LIGHTWEIGHT CONCRETE BRIDGES IN VIRGINIA

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ABSTRACT

Lightweight concrete has been successfully used for bridge decks in Virginia since at least 1959. In recent years, its use has been expanded to include pretensioned girders and even spliced post-tensioned girders, following a significant research effort and a number of demonstration projects where the performance of lightweight concrete elements was monitored. Recently, lightweight concrete has also been used for deck overlays and prewetted lightweight fine aggregate has been added to conventional overlay mixes to reduce shrinkage and cracking.

This paper highlights a number of bridges constructed in Virginia for which lightweight concrete has been used for decks or prestressed girders. Projects discussed include interstate bridges in Richmond installed using modular units during night-time closures, a dual swing span bridge super structure replaced in less than 10 days, post-tensioned precast deck panels, spliced post-tensioned bulb-tee girder bridges, a new inverted tee beam shape for short spans, and several smaller bridges. Experience related to lightweight concrete on these projects is discussed. Research conducted on the performance of lightweight concrete that support the recent advances is briefly described. Specifications for lightweight concrete are discussed, including recently developed specifications for reduced-cracking deck concrete that include lightweight concrete as one of the options.

Keywords: Lightweight concrete, Projects, Pretensioned girders, Bridge decks, Research, Durability, Specifications

INTRODUCTION

Lightweight concrete has been successfully used for bridge decks in Virginia since at least 1959. In recent years, its use has been expanded to include pretensioned girders and even spliced post-tensioned girders, following a significant research effort and a number of demonstration projects where the performance of lightweight concrete elements was monitored. Recently, lightweight concrete has also been used for deck overlays and prewetted lightweight fine aggregate has been added to conventional overlay mixes to reduce shrinkage and cracking.

This paper highlights a number of bridges constructed in Virginia for which lightweight concrete has been used for decks or prestressed girders. Projects discussed include interstate bridges in Richmond installed using modular units during night-time closures, a dual swing span bridge super structure replaced in less than 10 days, post-tensioned precast deck panels, spliced post-tensioned bulb-tee girder bridges, a new inverted tee beam shape for short spans, and several smaller bridges. Experience related to lightweight concrete on these projects is discussed. Research conducted on the performance of lightweight concrete that support the recent advances is briefly described. Specifications for lightweight concrete are discussed, including recently developed specifications for reduced-cracking deck concrete that include lightweight concrete as one of the options.

LIGHTWEIGHT CONCRETE

Lightweight concrete is made using lightweight aggregate for some or all of the aggregate in the mixture. The term “sand lightweight concrete” is used for concrete in which normal weight sand is used with coarse lightweight aggregate. The term “all lightweight concrete” indicates that all of the aggregate in a mixture, both coarse and fine, is lightweight. Sand lightweight concrete has been used for nearly all of the bridges in Virginia. This type of concrete will have a density ranging from about 110 lb/ft^3 to 125 lb/ft^3, depending on the specific mix design and the required compressive strength.

Several terms are used to define the unit weight or density of lightweight concrete. In this paper, the term “density” will be used rather than “unit weight” since this is the term currently used for bridge projects in Virginia.

DENSITY OF LIGHTWEIGHT CONCRETE

It is important to note that there are also several terms related to the density of lightweight concrete that can be used. The fresh, or plastic, density of concrete is used for quality control since it can be measured when the concrete is delivered and placed. Because of the typically greater quantity of absorbed water in lightweight aggregate, the density of lightweight concrete has been found to decrease with time, usually in the range of 5 to 10 lb/ft^3. This reduced density that is achieved after loss of moisture is called the “equilibrium density.” In the past, the density of the concrete after drying (usually for 28 days) was called the "air-dry density," but this term is no longer in use. A final type of density that may be used is the "oven dry" density which can be computed from the mix proportions using a method in ASTM C567 or measured by drying cylinders. While the equilibrium density is typically used in building construction, the current practice in Virginia is to specify the fresh density of lightweight concrete, neglecting the small additional reduction in density that occurs with loss of moisture. The type of lightweight aggregate that has been used in many bridges in Virginia has a low absorption, so the loss in density is relatively small.

It should be noted that when designers are computing dead loads for a bridge, an increment of density must be added to the specified concrete density to account for the weight of the reinforcement. This allowance is typically 5 lb/ft^3, but can be greater for some structures.

For some of the projects described in this paper, it is not clear what type of density was intended by the designers, but where known, the type of density is indicated. The lack of clarity in defining the density of lightweight concrete has led to confusion during construction for some projects. Therefore, designers should clearly state the intended type of density in the contract documents to avoid confusion.

COST OF LIGHTWEIGHT CONCRETE

Cost is an item of great interest when considering bridges constructed using lightweight concrete. However, it is not easy to obtain a clear indication of cost savings in most cases. Lightweight concrete costs more to produce than a comparable normal weight concrete because the lightweight aggregate costs more to manufacture (it is produced by heat treating to temperatures of about 2200ºF) and transportation costs are typically greater because the lightweight aggregate plants are usually not local to a project. Lightweight concrete is used because of the structural or durability benefits that it provides, which can, in many cases, allow cost savings that more than offset the additional cost of the lightweight concrete.

DURABILITY OF LIGHTWEIGHT CONCRETE

For bridges, the durability of construction materials is as important as the initial cost. Through laboratory testing and observation of projects, the Virginia Department of Transportation (VDOT) has found that "properly designed, proportioned, and constructed lightweight concrete with quality material provide satisfactory durability in structures."[1] Other researchers have also found that the durability of lightweight concrete can be as good as or even better than the durability of normal weight concrete of the same quality.[2,3,4]

LIGHTWEIGHT CONCRETE BRIDGES IN VIRGINIA

As is the case for most states, the VDOT does not have a list of bridges that incorporate lightweight concrete. Considering records from a number of sources, it appears that there are over 40 known bridges that have used lightweight concrete in some part of the structure. It is likely that there are quite a few bridges that could be added to the list.

A selection of bridges that use lightweight concrete is presented, representing the variety of applications and structure types. Bridges have been divided into three groups: bridges with lightweight concrete decks; lightweight concrete bridge decks used for accelerated bridge construction, and bridges with lightweight concrete for both decks and girders. The bridges are generally presented in chronological order by date of construction. Available information is presented for each bridge which is incomplete in some cases. References are given for information for bridges when documentation is available.

For most bridges discussed in this paper, special provisions were included in the contract documents to specify the requirements for lightweight concrete. Some provisions related to lightweight concrete, including the use of lightweight concrete as an option for low shrinkage deck concrete that is discussed later in this paper, were incorporated into the 2016 edition of the VDOT *Road and Bridge Specifications*. The VDOT *Manual of the Structure and Bridge Division - Part 2: Design Aids and Typical Details* includes prestressed concrete bulb-tee design tables for lightweight concrete along with normal weight concrete.

LIGHTWEIGHT CONCRETE BRIDGE DECKS

Lightweight concrete has been used for bridge decks in Virginia for a number of rehabilitation and new construction projects. Details are provided for these projects in this section. The projects are presented in chronological order.

Boulevard (Route 161) Bridge across the James River – Richmond, VA

The Boulevard Bridge was originally constructed in 1925 as a two-lane toll bridge crossing the James River at Richmond. The deck on this steel deck truss bridge was replaced using lightweight concrete in 1959. The minimum required concrete compressive strength was 5000 psi with an “air dry” density of 110 lb/ft^3.

The lightweight concrete deck performed well until it was removed during the rehabilitation of the steel truss in 1993. At that time, pieces of the deck were retrieved for evaluation. It was noted that there was only 1/8 in. of wear in the tire paths. The bridge is load restricted, so the traffic is limited to autos and small trucks.

Fig. 1 Photograph of the Boulevard Bridge deck in 1983, after 24 years in service.

Fig. 2 Photograph of deck section removed from the Boulevard Bridge in 1993.

Fig. 3 Close-up photograph of deck from the Boulevard Bridge in 1993.

It is significant to note in Fig. 3 that there was no evidence of freeze-thaw damage to the deck after 34 years in service, even though the interior of the lightweight aggregate particles had been exposed by traffic wear.

Route 36 Bridge over Appomattox River– Petersburg, VA

A lightweight concrete deck was placed on an experimental triangular aluminum girder span in approximately 1962. This was the first known use of lightweight concrete for a VDOT bridge. It was identified as the only lightweight concrete bridge owned by VDOT in a report by Brown.[5] A lightweight concrete overlay was applied on the bridge in 2007 after 45 years of service.

Fig. 4 Photograph of the Route 36 Bridge over Appomattox River (VDOT)

Route 269 (formerly Route 60) Bridge over Cowpasture River – Near Lexington, VA

In 1979, VDOT constructed a bridge deck with lightweight concrete that had coarse aggregate with an absorption of 18%.[1] The 212 ft long bridge is located on Route 269 (formerly Route 60) over the Cowpasture River. It has two lanes and two spans with a continuous deck on continuous steel beams.

Cylinders tested during construction exhibited an average 28-day compressive strength of 5,100 psi. The resistance to freezing and thawing was determined in accordance with ASTM C 666 Procedure A except that the specimens were air dried at least a week before the test and the test water contained 2% NaCl. There were pop outs and loss of material in the test beams associated with the coarse lightweight aggregate. However, the average values of weight loss, durability factor and surface rating met the acceptance criteria indicating satisfactory performance.

In 1984 a visual survey indicated good performance in the field. In 2007 another survey indicated that the deck is still in very good condition after 28 years of service. It had no transverse cracks common in continuous bridges and no visible cracks and very limited wear. It also had some shallow pop outs exposing the coarse aggregate in some areas.

Fig. 5 Photograph of the Cowpasture Bridge in 1983

Pungo Ferry Road Bridge over North Landing River (Intracoastal Waterway) – Virginia Beach, VA

This bridge replaced an existing moveable span over the Intracoastal Waterway south of Virginia Beach, VA. Sand-lightweight concrete was used for the deck to extend the spans that could be achieved by the simple span prestressed concrete girders used for the three main spans which were 120 – 136 – 120 ft. Normal weight concrete was used for the deck on the approach spans. Construction was completed in 1991 according to the National Bridge Inventory (NBI) listing.

Fig. 6 Photograph of the Pungo Ferry Road Bridge shortly after completion

a) Lightweight concrete

b) Normal weight concrete

Fig. 7 Photographs of the concrete deck of the Pungo Ferry Road Bridge taken in 2007

The photograph of the lightweight concrete deck taken in 2007, after nearly 20 years in service, shows exposed aggregates on the surface. However, it appears that the deck is otherwise intact and is still wearing well, with the tined marks still visible. Photographs of the normal weight concrete deck taken at the same time indicates less exposed aggregates. The NBI record for 2015 listed the deck condition for the entire bridge as good (rating of 7).

Massaponax Church Road (Route 608) Bridge over Interstate 95 - Spotsylvania County, VA

The original four-span bridge that carries Massaponax Church Road (Route 608) over Interstate 95 a few miles south of Fredericksburg, Virginia, was opened in 1964.[6] It was designed in accordance with the standards of the time period with a design live load of H 20, and a normal weight concrete deck that was only 20' wide. Recently, the area has seen significant growth, necessitating a wider deck and an upgrade to an HS 20 design live load to bring the widened bridge to existing VDOT standards. Furthermore, the existing normal weight concrete deck was deteriorating and had been classified as being in "poor" condition when inspected in 2008.

Due to the high and rising cost of steel beams, VDOT wanted to accomplish the upgrade with minimal additional steel superstructure. If normal weight concrete been used for the new deck, the existing steel beams would have been overstressed and the increased service load rating would not be achieved. Utilizing lightweight concrete with a maximum fresh density of 120 lb/ft^3 for the 8-in.-thick deck and parapets enabled the reuse of the existing steel beams.

The original design used two concrete columns per pier. Doubling the deck width from 20' to 40' and increasing the design service load required only one additional concrete column per pier and two additional plate girders.

Fig. 8 Photos of completed Massaponax Church Road (Route 608) Bridge over Interstate 95 (VDOT)

Project specifications included special provisions for lightweight concrete which was specified as VDOT Class A4 lightweight concrete with a minimum compressive strength of 4,000 psi. The concrete was required to be air entrained, have a maximum fresh density of 120 lb/ft^3, and have a maximum rapid chloride permeability of 1500 coulombs. The average compressive strength of the deck concrete was 5,930 psi with an average ASTM C1260 chloride permeability test result of 1015 coulombs. The 245-ft-long bridge used 300 yd^3 of lightweight concrete for the deck and parapets. Construction was completed in 2009.

Route 13 (Military Highway) over Southern Branch of Elizabeth River – Chesapeake, VA

This major bridge, also known as the Gilmerton Bridge, consists of a lift span over the waterway and prestressed concrete girder approach spans. The decks, parapets and median barriers for the 250 ft-long lift span and approach spans were sand-lightweight concrete with a maximum dry density of 110 to 115 lb/ft^3 (from plans). The main span was constructed on falsework and floated into position. Lightweight concrete is often used for decks on movable spans to reduce the load on the mechanical equipment.

Fig. 9 The new Gilmerton Bridge (City of Chesapeake, VA)

Fig. 10 Lightweight concrete being placed on new Gilmerton Bridge (PCL)

Construction on this bridge began in 2009 and the new bridge opened to traffic in 2013, with construction complete in 2015. Information for this project was obtained from communications with the contractor and from the VDOT project website.[7]

LIGHTWEIGHT CONCRETE BRIDGE DECKS USED FOR ACCELERATED BRIDGE CONSTRUCTION

Lightweight concrete has been used for several projects in Virginia where it assisted in meeting the goals for accelerated bridge construction (ABC). Virginia has been a leader in this area and was one of the first states to have several significant projects completed when the national move to ABC was just beginning. While some other projects that use lightweight concrete may also be considered as ABC projects, this section focusses on several projects that had clear ABC goals.

Interstate 95 (Woodrow Wilson) Bridge over the Potomac River – Alexandria, VA

An early example of using precast concrete deck panels for accelerating bridge construction was the deck replacement on the first Woodrow Wilson Bridge just south of Washington, DC. The original deck began to deteriorate at an early age and replacement was required. The deck replacement was completed in 1983. The project has been described in an article in the *PCI Journal.*[8]

For this bridge, precast deck panels with typical thickness of 8 in. were designed using sand-lightweight concrete for the following reasons:

- Since the lightweight concrete deck panels were lighter, the existing structure could support a thicker deck. The original normal weight concrete deck had been too thin, which had led to its early deterioration.

- The reduced deck weight also allowed the roadway width to be increased several feet without requiring any modifications to strengthen the existing superstructure or substructure elements.

- Since the precast lightweight concrete panels weighed less, the cost for shipping the panels from the precast plant to the site, which was about 75 miles away, was reduced. The erection loads were also reduced.

The realization of these benefits allowed reduced project cost and duration.

The specified "air-dry" density of the sand-lightweight concrete used for the deck was 115 lb/ft^3 without reinforcement. The use of lightweight concrete reduced the weight of the panels by about 20%.

The new lightweight concrete deck, which was post-tensioned in both the longitudinal and transverse directions, was protected by plant-applied epoxy-sand membrane and a field-applied asphaltic wearing surface. The deck system performed well until it was demolished in 2006 after construction of a new bridge to improve traffic capacity.

US 17 Bridge over the York River (Coleman Bridge) – Yorktown, VA

This major steel deck truss crossing the York River at Yorktown, VA, includes two 500 ft long swing spans. When it was determined in the late 1980s that the superstructure must be replaced and widened, accelerated construction methods were employed. This bridge is one of only a few crossings of the York River, so it was essential to keep the closure time for replacement to as short a duration as possible. Construction began in 1994 and was completed in 1996.[9]

Fig. 11 US 17 Bridge over the York River (Coleman Bridge)

Lightweight concrete was used in the bridge deck for the truss spans to reduce the weight of the deck, which resulted in a reduction in the quantity of steel required for the trusses and reduced the weight of the pieces that had to be transported and installed. The reduced superstructure load was also important so the existing piers could be reused by widening without requiring strengthening. Lightweight concrete had been successfully used on other bridges in Virginia, so VDOT was open to its use on this major crossing. The same specification was used for the lightweight concrete deck as the standard VDOT normal weight concrete deck with the exception of a higher concrete compressive strength (4,500 psi instead of 4,000 psi which was intended to account for the expected reduced shear capacity of the lightweight concrete) and a density of 115 lb/ft^3.[9] Abrahams also noted that the decks on the truss sections experienced minor cracking during transportation because they were supported at locations that introduced high tensile stresses in the deck. These cracks closed when the spans were placed on their supports.

Lightweight concrete was used for the decks on the truss spans, which were constructed on falsework in Norfolk, VA, then barged as completed units to the site for erection. The lightweight concrete decks were cast on removable forms. Installation of the truss bridge segments was completed in a single nine-day closure. Normal weight concrete was used for the decks on the approach spans.[10]

The lightweight concrete deck on the truss spans was ground as required to achieve the desired roadway profile and rideability, then transversely grooved for skid resistance. This work was completed prior to final erection of the trusses to make possible the rapid opening of the bridge to traffic. The surface of the deck remains exposed to traffic.

During a visit to the bridge in 2005 by several of the authors, no cracks were visible on the top or underside of the lightweight concrete deck. However, the normal weight concrete deck on the approach spans, which was conventionally constructed onsite, had suffered from significant transverse cracking at an early age and had been repaired by installing a ½" thick epoxy overlay to seal the deck. While lightweight concrete decks mixtures have been shown to have reduced cracking tendency compared to normal weight concrete,[11] there may be other factors that contributed to the significant difference in performance of the two types of decks, such as construction staging (the approaches were constructed under staged traffic conditions) and weather conditions during construction. The deck has been subject to fairly heavy traffic since it was completed in 1996.[10]

Fig. 12 Lightweight concrete deck on truss spans of the Coleman Bridge

.I-95 Bridges over the James River and overpasses north of the river – Richmond, VA

The superstructure of this major interstate bridge crossing the James River approaching the center of Richmond was replaced in 2002. The total bridge length was 4,185 ft, was comprised of 51 spans, and had a typical deck width of 88.6 ft. The ADT on the bridge in 1994 was 115,000.

To accelerate construction, a lightweight concrete deck was cast on full-span steel beam modular units at a site near the bridge. The superstructure was then replaced with night-time construction closures during which the existing superstructure was removed and the new beam/deck modular units were installed and post tensioned transversely. Longitudinal post-tensioning was also used across joint closure sections between modular unit spans. A significant reduction in disruption of traffic and the construction schedule resulted from the use of this construction method that was considered innovative at the time. Sand-lightweight concrete with a maximum "dry density" of 115 lb/ft^3 was specified for the deck to reduce the weight of the large superstructure panels. The lightweight concrete decks are exposed to traffic, i.e. there is no wearing surface, and have performed well.

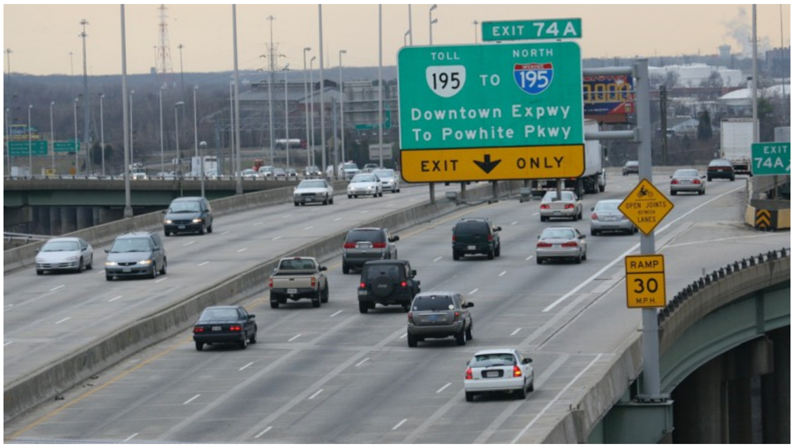

Fig. 13 Completed I-95 Bridge over the James River

A second contract to replace nine smaller overpass structures on I-95 just north of the James River Bridge was recently completed.[12] The bridges were again designed using the same system of partial width, span length modular units that were post tensioned in both directions. Sand-lightweight concrete decks were also placed on the steel girders. The use of sand-lightweight concrete reduced the weight of the precast slab unit by 16 tons or 12%.

US 15/29 Bridge over Broad Run near Gainesville, VA

The project involved the replacement of a deteriorated existing 53-year-old, two-lane structure that carried southbound traffic on U.S. 15/29, which was about 25,000 vehicles per day.[13] The three-span bridge was about 130 ft long and consisted of reinforced concrete T-beams. Staged construction was required because the presence of adjacent historic properties did not allow widening of the structure to provide two lanes of traffic on the bridge during construction or construction of an adjacent temporary bridge. A plan was developed to detour traffic around the bridge on three weekends to allow the superstructure to be replaced in three weekends.

Fig. 14 Completed U.S. 15/29 bridge over Broad Run, looking South[13]

The existing substructure units were extended and modified to support the new bridge that was widened to increase shoulder width. Four modular units, consisting of sand-lightweight concrete decks precast on steel girders, were used for each span to accelerate construction. A waterproofing membrane and a 3-in hot-mix asphalt overlay were placed over the concrete deck for the finished riding surface. The project was part of the FHWA's Highways for Life Program.

BRIDGES WITH CONCRETE FOR BOTH DECKS AND GIRDERS

VDOT has used lightweight concrete for both girders and decks on several recent projects.

Route 106 Bridge over Chickahominy River, east of Richmond, Va.

Lightweight high-performance concrete was used for the prestressed concrete beams and deck for the Route 106 bridge over the Chickahominy River. The bridge was constructed in 2001 and is 43.3 ft wide. It has a 7.9-in. thick deck and three spans of 85-ft-long prestressed concrete AASHTO Type IV beams made continuous for live load.[14,15]

Specifications for the lightweight concrete required a maximum fresh density of 120 lb/ft^3 for both the girders and deck and minimum compressive strengths of 8,000 psi and 4,000 psi for the girder and deck, respectively. The lightweight concrete was also required to have maximum rapid chloride permeability values of 1500 coulombs for the girders and 2500 coulombs for the deck.

This project demonstrated to VDOT that lightweight high performance concrete could be produced such that the material is workable, strong, volumetrically stable, and resistant to cycles of freezing and thawing, thus leading to a long service life with minimal maintenance. A condition survey after two years of exposure indicated only limited cracking including two transverse cracks above the piers. In 2015, the condition for the entire bridge was good (rating of 7), with the inspection report only noting two 6-ft-long hairline cracks in each lane at one abutment, but did not mention any transverse cracks at the piers.

Fig. 15 Route 106 Bridge

Route 33 Bridges over Mattaponi and Pamunkey Rivers – West Point, Va.

Two bridges were completed carrying Route 33 across the rivers that run on each side of West Point, Virginia. All units of both bridges with spans longer than 120 ft were constructed with lightweight concrete girders and lightweight concrete decks, including post-tensioned spliced girders on the four main units, all of which had span configurations of 200-240-240-200 ft. One of the bridges also had a bascule span which utilized lightweight concrete fill in the grid deck. The bridges were opened to traffic in 2006 and 2007.

The specified minimum concrete compressive strength for the cast-in-place composite deck was 5,000 psi with a fresh density of 120 lb/ft^3.[16] The specified minimum concrete compressive strength for all lightweight concrete girders was 8,000 psi with a fresh density of 123 lb/ft^3. The designers also specified limiting values for the modulus of elasticity, creep, shrinkage and permeability for both the girder and deck concrete. The lightweight concrete was also required to have a maximum rapid chloride permeability value of 1500 coulombs for the girders and 2500 coulombs for the deck. Researchers at the Virginia Transportation Research Council (VTRC) tested the materials used in the bridges and monitored their performance.[16] Lightweight concrete was used in this project to improve the efficiency of the design by increasing span lengths and by reducing foundation loads.

The photographs below are of the Route 33 Bridge over the Mattaponi River on the east side of West Point and show erection of the spliced girder spans and the completed bridge.

Fig. 16 Route 33 Bridge over the Mattaponi River under construction and completed

The deck received a textured finish after placement. Where necessary, the deck was ground to remove surface irregularities, then it was grooved transversely. Photographs of the deck on the Mattaponi River Bridge taken by one of the authors are shown in Figure 13. The photograph on the left is the typical condition, while the photograph on the right shows the deck with both grinding and grooving. At this location, lightweight concrete (LWC) had been used to fill around a modular joint in a span with normal weight concrete (NWC), so the two types of concrete appeared side-by-side across a cold joint. No difference in weathering or wear was evident between the two types of concrete, although the bridge had only been open less than a year at the time of the site visit.

Fig. 17 Deck of the Mattaponi River Bridge – Grooved Transversely and Ground

Specification requirements and average test results for the lightweight concrete deck for the Pamunkey River Bridge are shown in Table 1. Test results were obtained from the concrete supplier. The relatively consistent behavior and high average strengths of the lightweight concrete test results over a 6-month period demonstrated that the concrete supplier could produce lightweight concrete with satisfactory properties.

Some difficulties were encountered near the end of the project with the compressive strength not meeting the specified requirement as can be seen by the low minimum strength shown in Table 1. A reason for the low strengths has not been identified. The permeability of the lightweight concrete, as indicated by the rapid chloride permeability test (RCPT), was well below the limit for all samples tested. This indicates that the lightweight concrete deck has the necessary concrete quality to resist penetration of chlorides into the concrete that could lead to initiation of corrosion of the reinforcing steel. From observation of the decks at the west end of the Mattaponi River Bridge by one of the authors in 2007, both the normal weight and lightweight concrete decks were essentially free from cracking, the other critical measure of deck resistance to deterioration from corrosion.

Gilley[17] mentions that there were some difficulties in pumping the concrete during construction. With proper mix design and adequate prewetting of the lightweight aggregate prior to batching, this should not be an issue since lightweight concrete has been successfully pumped to the upper floors of high-rise buildings.

Table 1 Specified and Measured Concrete Properties for the Pamunkey River Bridge Deck[10]

Compressive Strength at 28 days (psi)		
Specification requirement:	5,000	
Average value:	5,998	59 samples over a 6 month period
Maximum value:	7,573	
Minimum value:	3,267	8 samples were < 5,000 psi
Standard deviation:	934	
Permeability at 28 days (coulombs)		
Specification requirement:	2500	
Average value:	989	17 samples over a 6 month period
Maximum value:	1467	
Minimum value:	593	
Standard deviation:	245	
Fresh Concrete Density (lb/ft^3)		
Specification requirement:	120	including weight of reinforcement
Range of values:	111.8 to 117.5	

Route 17 Bridge over Route 15/29 – Fauquier County, Virginia

For the bridge carrying Route 17 over Route 15/29 in Fauquier County, Virginia, self-consolidating lightweight high-performance concrete with slag cement was successfully used in the prestressed bulb-tee beams.[18] The deck also has lightweight high-performance concrete with slag cement. The bridge has two spans, each 128 ft long. Test beams 65 ft long with the same cross section as the actual beams were cast and tested prior to the fabrication of the bridge beams.[19] The lightweight high-performance self-consolidating concrete provided satisfactory strength and permeability in the test beams and bridge beams. The lightweight concrete bridge deck concrete had satisfactory strength and durability with no cracks after two winters.

Fig. 18 Completed Route 17 Bridge (VDOT)

Fig. 19 Completed Route 17 Bridge from beneath (VDOT)

Towlston Road Bridge over Rocky Run, Fairfax County

This bridge with a 47-ft-long span and a total width of 33.5 ft was designed to replace the existing bridge carrying Towlston Road over Rocky Run in northern Virginia.[20] This bridge was the second use of the new VDOT inverted tee section, but the first use of lightweight concrete for either the girders or the topping concrete. The new section was adapted from the "Poutre-Dalle" concept from France that was initially adapted for use in the US by the Minnesota Department of Transportation. The new system uses a series of shallow prestressed concrete beams with flanges at the bottom face that are placed adjacent to the next unit. Reinforcement is then placed over the beams and the concrete topping is placed to tie the beams together and provide the riding surface. Lightweight concrete was used to reduce the weight of the precast units as well as the total dead load on the substructure units. This could be helpful when existing substructure elements are reused.

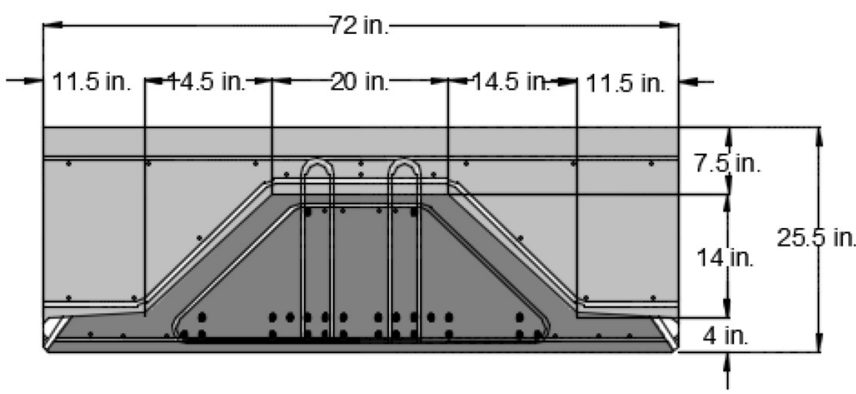

Fig. 20 Detail of VDOT Inverted-Tee section (dark gray) and topping concrete (light gray)[20]

Fig. 21 Erection photo of inverted tee beams[20]

Route 198 (Dutton Road) Bridge over Harper Creek – Gloucester Co., VA

The superstructure of the existing cast-in-place concrete T-beam bridge carrying Route 198 over Harper Creek was deteriorated and in need of replacement. The existing abutments were in relatively good condition and could be reused. However, the capacity of the timber piling supporting them was not known. Therefore, the weight of the new structure was limited to the approximate weight of the existing superstructure since the existing structure was performing well. The hydraulic opening also had to be maintained.

The designers selected concrete to reduce the weight of the new superstructure and the modifications to the existing abutments. The 29-in.-deep, 41 ft-4 in.-long prestressed concrete girders used sand-lightweight concrete with a specified maximum dry density of 115 lb/ft^3, a minimum compressive strength of 5,000 psi, and a maximum permeability of 1500 coulombs. The concrete used for the deck, rails and for abutment modifications was all-lightweight concrete with a specified maximum dry density of 105 lb/ft^3, a minimum compressive strength of 4,000 psi, and a maximum permeability of 1800 coulombs. The special provisions required the coarse lightweight aggregate to meet the requirements of AASHTO M 195 while the fine lightweight aggregate was required to meet the requirements of ASTM C1761. The field-placed concrete was "all lightweight concrete" to obtain the maximum reduction in structure weight. This may have been the first use of that type of lightweight concrete by VDOT. Its use was necessary to keep the weight of the new structure and modifications within the weight of the existing structure. Construction was completed in 2016. Information on this bridge was obtained from communications with VDOT, the consultant responsible for design, and the contract documents.

Fig. 22 Route 198 Bridge nearing completion

RESEARCH ON LIGHTWEIGHT CONCRETE

The Virginia Transportation Research Council (VTRC), a branch of the Virginia Department of Transportation, has done significant work on the lightweight concrete over the years. Several reports have been cited as references for the bridges presented in this report. These and other reports can be downloaded from VTRC's website: http://vtrc.virginiadot.org/. VTRC was also involved as a research partner with the recently completed National Cooperative Highway Research Program (NCHRP) project on lightweight concrete.[21]

SPECIFICATIONS FOR LIGHTWEIGHT CONCRETE

Special provisions have been included in contract documents when lightweight concrete has been used for a project. A section that would address lightweight concrete in the VDOT standard specifications has been under development, but has not yet been completed. Requirements of lightweight aggregate are given in the VDOT *Road and Bridge Specifications* (2016) in Section 206.

A recent VTRC study showed that seven lightweight concrete decks constructed 2012-2014 had fewer cracks compared to the normal weight concrete decks of the past 20 years.[22] Consequently, based on this recent study and the performance observed with many lightweight concrete bridge structures in Virginia, VDOT has developed a low shrinkage Class A4 modified concrete specification that is included in the 2016 edition of the standard specifications (Section 217.12). It provides contractors two options for providing low shrinkage concrete when specified. The first option is to use a cementitious materials concrete of less than 600 lb/yd^3 with a maximum limit on shrinkage of 0.035%. If the limit is exceeded, then shrinkage reducing admixture must be added to the mix. The second option is to use a sand-lightweight concrete mixture with a maximum cementitious content of 650 lb/yd^3. The maximum fresh density of the lightweight concrete shall be 120 lb/yd^3 or as specified in the plans. Shrinkage testing is not required for the lightweight concrete option.

CONCLUSIONS

The information presented in this paper showcases a number of the bridge projects in the Commonwealth of Virginia that have used lightweight concrete for decks and prestressed concrete girders. The performance of these structures has been satisfactory, generally with less cracking in decks when compared to conventional normal weight concretes. In most cases, sand-lightweight concrete has been used with a fresh density of about 115 to 123 lb/ft^3. The types of structures range from very small to very large and complex structures. The use of lightweight concrete for these and other projects, along with research efforts and the development of specifications and design guidance related to the use of lightweight concrete, demonstrate that lightweight concrete is an effective tool that can be used to provide improved structural efficiency in bridges and can also be used as a strategy to control cracking in bridge decks. Based on this experience, Virginia plans to continue to use lightweight concrete for future bridge projects.

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