DURABILITY OF STRUCTURAL LIGHTWEIGHT CONCRETE

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ABSTRACT

Hydraulic cement concrete with normal weight or lightweight aggregate is a durable material serving mankind since the antiquity. However, there are many concrete structures built that have service lives much shorter than intended. Since lightweight concrete is not as common as the normal weight one, some have concerns with its durability, especially in relation to resistance to freezing and thawing. This paper summarizes the durability aspects of structural lightweight concrete. The physical and chemical aspects of durability are addressed and the effect of cracking is included. Experience of others and the Virginia Department of Transportation indicate that properly designed, proportioned, and constructed lightweight concrete with quality material provide satisfactory durability in structures.

Keywords: Concrete, Lightweight Concrete, Durability, Freezing and Thawing, Air Entrainment, Permeability

NOTE:

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INTRODUCTION

Hydraulic cement concrete is the most widely used construction material because of its versatility in construction, satisfactory compressive strength, durability, and economy. There are many good examples of durable structures from antiquity constructed with normal weight and lightweight aggregates (ACI 213R, 2003). For example, Roman structures, such as the Pantheon, which was built around 126 A.D., still remain intact. The dome of the Pantheon contains lightweight concrete. The concrete in the dome varied in density from the bottom to the top and included natural lightweight aggregates from volcanic sources.

However, the fact that many concrete structures built today have a short service life, which results in costly repairs, emphasizes the importance of durability. Recently, high performance concrete (HPC) has been introduced which is expected to have higher workability, durability and strength than conventional concrete resulting in long-lasting and economical structures (Zia et al., 1993).

Structural lightweight concrete (LWC) is designed for and expected to provide the same compressive strength and durability for similar applications as normal weight concrete. There are many examples of durable LWC structures. However, many users have concerns about the durability of LWC for highway structures, especially regarding the resistance to cycles of freezing and thawing, salt scaling, and abrasion resistance.

PURPOSE AND SCOPE

This paper summarizes the durability aspects of structural lightweight concrete by addressing the physical and chemical aspects of durability and the effect of cracking. The physical distress mechanisms of freezing and thawing and abrasion or wear, and the chemical ones including corrosion, alkali-silica reactivity, and sulfate attack, are reviewed. Durability evaluations of LWC structures including field applications are given that also include studies by the Virginia Department of Transportation (VDOT).

BACKGROUND

Structural lightweight concrete is defined as structural concrete made with low-density aggregate that has an air-dry density of not more than 115 lb/ft^3 and a 28-day compressive strength of more than 2500 psi (ACI 116R, 2000). The density at the fresh state is usually considered to be less than 120 lb/ft^3. This is typically achieved by using lightweight coarse aggregate and normal weight fine aggregate. Structural lightweight concretes generally contain aggregates made from pyroprocessed shales, clays, slates, expanded slags, expanded fly ash, and those mined from natural porous volcanic sources (Holm and Ries, 2006).

There are many benefits to using LWC. Decks with lightweight HPC (LWHPC) can be used to replace the existing superstructure to improve lane capacity. For beams, reduced dead loads combined with high strength enable spanning longer distances. The low modulus of elasticity and high inelastic strain capacity, a more continuous contact zone between the aggregate and the paste, better compatibility between the elastic modulus values of the aggregate and the paste, and more moisture in the pores of aggregates for continued internal moist curing, lead to low permeability and less cracking in LWC (Holm and Ries, 2006).

Reinforced concrete with or without lightweight aggregate is subject to distresses that may cause rapid deterioration and costly repairs. The four major types of environmental distress affecting structures are (Ozyildirim, 1993):

- corrosion of the reinforcement
- alkali-aggregate reactions
- freeze-thaw deterioration
- attack by sulfates

In each case, water or solutions penetrate the concrete and initiate or accelerate damage. HPC, with or without lightweight aggregates, is designed for low permeability to resist infiltration of aggressive liquids and therefore is more durable. In alkali aggregate reactions, the pores within the expanded lightweight aggregate provide space for the expansion of reaction products, which reduces the disruptive expansion (Holm and Ries, 2006). Concretes that can get critically saturated and exposed to cycles of freezing and thawing must have adequate freeze-thaw resistance. However, low permeability and a proper freeze-thaw resistance do not always ensure durability if the concrete contains excessive cracks that facilitate the intrusion of aggressive solutions. This cracking can be due to many factors related to both environmental effects and structural loads (TR Circular E-C107, 2006). To reduce cracking, shrinkage should be reduced. However, cracking also depends on other factors such as restraint, elastic modulus, and creep. The internal curing and the low elastic modulus of the lightweight aggregate are helpful in minimizing cracking.

Thus, an ideal durable structure would have a low permeability concrete with a proper air-void system, no cracks, and not be subject to deleterious chemical reactions. To achieve these characteristics, whether in normal weight or lightweight concrete, requires special attention to design practices, material selection, construction practices, and specifications (Ozyildirim, 2007).

BASIC DESIGN ISSUES

In design, good drainage detail can minimize ponding and prolonged exposure of bridge components to solutions. Bridge decks supported by more rigid concrete beams exhibit less cracking compared to decks supported by flexible steel (Burke, 2001; TR Circular E-C107, 2006). LWC has a lower modulus than the normal weight concrete; however, the geometry of the section can be modified to maintain the high rigidity. Thicker concrete cover provides more resistance to the penetration of solutions to the level of reinforcement. For example, the investigation of five reinforced lightweight concrete ships after 55 to 80 years of exposure indicated that the extent and severity of distress was influenced by the depth of concrete cover (Sturm et al., 1999). Avoidance of skews on structures can aid in durability as this design feature introduces torsional stresses that lead to diagonal cracking at the corners near the abutments.

MATERIAL SELECTION ISSUES

In material selection, the use of pozzolans and slag, either alone or in combination, is very effective in reducing the permeability of concrete (Lane and Ozyildirim, 2000). With LWC, lower permeability is expected due to the improved contact zone (interface) between the lightweight aggregate and the paste. The improved contact zone is due to internal curing and to the vesicular nature of the aggregate enabling paste to seep into the lightweight aggregate particles for a better bond, and the pozzolanic nature of the aggregate surface enabling a chemical bond between the aggregate and paste (Holm and Ries, 206). In addition to reducing the permeability, concrete with SCMs also resist chemical degradation caused by ASR and sulfate attack. Also, the heat treated pyroprocessed lightweight aggregates are expected to have high resistance to ASR (Burke, 2002). In LWC, the expansive products caused in these chemical reactions, if they ever occur, can move into the pores of the lightweight aggregates minimizing distress (Holm and Ries, 2006).

MIXTURE PROPORTIONING

In mixture proportioning, a proper water-cementitious materials ratio (w/cm) is effective in achieving low permeability. A lower w/cm leads to lower permeability; however, low w/cm concretes usually have higher autogenous shrinkage, stiffer consistency, higher cement content, less bleed water, and are more prone to cracking, which negates the concrete impermeability. However, lightweight aggregate provides internal curing that can mitigate the harmful effect of autogenous shrinkage in mixtures with a high cementitious materials content and a low w/cm (Holm and Ries, 2006). Also,compared to conventional concrete, LWC has a lower elastic modulus and a higher inelastic strain capacity that minimize the tensile stresses resulting from restrained deformations related to thermal, shrinkage and other sources that often lead to cracking of structures.

AIR ENTRAINMENT AND RESISTANCE TO FREEZING AND THAWING

Air entrainment and a certain level of strength (dependent on w/cm) are essential for adequate resistance to cycles of freezing and thawing (Hover, 2006). Concrete that gets critically saturated and is exposed to the critical environment must possess proper air entrainment, have sound aggregates, and have the maturity to develop sufficient strength for long-lasting service (Mather, 1990). Air entraining admixtures provide small, closely spaced, and uniformly distributed air voids. The average spacing factor (distance of any point in a cement paste from the periphery of an air void) for satisfactory resistance to cycles of freezing and thawing is accepted as 0.20 mm (0.008 in.) or less (Mather, 1990; Whiting and Nagi, 1998). Studies of LWC have shown that they may perform equal to or better than normal weight concrete in freezing and thawing conditions (ACI 213, 2003; Holm and Ries, 2006). Lightweight aggregates vary in quality and some do not have the proper soundness for resistance to freezing and thawing. Also, the freeze-thaw behavior is dependent on moisture content and moisture condition of the aggregates (Brite EuRam III, 2000). The pore size distribution and pore structure of the lightweight aggregate are important factors which relate to the ability of the aggregate particles to absorb and lose moisture. Aggregates with pores large enough to expel water easily during freezing are less prone to damage than aggregates with small pores where easy transport of water is hindered.

Specifications require a particular volume of total air content. Total air content of LWC is measured at the fresh state using the volumetric meter due to aggregate porosity (Holm and Ries, 2006). Air content tests using the volumetric method take a long time, at least 15 minutes for a single test to ensure the release of the air voids. Using the batch weights, the density (unit weight) of fresh concrete can also be used as a quick and effective indication of the air content and supplement the volumetric test. If the air voids are large, a higher volume of total air content would be needed to ensure adequate protection.

The recommended minimum strength for concrete exposed to cycles of freezing and thawing and the deicing salts is 4,000 psi (ACI 201.2R, 2001). A minimum compressive strength of 4,000 psi is commonly specified in bridge decks. These minimum strength requirements should also be adequate for LWC bridge decks. Too much air in concrete should generally be avoided since it reduces the strength of concrete. In precast and prestressed concrete beams, the stringent air requirements used for bridge decks are not needed unless critical saturation occurs. Since these beams are under the deck and generally have low permeability concrete, they are protected from water intrusion, and critical saturation is not expected.

ABRASION RESISTANCE

Another physical distress of concern has been the abrasion resistance or the wear resistance of LWC. Abrasion resistance depends on strength, hardness and toughness characteristics of the cement matrix and the aggregates as well as the bond between these two phases (Holm and Ries, 2006). Most lightweight aggregates used in structural applications are composed of vitreous ceramic comparable to quartz in hardness and are expected to provide similar performance. LWC for arctic conditions has indicated in tests to provide similar resistance to ice abrasion as the normal weight concrete (Holm and Ries, 2006). Field experience in Virginia shows that wear or abrasion resistance of lightweight concrete is satisfactory considering the condition or retention of surface texture on the bridge decks.

CONSTRUCTION ISSUES

Proper consolidation and curing during construction are essential to ensure satisfactory strength and permeability. Handling of concrete affects the final product. Delay in placement, particularly on hot days, should be avoided as it can lead to stiffening of the concrete leading to finishing difficulties. Delivery of the concrete to the forms through pumping can result in loss of slump and air content. Loss of air occurs because bubbles shrink due to pressure in the pump line, bubbles crush from the impact of the falling concrete, and bubbles expand and dissipate due to the vacuum created when concrete slides in a vertical pipe (Yingling et al., 1992). A steady flow of concrete during pumping should be provided and a large free drop in the pump line eliminated. This generally results in satisfactory freeze-thaw resistance even though the total air content may be lower than specified (Ozyildirim, 2004). With lightweight concrete, proper moisture conditioning (prewetting) of the lightweight aggregate is also important in pumping because the paste cannot be pushed into the pores of the lightweight aggregate that are already filled with water (ACI 213, 2003). However, LWC with presoaked aggregates is more prone to freeze-thaw damage and a drying period before exposure to cycles of freezing and thawing is recommended (Klieger and Hansen, 1961). Therefore, a limited drying period that will render aggregates less than critically saturated (less than 91% filled pores) before exposure to cycles of freezing and thawing is desirable. No unusual problems have been encountered in finishing LWC decks.

FIELD APPLICATIONS

There are many types of lightweight structures performing satisfactorily in the field. One of the first uses of lightweight concrete in America was for the construction of the World War I ship, Atlantis (Holm, 1980). Following lightweight concrete’s successful use for the construction of the Atlantis, lightweight concrete was used for the construction of a fleet of ships in World War II (Holm, 1980). Following these successful enterprises, the use of structural lightweight concrete increased rapidly throughout the nation for other construction purposes, especially high rise buildings.

One of the first high profile lightweight concrete bridge construction projects was the San Francisco—Oakland Bay Bridge that was constructed shortly before the start of World War II. Lightweight concrete was used for the upper deck of this bridge (ESCSI, 1971), which is still in service today.

There are many other examples of well known structures where strength and light weight were of high importance in material selection. These structures include the Chicago’s Twin Towers of Marina City, which reach 588 feet and at the time of construction set a new world record for the height of its reinforced concrete members (ESCSI, 1971). Another well known project that has taken advantage of the properties of lightweight concrete are the two Chesapeake Bay Bridges. The first Chesapeake Bay Bridge was constructed in 1952 in Annapolis, Maryland, and the second parallel structure was opened to traffic in 1973 (Vaysburd, 1996). In 1975 there was concern about the durability of the bridge initial deck, so the asphalt wearing surface was removed, and an in-depth study of the lightweight concrete deck was performed. The study revealed that the lightweight deck was in excellent condition, even after the frequent exposure to freezing and thawing, road salt exposure, stress reversals and vibration (Holm, 1980).

Engineers across the country have also taken advantage of lightweight concrete for bridge deck repairs. On the bridge carrying Interstate 84 across the Hudson River in New York, two lanes of normal weight concrete were replaced with three lanes of lightweight concrete, which resulted in an overall increase in traffic capacity (ACI 213, 2003). Lightweight bridge redecking as well as the construction of lightweight bridges has become very common throughout the country including VDOT construction projects.

Also, there are many examples of successful use of LWC from outside the United States. (Ramirez et al., 2000; Fidjestol, 2003).

VDOT STRUCTURES

VDOT has been successfully using lightweight concrete in bridge structures since 1959, mainly in deck widening projects. A list of VDOT structures with lightweight concrete is presented in Table A. In most of these bridges, the coarse aggregate has been lightweight and the fine aggregate normal weight natural sand. In general, the resistance to cycles of freezing and thawing and the wear resistance of these concretes have been satisfactory.

OLD Rte 60 (now Rte 269) OVER COWPASTURE RIVER

In 1979, VDOT constructed a bridge deck with lightweight concrete that had coarse aggregate with a very high absorption of 18%. This 212 ft long bridge is located on old Rte 60 now Rte 269, 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**.** The acceptance criteria at 300 cycles are a weight loss (WL) of 7% or less, a durability factor (DF) of 60 or more, and a surface rating (SR) of 3 or less using the scale in ASTM C672. The laboratory test results presented in Table 1 indicated a varying DF in the 3 beams from a batch of concrete.

Table 1: Freeze-Thaw Data for Bridge Deck from Old Rte 60/Rte 269 at 300 cycles

Specimen #	Weight Loss (%)	Durability Factor	Surface Rating
B1	4.3	59	2.2
B2	3.8	32	1.5
B3	3.4	92	2.5
Average	3.8	61	2.1

Acceptance limits at 300 cycles: Weight Loss $\leq$7, Durability Factor $\geq$60, and Surface Rating $\leq$3.

There were pop outs and loss of material in the test beams associated with the coarse lightweight aggregate. However the average values of WL, DF, and SR 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.

Rte 106 over CHICKAHOMINY RIVER

In the late 1990s, studies with high performance lightweight concretes (HPLWC) were conducted that led to the construction in 2001 of the first HPLWC bridge structure, the Rte 106 Bridge over the Chickahominy River near Richmond. The bridge carries heavy truck traffic to an industrial park, a logging business, and a large waste disposal site. In the Rte 106 Bridge and the following HPC studies, a high quality expanded slate aggregate was used that had absorption values of 5 or 6 % and could easily produce concrete with the minimum compressive strength of 8,000 psi specified in these bridges and commonly used in Virginia. The LWC contained lightweight coarse aggregate and natural sand except that the beams of the Rte 106 bridge also contained lightweight fine aggregate and normal weight coarse aggregate (Ozyildirim, CBC2004).

The Route 106 Bridge used HPLWC AASHTO Type IV beams with a minimum 28-day compressive strength of 8,000 psi and a maximum permeability of 1500 coulombs. The length of the beams was 84 ft. The lightweight deck was required to have a compressive strength of 4,000 psi and a maximum permeability of 2500 coulombs at 28 days. The low coulomb requirement for the prestressed beam compared to a higher value for bridge decks is due to the typical low values obtained for the type of concrete used and the critical nature of the beams.

The results of the freeze-thaw tests are summarized in Table 2. Both batches for beams performed very well, exhibiting only minor weight loss, and had excellent surface ratings and acceptable durability factors. Since the freeze-thaw tests were successful, an air void analysis was not conducted. After three winters, the structure was in very good condition (Ozyildirim, CBC2004).

Freeze-thaw data for the deck concrete are also given in Table 2. The results indicated acceptable values for weight loss and surface rating indicative of scaling. The durability factor was satisfactory for batches Deck1 and Deck3 but was questionable for batches Deck2 and Deck4. Similarly the linear traverse data to determine the air-void parameters shown in Table 3 indicate that batches Deck1 and Deck3 had the lowest spacing factors with Deck1 being marginally higher than the generally accepted limit. Batches Deck2 and Deck4 had unsatisfactory void systems with spacing factors above 0.20 mm (0.008 in) and the specific surface below 24 mm^2/mm^3 (600 in^2/in^3). Thus, the deck concrete provided varying level of freeze-thaw resistance. However, at this time no distress is evident. The low permeability of the concrete and good drainage on the deck can minimize critical saturation and therefore assist in providing the desired resistance to cycles of freezing and thawing.

Table 2: Freeze-Thaw Data from Rte 106 Bridge at 300 cycles

Batch #	Air (fresh conc) (%)	Weight Loss (%)	Durability Factor	Surface Rating
Beam1	5.5	1.77	84	1.70
Beam2	6.0	3.10	62	0.99
Deck1	5.0	1.80	94	1.28
Deck2	5.5	4.35	89*	1.89
Deck3	5.0	2.75	99	1.91
Deck4	5.7	6.92	70*	3.05

* The durability factor test for Deck2 ended at 150 cycles and for Deck4 at 100 cycles because of problems with testing.
Acceptance limits at 300 cycles: Weight Loss ≤7, Durability Factor ≥60, and Surface Rating ≤3.

Table 3: Air-void Parameters for Deck Concrete from Rte 106 Bridge

Batch	Voids > 1 mm (%)	Total Voids (%)	Specific Surface (mm^{-1})	Spacing Factor (mm)
Deck1	0.7	2.5	24.8	0.2671
Deck2	2.6	3.7	6.7	0.8209
Deck3	0.5	5.4	28.3	0.1641
Deck4	1.4	4.5	15.5	0.3261

Prior to the construction of bridge beams, test beams were cast and tested to failure (Ozyildirim et al., 2004). The freeze-thaw data for the concrete in these test beams are given in Table 4 and the air void parameters in Table 5.

Table 4: Freeze-Thaw Data for Concrete in Test Beams at 200 cycles

Batch #	Weight Loss (%)	Durability Factor	Surface Rating
1	7.67	94	2.61
2	17.10	85	3.90
3	10.96	100	2.55
4	11.39	100	2.64

Note: Testing terminated at 200 cycles for all test since weight loss > 7%
Acceptance limits at 300 cycles: Weight Loss ≤7, Durability Factor ≥60, and Surface Rating ≤3.

The resistance to freeze-thaw of the beams was low. Again the spacing factors were high indicating the lack of a satisfactory air void distribution in the concrete. One of the test beams had NWC and it also had poor resistance to freezing and thawing and a high spacing factor. The HRWRA used in these beams tended to cause coarser air voids leading to high spacing factors. The level of protection required for beams is not generally as critical as that required for decks since the beams are not directly exposed to as harsh an environment as the decks. However, to achieve satisfactory field performance, it is universally accepted that the proper air void system is required for concrete that can get critically saturated and be subjected to cycles of freezing and thawing.

Table 5: Air-void Parameters for Concrete in Test Beams

Type	Batch	Air (fresh) (%)	Voids > 1 mm (%)	Total Voids (%)	Spacing Factor (mm)
NW	B1	5.2	2.3	5.4	0.3813
LW	B2	5.6	2.4	6.5	0.3467
LW	B3	5.0	2.9	7.9	0.3067
LW	B4	4.6	3.4	7.3	0.4216

NW=Normal weight, LW=Lightweight

Rte 33 over MATTAPONI and PAMUNKEY RIVERS

Recently, VDOT completed two long bridges on Route 33 near West Point, with long spans containing HPLWC Bulb-T beams and deck. HPLWC was chosen because of poor soil conditions. The first bridge is over the Mattaponi River. It is 3,454 ft long, with 2,195 ft of its length constructed with HPLWC. HPLWC was used in the longer spans of 136 ft-4 in, 200 ft, and 240 ft. The latter two spans were constructed using 160-ft-long drop-in beams spliced to haunched girder segments over the piers with post-tensioning. For the beams, the specifications required a minimum compressive strength of 8,000 psi and a maximum permeability of 1,500 coulombs. The other bridge is over the Pamunkey River. It is 5,354 ft long, with 2,169 ft being HPLWC with span lengths of 145 ft, 200 ft, and 240 ft. Again, the latter two spans was constructed using drop-in beams spliced to haunched girder segments over the piers. The deck on the HPLWC beams in both bridges is also HPLWC with the specifications requiring a minimum compressive strength of 5,000 psi and a maximum permeability of 2,500 coulombs.

The freeze-thaw data and air content for the deck concretes tested in the Route 33 bridges are summarized below in Table 6. The results indicate satisfactory durability factors in both the normal weight and lightweight concretes. However, the normal weight concrete had higher weight losses which can be further investigated by petrographic analysis.

DISCUSSION AND CONCLUSIONS

Durable structures have been built and can be built with LWC. For improved durability in LWC and normal weight concrete, proper structural design, material selection, proportioning, and construction practices must be followed. In general, less cracking is exhibited in LWC structures due to internal curing, better contact zone between the aggregate and the paste, lower elastic modulus and the higher inelastic strain capacity.

Properly air-entrained LWC made with high quality lightweight aggregates provides satisfactory resistance to freezing and thawing in structures. They also show satisfactory results in the harsh freeze-thaw tests when limited air drying is provided prior to testing. The field performance with LWC has been satisfactory.

Table 6: Freeze-thaw and air content for the deck mixes used in the Rte. 33 bridges

Batch	Air (fresh conc) (%)	Weight Loss (%)	Durability Factor	Surface Rating
Pamunkey NW B1	6.0	17	96	3.1
Pamunkey NW B2	7.0	26.7	70	1.8
Pamunkey NW B3	5.7	8.6	91	1.4
Mattaponi LW B1	7.0	6.6	102	1.5
Mattaponi LW B2	5.2	2.8	103	0.9
Pamunkey LW	5.7	6.1	107	1.0

NW=Normal weight, LW=Lightweight
Acceptance limits at 300 cycles: Weight Loss ≤ 7, Durability Factor ≥ 60, and Surface Rating ≤ 3.

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Table A: VDOT Bridges with LWC

Route on Bridge	***Crosses***	***Year***	***Type (Deck, Rehab, etc.)***
Route 161	James River	1993	Replaced deck (Boulevard Bridge)
BR US 460	NS RR	1990s	Deck
Route 106	Chickahominy River	2001	Girders and deck
US 17	York River & SR 238	1996	Deck on truss spans (Coleman Bridge)
Old Route 60	Cowpasture River	1979	
Duke Street	RF&P Railroad	1980	
Franklin Rd	Roanoke River		Deck
Route 301	Potomac River	1985	
	Route 29 Expressway	1991	
Hunter Street	Norfolk Southern RR	1999	Deck
I-464 NB	Gilligan Creek & NS RR	1987?	Deck
I-95 SB	Occoquan River	1996	Deck
Laburnum Ave	CSX Railroad	1991	
Route 33	Mattaponi River	2006	Girders and deck for spans > 120 ft
	Maury River	1984	
Route 3	Rappahannock River	1994	Filled steel grid
Odd Fellows Rd	Southern Railroad	1989	Rehabilitation
Odd Fellows Rd	Route 29 Expressway	1991	
Route 33	Pamunkey River	2007	Girders and deck for spans > 120 ft
Pinner Street	N & W & SCL Railroads	1984	
Pungo Ferry Rd	North Landing River (ICW)	1990	Deck on 3 main spans
Route 1			Deck and parapets (169’ – 241’ – 241’ -184’)
Route 11/460	NS RR & Roanoke River	1993/94	Replaced deck
Route 15	Grassy Creek	2001	Replaced deck
Route 16	North Fork of Holston River	1980	
Route 269	Simpson Creek	1994/95	Decks and parapet walls for widening
Route 269	Simpson Creek	1994/95	Decks and parapet walls for widening
Route 269	Simpson Creek	1994/95	Decks and parapet walls for widening
US 29B	Staunton River & NS RR	1988	Replaced deck on 4 truss spans
Route 36	Appomattox River	1960	
Route 43	Otter River	1989	Rehabilitation
Route 58 EB	Sandy River	1989	Eastbound Lane Parapet Wall
Kellogg Mill Rd	Potomac Run	1993	Replaced deck & parapet
Route 664		1985	
Route 7	Route 50 EB	1999	Precast deck panels for rapid deck replacement
Route 7	Route 50 WB	1999	Precast deck panels for rapid deck replacement
Route 718	White Oak Creek	1994	Replaced bridge deck on existing bridge
Wards Road	Route 29 Expressway	1991	
I-95	Potomac River	1983	Full depth deck panels for deck replacement
I-95	Potomac River	2006	Deck on bascule piers and filled grid on bascule leaves