"Design and Construction of Concrete Pavement On Interstate 66 in Fairfax County, Virginia Applications of New Technologies"

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INTRODUCTION

The project described was recently completed by the Virginia Department of Transportation (VDOT) as part of a $140 million reconstruction program on a section of Interstate 66 (I-66) in Fairfax and Prince William counties, Virginia. Specifically, applications of new technologies during design and construction of 10.3 kilometers (6.4 miles) of concrete pavement in Fairfax county are described. These technologies include the use of cement stabilization for the weak micaceous soil subgrade, a stabilized open graded drainage layer (OGDL), pavement edge drains, recycling of the original concrete pavement as cement treated aggregate (CTA) subbase material, use of a sand blinding layer to prevent concrete paste penetration into the stabilized OGDL, FAST TRACK concrete paving and use of automatic dowel bar inserters on the concrete paving machine.

The condition of the original concrete pavement, which was constructed in the early 1960s, began to deteriorate dramatically in the early 1990s under rapidly increasing traffic volumes and loads, necessitating the reconstruction project described in this paper. With a total of only four lanes available to carry average daily traffic volumes in excess of 120,000 vehicles per day, demolition of the original concrete pavement and construction of an additional four lanes of concrete pavement required that extremely careful consideration be given to maintenance of traffic during construction. The anticipated traffic congestion nightmare did not materialize due to an innovative maintenance of traffic plan, extensive night work, the use of incentives and disincentives, frequent media announcements and an excellent partnering relationship between the contractor, VDOT and the Federal Highway Administration (FHWA).

DESIGN

Original Pavement

The original pavement on I-66 between the Route 50 in Fairfax and Route 29 in Centreville consisted of a 229 mm (9") thick hydraulic cement concrete pavement, reinforced with welded wire mesh (Reinforcing Steel Institute designation 6x12-W5.5xW4), giving 0.1% reinforcing steel in the longitudinal direction and 0.037% reinforcing steel in the transverse direction. Contraction joint spacing averaged approximately 18.76 m (61.5'). The original subbase consisted of an average of 152 mm (6") of plain aggregate over 152 mm (6") of cement stabilized soil subgrade.

An extensive visual and mechanical survey, using a Falling Weight Deflectometer (FWD), was performed to assess the structural integrity and extent of the distresses evident in the original concrete pavement which had already exceeded its design life. These distresses included joint faulting, joint spalling, corner breaks, mid-slab spalls (above wire mesh), settlement, popouts, patch deterioration, edge breaks at joints, longitudinal cracks, mid-slab transverse cracks, asphalt shoulder drop-offs, and numerous instances of pumping and water seepage at joints. Some of the original joints had been repaired with full depth patches but these patches were also showing signs of deterioration and failure.

The visual survey indicated that all of the above distresses ranged from moderate to severe with more than 80% of the existing transverse joints requiring full depth patching over at least one of the two lane widths. The results of the FWD testing confirmed visual observations that the existing pavement was structurally deficient with typical composite stiffnesses of 298 kN/mm (1700 lbf/mil) and 315 kN/mm (1800 lbf/mil) for the east and west bound lanes, respectively, and typical joint load transfer efficiencies of about 75 percent.

Design of New Concrete Pavement

Several alternatives were considered for incorporating the existing pavement into the long term pavement design. Alternatives considered included Concrete Pavement Rehabilitation (CPR), crack and seat of the existing concrete, use of a bonded or unbonded overlay and complete replacement. The unbonded overlay and crack and seat alternatives were ruled out early in the evaluation process due to inadequate bridge clearances and the numerous grade restraints imposed by the urban nature of the project. The cost of the full depth and partial depth patching required to salvage the existing pavement using a bonded overlay was estimated to be comparable with the cost of complete replacement and did not address the problem of inadequate subbase and subgrade drainage. Considering the amount, type and severity of the distresses observed and the results of the FWD testing (which indicated structural deficiencies), the volume of projected traffic and the age of the existing pavement, it was decided to demolish the existing pavement and construct an entirely new pavement structure with enhanced drainage capabilities.

A complete soil survey was performed with auger borings completed at 30.5 m (100') intervals in the areas of the proposed widenings. The soils encountered consisted predominantly of micaceous silts, derived from the Peters Creek Schist Formation (*1*) on the eastern portions of the project, with a transition through highly plastic clays and sands (diabase dyke) in the central portions to Triassic Age shales, siltstones and sandstones on the western extremities. For design purposes, these soils were divided into two broad categories. Typical soil properties for each category are given in Table 1.

Analysis of the historic traffic data for this section of I-66 yielded an estimated Average Daily Traffic (ADT) volume of 148,339 vehicles per day (vpd) with an Average Daily Truck Traffic (ADTT) volume of 10,709 for the design year of 2010. Based upon this ADTT and using the design methodology recommended by the American Association of State Highway and Transportation Officials (*2*), the cumulative 18 kips rigid equivalent single axle load (ESAL) for a 30 year design life based on the maximum legal loads was estimated to be approximately 68 million. This estimate was considered to be unrealistically conservative because it assumed that all trucks had maximum legal axle loads on all days over the projected design life of 30 years. A more realistic estimate based upon the actual truck weights was calculated at 41 million 18-kip rigid ESALs. This data was considered to be highly reliable since truck weigh stations were located on both the east and west bound lanes near the Fairfax County Parkway (Route 7100) interchange. Table 2 is a summary of design parameters used for the new concrete pavement.

Early in the design process, the decision was made to include enhanced drainage systems in the design based on recent research (*3*) which concluded that improving drainage of the pavement subgrade and base layers can significantly extend pavement service. The drainage systems specified for this project included a stabilized open graded drainage layer (OGDL) and pavement edge drains (VDOT, Standard UD-4). A stabilized OGDL typically consists of an open graded aggregate stabilized with 2% liquid asphalt (normally AC-30 or AC-40) or stabilized with 131 to 136 kg/m^3 (220 to 230 lbs/cy) hydraulic cement. Cross drains (VDOT, Standard CD-2) were also provided at sag points of vertical curves, at transitions from cut to fill and at the low ends of undercut areas to improve subgrade drainage.

Based upon a life cycle cost analysis, a concrete pavement was determined to be competitive with asphalt and considering the poor soil conditions, the heavy volume of truck traffic and the proven past performance of the existing rigid pavement, it was decided to use a rigid pavement with a tied concrete shoulder. The additional edge support provided by a tied concrete shoulder reduced the depth of concrete required for the mainline pavement by approximately 25 mm (1"). Figure 1 shows the typical pavement section for this project.

Cement stabilized subgrade was specified for the eastern portions of the project to provide a stable platform for placement of subsequent pavement layers due to the very low CBR values of the native micaceous silts encountered at subgrade. An added benefit of cement stabilization of the subgrade was that the amount of unsuitable soils which had to be excavated and wasted from the project was minimized. A CTA subbase provided a rigid base for placement of the stabilized OGDL. In addition, the CTA layer protects the stabilized soil from possible erosion caused by the potentially high transmissivity of the stabilized OGDL which has a minimum specified permeability of 0.35 cm/sec (1,000 feet/day) but actual

in-place permeabilities on the order of 2.47 cm/sec (7,000 feet/day). Due to the need for maintenance of traffic, the inside shoulder was designed as 241 mm (9.5") of bituminous concrete over 152 mm (6") of free draining densely graded aggregate, type I, size no. 21B. This did not affect the thickness design of the concrete pavement since the design lane was on the outside of the pavement and minimal truck traffic was anticipated on the inside lane which is designated for High Occupancy Vehicle (HOV) use only.

A Special Provision was also included in the contract which required the contractor to recycle the existing concrete pavement as coarse aggregate for new hydraulic cement concrete, as aggregate for CTA or as backfill for replacement of unsuitable materials. A total of 182,532 m^2 (218,340 yds^2) of concrete pavement was specified for recycling. The contractor was given the option of recycling the existing base aggregate as embankment or as aggregate for production of CTA. Any surplus of recycled concrete was to be used as embankment or to be crushed and stockpiled for use in subsequent VDOT projects. All costs for recycling of the existing concrete were to be included in the price bid for demolition of the existing pavement.

CONSTRUCTION

The contract involving construction of the concrete pavement was accepted by VDOT on January 5, 1994 with Cherry Hill Construction, Inc. of Jessup, Maryland as the successful bidder at a total of almost $55 million. The partnering process which was ratified by all parties early in the project proved to be very successful in facilitating early and mutually successful resolution of potential conflicts. The partnering on this project was a formal agreement between all parties whereby each party committed to early and mutually agreeable resolution of differences with honesty and integrity by identifying common goals and objectives in an atmosphere of trust while maintaining or enhancing the quality and cost effectiveness of the finished project. This undoubtedly contributed to completion of the project on schedule despite several unforeseen conditions which necessitated additional work.

Subgrade Stabilization

The original design for stabilization of the extremely weak highly micaceous subgrade soils encountered on the eastern portions of the project specified 10% by volume of hydraulic cement to be manipulated to a depth of 152 mm (6"). In the early stages of the project, several areas of the stabilized subgrade began to fail under passage of equipment used to place the CTA subbase. This was attributed to the highly micaceous nature of the saprolitic soils encountered as well as areas of high natural moisture content.

In order to investigate the problem of premature subgrade failures, the effect of increasing the cement content to 12% by volume was evaluated by measuring the unconfined compressive strengths at 7, 14 and 28 days. These strengths were compared to a split sample tested with the original design of 10% cement by volume. Although the sample tested with 12% cement by volume only produced a 7-day unconfined compressive strength of 1.80 MPa (261psi), there was a significant increase in the 14-day strength and the 28-day strength exceeded 2.41 MPa (350 psi). Since previous experience had shown that increasing the percentage of cement above 12% by volume did not yield any significant increase in the 7-day unconfined compressive strength, the depth of manipulation was increased to 203 mm (8") to compensate for the weak micaceous silts. This was only necessary in the areas of high mica contents and where moisture contents exceeded optimum by 30%-80%. This proved to be highly successful in eliminating subgrade failures and ensuring that adverse impacts on the construction schedule were minimized. Figure 2 shows a typical strength versus time relationship for a sample of micaceous silt soil.

Demolition and Recycling of the Original Concrete Pavement

The contractor tried several methods for demolishing the original concrete pavement. The most successful method was an initial pass of a 5.9 Mg (13,000 lb) "guillotine" breaker followed by breaking and loading with a CAT 235 tracked hoe into dump trucks. The broken concrete was hauled to an on-site stockpile for crushing. A 4 hectare (9.9 acre) site had been provided by VDOT for this purpose. During crushing, an electro-magnet was used to successfully remove approximately 99% of the wire mesh. Complete removal of the wire mesh proved to be practically impossible. After crushing to a VDOT #21A gradation, 4% by weight of hydraulic cement and water were added in the on-site batch plant to produce the CTA subbase. Placement of the CTA subbase was achieved by use of a vibratory screed with automatic grade control referenced to a longitudinal string line. Transverse grades were checked manually with string lines. Although the vibratory screed was capable of placing the CTA subbase in widths of up to 7.32 m (24'), limited space for access of supply trucks and problems

with segregation of the subbase limited operations to a maximum width of 3.66 m (12'). Only 2 to 4 passes of a 9.1 Mg (10 ton) smooth drum vibratory roller were required to achieve final compaction.

Strength of Recycled Cement Treated Aggregate Subbase

The physical properties of the CTA subbase produced from the recycled concrete aggregate (recycled CTA) proved to be very difficult to predict due to variabilities in gradation, minimal rehydration of the crushed cement, low unit weights and a high water demand. The strength versus time relationships obtained from the recycled CTA subbase were also considerably different than those obtained from virgin aggregate. Theoretically, a recycled CTA subbase should produce higher unconfined compressive strengths than a CTA produced from virgin aggregates (virgin CTA). However, unconfined compressive strength test results of the recycled CTA subbase produced on-site actually showed a reduction in strength when compared with virgin CTA. This difference was primarily attributed to slight contamination with the underlying micaceous silts, a slightly coarser gradation with less fines in the recycled aggregate, significantly lower unit weights of recycled aggregates and no rehydration of the cement fines from the original concrete. Rehydration of cement fines is normally observed with hydraulic cement concrete which has been crushed but no rehydration was observed during this project, probably due to the age of the original concrete pavement. Figure 3 shows the relationship between unconfined compressive strength and time for recycled CTA and virgin CTA. Figure 4 is a comparison of gradations between recycled CTA and virgin CTA.

Concrete Paving Operations

Concrete paving operations began early in October 1994. The contractor submitted several mix designs for approval prior to paving, each with slightly different water to cement ratios to allow rapid adjustment of mixes for varying ambient weather conditions. All mixes included 20% Class F fly ash and water reducing and air entraining admixtures. Cylinder (28-day) compressive strengths averaging 33.76 MPa (4,900 psi) were well in excess of the minimum 20.67 MPa (3,000 psi) requirement. A special mix design using 262.9 kg (579 lbs) of cement per batch instead of the normal 217.5 kg (479 lbs), with a water to cement ratio of 0.4, was used to obtain high early strengths for FAST TRACK paving in areas critical to maintenance of traffic. Although VDOT specifications allow slumps of up to 76 mm (3"), most of the concrete produced had slumps of 25 mm (1") to 38 mm (1.5"). Since VDOT specifications do not allow traffic on concrete pavement until a center point flexural strength of 4.1 MPa (600 psi) has been achieved, numerous test beams were cast for each placement with 4 or 5 beams being cast on critical placements.

In order to achieve as smooth a riding surface as possible, the contractor installed longitudinal string lines which were used to establish subgrade and for placement of all subsequent pavement layers including the 279 mm (11") thick concrete pavement which was placed with computerized grade controls referenced to the longitudinal string lines. A CMI 450 paver with mid-mount automatic dowel bar inserters and automatic grade controls was used in two 7.32 m (24') wide pulls to place the mainline pavement while a REX paver with a belt feed attachment was used to place the outside (concrete) shoulder and ramp sections, some of which were placed by hand. Longitudinal tie bars were also placed using automatic dowel bar inserters. Joints were sawn and curing compound applied as soon as possible after initial placement of the concrete with very careful attention being paid to marking dowel bar locations during placement. Preformed asphaltic boards with a thickness of 19 mm (3/4") were installed as bond breakers in widened areas where transverse joint locations did not align due to differences in joint spacing between the old and new pavements.

Overall smoothness was improved by using the 7.32 m (24') wide paver which eliminated a longitudinal "cold" joint and by maintaining a constant speed with the paving train. Recognizing the importance of a stable track line for the smoothness of the final riding surface, the CTA subbase was extended beneath the track line in order to maintain production during periods of wet winter weather. Also, by maximizing the amount of concrete in each placement, the contractor not only improved efficiency and saved time but also minimized the number of transverse "cold" joints which improved overall smoothness. Placements of 4,180 m^2 (5,000 yds^2) were common with the largest placement being 6,354 m^2 (7,600 yds^2) or 793 linear meters (2,600 linear feet of pavement). Mechanical floating and tining of the surface also contributed to a very uniform finish. IRI values as low as 0.66 m/km (42 ins./mi.) were achieved with average values of 1.36 m/km (85.9 ins./mi.) for the eastbound lanes and 1.47 m/km (92.8 ins./mi.) for the westbound lanes. These average values would have been reduced if bridge approaches and other discontinuities had not been included the averages.

Clogging of Stabilized Open Graded Drainage Layer

A 76 mm (3") layer of asphalt stabilized OGDL was placed directly over the CTA using standard asphalt paving equipment to enhance internal drainage of the pavement structure. An interesting problem which arose during construction was penetration of paste from the paving concrete into the upper 25 mm to 51 mm (1"-2") of the 76 mm (3") thick stabilized OGDL. Initially this was discovered by a relatively high yield loss of 10-12 percent for the paving concrete. This was undesirable since the drainage capacity of the OGDL could have been significantly reduced as well as reducing the contractor's profitability. A total of 20 locations were cored to investigate the problem. The locations investigated included areas paved with the large CMI paver as well as locations placed with a smaller REX paver, hand placed locations and areas placed with a medium sized paver during a previous project. The maximum average penetration of 22.9 mm (0.9") was obtained in sections which had been paved with the large CMI paver. This was almost twice the average penetration obtained in sections placed with smaller pavers or by hand which ranged from 7.6 mm (0.3") to 12.7 mm (0.5") respectively. The maximum penetration of 30.5 mm (1.2") was cause for concern since the total thickness of the stabilized OGDL was only 76 mm (3") and the rate of dissipation of water from coring was markedly slower than in other areas. This was unfortunate since the CMI paver and automatic dowel bar inserters were producing excellent consolidation of the concrete especially around the dowel bars, an area which historically has proven to be very difficult to consolidate with dowel baskets.

In order to limit the amount of paste penetration into the stabilized OGDL, several alternatives were considered before broadcasting a coarse sand at a depth of approximately 6 mm (0.25") over the stabilized OGDL prior to concrete placement. The advantages of the sand "blinding" layer were that the vertical permeability of the OGDL was maintained at joint locations, the sand was readily available and cost effective and any sand which penetrated into the stabilized OGDL would not significantly reduce the permeability of the stabilized OGDL. These assumptions were verified during coring by rapid dissipation of the water used for coring. The sand application was extremely successful with maximum paste penetrations limited to 12.7 mm (0.5") and the maximum average penetrations limited to 7.6 mm (0.3") for all concrete placement methods. The sand penetration was generally limited to 6 mm (0.25") below the top of the stabilized OGDL and was concentrated at the surface where it had formed a very thin, weak "paste" with the concrete. The small amount of sand below this paste was bonded to the liquid asphalt coating on the stabilized OGDL. Table 3 is a summary of paste penetration into the stabilized OGDL versus placement method.

Maintenance of Traffic

Movable jersey barrier was installed to facilitate access of paving equipment and concrete trucks to placement locations. A high volume ramp from eastbound Route 50 to eastbound I-66 was closed to traffic for a 48 hour period over a weekend to allow FAST TRACK paving operations to be completed on mainline I-66 in time for the Monday morning rush hour. Incentives of $2,000 per day for early completion and disincentives of $2,000 per day for late completion of this and other critical areas ensured that major traffic disruptions were minimized. One section of the mainline pavement was closed to traffic late on a Friday night, temporary pavement demolished, new concrete pavement placed, joint sealing completed and reopened to traffic by rush hour on Monday morning, the concrete having attained the required 4.1MPa (600 psi) flexural strength early on Sunday morning.

All major traffic switches and closures were announced through all available media sources as well as on several variable message boards placed at strategic locations throughout the project. Two new commuter park and ride lots were also constructed to reduce traffic volumes and a free shuttle bus service further helped reduce rush hour congestion. Strengthening of the shoulders on an existing collector-distributor road allowed traffic to be temporarily diverted from a 1.6 km (1 mile) section of the mainline, allowing for easier access and staging of equipment.

Scheduling of Operations

Although not strictly an application of new technology, scheduling of paving operations during less heavily trafficked night time hours ensured that disruption to commuter traffic was minimized as well as ensuring a smooth supply of concrete to the paving train. During the summer months, the cooler night time temperatures reduced problems with flash setting of concrete, allowed for efficient application of curing compound and sawing of joints, as well as minimizing cancellation of pours due to thunderstorms, a frequent summer afternoon occurrence in the Washington metropolitan area. Night paving operations allowed the on-site batch plant to be used during the day for production of cement stabilized subbase. In addition, creative scheduling and shift work ensured equipment and manpower use was maximized allowing pavement breaking, demolition, hauling, crushing, mixing and placement of new materials to continue efficiently 24 hours a day over six, and

sometimes seven, days a week. Also, the contractor's innovative approach to management of construction which emphasized coaching, team work and financial rewards significantly improved morale and production.

PERFORMANCE DATA

After almost two years of service, the new concrete pavement has demonstrated excellent performance. There is no apparent faulting at the joints, slab cracking , joint spalls or water problems. All of the joint seals are in excellent condition. The only observed distresses which have occurred are some slight spalls of the old concrete at the longitudinal joint tie-ins where the original tie bars in the old concrete were left in place, two small corner breaks at a "stepped" longitudinal joint required for maintenance of traffic and approximately twelve slabs which cracked during jacking operations to correct settlement caused by an old underlying clay fill at a bridge approach.

SUMMARY

Innovations and new technologies in design included an extensive study of the condition of the original concrete pavement distresses; accurate traffic analyses using truck weigh station data; cement stabilization of very weak micaceous subgrade soils to minimize undercuts and to provide a stable working platform for placement of subsequent pavement layers; provision of a stabilized OGDL placed on a non-erodible CTA subbase connected to a pavement edge drain system and specifications for recycling of the existing concrete pavement.

New technologies used during construction included a 7.32 m (24') wide paver with automatic dowel bar inserters for both the transverse dowel bars and longitudinal tie bars; use of increased cement content and increased depth of manipulation for stabilization of weak subgrade soils; installation of an on-site batch plant for production of pavement concrete and recycled CTA subbase material; use of a blinding layer of coarse sand to minimize penetration of concrete paste into the asphalt stabilized OGDL; FAST TRACK concrete placement and use of incentives and disincentives for critical portions of paving operations to minimize user delays and 24 hour scheduling of operations to maximize use of men and equipment.

CONCLUSIONS

This project was successfully completed on schedule despite a considerable amount of additional work due to implementations of several innovative techniques and new technologies during the design and construction phases and the successful application of partnering. Rapid construction of concrete pavement is possible by innovation and application of new technologies in design, planning and construction. Recycling of the original pavement was economically viable due to economies of scale realized by the use of versatile equipment and innovative scheduling of operations. Careful monitoring of construction, attention to detail and adjustment of operations in response to observed material behaviors ensured that critical design assumptions and material specifications were achieved during construction by rapid responses and adjustment to variable site conditions.

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TABLE 1 Typical Properties of Subgrade Soils

Category	Soil Description	Liquid Limit (%)	Plasticity Index	% Passing No. 200 Sieve	Range of CBR[a] Values	Design[b] CBR[a] Value
I	Micaceous Silts	29-38	NP-16	40-65	0.3-11.0	2.0
II	Triassic Shales, Siltstones	26-32	5-12	50-65	0.7-69.0	14.6

[a] CBR determined in accordance with Virginia Test Method No. 8

[b] Design CBR = Soaked Average Laboratory CBR (excluding high and low values) x 0.67

TABLE 2 Design Parameters for Concrete Pavement

Parameter	Value (MPa)
Modulus of Rupture	4.66
Subgrade Resilient Modulus	
- micaceous silts	20.67
- shales, siltstones	150.89
Subbase Resilient Modulus	4823.00
Modulus of Subgrade Reaction	
- micaceous silt (Loss of Support=0)	3.29
- shale (Loss of Support=1)	3.08

Note: 1 psi = 6.89×10^{-3} MPa

TABLE 3 Penetration of Concrete Paste into Stabilized Open Graded Drainage Layer

	Without Sand		With Sand	
Placement Method	Penetration Range (mm)	Penetration Average (mm)	Penetration Range (mm)	Penetration Average (mm)
CMI Paver	15.2 - 30.5	22.9	2.5 - 10.2	5.1
REX Paver	5.1 - 25.4	12.7	5.1 - 12.7	7.6
Hand Pours	2.5 - 10.2	7.6	5.1 - 12.7	7.6
Similar Project	7.6 - 17.8	10.2	N/A[a]	N/A[a]

Note: 1 inch = 25.4 mm

[a] N/A indicates that sand was not used on this project

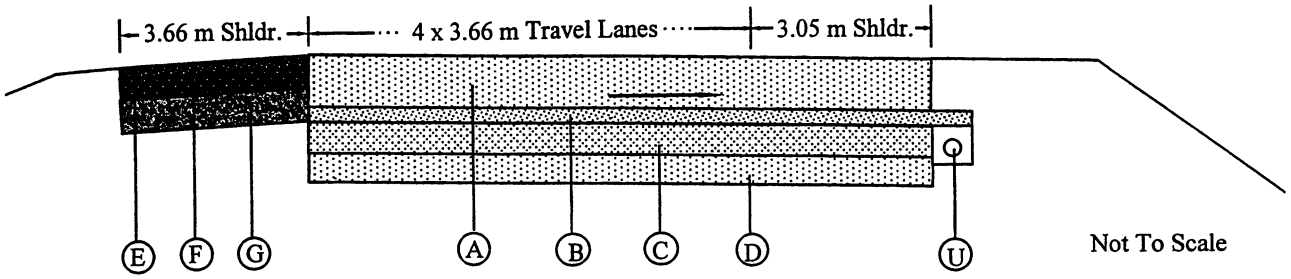
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Ⓐ 279 mm Plain Hydraulic Cement Concrete Pavement, VDOT Std. PR-2

Ⓑ 76 mm Stabilized Open Graded Drainage Layer

Ⓒ 152 mm Cement Treated Aggregate, Type I, Size No. 21A, with 4% Hydraulic Cement by Weight

Ⓓ 152 mm stabilized Subgrade with 10% Hydraulic Cement by Volume
(Sta 114+50 to Sta 357+00 only)

Ⓔ 38 mm Asphalt Concrete, Type SM-2C

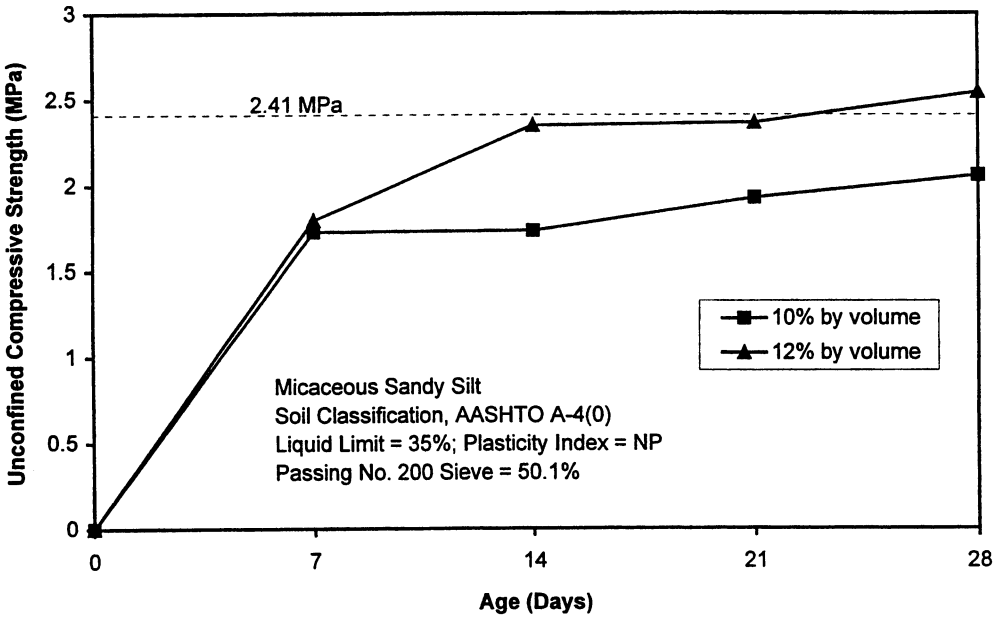
Ⓕ 203 mm Asphalt Concrete, Type BM-2

Ⓖ 152 mm Aggregate Material, Type I, No. 21B

Ⓤ Pavement Edge Drain, VDOT Std. UD-4

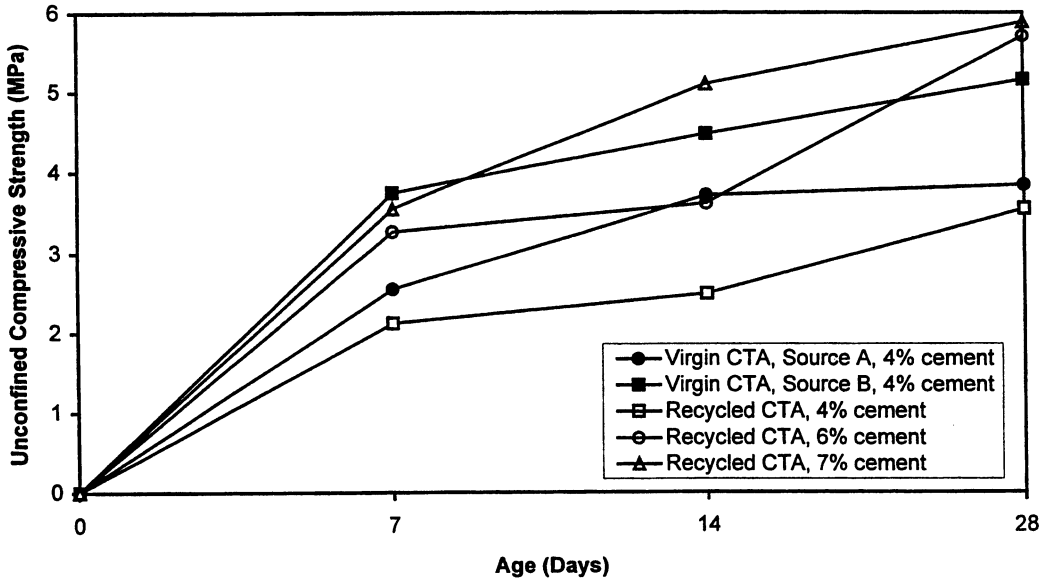
Note: 1 inch = 25.4 mm
1 foot = 0.305 m

FIGURE 1 Typical Pavement Section



Note: 1 psi = 6.89×10^{-3} MPa

FIGURE 2 Unconfined Compresive Strength vs. Time for Soil Cement



Note: 1 psi = 6.89×10^{-3} MPa

FIGURE 3 Unconfined Compressive Strength vs. Time for Cement Treated Aggregate

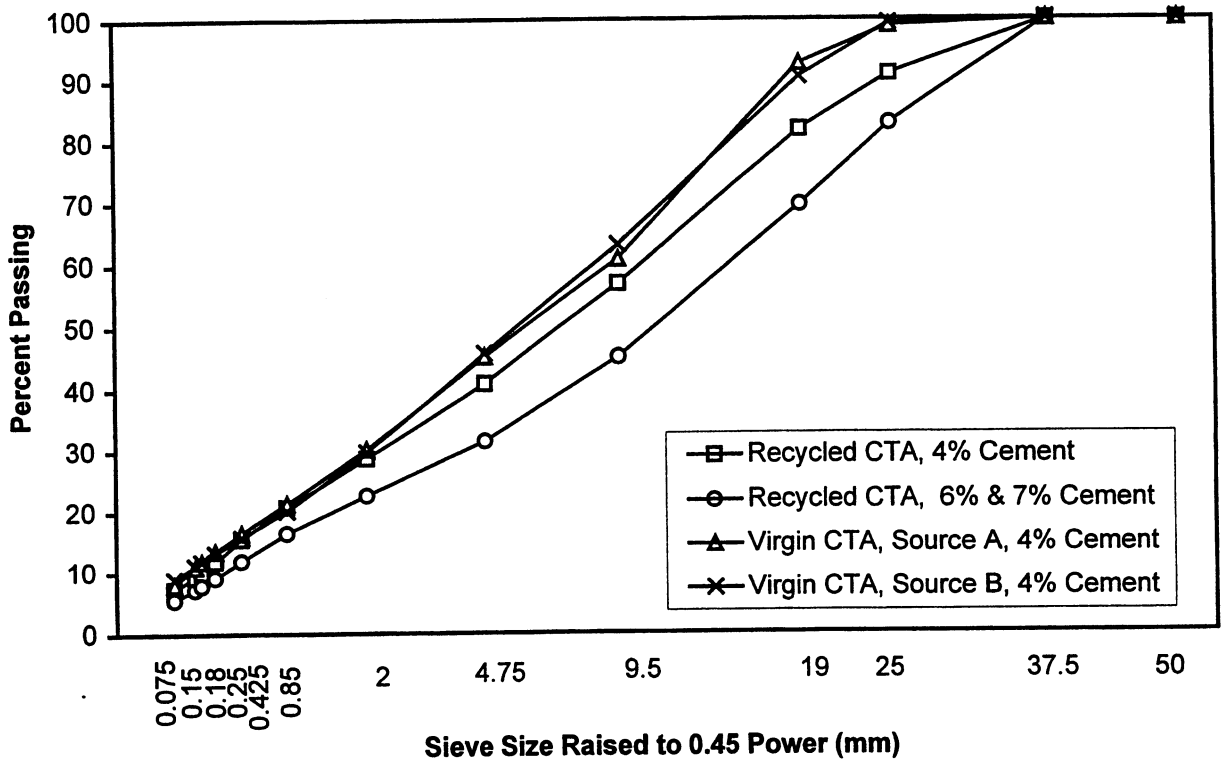


FIGURE 4 Gradations for Recycled CTA and Virgin CTA

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