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Use of Lightweight Concrete for Bridge Decks in Kansas

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Final Report

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Abstract

The purpose of this report is to present a summary of the work that has been done with lightweight aggregate concrete in Kansas.

Acknowledgments

Thanks to the many people at the Kansas Department of Transportation, Riley County, Atchison County, Dickinson County, and BG Consultants for all the office, laboratory work, and field work that went into the gathering of the data to allow for this summary of Lightweight Aggregate use in Kansas.

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Chapter 1: Background

The Kansas Department of Transportation (KDOT) (then the Kansas Highway Commission) began evaluating lightweight aggregate for use in bridge decks as far back as 1953. The report “Report on Availability and Suggested Usage of Lightweight Aggregate for Kansas Highway Construction” evaluated three lightweight aggregates available in and near Kansas.

Initially three materials were to be tested for use as lightweight aggregate for concrete. These included two expanded shales and one sintered clay. Preliminary testing led the researchers to evaluate only the expanded shales. The sintered clay was removed from the study due to the gradation needing a separate grading specification and was found to have a considerable amount of improperly sintered material. Additional laboratory testing for durability and soundness were run on the sintered clay.

The expanded shales were produced in Ottawa, Kansas, and New Market, Missouri. The Ottawa facility moved to Marquette, Kansas, and has recently quit producing product. Shale from the three locations is from the same geological formation but differences do exist in some of the physical properties. The New Market facility has the capability of vacuum saturation.

At the time of testing, other cities and states had constructed lightweight bridge decks. Those include the Oakland Bay Bridge in Oakland, California, and the Tacoma Narrows Bridge and Eleventh Street Bridge in Tacoma, Washington. One segment of the Fairfax Bridge in Kansas City, Kansas, was constructed with the New Market material and was reported in good condition after 19 years of service (Davis, 1961). The report stated slight spalling at a joint with less cracking than standard weight concrete sections. The reduced cracking was probably due to the internal curing action of the lightweight aggregate.

A number of tests were performed during the 1953 evaluation including Specific Gravity, Gradation, Compressive and Flexural Strength, Abrasion, Freeze-Thaw Durability, and Alkali Reactivity. Two mixes were produced using the New Market material, one without air entrainment and one with air entrainment. Six mixes were produced with the Ottawa material. Four mixes contained a typical gradation of the lightweight material and two mixes with increased material on the 3/8-inch, No. 4, and No. 8 sieves. The aggregate in the six mixes was pre-wetted.

There were a number of bridges built in Kansas using lightweight aggregate in the 1950s and early 1960s. Some were built by the Kansas Highway Commission, and others by individual counties. Several bridges were referenced in Highway Highlights (June 1955). One structure included the Kansas River Bridge at Belvue, Kansas, on Paxico Road in the mid-1950s. The Willard Bridge was also mentioned but was decked with an open grate steel deck. KDOT constructed a bridge over Tuttle Creek Reservoir, on K-16 Highway, near Randolph, Kansas, in 1961, which is still in use today. Most of the structures have been removed over the years and most of the records have been lost, but a few bridges and some information remain. Most were built following the 1945, 1955, and 1960 Kansas Highway Commission Standard Specifications. There were reports that several of the early bridge decks expanded to the point of having to have material removed from the end of the units, however, there is no written records of this occurring available. This would be expected to be caused by Alkali-Silica Reaction (ASR) or ettringite, but testing in 1965–1970 indicated that the lightweight aggregate was not significantly reactive, and recent petrographic analysis of cores from remaining lightweight bridge decks gave no indication of deleterious ettringite deposits (Lee, 2008a). Cores removed from three structures, one built in 1955, the second built in 1962, and the third built in 1975, indicated no ASR when petrographically examined. Deterioration appeared to be caused by little or no air entraining.

The Kansas Highway Commission published "Expanded Shale Used as an Admixture for Sand-Gravel Aggregate Concrete" (Bukovatz et al., 1970). This report evaluated the effectiveness of using lightweight aggregate for a sweetener for concrete mixes containing alkali reactive aggregates. This work included both field application and laboratory evaluation of the effectiveness of the lightweight aggregate as a sweetener. The field portion was started in 1965 and included widening an existing structure and tracking expansions, while the laboratory portion involved testing additional mixes and evaluating the material properties of the concrete. Twelve mixes were tested in the laboratory, four with total mixed aggregate, four with limestone sweetener, and four with lightweight sweetener varying the cement brands. Two non-air entrained mixes were tested in the field, one with limestone sweetener and one with lightweight sweetener. The aggregate used was Republican River sand, which is reactive. Expansion in the field was measured by placing brass gage points in the concrete. In September 1969 the structure was covered with asphalt, and at that point field evaluation stopped.

Lightweight bridge deck construction stopped in the early- to mid-1960s, however, the Kansas River Bridge near Maple Hill on Maple Hill Road, a county structure, was built in 1975.

There may have been others, but the records are difficult to find to determine where they may have been constructed as they would have been county structures and records remain with the counties. At this point interest in lightweight structures dropped until 2006 when KDOT Bridge Design began to inquire into the use of lightweight aggregate for structures.

In 2008 KDOT contracted with Kansas State University (KSU) for a project to evaluate the use of lightweight aggregate in concrete for structures including prestress concrete beams (Grotheer & Peterman, 2009; Perkins & Peterman, 2010). Testing was performed for compressive strength, tensile strength, modulus of elasticity, freeze-thaw, wet-dry, shrinkage, and permeability. Concrete mixes were designed with optimized gradations using lightweight aggregate and standard sand. These mixes were high in cementitious content but with a somewhat lower water/cementitious ratio than had been used previously.

After completion of the KSU project, several county projects were initiated in Kansas. The first project was in Riley and Pottawatomie Counties in 2010. This project involved the redecking and widening of an existing bridge across the Big Blue River near Manhattan, Kansas, on Rocky Ford Road. The purpose of this project was to improve safety and maintain load carrying capacity. Due to minimum cover to reduce the deck thickness and dead load a polymer overlay was installed after the concrete had completely cured. In 2011 a historic Warren truss on RS-24 (Haskell Road), was redecked in Atchison County, Kansas, to allow for increase in load carrying capacity. Again, minimum cover and minimum deck thickness were used to minimize dead load and a polymer overlay was installed. In 2012, a three-span haunch slab bridge was constructed in Dickinson County, Kansas, near Abilene on FAS 191. This project was of standard haunch slab design. All three projects were structures on county roads, and all used a sand-lightweight concrete. There were some problems pumping the concrete on the Riley County project and some difficulty controlling moisture on the Dickinson County project. Control of surface moisture on the lightweight aggregate was a key item for all three projects as was noted on the 1965 project. Changes in the KDOT stockpile handling specifications corrected these issues for later projects.

Chapter 2: Material Properties and Mix Designs

2.1 Aggregate Gradations

The Kansas Department of Transportation (then the Kansas Highway Commission) performed a review and testing in 1953. As stated, the two expanded shale aggregates available in Kansas were tested. Two mixes were made containing "Haydite" from New Market, Missouri, and six mixes were made containing the Buildex material from Ottawa, Kansas. Gradation of the materials has changed somewhat over the years with both the New Market and Marquette plants producing a coarser aggregate portion (3/8x0). The fine gradations are identified as 1/4x0 by the manufacturer (Buildex, n.d.). The 1953 gradations were used as a total aggregate for building many of the Kansas lightweight structures in the 1950s and early 1960s. The 1965 study was performed to evaluate lightweight aggregate as a sweetener to prevent Alkali–Silica Reaction. The lightweight aggregate was 30% of the total aggregate gradation by volume. The 2008 gradation in Table 1 was used as the coarse aggregate for the Kansas State University testing and for the bridge deck construction of the three county bridges in 2010, 2011, and 2012. The 2014 gradation, a fine gradation, was used for internal curing for pavement on US 54 near Iola, Kansas, in 2014. The lightweight aggregate gradations for the projects reviewed in this report can be found in Table 1.

Table 1: Lightweight Aggregate Project Gradations

Percent Retained Square Mesh Sieves*									
Sieve	**3/4"**	**1/2"**	**3/8”**	**4**	**8**	**16**	**30**	**50**	**100**
Haydite 1953	0	0	2	14	41	66	81	90	100
Buildex 1953	0	0	0	16	43	76	86	91	94
Buildex 1961**	0	0-5	0-10	5-20	30-50	60-75	77-84	85-90	90-95
Marquette 1965***	0		59	97	97	97	97	98	99
New Market 2008	0	4	20	76	95	98	98	99	99
Marquette 2008	1	14	41	96	98	99	99	99	99
New Market 2010&	0	0-35	30-70	75-100	95-100				
New Market 2011&	0	0-35	30-70	75-100	95-100				
New Market 2012&	0	0-35	30-70	75-100	95-100				
KDOT FA-A			0	0-10	0-27	15-55	40-77	70-93	90-100
New Market 2014#	0	0	0	20	46	65	80	90	95

*Gradation used for projects.
**Actual Field Gradation Unavailable
***Sweetener Only.
#Internal Curing US 54
&Combined with KDOT FA-A, Fine Aggregate

2.2 Absorption

In the 1953 study, 20-minute absorption tests were run, and the apparent absorption was found to be 9.7% for the New Market material and 7% for the Ottawa material. Information taken from the mix design for Bridge 17 (Randolph, Kansas) in Riley County in 1961 indicated that the Buildex aggregate had absorption of 16%. Work done by KDOT in 1965 indicated that the absorption of the Marquette aggregate was 10.9%, the soak time is unknown. Testing performed by Kansas State University in 2008 found the absorption to be 6.5% for New Market and 10% for Marquette with a 24-hour soak. Extended soaking indicated absorption in excess of 20% for both products. For the bridge constructed in Dickinson County in 2012, absorption was determined to be 30%, this was with an extended soak. The internal cure material used on US 54 in Iola was vacuum saturated and determined to have 20% absorption. Given this information it is apparent that the absorption can and does change as the gradation of the aggregate, location of shale removal, and process changes. Thus, the concrete supplier must take care in determining actual absorption and moisture content when batching concrete with lightweight aggregate. Determining the absorption of aggregates can be time consuming and, with some methods, subjective. However, recently a procedure was developed by Purdue University using a centrifuge to separate the surface moisture from the aggregate (AASHTO TP 139-20). Using this method both the excess moisture and the absorption can be determined for both coarse and fine aggregates.

2.3 Specific Gravity

Data that is available from the various projects and available from Buildex indicates that the specific gravity varies considerably. Field and experimental values varied from 1.23 to 1.88. Values obtained from Buildex varied between 1.05 and 1.80 depending on the source and the particular gradation. Buildex provides material in four production sizes which can be blended by them or at the concrete supplier. The New Market material typically has a higher specific gravity. Determination of the specific gravity for a particular combination of lightweight aggregate gradations is a must for consistent lightweight concrete.

2.4 Mix Design

Mix designs have varied from project to project; some changes were due to the particular project and other changes were due to specification changes. Typically, the early mix designs included very high cementitious contents with high water cementitious ratios and high paste volumes, as seen in Table 2. Mix designs through 2012 typically had a 50-50 blend of coarse and fine aggregates; this was due to KDOT Specifications requiring the 50-50 aggregate blend. Previous to 2008, the KDOT Concrete Specifications had no requirement for permeability for bridge deck concrete. The major concerns were air content and strength, thus high cementitious/paste contents were acceptable. In 2008 KDOT contracted with Kansas State University to develop better bridge deck lightweight concrete and lightweight prestress beam concrete. As part of the project was to develop a lightweight aggregate concrete for prestress beams, the KSU laboratory mixes contained high cementitious content but with a lower water cementitious ratio in an effort to increase compressive strength (Grotheer & Peterman, 2009; Perkins & Peterman, 2010). Because the 2008 field application was for a bridge deck it was necessary for the concrete mix to meet specified permeability requirements. This necessitated the reduction in cement and addition of a supplemental cementitious material (SCM), as seen in Table 3.

As stated previously three counties constructed bridges with lightweight bridge decks in 2010, 2011, and 2012. The mix designs for the three structures used a 50-50 by volume combination of standard density fine aggregate (FA-A) and lightweight coarse aggregate. See Table 1 for aggregate gradations used. Two of the three structures included SCMs to reduce the permeability of the concrete. The mix designs for all three bridges were very similar, as seen in Table 3.

The construction of the structures was successful but there were issues that the three structures shared. Cement contents for each structure were at high levels, above 600 lbs per cu. yd. The high cement contents were used to ensure high enough 28-day compressive strengths. The high cement and high paste contents did however have an adverse effect on permeability.

In 2014 lightweight aggregate was used in a paving project on US 54 in Allen County, Kansas. The mix design is not included below as the focus of this report is bridge decks. However, the substitution rate is typically approximately a 7-lb. substitution of the fine lightweight aggregate per 100 pounds of cementitious material. This rate changes slightly according to absorption and desorption of the aggregate.

Table 2: Early Mix Designs

	1953	1961	1965–1970
	Lightweight	**Lightweight Bridge 17**	**Laboratory/ Field**
Cement, lbs	719	696	639
SCM, lbs	0	0	0
Water, lbs			297
Water/Cement	0.49*	0.44	0.46
Air, %	Optional (7%)	7.5**	1.5
Coarse, lbs	Total 1804	Total 1894	2104
Fine, lbs			522***
Paste, %	41.5	31.8	29.6

*Based on required slump.
**Actual Field 2%±
***Sweetener Portion

Table 3: Recent Mix Designs

	2008	2010	2011	2012
	KSU Laboratory	**Riley/ Pottawatomie***	**Atchison***	**Dickinson**
	Sand Lightweight			
Cement, lbs	725	455	611	527
SCM, lbs	0	245		93
Water, lbs	276	282	250	248
Water/Cement	0.38	0.402	0.409	0.40
Air, %	6.5	3.2	8.0	6.5
Coarse, lbs	40%	823	710	872
Fine, lbs	60%	1458	1423	1474
Paste, %	36.5	33.5	37.7	33.3

*Field Concrete-Calculated Averages

Chapter 3: Project Details

3.1 1953 Study Details

As previously stated, testing was performed on both expanded shale lightweight aggregates available in Kansas (Ottawa, Kansas, and New Market, Missouri). Testing included density, compressive strength, flexural strength, abrasion resistance, freeze-thaw resistance, modulus of elasticity, absorption, and others (State Highway Commission of Kansas, 1953). At 30 days of age and previous to testing, all beams were measured for weight, length, and sonic modulus of elasticity, and three beams of each size were tested for modulus of rupture and compressive strength.

Durability testing included both aggregates, 3×4×16-inch beams were cast with stainless steel gage pins in each end. Three beams were subjected to standard laboratory wetting and drying testing for alkali-silica reactivity of the aggregate. Three beams were subjected to natural exposure wetting-and-drying and freeze-and-thaw action.

Six 4½ × 6 × 22½-inch beams were also cast with stainless steel gage pins. Three beams were tested for modulus of rupture and compressive strength (modified cube) at 30 days. The other three were subjected to laboratory freeze-thaw testing.

Wetting and drying test procedures involved placing the beams in water at 60° to 80° F for 16 hours and in an oven at 128° to 130° F for 8 hours. This process was continued for 300 cycles. Freeze-thaw testing was performed by placing the beams in air at -20° F for 22 hours then placing in water at 70° to 80° F for 2 hours. The process was continued for 275 cycles. At the end of the wet/dry and freeze-thaw testing cycles the beams were once again tested for weight, length, sonic modulus of elasticity, modulus of rupture and compressive strength. Compressive strength was performed on the beam ends and determined by modified cube.

Compressive tests performed on 6×12-inch cylinders of concrete with 749 lbs of cement and a water cement ratio of 0.51 resulted in strengths of 4280 psi to 4952 psi with an average of 4689 psi. Four day and 10-day average modulus of rupture were 579 and 747 psi respectively.

The wet dry beams indicated an expansion of 0.024 percent, well below the specified allowable expansion of 0.07 percent. Sonic modulus increased by 7.2 percent from a 30-day age baseline. Modulus of rupture increased from 890 psi to 947 psi and compressive strength increased from 4637 psi to 5781 psi. Initial testing was performed at 30 days and final testing at 368 days.

The freeze-thaw beams indicated an expansion of 0.013 percent; again, well below the specified allowable expansion of 0.07 percent. Sonic modulus increased by 5.0 percent from a 30-day age baseline. There was very little increase in the modulus of rupture however the compressive strength increased from 4340 psi to 5440 psi.

Neither wet-dry testing nor the freeze-thaw testing indicated any significant loss of integrity of the concrete. The testing indicated that the lightweight aggregate had superior durability to many of the aggregates in use at that time. The cement content and the water cement ratio would not be acceptable for use today as the high paste content would produce unacceptably high permeability.

3.2 1955 Belvue Bridge

Belvue Bridge was constructed in 1955. This structure is on Schoeman Road over the Kansas River in Pottawatomie County. No construction information is available on this structure except for the specifications (State Highway Commission of Kansas, 1955) that were in force when the structure was built. Cores were taken from the structure in January 2008 and sent to CTL Group for petrographic evaluation. The report indicates that B1 and BNT1 were taken from separate bridges. This is not the case, both cores were removed from the same structure, and the structure was approximately 50 years old when the cores were removed. BNT1 was removed from a destressed area and B1 was removed from an area in better condition (Lee, 2008b). Both Core B1 and BNT1 indicated considerable freeze-thaw damage; this is probably due to the fact that there was no air entraining as indicated by the petrographic analysis. Air content was found to be less than 1% in both cores. The evaluation also indicated that the concrete was placed with a moderate to high water cement ratio (0.5 to 0.6). Petrographic evaluation indicated the concrete consisted of total lightweight aggregate and no siliceous sand. The cores showed no indication of alkali–silica reaction, chemical attack, or other deleterious reactions.

3.3 1961 Randolph Bridge

The Randolph Bridge (Bridge 17) was constructed in 1961. It is on state route K-18 over the Tuttle Creek Reservoir in Riley County, Kansas. There is very little information available concerning materials and concrete mix designs for this structure other than the State Highway Commission of Kansas, 1960 Standard Specifications. In 2008 three cores were removed from Bridge 17 (Randolph). The cores were sent to CTL Group for petrographic analysis for aggregate type and size and air content. Evaluation indicated that the aggregate in the structure was 100% lightweight aggregate as was indicated in the few available construction documents. Petrographic evaluation confirmed there was no siliceous sand.

Hardened air contents were determined to be 1 to 3 percent in core C1S2 and 2 to 4 percent in cores C2S3 and C3S4. The structure was approximately 47 years old when the cores were removed. The CTL report stated that the concrete was not air entrained. This did not agree with construction documents which specified the air content would be between 7 and 7½ percent. The evaluation also indicated that the concrete was placed with a moderate water cement ratio (0.45 to 0.55). The report also stated that there was no indication of alkali–silica reaction, chemical attack, or other deleterious reactions, just as was noted on the Belvue Bridge. The cores indicated damage near the interface of the concrete and asphaltic overlay. The damage appeared to be a combination of freeze-thaw and milling action. An asphaltic overlay was placed on this structure in 1994 due to extensive spalling due to freeze-thaw action. The structure was milled to remove most of the damaged concrete previous to the placement of the asphalt overlay system. The structure is in service today, the overlay is performing well in preventing the ingress of water and chlorides and preventing additional freeze-thaw damage and reinforcement corrosion.

3.4 1965 Study Details (Published in 1970)

In 1965 a study was started by KDOT to evaluate the effectiveness of lightweight aggregate in reducing potential alkali–silica reactivity. Many of the sand-gravel aggregates in Kansas are alkali reactive causing premature deterioration of the concrete that it is used in. The typical approach was to add a “sweetener” to the concrete mix. This sweetener is typically limestone or another non-siliceous aggregate. The study included laboratory testing of several concrete mix designs and evaluation of a bridge structure in the field. The mixes used in this study were non air-entrained concrete. The field study extended over several years and included measurement of expansion and observation of surface distress. Half of the concrete in the project had lightweight aggregate substituted in at 30% by volume of the total aggregate, while the other half of the concrete had limestone substituted in at 30% by weight. The substitution rate was determined by the Kansas Highway Commission, 1960 Standard Specifications. Volume was used for proportioning the aggregates due to the difference in specific gravity of the lightweight coarse aggregate and the sand gravel aggregate. This method allowed for consistent volumes of sand gravel and sweetener in each concrete mix. The lightweight aggregate used was from the Buildex Marquette plant which was saturated, and the moisture level was maintained in the field. The limestone sweetener was Towanda Limestone from Milford, Kansas. The remainder of the aggregate was Republican River sand, a known reactive Kansas aggregate (Bukovatz et al., 1970).

The field portion of the study involved widening an existing bridge on US 24 in Clay County, Kansas. As the concrete was placed gage points were set in the concrete to allow for tracking changes in length of the structure. Gage points were set in sections containing lightweight and limestone sweeteners for comparison. Readings were taken at 24 hours (initial), seven (7), 30, and 60 days and at 6 months after placement. Readings continued to be taken annually until September of 1969. At that time the bridge received an asphalt chip seal by maintenance forces. According to KDOT records the structure was replaced in 1993.

The laboratory portion of the study was performed using the same aggregates with four cements, one of which had an alkali content over 6.0%. Mix design proportions were the same as used for the field portion. Test specimens were standard 3×4×16-inch beams used for wetting and drying testing. The material combinations used are as follows:

- Field mixed concrete containing lightweight aggregate sweetener.
- Field mixed concrete containing crushed limestone sweetener.
- Laboratory mixed concrete with sand-gravel and field cement and three other cements.
- Laboratory mixed concrete with lightweight aggregate sweetener with the four cements.

- Laboratory mixed concrete with limestone aggregate sweetener with the four cements.

Test specimens were cast in sets of six, one set for each combination of materials. The beams were tested according to the standard KDOT wet-dry testing method. The contractor/supplier chose to use the high alkali cement for the field portion.

Results from the field portion of the study indicated no significant expansion of the bridge deck concrete but differences between the two aggregate blends were noted. The report indicated that surface moisture of the lightweight concrete affected the slump causing some placement issues. The concrete with the limestone aggregate sweetener expanded slightly less than the concrete with the lightweight aggregate sweetener. The limestone sweetened segments expanded an average of 0.022 percent while the lightweight sweetened segments expanded an average of 0.029 percent. Both values are well below the allowable expansion of 0.07 percent for wet-dry testing.

Results from the laboratory portion of the study included 30-day and 365-day Modulus of Rupture and 180-day and 365-day Percent Change in Length. Neither of the two sweeteners were totally successful in mitigating the expansion but the limestone sweetener did perform better with only four failures out of 12 beams, compared to the lightweight sweetener which had seven failures out of 12 beams. The unsweetened mixes had nine failures out of 12 beams. Field mix beams indicated an equal ability to protect the concrete; each sweetener had one out of three failures. All of the mixes in this study had high cementitious materials contents that would not work today due to KDOT's specification on permeability, see Table 2. The final evaluation should be based on field performance, and both sweeteners performed well in the field application.

3.5 1975 Maple Hill Bridge

The Maple Hill Bridge was constructed in 1975 on RS 1761 in Shawnee County, Kansas. No information is available on this structure except for specifications that were in force at the time of construction: Kansas Highway Commission, 1973, Standard Specifications. In 2008 one core (MH1) was removed from the structure and sent to CTL Group for petrographic analysis (Lee, 2008b). At the time the structure would have been approximately 33 years old. The core indicated the concrete consisted of both coarse lightweight aggregate and siliceous sand. This mix most likely would have been near 50 percent each by volume. The water cement ratio was estimated to be 0.45 to 0.55, this would have been slightly lower than earlier mix designs.

Petrographic analysis also indicated that the concrete had 3 to 5 percent entrained air. This would account for the good condition of the bridge deck. The entrained air prevented freeze-thaw deterioration and extended the life of the structure. The core also exhibited no indications of alkali–silica reaction, chemical attack, or other deleterious reactions.

Cement content would have most likely been between 600 and 658 lbs per cubic yard with an allowable maximum water-cement ratio of 0.50. The 1973 specifications state that "The consistency shall be controlled by the slump test and the slump shall not exceed two (2) inches." This amount of cement and apparent high water cement ratio would have produced concrete with a paste content that would not pass present requirements for permeability.

3.6 2008 Kansas State University Projects

In 2008, KDOT contracted with Kansas State University for the development and testing of lightweight concrete mixes to be used for bridge deck and prestress beam construction. The project focused on the development of lightweight concrete mixes that would meet KDOT Specifications for entrained air, strength, and permeability. The prestress project was focused on evaluating the bond between prestressing strands, and the concrete and developing concrete that could be used for prestress beams with the requirement of a compressive strength of 5000 psi in 16 hours and a compressive strength of 7000 psi in 28 days (Perkins & Peterman, 2010).

Both studies tested the same three aggregates. Materials from Buildex, both the New Market material and the Marquette material, plus an additional lightweight aggregate, expanded slate from the Stalite Corporation of North Carolina, was tested.

As this report is focusing on lightweight concrete use for bridge decks the prestress will not be addressed. Information presented in this section will be from Grotheer and Peterman (2009).

Over 150 lightweight concrete mixtures were created and tested and several mix design variables such as water-to-cement ratio, cementitious content, and aggregate blends were tested. Cement contents varied from 639 pcy to 750 pcy. Water cementitious ratios varied from 0.36 to

0.44 the focus was primarily on 0.38 and 0.40. Aggregates were blended to meet the MA-2 gradation that KDOT required at the time, with very little flexibility to move beyond a typical 50-50 blend (KDOT, 2007). However, 40-60, 50-50, and 60-40 coarse to fine aggregate ratios were tested and the final choice was a 40-60 aggregate blend by volume to account for the difference in specific gravity between the sand and the lightweight coarse aggregate. Specific gravity used for this work were 1.52 for New Market, 1.44 for Marquette, and 1.52 for Stalite.

During early trial mixes it was determined that more strength was needed to meet specifications and the cement content was increased to 725 pcy. After this adjustment, the mixes were tested for concrete properties of compressive strength, tensile strength, modulus of elasticity, freeze-thaw resistance, permeability, alkali–silica reactivity, drying, shrinkage, and autogenous shrinkage. All properties met KDOT requirement except for the permeability. Permeability values ranged from 3500 to 4000 coulombs which were above the KDOT requirement of 3000 coulombs maximum for standard permeability concrete (KDOT, 2007). This was probably due to the high cement and paste content needed to attain the required strength consistently.

The researchers were confronted with the same issues concerning the absorption and moisture content of the lightweight aggregate and the free moisture on the lightweight aggregate during actual field application. Efforts were made to minimize variations in moisture during use. This included tracking absorption for a period of 90 days to determine the maximum and rate of absorption. A seven-day soak was settled on as this was the point the absorption curves flattened out to some extent. The absorption by the seven-day soak were determined to be 13.4% for New Market, 17.5% for Marquette, and 4.0% for Stalite. This would be accomplished by the use of soaker hoses or rainbirds on the aggregate stockpile previous to placing the deck.

The optimized concrete mix settled on included 725 pcy Type I cement content, 0.38 water-cementitious ratio with 40 percent coarse aggregate and 60 percent fine aggregate by volume. The concrete mixes produced had a unit weight between 121.9 and 124.3 pounds per cubic foot depending on the coarse aggregate used. Concrete strengths were between 5220 psi and 6210 psi again, depending on the coarse aggregate used.

Work was performed to develop a true lightweight concrete, unit weight below 120 lbs per cubic foot. This was accomplished using 675 pcy Type I cement with a water cement ratio of 0.36

to 0.37. Aggregate blends were 57.2-41.8 for the Marquette material and 68.4-38.6 for the New Market and Stalite material. Unit weights varied between 117 pcf and 118.6 pcf and strengths varied between 5800 and 6300 depending on the aggregate.

The adjusting of the aggregate blends did affect workability of the mixes as does occur at times. The 2007 KDOT Specifications were stringent on aggregate gradations and very limited on allowing adjustment to the gradations. The 2015 KDOT Specifications, however, encourage aggregate adjustments to improve the concrete mix properties and strength requirements (MA-3, MA-4, and MA-7 gradations). These changes in the KDOT Specifications would have allowed for a much better concrete mix with lower cement contents, acceptable strengths, and better permeability results.

3.7 Riley County, Pottawatomie County Bridge, 2010

On April 20, 2010, a lightweight structure was placed over the Big Blue River between Riley and Pottawatomie Counties on Rocky Ford Road. The bridge deck was designed with minimum thickness and minimum cover to allow for the addition of shoulders without additional substructure. After the curing of the bridge deck, a multi-layer polymer overlay was installed.

The approved mix design indicated 600 pounds cementitious per cubic yard, however, the delivered concrete was metered at 700 pounds cementitious per cubic yard. Water cement ratios varied from 0.382 to 0.422. The mix included an SCM to reduce the permeability. The concrete supplier struggled with water control of the aggregate and had difficulty controlling the air content. The air content issue was later determined to be caused by adding water to the trucks after the air-entraining agent had been added. Adding water at the job site also caused issues with the water control.

The mix design development followed much of the Kansas State Study from 2008 (Grotheer & Peterman, 2009). The aggregate used was the Buildex New Market Material. Aggregate blends targeted an MA-2 final gradation using a Buildex coarse aggregate and a KDOT (KDOT, 2007) FA-A sand gradation.

Unit weight of lightweight as reported and used for batch calculations was in error. Noted by Buildex as 1.59, was reported on the approved mix design as 1.46, and back calculating the value from the load tickets indicates a specific gravity of 1.31. This issue would have caused additional problems when withholding and adding back water as it is questionable that the cubic yard volumes were correct.

The concrete supplied in the field included 700 pcy cementitious with 35% slag, and an average water cementitious ratio of 0.367 upon leaving the plant, but after adding the approximate 2 gallons (16.67 lbs) of withheld water per truck the final average water cementitious ratio was 0.402. The final gradation that was produced in the field was near a 50-50 combination by volume. This would also have been affected by the specific gravity of lightweight aggregate that was used to batch the concrete. Moisture content of the lightweight aggregate was determined to be near 29.6%.

Limited information is available on concrete strength and permeability. Concrete strength varied from 6000 to 7200 psi for 28-day breaks with no failing tests, however, one failing test was noted at 56 days, this is believed to be from the first accepted truck. Results from one permeability test are available. The material passed the Rapid Chloride Permeability requirements but failed the Volume of Permeable Voids requirement (KDOT, 2007).

3.8 Atchison County 2011

On November 23, 2011, a Warren truss was redecked in Atchison County, Kansas, using lightweight aggregate. The focus on this project was to maintain the load carrying capacity of a structure on the Historic Register. To accomplish this the deck was of minimum thickness with minimum cover. A multi-layer polymer overlay was installed to protect the structure. There is very little information available on this project.

The mix design consisted of 611 pcy of cement, a near 50-50 blend of lightweight coarse aggregate, and normal weight sand with a water cement ratio of 0.413. The final unit weight of the concrete was 116.6 lbs per cu.ft. The results of only one Rapid Chloride Permeability test are available and that test indicated failing results. No concrete strength test results are available.

3.9 Dickinson County 2012

During August and September of 2012, a 3-span haunch slab bridge was cast in Dickinson County, Kansas, on FAS 191. The piers and deck were of sand-lightweight concrete. The deck had a unit weight between 118.5 pcf and 124.04 pcf. Concrete for the piers had a slightly lower specific gravity and slightly higher water to cementitious ratio.

The specific gravity for the lightweight was determined as 1.52 by Buildex and 1.55 by Monarch Cement. Consistent values of the lightweight aggregate helped reduce confusion and errors during batching.

The sand-lightweight mix design consisted of 527 pcy cement, 93 pcy Type F fly-ash for a total cementitious content of 620 pcy. Target water to cementitious ratio was 0.40. Aggregate blend was 50-50 by volume lightweight coarse and FA-A sand.

As stated, the piers were also cast with the bridge deck concrete. Several items were smoothed out through the pier placements that led to a smoother deck placement. Concrete strengths all exceeded the required 4000 psi except one set for Pier 2 and that set may have been mishandled. None of the compression tests meet the 5200 psi required by KDOT Specification for pre-qualification (KDOT, 2007). Concrete strengths varied between 4140 psi and 4860 psi. No Rapid Chloride permeability tests or Volume of Permeable voids tests passed the KDOT requirement. This is most likely due to the high paste content, 33.3%, of the mix.

Chapter 4: Discussion

In recent years there has been concern about the durability of the lightweight (expanded shale) aggregates available in Kansas. A number of projects have involved extensive testing on concrete using the lightweight aggregates with no indication of a consistent issue with the use of the aggregate.

A study that occurred in 1953 (State Highway Commission of Kansas, 1953) performed testing on density, compressive strength, flexural strength, abrasion resistance, freeze-thaw resistance, and others with no failure of the lightweight aggregate. In 1965 a study was started to evaluate the effectiveness of lightweight aggregate as a sweetener. The 1970 report indicates that expanded shale does not work as well for a sweetener as limestone for mixes with potentially reactive aggregate (Bukovatz et al., 1970). However, increasing the amount of lightweight material to 40 percent may improve the performance. Present KDOT (2017) Specifications require 40 percent sweetener if not using SCM material to prevent the ASR reaction. The wet dry test results from the 1965 study indicated no unexpected results.

Lightweight aggregate did not appear in Highway Commission or KDOT Specifications until 1960 (State Highway Commission of Kansas, 1960). The 1960 Specifications stated a required gradation for the lightweight aggregate and several quality requirements. This specification indicates it was being accepted as a "total" aggregate. The Highway Commission Specifications for 1966 began referring to lightweight aggregate as Light Weight Aggregate (Modified). This specification had the same gradation requirements as the 1960 specification but included the requirement that it be combined with FA-1 fine aggregate at a rate of 45-55, FA-1 to lightweight aggregate (expanded shale) (State Highway Commission of Kansas, 1966). This specification also retained the same quality requirements. In 1973 the Highway Commission released a new set of standard specifications. In this specification the lightweight aggregate was still noted as Light Weight Aggregate (Modified). The 1973 specification includes the same aggregate gradation but is now blended with a standard sand FA-A at a rate of 45-55, to lightweight aggregate. The specification has the same additional quality requirements (State Highway Commission of Kansas, 1973). The early work performed with the lightweight aggregate would have been in conformance with the 1960 and earlier specifications. The structures built between 1955 and 1975 would have been constructed under specifications that may have required a combination of aggregates, but many were built with a complete lightweight aggregate (coarse and fine) not a modified lightweight by specification definition.

The specifications remained basically the same between 1960 and 1990 when KDOT released new specifications. The 1990 specification identified the material as Modified Lightweight Aggregate. This specification still requires that the lightweight aggregate be combined with a fine FA-1 material. One of two lightweight aggregate gradations are required and are both coarse aggregate gradations with the intent that the FA-A and the lightweight aggregate be blended at a rate of 50-50 as stated in the specification, FA-A to lightweight aggregate. The lightweight is not a modified lightweight until actually blended with the FA-A at the time of batching (KDOT, 1990).

In 2007 KDOT released new specifications that retained the same coarse gradation requirements for the lightweight aggregate with the requirement that coarse and fine aggregates be blended at a 50-50 rate, coarse to fine. Projects performed and constructed between 2007 and 2015 were all attempting to meet the gradation requirements and the 50-50 blend requirement; the inability to truly optimize is a factor in the high cementitious ratios. The specifications very much limited the suppliers' ability to supply a true quality optimized mix that would meet all specification requirements (KDOT, 2007). In the 2015 Specifications, the lightweight material is listed as Lightweight Aggregate. The gradations have been removed and the supplier is referenced to the mixed aggregate gradation tables, and the supplier is allowed to fully optimize the sand-lightweight or the complete lightweight mix design (KDOT, 2015).

Chapter 5: Conclusions

Kansas has tested and used lightweight aggregates for a significant time period. The specifications that have been enforced over that time period has caused a number of issues with the quality of the sand-lightweight and lightweight concrete.

None of the testing or field experience in Kansas has indicated that the problems with the bridge decks were centered on the lightweight aggregate. The problems appeared be more due to low entrained air contents, high cement contents, high water to cement ratios, and potentially the use of “hot” reactive sands.

One of the issues that must be addressed is the use of higher cementitious contents to provide the required concrete strengths; this trend is seen in both the early structures and recent structures. The extra cementitious content increases the paste content and thus increases permeability and still may have occasional strength issues. The mix must be designed to give both required strength and meet permeability requirements. With the higher cementitious contents, the water must be reduced, but not to a point of resulting in poor admixture/concrete interaction, or the use of SCMs must be considered.

KDOT Specifications have changed since the recent work was done. This work was based on the Standard Specifications of 2007. A new set of specifications were developed and published in 2015. MA-2 no longer exists, and gradations have been revised to allow a more open optimization of the aggregates, MA-3, MA-4, and MA-7. The 2015 KDOT Specifications should help the supplier to optimize the mix designs and have a much more consistent high-quality product.

Field issues have also been identified over the years and with various projects. The concrete supplier must take care to verify absorption and excess moisture content of the lightweight aggregate. Working closely with the lightweight aggregate supplier is a necessity.

Stockpile management is also a necessity. Some form of soaker equipment must be used such as soaker hoses or Rain-birds to maintain the saturation of the lightweight aggregate. Stockpile management is addressed in KDOT Special Provision 15-PS0174 “Concrete (Grade 4.0) (AE) (Lightweight Aggregate)”: “Turning the stockpiles daily and immediately prior to sampling and batching concrete will be necessary to assure uniform pre-wetting and drainage, and care should be taken to prevent segregation. Pre-wetting of lightweight aggregate shall stop 24 hours prior to batching to allow the stockpile to drain. As placement proceeds, turn the pile as necessary to equalize the moisture content of the aggregate". If at all possible, no water should be withheld from the mix and added back. Where this has occurred has led to confusion, unacceptable reaction with plasticizers, and excess water in the mix during placing of the concrete.

In the long term, if the issue of high cement contents to get the required strengths cannot be solved it may be more reasonable to minimize the unit weight, add cement as necessary for strength, and install a multi-layer polymer overlay to prevent intrusion of water and chlorides. Another answer to the strength/permeability issue may be to reduce the lightweight concrete strength required for prequalification. At the present time the specifications require 5200 psi, several projects indicated the ability to maintain a strength of 4500 psi. The strength of the lightweight aggregate itself is lower than the other aggregates that are typically used in Kansas so the concrete strength itself can be affected. Overall testing and field experience show that lightweight concrete is a viable structural material in Kansas.

During the summer of 2020 a lightweight bridge deck was placed on a structure on K-147 in Trego County, Kansas. This project will be reviewed and reported on in a future report by the KDOT Bureau of Research. Additional structures should be identified, and the supplier, contractor, and KDOT should work closely with the lightweight aggregate supplier to evaluate and solve the few issues that have been identified in recent structures.

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