Report No. FHWA-KS-16-15 ▪ FINAL REPORT ▪ October 2016

Determination of Need for Water Soaking Period in Measurement of Concrete Volume of Permeable Voids

Kyle A. Riding, Ph.D., P.E.
Ahmad A. Ghadban, Ph.D.

Kansas State University Transportation Center

Kansas Department of Transportation

1 Report No. FHWA-KS-16-15	2 Government Accession No.	3 Recipient Catalog No.
4 Title and Subtitle Determination of Need for Water Soaking Period in Measurement of Concrete Volume of Permeable Voids		5 Report Date October 2016 6 Performing Organization Code
7 Author(s) Kyle A. Riding, Ph.D., P.E., Ahmad A. Ghadban, Ph.D.		7 Performing Organization Report No.
9 Performing Organization Name and Address Kansas State University Transportation Center Department of Civil Engineering 2118 Fiedler Hall Manhattan, Kansas 66506		10 Work Unit No. (TRAIS) 11 Contract or Grant No. C2091
12 Sponsoring Agency Name and Address Kansas Department of Transportation Bureau of Research 2300 SW Van Buren Topeka, Kansas 66611-1195		13 Type of Report and Period Covered Final Report May 2016–September 2016 14 Sponsoring Agency Code RE-0667-16
15 Supplementary Notes For more information write to address in block 9.		

Water permeability of concrete is one of the key factors concerning many concrete deterioration problems. It is often evaluated indirectly by measuring the volume of permeable voids through the KT-73 (2012) testing procedures. These procedures include a 48-hour water soaking period of the concrete samples. It is desired to omit the step of water soaking in order to simplify the test and reduce the time required to carry it out. In order to examine the significance of the water soaking step, 31 different concrete mixtures were tested with and without the 48-hour water soaking period. A statistical *F*-test was performed on the obtained data and it was concluded that the effect of the water soaking period on the measured volume of permeable voids was statistically insignificant. Therefore, it is recommended to omit the water soaking step from the KT-73 testing procedures.

17 Key Words Volume of Permeable Voids, Water Soaking Period, Concrete Deterioration, Water Permeability		18 Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service www.ntis.gov.	
19 Security Classification (of this report) Unclassified	20 Security Classification (of this page) Unclassified	21 No. of pages 26	22 Price

Form DOT F 1700.7 (8-72)

This page intentionally left blank.

Determination of Need for Water Soaking Period in Measurement of Concrete Volume of Permeable Voids

Final Report

Prepared by

Kyle A. Riding, Ph.D., P.E.
Ahmad A. Ghadban, Ph.D.

Kansas State University Transportation Center

A Report on Research Sponsored by

THE KANSAS DEPARTMENT OF TRANSPORTATION
TOPEKA, KANSAS

and

KANSAS STATE UNIVERSITY TRANSPORTATION CENTER
MANHATTAN, KANSAS

October 2016

NOTICE

The authors and the state of Kansas do not endorse products or manufacturers. Trade and manufacturers names appear herein solely because they are considered essential to the object of this report.

This information is available in alternative accessible formats. To obtain an alternative format, contact the Office of Public Affairs, Kansas Department of Transportation, 700 SW Harrison, 2nd Floor – West Wing, Topeka, Kansas 66603-3745 or phone (785) 296-3585 (Voice) (TDD).

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the views or the policies of the state of Kansas. This report does not constitute a standard, specification or regulation.

Abstract

Water permeability of concrete is one of the key factors concerning many concrete deterioration problems. It is often evaluated indirectly by measuring the volume of permeable voids through the KT-73 (2012) testing procedures. These procedures include a 48-hour water soaking period of the concrete samples. It is desired to omit the step of water soaking in order to simplify the test and reduce the time required to carry it out. In order to examine the significance of the water soaking step, 31 different concrete mixtures were tested with and without the 48-hour water soaking period. A statistical *F*-test was performed on the obtained data and it was concluded that the effect of the water soaking period on the measured volume of permeable voids was statistically insignificant. Therefore, it is recommended to omit the water soaking step from the KT-73 testing procedures.

Acknowledgements

Funding for this project was provided by the Kansas Department of Transportation (KDOT) and is gratefully acknowledged. The work of Hanwen Liu and Koby Daily in helping with concrete mixture preparation and testing is also gratefully acknowledged.

Table of Contents

List of Tables

List of Figures

This page intentionally left blank.

Chapter 1: Introduction

1.1 Research Background

The presence or migration of water in concrete is a necessary and contributing factor in most concrete deterioration problems. A key goal of concrete mixture design and curing is to reduce the concrete water penetrability by reducing the volume and connectivity of concrete pores. The Kansas Department of Transportation (KDOT) helps accomplish this goal by requiring concrete mixtures be designed with either a rapid chloride penetration value of 3,000 Coulombs or less at 56 days as measured by AASHTO T 277 (2015), a surface resistivity value of at least 9 kΩ-cm as measured using KT-79 (2014), or have a volume of permeable voids less than 12.0% at 28 days as measured by KT-73 (2012). Many studies have looked at the effects of different factors on the permeability of concrete. These factors include type (Zhang, Li, Guo, & Chi, 2014; Pereira-de-Oliveira, Nepomuceno, Castro-Gomes, & Vila, 2014), volume fraction, and size of coarse aggregates (Zhang et al., 2014). Some researchers have also studied the effects of the water to cementitious materials ratio, or w/cm (Somna, Jaturapitakkul, Chalee, & Rattanachu, 2012), cementitious materials (Somna et al., 2012; Chen, Kwan, & Jiang, 2014), and gradation of coarse aggregate (Warda & Munaz, 2012) on the permeability of concrete. A similar test to KT-73, AASHTO T 280 (2014), is used to measure the absorption potential of concrete pipe. There are several differences between AASHTO T 280 and KT-73. One of the most prominent differences is that the samples in KT-73 are immersed in water for 48 hours after drying and before boiling, whereas the samples in AASHTO T 280 are not soaked in water for 48 hours between drying and boiling.

1.2 Problem Statement

There is a desire to reduce the time required to perform the volume of permeable voids test and simplify it by omitting the step of soaking the samples in water for 48 hours. A reduction in the time required to measure the concrete volume of permeable voids will decrease the time required to make adjustments to concrete mixtures that are not up to specification and preserve the concrete infrastructure.

1.3 Research Objectives

The research objective of this study is to determine the significance of the 48-hour water soaking period in KT-73 and whether it can be eliminated without affecting the measured value of volume of permeable voids.

1.4 Scope of Research

This study examined the significance of the 48-hour soaking period by performing the volume of permeable voids test for each concrete mixture according to KT-73 with and without the soaking step. Thirty-one different concrete mixtures were examined to determine whether the significance of the soaking step is dependent on the concrete mixture characteristics such as type of coarse aggregates, gradation of coarse aggregates, w/cm, and type of cementitious materials.

Chapter 2: Materials

All concrete mixtures were prepared in the laboratory with varying aggregates, w/cm, and cementitious materials combinations. Table 2.1 shows the materials used in all 31 mixtures. All mixtures used a total cementitious material content of 550 lb/yd^3. The size of each mixture was 0.9 ft^3.

Table 2.1: Tested Concrete Mixtures

Mixture No.	Coarse Aggregate	Coarse Aggregate-to-Fine Aggregate Ratio	w/cm	Class F Fly Ash (%)	Class C Fly Ash (%)	Slag Cement (%)	Silica Fume (%)
1	Granite	0.43	0.4	25	-	-	-
2	Granite	0.43	0.4	-	25	-	-
3	Granite	0.43	0.4	25	-	-	3
4	Granite	0.43	0.4	-	25	-	3
5	Granite	0.43	0.4	-	-	35	3
5a	Granite	0.43	0.4	-	-	-	-
6	Granite	1	0.4	25	-	-	3
7	Granite	1	0.4	-	25	-	3
8	Granite	1.5	0.4	-	-	35	3
9	Limestone	0.67	0.4	-	-	-	-
10	Limestone	0.67	0.5	-	-	-	-
11	Limestone	0.67	0.4	25	-	-	-
12	Limestone	0.67	0.4	-	25	-	-
13	Limestone	0.67	0.5	-	25	-	-
14	Limestone	0.67	0.4	-	-	35	-
15	TMA	0.35	0.4	-	-	-	-
16	TMA	0.35	0.4	25	-	-	-
17	TMA	0.35	0.4	-	25	-	-
18	TMA	1	0.4	-	-	-	-
19	TMA	1	0.5	-	-	-	-
20	TMA	1	0.4	25	-	-	-
21	TMA	1	0.4	-	25	-	-
22	TMA	1	0.5	-	25	-	-
23	Sandstone	0.54	0.4	-	-	-	-
24	Sandstone	0.54	0.4	25	-	-	-
25	Sandstone	0.54	0.4	-	25	-	-
26	Sandstone	0.54	0.4	-	-	35	-
27	Sandstone	1.5	0.4	-	-	-	-
28	Sandstone	1.5	0.4	25	-	-	-
29	Sandstone	1.5	0.4	-	25	-	-
30	Sandstone	1.5	0.4	-	-	35	-

All concrete mixtures contained sand from Midwest Concrete Materials (MCM) in Riley County, Kansas, as their fine aggregate except those containing optimized TMA with fine aggregate from Huber Sand in Finney County, Kansas. All of the granite coarse aggregate was nepehline syenite from Granite Mountain Quarries in Pulaski County, Arkansas. The optimized-gradation granite had a specific gravity of 2.61 and 0.51% absorption and the non-optimized-gradation granite had a specific gravity of 2.54 and 0.44% absorption. The limestone from Bayer Construction Company in Riley County, Kansas, had a specific gravity of 2.61 and absorption of 2.2%. The MCM sand had a specific gravity of 2.63 and absorption of 0.8%. The calcite-cemented sandstone from APAC Kansas in Lincoln County, Kansas, had a specific gravity of 2.66 and absorption of 0.82%. The difference between the optimized and the non-optimized sandstone was the ratio of coarse aggregate to fine aggregate. The optimized TMA contained ¾” rock, $^{1}/_{8}$” rock, sand, and fines. The ¾” rock had a specific gravity of 2.57 and absorption of 0.74% and the $^{1}/_{8}$” rock had a specific gravity of 2.63 and 1.02% absorption. The sand had a specific gravity of 2.67 and 1.01% absorption and the fines had a specific gravity of 2.51 and absorption of 0.98%. The non-optimized TMA from Geary County Sand in Geary County, Kansas, was comprised of Large Well and Small Well sand-gravels. The Large Well had a specific gravity of 2.52 and absorption of 0.66% and the Small Well had a specific gravity of 2.52 and absorption of 1.81%.

Chapter 3: Methodology

Concrete mixing was performed according to ASTM C192 (2016) after determining that all materials were preconditioned to laboratory temperature. Temperature and unit weight were immediately taken following the mixing process. Fresh air content was measured in accordance with ASTM C231 (2014) and slump was measured according to ASTM C143 (2015). After measuring the fresh air content and verifying that it was within the limits of 5% to 8%, nine 4 × 8-inch cylinders were made for each mixture. All cylinders were removed from their molds one day after mixing and placed in the moisture room for curing. For each mixture, three of the cylinders were sent to KDOT to measure surface resistivity at 28 days. Another three cylinders were used to measure volume of permeable voids according to KT-73 (2012). The last three cylinders were used to measure volume of permeable voids using KT-73 while omitting the 48-hour water soaking period.

For each mixture, the six cylinders used for the KT-73 test were all saw-cut (Figure 3.1) to obtain 2-inch-thick discs from each cylinder. The discs were then oven-dried for 2 days to ensure complete drying. Three of the discs were then soaked in water for 48 hours after which all six discs were placed in boiling water for 5 hours on the 28th day as shown in Figure 3.2. The weight of each disc was measured after each step in the process and the equations of KT-73 were used to calculate the volume of permeable voids for each disc. The values presented in the results section are the average of each three cylinders.

Figure 3.1: Saw-Cutting Cylinders

Figure 3.2: Boiling Test Apparatus

A statistical test called the *F*-test was performed on the obtained data using SAS statistical software in order to see the significance of the 48-hour water soaking period on the obtained value of volume of permeable voids. This test works by calculating an *F*-parameter which is the ratio of variation in data among different groups to the variation in data within a certain group. Considering the 48-hour water soaking treatment, the *F*-value compares the ratio of variation between data treated with 48-hour water soaking and data untreated with 48-hour water soaking to the variation between data obtained from the different mixtures while holding the water soaking treatment constant. If the *F*-value is small, the variation due to the particular treatment is not statistically significant and the treatment does not have an impact on the volume of permeable voids. Another important value looked at in this test is the *p*-value, which is the probability that random sampling will result in means as different as those observed in this particular data set, assuming the treatment is indeed not significant. A high *p*-value confirms the treatment is not statistically significant, and a low *p*-value the opposite. A *p*-value below 0.05 is commonly used to show statistical significance of a treatment.

Chapter 4: Results and Discussion

Table 4.1 presents the fresh and hardened outputs for all 31 concrete mixtures.

Table 4.1: Fresh and Hardened Results

Mixture No.	Mixing Date	Temperature (°F)	Unit Weight (lb/ft^3)	Slump (in.)	Fresh Air Content (%)	Volume of Permeable Voids Without 48-hr Soaking (%)	Volume of Permeable Voids With 48-hr Soaking (%)
1	14-Jul-16	72.4	139.88	1	8	11.7	11.2
2	8-Jul-16	71.7	145.8	0	5.4	11.7	10.3
3	14-Jul-16	71.7	140.2	0	7.2	10.1	9.7
4	1-Aug-16	71.6	144.84	0	5	9.8	9.2
5	6-Jul-16	71.3	143.44	0	7.1	10.4	10.3
5a	1-Aug-16	72.2	144.24	0	6	9.1	9.5
6	21-Jul-16	70.1	137.24	7.75	8	12.1	12.7
7	8-Jul-16	73.1	145.36	0	5.1	15.9	14.8
8	20-Jun-16	70.8	145.12	0	5.1	10.6	8.6
9	7-Jul-16	72	146.48	0	5.6	10.9	10.3
10	7-Jul-16	71.7	142.72	3.75	5.8	13.3	13.3
11	13-Jul-16	71.8	144	0.5	6.2	11.8	11.5
12	7-Jul-16	71.9	144.76	1.125	6	11.5	11.4
13	13-Jul-16	71.9	141.48	6	6.4	13.9	14.1
14	7-Jul-16	71.7	142.92	0	5.1	12.0	11.4
15	22-Jul-16	73.3	139.92	0	7.6	10.3	10.3
16	4-Aug-16	72.9	144.04	0	5.8	10.6	8.9
17	5-Aug-16	72	139.6	0	5	10.1	10.3
18	15-Jul-16	72.2	144	0.5	5	11.1	10.9
19	20-Jul-16	69.8	138.68	8	6.8	13.1	16.0
20	22-Jul-16	72.6	141.08	7.5	5.9	12.4	12.3
21	19-Jul-16	71	141.76	1.75	6.3	11.4	11.5
22	19-Jul-16	70.3	141.68	8.5	5	14.3	14.4
23	16-Jun-16	73.5	144	0.5	7	9.9	9.6
24	21-Jul-16	71.4	140.32	1.5	7.7	10.5	10.8
25	12-Jul-16	72.6	146	0	5.2	11.9	12.1
26*	16-Jun-16	73.2	145.96	0.0625	5.6	9.2	8.7
27	16-Jun-16	74	134.24	0.0625	7.9	9.9	9.9
28	20-Jul-16	70.4	142.44	3	5.8	11.3	11.5
29	14-Jul-16	72.2	144.08	2.75	6	11.5	14.8
30	17-Jun-16	74.1	143.88	1.5	6.9	13.0	10.2

Figure 4.1 illustrates the correlation between the volume of permeable voids values with water soaking and the volume of permeable voids values without water soaking. It can be observed that most of the mixtures produced values extremely close to the line of equality, therefore indicating the null effect of the water-soaking step on the measured volume of permeable voids of concrete. A recent study showed that "the expected range of individual 'Boil Test Results' of three tests conducted in a single laboratory should not be more than 6% of the average of the three samples" (Montney & Barker, 2015). Twenty-three of the 31 mixtures (or 74%) showed the average of three boil results with the 48-hour soak period to be within 6% of the average of three boil results without the 48-hour soak period.

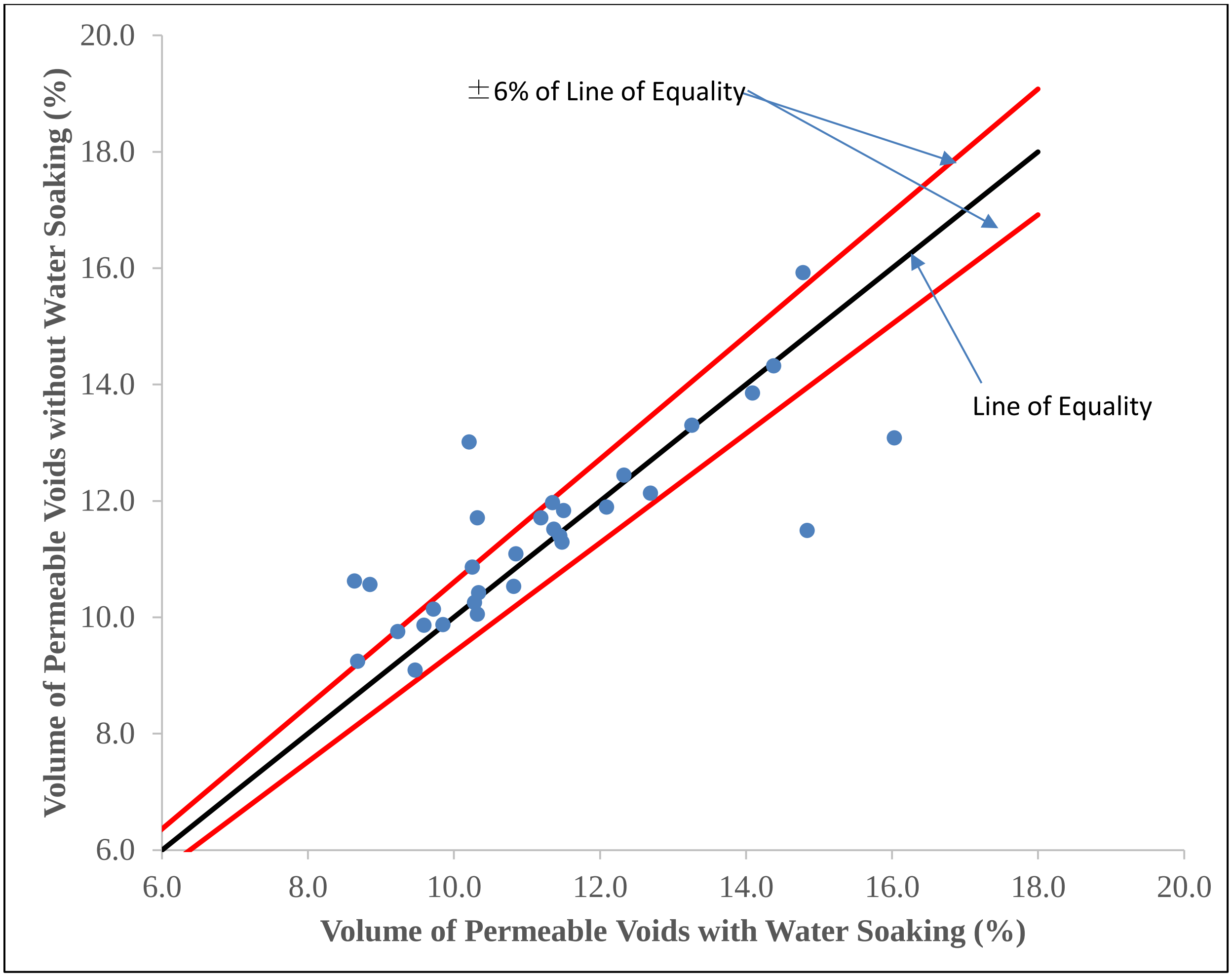

Figure 4.1: Volume of Permeable Voids With and Without Water Soaking

In order to statistically determine the significance of the effects of all factors on the volume of permeable voids, an *F*-test was performed on the data. Table 4.2 shows the *F*-values and *p*-values associated with the main effects of each factor while averaging over the other factors. It also shows the *F*-values and *p*-values associated with the two-way interaction effects between water soaking and every other factor. Higher multi-way interaction effects could not be evaluated due to the lack of a full or partial factorial in the testing matrix. Keeping in mind that a *p*-value less than 0.05 is an indication of significance, it is evident from Table 4.2 that the effect of water soaking on volume of permeable voids is not statistically significant even when studied in two-way interactions with every other factor. It is also interesting to point out the insignificance of the effect of the coarse aggregate type on the volume of permeable voids. On the other hand, w/cm, aggregate gradation, and cementitious material may have significant effects on the volume of permeable voids. It was expected that w/cm and cementitious material would have a significant effect on the volume of permeable voids because low w/cm and the addition of supplementary cementitious materials are known to refine the concrete pore structure.

Table 4.2: *F*-Test Results

Factor	***F*-value**	***p*-value**
Coarse Aggregate Type	1.35	0.2903
w/cm	26.42	<.0001
Aggregate Gradation	10.88	0.004
Cementitious Material	4.31	0.0058
48-hr Water Soaking	0.00	0.9919
Coarse Aggregate Type x 48-hr Water Soaking	0.42	0.7439
w/cm x 48-hr Water Soaking	1.09	0.3105
Aggregate Gradation x 48-hr Water Soaking	0.23	0.6364
Composition x 48-hr Water Soaking	0.81	0.5874

Chapter 5: Conclusions and Recommendations

5.1 Conclusions

The impact of the 48-hour water soaking period used in the KT-73 test on the measured volume of permeable voids in concrete was studied in this research project. The volume of permeable voids was measured with and without water soaking for 31 different concrete mixtures. It was concluded through a statistical *F*-test that, accounting for all other factors, the effect of water soaking on the volume of permeable voids is statistically insignificant with a high *p*-value of 0.9919. The same conclusion held even when two-way interactions between water soaking and every other factor were considered. Studying more than two-way interactions was inapplicable due to the lack of a complete factorial or at least a partial factorial in the testing matrix.

5.2 Implementation Recommendations

Based on the results obtained in this study, it is recommended to omit the 48-hour water soaking period from the KT-73 testing procedures as it does not significantly affect the measured value of the volume of permeable voids of concrete.

References

AASHTO T 277-15. (2015). *Electrical indication of concrete's ability to resist chloride ion penetration (ASTM C 1202-12)*. Washington, DC: American Association of State Highway and Transportation Officials.

AASHTO T 280-14. (2014). *Standard method of test for concrete pipe, manhole sections, or tile (ASTM C 497-13)*. Washington, DC: American Association of State Highway and Transportation Officials.

ASTM C143 / C143M-15a. (2015). *Standard test method for slump of hydraulic-cement concrete*. West Conshohocken, PA: ASTM International. doi: 10.1520/C0143_C0143M-15A, www.astm.org

ASTM C192 / C192M-16a. (2016). *Standard practice for making and curing concrete test specimens in the laboratory*. West Conshohocken, PA: ASTM International. doi: 10.1520/C0192_C0192M-16A, www.astm.org

ASTM C231 / C231M-14. (2014). *Standard test method for air content of freshly mixed concrete by the pressure method*. West Conshohocken, PA: ASTM International. doi: 10.1520/C0231_C0231M-14, www.astm.org

Chen, J.J., Kwan, A.K.H., & Jiang, Y. (2014). Adding limestone fines as cement paste replacement to reduce water permeability and sorptivity of concrete. *Construction and Building Materials, 56*, 87–93.

KT-73 Kansas Test Method. (2012). Density, absorption and voids in hardened concrete. *Kansas Department of Transportation construction manual, Part V*. Topeka, KS: Kansas Department of Transportation.

KT-79 Kansas Test Method. (2014). Surface resistivity indication of concrete's ability to resist chloride ion penetration. *Kansas Department of Transportation construction manual, Part V*. Topeka, KS: Kansas Department of Transportation.

Montney, R.A., & Barker, S.F. (2015). *Evaluation of repeatability of Kansas Test Method KT-73, "Density, absorption and voids in hardened concrete," boil test* (Report No. KS-15-04). Topeka, KS: Kansas Department of Transportation.

Pereira-de-Oliveira, L.A., Nepomuceno, M.C.S., Castro-Gomes, J.P., & Vila, M.F.C. (2014). Permeability properties of self-compacting concrete with coarse recycled aggregates. *Construction and Building Materials*, *51*, 113–120.

Somna, R., Jaturapitakkul, C., Chalee, W., & Rattanachu, P. (2012). Effect of the water to binder ratio and ground fly ash on properties of recycled aggregate concrete. *Journal of Materials in Civil Engineering*, *24*(1), 16–22.

Warda, B.A., & Munaz, A.N. (2012). Effects of aggregate gradation on water permeability of concrete. *Advanced Materials Research*, *488–489*, 248–252.

Zhang, F., Li, N., Guo, M., & Chi, X. (2014). Coarse aggregate effects on compressive strength and permeability coefficient of non-fine concrete. *Electronic Journal of Geotechnical Engineering*, *19*, 8905–8913.


AD ASTRA PER ASPERA
Kansas
Department of Transportation