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Permeability of the Special Base Used on US 63 La Plata, Missouri

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Final Report on the
Permeability of the Special Base
Used on US 63 La Plata, Missouri

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and
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16. Abstract:

Koch Industries specified an aggregate base special for the expansion of US 63 in Macon and Adair counties of Missouri. The base deviates from MoDOT's standards, raising concern about its performance. The Institute for Interdisciplinary Geotechnics was contracted, specifically to evaluate the in situ permeability of the base. In situ permeability tests, laboratory gradation analyses, laboratory permeability and aging tests were performed on the base to quantify its permeability characteristics.

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Executive Summary

Koch Industries specified an aggregate base special for the expansion of US 63 in Macon/Adair Counties. The base deviates from MoDOT's standard (Type 5 and Type 1 bases) raising concern about its performance. The Institute for Interdisciplinary Geotechnics was contracted, specifically to evaluate the in situ permeability of the base. In situ permeability tests, laboratory gradation analyses, laboratory permeability and aging tests were performed on the base to quantify its permeability characteristics.

In situ permeability tests were performed at five sites on US 63 near La Plata, Missouri. Samples of the base course were recovered after the in situ tests, returned to the Institute for Interdisciplinary Geotechnics labs, and analyzed.

The following conclusions are based on the results of our testing:

- The base classifies as a poorly graded gravel (GP) (Unified Soil Classification System).
- The base contains five to 10 percent fines.
- In situ permeability ranges from 5 to 125 ft/day.
- Laboratory permeability ranges from 0.3 to 3 ft/day (initially).
- Aging (curing) tended to decrease the permeability by about one order of magnitude.
- The permeability decreased to 0.3 ft/day after 30 days of flow.

The subject base has a permeability about 100 times higher than MoDOT's Type 5 base but still falls short of a freely draining base. Freely draining bases typically have permeabilities in the range of 3000 ft/day (FHWA): however, bases with lower permeabilities may still provide adequate drainage provided the quantity of water to be removed is proportionate to the available permeability. In other words, a drainage analysis should be performed (DRIP 2.0, FHWA).

The following recommendations are made in order to more fully characterize the potential for long-term support of the overlying pavement by the subject base course:

- Additional in situ permeability tests should be conducted to better characterize the effect of aging of the base under field conditions.
- Laboratory aging tests should be performed to assess effects on drainage and strength of the base.
- Resilient modulus and/or cyclic triaxial strength tests should be performed on the base to quantify possible strength loss or gain given the potential for aging and changes in the permeability of the base.
- Field performance tests (Falling Weight Deflectometer or Geophysical tests) should be performed to assess the deformation behavior of the base and overlying pavement.

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Introduction

Koch Industries specified an aggregate base special for the expansion of US 63 in Macon/Adair Counties. The base deviates from MoDOT's standard (Type 5, Type 1) raising concern about its performance. The Institute for Interdisciplinary Geotechnics was contracted, specifically to evaluate the in-place hydraulic conductivity of the base. In situ permeability tests and laboratory gradation analyses were performed on the base. Our findings and recommendations are presented in this report.

Methodology

We performed index property analyses on the base in our laboratories. Tests included grain size analysis, wash sieves, and compaction. We followed ASTM standard methods (Table 1).

Table 1 –Test procedures utilized

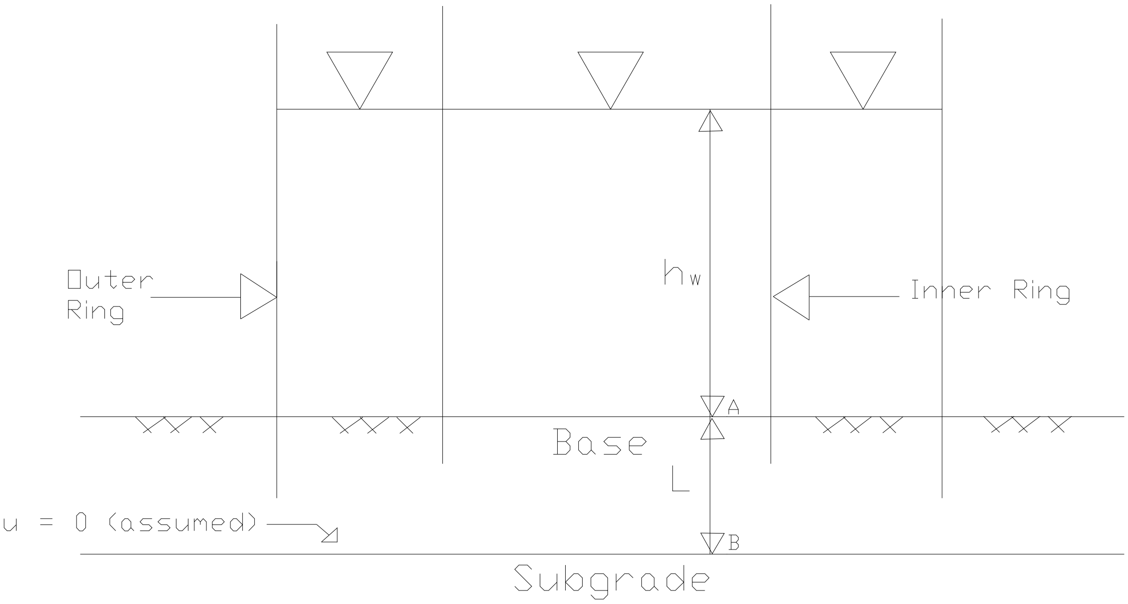
Test	Procedure
Grain Size Distribution	ASTM D422
Wash Sieve (% Passing No. 200)	ASTM D1140
Moisture - Density	ASTM D698

In addition to the index tests, laboratory permeability tests were performed on compacted specimens of the base. The specimens were compacted in rigid-wall molds, allowed to cure (age) for periods ranging from 1 day to 60 days, and then permeated under constant-head conditions. The initial flow rates were used to ascertain the effect of aging on the permeability. Water flow was continuous through the specimens and permeability was measured periodically to assess the effect of intermediate-term flow on the permeability of the base.

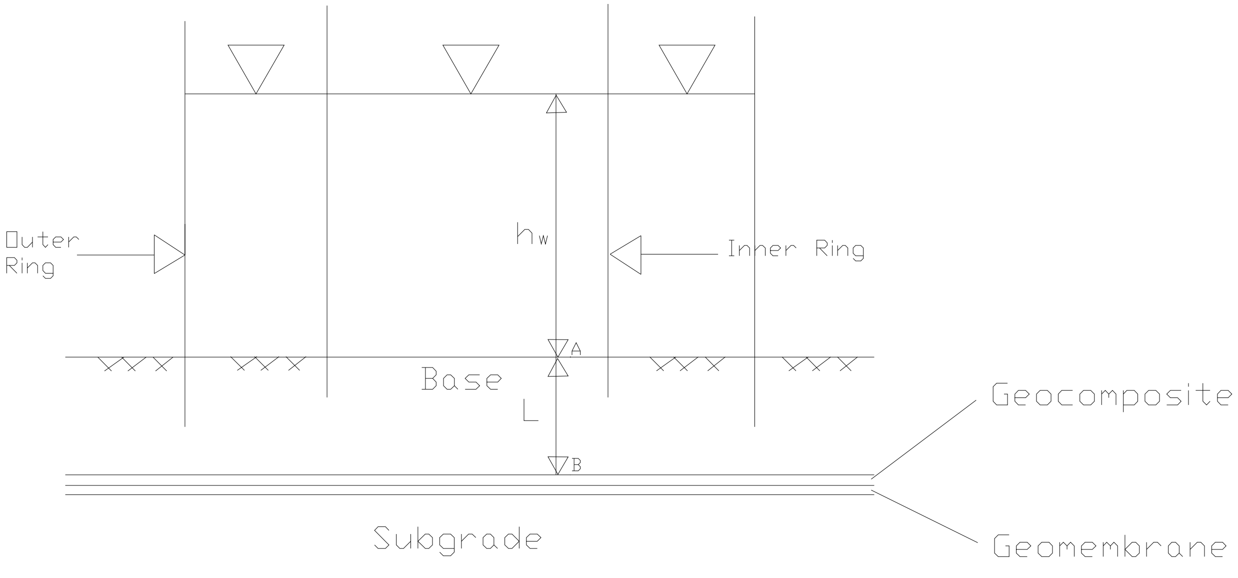
The field permeability tests were performed using a double-ring infiltrometer (DRI), following ASTM D3385 procedures in general. The hydraulic gradient for the first test was calculated by assuming full saturation at the base and no pore water pressures at the interface of the bottom of the base and subgrade (Figure 1).

In several field permeability tests we installed lysimeters (underdrains) beneath the base (at the base/subgrade interface, Fig. 2). The lysimeters consisted of a geomembrane (1.5 mm HDPE) placed directly on the compacted subgrade. A geocomposite (double sided geotextile/geonet) was placed on top of the geomembrane. The layers were held in place by driving four inch long nails through them (along the perimeter of the lysimeters) into the subgrade.

The lysimeters (Figure 3) enabled us to accurately know the boundary conditions and hydraulic gradient in the field permeability test and to collect and quantify the outflow through the base.

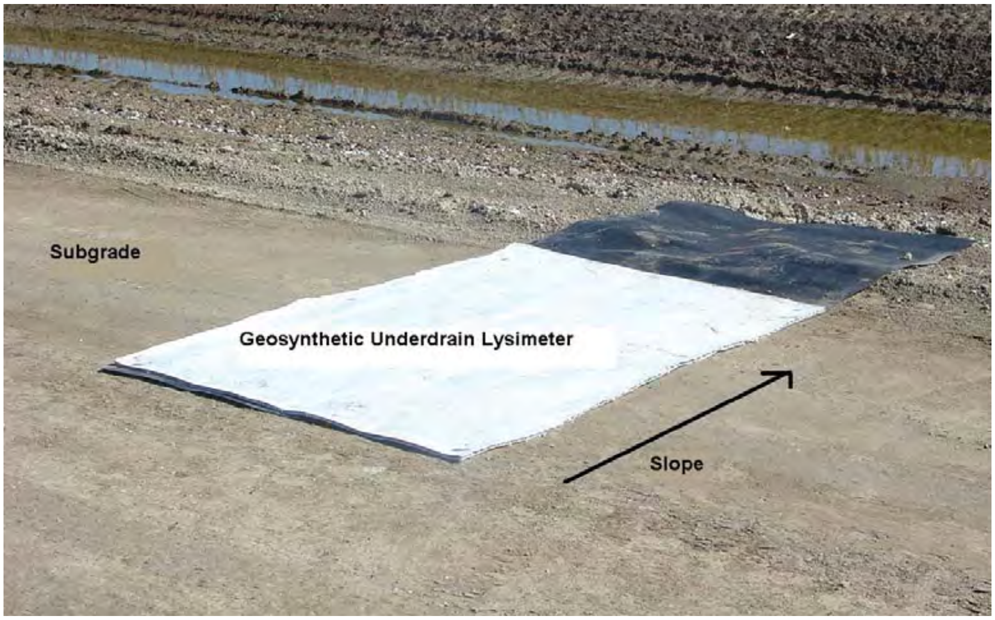


(a) Schematic without lysimeter

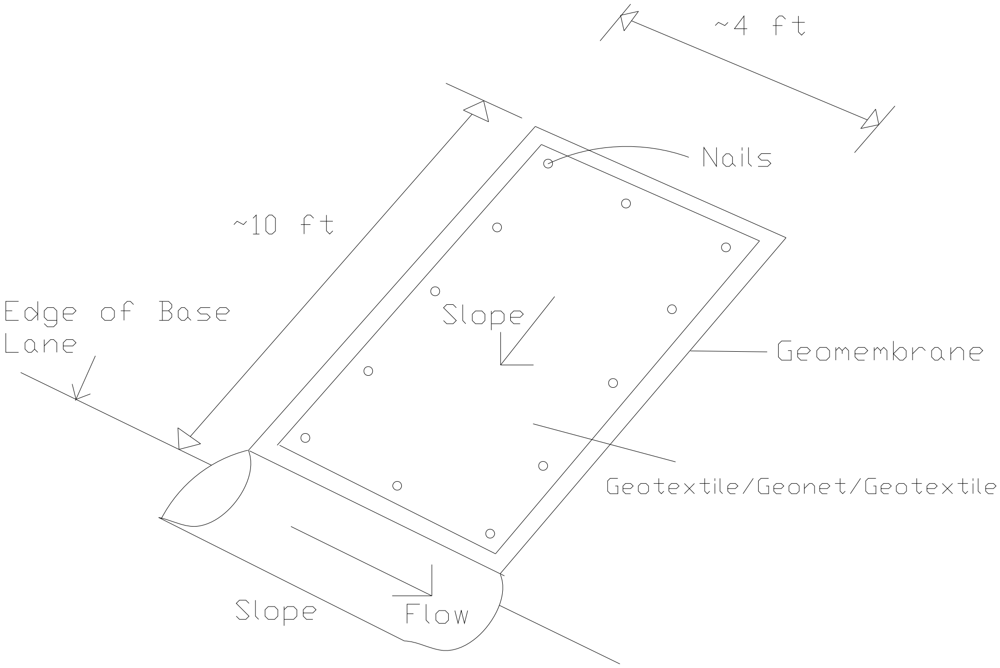


(b) Schematic with lysimeter

Figure 1 – Elevation views of the double ring infiltrometer (DRI)



(a) Photograph of lysimeter Rte 63 La Plata, Missouri



(b) Schematic

Figure 2 – Underdrain lysimeter for controlling boundary conditions and collecting water flowing through the base.

Figure 3 – Double ring infiltrometer

The hydraulic conductivity for the slower flow rate bases was calculated using Darcy's law and constant head procedures (Eqn 1)

$$q = kiA$$

$$k = {}^{q}\!/_{iA} = \frac{{}^{Q}\!/_{t}}{{}^{\Delta H}\!/_{L} * A} \qquad \text{(Eqn. 1)}$$

Where:
Q = volume of flow $\left(L^3\right)$
t = time for flow (t)
$\Delta H = h_a - h_b \quad (L)$
L = thickness of base (L)
A = x-sectional area, inner ring $\left(L^2\right)$

The hydraulic conductivity for the higher flow rates was calculated using falling head procedures. The complete outer ring was used as the cross sectional area of the base and the water reservoir. The hydraulic conductivity was calculated using Equation 2:

$$k = \frac{aL}{A(\Delta t)} * \ln\left(\frac{h_1}{h_2}\right) \qquad \text{(Eqn. 2)}$$

Where:
k = hydraulic conductivity $(cm/\sec)$
a = x-sectional area, outer ring (L^2)
L = thickness of base (L)
A = x-sectional area, outer ring (L^2)
$\Delta t =$ time for flow (t)
$h_1 =$ initial height of water (L)
$h_2 =$ final height of water (L)

Results

The grain size distribution specification and the moisture-density curve for the special base course used on US 63 at La Plata, Missouri were obtained from MoDOT and their on-site inspector (Terracon). Samples of the base course were recovered from in situ test sites 1, 2, and 3. Gradation analyses and wash sieves were performed on the recovered samples. The results are shown in Figure 4.

The grain size distribution results indicate that the base course falls within or at the upper size limit for the specification. The base classifies as a poorly graded (uniform) gravel (GP). The wash sieves show five to eleven percent fines. In general, the gradations meet the specification which states less than 10% fines.

The moisture-density curve (by Terracon) was performed on material from the quarry stockpile. Maximum dry density was 135 pcf at an optimum moisture content of 7.5 percent (Figure 5).

In situ hydraulic conductivity tests on the special base course were performed at five sites on Rte 63 near La Plata, Missouri (Table 2). At Site #1 no underdrain lysimeter was used and a constant head hydraulic conductivity test was performed. The resulting hydraulic conductivity was 6 ft/day.

Lysimeters were installed at Sites #2 through #5, and falling-head hydraulic conductivity tests were performed at these sites. The measured hydraulic conductivities ranged from 23 to 113 ft/day (Appendix: Figures 6 through 10).

Laboratory permeability tests are were performed to evaluate the effects of aging (curing) and intermediate-term flow on the permeability of the base course. The results of the aging test are shown in Figure 11. Specimens permeated shortly after compaction showed permeabilities slightly above 3 ft/day (0.001 cm/s). The permeability tended to decrease with increased aging and the specimen aged for 60 days had a permeability of about 0.3 ft/day (0.0001 cm/s).

The intermediate-term flow behavior was evaluated for four of the compacted base specimens (Figure 12). In all specimens, the permeability decreased with increasing flow time. After about 30 days, all four specimens exhibited a permeability of about 0.3 ft/day (0.0001 cm/s). The permeability continued to decrease for the specimens as the flow period continued.

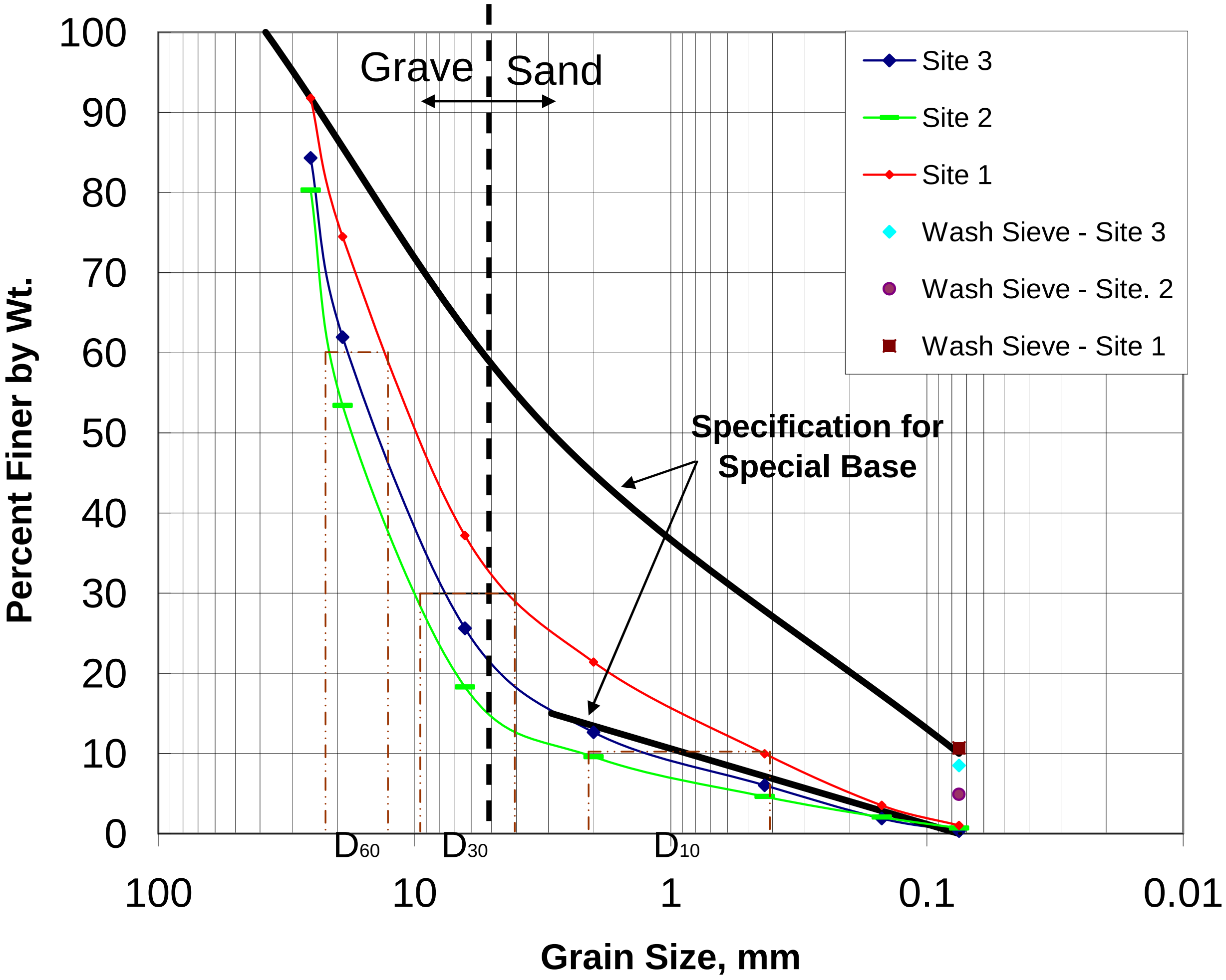


Figure 4 – Gradation curves of selected field samples, base material, US 63 La Plata, MO

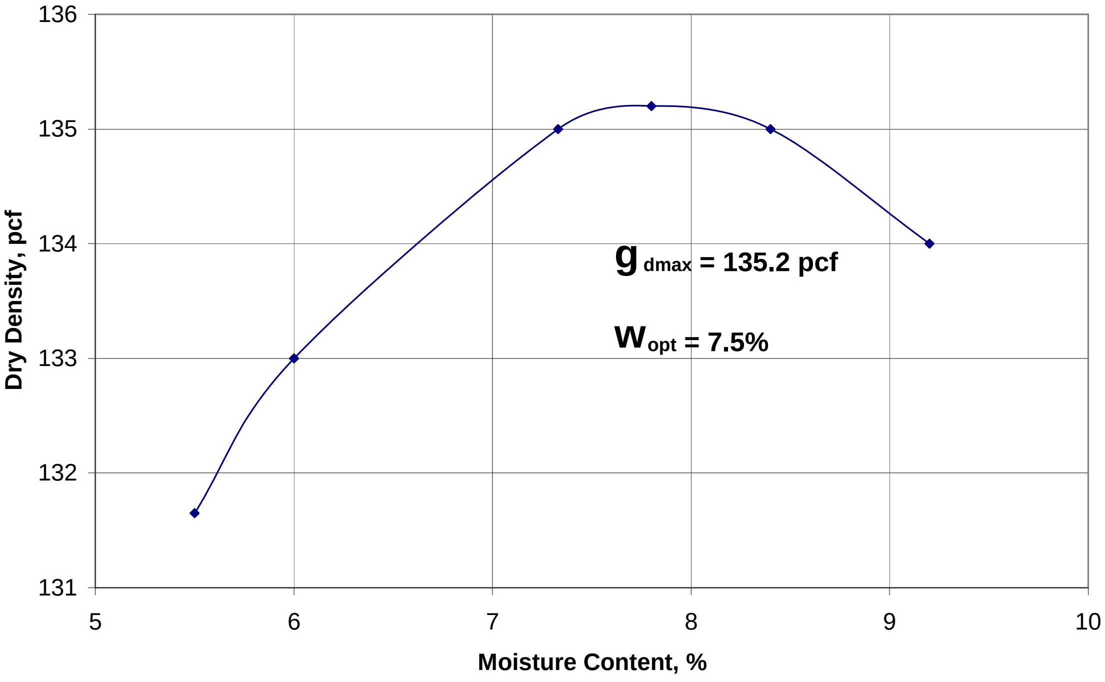


Figure 5 - Compaction curve for base material from the stockpile at the quarry provided by Terracon/MoDOT (2005)

Table 2 – In situ hydraulic conductivity of special base

Date Measured	Site	Conditions	$\%P_{200}$	$K_{field}, cm/s(ft/day)$
8/30/05	1	No Lysimeter (constant head)	11	0.002 (6)
9/1/05	2	Lysimeter (falling head)	8	0.01 (34)
9/1/05	3	Lysimeter (falling head)	5	0.04 (113)
9/21/05	4	Lysimeter (falling head)	N/A	0.02 (57)
9/21/05	5	No Lysimeter (falling head)	N/A	0.01 (23)

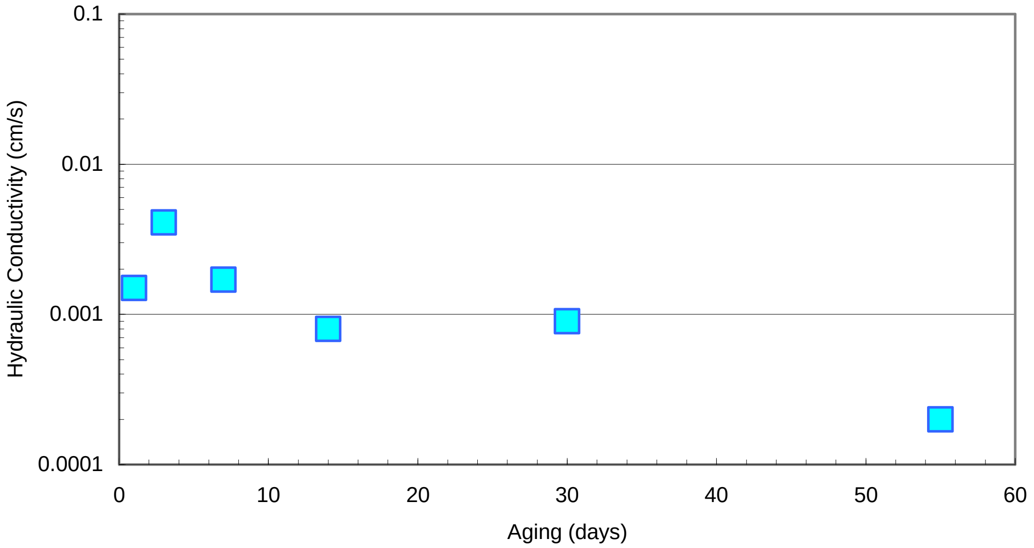


Figure 11 – Effect of aging on the permeability of the compacted base.

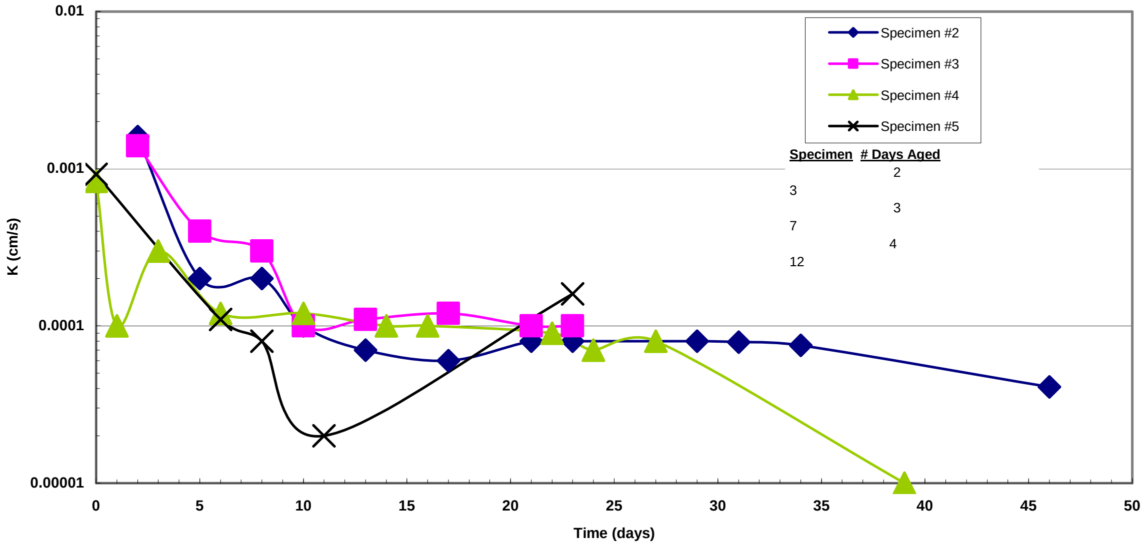


Figure 12 – Effect of intermediate-term flow on the permeability of the compacted base.

Discussion

The base course is poorly graded gravel and contains 5 to 10 percent fines (size fraction passing #200 sieve (0.075 mm)). A rough estimation of the permeability can be made using Hazen's (1892) expression which relates permeability to the particle size of the material at the 10 percent (D_{10}) passing. For the special base course, D_{10} ranges from 0.4 mm to 1.5 mm and the resulting estimate of permeability ranges from 500 ft/day to 5000 ft/day. We emphasize that the Hazen expression is only a rough idea of the permeability.

The in situ permeability tests show ranges from 6 to 113 ft/day for the special base course. The base material with the 6 ft/day in situ permeability, (Site #1) had been in place for some unknown time period and was well cemented, difficult to excavate, and as such appeared to be more dense than that for Sites #2 through #5. Sites #2 through #5 were tested for permeability within 24 hours or less after being placed and compacted. They were easy to excavate, loose, and seemingly less dense than the base at Site #1. The resulting in situ permeabilities (6 to 113 ft/day) are deemed representative of the materials tested and likely represent the inherent variability within the base. Although the base is primarily course material (on average $\geq$ 80% gravel size fraction by weight), there is 5 to 10% fines content which tends to control the permeability.

Cedergren (1989) showed that when the percentage passing the #100 sieve for a washed filter aggregate was increased from 0 to 7% the permeability decreased from a range of 80 to 300 ft/day to less than 3 ft/day (Table 3). It is possible that the fines in the base course are collecting in one location and acting as a low permeability layer, thus control the permeability of the base course.

Table 3 – Influence of percent of passing the No. 100 sieve (0.15 mm) fraction on permeability of washed filter aggregates (Cedergren, 1989)

Percentage passing #100 sieve	Permeability, ft/day
0	80 to 300
2	10 to 100
4	2 to 50
6	0.5 to 20
7	0.2 to 3

Prachantrikal (2002) tested MoDOT's Type 5 base and the effect of percentage of fines (fraction less than 0.075 mm) on the permeability. He found that with all of the fines removed, the Type 5 base has a permeability of about 300 ft/day. With six percent fines the permeability was about 3 ft/day and with 15 percent fines the permeability was 0.03 ft/day. Prachantrikal concluded that for any meaningful drainage the base could not have more than three percent fines.

Field observations indicate that the base course tends to “cure” or cement itself with time. Site #1 was very difficult to excavate and had been in place for an unknown time period. Sites #2 through #5 were tested within 24 hours of placement and all were loose and easy to excavate. Our laboratory aging tests also showed a reduction in permeability with increased aging time, i.e., time between compaction and permeability testing. In fact, the specimen that was compacted but not permeated for almost 60 days, exhibited a permeability almost one 10 times lower than the specimen which was permeated immediately after compaction. While this laboratory study was limited in time and no replicates were performed, the trend of decreasing permeability with increasing aging time is readily evident. We saw a similar behavior in the field permeability tests.

The intermediate-term flow tests showed decreasing permeability of the base material with time. After 30 days of flow, all four specimens converged at a permeability of about 0.3 ft/day. The specimens with flows longer than 30 days continued to show decreasing permeability. Blanco et al. (2004) performed long term flow tests on compacted Type 5 base with fines contents ranging from six to 15 percent. The results showed an order of magnitude decrease in permeability over about a 70 day flow period. This was followed by a relatively stable flow rate.

Conclusions and Recommendations

Koch Industries specified an aggregate base special for the expansion of US 63 in Macon/Adair Counties. The base deviates from MoDOT’s standard (Type 5, Type 1) raising concern about its performance. The Institute for Interdisciplinary Geotechnics was contracted, specifically to evaluate the in-place permeability of the base. In situ permeability tests, laboratory gradation analyses, aging and intermediate-term flow tests were performed on the base.

The following conclusions are based on the results of our testing on the special base course:

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- Laboratory permeability ranges from 0.3 to 3 ft/day (initially).
- Aging or curing tends to decrease the permeability by about one order of magnitude.
- The permeability decreased to 0.3 ft/day after 30 days of flow for all specimens.

Some recommendations for consideration are as follows:

- Additional in situ permeability tests should be conducted to better characterize the effect of aging in the field conditions.
- Laboratory aging tests should be performed to assess effects on drainage and strength of the base.
- Resilient modulus and/or cyclic triaxial strength tests should be performed on the base to quantify possible strength loss or gain given the potential for aging of the base.
- Field performance tests (Falling Weight Deflectometer or Geophysical tests) should be performed to assess the deformation behavior of the base and overlying pavement.

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Blanco AM, Deeken JJ, Bowders JJ, Likos WJ and Donahue JP (2004) “Observations on drainage and strength characteristics of Missouri roadway base,” *Proceedings* of the 55th Highway Geology Symposium, Kansas City, Missouri, September 7-10.

Cedergren HR (1989) *Seepage, Drainage and Flow Nets*, 3rd Edition, John Wiley and Sons, New York.

Hazen A (1930) Water Supply, *American Civil Engineers Handbook*, John Wiley and Sons, New York.

Prachantrikal W (2002) “Hydraulic conductivity of MoDOTs Type 5 base,” MS Thesis, Civil & Environmental Engineering, University of Missouri, Columbia, MO.

Appendix A – Permeability versus cumulative flow volumes for the in situ permeability tests performed on the special base course used on US 63 at La Plata Missouri.

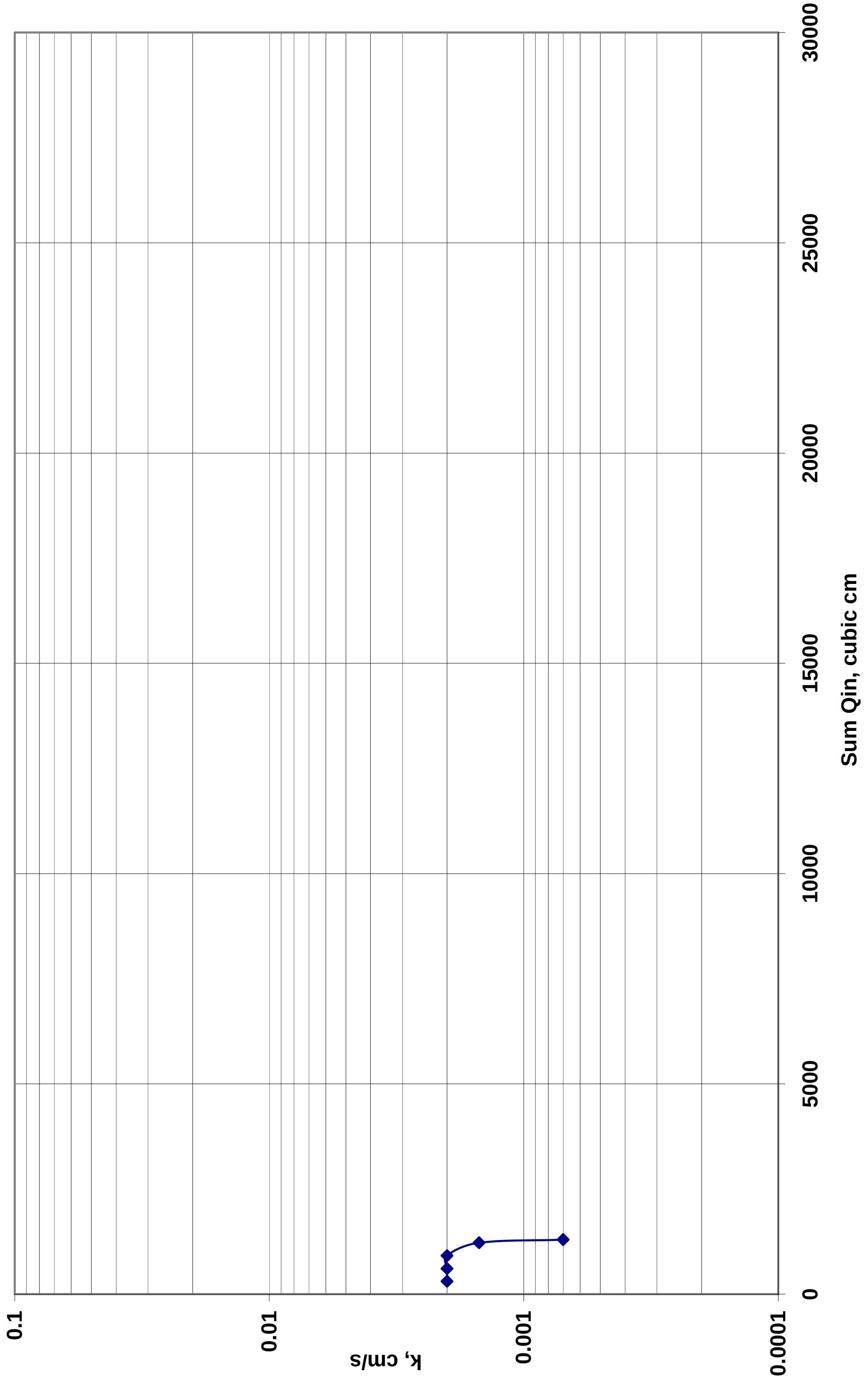

Figure 6 - In situ hydraulic conductivity vs cumulative inflow for field test #1 on Rte 63 La Plata, Missouri base material

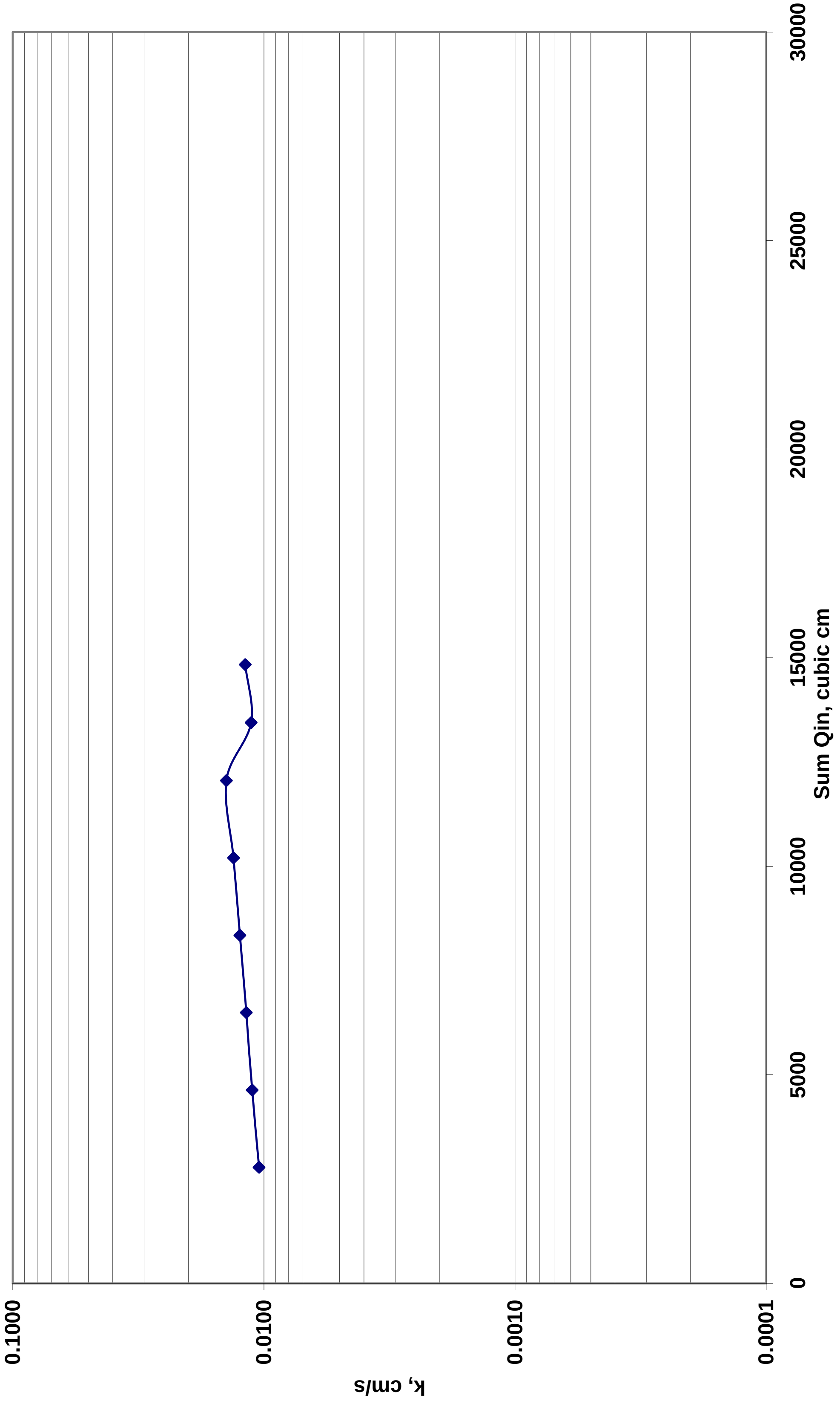

Figure 7 - In situ hydraulic conductivity vs cumulative inflow for field test #2 on Rte 63 La Plata, Missouri base material

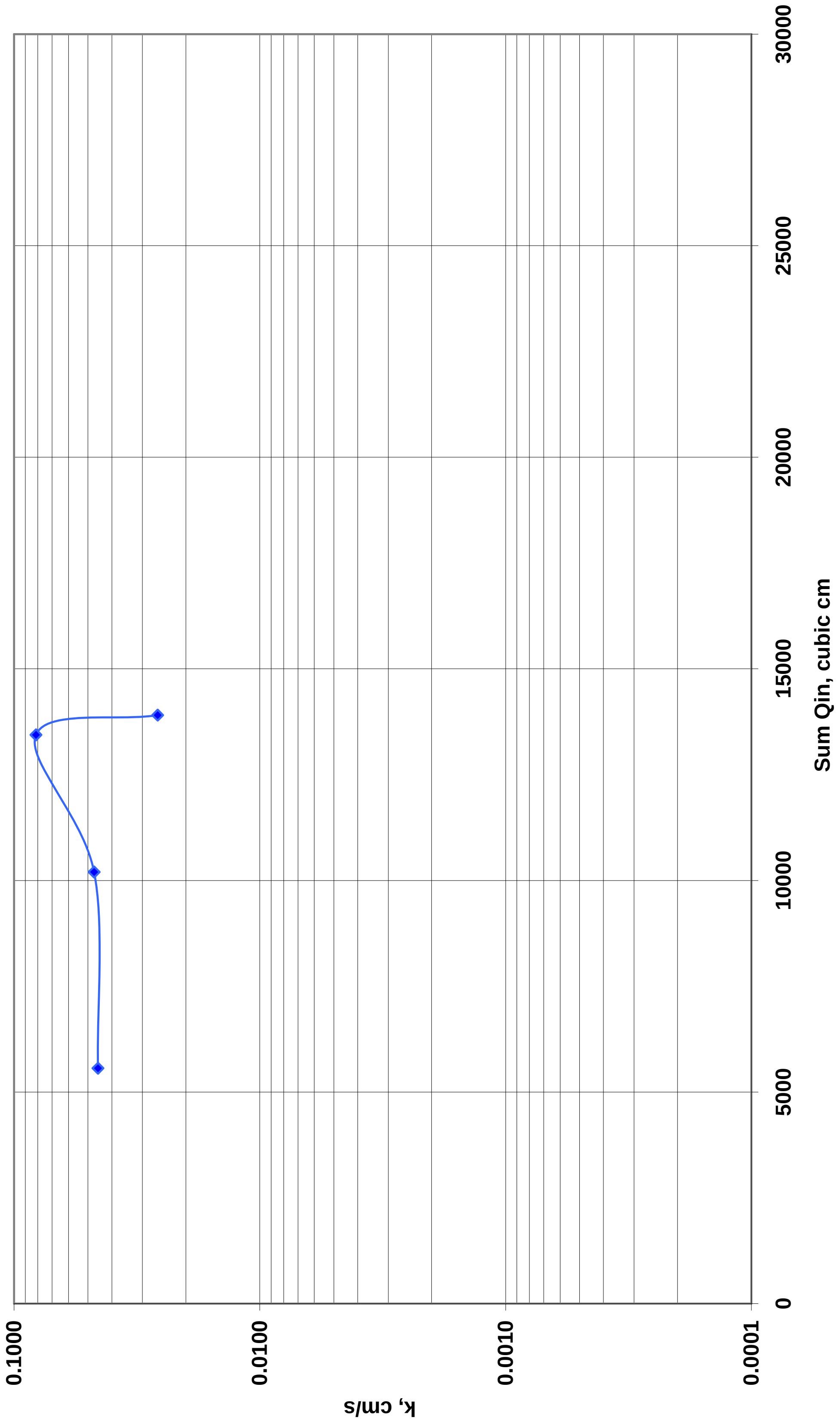

Figure 8 - In situ hydraulic conductivity vs cumulative inflow for field test #3 on Rte 63 La Plata, Missouri base material

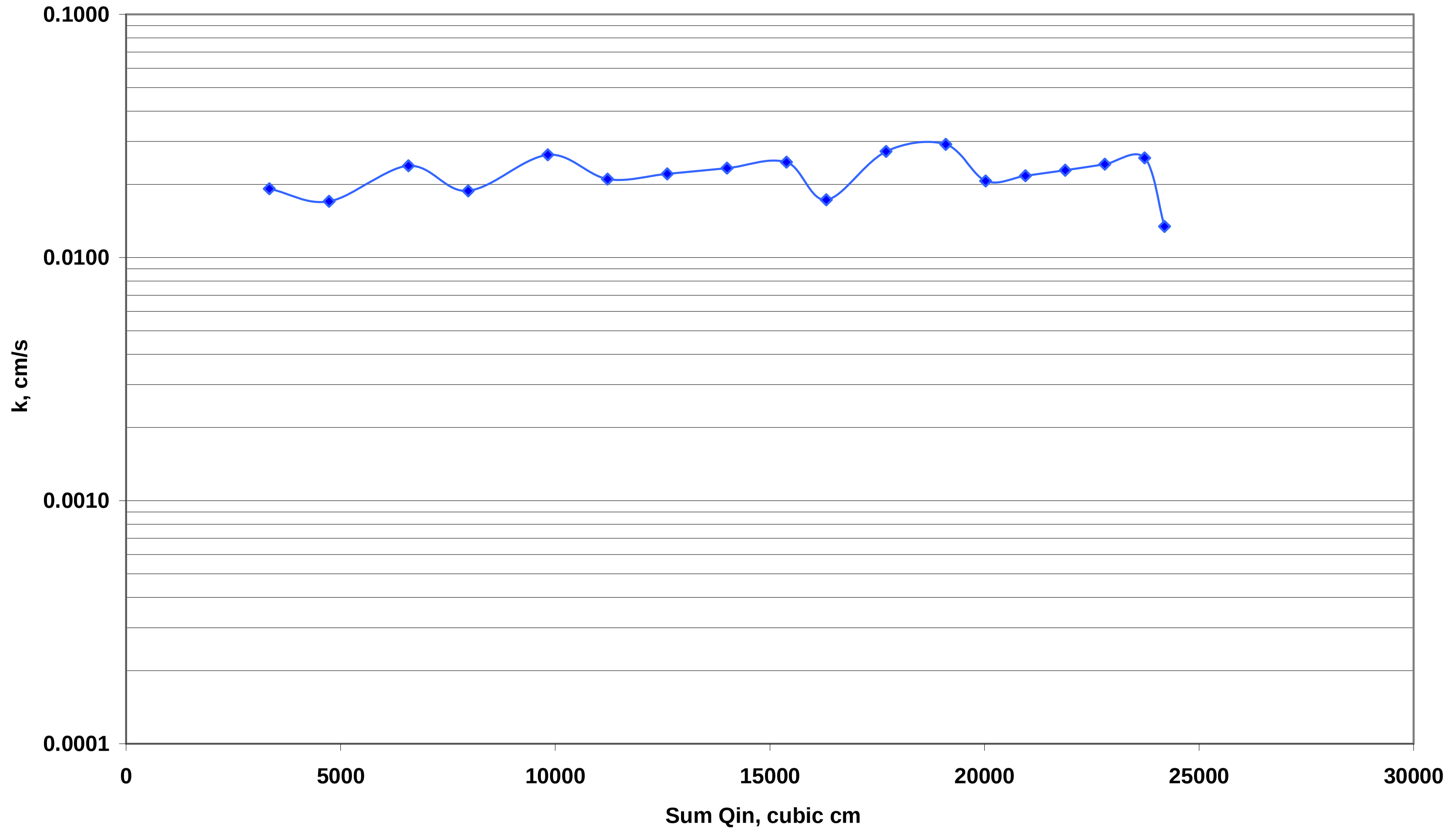

Figure 9 - In situ hydraulic conductivity vs cumulative inflow for field test #4 on Rte 63 La Plata, Missouri base material

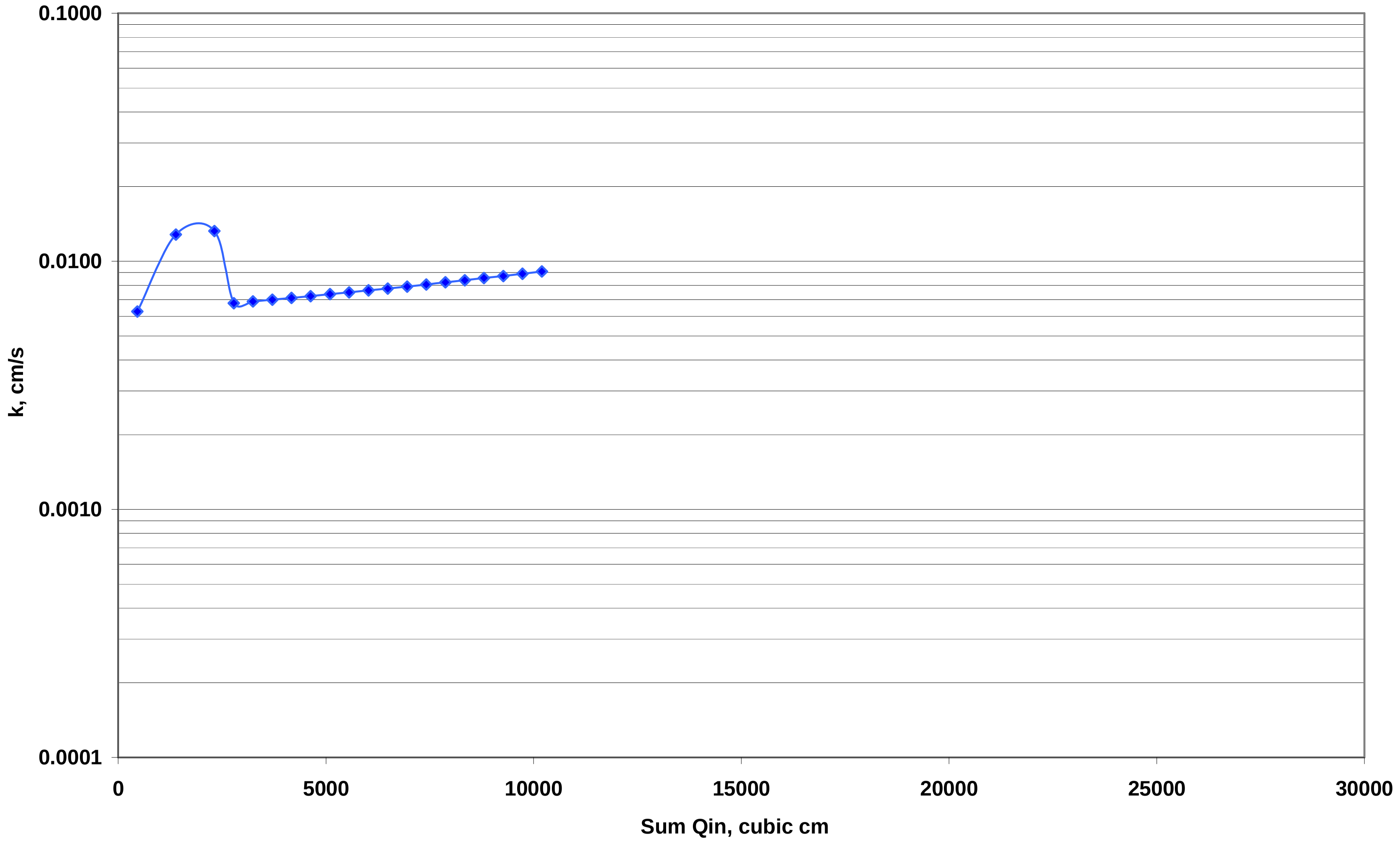

Figure 10 - In situ hydraulic conductivity vs cumulative inflow for field test #5 on Rte 63 La Plata, Missouri base material

Appendix B – Estimation of Permeability Using Hazen Equation

Hazen equation: k (cm/s) = ${D_{10}}^2 (mm)$

Can estimate k (cm/s)

${D_{10}}^2 (mm)$ = k (cm/s)

Range in k (from grain-size distribution curve)

1.5 mm > D_{10} > 0.4 mm

2.2 cm/s $\geq$ k $\geq$ 0.16 cm/s

~ 5000 ft/day $\geq$ k $\geq$ 500 ft/day

1 cm/s = 2880 ft/day