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Optimized Aggregates Gradations for Portland Cement Concrete Mix Designs Evaluation

Wally Heyen

Lieska Halsey

Robert Rea

Mick Syslo

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Principle Investigators:
Wally Heyen
NDOR-PCC Engineer

Lieska Halsey
NDOR Research

Investigation Collaborators:
Robert Rea
NDOR-Assistant M&R Engineer-Flexible Pavement Engineer

Mick Syslo
NDOR-Materials & Research Engineer

PCC Laboratory:
Tim Krason
NDOR-Highway Quality Assurance Manager

Tom Gernert
NDOR-Highway Materials & Test Technician III

Jeremy Weigel
NDOR-Highway Materials & Test Technician II

Debra Swanson
NDOR-Highway Materials & Test Technician II

Aggregate Laboratory:
Jim Beason
NDOR-Highway Quality Assurance Manager

ABSTRACT

This research main purpose was to optimize aggregate blends utilizing more locally available materials. With the industry collaboration and partnership, the Department embraced a change that impacts a specification implemented in the 1947 for Class of 47B concrete. This aggregate optimization embraces today's availability of new blended cements in Nebraska. These new blended cements enhanced the Alkali Silica Reaction of Nebraska's sand and gravel. As well as, and not short of improving future gradation from a gap-graded to a more dense gradation. Combined aggregate gradations were evaluated for mechanical and durability characteristics for paving mix designs. The outcome of these evaluations resulted in the introduction of a new blend aggregate grading band for the Department named 47B Revised (47BR), which would allow the use of more locally available materials currently being produced in the state, thereby optimizing its economy.

The goal for the new 47BR Combined Aggregate Gradation is to have the contractor, with agency oversight, develop a concrete mix design with an optimum combined aggregate gradation and provide the Contractor with the testing and control responsibilities to ensure a quality product. This report presents the results of the evaluation and optimization of the 47BR Concrete Specification.

SUMMARY OF PHASE I

Phase I Purpose:

The Nebraska Department of Roads began to explore various blended aggregate gradations for the Nebraska 47B concrete in January 2008. The purpose was to optimize aggregate blends utilizing more locally available materials. These blends were evaluated for mechanical and durability characteristics for paving mix designs. The outcome of these evaluations would result in the introduction of a new blend aggregate grading band 47B Revised (47BR), which would allow the use of more locally available materials currently being produced in the state, thereby optimizing its economy.

Phase I Project Scope:

- To determine the effect of blending locally available materials and determine the potential benefits resulting from using optimized gradation in concrete mixes.

- To ensure workability and constructability so that the mixes can be easily used in engineering applications.

- To evaluate concrete mixes for mechanical properties and durability characteristics that are compatible with NDOR requirements for a good performance mix design.

Actions in the Field and Laboratory:

In order to assess the performance and effects of an optimized gradation, ready-mix field trials were proposed to analyze the effects on constructability, strength, segregation, and required water and air-entraining agent dosage. NDOR, Paulsen Construction Concrete Company, Inc, Lyman-Richey Corporation, and Hooker Bros. Sand & Gravel worked together on these ready-mix field trials by providing their available ready-to-use aggregate.

Phase I Field and Laboratory Testing:

In order to analyze what type of guidelines NDOR would need to set on the proportioning and optimization of aggregates, five concrete mixes were proportioned or analyzed using different aggregates currently produced in the western and central part of the state. The plan of action in the field is described as follows:

Plan of Action in the Field (Ready-Mix Plant) and Laboratory Phase I by Tasks:

Conducted in the Field-Sampling & Testing:

1. Standard Test Method for Slump of Hydraulic Cement Concrete (ASTM C 143)

2. Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method (ASTM C 231)

Conducted in the Laboratory:

1. Standard Test Method for Microscopical Determination Parameters of the Air Void System in Hardened Concrete (ASTM C 457 – Method B)

2. Standard Test Method for Determining the Potential Alkali Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar Bar Method) (ASTM C 1567)

3. Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration (ASTM C 1202)

4. Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing (ASTM C 666)

Coarser Gravel- Western, Nebraska

5. Mechanical Properties:
   i. Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens (ASTM C39)
   ii. Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)

Test results for the testing conducted in the field and laboratory testing for the five trials mixes in the ready mix plants at the locations of Gothenburg, NE Kimball, NE and Grand Island, NE are presented in Table 1.

Table 1 - Description of Proportioned Mix Designs and Test Results - Phase I

Performed	*Proportioned Mix Designs	W/CM ratio	14 Days Compressive Strength (psi)	28 days Compressive Strength (PSI)	28 days Flexure Strength (PSI)	84 days Flexure Strength (PSI)	Freeze & Thaw (Percentage)	Total Air Count (Percentage)	ASTM C 1567
NDOR's Req.		Max 0.48	3500 min. psi @ 28 days		(***) To be Determined	-	Durability >70% 300 cycles	7.5-10 %	28 Day % Expansion < 0.10%
June-08	30% Coarse Gravel Gothenburg-70% 47B Fine Paulsen Inc.	0.41	4060	5010	575	650	88%	10.5%	0.06
Oct-08	40%Coarse Gravel Gothenburg-60% 47B Fine Paulsen Inc	0.40	3500	3910	520	620	80%	13.5%	0.06
Sep-08	40% Coarse Gravel Crushed-60% 47B Fine Lyman Rickey-Kimball (**)	0.35	3740	4300	450	470	71%	6.0%	0.07
Sep-08	70% 47M Coarse Gravel Crushed-30% Coarse Gravel Crushed Lyman Rickey- Kimball (**)	0.37	3120	3730	470	520	76%	8.8%	0.07
Dec-08	45% Grand Island Coarse Gravel-55% Grand Island Fine Hooker, Bros	0.36	4060	4460	580	640	81%	6.1%	0.05
NA	47B-Paving Blend Average Performance	NA	3500	5000	680	NA	71%	NA	NA

(*) All Proportioned Mix designs followed NDOR specifications for concrete paving using IPF class of concrete.

(**) These two mixes were performed with a high slump, which was not an ideal a good mix for paving operation.

(***) NDOR is investigating the actual requirement/value for this test since the test procedures are variable.

<u>Phase I Project Results Summary</u>:

Based on the field trial performance, the results have assisted NDOR in identifying the combined aggregate gradations that would help improve the current mix design the Nebraska Department of Roads has had for the last 60 plus years. These initial efforts have dealt with the concept of maximum density with the idea of a denser gradation. A denser gradation helps to improve air entrainment for a better spacing factor, reduces entrapped air voids, and can give less shrinkage due to fewer voids needed to be filled with cement paste. The 47B Revised (47BR) gradation band was developed from the analysis of the current 47B gradation band with the identification of the best combined gradation and its mechanical properties. Figure 1 represents the five blends plotted and compared with the current 47B gradation band. Four of the five gradations plotted were outside the 47B maximum and minimum tolerance. With the development of the 47BR combined aggregate gradation limits, which is shown in Table 2, the mechanical properties will exhibit a better and closer performance due to the denser gradation. This new 47BR combined gradation limits gives an opportunity that would allow the use of more locally available materials currently being produced in the state, thereby optimizing its economy.

Figure 1. 47B Standard - All Gradations Combined

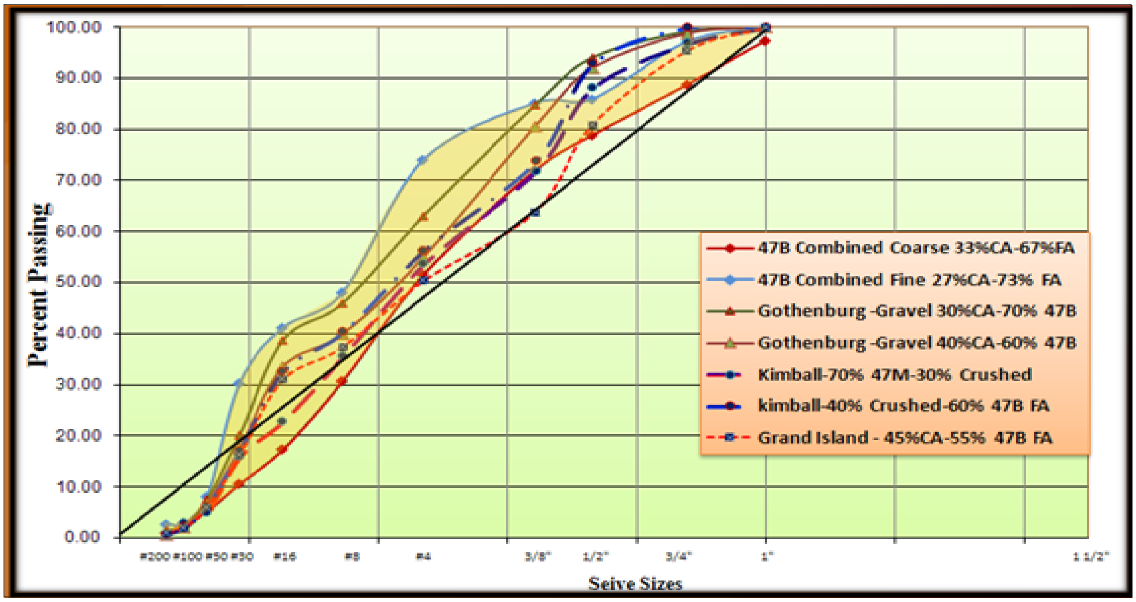


Table 2. 47BR Combined Aggregate Gradation Limits (Percent Passing)

Combined Aggregate Gradation Limits (Percent Passing)								
Sieve Size	No.1"	No.3/4"	No.4	No.8	No.16	No.30	No. 50	No.200
Minimum	92.0	98.0	45.0	31.0	17.0	10.0	3.0	0
Maximum	100	85.0	65.0	48.0	41.0	30.0	8.0	3.0

SUMMARY OF PHASE II

Phase II Purpose:

The purpose of Phase II was to evaluate the properties and performance of these blended aggregate gradations on a full-scale project and investigate the saving potential for each individual project. NDOR started writing a specification to launch on a project for the 2010 construction season. This new specification was a major change from current Nebraska Specifications for highway construction for paving operations. Since 1947, Nebraska Department of Roads has provided a mix design for all paving operations. The new specification will require the contractor to be responsible to submit the combined aggregate gradation for approval and verify mix properties such as, but not limited to, workability, resistance to segregation, a stable air system, and good finishing and consolidation properties.

Phase II Project Scope:

Proposed for Phase II was the testing evaluation of the 47BR combined aggregate gradation limits developed in Phase I. The testing evaluation was based on the required sampling and testing for the trial batch that would be required in the specification.

The first objective of this project was to verify that the combined aggregate gradation performance and its feasibility with Nebraska's aggregates. Thus, the second objective was to verify that the required sampling and testing is reasonable for the specifications proposed for the contractor to meet. During Phase II, Pine Bluffs Aggregate worked with NDOR by providing their available ready-to-use aggregate.

Phase II Proposed Testing Program:

The Department sampled, tested, and collected the data. The material was to conform to the requirements in Table 3.

Table 3. Required Sampling and Testing for each Trial Batch

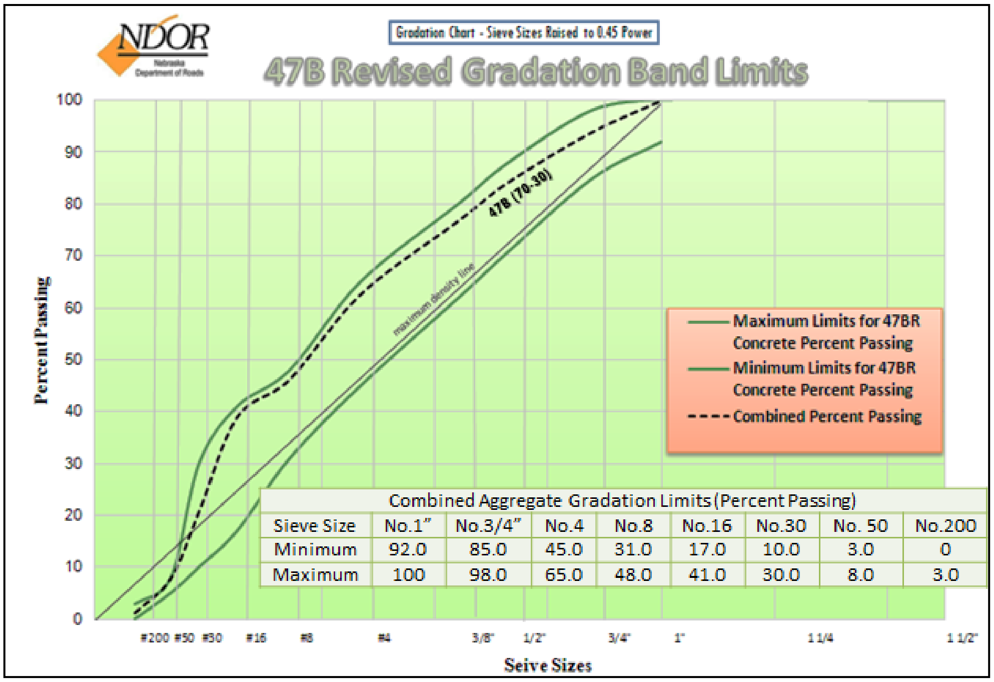
Test	Test Sample
7,14, and 28 days: Compressive Strength (3500 psi minimum) – As determined by ASTM C 39, "Compressive Strength of Cylindrical Concrete Specimens"	Average of Three Cylinders One set of 6 x 12 inch and a set of 4 x 8 inch
7, 14, 28 and 56 days: Flexure Strength (to be determined) – As determined by ASTM C 78, "Flexural Strength of Concrete Using Simple Beam with Third Point Loading"	Average of Three Beams Specimen size 7 x 7 x 21 inch
28 and 56 days: Modulus of Elasticity – As determined by ASTM C 469, "Static Modulus of Elasticity of Concrete in Compression"	Specimen size 4 x 8 inch Total (4) cylinders
28 Day Expansion < 0.10% - As determined by ASTM C 1567, "Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate"	Average of Three Beams Specimen Size 1 x 1 x 11 inch

Phase II Timeline:

- **2009 - Actions in the Field and Laboratory:**

Two full-scale ready-mix concrete trials were tested in December of 2009. These two mixes followed the proposed 47BR combined gradation shown in Figure 2. The testing of each specimen met the specified requirements in Table 3. Each specimen was tested by the NDOR Portland Cement Concrete laboratory at the Materials & Research facility in Lincoln.

Figure 2. 47BR Gradation Limits



The results of the two full-scale ready-mix concrete trials are shown in Table 4.

Table 4. Description of Proportioned Mix Designs and Test Results – 2009 Phase II

Performed	Paving Blends	W/CM Ratio	ASTM C 1567 28 Days	Compressive Strength (psi)			Flexure Strength (psi)			Permeability (Coulombs)	Total Hardened Air Count
NDOR's Req.		Max 0.48	% Expansion <0.10%	3500 min. psi @ 28 days			To be determined			56 Days	7.5-10 %
				7 Days	16 Days	28 Days	7 Days	28 Days	56 Days		
Dec, 2009	80% Pine 20 % NP	0.45	0.04	3820	4340	5020	490	580	580	Moderate	7.0
	80 % Pine 10% NP 10% 47B Coarse	0.44		3670	4200	4770	480	560	590	Low	8.4
	47B Concrete Control Mix	0.44		4370	4990	5680	460	630	660	Very Low	9.5

- **<u>2009 Summary of Testing</u>:**

The main objective of the work conducted with these two mixes meeting the 47BR combined aggregate specification was to determine the effect of the concrete quality in comparison with the regular 47B combined aggregate specification on pavement performance, especially the effect of strength and altering associated properties. One of the specified requirements for paving operations were defined by flexure strength, which was set for 600 psi at 28 days for pavement design, compressive strength at 28 days for final pavement acceptance, and air content. During the work of 2009, the research team found that the flexure strength variability within a single operator can be an issue when approving a mix design. Meanwhile, the Department was set to develop a special provision called 47BR Class of Concrete keeping all the mix design requirements the same but the aggregates in order to use the 47BR concrete in a construction project and to continue monitoring its performance.

- **<u>2010 - Actions in the Field and Laboratory</u>:**

A special provision for Class 47BR concrete was let in April of 2010. The primary goal for the new 47BR combined aggregate gradation was to have the contractor, with agency oversight, develop a concrete mix design with an optimum combined aggregate gradation and provide the contractor with the testing and quality control responsibilities to ensure a quality product. For the mix design approval process, the contractor was responsible for the following:

1. The contractor was responsible for the design and control of the mix design. This included the target combined gradation percent passing.

2. Material information was to be included: aggregates and cement sources.

3. Test information for mix design include: Air, Unit Weight, Compressive Strength and Flexure Strength.
   a. 3500 psi @ 28 days Compressive Strength - ASTM C 39.
   b. Average of three beams @ 28 days would have a Flexure Strength target of 600 psi - ASTM C 78.

4. ASR testing – The results at 28 days would be less than 0.10% per ASTM C 1567.

5. During Construction - NDOR Verification Testing:
   a. Production and Testing of Aggregate:
      i. The aggregate combination shall not vary greater than 3% of the original submitted aggregate combination.
      ii. Blended Aggregate Production Tolerances (Table 5)

Table 5.

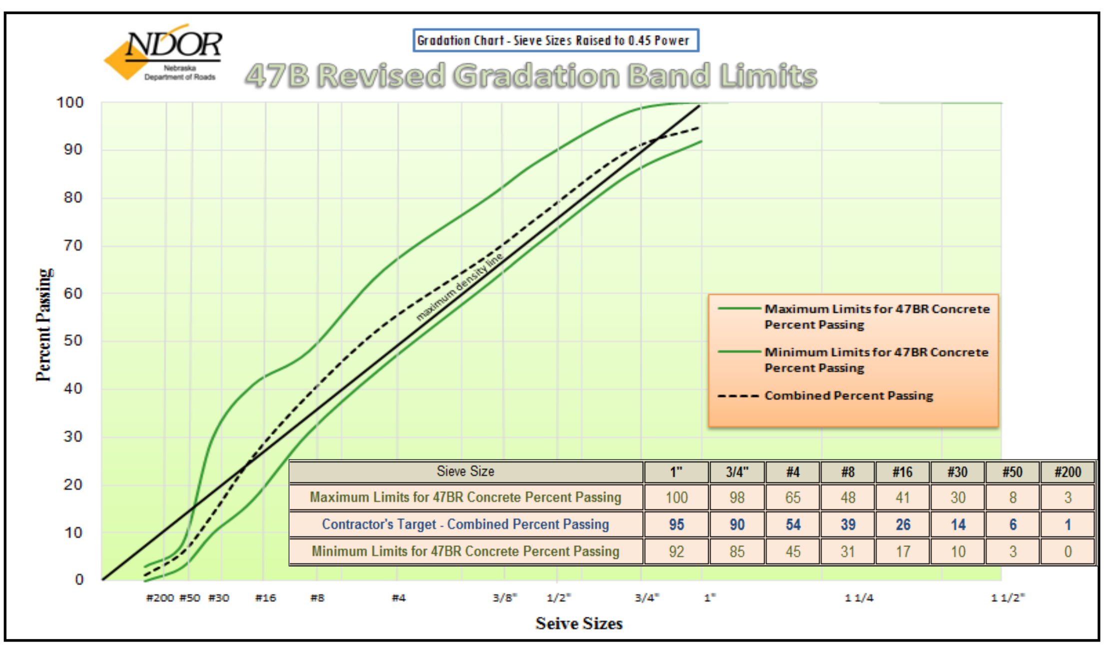
Sieve Size	Tolerances
No. 4 or greater (4.75 mm or greater)	+ 5%
No. 8 to No. 30 (2.36 to 600 μm)	+ 4%
No. 50 (300 μm)	+ 3%
Minus No. 200 (75 μm)	+ 1%

The 47BR specification was used on a project north of Kimball in the summer of 2010. Figure 3 shows the aggregate production facility in the western part of the state that was providing aggregates to the Kimball's project.

Figure 3. Aggregate Production Facility Pine Bluffs at Kimball, Nebraska

A 100% combined local aggregate blend, without any use of limestone coarse aggregate, was submitted for approval, as shown in Figure 4. The combined gradation was evaluated by the use of the 0.45 power plot. The reference to a maximum density line drawn from the origin to the intersection of 100 percent passing line with the first sieve to retain aggregate or the maximum sieve 1 inch served to evaluate how dense the combined aggregate gradation was going to be in the mix design.

Figure 4. Combined Aggregate Gradation Band and Combined Aggregate Gradation (Contractor's Target)



Sieve Size	1"	3/4"	#4	#8	#16	#30	#50	#200
Maximum Limits for 47BR Concrete Percent Passing	100	98	65	48	41	30	8	3
Contractor's Target - Combined Percent Passing	**95**	**90**	**54**	**39**	**26**	**14**	**6**	**1**
Minimum Limits for 47BR Concrete Percent Passing	92	85	45	31	17	10	3	0

The follow-up evaluation of the Department's parallel testing with the Contractor's testing is shown in Figure 5. Specimens were made at the Pine Bluffs Ready-Mix Facility in Kimball, NE. Specimens were transported to NDOR PCC's Laboratory in Lincoln, NE after 24 hours of curing.

Figure 5. Department's Parallel Testing.

The combined aggregate gradation submitted for this project was a coarser blend. The research team tested mechanical properties (compressive and flexure strength), durability properties, alkali-silica reaction, hardened air, and shrinkage for this blend. The research team obtained samples during the ASTM C 94 "Standard Specification for Ready-Mixed Concrete Testing". This test covers the mixing time and the manufactured freshly mixed concrete properties of a Portable or Stationary ready mix plant before the paving operations begins. Also, the mechanical and durability properties were tested for the mixed concrete delivered to the project. This concrete would represent the in-situ concrete. The test results of mechanical and durability properties are shown in Table 6.

Table 6. Contractor's Mix Designs and Test Results – 2010 Phase II

Performed	Paving Blends	W/CM Ratio	Slump (inches)	ASTM C 1567 28 Days	Compressive Strength (PSI) (Average of Three Specimens)				Flexure Strength (psi) (Average of Three Specimens)		
NDOR's Req.		Max 0.48	-	% Expansion <0.10 %	3500 min. psi				600 min. psi		
					3 Days	7 Days	16 Days	28 Days	7 Days	14 Days	28 Days
August 2010	47BR Concrete 100% Sand & Gravel	0.41	3/4	0.04	2830	3400	4040	4810	470	520	590

During placement the mix design exhibited fairly low workability and finish ability in the slab. It was noted that the finishers had a slight amount of trouble when finishing. In fact, the contractor tempered the surface of the slab during the paving operations, as shown in Figure 6. As more mixes were evaluated, the Department recognized the need of High Range Water Reducers as an option to improve the workability for this type of coarser mix design.

Figure 6. Slab Surface Tempered During Paving Operations.

The contractor's targeted combined aggregate gradation met NDOR's requirements for the 47BR blended aggregate specification. However, this gradation was characterized as being a coarser type mix design, which tends to have low workability. In fact, due to low workability of the mix design being used on the Kimball Project during paving operations, the research team proposed performing two additional mix designs changing the admixture type. In one of the two mixes, the cementitious material was increased, as shown in Table 7. Tables 8 and 9 reflect the project mix design, except for the change in admixture type. Table 8 shows the use of a mid-range water reducer and Table 9 shows a low-range water reducer which was supplied by the contractor.

Table 7. Mix Design #1

Components	**Weights 1 Cubic Yard**
Cement	610 lbs
Aggregate Pine Bluffs Sand & Gravel Aggregate	2908 lbs
Target W/SCM Ratio	0.39
Target % Air Content	7.5
Water	238 lbs
Air Entraining	2.9 oz
Water Reducer – Mid Range (Type F)	8 oz

Table 8. Mix Design #2

Components	Weights 1 Cubic Yard
Cement	564 lbs
Aggregate Pine Bluffs Sand & Gravel Aggregate	2908 lbs
Target W/SCM Ratio	0.39
Target % Air Content	7.5
Water	238 lbs
Air Entraining	2.9 oz
Water Reducer – Mid Range (Type F)	8 oz

Table 9. Control- Mix Design #3

Components	Weights 1 Cubic Yard
Cement	564 lbs
Aggregate Pine Bluffs Sand & Gravel Aggregate	2908 lbs
Target W/SCM Ratio	0.41
Target % Air Content	7.5
Water	Same as Project
Air Entraining	Same as Project
Water Reducer – Low Range (Type A)	Same as Project

On November 18th of 2010, the research team tested mechanical and durability properties of all three mixes. The tests that where conducted was compressive strength, flexure strength, modulus of elasticity, hardened air, shrinkage and freeze/thaw. The research team obtained the samples at the contractors' plant site in Kimball, NE. The research mixes were tested as shown in Figures 7 and 8.

Figures 7 & 8. Mechanical PropertiesTesting.

The test results from the research mixes shown in Table 10, show the evaluation of the mixes with change in the type of admixure from low-range to mid-range and the evaluation of performance by increasing the cement content. The results show the workability was improved by the use of the mid-range water reducer; however, the increase in cement content did not help for the final mechanical properties.

Table 10. Research Designs and Test Results – 2010 Phase II

Performed	Paving Blends	W/CM Ratio	Slump (in)	Permeability (Coulomb Passed)	Compressive Strength (psi) (Average of Three Specimens)				Flexure Strength (psi) (Average of Three Specimens)		
NDOR's Req.		Max 0.48	-	-	3500 min. psi				600 min. psi		
					3 Days	6Days	14 Days	28 Days	14 Days	28 Days	56 Days
Nov 2010	47BR Concrete 6 Sacks w/ Low-Range	0.41	½		2600	3000	3400	4350	400	460	510
Nov 2010	47BR Concrete 6 Sacks w/ Mid-Range	0.39	¾	Low	3300	3890	4710	5362	470	510	560
Nov 2010	47BR Concrete 6 1/2 Sack	0.40	1		3170	3620	4340	5110	440	500	520

- **<u>2010 Summary of Testing</u>:**

Using the 47BR concrete specifications during the 2010 paving operation, the lessons learned are described and highlighted as follows:

1. Pre-Construction Meeting – Material and Research must attend these meetings in order to introduce and discuss the new specification.

2. Contractor and NDOR field personnel must be familiar with the new specifications; such as, but not limited to:
    a. The use of a 0.45 power plot to evaluate the combined aggregate gradation proposed.
    b. The contractors' familiarity with the maximum and minimum tolerance for the maximum density line combination of aggregates.

3. Due to the Coarser Aggregate – the concrete placement was improved by using the mid-range water reducer instead of low-range water reducer. The use of a mid-range water reducer will be only required for the 47BR specification.

4. The stockpile at the plant site was a challenge (Figure 9) due to the coarser gravel and a dust coating of the aggregate. This was found to be an issue when reviewing the dry pit aggregate pumping operation.

Figure 9. Aggregate Stock Pile at the Project site Kimball, Nebraska.

5. Sand Equivalent (dry pit aggregate dust coating) - the sand equivalent is a test that covers the determination of the effects of organic matter found in fine aggregate. The dust coating found on the aggregate did not allow the paste to adhere to the aggregate during concrete production and placement, as shown in Figure 10.

Figure 10. Aggregate's dust coating observed during paving operations.

6. Mechanical Properties – Flexure strength was not consistent when correlating field cure flexural beam strength results. The research team found variability in test results while trying to complete the approval process of the mix design for this project. The reported flexural strength test results frequently exhibited excessive variability, and since there are numerous potential sources for this variability such as, but not limited to, number of days for cure time, sample molding, handling, testing, and transportation. Therefore, further evaluation is needed. Figure 11. shows flexure beam specimens.

Figure 11. Flexure Beam Specimens.

The research team found, during the 2010 47BR concrete paving project in Kimball, NE, that the coarser plus value of the aggregate needed further evaluation; as well as, the sand equivalent and flexure strength testing in order to enhance the 47BR Concrete Specification.

- **<u>2011 - Actions in the Field and Laboratory</u>:**

The evaluation of the 47BR specification continued in order to investigate the following:

1. Sand Equivalent for Dry Pit Aggregate Sources
2. Flexure Strength Variability
3. Coarser Factor to improved Mechanical Properties

1. <u>Sand Equivalent Evaluation</u>:

Sand Equivalent testing evaluates the dust ratio effect in final mechanical properties in accordance with AASTHO T 176 in fine aggregates from a dry pit aggregate source. This test separates the fine aggregate sample's sand, plastic fines and dust portion to determine the content of the impurities. Lower sand equivalent values indicate higher plastic fines and dust content. The result for comparison of the dry pit aggregates versus wet pit aggregates as shown in Figure 12.

Figure 12. Sand Equivalent Comparison of Dry Pit vs. Wet Pit Results

The Department define the fine aggregate (FA) as pit run (gravel found in natural deposits) that is produced from wet and dry pits. Wet pits are excavated by methods of pumping and this material is considered washed. The wet pits, based on past performance of the sand equivalent history, run an average of 98 percent. For aggregate from a dry pit location, the Department stipulates that aggregates shall be washed and clean of any coating. However, the Department does not specify a SA value to be met.

During the summer of 2011, the research team received crushed material from the western part of the state that had passed the ¾ inch sieve. This dry pit material was to be evaluated for mechanical properties that where enhanced from the crushed aggregate that was retained on the No. 4 sieve. This material was tested in the PCC laboratory as a preliminary screening for the mechanical performance of compressive and flexure strength. Full-scale testing took place at a ready-mix location for the mechanical properties as well.

The sand equivalent test was based on washed and unwashed aggregate received from the Pine Bluffs source aggregate (dry pit). Figures 12 & 13 show the coating particles on the aggregate received from Pine Bluffs.

Figures 12 & 13. Aggregate Coating Dust

The laboratory aggregate method of washing is displayed in Figures 14, 15, and 16.

Figure 14.

Figure 15.

Figure 16.

To verify the loss of any material on sieve No. 50 and No. 200 was performed by running gradation and compared to the gradation of unwashed aggregate (Table 11). The washed material was checked according to the tolerances set during production of the combined aggregate gradations 47BR specification. The results showed that the material lost by the laboratory means of washing was within the production tolerances.

Table 11. Washed Material Verification

Nebraska Department of Roads
Optimized Aggregate Gradation for Concrete

Project Name/ Control Number:	Dry Pit									
Project No.	NA									
Production Date:	Sep 13,2011									
Class of Concrete	47BR									
Site Manager No..										
Station										
Aggregate Legal Location	Pit No:		Location	SW 1/4	Section	13	T 15N	R 56		
Sample From:(Pit,Car,Truck, Windrow,Stockpile)										
Blend #	100% Blend									
	Aggregate	Sieve Size (Percent Passing)								
Material Data (Production No. Run/Date)	%	1"	3/4"	No.4	No.8	No.16	No.30	No.50	No.200	Sand Equivalent AASTHO T 176
Contractor's Target Gradation	**100**	**95.0**	**90.0**	**53.5**	**39.0**	**26.0**	**14.0**	**6.0**	**1.2**	78.6
Washed Constractor's Target		100.0	90.7	50.4	40.2	28.4	15.1	3.7	0.2	91.0
Production Tolerances	±	**5.0**	**5.0**	**5.0**	**4.0**	**4.0**	**4.0**	**3.0**	**1.0**	
Washed Constractor's Target		-5.0	-0.7	3.1	-1.2	-2.4	-1.1	2.3	1.0	

Table 12 shows the results from the mechanical properties during the ready-mix trial in Lincoln. It was clear that the lower sand equivalent value of 78.6% affected the final mechanical properties.

Table 12. Mechanical Properties (Washed and Unwashed) Results

Performed	Paving Blend	Compressive Strength (psi)		Flexure Strength (psi)	
NDOR's Req.		3500 min. psi @ 28 days		600 min. psi @ 28 days	
		Washed	Unwashed	Washed	Unwashed
September 2011	47BR Concrete	4920	4190	600	560

Due to the findings of lower sand equivalent values, which indicate higher plasticity and dust content and its effect on final strength in the mechanical properties, the 47BR specification was changed for dry pit aggregates. The following are the changes:

- Section 1033.02 Paragraph 3. a. (3) will be replaced by the following:
  Aggregates from a dry pit shall be washed and have a sand equivalent not less than 90 percent.

- Section 1002.03 Paragraph 8.
  Aggregate from a dry pit and coarse aggregate shall be uniformly saturated with water before it is used. The wetting shall begin 24 hours before concrete mixing to allow complete saturation.

2. <u>Flexure Strength Variability Evaluation</u>:

The research team continued pursuing the variability and perhaps error, which was demonstrated during the reported flexural strength results since the 2008 testing evaluation. There were concerns, foremost among these were the potential variability in molding of test specimens, initial curing methods, transportation to a final curing facility, and the actual testing of the samples.

The objective of the flexure strength variability evaluation was to provide some quantification of the collective impact of potential variability by generating field-cured flexural beam samples and test results within the parameters of a controlled test matrix. The evaluation consisted of the following parameters of testing of a single concrete batch, as follows:

i. Initial Curing Time Evaluation:

   a. 24 hours, 48 hours and 5 days
      i. Transportation to a final curing facility
      ii. Number of specimens 3 to 11 specimens average
      iii. Actual testing by single operator

   b. 48 hours Moisture and Water Bath Cure

The evaluation focused on the care exercised in handling and transporting the flexural beam specimens, which can have a major impact on whether sample specimens are damaged prior to testing. Likewise, care in insuring that adequate curing procedures are followed can result in acceptable test results. The procedural practices and errors may indeed play a large part in the derivation of unacceptable flexural strength test results, even if there is no real strength and variability problem with the actual concrete in the placement.

i. Initial Curing Evaluation:

a. 24 and 48 hours Field Cure and Transport:

The field test batch was tested at the contractor’s project site. The technicians returned within 24 and 48 hours after casting to pick up the specimens and transport them to the testing facility. Four flexure beams were made for the field curing period of 24 and 48 hours. They were transported to the final curing facility and tested in Lincoln. All specimens were placed in a water bath cure tank at the laboratory and moisture cured according to ASTM C78. The transport distance for this specific field trial was about 30 minutes, which does not compare to the transport distance from the western part of the state, which could be up to 8 – 9 hrs. It is important to mention that during transportation the beam specimens were not kept moist, but plastic covers were placed on each specimen. The covers did not guarantee the prevention of moisture loss from the specimens. Table 13 below shows the results obtained from the evaluation of 24 hours versus 48 hours field cure and transport effects. The results showed there is an impact in handling and transporting the flexural beam specimens within 24 hours versus 48 hours, resulting in a 60 psi increase in final flexure strength. However, the flexure strength variability still remained within the 4 specimens tested, averaging only 2 specimens that met ASTM C 78 coefficient of variation of 16% within a single operator.

Table 13. 24 and 48 hours Field Cure and Transport Results

Performed	Paving Blend	Compressive Strength (psi)	Flexure Strength (psi)	
NDOR's Req.		3500 min. psi @ 28 days	600 min. psi @ 28 days	
		Project Compressive Strength	24 hrs 4 Specimens	48 hrs 4 Specimens
September 2011	47B Concrete	5490	610 (2 Specimens Averaged)	670 (2 Specimens Averaged)

b. 48 hours Moisture and Water Bath Cure:

The ready-mix test batch, which was delivered to the Materials & Research facility, was cast inside the PCC laboratory (see Figures 17 & 18), which protected the flexure beams from the sun and direct wind, causing the moisture cure to be maintained. The specimens were all cured for two days at the site of casting. At the end of the 48 hours cure, laboratory technicians stripped the molds and placed 8 beams in the water bath and 8 beams in the moisture room for 28 days. Table 14 displays the results of specimens cured in temperature controlled lime water baths and a curing room meeting the specification of ASTM C 31 for curing concrete test specimens.

Figures 17 & 18. Flexure Beam Specimens

Details of the testing process were also collected and reported along with the flexure strength test results. These included loading rate, gap measurement, beam size, beam weight, moisture condition, etc. The results showed no strength gain was measured within the moisture and water bath cure. However, the specimen variability continued to be an issue when averaging all specimens and then compared to the coefficient of single operator precision. Table 14 describes the results of the 48 hours cure and transfer to the moisture room and water bath cures.

Table 14. 48 hours Moisture and Water Bath Cure Results

Performed	Paving Blend	Compressive Strength (psi)	Flexure Strength (psi)	
NDOR's Req.		3500 min. psi @ 28 days	600 min. psi @ 28 days	
		Project Compressive Strength	Moisture Cure Total 8 Specimens	Water Bath Cure Total 8 Specimens
October 2011	47B Concrete	5490	640 (3 Specimens Averaged)	640 (6 Specimens Averaged)

Analysis of variance was conducted for the following during the fall of 2011:

- Initial Curing Time Evaluation
    - 24 hours, 48 hours and 5 days.
- Transportation to a final curing facility
- Number of specimens

Within the controlled ranges for those variables maintained within the investigation and testing, the cure time of 24 and 48 hours at the time of testing was found to have a small, but significant impact on the flexural strength of only 60 psi. However, the initial curing time evaluation will continue to narrow down the variability of total specimens averaged, in which 5 days cure will be further investigated. As discussed previously, there are other impact factors related to testing which were identified, including specimen drying during transportation, haul distance, and curing time in order to control the moisture loss during transportation. Every attempt was made to control these factors so they would not affect the results of the flexural strength testing. While ranges for these variables were reported as noted in Tables 13 & 14, they were not found to have a statistically significant effect within these controlled ranges. The objective for the testing in 2012 is an effort to demonstrate that the flexure strength could indeed be reasonably achieved and be reliable for mix approval.

- **<u>2012 – Actions base on findings in the Field and the Laboratory</u>:**

Based on the findings in 2011, the following changes were made for the 47BR Specification and were carried out during the remainder of the evaluation:

- Aggregates from a dry pit shall be washed and have a sand equivalent not less than 90 percent.

- Aggregate from a dry pit and coarse aggregate shall be uniformly saturated with water before it is used. The wetting shall begin 24 hours before concrete mixing to allow complete saturation.

- 47BR Concrete shall use a mid-range water-reducing admixture.

In 2012, NDOR continued the partnership with Paulsen Construction Concrete Company, Inc, Lyman-Richey Corporation and Pine Bluffs Sand & Gravel to explore gravels from the eastern, central and western parts of the state. These producers continued to work with the Department on the pursuit and endeavor of mix field trials providing their available ready-to-use aggregate.

The research team performed on all 47BR -mix trials the following concrete properties:

- Concrete Temperature at Time of Sampling.
- Water/Cement Ratio.
- Air Content of Plastic Concrete – ASTM C 231.
- Unit Weight of Plastic Concrete – ASTM C 138.
- Sieve Analysis of Combined Aggregate (Accumulative Combined-Percent Passing).
- 7, 14 and 28-Day Compressive Strength – ASTM C 39.
- 28-day Flexure Strength (5 Days of Field Curing) – ASTM C 78.
- Test Method-Surface Resistivity Indication of Concrete's Ability to Resist Chloride Ion Penetration AASHTO (TP 95-1)

Eastern Aggregate Sources Evaluation:

Two mixes were performed with Central Sand & Gravel's Aggregate at Gerhold Concrete located in Columbus. The material used was a coarser intermediate with sieve sizes ranging from #4 to #50 with no fines on the #200 sieve. On August 1st, one mix design was performed with 85 percent nominal gravel (SG) with 15 percent limestone (L) described as (85%SG-15%L) shown in Table 14.

A second mix design was performed with the same proportioning, but the 15% material was replaced with coarser nominal gravel (C) described as (85%SG-15%C). The sieve analysis of the combined aggregates is shown in Table 15. Since a coarser intermediate gradation was used, workability was expected to be affected; therefore, a mid-range water reducer was used on these two mix designs to enhance workability.

Table 14. Sieve Analysis of Combined Aggregate (85%SG-15%L)

Combined Aggregate Gradation Limits (Accumulative Combined Percent Passing)*								
Sieve Size	**No.1”**	**No.3/4”**	**No.4**	**No.8**	**No.16**	**No.30**	**No. 50**	**No.200**
Minimum	**92.0**	**85.0**	**45.0**	**31.0**	**17.0**	**10.0**	**3.0**	**0**
Combined Gradation	99.7	97.0	**90.5**	**18.8**	**10.8**	**8.0**	**4.4**	0.3
Maximum	**100**	**98.0**	**65.0**	**48.0**	**41.0**	**30.0**	**8.0**	**3.0**

* *For the purpose of this investigation, the intermediate sieve size was out on the 47BR specification.*

Table 15. Sieve Analysis of Combined Aggregate (85%SG-15%C)

Combined Aggregate Gradation Limits (Accumulative Combined Percent Passing)*								
Sieve Size	**No.1”**	**No.3/4”**	**No.4**	**No.8**	**No.16**	**No.30**	**No. 50**	**No.200**
Minimum	**92.0**	**85.0**	**45.0**	**31.0**	**17.0**	**10.0**	**3.0**	**0**
Combined Gradation	100	**99.6**	56.6	**18.2**	**10.4**	**7.8**	**4.3**	0
Maximum	**100**	**98.0**	**65.0**	**48.0**	**41.0**	**30.0**	**8.0**	**3.0**

** For the purpose of this investigation, the intermediate sieve size was out on the 47BR specification*

Table 16 shows the initial mix trial and laboratory test results. The (85%SG-15%L) presented good concrete mechanical properties of compressive and flexure strengths. A low permeability will help to keep the salt and deicers from penetrating the concrete surface. However, the second mix design with the coarser nominal gravel has shown low gain in concrete mechanical properties in compressive and flexure strengths. The compressive strength gains at early age were low; as well as, the flexure strengths results were also found variable by having two specimens outside of the total average.

Table 16. Concrete Properties Evaluated Results

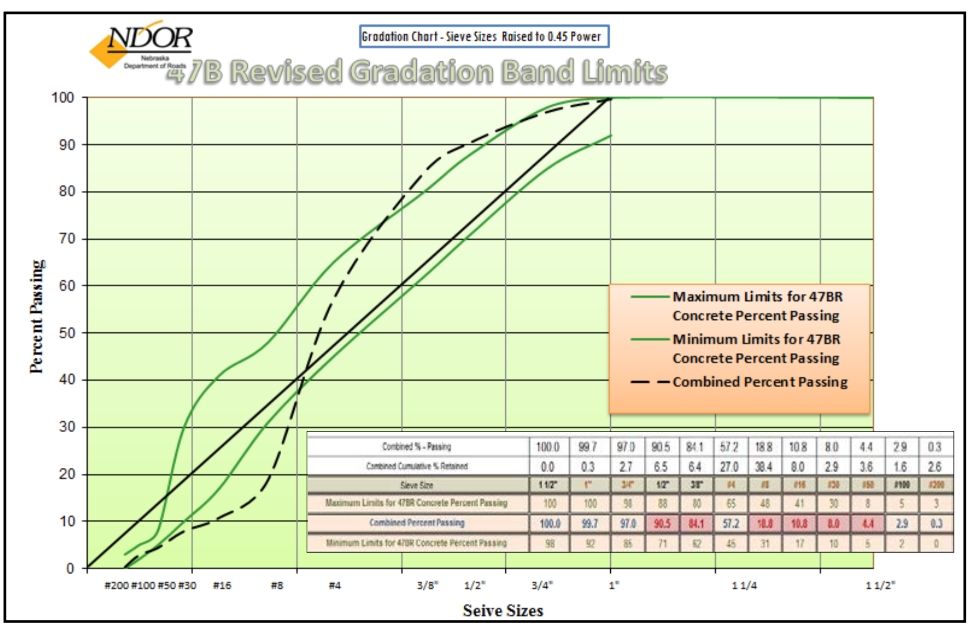
Performed	Proportioned Mix Designs	W/CM Ratio	Air Content (%)	Unit Weight Cu.yd	14 Days Compressive Strength (psi)	28 Days Compressive Strength (psi)	28 Days Flexure Strength (psi)	Chloride Ion Permeability KOhm-cm
NDOR’s Req.		Max 0.48	7.5- 10	-	3500 min. psi @ 28 days		Min. 600 psi	-
August 2012	85% Sand & Gravel - 15% Limestone	0.43	7.9	137	3890	4110	600 (6 Specimens Averaged)	Low
	85% Sand & Gravel - 15% Coarser Nominal Gravel	0.44	9.5	135	3130	3530	560 (6 Specimens Averaged)	Moderate

During these mix trials the flexure strength beam specimens were increased from 3 to 11 specimens for total average for each mix tested. All specimens were evaluated according to ASTM C 78 for precision for the coefficient of variation of test results with the same operator. The aggregate in the beams for flexure strength break through the aggregate with a minimum aggregate pop outs, as shown in Figure 19.

Figure 19. Flexure Strength Break Through Aggregate

Mechanical properties were obtained with the combined aggregate gradation of 85% S&G and 15% Limestone. However, this coarser sand may not be available from local suppliers and it may not be economical to be manufactured for production. Thus the mixes tend to be gap-graded (Figure 20) and highly coarser on the fine side, and prone to be very hard to finish due to the workability factor.

Figure 20. Combined Aggregate Gradation Band and Combined Aggregate Gradation (85%S&G and 15%L)



Combined % - Passing	100.0	99.7	97.0	90.5	84.1	57.2	18.8	10.8	8.0	4.4	2.9	0.3
Combined Cumulative % Retained	0.0	0.3	2.7	6.5	6.4	27.0	38.4	8.0	2.9	3.6	1.6	2.6
Sieve Size	1 1/2"	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
Maximum Limits for 47BR Concrete Percent Passing	100	100	98	88	80	65	48	41	30	8	5	3
Combined Percent Passing	100.0	99.7	97.0	90.5	84.1	57.2	18.8	10.8	8.0	4.4	2.9	0.3
Minimum Limits for 47BR Concrete Percent Passing	98	92	85	71	62	45	31	17	10	5	2	0

Western Aggregate Sources:

During the summer of 2012 there were several mixes evaluated from the Sidney's available aggregate material. Figures 20, 21 and 22 shows the aggregate plant site at Sidney's pit location and the quantity of aggregate produced, which are in abundance of coarser sand and gravel material as found in the dry deposit in the western part of the state. There was a lot of communication that took place between the aggregate producer and the research team before mix trails began.

Figure 20. Aggregate Plant Site

Figure 21. Aggregate Produced

Figure 22. Plant Site

There were five different mix designs evaluated during summer through the fall of 2012. The purpose of these 47BR combined aggregate gradations, as shown in Table 17, was to evaluate the potential of coarser nominal gravel from the western part of the state utilizing their available ready-to-use material.

Table 17. Sieve Analysis of Combined Aggregate Tested

Combined Aggregate Gradation Limits (Percent Passing)*								
Sieve Size	**No. 1"**	**No.3/4"**	**No.4**	**No.8**	**No.16**	**No.30**	**No. 50**	**No.200**
Minimum	**92.0**	**85.0**	**45.0**	**31.0**	**17.0**	**10.0**	**3.0**	**0**
(#1) 55% S&G - 45%Coarser Nominal	100	94.2	46.0	32.4	24.1	14.2	5.4	1.1
(#2) 60% S&G - 40% Coarser Nominal	100	94.8	50.0	35.2	26.2	15.4	5.8	1.2
(#3) 60% S&G - 20% Coarser Nominal - 20% ¾ Crushed Nominal	100	96.8	51.6	36.0	31.3	15.4	5.8	1.4
(#4) 70% S&G - 30% Coarser Nominal	99.7	94.6	57.7	40.9	30.4	17.5	6.3	1.4
(#5)* 85% finer 2A - 15% Coarser Nominal	99.9	97.3	45.2	21.2	12.1	6.4	1.8	0.6
Maximum	**100**	**98.0**	**65.0**	**48.0**	**41.0**	**30.0**	**8.0**	**3.0**

**For the purpose of this investigation, the intermediate sieve was out on the 47BR specification*

For each combined aggregate tested, Test Method NDR T 27 Sieve Analysis was performed as shown in Figures 23 to 27 at the Aggregate Laboratory in Lincoln. The combined gradation of a particular mix design was determined by a sieve analysis. In a sieve analysis, a sample of dry aggregate of known weight is separated through a series of sieves with progressively smaller openings. Once separated, the weight of particles retained on each sieve was measured and compared to the total sample weight as shown in Figure 27.

Figure 23. Dry Sample

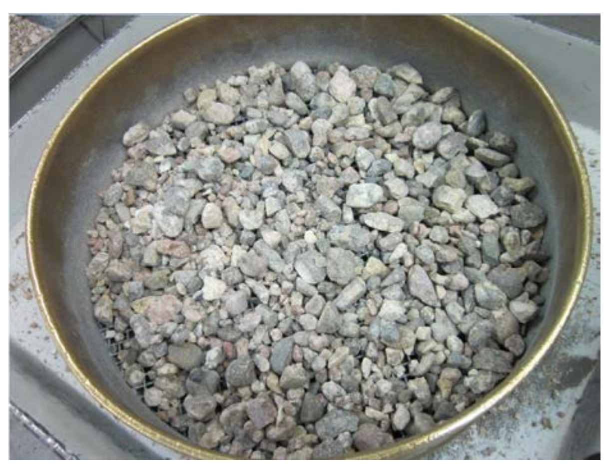


Figure 24. Sample Preparation

Figure 25. Weighing Sample

Figure 26. Aggregate Through a Series of Sieves

Figure 27. Weighing of Particles Retained on Each Sieve

Particle size distribution was then expressed and calculated as a percent passing by weight on each sieve size to compare it to the maximum and minimum tolerance limits per the 47BR Specification. The results were then plotted in a spreadsheet developed by the 0.45 power curve concept. It was created by plotting the cumulative percent passing (y-axis) versus the sieve raised to the 0.45 power (x-axis). The chart displays the maximum and minimum limits for the 47B Revised gradation band by plotting the cumulative percent passing versus the sieve sizes.

Figure 28 shows the sample of material gradation input and Figure 29 shows the gradation chart associated with the combined gradation. The research team developed an excel spreadsheet allowing the user to input sieve analysis results and aggregate percentages. The spreadsheet creates the chart needed for the cumulative aggregate percent passing to meet the specification.

NDOR

Nebraska Department of Roads
Optimized Aggregate Gradation for Concrete

Project Name/ Control Number:	NA
Project No.	NA
Date:	7/13/2009
Class of Concrete	1PF
Blend #	60% Sand & Gravel-20% Road Gravel-20% Guerney Stone)

	Aggregate	Sieve Size											
Material Data (Source/Type)	%	1 1/2"	1"	3/4"	1/2"	3/8"	No.4	No.8	No.16	No.30	No.50	No.100	No.200
G3 Enterprises, Inc Sand/Gravel	60	100.0	100.0	100.0	100.0	99.9	88.7	64.0	38.0	23.0	12.0	6.0	0.5
Road Gravel	20	100.0	100.0	100.0	97.0	83.0	31.0	20.0	3.8	1.0	0.7	0.5	0.5
1" x# 3/8" (Guernsey Stone)	20	100.0	100.0	69.0	19.0	5.5	0.6	0.6	0.6	0.6	0.5	0.5	0.5
	100%												

Combined % - Passing	100.0	100.0	93.8	83.2	77.6	59.5	42.5	23.7	14.1	7.4	3.8	0.5
Combined Cumulative % Retained	0.0	0.0	6.2	10.6	5.6	18.1	17.0	18.8	9.6	6.7	3.6	3.3
Sieve Size	1 1/2"	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
Maximum Limits for 47BR Concrete Percent Passing	100	100	98	88	80	65	48	41	30	8	5	3
Combined Percent Passing	100.0	100.0	93.8	83.2	77.6	59.5	42.5	23.7	14.1	7.4	3.8	0.5
Minimum Limits for 47BR Concrete Percent Passing	98	92	85	71	62	45	31	17	10	5	2	0

Created by BR (2005)
Modified by LKH (2005)

Figure 28. Identified Sample of Material Gradation Input

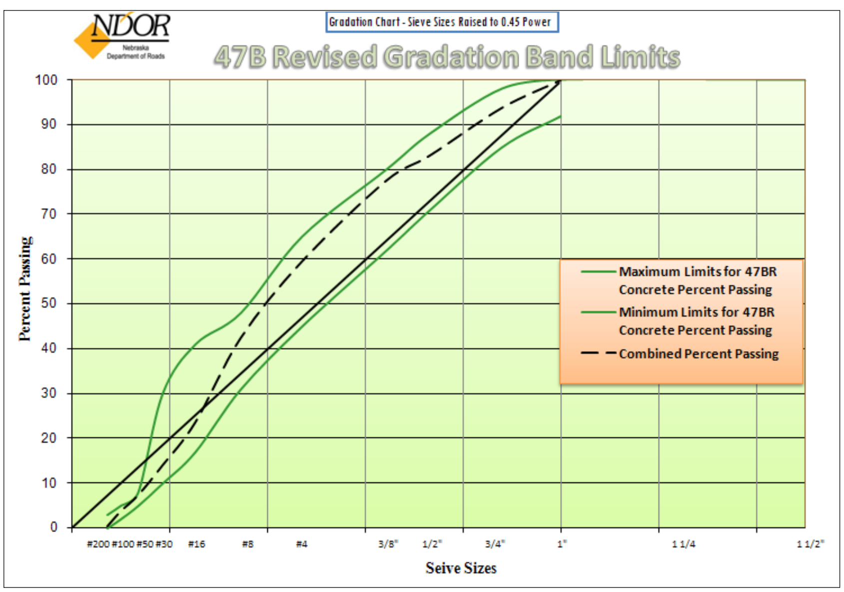


Figure 29. Gradation Chart associated with Sample of Material Gradation Input

All specimens were cast in the garage of the concrete ready-mix facility as shown in Figures 30, 31 and 32. The specimens were cured for 5 days and were kept in the garage facility. During the initial curing, the ambient temperature during fabrication was 68°F. Specimens were transported after 5 days to the PCC Laboratory in Lincoln. Per previous discussion, the flexure beams are protected from moisture loss by covering with plexi-glass, but traveling for 8 hours in the back of the pickup truck and the shifting of the load, the flexure beams may not have been protected from moisture loss with a travel distance of 8 hours. Table 18. displays the concrete properties obtained from each mix design tested at the Cornhusker Concrete in Kimball, Nebraska.

Figure 30. Concrete Workability

Figure 31. Casting of beams at the Concrete Ready Mix's Garage Facility

Figure 32. Finishing of Flexure Beams

The coarseness content of the sand was increased in all five mixes and to enhance the workability a mid-range water-reducer admixture was used. These mixes examined the effect of adding intermediate size aggregates from #4 to #50 with no fines on the #200 sieve as shown in Figure 33, which represents combined aggregate gradation for 60% S&G - 20% Coarser Nominal - 20% ¾ Crushed Nominal (Mix #3). This mix design was a coarser gradation close to the maximum side of the gradation band. As the percent of fine was decreased, the mixing water requirement was decreased. Table 18 noticeably shows; the compressive strength was enhanced when the fine side of the sand and gravel was reduced in Mixes #3 and #5.

Figure 33. Gradation Chart Associated With the Use of Three Aggregate Sizes

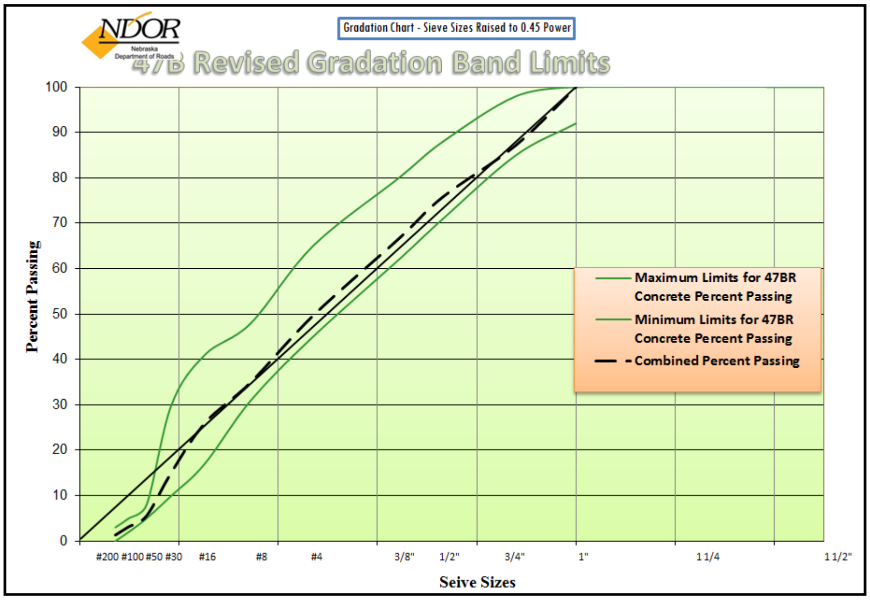


Table 18. Concrete Properties Evaluated Results

Performed	Proportioned Mix Designs	W/CM Ratio	Air Content (%)	Unit Weight Cu.yd	14 Days Compressive Strength (psi)	28 Days Compressive Strength (psi)	28 Days Flexure Strength (psi)	Chloride Ion Permeability KOhm-cm
NDOR's Req.		Max 0.48	7.5-10%	-	3500 min. psi @ 28 Days		600 psi	-
August 2012	**(#1)** 55% S&G - 45%Coarser Nominal	0.42	8.2	144.0	3910	5340	550 (4 Specimens Averaged)	Low
	(#2) 60% S&G - 40% Coarser Nominal	0.42	6.8	140.8	3100	4250	530 (4 Specimens Averaged)	Low
November 2012	**(#3)** 60% S&G - 20% Coarser Nominal - 20% ¾ Crushed Nominal	0.41	9.0	137.0	4720	5760	590 (6 Specimens Averaged)	Moderate
	(#4) 70% S&G - 30% Coarser Nominal	0.42	7.5	139.2	4620	5500	560 (9 Specimens Averaged)	Moderate
	(#5) 85% finer 2A S&G - 15% Coarser Nominal	0.42	7.5	139.6	5090	5930	615 (6 Specimens Averaged)	Moderate

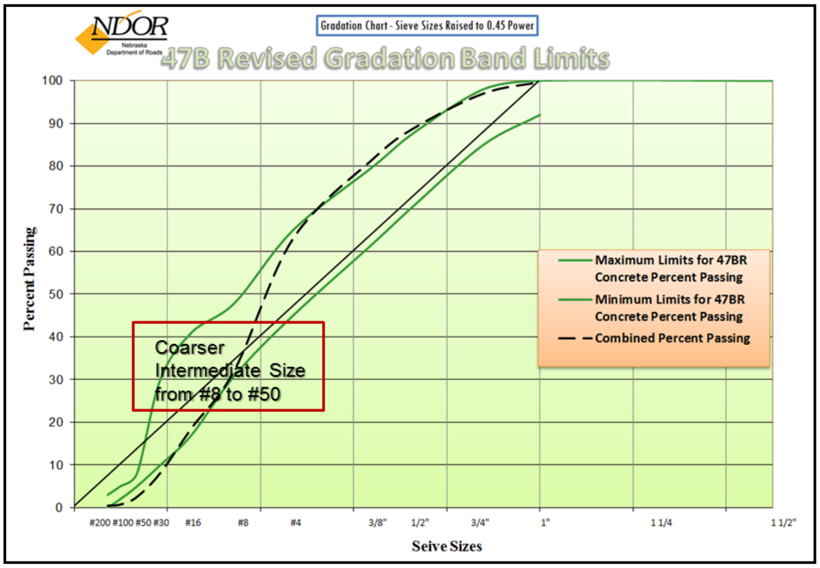


Figure 34. Gradation Chart Associated With the Intermediate Size Material Gradation Input

Mix #5, as described in Table 17, was performed by adding intermediate particles. It produced a mix that worked well with the use of a mid-range water reducer. The rounded gravel and crushed gravel (intermediate size material - Figure 34) further improved the cohesiveness and resulted in an increase of flexure strength, but the 60% fine is a 2A coarser fine aggregate making it a gap-graded combined gradation. However, this coarser sand crushed material may not be available from local suppliers and it may not be economical to be manufactured for production. Thus the mixes tend to be gap-graded (see Figure 34), highly coarser in the fine side, and prone to be very hard to finish due to the workability factor.

During the testing of aggregates from a dry pit source location, special attention was paid to the sand equivalent in order for it to meet the specification of not less than 90 percent. Also, the nominal coarse aggregate was saturated with water 24 hours in advance before the use of this material in the concrete research mixes to allow complete saturation. The contractor had double washed the aggregate from a dry pit; the aggregate was tested for sand equivalent according to AASTHO T 176. While checking the quality of the material, the Department and Contractor's testing results was found to be in variance. The Department agreed to perform additional testing when there is a variance of results. The propose change was submitted under 1033 Aggregate (Sand and Gravel Aggregate) as follows:

- If the Sand Equivalent is less than 90 percent, the Engineer may elect to stop aggregate production until such a time ASTM C 109 has been completed. The aggregate, when subjected to the test for mortar-making properties, shall produce a mortar having a compressive strength at the age of 7 days equal to or greater than that developed by mortar of the same proportions and consistency made of the same cement and aggregate after the aggregate has been washed to a sand equivalent greater than 90 percent. Materials failing to produce equal or greater strength shall be unacceptable.

Central Aggregate Sources:

The Department tested and evaluated aggregate from the Gothenburg area in accordance to the 47BR specification. The testing was performed at the contractor's facility in Lexington, Nebraska. The aggregate was supplied from one of Paulsen, Inc. wet pits. All samples of aggregates were tested and verified by NDOR's aggregate laboratory in Lincoln. Figure 35 and 36 show the gradations that where produced and the combination used to meet the 47BR specification.

Nebraska Department of Roads
Optimized Aggregate Gradation for Concrete

Project Name/ Control Number:	Gothenburg
Project No.	STR-47-2(1009)
Date:	7/4/1905
Class of Concrete	47 BR
Blend #	

	Aggregate	Sieve Size											
Material Data (Source/Type)	%	1 1/2"	1"	3/4"	1/2"	3/8"	No.4	No.8	No.16	No.30	No.50	No.100	No.200
47B- fine	70	100.0	100.0	100.0	100.0	97.0	87.0	64.0	54.0	28.0	10.0	3.0	1.0
1 1/4" roof + reg roof 50/50	30	100.0	95.6	82.9	55.7	27.9	1.7	1.0	1.0	1.0	1.0	1.0	1.0
	100%												
Combined % - Passing		100.0	98.7	94.9	86.7	76.3	61.4	45.1	38.1	19.9	7.3	2.4	1.0
Combined Cumulative % Retained		0.0	1.3	3.8	8.2	10.4	14.9	16.3	7.0	18.2	12.6	4.9	1.4
Sieve Size		1 1/2"	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
Maximum Limits for 47BR Concrete Percent Passing		100	100	98	88	80	65	48	41	30	8	5	3
Combined Percent Passing		100.0	98.7	94.9	86.7	76.3	61.4	45.1	38.1	19.9	7.3	2.4	1.0
Minimum Limits for 47BR Concrete Percent Passing		98	92	85	71	62	45	31	17	10	5	2	0

Figure 35 Sample of material gradation

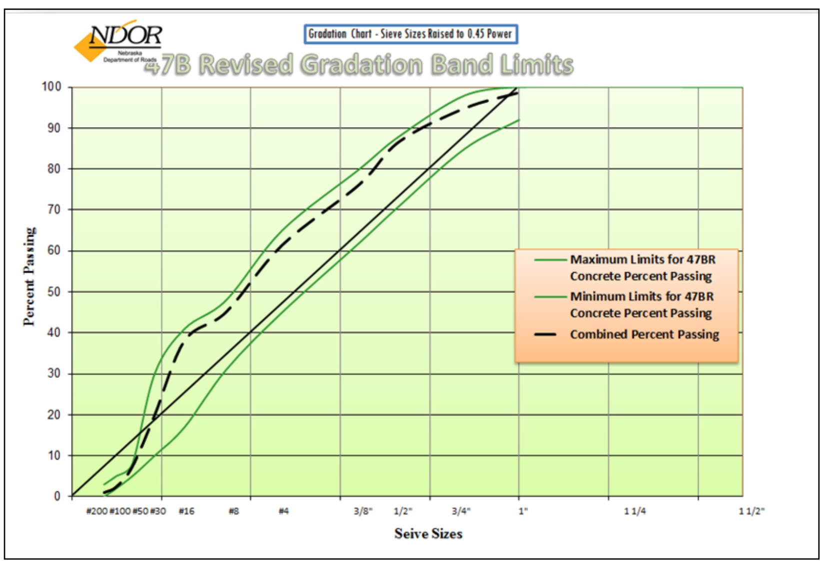


Figure 36. Gradation chart associated with second mix design.

A second combined aggregate gradation was tested and analyzed for its mechanical performance. The second mix design increased o the fines in the coarser side of the fine side of the maximum density line of the gradation band as shown in Figure 36 from sieves #8 to #50.

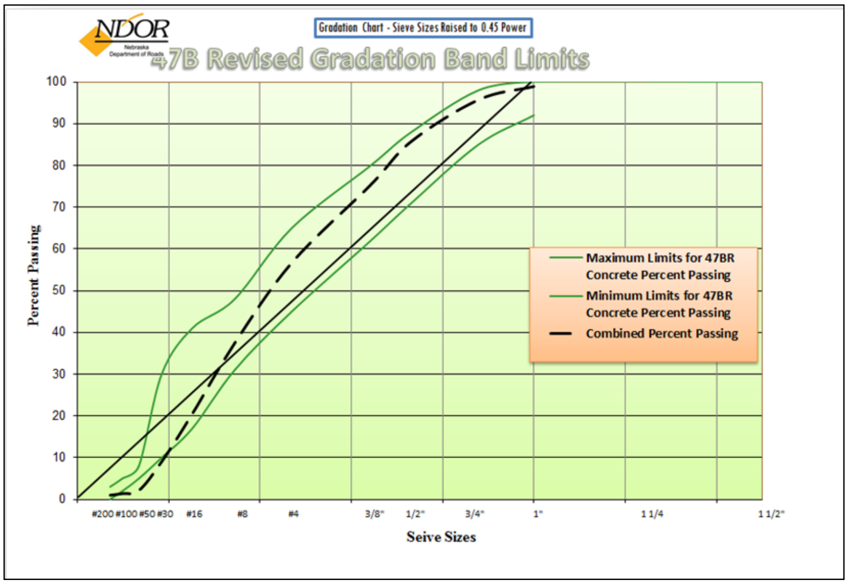


Figure 37. Gradation chart associated with second mix design.

The ready mix trial performed in Lexinton involved the analysis and trying to reduce the variability of the precision of correlation within a single operator for flexure strength. The proportions of the two gravels using the 47B fine and the use of coarser gravel commonly known as roofing gravel was analyzed in order to optimize the final flexure strength. Figures 38 and 39, show the flexure beams being cast for each mix design and the quantity of flexure beams being tested during the Lexinton ready mix field testing.

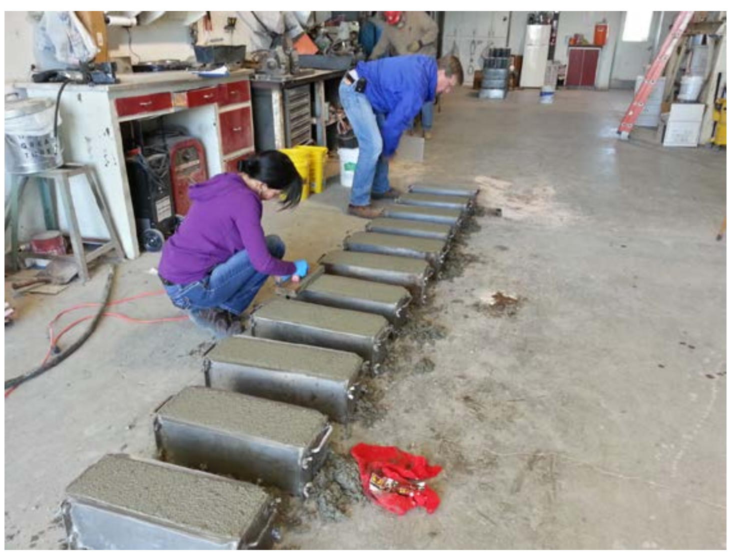


Figure 38. Samples prepared for Flexure Strength Testing

Figure 39. Samples Tested for Flexure Strength

Table 19, displays the concrete properties obtained from each mix design tested at the Paulsen Ready Mix plant. All specimens were cast and stored in the concrete ready mix's garage facility. The temperature of the concrete during fabrication of specimens was 65°F and the specimens were cured for 5 days. Specimens were transported after 5 days to PCC laboratory in Lincoln. These two mix designs were evaluated using 11 specimens for total average flexure strength, which resulted with only 9 of the 11 specimens meeting the precision of coefficient of variation with a single operator. This evaluation proves the sensitive nature of test specimens for flexure strength. In fact, the departments procedural evaluation of the practices indeed play a large part of the unacceptable flexural strength test results, the variation of transportation, the possibility of specimen losing moisture, individual practices from molding and testing of specimens. Therefore it was concluded that the Department will not require flexure strength for approval for combined aggregates gradation. Flexure strength results show no real strength and variability problems with the actual concrete tested. However, the department will continue the flexure strength testing of new mix designs for information only.

Table 19. Mechanical Properties Test Results

Performed	Proportioned Mix Designs	W/CM ratio	Air Content (%)	Unit weight Cu.yd	14 Days Compressive Strength (psi)	28 days Compressive Strength (psi)	28 days Flexure Strength (psi)	Chloride Ion Permeability KOhm-cm
NDOR's Req.		Max 0.48	7.5-10%	-	3500 min. psi @ 28 days		600 psi	-
December 2012	**(#1)** 55% S&G - 45%Coarser Nominal	0.40	8.0	140.1	3670	4290	550 (9 specimens Averaged from 11 specimens)	NA
	(#2) 60% S&G - 40% Coarser Nominal	0.38	7.6	140.8	3850	4260	570 (9 specimens Averaged from 11 specimens)	NA

CONCLUSION

During the long journey and endeavor with the industry collaboration and partnership, the Department has embraced a change that impacts a specification implemented in the 1947 for Class of 47B concrete. This change embraces today's availability of new blended cements in Nebraska. These new blended cements enhanced the Alkali Silica Reaction of Nebraska's sand and gravel. As well as, and not short of improving future gradation from a gap-graded to a more dense gradation. Optimized gradations are those that have been enhanced in some manner, such as making the material better graded, in order to enhance some property of the concrete (durability, less water demand, the use of admixtures to embrace workability). The optimized gradation utilizes available materials that will play a role in economics as the Department embraces the endeavor of planning projects for the western part of the state. Figure 40 shows the available Aggregates sources for Nebraska and also shows the Fine Aggregate-Sand and Gravels and the available sources of the coarse aggregate-Limestone. The amounts of gravels sources available in Nebraska are greater than the Limestone sources. Thus, the sand and gravel sources found in the western part of the state are coarser in nature resulting with potential benefits in a mix design, which has been proven throughout this study.

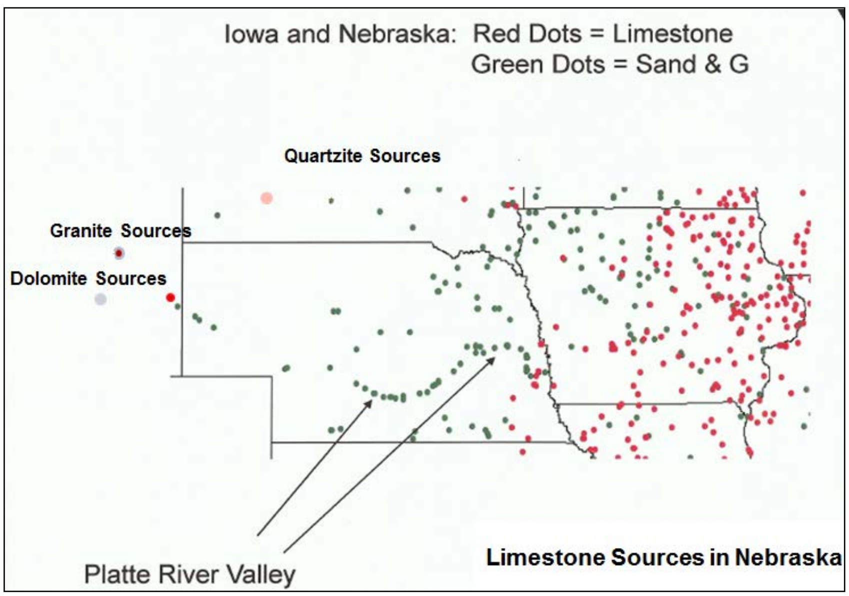


Figure 40. Nebraska's Aggregate Sources

Transportation cost plays a role in the economic impact of concrete. The average cost plus transportation for Sand & Gravel range from $6-8 per ton for the central and western part of the state. However, the average cost for a coarse material to be transported from eastern part of the state to the central-western part of the state ranges from $25-35 per ton. Therefore, having a combined aggregate gradation which allows the use of distinct aggregates fractions, coarse and fine would bring the Department lower cost and improve concrete pavements.

The goal for the new 47BR Combined Aggregate Gradation is to have the contractor, with agency oversight, develop a concrete mix design with an optimum combined aggregate gradation and provide the Contractor with the testing and control responsibilities to ensure a quality product. During the evaluation and optimization of the 47BR Concrete Specification, the specification was refined due to the finding stated in this report. The following are the changes from aggregates to mix design approval which have been implemented and accepted for Nebraska's paving construction.

Aggregates Acceptance Requirement:

The contractor shall design and meet the specification requirements. It is the contractor's responsibility to provide desirable mix properties; such as, but not limited to, workability, resistance to segregation, stable air void system, good finishing properties and good consolidation properties. The combined blended aggregate shall meet the gradation requirement in shown in Table 20.

Table 20. Contractor's Target Combined Gradation

Combined Aggregate Gradation Limits (Percent Passing)								
Sieve Size	1 inch	3/4 inch	No.4	No.8	No.16	No.30	No. 50	No.200
Minimum	92.0	85.0	45.0	31.0	17.0	8.0	2.0	0
Maximum	100	98.0	65.0	48.0	41.0	30.0	8.0	3.0

- Aggregates from a dry pit shall be washed and have a sand equivalent greater than 90 percent.

- Aggregate from a dry pit and coarse aggregate shall be uniformly saturated with water before it is used. The wetting shall begin 24 hours before concrete mixing to allow complete saturation.

- If the Sand Equivalent is less than 90 percent, the Engineer may elect to stop aggregate production until such a time ASTM C 109 has been completed. The aggregate, when subjected to the test for mortar-making properties, shall produce a mortar having a compressive strength at the age of 7 days equal to or greater than that developed by mortar of the same proportions and consistency made of the same cement and aggregate after the aggregate has been washed to a sand equivalent greater than 90 percent. Materials failing to produce equal or greater strength shall be unacceptable.

Concrete Mix Design Submittal:

The contractor will notify the PCC Engineer a minimum of 35 days, to approve the concrete mix design and schedule the trial mix prior to the start of any concrete operations. The trial concrete mix testing will be performed by Materials & Research.

Materials and Research will perform and approve the submitted 47BR combined aggregate gradation mix design.

- Mix Design Test information includes:
  - Fresh Properties –(Air, Unit weight-W/CM Ratio)
  - Compressive strength of 3500 psi @ 28 days
  - 47BR Concrete shall use a mid-range water reducer admixture.

Aggregate Production and Testing after Approval:

Any change greater than 3% in the original verified constituent percentage of the combined aggregates gradation will be considered non-compliant. Any change of the combined gradation targets must remain within the Combined Aggregate Gradation Limits in Table 20. The blended gradation tolerance ranges from the approved mix design are established in Table 21.

Table 21. Blended Aggregate Production Tolerances

Sieve Size	Tolerances
No. 4 or greater (4.75 mm or greater)	± 5%
No. 8 to No. 30 (2.36 to 600 µm)	± 4%
No. 50 (300 µm)	± 3%
Minus No. 200 (75 µm)	± 1%

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