

A Comparative Experimental Study on the Hydraulic Conductivity of Treated and Untreated Open-Graded Base Courses

Abdul A. Koroma¹, Victor S. Kamara²

¹Department of Civil and Environmental Engineering,
Michigan Technological University, Michigan,

²Department of Civil and Environmental Engineering,
Namibia University of Science and Technology, Windhoek, Namibia

Abstract: An experimental program was conducted to determine the coefficient of hydraulic conductivity of both treated and untreated open-graded base samples made from four different gradations, three aggregate types and two binder types. For the same gradation, dolomite samples have the highest K value, followed by natural gravel and recycled concrete aggregate respectively. Treated open-graded samples have K values in excess of an order of magnitude while the difference in K value between the asphalt-treated open-grade samples was less than an order magnitude

Keywords: Base course, hydraulic, c conductivity, open-graded, aggregates

I. Introduction

The provision of adequate subsurface drainage in pavements in order to prevent or minimize moisture induced distresses is an important design consideration in pavement design. This is largely due to the pioneering work of Cedergren and others. Cedergren, through extensive research had shown that adequate subsurface drainage underneath pavements can drastically reduce the life cycle cost of pavements (Cedergren 1974). Premature failure of the pavement system due to a malfunction of the subsurface drainage feature can be costly, but if the permeability and stability of the drainable bases can be maintained, pavement design life and significant lower life cycle cost would be realized.

In an effort to produce non-erodible and drainable base layer, many state highway agencies have moved from the traditional dense graded base course gradation specifications to more open graded base course specifications that allow for greater drainage in the pavement sub-layers. One major reason for this transition is due to the fact that dense gradations, even though they offer stiffer bases with good constructability have serious long term stability problems as a result of prolonged saturation of the pavement structural section leading to a reduction in 3 the stiffness as the pavement ages. As a result of this, open-gradation specifications like the 4G and 5G aggregate specifications used in Michigan have been developed in order to allow for greater permeability and lower field saturation levels in subsurface pavement layers (Mayrberger and Hodek 2007).

There has been a marked increase in the use of open-graded base courses by many highway agencies in an effort to provide an effective and durable subsurface drainage system. This has led to many research opportunities in order to characterize the drainage characteristics of these free draining materials. The aggregate materials used for this purpose have different maximum size gradation, binder types and content, and as such are expected to have different hydraulic, mechanical and durability properties. The practical and economic combinations of these materials have resulted in different types of subsurface design options available to pavement designers.

II. Experiment Programme

The experimental program was designed to determine the coefficient of hydraulic conductivity of each aggregate type and how it varies within certain gradation limits and under varying environmental constraints

Aggregate Base Materials

Three aggregate base materials were investigated consisting of two natural aggregates and one recycled aggregate. The natural aggregates were Natural Gravel and Dolomite while the recycled material was Recycled Crushed Concrete.

Figure1: Photo showing crushed surfaces of the three aggregate types





Table 1: Aggregate material properties

Material type	SSD, specific gravity	Absorption (%)
Natural gravel	2.65	2.62
Limestone	2.80	2.8
Recycled Portland cement concrete	2.53	5.3

Table 2: Physical properties of aggregates

Aggregate type	Absorption (%)	SSD (specific gravity)	SSD (density) (lbs/ft ³)	Uncompacted air void (%)
Dolomite	2.8	2.8	112.4	43.6
Natural Gravel	2.62	2.65	96.4	40.2
Recycled concrete	5.3	2.53	107.4	38.7

Stabilizing Agents

The two binding agents used to stabilize drainable bases are Portland cement and asphalt. In an effort to provide answers as to which binder can provide an efficient and economical treated open-graded drainage layer, this research utilized both binders. For this research program Type 1 cement was utilized for the cement treated open-graded samples and an asphalt grade of PG grade of 58-28 was used for the asphalt treated open-graded samples.

Aggregates' Gradations

Four gradation types were employed, two for the untreated open-graded drainage layer and two for the treated open-graded drainage layer. Both the MDOT 4G and the NJ unstabilized Mix were used for the untreated aggregate materials while the AASHTO #67 and MDOT 5G gradations were used for the treated open-graded aggregate materials.

Considering the very open nature of these gradation specifications, three gradations bands were established in order to adequately determine the variations of material properties within the gradation bands. These

gradation bands were a lower bound, which leans toward coarser size particles, an upper bound which represent a finer gradation and a middle gradation which is the average of the lower and upper bound gradations. The sampled gradations and specification limits are shown in Table 3.4.

Table 3: Aggregate specifications – percent finer by weight

Sieve Size (inches)	AASHTO'S NO.67	New Jersey Mix	Michigan 4G	Michigan 5G
2 1/2				
2				
1 1/2		100	1	100
1	100	95-100		
3/4	90-100		60	
1/2		60-80	35	0-90
3/8	20-55			
#4	0-10	40-55		0-8
#8	0-5	5-25	10	
#16		0-8		
#30			5	
#40				
#50		0-5		
#200		0	0	0-3

III. Laboratory Permeability Test Program

The test procedures contained in ASTM D5084-03 titled “Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter” the falling head rising tail water method was used to measure the coefficient of hydraulic conductivity of the untreated open-graded samples and the cement treated open-graded samples. For the asphalt treated open-graded samples, a provisional ASTM standard was used measured the coefficient of hydraulic conductivity.

IV. Specimen Preparation and Testing Procedures

Bulk materials from various bins were sieved and then grouped into different size particles. The different particle sizes are then recombined to produce the targeted gradations bands shown on Table 3.4. However, for the treated open-graded aggregate materials, a mix design was prepared in order to obtain the design mixes

required for the experimental program. The mix design process for the two treated permeable bases is outlined below:

Table 4: Mix proportion for CTPB

Mixture ID.	Cement Content (lb/yd ³)	Design air void content (%)
1	200	15
2	200	25
3	200	35

Table 5: Types of ATPB samples prepared

Material type	15%	25%	35%
Recycled Concrete	RC_5G_15	RC_5G_25	RC_5G_30
	RC_67_15	RC_67_25	RC_67_30
Natural Gravel	NG_5G_15	NG_5G_25	NG_5G_30
	NG_67_15	NG_67_25	NG_67_30
Dolomite	DL_5G_15	DL_5G_25	DL_5G_30
	DL_67_15	DL_67_25	DL_67_30

Legend: X_Y_Z

X= Material type, Y= Gradation type Z= target air voids content %

After making several the trial compaction runs, the following level of compaction efforts were used to arrive at the designated % air voids content:

1. CTPB mixes with air voids content of 15%- 3 layers, 25 Marshall Hammer blows per layer and rodded 25 times per layer.
2. CTPB mixes Air voids content of 25%- 2 layers, rodded 25 times per layer, 20 Marshall Hammer blows per layer.
3. CTPB mixes with air voids content of 35%- 2 layers, no rodding, 2 Marshall Hammer blows per layer

An asphalt content of 3% by weight of the dry weight of the aggregate was used in this research project. A PG 58-28 grade asphalt binder provided by the Pavement Research Group of Michigan Technological University (MTU) was used to make the asphalt treated open-graded samples.

After several trial runs, the following mixes and number of gyrations were used to arrive at the designated % air voids content:

- 15% air voids content: total weight of sample 3500g and 40 gyrations
- 25% air voids content: total weight of sample 2500g and 25 gyrations

- 35% air voids content: total weight of sample 4200g and 20 gyrations

For each material, percent air voids content and gradation type, four samples were prepared and tested. This resulted in a total of 72 samples. Hydraulic conductivity was done in accordance with the AASHTO provisional procedure P-125 titled: “*Determination of Saturated Hydraulic Conductivity using a Flexwall Permeameter*.” The apparatus set up is shown in Fig 3.10 and the procedure employed a falling head approach. The test procedure however requires that the height of the test specimen to be about 80mm. Therefore some of compacted samples with height greater than 80mm were cut while some within +/- 5 were not cut.

V. Testing procedure for Untreated Open-Graded Aggregate Materials

For the untreated open-graded aggregate materials, the two gradation types investigated were that of Michigan Department of Transportation (MDOT) 4G gradation and the New Jersey (NJ) open-graded gradations. Experimental procedure for conducting the hydraulic conductivity test was done strictly in accordance with ASTM D5068 “*Determination of Hydraulic Conductivity of Porous Stone Using a Flexwall Permeameter*”. For each specimen, five hydraulic conductivity measurements were made and then averaged. Standard practice also requires that the coefficient of hydraulic conductivity be reported to a base temperature of 20 degrees Celsius, the temperature for each test was recorded and correction to the hydraulic conductivity value was made using the appropriate formula. Two correction factors were applied to the measured K value in order to arrive at the corrected measured K value. Corrections were made for the hydraulic conductivity of the ceramic porous stones and for the head loss across the specimen. The hydraulic conductivity of the porous ceramic stones was measured by setting up the flexwall permeameter using the two porous stones without the specimen in it. The head loss through the specimen was a dummy sample of similar dimension as the actual specimen made of cast steel was fitted in the laboratory set up using identical procedures was used for the actual specimen. For this case it was assumed that the head loss across the dummy sample is negligible so that head loss measured will be attributed only to that of the system (Smith 2004).

As compacted unit weight MDOT 4G gradation

Material type	Gradation band	Unit weight (pcf)	OMC (%)
Limestone	lower	128	2.6
	Middle	144	3.5
	Upper	148	3.2
Recycled Concrete	Lower	102	6
	Middle	115	5.5
	Upper	119	7
Natural gravel	lower	122	3.5
	Middle	137	4.2
	Upper	140	3.5

As compacted unit weight NJ unstabilized mix

Material type	Gradation band	Unit weight (pcf)	OMC (%)
Limestone	lower	120	2.1
	Middle	138	4.2
	Upper	143	3.4
Recycled Concrete	Lower	93	6.3
	Middle	98	5.2
	Upper	102	6.4
Natural gravel	lower	108	3.0
	Middle	115	4.5
	Upper	120	3.2

VI. EXPERIMENTAL RESULTS AND DISCUSONS

Table 6: Coefficient of hydraulic conductivity results for untreated open-graded aggregate material

Sample ID	Dry unit weight (lb/ft ³)	Void Ratio	K ₂₀ (cm/s) (cm/s)
RC_4G_L	102	0.312	0.13
RC_4G_U	119	0.232	0.04
RC_4G_M	113.4	0.273	0.05
RC_NJ_L	93.4	0.554	0.23
RC_NJ_U	102.4	0.423	0.08
RC_NJ_M	98.3	0.487	0.11
NG_4G_L	122	0.347	0.15
NG_4G_U	140	0.248	0.06
NG_4G_M	133.2	0.308	0.12
NG_NJ_L	108.4	0.324	0.18
NG_NJ_U	120.2	0.228	0.09
NG_NJ_M	115	0.297	0.13
DL_4G_L	128	0.426	0.24
DL_4G_U	148	0.385	0.06
DL_4G_M	140.4	0.402	0.15
DL_NJ_L	130.2	0.525	0.27
DL_NJ_U	142.3	0.407	0.07
DL_NJ_M	136.4	0.433	0.18

Table 7: Average percent air void content and coefficient of hydraulic conductivity of ATPB samples

Specimen	Number of samples	Rice Specific gravity	Nominal Asphalt content (%)	Avg. Air void content for control group (%)	Average Air void content, for conditioned group (%)	K (cm/s)
RC_15_5G	4	2.426	3	16.2	15.8	2.73
RC_25_5G	4	2.426	3	20.4	21.4	3.50
RC_35_5G	4	2.426	3	29.6	30.8	5.13
RC_15_67	4	2.44	3	15.3	15.1	2.58
RC_25_67	4	2.44	3	19.2	19.7	3.30
RC_35_67	4	2.44	3	29.1	29.3	4.96
NG_15_5G	4	2.65	3	17.7	17.2	2.96
NG_25_5G	4	2.65	3	22.4	21.2	3.70
NG_35_5G	4	2.65	3	33.2	33.6	5.67
NG_15_67	4	2.62	3	16.4	16.8	2.82
NG_25_67	4	2.62	3	20.7	21.4	3.58
NG_35_67	4	2.62	3	30.1	31.4	5.22
DL_15_5G	4	2.744	3	18.4	18.7	3.15
DL_25_5G	4	2.744	3	24.3	25.2	4.20
DL_35_5G	4	2.744	3	35.4	36.3	6.09
DL_15_67	4	2.722	3	17.2	17.6	2.96
DL_25_67	4	2.722	3	22.4	23.1	3.92
DL_35_67	4	2.722	3	31.4	32.6	5.44

Table 8: Coefficient of hydraulic conductivity of CTPB samples

Specimen	Nominal Cement content (lb/yd³)	K (cm/s)
RC_5G_15	200	1.02
RC_5G_25	200	1.50
RC_5G_35	200	2.66
RC_67_15	200	0.80
RC_67_25	200	1.14
RC_67_35	200	2.17
NG_5G_15	200	1.22
NG_5G_25	200	2.06
NG_5G_35	200	3.35
NG_67_15	200	1.06
NG_67_25	200	1.39
NG_67_35	200	2.88
DL_5G_15	200	1.29
DL_5G_25	200	2.53
DL_5G_35	200	3.84
DL_67_15	200	1.01
DL_67_25	200	2.04
DL_67_35	200	2.96

VII. Result Comparison between Different Gradation types

Since the middle gradation band represents average of the lower and upper gradation bands, it was used to make comparison between the two gradation types. For subsequent analysis of the measured laboratory hydraulic conductivity values, the K value of the middle gradation was assumed to be the representative K value for each gradation band. Even though the K value of the middle gradation is not the average of the K value of the lower and upper gradation bands, this assumption does help in facilitating the comparison of hydraulic conductivity values between different gradation types.

A closer examination of the measured laboratory K values of the various aggregate samples will show that the

gradation parameter D_{10} is directly proportional to the K value. Samples with higher D_{10} values also have higher K values. Based on this relationship between K and D_{10} , the NJ unstabilized gradation with the higher D_{10} value has the higher measured coefficient of hydraulic conductivity. For the NJ unstabilized Mix samples, the variation between two gradation bands like that between the lower and upper bands can be as high as 109% for some materials, while that of the MDOT 4G gradation can be as high as 52%. However, the difference in the measured value of K between the two gradations is less than an order of magnitude for all the samples. Also, the differences in K among the gradation bands even though they can be as high as 100% in some cases, are still less than an order of magnitude. One can therefore conclude that on the basis of coefficient of hydraulic conductivity alone, there is not much to choose between the two gradations. Furthermore, choosing any of the gradation bands within those two gradations for drainage consideration is justifiable since there was no significant difference in measured K values among the three gradation bands.

Table 4.3 shows the D_{10} values for the samples tested and their corresponding coefficient of hydraulic conductivity.

Table 9: Variation of K within the gradation bands for untreated open-graded materials

Sample ID	Dry unit weight (pcf)	D_{10} (in)	Cu	K_{20} (cm/s)
RC_4G_L	102	0.0929	8.05	0.13
RC_4G_M	105	0.0184	33.38	0.05
RC_4G_U	119	0.0074	55.24	0.04
NG_4G_L	128	0.0929	8.05	0.15
NG_4G_M	133.2	0.0184	33.38	0.12
NG_4G_U	140	0.0074	55.24	0.06
LS_4G_L	128	0.0929	8.05	0.24
LS_4G_M	135	0.0184	33.38	0.15
LS_4G_U	148	0.0074	55.24	0.06
RC_NJ_L	103.2	0.1042		0.23
RC_NJ_M	107.7	0.0696	4.84	0.11
RC_NJ_U	110.5	0.051		0.08
NG_NJ_L	108.4	0.1042		0.18
NG_NJ_M	109.4	0.0696	4.84	0.13
NG_NJ_U	120.2	0.051		0.09
LS_NJ_L	108.3	0.1042		0.27
LS_NJ_M	116	0.0696	4.84	0.18
LS_NJ_U	134	0.051		0.07

Comparison of Hydraulic conductivity values between material types

From the measured laboratory hydraulic conductivity listed on Table 4.3, one can observe that for the same gradation and percent air voids content, the general trend was that dolomite samples have the highest measured K value and the recycled concrete samples have the least measured K value. However there are a couple of test results where the coefficient of hydraulic conductivity of recycled concrete was higher than that of natural gravel. One likely reason for that deviation from the general trend may be due to testing errors. The variation of hydraulic conductivity values between different material types can be attributed to the

particle shape, texture and void ratio of the various aggregate types.

For both the cement and asphalt treated open-graded specimens, three mix types were prepared and tested. These are designated as Mix_15, Mix_25 and Mix_35 wherein the numbers 15, 25 and 35 represent the design percent air void content of the mixes. As was expected, samples with higher percent air voids content also have higher K values. However, MDOT 5G samples because of its more open-ended nature have higher K values than AASHTO # 67 samples. For the same percent air void content and gradation, the asphalt treated samples have higher K values than the cement treated samples. However, the difference in K values may be largely due to the asphalt samples attaining higher target percent air void contents than the cement treated samples.

VIII. Conclusion

1. The quality of aggregate plays a critical role in defining the hydraulic, mechanical and durability characteristics of both treated and untreated drainage layers. Dolomite which is the superior aggregate of the three aggregates under investigation did produced open-graded samples with better hydraulic properties than the other two aggregate types.
2. From a material perspective, dolomite mixes have the highest K values followed by those of natural gravel and recycled concrete being the least. This difference in K values due to aggregate material type was even noticeable in the asphalt and cement treated samples.
3. Treated permeable samples i.e. both ATPB and CTPB samples have K values far in excess of untreated permeable base samples. However, since both set of samples were made from different gradations, the difference in K values between the two set of samples can be attributed largely to the differences in gradation rather than to the influence of binder. The results may have been completely different if both treated and untreated samples were made from the same gradation types.

IX. References

- [1] American Association of State Highways Transportation Officers (AASHTO) provisional procedure P-125 .Determination of Saturated Hydraulic Conductivity using a Flexwall Permeameter
- [2] American Society for Testing and Materials (ASTM) D5084. Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexwall Permeameter. Annual Book of ASTM Standards, Vol.08.12 2007
- [3] H. R Cedergren. "Drainage of Highway and Airfield Pavements" John Wiley, New York 1974.
- [4] L. A Cooley, Jr., B. D Prowell and E. R Brown. "Issues Pertaining to the Permeability Characteristics of Coarse-Graded Superpave Mixes" National Center for Asphalt Technology, Auburn, AL. 2002
- [5] T, Mayrberger and R. J. Hodek , "Resilient Modulus at the Limits of Gradation and Varying Degrees of Saturation," Final Report Research Report RC-1497. Michigan Department of Transportation, Lansing, MI, 2007.
- [6] N. Smith "Permeability of Pervious Portland Cement Pavement," Master of Science Thesis, Tennessee Technological University, 2004
- [7] R. Tangpithakkul, "Study of Permeability of Base Materials. Master's Thesis, Ohio University, OH. 1997

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