 8900 psi which is more than double the strength used in our structural calculations.

As with all vehicular traffic paving systems, the subgrade soil and base preparation for the PaveDrain blocks must be properly prepared and is critical to the performance of the system.

Sincerely,

PENNONI ASSOCIATES INC.

Germaine E. Lenz, PE, SECB
Structural Project Engineer

GEL/gel

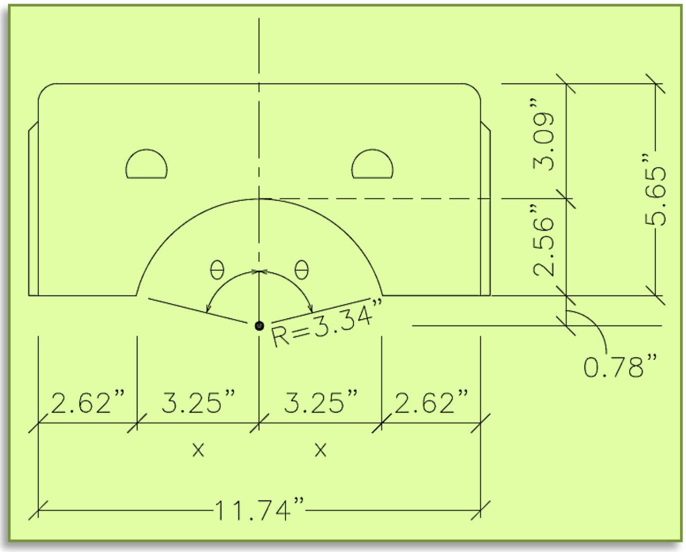
Attachment: Calculations (5 pages)

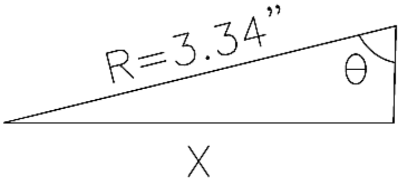
cc: File

GERMAINE E. LENZ
ENGINEER
No. 041325-E

L:\PROJECTS\PVDR\PVDR1401-BlockAnalysisHS25AASHTOTruckLoading\CORRESPONDENCE\SENT\PaveDrain letter 2014-11-19.docx

SECTION PROPERTIES OF A PAVEDRAIN BLOCK

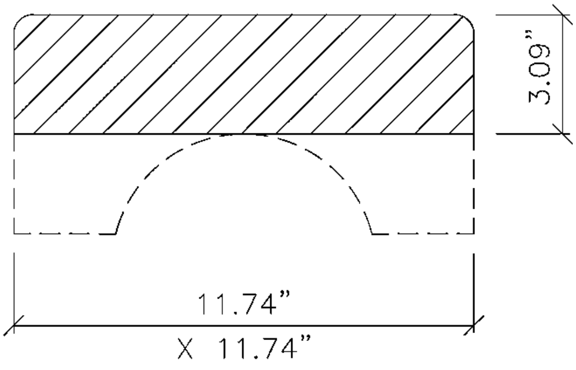




$3.34-2.56=0.78"$

$$\cos \Theta = \frac{0.78"}{3.34"} \Rightarrow \Theta = 76.5°$$

$$x = \sin \Theta \, (3.34") = 3.25"$$



-Using the top of the block only, ignoring the curved portions.

$$I = \frac{bd^3}{12} = \frac{b\,(3.09^3)}{12} = 2.46\ b$$

$$A = 3.09"\ b \qquad S = \frac{bd^2}{6} = \frac{b\,(3.09)^2}{6} = 1.59\ b$$

For 1” wide strip (b = 1”) $I = 2.46\ in^4$ $S = 1.59\ in^3$ $A = 3.09\ in^2$

Pennoni Associates Inc.
Consulting Engineers

PROJECT	PAVEDRAIN	JOB NO.	PVDR 1401
SUBJECT	AASHTO HS-25 TRUCK	SHEET	2 OF 5
		BY:	GEL
		DATE	11/19/2014

TRUCK TIRE PRESSURE

Typical Pressure = 100 psi Standard
Increase 20% for Heat
Increase 30% for Impact
ω = 100 psi (1.2)(1.3) = 156 psi
For 1" strip ω = 156 #/in

CHECK BEARING COMPRESSION

Use Bearing Area on Stone = 2.62" x 11.74" x 2 sides

A_{BRG} = 61.5#

HS 25 40,000 #/axle

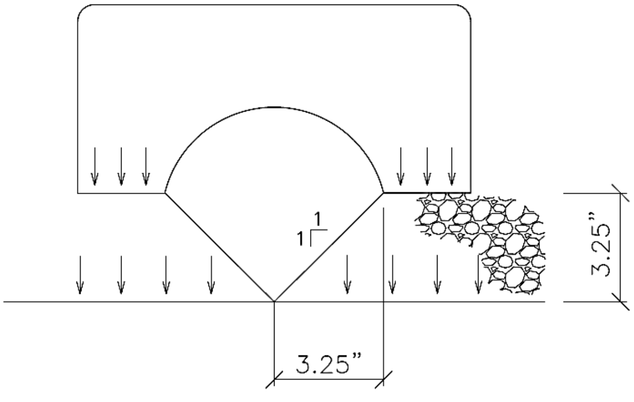
$$\text{Wheel Load} = \frac{40,000}{2\ sides} \times \overset{\text{Impact}}{1.3} \times \overset{\text{ULT}}{1.7} = 44.20^{k}$$

$$fpu = \frac{44.20}{61.50} = 720\ psi$$

$$\emptyset fp = 0.7(0.85)\overset{fc^1}{4000} = 2380 \text{ psi} > 720 \text{ psi}$$

Factor of Safety = 3.31

CHECK SUBGRADE BEARING PRESSURE



Stone must be 3.25" min. depth to attain full bearing to subgrade. OK

Check arch using R.J. Roark's "Formulas for Stress and Strain"

R = 3.34
S = sin Θ = 0.97
C = cos Θ = 0.23
I = 2.46 min
A = 3.09 min
S_m = 1.59 min
Θ = 1.34 radians
∝ = 0.07
Ω = 156 #/in

$$\propto = \frac{I}{AR^2} = \frac{2.46}{3.09(3.34)} =$$

∝ = 0.07

Check Case 29

$$H = \tfrac{1}{2}(156)(3.34)\left[\frac{\frac{4(0.97)^3}{3}+1.34(0.23)-2(1.34)\left(0.97^2\right)(0.23)-0.97(0.23)^2+\beta}{2(1.34)(0.23^2)+1.34-3(.97)(0.23)+0.07(1.34+0.97(0.23)}\right]$$

Where $\beta = 2\,(0.07)(1.34(0.23^2)-\tfrac{1}{2}(1.34)-\tfrac{1}{2}(0.97)(0.23))$

$H = 224^{\#}$

$V = 156(3.34)(0.97) = 505^{\#}$

Resultant = $\sqrt{H^2+V^2} = 552^{\#}$

$fc = 552^{\#}/3.09^{\#}$ = 179 psi compression

Ultimate compression force = 179(1.7) = 304 psi

Allowable – use 0.7(0.85)fc^1 = 0.7(0.85)4000 = 2380 psi

Factor of Safety = $\frac{Allowable}{Actual} = \frac{2380}{304}$ = 7.82

Check Case 30

$$H = 156(3.34)\left[\frac{\frac{1}{4}\left(\frac{0.97^2(0.23)}{1.34} - 0.97\right) + \frac{0.97^3}{6} + 0.07\left(\frac{1}{4}(1.34) - \frac{1}{2}(1.34)0.23^2 + \frac{1}{4}(0.97)0.23\right)}{\frac{(1.34-0.97)^2}{1.34} - \frac{3}{2}(1.34) + 2(0.97) - \frac{0.97(0.23)}{2} - 0.07\left(\frac{1.34}{2} + \frac{0.97(0.23)}{2}\right)}\right]$$

$H = 97^{\#}$ $\qquad V = 505^{\#}$ $\qquad$ Resultant = $514^{\#}$

$$M = 156(3.34)^2\left(\frac{0.97^2}{2} - \frac{1}{4} + \frac{0.97(0.23)}{4(1.34)}\right) - 97(3.34)\left(\frac{0.97}{1.34} - 0.23\right)$$

$M = 296''\ ^{\#}$ $\qquad Mu = 296(1.7) = 503''\ ^{\#}$

$S = \frac{1''(5.65)^2}{6} = 5.32\ in^3$ (ignore hole, near centroid)

$$ft_{ULT} = \frac{296}{5.32} = 56\ psi\ x\ 1.7 = 95\ psi$$

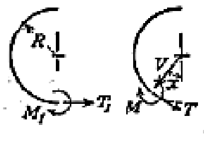
ACI 22.5.1.

$$\Phi Mn = 0.55(5)\overset{fc^1}{\sqrt{4000}}(5.32) = 925''\ ^{\#} \gg Mu \quad \underline{\text{OK}}$$

Factor of Safety = $\frac{925}{503} = 1.84$

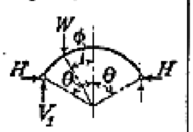
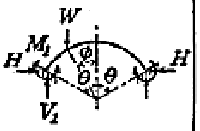
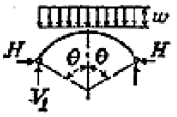
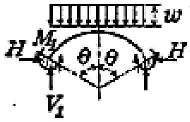
EXCERPT FROM ROARK'S FORMULA

TABLE VIII.—FORMULAS FOR CIRCULAR RINGS AND ARCHES



M_1, T_1, V_1, M, T, and V are positive when as shown, negative when reversed. All applied forces and couples are positive when as shown, negative when reversed. The following notation is employed: E = modulus of elasticity (lb. per sq. in.); I = moment of inertia of ring cross section (in.⁴); W or F as shown = applied load or reaction (lb.); w = applied load (lb. per lin. in.); k = weight of contained liquid (lb. per cu. in.); $z = \sin x$, $u = \cos x$; $s = \sin\theta$, $c = \cos\theta$; $n = \sin\phi$, $e = \cos\phi$; $p = \sin\beta$, $q = \cos\beta$. All angles in radians, distances in inches, forces in pounds, moments in inch-pounds. $+D_x$ or $+D_y$ means increase, $-D_x$ or $-D_y$ means decrease in diameters. $+\Delta R$ means increase, $-\Delta R$ means decrease, in upper half of vertical diameter.

TABLE VIII.—FORMULAS FOR CIRCULAR RINGS AND ARCHES.—(*Continued*)

Loading, support, and case number	Formulas for end reactions	
	Circular arch	Parabolic arch; l = span; f = rise; a = distance load from left end, b from right
27. Ends pinned; concentrated load W at any point ϕ 	$H=\frac{1}{2}W\left[\frac{s^2-n^2-2c(\theta s-\phi n+c-e)-\alpha(s^2-n^2)}{\theta-3sc+2\theta c^2+\alpha(\theta+sc)}\right]$ $V_1=\frac{1}{2}W\left(\frac{s+n}{s}\right)$ $\left(\text{Here } \alpha=\frac{I}{AR^2} \text{ where } A = \text{cross-sectional area}\right)$	$H=W\frac{5b}{8f}\left[1-2\left(\frac{b}{l}\right)^2+\left(\frac{b}{l}\right)^3\right]$ $V_1=W\frac{b}{l}$ (Ref. 72)
28. Like Case 27 except ends fixed 	$H=\frac{1}{2}W\left[\frac{\frac{2}{\theta}(\theta s+\phi sn-sc)-s^2-n^2-\alpha(s^2-n^2)}{\theta+sc-\frac{2s^2}{\theta}+\alpha(\theta+sc)}\right]$ $V_1=\frac{1}{2}W\left(\frac{\theta+\phi-cs+en-2nc}{\theta-cs}\right)$ $M_1=V_1Rs+HR\left(\frac{\theta c-s}{\theta}\right)+\frac{1}{2}WR\left(\frac{c-e-\phi n-\theta n}{\theta}\right)$ (α as for Case 27)	$H=\frac{15W}{4}\left(\frac{a^2b^2}{l^3f}\right)$ $V_1=W\left[1-\left(\frac{a}{l}\right)^2-\frac{2a^2b}{l^3}\right]$ $M_1=Wa\left(\frac{5ab^2}{2l^3}-\frac{b^2}{l^2}\right)$ (Ref. 72)
29. Ends pinned; uniform load w lb. per linear in. 	$H=\frac{1}{2}wR\left[\frac{\frac{4}{3}s^3+\theta c-2\theta s^2c-sc^2+2\alpha(\theta c^2-\frac{1}{2}\theta-\frac{1}{2}sc)}{2\theta c^2+\theta-3sc+\alpha(\theta+sc)}\right]$ $V_1=wRs$ (α as for Case 27) CASE 29	$H=\frac{wl^2}{8f}$ $V_1=\frac{1}{2}wl$ (Ref. 72)
30. Like Case 29 except ends fixed 	$H=wR\left[\frac{\frac{1}{4}\left(\frac{s^2c}{\theta}-s\right)+\frac{1}{6}s^3+\alpha\left(\frac{1}{4}\theta-\frac{1}{2}\theta c^2+\frac{1}{4}sc\right)}{\frac{(\theta-s)^2}{\theta}-\frac{3}{2}\theta+2s-\frac{1}{2}sc-\alpha\left(\frac{1}{2}\theta+\frac{1}{2}sc\right)}\right]$ $M_1=wR^2\left(\frac{1}{2}s^2-\frac{1}{4}+\frac{1}{4}\frac{sc}{\theta}\right)-HR\left(\frac{s}{\theta}-c\right)$ $V_1=wRs$ (α as for Case 27) CASE 30	$H=\frac{wl^2}{8f}$ $V_1=\frac{1}{2}wl$ $M_1=0$ (Ref. 72)