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FINAL REPORT

# MULTI-STATE ANALYSIS OF THE SOUNDNESS TEST OF AGGREGATES BY FREEZING AND THAWING

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JANUARY 2007

**KANSAS DEPARTMENT OF TRANSPORTATION**

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**16 Abstract**

Soundness is one of the basis for acceptance for aggregates used by most state departments of transportation. AASHTO provides two test procedures for determining the soundness of aggregates. T-103 determines the freeze-thaw soundness and T-104 determines the sodium or magnesium sulfate soundness of aggregates. Fewer than 10 states utilize the freeze-thaw soundness test, and most of the states that use it have made some modifications to T-103. Four Midwestern states (Iowa, Missouri, Nebraska, and Ohio) were requested to attempt to conduct the freeze-thaw soundness test using Kansas' modifications. Each state received limestone aggregate from the same source in Kansas. These states were also requested to test the aggregate using their own variations of T-103. Ohio tested the material using T-104. Each state found it difficult to exactly duplicate the Kansas test method due to equipment and scheduling constraints. The necessary deviations are taken into account during the evaluation of the data obtained in this round robin.


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**Final Report**

Prepared by

Rodney A. Montney, P.E.

A Report on Research Sponsored By

THE KANSAS DEPARTMENT OF TRANSPORTATION
TOPEKA, KANSAS

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## Executive Summary

Aggregate was sampled from a Kansas Limestone quarry to be distributed to 5 other states for comparison testing of the Soundness Test Method. Four of the other states participated in this Soundness Round Robin. A fifth state was sent aggregate, but did not submit test results. Missouri, Nebraska, and Ohio were each given three samples. Each of these states tested two of the samples according to KDOT's test procedure and one sample according to their own freeze-thaw or Soundness procedure. **Appendix A** was sent to each state as a guideline to the Kansas Test Method. The attachment is an abbreviated version of the KDOT Method KT-MR-21, which is a modified procedure based on AASHTO T-103 Soundness of Aggregates by Freezing and Thawing. All the samples were prepared at KDOT's Central Laboratory in Topeka, KS.

Iowa's test procedure is very similar to the Kansas test procedure, and they have two freezers. Iowa agreed to run two samples in each of their freezers (total four samples) with different cycle times set for each freezer. Missouri, Nebraska, and Ohio's routine test procedures vary more from the Kansas test procedure than does Iowa's.

# ACKNOWLEDGEMENT

The Kansas Department of Transportation (KDOT) would like to thank the laboratory staffs from the Iowa, Missouri, Nebraska, and Ohio State Highway Agencies for their participation in this study.

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# BACKGROUND

A small minority of the Aggregate Producers in the state of Kansas have expressed concerns that new freezer equipment installed at the Central Materials Laboratory in Topeka may be causing their aggregates to fail the Freeze Thaw Soundness Test (KT-MR-21). These failing samples were in the new freezer at the same time that any number of passing samples were being tested. The new freezer was installed in 2002. It is comparable to the old freezer in that it meets the requirements of KT-MR-21; it freezes within the same time limits, and it reaches the same low temperature as the old freezer. In order to address the Aggregate Producers concerns, KDOT agreed to find other states that conduct similar freeze thaw tests and request their participation in a round robin.

Five states participated in the Soundness Round Robin; Iowa, Kansas, Missouri, Nebraska, and Ohio. A sixth state initially agreed to participate, but withdrew. The aggregate chosen for the round robin was sampled by personnel from KDOT's Central Materials Laboratory in Topeka. The Aggregate Producer was asked to provide an aggregate from a recent Official Quality. The soundness value on the Official Quality was 85, which is the lower limit for KDOT's Aggregate Base specifications. This aggregate was specifically chosen due to the marginal test results for soundness. The test results from all the states that participated in the round robin indicate that the soundness of the aggregate provided was some what lower than the quality requested. **Appendix B** shows a summary of the data collected from each state.

Eighteen samples meeting Grading Designation I was prepared at the Central Laboratory. There was still some aggregate left over, so two additional samples meeting Grading Designation II were prepared for testing by KDOT. The total mass of each sample was 5000 grams. All the samples suffered degradation during the shipping process, even the Kansas samples.

Missouri, Nebraska, and Ohio were each sent three samples. Each of these states tested two of the samples according to KDOT's test procedure and one sample according to their own test procedure. One of Iowa test methods is very similar to the Kansas test procedure. Iowa has two freezers and agreed to test four samples. **Appendix A** was sent to each state as a guideline to the Kansas Test Method.

**TABLE 1: Soundness Grading Requirements from KT-MR-21**

| Grading Designation | Cumulative Mass Retained (grams) Individual Square Mesh Sieves | | | | |
|---|---|---|---|---|---|
| | 25.0 mm (1 in) | 19.0 mm (3/4 in) | 9.5 mm (3/8 in) | 4.75 mm (No. 4) | 2.36 mm (No. 8) |
| I | 0 | 2250 | 1750 | 500 | 500 |
| II | … | 0 | 3500 | 1000 | 500 |
| III | … | … | 0 | 4000 | 1000 |

I-buttons were sent to each state with the samples to monitor the temperature of the aggregate during testing. They were placed in the center of the aggregate mass as the aggregate was subjected to the KDOT test procedure in each state. I-buttons were not used in the samples subjected to the individual states' freeze-thaw procedure. The I-buttons recorded the temperature at pre-specified intervals. Due to the timing of the testing, temperature data was not collected for all cycles of testing at some of the laboratories. However, the I-buttons do provide a representative look at the interior aggregate temperature during the testing. The I-button data is in **Appendix C**.

All the states made an extra effort to perform the testing as requested, however, each state had to modify the test method that was sent to them. Kansas uses a propylene glycol bath as the freezing medium for this test. The containers are placed in the propylene glycol and it does not touch the aggregate during the freeze cycle. All the other states freeze in air. Most of the states had to modify the cycle times in order to not interrupt their normal production testing. Another modification the states had to make was the size and shape of the sample container. The other states were able to modify their test procedure enough to thaw in water-only, instead of the alcohol-water solution that most of them routinely use.

None of the states that participated in the Round Robin have temperature requirements on the aggregate itself. Every state, including Kansas, places the temperature requirements on the equipment. The freezer chambers and thaw tanks shall maintain certain temperature ranges during the testing. The I-buttons indicated that some of the interior aggregate did not achieve the same temperature as the freezer and/or the thaw tank chambers.

# DISCUSSION

The Kansas Test Method is comparable to the actual test methods utilized by the other states participating in the round robin. This Aggregate would not have passed any one of the states' requirements when subjected to each state's freeze-thaw or Soundness procedures. Table 2 shows the Soundness when subjected to each state's procedures. The Ohio Sodium Sulfate Soundness test method is similar to AASHTO T-104 Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate. Ohio also conducts Freeze-Thaw Soundness tests according to AASHTO T-103. Nebraska and Missouri both use 0.5% methyl alcohol-water solution in their thaw tanks. Both states leave a measured amount of the alcohol-water solution in the container with the aggregated during the freeze cycle. Nebraska subjects the immersed sample to a vacuum prior to the first cycle. Missouri and Nebraska routinely run 16 freeze-thaw cycles. The Nebraska and Missouri test procedures have fewer modifications from AASHTO T-103 than the KDOT Procedure.

**TABLE 2:**

| Testing State | Soundness | Notes |
|---|---|---|
| Nebraska | 48 | 0.5% methyl alcohol w/vacuum |
| Kansas | 48 | Gradation II |
| Kansas | 51 | Gradation II |
| Kansas | 55 | Gradation I |
| Kansas | 56 | Gradation I |
| Ohio | 56 | Subjected to Sodium Sulfate |
| Missouri | 60 | 0.5% methyl alcohol |
| Iowa | 64 | Method C |
| Iowa | 66 | Method C |

Iowa's test method "A" is similar to Missouri's and Nebraska's methods, and AASHTO T-103. Method "A" vacuum saturates the sample in water. Method "A" uses 0.5% methyl alcohol-water solution as the thawing medium, leaves a measured amount of alcohol-water solution in the container during freezing, and requires 16 freeze-thaw cycles. Iowa also has a Method "C" that utilizes water-only as the thawing medium and requires 25 cycles. Iowa has two automated freezers and requested 4 samples to test according to Method "C", which is comparable to the Kansas test method.

Iowa samples 1 and 7 were tested in a different freezer than samples 13 and 18. The Soundness values for Samples 1 and 7 were 73 and 68 respectively. The freezer for samples 13 and 18 was programmed to uniform cycle times (total cycle 4 hours). The freezer for samples 1 and 7 was programmed to trigger off of temperature and cycled when the freezer temperatures reached specified levels ($-10^{o}$ to $-20^{o}$ F). The Iowa test method requires only 2500 grams of material. Their freezers yield satisfactory results when testing 2500 gram samples. The 5000 grams may have been too much material for their sample pans and may have provided an insulating effect for the I-buttons. The interior aggregate may not have been getting frozen during the 1 hour freeze cycle that samples 1 and 7 were subjected to, even though the freezer temperature had dipped below $-10^{o}$ F. I-button data indicates that samples 1 and 7 each had an average freeze temperature of $30^{o}$ F. I-buttons from samples 13 and 18, which were in the freezers over 2.5 hours per cycle instead of 1 hour, had average freeze temperatures of $-11^{o}$ and $-10^{o}$ F. The Soundness values for samples 13 and 18 were 66 and 64 respectively. Iowa has conducted additional I-button testing and has confirmed that the interior aggregate is achieving temperatures between -10$^o$ and -20$^o$ F when testing 2500 grams and keying off of temperature to determine the freeze cycle times.

The two states with the highest Soundness values, Missouri and Ohio, were also the two states with the longest cycle times. Missouri ran one 6 ½ hour freeze cycle each day and one 15 ½ hour freeze cycle each night. Ohio averaged fewer than two 3 hour freeze cycles each day and had 13 overnight freeze cycles that averaged more than 16 hours per cycle. During the daytime cycles the I- buttons in the aggregate tested by Missouri rarely achieved temperatures below 20$^o$ F. The I-buttons in the aggregate tested by Ohio never achieved temperatures below 30$^o$ F during the daytime cycles. The Ohio freeze-thaw test procedure routinely uses 1000 gram or 1500 gram samples, depending on the aggregate gradation. The Missouri test procedure routinely uses 2500 gram samples. The 5000 gram samples provided by KDOT may have had the same insulating effect on the I-buttons provided to Missouri and Ohio that Iowa experienced.

I-button data indicates that the aggregate samples with the lower Soundness values took less time to go from the thawed temperature down to 0$^o$ F than the samples with the higher Soundness values. The Iowa I-buttons 13 and 18 took about 2 hours to reach 0$^o$ F when the aggregate was placed in the freezer. The Nebraska I-buttons 4 and 10 reached 0$^o$ F within 1 hour and 10 minutes of the aggregate being placed in the freezer. The Kansas I-buttons 2 and 8 reached 0$^o$ F within 1 hour and 50 minutes. The Ohio I-buttons took over 9 hours and the Missouri I-buttons took over 13 hours to reach 0$^o$ F. The Missouri and Ohio I-buttons each took over 2 hours to reach 32$^o$ F after the aggregate was placed in the freezer. The I-buttons in the other three states' freezers were already at 0$^o$ F by that time. This could have a reflection on the Soundness values. The data indicates that aggregate that does not routinely reach the "frozen solid state" (below 0$^o$ F) has a much higher Soundness than the aggregates that do not reach the "fully thawed" state (above 40$^o$ F). The Missouri and Ohio freezers were set at 0$^o$ F. The Iowa, Kansas, and Nebraska freezers were set at -15$^o$ F to -24$^o$ F.

One of the problems in comparing Freeze-Thaw Soundness test results is that AASHTO T-103 does not have a precision statement. It is not the purpose of this study to develop a precision statement. There are too many deviations between the states and not enough data was collected. However, since the test method involves determining the gradation, perhaps some type of implied precision may be derived from AASHTO T-27 Sieve Analysis of Fine and Coarse Aggregate.

Table 3 includes part of the Multilaboratory precision statement from AASHTO T-27. The gradation of the sample is determined twice during the Freeze-Thaw Soundness test. The acceptable range of two test results for each sieve is dependant on the total percentage of material passing that particular sieve. The allowable range is expressed as a percent of the average, percent passing or retained, between the two laboratories. The nature of this test causes less material to be retained on each sieve during the second sieving operation than the first. Therefore the same sieve would have a different acceptable range for each sieving operation. It was assumed that the total error would have some accumulative effect, but would not be additive. An average of the acceptable ranges for the two gradings was used to determine this implied precision statement. The development of this implied precision statement can be found in **Appendix D.**

**TABLE 3: Multilaboratory Precision from AASHTO T-27**

| Total % Material Passing | Coefficient of Variation (1S%) | Acceptable Range of 2 Test Results (D2S%) |
|---|---|---|
| < 85 ≥ 80 | 1.92 | 5.4 |
| <80 ≥ 60 | 2.82 | 8.0 |
| <60 ≥ 20 | 1.97 | 5.6 |
| <20 ≥ 15 | 1.60 | 4.5 |
| <15 ≥ 10 | 1.48 | 4.2 |
| <10 ≥ 5 | 1.22 | 3.4 |
| <5 ≥ 2 | 1.04 | 3.0 |
| <2 ≥ 0 | 0.45 | 1.3 |

Figure 1 shows a graphical representation of the implied precision statement for the freeze thaw data that was collected from this Round Robin. The Soundness value is dependent on the difference between the two gradations conducted during the evaluation of the material. The greater the difference between the two gradations, then the lower the Soundness value. As the difference between the two gradations changes, so do the acceptable range of test results. Therefore it makes since that the precision of the test procedure would change as the Soundness values change. The acceptable range of test results increases as the Soundness value decreases because the difference between the two gradations increases.

Two additional points were added to the data. One of the additional points was derived from the data from the original Official Quality. The Soundness of the Official Quality was 85. The other data point was the theoretical allowable range for a

Soundness value of 100. The allowable range for a Soundness value of 100 under this implied precision exercise is 4.6.

Figure 2 shows a graphical representation of the implied precision statement for the 6 samples that contained I-buttons that routinely achieved a temperature below $0^o$ F during the freeze cycle. Data for Soundness values of 85 and 100 were also added to this graph. The predictive power of the second model ($R^2$) is slightly better than the first. The second graph eliminates some of the variability introduced by the variations in cycle times and temperatures.

The average Soundness for sample numbers 2, 4, 8, 10, 13, and 18 is 60.8 or 61. Based on the equation provided in Figure 2 the acceptable range of test results for a Soundness of 61 is 8.9. The actual range of values for sample numbers 2, 4, 8, 10, 13, and 18 is 11. This implied precision is based only on the variability introduced during the grading of the aggregates. The other equipment such as freezers and thaw tanks, and procedures such as cycle times would contribute additional variability that at this time cannot be quantified. Therefore it is reasonable to assume that the data from these 6 samples is acceptable and within any range of allowable values for their average Soundness.

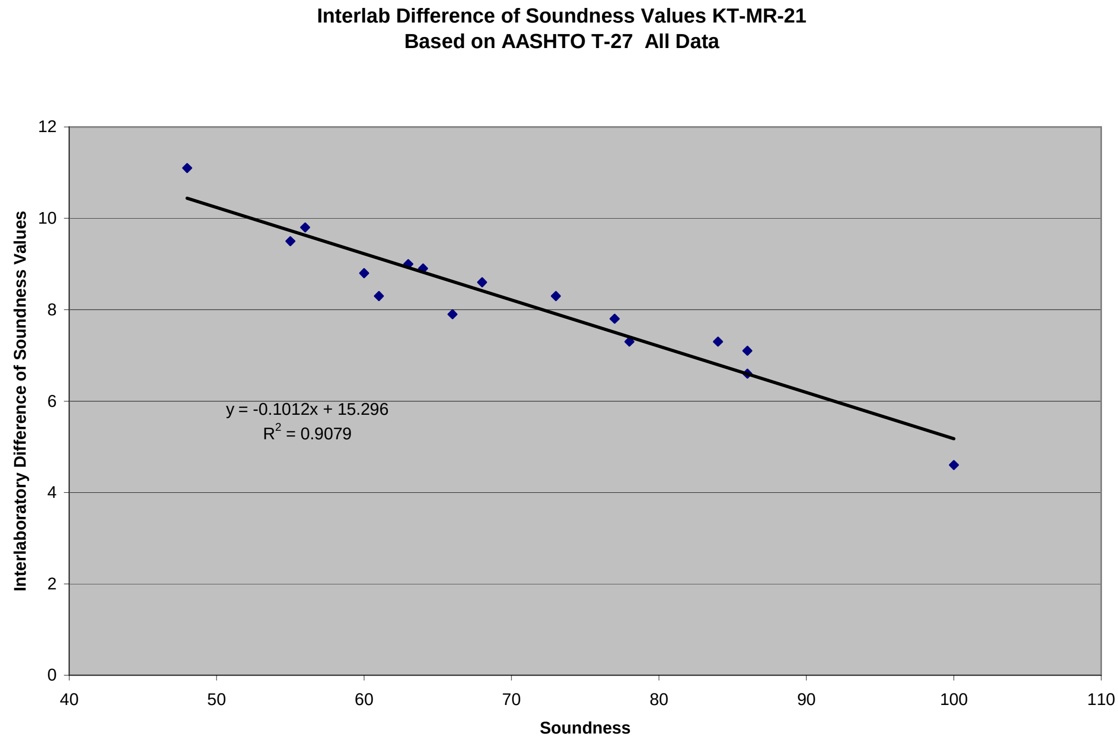



**FIGURE 1**

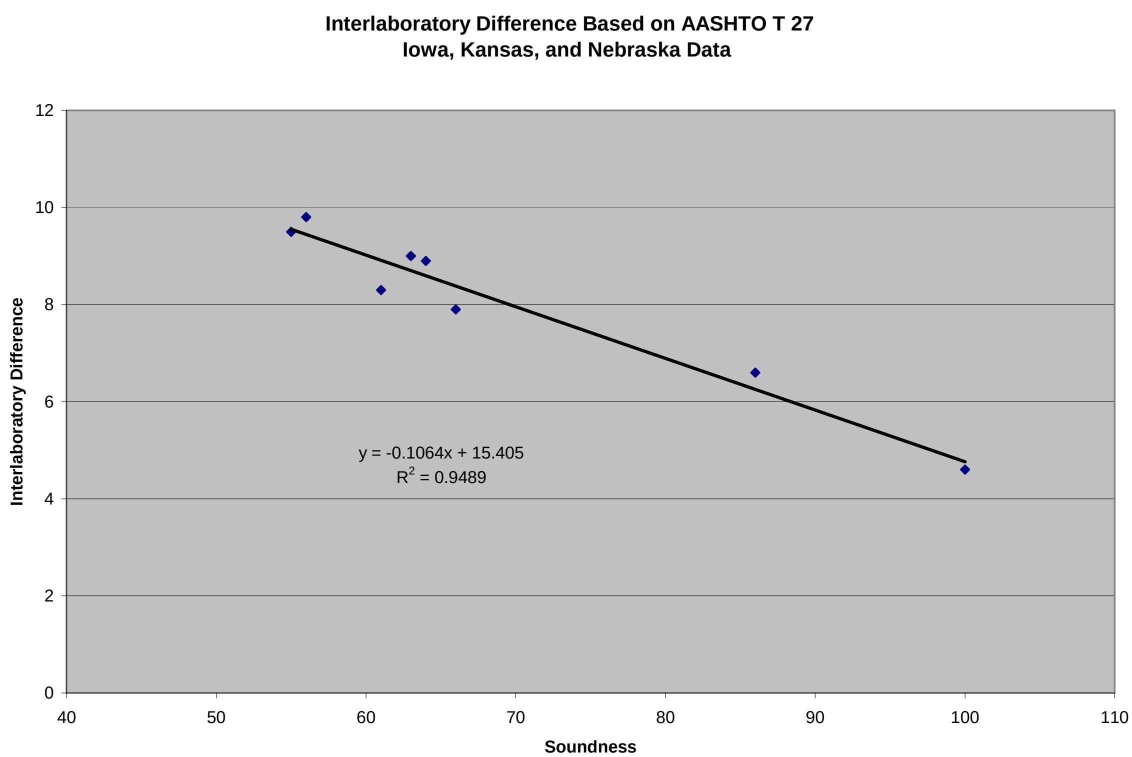



**FIGURE 2**

The Soundness values for Gradation II are slightly lower than the Soundness values for Gradation I. KDOT has noticed this trend in previous Soundness Studies. No explanation is available as to why Gradation II tends to have a lower Soundness value than Gradation I.

## CONCLUSIONS

1. The propylene glycol that KDOT places the sample containers in during the freeze cycle is a suitable substitute for the alcohol-water solution used by some of the other states, and specified in AASHTO T-103, as the thawing medium. KDOT's test results were very comparable to those states that more closely follow T-103.

2. The temperature at which the aggregate is frozen is critical when evaluating aggregate Soundness by the Freeze-Thaw Method. The internal aggregate must routinely achieve a temperature below 0° F for the test procedure to have any repeatability of results.

3. Cycle time may also be critical, although the samples with the longest cycle times did not routinely achieve a temperature below 0° F. One hour is not enough time for the internal aggregate in a 5000 gram sample to achieve a temperature below 0° F.

4. Size of the sample is also critical. Some of the states that are successful in testing 2500 gram or lighter samples with their test equipment and cycle times were not able to repeat KDOT's results with the 5000 gram samples that were provided.

5. The within laboratory repeatability of the Freeze-Thaw Soundness test method is very good. The average difference between the two samples tested in each laboratory was less than 3.

6. The between laboratory repeatability of the Freeze-Thaw Soundness test method is not available. However the data collected in this round robin from the 6 samples from the tests that more closely followed KTMR21 appears to be within any implied range of allowable values when differences in equipment such freezers and thaw tank temperatures, and cycle times are taken into consideration.

## ADDITIONAL COMMENTS

AASHTO has recommended several changes to T-103-2004. The proposed procedure will no longer thaw the aggregate in water. The aggregate will thaw in the same apparatus in which it is frozen (a Freeze Thaw apparatus). AASHTO is proposing the use of temperature measuring devices to assure the center of the aggregate is held in a frozen state at -9$^{o}$ F for a minimum of 2 hours and thawed for 30 minutes at 70$^{o}$ F. The proposed procedure also allows the use of a 3% NaCl and water solution in place of the alcohol and water mixture. The required number of cycles will become 25 instead of the current 50, 16, and 25 cycle options. The proposed changes have been approved by the Technical Section and will be sent to the full Subcommittee on Materials for approval.

All of the states that participated in the Round Robin thaw the aggregate in water. None of the states have temperature requirements on the aggregate itself. Every state, including Kansas, places the temperature requirements on the equipment.

The freezer chambers and thaw tanks shall maintain certain temperature ranges during the testing. Although none of the participating states use the NaCl, there are at least 3 states that do. These three states were not asked to participate in the Round Robin because of this added variable.

It is very unlikely that KDOT will adopt any of the changes to AASHTO T-103. KT-MR-21 has always varied from the AASHTO procedure. One of the major deviations between T-103 and KT-MR-21 is the beginning gradations of the aggregate samples, and the sieves used to determine the final loss of aggregate during testing. Partial changes in the KDOT procedure without full implementation of T-103 would not be practical. To introduce change now would cause a complete loss of compatibility with historical data.

# RESOURCES


2002 Construction and Material Specifications, *Ohio Department of Transportation.* Section 703 Aggregates.  Columbus, Ohio.  2002

Method of Test for Determining the Soundness of Coarse Aggregate by Freezing and Thawing.  *Iowa Department of Transportation.* Iowa 211-B.  Ames, Iowa.  2000

Sieve Analysis of Fine and Coarse Aggregates, *American Association of State Highway and Transportation Officials*, AASHTO T-27-06, Washington, D.C. 2006

Soundness of Aggregates by Freezing and Thawing.  *American Association of State Highway and Transportation Officials.* AASHTO T-103-91 (2004). Washington D.C. 2006

Soundness of Aggregates by Freezing and Thawing.  *American Association of State Highway and Transportation Officials.* AASHTO T-103-91 (2006). Washington D.C. 2006

Soundness of Aggregates by Freezing and Thawing.  *Nebraska Department of Roads.* NDR T 103.  Lincoln, Nebraska. 1992

Soundness and Modified Soundness of Aggregate by Freezing and Thawing. *Kansas Department of Transportation.*  KT-MR-21. Topeka, Kansas. 1999

Soundness Test of Coarse Aggregate Water-Alcohol Freeze Method.  *Missouri Department of Transportation.*  MoDOT T14.  Jefferson City, Missouri.  2000

# APPENDIX A

## KTMR-21 SOUNDNESS & MODIFIED SOUNDNESS OF AGGREGATES BY FREEZING AND THAWING (Revised for Multi-State Round Robin)

### SCOPE

This test method covers the procedures for the determination of aggregate resistance to disintegration by freezing and thawing.

### REFERENCED DOCUMENTS

AASHTO M 92; Wire-Cloth Sieves for Testing Purposes

AASHTO M 231; Balances Used in the Testing of Materials

AASHTO T 103; Soundness of Aggregates by Freezing and Thawing

### APPARATUS

A freezing tank capable of maintaining a uniform temperature between -32.2 to -17.7°C (-20 to 0°F).

Sieves shall conform to the requirements of AASHTO M 92.

A balance of sufficient capacity, be readable to 0.1% of the sample mass, or better, conforming to the requirements of AASHTO M 231.

The drying oven shall provide a free circulation of air through the oven and shall be capable of maintaining a temperature of 110 ± 5°C (230 ± 9°F).

A thawing tank of suitable size to hold the samples and containers, allowing total submersion of the samples. The water shall be maintained at 21-27°C (70-80°F) during the thaw period.

Kansas Dept of Transportation furnished I-Buttons for monitoring the temperature of the aggregate during testing.

### PROCEDURE

Dry the sample and cool to room temperature. Screen over the 25.0, 19.0, 9.5, 4.75, and 2.36 mm (1 in, 3/4 in, 3/8 in, No. 4, and No. 8) sieves and record the cumulative mass retained on each sieve.

The material shall be placed in an open top container. Place the i-button near the center of the sample in the container.

Soak the aggregate in tap water maintained at a temperature from 21-27$^{o}$C (70-80$^{o}$F) for a period of 24 $\pm$ 4 hours.

Remove sample from the water and drain the water from the sample. While in a saturated and drained condition place the sample and container in the freezing equipment that maintains a temperature between -29 and -18$^{o}$C (-20 and 0$^{o}$F). The sample remains in the freezing equipment until frozen, but in no case shall this period of time be less than two hours. During any interruptions (nights, weekends, and holidays) the samples remain in the freezer.

Remove sample from the freezer and place in a tap water bath maintained at 21-27$^{o}$C (70-80$^{o}$F) for a minimum period of 40 minutes.

One freezing period and one thawing period shall be considered one cycle. Always drain the thaw water from the container before freezing.

At the end of 25 cycles, remove the I-buttons from the aggregate, oven dry samples to a constant mass at a temperature of 110 $\pm$ 5$^{o}$C (230 $\pm$ 9$^{o}$F), cool to room temperature and screen over the 25.0, 19.0, 9.5, 4.75, and 2.36 mm (1 in, 3/4 in, 3/8 in, No. 4, and No. 8) sieves and record the cumulative mass retained on each sieve.

## APPENDIX B

| | | Data Obtained From the I-Buttons | | | | | | | | Data Provided by Participating Laboratories | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sample Number** | **Soundness** | **High Thaw Temp** | **Low Thaw Temp** | **Avg. Thaw Temp** | **High Freeze Temp** | **Low Freeze Temp** | **Avg. Freeze Temp** | **Avg. Time from Thawed to 0 ° F** | **Avg. Time from Thawed to 32 ° F** | **Average Daytime Cycle** | **Freezer Temperature** | **Thaw Tank Temperature** | **Container Dimensions** |
| Iowa 1 | **73** | 71.6 | 61.7 | 69.3 | 31.1 | 20.3 | 29.8 | N/A | | 1 Hour Freeze 30 Minutes Thaw | -20 ° F | 72 ° F | 12" L X 7" W X 4" D |
| Kansas 2 | **55** | 75.2 | 29.3 | 57.0 | 16.7 | -13.9 | -3.1 | 1 hours 52 minutes | | 2 Hours Freeze 40 minutes Thaw | -15 ° F | 72 ° F | 4 1/2" Diameter by 22" high Cylinder |
| Missouri 3 | **78** | 72.5 | 46.4 | 64.2 | 28.4 | -0.4 | 10.1 | 13 hours 48 minutes | 2 hours 6 minutes | 6 1/2 Hours Freeze 1 Hour Thaw | 0 ° F | 74 ° F | Round Pans 10 1/2" at Top, 8 1/2" at Bottom, 3 1/2" deep |
| Nebraska 4 | **63** | 75.2 | 63.5 | 68.3 | 29.3 | -26.5 | -0.9 | 1 hour 12 minutes | | 1 1/2 Hours Freeze 30 Minutes Thaw | -24 ° F | 76 ° F | 7 3/4" X 22" X 2" |
| Ohio 5 | **86** | 83.3 | 66.2 | 69.4 | 31.1 | -5.8 | 13.1 | 9 hours 40 minutes | 2 hours 25 minutes | N/A | 0 ° F | 70 ° F | 6" Diameter by 12" high Cylinder |
| Iowa 7 | **68** | 72.5 | 68.9 | 70.3 | 31.1 | 18.5 | 29.9 | N/A | | 1 Hour Freeze 30 Minutes Thaw | -20 ° F | 72 ° F | 12" L X 7" W X 4" D |
| Kansas 8 | **56** | 75.2 | 30.2 | 55.6 | 9.5 | -16.6 | -4.1 | 1 hours 52 minutes | | 2 Hours Freeze 40 minutes Thaw | -15 ° F | 72 ° F | 4 1/2" Diameter by 22" high Cylinder |

## APPENDIX B (Cont)

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Missouri 9 | **77** | 73.4 | 35.6 | 61.9 | 31.1 | -0.4 | 12.2 | 13 hours 48 minutes | 2 hours 6 minutes | 6 1/2 Hours Freeze 1 Hour Thaw | 0 $^{0}$ F | 74 $^{0}$ F | Round Pans 10 1/2" at Top, 8 1/2" at Bottom, 3 1/2" deep |
| Nebraska 10 | **61** | 78.8 | 60.8 | 69.6 | 23.0 | -25.6 | -6.6 | 1 hour 12 minutes | | 1 1/2 Hours Freeze 30 Minutes Thaw | -24 $^{0}$ F | 76 $^{0}$ F | 7 3/4" X 22" X 2" |
| Ohio 11 | **84** | 84.2 | 64.4 | 69.6 | 32.0 | -4.9 | 16.2 | 9 hours 40 minutes | 2 hours 25 minutes | N/A | 0 $^{0}$ F | 70 $^{0}$ F | 6" Diameter by 12" high Cylinder |
| Iowa 13 | **66** | 76.1 | 60.8 | 72.8 | -7.6 | -13.9 | -11.1 | 2 hours | | 2 3/4 Hours Freeze 1 1/4 Hours Thaw | -20 $^{0}$ F | 77.7 $^{0}$ F | 12" L X 7" W X 4" D |
| Missouri 14 | **60 (1)** | N/A | N/A | N/A | N/A | N/A | N/A | N/A | | 6 1/2 Hours Freeze 1 Hour Thaw | 0 $^{0}$ F | 74 $^{0}$ F | Round Pans 10 1/2" at Top, 8 1/2" at Bottom, 3 1/2" deep |
| Nebraska 15 | **48 (1)(2)** | N/A | N/A | N/A | N/A | N/A | N/A | N/A | | 1 1/2 Hours Freeze 30 Minutes Thaw | -24 $^{0}$ F | 76 $^{0}$ F | 7 3/4" X 22" X 2" |
| Ohio 16 | **56 (3)** | N/A | N/A | N/A | N/A | N/A | N/A | N/A | | N/A | N/A | N/A | N/A |
| Iowa 18 | **64** | 77.0 | 69.8 | 74.6 | -5.8 | -12.1 | -10.0 | 2 hours | | 2 3/4 Hours Freeze 1 1/4 Hours Thaw | -20 $^{0}$ F | 77.7 $^{0}$ F | 12" L X 7" W X 4" D |

## APPENDIX B (Cont)

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Kansas 19 | **48 (4)** | N/A | N/A | N/A | N/A | N/A | N/A | N/A | | 2 Hours Freeze 40 minutes Thaw | -15 $^0$ F | 72 $^0$ F | 4 1/2" Diameter by 22" high Cylinder |
| Kansas 20 | **51 (4)** | N/A | N/A | N/A | N/A | N/A | N/A | N/A | | 2 Hours Freeze 40 minutes Thaw | -15 $^0$ F | 72 $^0$ F | 4 1/2" Diameter by 22" high Cylinder |

**FOOTNOTES**

**(1)** Thaw tank is ½% methyl alcohol solution. ½" of thaw water solution was left in container when freezing samples.

**(2)** Vacuum saturated sample with methyl alcohol solution before first freeze cycle.

**(3)** Sodium Sulfate Soundness

**(4)** Gradation II with no +3/4" material.

# APPENDIX C

| IOWA | | | | | | | |
|---|---|---|---|---|---|---|---|
| Button Number 1 | | | | Button Number 7 | | | |
| Cycle | High Temp $^{o}$F | Low Temp $^{o}$F | | Cycle | High Temp $^{o}$F | Low Temp $^{o}$F |
| 1 | 61.7 | 20.3 | | 1 | 72.5 | 18.5 |
| 2 | 68.9 | 27.5 | | 2 | 69.8 | 27.5 |
| 3 | 71.6 | 28.4 | | 3 | 72.5 | 28.4 |
| 4 | 70.7 | 29.3 | | 4 | 70.7 | 29.3 |
| 5 | 68.9 | 30.2 | | 5 | 69.8 | 28.4 |
| 6 | 71.6 | 30.2 | | 6 | 72.5 | 30.2 |
| 7 | 69.8 | 30.2 | | 7 | 70.7 | 29.3 |
| 8 | 68.9 | 30.2 | | 8 | 69.8 | 30.2 |
| 9 | 71.6 | 30.2 | | 9 | 72.5 | 30.2 |
| 10 | 69.8 | 30.2 | | 10 | 70.7 | 31.1 |
| 11 | 68.9 | 30.2 | | 11 | 68.9 | 30.2 |
| 12 | 70.7 | 30.2 | | 12 | 71.6 | 31.1 |
| 13 | 69.8 | 30.2 | | 13 | 70.7 | 30.2 |
| 14 | 68.9 | 31.1 | | 14 | 68.9 | 31.1 |
| 15 | 70.7 | 31.1 | | 15 | 71.6 | 31.1 |
| 16 | 69.8 | 30.2 | | 16 | 69.8 | 31.1 |
| 17 | 68.9 | 30.2 | | 17 | 68.9 | 31.1 |
| 18 | 70.7 | 31.1 | | 18 | 71.6 | 31.1 |
| 19 | 68.9 | 30.2 | | 19 | 68.9 | 31.1 |
| 20 | 68.0 | 31.1 | | 20 | 68.9 | 31.1 |
| 21 | 68.9 | 31.1 | | 21 | 68.9 | 31.1 |
| 22 | 68.9 | 31.1 | | 22 | 68.9 | 31.1 |
| 23 | 68.0 | 30.2 | | 23 | 68.9 | 31.1 |
| 24 | 69.8 | 30.2 | | 24 | 69.8 | 31.1 |
| 25 | 68.9 | 30.2 | | 25 | 68.9 | 31.1 |
| High | 71.6 | 31.1 | | High | 72.5 | 31.1 |
| Low | 61.7 | 20.3 | | Low | 68.9 | 18.5 |
| Avg. | 69.3 | 29.8 | | Avg. | 70.3 | 29.9 |
| Soundness | | 73 | | Soundness | | 68 |

| | |
|---|---|
| Average Continuous Cycle | 1 hours Freeze and 30 minutes Thaw |
| Freezer Temperature | -20 $^{0}$ F |
| Thaw Tank Temperature | 72 $^{0}$ F |
| Container Dimensions | 12" L X 7" W X 4" D |

| IOWA | | | | | | |
|---|---|---|---|---|---|---|
| Button Number 13 | | | | Button Number 18 | | |
| Cycle | High Temp $^oF$ | Low Temp $^oF$ | | Cycle | High Temp $^oF$ | Low Temp $^oF$ |
| 1 | 71.6 | -13.9 | | 1 | 73.4 | -12.1 |
| 2 | 69.8 | -10.3 | | 2 | 70.7 | -9.4 |
| 3 | 75.2 | -12.1 | | 3 | 76.1 | -12.1 |
| 4 | 76.1 | -12.1 | | 4 | 77.0 | -12.1 |
| 5 | 75.2 | -12.1 | | 5 | 77.0 | -12.1 |
| 6 | 75.2 | -13.0 | | 6 | 76.1 | -12.1 |
| 7 | 75.2 | -7.6 | | 7 | 76.1 | -8.5 |
| 8 | 76.1 | -13.0 | | 8 | 77.0 | -11.2 |
| 9 | 75.2 | -11.2 | | 9 | 76.1 | -11.2 |
| 10 | 75.2 | -12.1 | | 10 | 77.0 | -11.2 |
| 11 | 75.2 | -12.1 | | 11 | 76.1 | -11.2 |
| 12 | 74.3 | -11.2 | | 12 | 76.1 | -11.2 |
| 13 | 75.2 | -11.2 | | 13 | 76.1 | -10.3 |
| 14 | 73.4 | -11.2 | | 14 | 75.2 | -10.3 |
| 15 | 71.6 | -11.2 | | 15 | 72.5 | -10.3 |
| 16 | 74.3 | -11.2 | | 16 | 75.2 | -9.4 |
| 17 | 71.6 | -11.2 | | 17 | 73.4 | -10.3 |
| 18 | 60.8 | -13.9 | | 18 | 69.8 | -11.2 |
| 19 | 72.5 | -9.4 | | 19 | 74.3 | -8.5 |
| 20 | 69.8 | -7.6 | | 20 | 72.5 | -5.8 |
| 21 | 72.5 | -10.3 | | 21 | 74.3 | -8.5 |
| 22 | 69.8 | -7.6 | | 22 | 72.5 | -6.7 |
| 23 | 72.5 | -11.2 | | 23 | 74.3 | -8.5 |
| 24 | 68.9 | -10.3 | | 24 | 71.6 | -8.5 |
| 25 | 71.6 | -9.4 | | 25 | 74.3 | -8.5 |
| High | 76.1 | -7.6 | | High | 77 | -5.8 |
| Low | 60.8 | -13.9 | | Low | 69.8 | -12.1 |
| Avg. | 72.8 | -11.1 | | Avg. | 74.6 | -10.0 |
| Soundness | | 66 | | Soundness | | 64 |

| | |
|---|---|
| Average Daytime Cycle | 2.75 hours Freeze and 1.25 hour Thaw |
| Freezer Temperature | -20 $^0$ F |
| Thaw Tank Temperature | 77.7 $^0$ F |
| Container Dimensions | 12" L X 7" W X 4" D |
| Avg. Time from Thawed to 0 $^o$ F | 2 hours |

| NEBRASKA | | | | | | |
|---|---|---|---|---|---|---|
| Button Number 4 | | | | Button Number 10 | | |
| Cycle | High Temp °F | Low Temp °F | | Cycle | High Temp °F | Low Temp °F |
| 1 | 74.3 | -13.0 | | 1 | 78.8 | -4.9 |
| 2 | 69.8 | -13.9 | | 2 | 70.7 | -17.5 |
| 3 | 69.8 | -15.7 | | 3 | 68.0 | -16.6 |
| 4 | 68.0 | -13.0 | | 4 | 68.0 | -18.4 |
| 5 | 64.4 | -26.5 | | 5 | 67.1 | -25.6 |
| 6 | 71.6 | 8.6 | | 6 | 72.5 | 5.9 |
| 7 | 68.9 | -4.9 | | 7 | 68.0 | -16.6 |
| 8 | 69.8 | -5.8 | | 8 | 69.8 | 9.5 |
| 9 | 67.1 | 9.5 | | 9 | 65.3 | -0.4 |
| 10 | 64.4 | -26.5 | | 10 | 68.0 | -25.6 |
| 11 | 75.2 | 3.2 | | 11 | 74.3 | 23.0 |
| 12 | 73.4 | 29.3 | | 12 | 72.5 | -3.1 |
| 13 | 64.4 | -0.4 | | 13 | 64.6 | -4.9 |
| 14 | 66.4 | -3.1 | | 14 | 67.1 | -1.3 |
| 15 | 67.1 | -26.5 | | 15 | 68.9 | -15.9 |
| 16 | 68.9 | 4.1 | | 16 | 73.4 | -14.8 |
| 17 | 68.0 | 15.7 | | 17 | 68.9 | 5.9 |
| 18 | 70.7 | 1.4 | | 18 | 69.8 | 0.5 |
| 19 | 68.9 | -1.3 | | 19 | 69.8 | -15.7 |
| 20 | 71.6 | -26.5 | | 20 | 72.5 | -25.6 |
| 21 | 63.5 | 4.1 | | 21 | 69.8 | -5.8 |
| 22 | 63.5 | -12.1 | | 22 | 60.8 | -19.3 |
| 23 | 66.2 | 14.0 | | 23 | 67.1 | 13.1 |
| 24 | 69.8 | 9.5 | | 24 | 72.5 | -2.2 |
| 25 | 69.8 | 14.9 | | 25 | 70.7 | 11.3 |
| High | 75.2 | 29.3 | | High | 78.8 | 23 |
| Low | 63.5 | -26.5 | | Low | 60.8 | -25.6 |
| Avg. | 68.3 | -0.9 | | Avg. | 69.6 | -6.6 |
| Soundness | | 63 | | Soundness | | 61 |

| | |
|---|---|
| Average Daytime Cycle | 1.5 hours Freeze and 30 minutes Thaw |
| Freezer Temperature | -24 °F |
| Thaw Tank Temperature | 76 °F |
| Container Dimensions | 7 3/4" X 22" X 2" |
| Avg. Time from Thawed to 0 °F | 1 hour 12 minutes |

| MISSOURI | | | | | | |
|---|---|---|---|---|---|---|
| Button Number 3 | | | | Button Number 9 | | |
| Cycle | High Temp °F | Low Temp °F | | Cycle | High Temp °F | Low Temp °F |
| 1 | 59.0 | 0.5 | | 1 | 59.0 | 0.5 |
| 2 | 49.1 | 13.1 | | 2 | 45.5 | 17.6 |
| 3 | 50.9 | 1.4 | | 3 | 46.4 | 0.5 |
| 4 | 46.4 | 14.0 | | 4 | 35.6 | 14.9 |
| 5 | 65.3 | 2.3 | | 5 | 64.4 | 1.4 |
| 6 | 67.1 | 21.2 | | 6 | 61.7 | 24.8 |
| 7 | 69.8 | -0.4 | | 7 | 68.0 | 0.5 |
| 8 | 67.1 | 16.7 | | 8 | 67.1 | 19.4 |
| 9 | 70.7 | 0.5 | | 9 | 70.7 | 0.5 |
| 10 | 67.1 | 15.8 | | 10 | 57.2 | 16.7 |
| 11 | 58.1 | 0.5 | | 11 | 51.8 | -0.4 |
| 12 | 61.7 | 17.6 | | 12 | 61.7 | 27.5 |
| 13 | 68.0 | 0.5 | | 13 | 68.0 | 0.5 |
| 14 | 57.2 | 22.1 | | 14 | 58.1 | 23.9 |
| 15 | 69.8 | 0.5 | | 15 | 66.2 | 0.5 |
| 16 | 64.4 | 17.6 | | 16 | 65.3 | 19.4 |
| 17 | 68.9 | -0.4 | | 17 | 65.3 | 0.5 |
| 18 | 67.1 | 23.0 | | 18 | 61.7 | 23.0 |
| 19 | 72.5 | 1.4 | | 19 | 73.4 | 27.5 |
| 20 | 66.2 | 23.0 | | 20 | 69.8 | 1.4 |
| 21 | 70.7 | 0.5 | | 21 | 65.3 | 0.5 |
| 22 | 67.1 | 21.2 | | 22 | 65.3 | 27.5 |
| 23 | 68.9 | 0.5 | | 23 | 68.9 | 0.5 |
| 24 | 67.1 | 28.4 | | 24 | 66.2 | 31.1 |
| High | 72.5 | 28.4 | | High | 73.4 | 31.1 |
| Low | 46.4 | -0.4 | | Low | 35.6 | -0.4 |
| Avg. | 64.2 | 10.1 | | Avg. | 61.9 | 12.2 |
| Soundness | | 78 | | Soundness | | 77 |

| | |
|---|---|
| Average Daytime Cycle | 6 1/2 Hours Freeze and 1 Hour Thaw |
| Freezer Temperature | 0 °F |
| Thaw Tank Temperature | 74 °F |
| Container Dimensions | Round Pans 10 1/2" at the Top<br>8 1/2" at the bottom and 3 1/2" deep |
| Avg. Time from Thawed to 0 °F | 13 hours 48 minutes |
| Avg. Time from Thawed to 32 °F | 2 hours 6 minutes |

| KANSAS | | | | | | |
|---|---|---|---|---|---|---|
| Button Number 2 | | | | Button Number 8 | | |
| Cycle | High Temp °F | Low Temp °F | | Cycle | High Temp °F | Low Temp °F |
| 1 | 75.2 | -1.3 | | 1 | 75.2 | -1.3 |
| 2 | 75.2 | -0.4 | | 2 | 72.5 | -1.3 |
| 3 | 71.6 | -11.2 | | 3 | 72.5 | -11.2 |
| 4 | 57.2 | -3.21 | | 4 | 50.0 | -1.3 |
| 5 | 51.8 | -6.7 | | 5 | 42.8 | -8.5 |
| 6 | 74.3 | 4.1 | | 6 | 75.2 | 3.2 |
| 7 | 71.6 | -11.2 | | 7 | 70.7 | -11.2 |
| 8 | 67.1 | 6.8 | | 8 | 69.8 | 9.5 |
| 9 | 69.8 | 0.5 | | 9 | 68.0 | 2.3 |
| 10 | 73.4 | 16.7 | | 10 | 71.6 | -11.2 |
| 11 | 53.6 | -11.2 | | 11 | 48.2 | 0.5 |
| 12 | 49.9 | 0.5 | | 12 | 36.5 | 2.3 |
| 13 | 68.0 | 0.5 | | 13 | 63.5 | 5.0 |
| 14 | 59.9 | -0.4 | | 14 | 57.2 | -11.2 |
| 15 | 58.1 | -11.2 | | 15 | 51.8 | -16.6 |
| 16 | 30.2 | -13.9 | | 16 | 30.2 | -5.8 |
| 17 | 30.2 | -5.8 | | 17 | 30.2 | -13.9 |
| 18 | 71.6 | 3.2 | | 18 | 70.7 | 2.3 |
| 19 | 69.8 | -11.2 | | 19 | 68.9 | -11.2 |
| 20 | 30.2 | -2.2 | | 20 | 33.8 | -1.3 |
| 21 | 30.2 | -1.3 | | 21 | 37.4 | -1.3 |
| 22 | 60.8 | -2.2 | | 22 | 59.9 | -2.2 |
| 23 | 66.2 | -11.2 | | 23 | 65.3 | -11.2 |
| 24 | 30.2 | -0.4 | | 24 | 31.1 | -0.4 |
| 25 | 29.3 | -5.8 | | 25 | 30.2 | -5.8 |
| High | 75.2 | 16.7 | | High | 75.2 | 9.5 |
| Low | 29.3 | -13.9 | | Low | 30.2 | -16.6 |
| Avg. | 57.0 | -3.1 | | Avg. | 55.3 | -4.1 |
| Soundness | | 55 | | Soundness | | 56 |

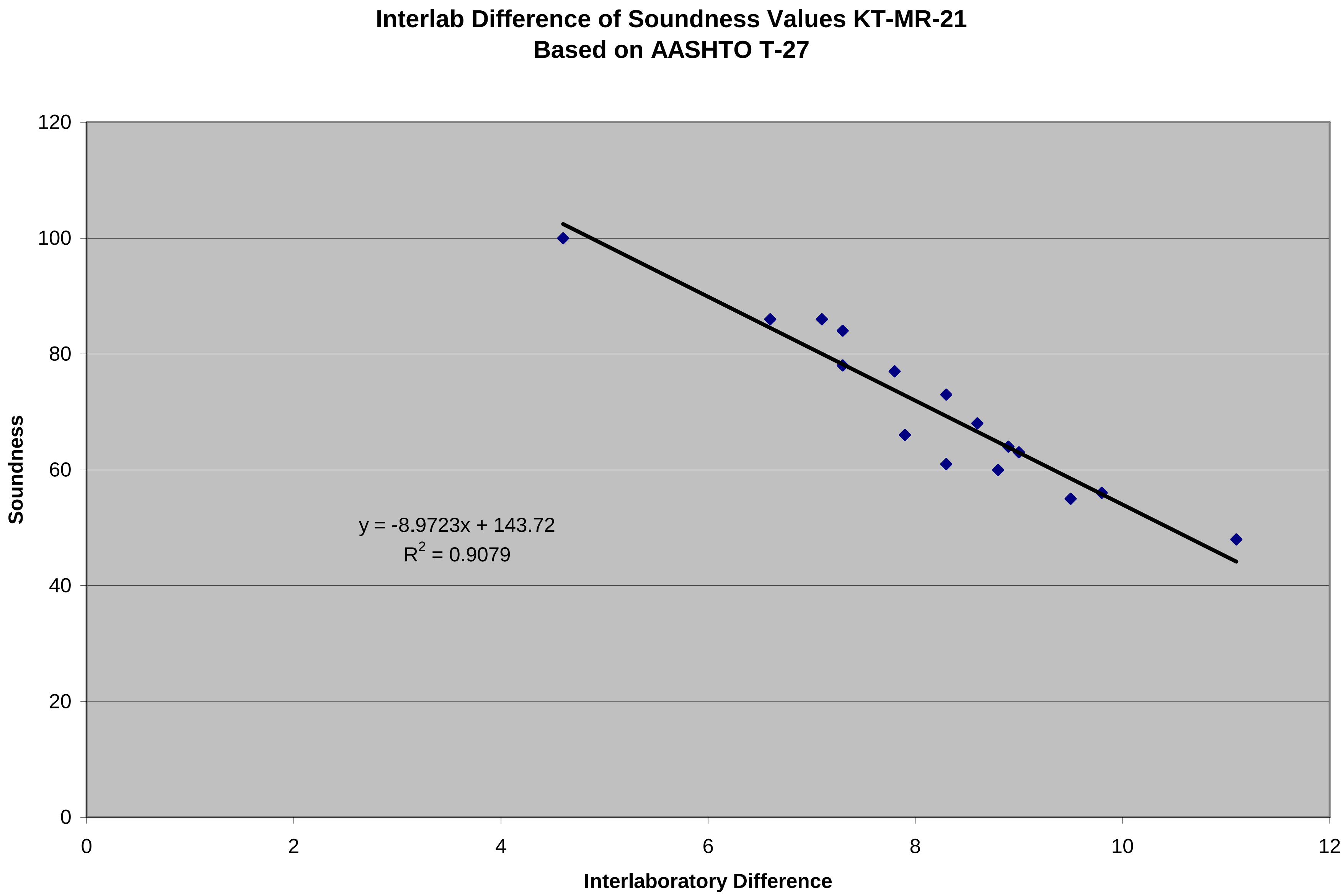
| | |
|---|---|
| Average Daytime Cycle | 2 hours Freeze 40 minutes Thaw |
| Freezer Temperature | -15 °F |
| Thaw Tank Temperature | 72 °F |
| Container Dimensions | 4 1/2" Diameter by 22" high Cylinder |
| Avg. Time from Thawed to 0 °F | 1 hours 52 minutes |

| OHIO | | | | | | |
|---|---|---|---|---|---|---|
| Button Number 5 | | | | Button Number 11 | | |
| Cycle | High Temp $^oF$ | Low Temp $^oF$ | | Cycle | High Temp $^oF$ | Low Temp $^oF$ |
| 1 | 76.1 | 31.1 | | 1 | 77.0 | 32.0 |
| 2 | 83.3 | -4.9 | | 2 | 84.2 | -4.0 |
| 3 | 71.6 | 31.1 | | 3 | 72.5 | 32.0 |
| 4 | 69.8 | -4.9 | | 4 | 70.7 | -4.0 |
| 5 | 67.1 | 31.1 | | 5 | 68.0 | 32.0 |
| 6 | 67.1 | -4.0 | | 6 | 64.4 | -4.0 |
| 7 | 66.2 | 31.1 | | 7 | 67.1 | 32.0 |
| 8 | 66.2 | -5.8 | | 8 | 66.2 | -4.0 |
| 9 | 66.2 | 31.1 | | 9 | 67.1 | 32.0 |
| 10 | 66.2 | -4.9 | | 10 | 66.2 | -3.1 |
| 11 | 67.1 | -4.9 | | 11 | 67.1 | -3.1 |
| 12 | 68.9 | 31.1 | | 12 | 67.1 | 31.1 |
| 13 | 67.1 | -4.9 | | 13 | 68.9 | 32.0 |
| 14 | 68.0 | 31.1 | | 14 | 68.9 | 31.1 |
| 15 | | | | 15 | 68.9 | 32.0 |
| 16 | | | | 16 | 68.9 | -4.9 |
| 17 | | | | 17 | | |
| 18 | | | | 18 | | |
| 19 | | | | 19 | | |
| 20 | | | | 20 | | |
| 21 | | | | 21 | | |
| 22 | | | | 22 | | |
| 23 | | | | 23 | | |
| 24 | | | | 24 | | |
| High | 83.3 | 31.1 | | High | 84.2 | 32.0 |
| Low | 66.2 | -5.8 | | Low | 64.4 | -4.9 |
| Avg. | 69.4 | 13.1 | | Avg. | 69.575 | 16.2 |
| | Soundness | 78 | | | Soundness | 77 |

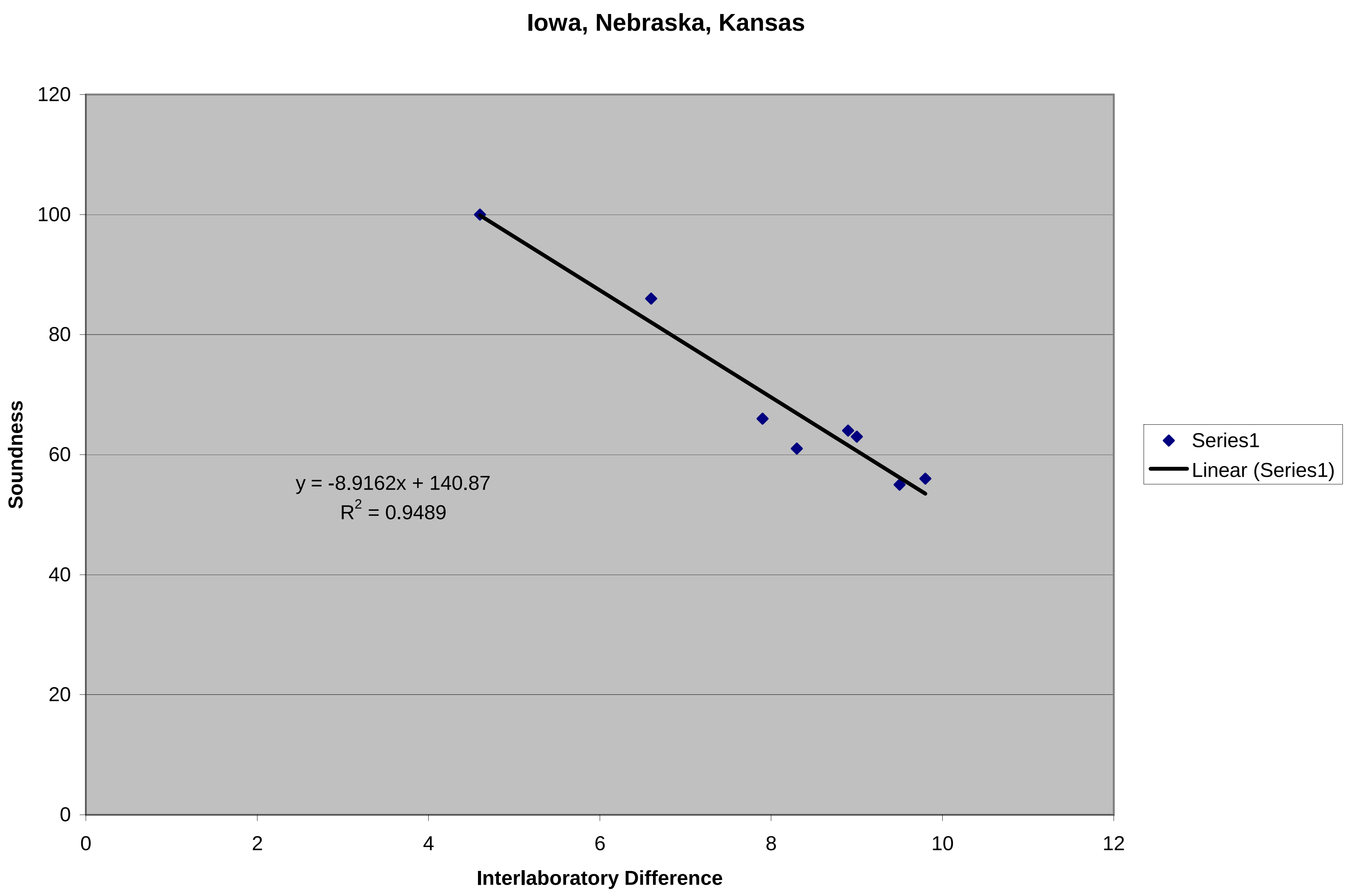
Average Daytime Cycle

| | |
|---|---|
| Freezer Temperature | 0 $^0$ F |
| Thaw Tank Temperature | 70 $^0$ F |
| Container Dimensions | 6" Diameter by 12" high Cylinder |
| Avg. Time from Thawed to 0 $^o$ F | 9 hours 40 minutes |
| Avg. Time from Thawed to 32 $^o$ F | 2 hours 25 minutes |

# APPENDIX D



Interlab Difference of Soundness Values KT-MR-21
Based on AASHTO T-27
120
100
80
60
40
20
0
0
2
4
6
8
10
12
Soundness
Interlaboratory Difference
y = -8.9723x + 143.72
R2 = 0.9079


Iowa, Nebraska, Kansas
Soundness
120
100
80
60
40
20
0
0
2
4
6
8
10
12
Interlaboratory Difference
y = -8.9162x + 140.87
R2 = 0.9489
Series1
Linear (Series1)

## *RECAP*

| Soundness | Allowable Range | Soundness | | Soundness | | |
|---|---|---|---|---|---|---|
| | 11.1 | 48 | ne | | | |
| 55 | 9.5 | 55 | ks | 55 | | 9.5 |
| 56 | 9.8 | 56 | ks | 56 | | 9.8 |
| | 8.8 | 60 | mo | | | |
| 61 | 8.3 | 61 | ne | 61 | | 8.3 |
| 63 | 9 | 63 | ne | 63 | | 9 |
| 64 | 8.9 | 64 | IA | 64 | | 8.9 |
| 66 | 7.9 | 66 | IA | 66 | | 7.9 |
| | 8.6 | 68 | IA | | | |
| | 8.3 | 73 | IA | | | |
| | 7.8 | 77 | mo | | | |
| | 7.3 | 78 | mo | | | |
| | 7.3 | 84 | Oh | | | |
| | 6.6 | 86 | ks ofq | 86 | | 6.6 |
| | 7.1 | 86 | oh | | | |
| | 4.6 | 100 | theo | 100 | | 4.6 |
| 60.8 | | 70.3 | | 68.9 | Average | |
| 4.4 | | 14.0 | | 15.8 | Esd | |
| 11 | | 38 | | 11 | Range | |
| 69.7 | | 98.2 | | 100.5 | Average + 2 ESD | |
| 51.9 | | 42.4 | | 37.3 | Average - 2 ESD | |

## *T-103*

| Total % Material Passing | | Coefficient of Variation (%1S) | Acceptable Range 2 Test Results (%D2S) |
|---|---|---|---|
| < 85 | ≥ 80 | 1.92 | 5.4 |
| <80 | ≥ 60 | 2.82 | 8.0 |
| <60 | ≥ 20 | 1.97 | 5.6 |
| <20 | ≥ 15 | 1.60 | 4.5 |
| <15 | ≥ 10 | 1.48 | 4.2 |
| <10 | ≥ 5 | 1.22 | 3.4 |
| <5 | ≥ 2 | 1.04 | 3.0 |
| <2 | ≥ 0 | 0.45 | 1.3 |

## *IA #1*

| Iowa #1 | Amount Retained | % Passing | % D2S | Acceptable Range |
|---|---|---|---|---|
| **3/4" (19.0 mm)** | 2050.9 | 59 | 5.6 | 3.30 |
| **3/8" (9.5 mm)** | 3948.1 | 21 | 5.6 | 1.18 |
| **#4 (4.75 mm)** | 4451.5 | 11 | 4.2 | 0.46 |
| **#8 (2.36 mm)** | 4926.3 | 1 | 1.3 | 0.02 |
| | | Total | 16.7 | 5.0 |
| **3/4" (19.0 mm)** | 1303.3 | 74 | 8.0 | 5.91 |
| **3/8" (9.5 mm)** | 2689.3 | 46 | 5.6 | 2.59 |
| **#4 (4.75 mm)** | 3265.9 | 35 | 5.6 | 1.94 |
| **#8 (2.36 mm)** | 4010.4 | 20 | 5.6 | 1.11 |
| | | Total | 24.8 | 11.6 |
| | | | **Grand Total** | **16.5** |
| | | | **Average** | **8.3** |
| | | | **Soundness** | **73** |

## ***KANSAS OFQ***

| KANSAS OFQ | Amount Retained | % Passing | % D2S | Acceptable Range |
|---|---|---|---|---|
| 3/4" (19.0 mm) | 2250 | 55 | 5.6 | 3.08 |
| 3/8" (9.5 mm) | 4000 | 20 | 5.6 | 1.12 |
| #4 (4.75 mm) | 4500 | 10 | 4.2 | 0.42 |
| #8 (2.36 mm) | 5000 | 0 | 1.3 | 0.00 |
| | | Total | 16.7 | 4.6 |
| 3/4" (19.0 mm) | 1589.2 | 68 | 8.0 | 5.46 |
| 3/8" (9.5 mm) | 3373.5 | 33 | 5.6 | 1.82 |
| #4 (4.75 mm) | 4105.6 | 18 | 4.5 | 0.80 |
| #8 (2.36 mm) | 4495.8 | 10 | 4.2 | 0.42 |
| | | Total | 22.3 | 8.5 |
| | | | **Grand Total** | **13.1** |
| | | | **Average** | **6.6** |
| | | | **Soundness** | **86** |

## ***KANSAS #2***

| KANSAS #2 | Amount Retained | % Passing | % D2S | Acceptable Range |
|---|---|---|---|---|
| 3/4" (19.0 mm) | 2239.7 | 55 | 5.6 | 3.09 |
| 3/8" (9.5 mm) | 3909.6 | 22 | 5.6 | 1.22 |
| #4 (4.75 mm) | 4420.4 | 12 | 4.2 | 0.49 |
| #8 (2.36 mm) | 4889.6 | 2 | 3.0 | 0.07 |
| | | Total | 18.4 | 4.9 |
| 3/4" (19.0 mm) | 964.2 | 81 | 5.4 | 4.36 |
| 3/8" (9.5 mm) | 1962.1 | 61 | 8.0 | 4.86 |
| #4 (4.75 mm) | 2430.2 | 51 | 5.6 | 2.88 |
| #8 (2.36 mm) | 3181.9 | 36 | 5.6 | 2.04 |
| | | Total | 24.6 | 14.1 |
| | | | **Grand Total** | **19.0** |
| | | | **Average** | **9.5** |
| | | | **Soundness** | **55** |

## ***MISSOURI #3***

| Missouri #3 | Amount Retained | % Passing | % D2S | Acceptable Range |
|---|---|---|---|---|
| **3/4" (19.0 mm)** | 2316.7 | 54 | 5.6 | 3.01 |
| **3/8" (9.5 mm)** | 4018.2 | 20 | 5.6 | 1.10 |
| **#4 (4.75 mm)** | 4488.7 | 10 | 4.2 | 0.43 |
| **#8 (2.36 mm)** | 4953.6 | 1 | 1.3 | 0.01 |
| | | Total | 16.7 | 4.5 |
| **3/4" (19.0 mm)** | 1201.3 | 76 | 8.0 | 6.08 |
| **3/8" (9.5 mm)** | 2770.9 | 45 | 5.6 | 2.50 |
| **#4 (4.75 mm)** | 3789.4 | 24 | 4.5 | 1.09 |
| **#8 (2.36 mm)** | 4494.6 | 10 | 4.2 | 0.42 |
| | | Total | | 10.1 |
| | | | **Grand Total** | **14.6** |
| | | | **Average** | **7.3** |
| | | | **Soundness** | **78** |

## ***NEBRASKA #4***

| Nebraska #4 | Amount Retained | % Passing | % D2S | Acceptable Range |
|---|---|---|---|---|
| **3/4" (19.0 mm)** | 1973.6 | 61 | 8.0 | 4.84 |
| **3/8" (9.5 mm)** | 3944.5 | 21 | 5.6 | 1.18 |
| **#4 (4.75 mm)** | 4441.6 | 11 | 4.2 | 0.47 |
| **#8 (2.36 mm)** | 4952.0 | 1 | 1.3 | 0.01 |
| | | Total | 19.1 | 6.5 |
| **3/4" (19.0 mm)** | 857.9 | 83 | 5.4 | 4.47 |
| **3/8" (9.5 mm)** | 2258.9 | 55 | 5.6 | 3.07 |
| **#4 (4.75 mm)** | 2823.1 | 44 | 5.6 | 2.44 |
| **#8 (2.36 mm)** | 3724.0 | 26 | 5.6 | 1.43 |
| | | Total | 22.2 | 11.4 |

| | |
|---|---|
| **Grand Total** | **17.9** |
| **Average** | **9.0** |
| **Soundness** | **63** |

## *OHIO #5*

| Ohio #5 | Amount Retained | % Passing | % D2S | Acceptable Range |
|---|---|---|---|---|
| **3/4" (19.0 mm)** | 2080.0 | 58 | 5.6 | 3.27 |
| **3/8" (9.5 mm)** | 3950.0 | 21 | 5.6 | 1.18 |
| **#4 (4.75 mm)** | 4438.0 | 11 | 4.2 | 0.47 |
| **#8 (2.36 mm)** | 4909.0 | 2 | 3.0 | 0.05 |
| | | Total | 18.4 | 5.0 |
| **3/4" (19.0 mm)** | 1444.1 | 71 | 8.0 | 5.69 |
| **3/8" (9.5 mm)** | 3200.9 | 36 | 5.6 | 2.01 |
| **#4 (4.75 mm)** | 3984.1 | 20 | 5.6 | 1.14 |
| **#8 (2.36 mm)** | 4547.4 | 9 | 3.4 | 0.31 |
| | | Total | | 9.2 |
| | | | **Grand Total** | **14.1** |
| | | | **Average** | **7.1** |
| | | | **Soundness** | **86** |

## *IOWA #7*

| Iowa #7 | Amount Retained | % Passing | % D2S | Acceptable Range |
|---|---|---|---|---|
| **3/4" (19.0 mm)** | 1990.1 | 60 | 8.0 | 4.82 |
| **3/8" (9.5 mm)** | 3950.9 | 21 | 5.6 | 1.17 |
| **#4 (4.75 mm)** | 4442.3 | 11 | 4.2 | 0.47 |
| **#8 (2.36 mm)** | 4917.8 | 2 | 3.0 | 0.05 |
| | | Total | 20.8 | 6.5 |
| **3/4" (19.0 mm)** | 1083.4 | 78 | 5.4 | 4.23 |
| **3/8" (9.5 mm)** | 2468.1 | 51 | 5.6 | 2.84 |
| **#4 (4.75 mm)** | 3015.7 | 40 | 5.6 | 2.22 |
| **#8 (2.36 mm)** | 3765.6 | 25 | 5.6 | 1.38 |
| | | Total | | 10.7 |
| | | | **Grand Total** | **17.2** |
| | | | **Average** | **8.6** |
| | | | **Soundness** | **68** |

## ***KANSAS #8***

| KANSAS #8 | Amount Retained | % Passing | % D2S | Acceptable Range |
|---|---|---|---|---|
| **3/4" (19.0 mm)** | 2072.0 | 59 | 5.6 | 3.28 |
| **3/8" (9.5 mm)** | 3838.5 | 23 | 5.6 | 1.30 |
| **#4 (4.75 mm)** | 4352.8 | 13 | 4.2 | 0.54 |
| **#8 (2.36 mm)** | 4823.8 | 4 | 3.0 | 0.11 |
| | | Total | 18.4 | 5.2 |
| **3/4" (19.0 mm)** | 907.9 | 82 | 5.4 | 4.42 |
| **3/8" (9.5 mm)** | 1945.0 | 61 | 8.0 | 4.89 |
| **#4 (4.75 mm)** | 2447.2 | 51 | 5.6 | 2.86 |
| **#8 (2.36 mm)** | 3111.1 | 38 | 5.6 | 2.12 |
| | | Total | 24.6 | 14.3 |

| | |
|---|---|
| **Grand Total** | **19.5** |
| **Average** | **9.8** |
| **Soundness** | **56** |

## ***MISSOURI #9***

| Missouri #9 | Amount Retained | % Passing | % D2S | Acceptable Range |
|---|---|---|---|---|
| **3/4" (19.0 mm)** | 2193.7 | 56 | 5.6 | 3.14 |
| **3/8" (9.5 mm)** | 3993.8 | 20 | 5.6 | 1.13 |
| **#4 (4.75 mm)** | 4474.6 | 11 | 4.2 | 0.44 |
| **#8 (2.36 mm)** | 4917.1 | 2 | 3.0 | 0.05 |
| | | Total | 18.4 | 4.8 |
| **3/4" (19.0 mm)** | 1070.0 | 79 | 8.0 | 6.29 |
| **3/8" (9.5 mm)** | 2708.0 | 46 | 5.6 | 2.57 |
| **#4 (4.75 mm)** | 3722.6 | 26 | 5.6 | 1.43 |
| **#8 (2.36 mm)** | 4443.5 | 11 | 4.2 | 0.47 |
| | | Total | 23.4 | 10.8 |
| | | | **Grand Total** | **15.5** |
| | | | **Average** | **7.8** |
| | | | **Soundness** | **77** |

## ***NEBRASKA #10***

| Nebraska #10 | Amount Retained | % Passing | % D2S | Acceptable Range |
|---|---|---|---|---|
| **3/4" (19.0 mm)** | 2060.6 | 59 | 5.6 | 3.29 |
| **3/8" (9.5 mm)** | 3966.2 | 21 | 5.6 | 1.16 |
| **#4 (4.75 mm)** | 4464.1 | 11 | 4.2 | 0.45 |
| **#8 (2.36 mm)** | 4933.3 | 1 | 1.3 | 0.02 |
| | | Total | 16.7 | 4.9 |
| **3/4" (19.0 mm)** | 919.4 | 82 | 5.4 | 4.41 |
| **3/8" (9.5 mm)** | 2113.7 | 58 | 5.6 | 3.23 |
| **#4 (4.75 mm)** | 2681.3 | 46 | 5.6 | 2.60 |
| **#8 (2.36 mm)** | 3638.5 | 27 | 5.6 | 1.52 |
| | | Total | 22.2 | 11.8 |

| | |
|---|---|
| **Grand Total** | **16.7** |
| **Average** | **8.3** |
| **Soundness** | **61** |

## *OHIO #11*

| Ohio #11 | Amount Retained | % Passing | % D2S | Acceptable Range |
|---|---|---|---|---|
| **3/4" (19.0 mm)** | 2036.0 | 59 | 5.6 | 3.32 |
| **3/8" (9.5 mm)** | 3964.0 | 21 | 5.6 | 1.16 |
| **#4 (4.75 mm)** | 4453.0 | 11 | 4.2 | 0.46 |
| **#8 (2.36 mm)** | 4920.0 | 2 | 3.0 | 0.05 |
| | | Total | 18.4 | 5.0 |
| **3/4" (19.0 mm)** | 1232.3 | 75 | 8.0 | 6.03 |
| **3/8" (9.5 mm)** | 3160.0 | 37 | 5.6 | 2.06 |
| **#4 (4.75 mm)** | 3969.5 | 21 | 5.6 | 1.15 |
| **#8 (2.36 mm)** | 4550.8 | 9 | 3.4 | 0.31 |
| | | Total | 22.6 | 9.5 |
| | | | **Grand Total** | **14.5** |
| | | | **Average** | **7.3** |
| | | | **Soundness** | **84** |

## *IOWA #13*

| Iowa #13 | Amount Retained | % Passing | % D2S | Acceptable Range |
|---|---|---|---|---|
| **3/4" (19.0 mm)** | 2026.9 | 59 | 5.6 | 3.33 |
| **3/8" (9.5 mm)** | 3961.3 | 21 | 5.6 | 1.16 |
| **#4 (4.75 mm)** | 4466.3 | 11 | 4.2 | 0.45 |
| **#8 (2.36 mm)** | 4918.5 | 2 | 3.0 | 0.05 |
| | | Total | 18.4 | 5.0 |
| **3/4" (19.0 mm)** | 1044.0 | 79 | 5.4 | 4.27 |
| **3/8" (9.5 mm)** | 2371.7 | 53 | 5.6 | 2.94 |
| **#4 (4.75 mm)** | 2950.8 | 41 | 5.6 | 2.30 |
| **#8 (2.36 mm)** | 3763.4 | 25 | 5.6 | 1.38 |
| | | Total | 22.2 | 10.9 |
| | | | **Grand Total** | **15.9** |
| | | | **Average** | **7.9** |
| | | | **Soundness** | **66** |

## ***MISSOURI #14***

| Missouri #14 | Amount Retained | % Passing | % D2S | Acceptable Range |
| --- | --- | --- | --- | --- |
| **3/4" (19.0 mm)** | 2288.0 | 54 | 5.6 | 3.04 |
| **3/8" (9.5 mm)** | 4020.4 | 20 | 5.6 | 1.10 |
| **#4 (4.75 mm)** | 4492.9 | 10 | 4.2 | 0.43 |
| **#8 (2.36 mm)** | 4952.7 | 1 | 1.3 | 0.01 |
| | | Total | 16.7 | 4.6 |
| **3/4" (19.0 mm)** | 782.4 | 84 | 5.4 | 4.56 |
| **3/8" (9.5 mm)** | 1928.0 | 61 | 8.0 | 4.92 |
| **#4 (4.75 mm)** | 2857.7 | 43 | 5.6 | 2.40 |
| **#8 (2.36 mm)** | 3909.6 | 22 | 5.6 | 1.22 |
| | | Total | | 13.1 |

| | |
| --- | --- |
| **Grand Total** | **17.7** |
| **Average** | **8.8** |
| **Soundness** | **60** |

## ***NEBRASKA #15***

| Nebraska #15 | Amount Retained | % Passing | % D2S | Acceptable Range |
|---|---|---|---|---|
| **3/4" (19.0 mm)** | 1934.3 | 61 | 8.0 | 4.91 |
| **3/8" (9.5 mm)** | 3951.6 | 21 | 5.6 | 1.17 |
| **#4 (4.75 mm)** | 4462.7 | 11 | 4.2 | 0.45 |
| **#8 (2.36 mm)** | 4944.0 | 1 | 1.3 | 0.01 |
| | | Total | | 6.5 |
| **3/4" (19.0 mm)** | 698.8 | 86 | 5.4 | 4.65 |
| **3/8" (9.5 mm)** | 1555.5 | 69 | 8.0 | 5.51 |
| **#4 (4.75 mm)** | 2130.1 | 57 | 5.6 | 3.21 |
| **#8 (2.36 mm)** | 2958.7 | 41 | 5.6 | 2.29 |
| | | Total | 24.6 | 15.7 |
| | | | **Grand Total** | **22.2** |
| | | | **Average** | **11.1** |
| | | | **Soundness** | **48** |

## *IOWA #18*

| Iowa #18 | Amount Retained | % Passing | % D2S | Acceptable Range |
|---|---|---|---|---|
| 3/4" (19.0 mm) | 1984.8 | 60 | 8.0 | 4.82 |
| 3/8" (9.5 mm) | 3960.8 | 21 | 5.6 | 1.16 |
| #4 (4.75 mm) | 4462.3 | 11 | 4.2 | 0.45 |
| #8 (2.36 mm) | 4939.9 | 1 | 1.3 | 0.02 |
| | | Total | 19.1 | 6.5 |
| 3/4" (19.0 mm) | 940.9 | 81 | 5.4 | 4.38 |
| 3/8" (9.5 mm) | 2237.9 | 55 | 5.6 | 3.09 |
| #4 (4.75 mm) | 2873.1 | 43 | 5.6 | 2.38 |
| #8 (2.36 mm) | 3724.5 | 26 | 5.6 | 1.43 |
| | | Total | | 11.3 |
| | | | **Grand Total** | **17.7** |
| | | | **Average** | **8.9** |
| | | | **Soundness** | **64** |

DEPARTMENT OF TRANSPORTATION

KANSAS