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Roundabout Construction Using Precast Concrete in Virginia

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16. Abstract:

Roundabouts are a special type of intersection that ensures continuous vehicle movement while maintaining slow and safe speeds. Many state departments of transportation are converting existing intersections into roundabouts, but roundabout construction can create significant traffic closures and disruptions. Thus, accelerated construction can be very beneficial in places where extended traffic closure is not practical or possible. Using precast concrete panels in roundabout construction can shorten closure times and create less disruption for the traveling public.

The Virginia Department of Transportation has constructed two precast roundabouts in the Richmond District—a mini roundabout on the I-195 South ramp at the Laburnum Avenue exit in December 2020 and a regular, full-sized roundabout with an unpaved central island at the intersection of Hopkins and Kingsland Roads in July 2022. The panels were cast in New York and delivered to the jobsite for installation. The Laburnum Avenue roundabout was the first of its kind in the United States to be successfully completed and has performed satisfactorily since. The contractor was unfamiliar with this type of application but was able to complete both projects with weekend closures, thus minimizing weekday traffic disruptions. For comparison, the research team investigated five other roundabouts—four cast-in-place concrete and one asphalt truck apron with concrete curb containing rapid-setting cement. The roundabouts are constructed successfully using either precast panels or cast-in-place concretes and performing satisfactorily after at least a year of traffic exposure. The precast roundabout construction needs special attention to the base preparation, panel installation, and grouting. It is recommended that precast roundabouts be considered when short traffic disruptions are needed such that only weekend closures are permitted or when the supply of fresh concrete is of concern. Roundabouts with precast panels are expected to be more durable than the cast-in-place alternatives because the precast panels are cast in a controlled environment.

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FINAL REPORT

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Charlottesville, Virginia

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ABSTRACT

Roundabouts are a special type of intersection that ensures continuous vehicle movement while maintaining slow and safe speeds. Many state departments of transportation are converting existing intersections into roundabouts, but roundabout construction can create significant traffic closures and disruptions. Thus, accelerated construction can be very beneficial in places where extended traffic closure is not practical or possible. Using precast concrete panels in roundabout construction can shorten closure times and create less disruption for the traveling public.

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FINAL REPORT

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INTRODUCTION

Roundabouts are a special type of intersection that ensures continuous vehicle movement while maintaining slow and safer speeds. Roundabouts are a proven safety countermeasure that substantially reduce the occurrence of crashes resulting in serious injury or death (FHWA, 2023). In addition to improving safety, roundabouts can encourage lower speeds and provide traffic calming. A roundabout is a form of circular intersection in which traffic travels counterclockwise (in the United States) around a central island, and the entering traffic must yield to circulating traffic (Rodegerdts et al., 2010). Many state departments of transportation (DOTs) are converting existing intersections to roundabouts, but roundabout construction can create significant traffic closures and disruptions. An accelerated construction in concrete placement could be very beneficial, where extended traffic closures are not practical or possible. Strategic Highway Research Program (SHRP2) research identified precast technology as a renewable solution for aging infrastructure that can be deployed rapidly. Using precast concrete panels could provide such an opportunity to construct a roundabout in a shortened closure time, thus creating less disruption to the traveling public (Tayabji, 2021).

In 2016, the Virginia Department of Transportation (VDOT) received incentive funding to promote precast technology through the SHRP2, Round 6, Implementation Assistance Program (FHWA, 2015). As part of this effort, FHWA provided a workshop for VDOT engineers and respective industry partners in 2018. During this workshop, VDOT presented the idea of using precast panels for the rapid construction of a roundabout to replace an existing four-way intersection. Using precast panels for this roundabout was expected to provide many benefits, as follows:

1. Easier maintenance of traffic.
2. Accelerated construction. The precast roundabout could be constructed during a weekend closure for improved safety and convenience.
3. Easy future maintenance. One panel could be replaced at a time.
4. Durability. Precast panels are fabricated under controlled conditions at a plant and have already attained satisfactory strengths when installed.

VDOT is committed to implementing innovative intersections and interchanges to improve safety and mobility for the traveling public (VDOT, 2023). To that end, VDOT actively uses and promotes the use of roundabouts and completed three innovative roundabouts using modular units in September 2020 (VDOT, 2020). The prefabricated units are made from recycled plastic. Because of plastic being lightweight material, installing the central island was easy and quick. In these cases, the central islands were not used for vehicular traffic. On the other hand, a mini roundabout shown in Figure 1 allows larger vehicles such as trucks or buses to drive over the central islands if needed (VDOT, 2023). These central islands, also known as "truck aprons," are slightly elevated (raised about 3 inches or so) to discourage regular traffic from driving onto them, but trucks can easily climb over them. When a truck drives over the apron, a rigid edge, such as concrete, would perform better, and recycled plastic materials may not provide enough rigidity.

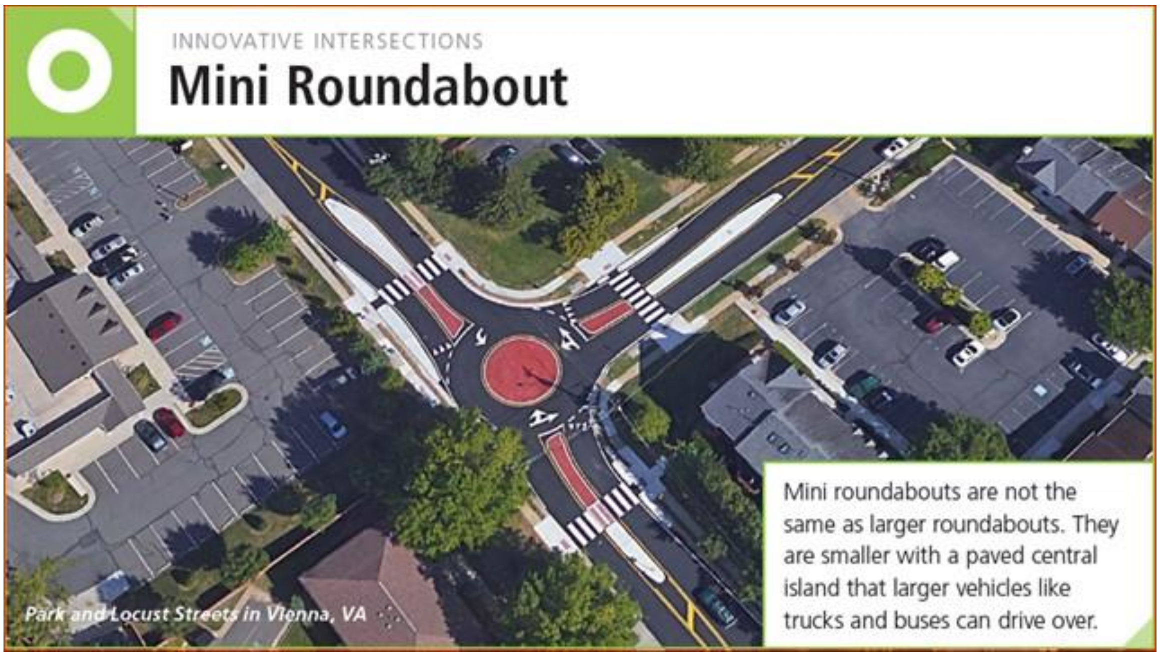

Figure 1. Typical Mini Roundabout (VDOT, 2023)

VDOT's Richmond District recently constructed two roundabouts using precast panels in December 2020 and July 2022 (Hossain et al., 2024). The first project was a mini roundabout in Richmond near a freight train station on Laburnum Avenue. The second project, a single-lane roundabout, was in Chesterfield on Hopkins and Kingsland Roads. It was a conventional roundabout with an unpaved central island surrounded by a raised truck apron. In both roundabout projects, only the truck apron was constructed using precast concrete panels, and the main travel lane was constructed from asphalt pavement.

PURPOSE AND SCOPE

The purpose of this study was to document VDOT's experience constructing a roundabout truck apron using precast concrete panels. Documenting precast roundabout construction involves field construction steps and challenges, lessons learned, early life performance evaluation, and an assessment of the expedited construction. Seven roundabouts with various materials and construction techniques for truck aprons were included in the study. Although all the circulatory roads were asphalt pavement, the truck aprons were different. Two truck aprons were constructed using precast concrete panels, four truck aprons were constructed with cast-in-place (CIP) concrete, and one truck apron was constructed with asphalt.

METHODS

Overview

Researchers performed the following tasks to achieve the study's objectives:

1. Information collection on selected roundabouts—gathering construction- and design-related information on seven selected roundabouts.
2. Construction documentation—gathering information on construction steps, challenges, and lessons learned through field visits and consultations with the respective construction team.
3. Performance evaluation—evaluating in-service performance of the precast roundabouts through visual observations of surfaces and falling weight deflectometer (FWD) measurements.
4. Benefit assessment—including evaluating expedited construction and a relative cost comparison from bid documents.
5. Lessons learned and updating the special provision—analyzing construction challenges and experiences and suggesting changes to the special provision based on lessons learned.

Information on Selected Roundabouts

In addition to two precast roundabouts, five other roundabouts with CIP concrete and asphalt options were selected for comparison. Most information on these roundabouts was collected from the design and construction contract documents. The respective VDOT districts administered all roundabout construction except Winterpock, which the locality managed. The following seven sections discuss roundabouts considered for this study.

Laburnum Avenue Mini Roundabout

This project is in Henrico County, Virginia, under the jurisdiction of VDOT's Richmond District at the intersection of the Interstate 195 (I-195) South ramp to the Laburnum Avenue exit. Figure 2 shows the project's Google map location. This intersection leads to a railway freight terminal that causes a high volume of truck traffic, so closure was limited only to the weekend. The existing intersection was milled off and replaced with a roundabout, and the central island and the truck apron were constructed with precast concrete panels. The remaining lanes were asphalt.

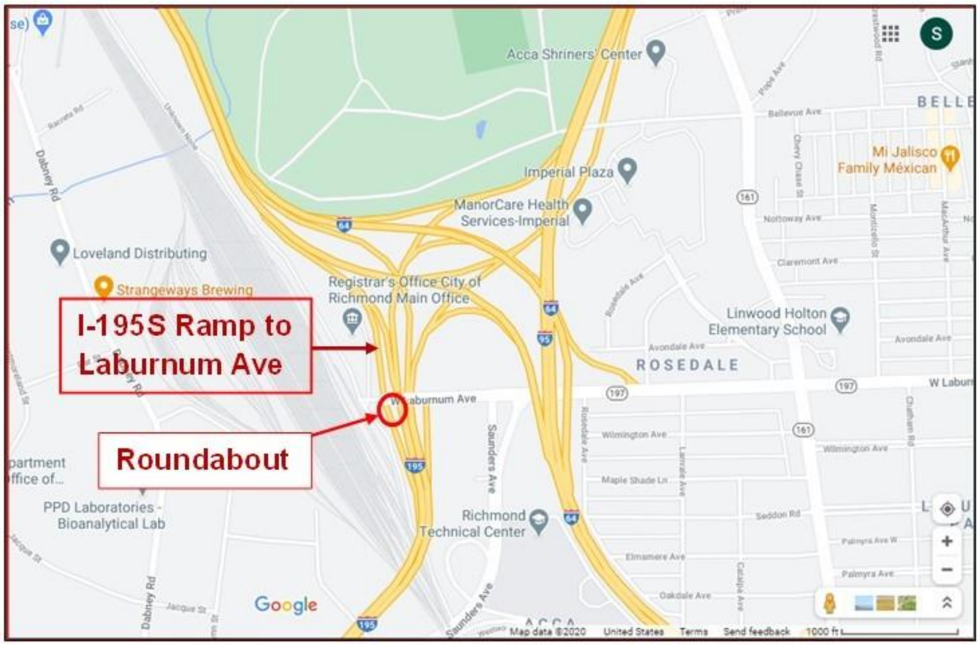

Figure 2. Roundabout Location at the Intersection of the I-195 South Exit Ramp and Laburnum Avenue in Richmond, Virginia (Courtesy of Google Maps)

Hopkins Road Roundabout

An existing four-way intersection of Route 637 (Hopkins Road) and Route 611 (Kingsland Road) was converted into a roundabout in Chesterfield, Virginia. Similar to Laburnum Avenue, the truck apron was precast concrete, but the central island was unpaved. Figure 3 shows the location.

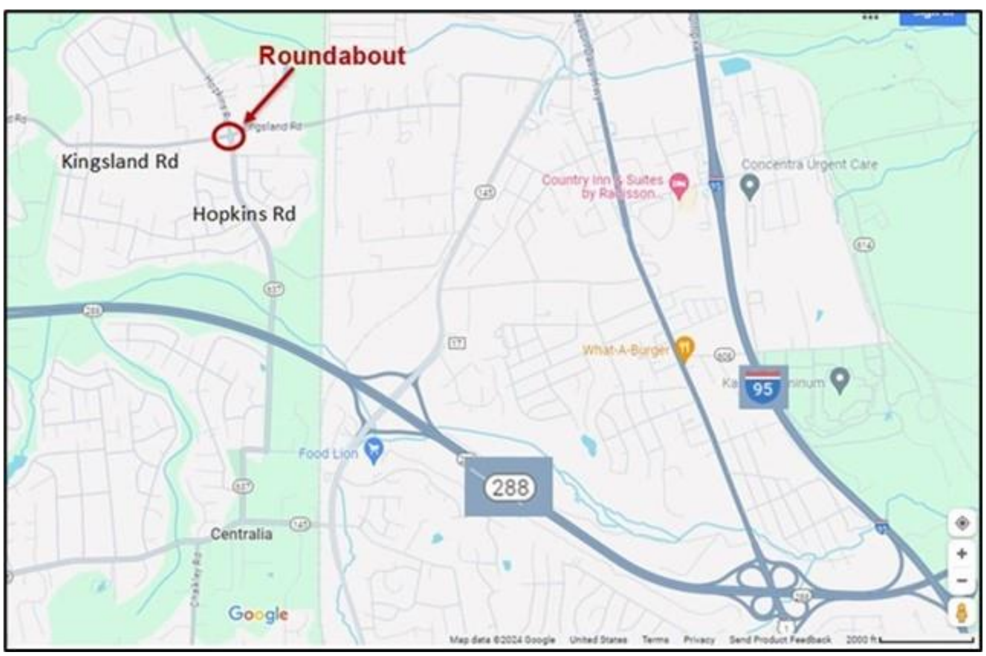

Figure 3. Precast Truck Apron in a Roundabout at the Intersection of Hopkins and Kingsland Roads in Chesterfield, Virginia (Courtesy of Google Maps)

Maury Street Roundabout

A CIP concrete truck apron was used on this roundabout at Maury Street. The ramps from I-95 at exit 73 lead to this roundabout at the intersection of Maury Street and East 4th Street. Figure 4 shows the Google map location. The circular roads were asphalt, and the central island was unpaved. This roundabout also used red colored concrete and brick-pattern texturing. The truck apron was constructed from 16-inch-thick concrete with welded wire mesh reinforcement. Construction was completed in early 2022.

Figure 4. Cast-in-Place Concrete Truck Apron at Maury Street in Chesterfield, Virginia (Courtesy of Google Maps)

Fairground Road Roundabout

This roundabout at the intersection of US 522 and Route 632 (Fairground Road) in Goochland, Virginia, also used a CIP concrete truck apron. Regular A-3 and A-4 concretes were used without any coloring or texturing. This roundabout has an unpaved central island with a two-lane concrete truck apron, and the circular road is asphalt, like the others. Figure 5 shows the roundabout's Google map location.

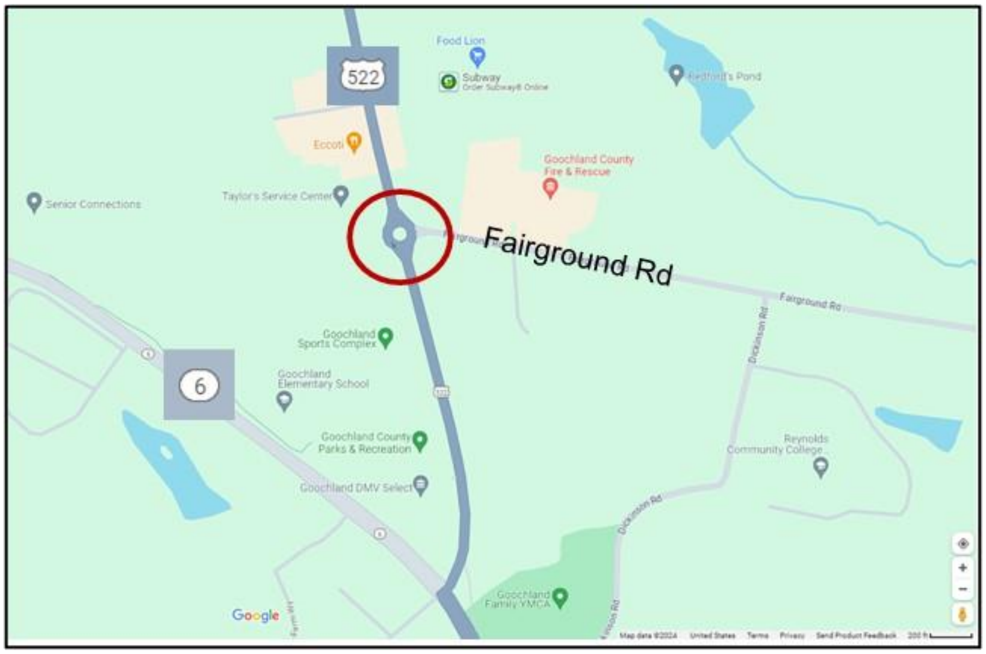

Figure 5. Fairground Road Roundabout with Cast-in-Place Concrete Truck Apron in Goochland, Virginia (Courtesy of Google Maps)

Luray Roundabout

This roundabout in the town of Luray near Luray Caverns used a CIP concrete truck apron and a paved concrete central island. It also used regular concrete without any reinforcement, color, or texture. This roundabout is at the intersection of West Main Street (Business US 211 near US 340) and Northcott Drive in Page County, Virginia. Figure 6 shows the roundabout's Google map location relative to Luray Caverns.

Figure 6. Luray Roundabout in Page County, Virginia (Courtesy of Google Maps)

Winterpock Road Roundabout

This roundabout is a locally administered project in Chesterfield, Virginia. Winterpock Road was a single-lane roadway that was widened to accommodate four-lane divided roadways with a roundabout at the intersection of McEnnally Road and Ashbrook Parkway (Figure 7). This roundabout used a CIP concrete truck apron with color tone that was internally colored using pigments and has a stamped texture.

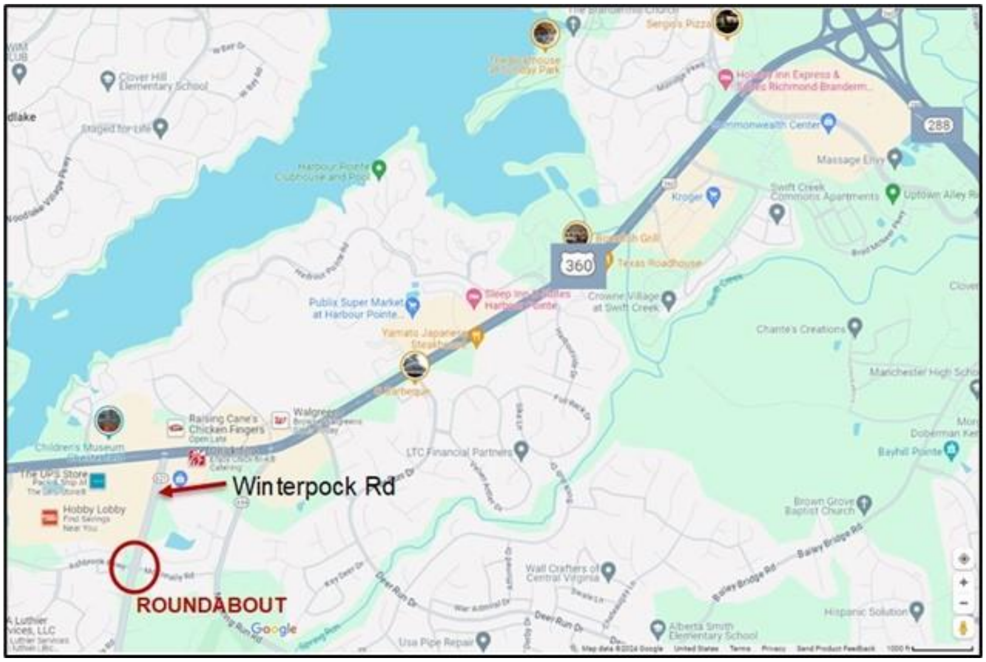

Figure 7. Winterpock Road Roundabout, Cast-in-Place Concrete in Chesterfield, Virginia (Courtesy of Google Maps)

Gum Spring Roundabout

This roundabout is unique from the others in that hot mix asphalt was used for the truck apron, which was lined (covered) with red-colored thermoplastic sheets with brick imprints. The truck-climbing edge (curb) used CIP concrete with rapid-setting cement. This roundabout is at the intersection of US 250 (Broad Street) and US 522 (Cross County Road) in Gum Spring, Virginia (Figure 8). This project allowed alternate bid options for truck apron construction; one bidder opted to use precast concrete out of five bidders.

Figure 8. Asphalt Roundabout in Gum Spring, Virginia (Courtesy of Google Maps)

Construction Documentation

VDOT is the first agency in the United States to use precast concrete panels for constructing roundabout truck aprons. Since 2020, precast concrete panels were used in two roundabouts in the Richmond District:

1. Laburnum Avenue at the intersection of the I-195 South ramp in Richmond, Virginia.
2. Hopkins Road (State Route 637) at the intersection of Kingsland Road (State Route 611) in Chesterfield, Virginia.

The research team visited both Richmond sites during construction to collect important construction information and develop lessons learned from observations and discussions with construction crews. Although the research team did not visit the construction sites of other roundabouts, discussions with the respective construction teams provided information on construction methods included in this report.

Performance Evaluation

The research team visually observed both precast roundabouts for any surface distresses and for any joint deterioration after several months, up to 3 years, of traffic exposure. In addition, joint load transfer efficiencies (LTEs) were measured at the joints between the slabs using a FWD device. LTE was calculated as the ratio of deflections, measured at 6 inches from the joint, on two sides of a joint in response to a load dropped on one side. One deflection was measured right under the drop-load, and another deflection was measured on the other side of the joint. Two drop-load levels, 9 kips and 16 kips, were used. Loads were also dropped on both the approaching and leaving sides of the joint, resulting in 4 LTEs per joint.

Visual Observation

Visual observations involved assessment of surface conditions, such as cracking, joint sealing, and apparent slab movement. The research team visited four of the seven roundabouts considered for this study to assess their performance in terms of surface distress.

Falling Weight Deflectometer Testing

LTEs were measured only in two roundabouts because of time constraints, one CIP concrete (Fairground Road) and one precast (Hopkins Road). As these roundabouts are jointed concrete pavement, LTEs would indicate the performance of the respective joints.

Benefit Assessment

The use of precast concrete is expected to expedite construction and provide long-lasting pavements. The two precast roundabouts have been in service for less than 4 years, a short time for a long-term performance evaluation. However, the information gathered in the study provides a baseline condition for future performance evaluations. To assess the expedited construction ability of precast concrete, the research team included recently constructed roundabouts that use asphalt and CIP concrete in the comparative study. Researchers obtained the relevant construction steps from interviews with the construction teams. In addition, researchers collected the bid documents and performed a relative cost comparison based on the bid prices.

Lessons Learned and Updating the Special Provision

The Virginia Transportation Research Council (VTRC) developed a special provision for pavement construction with precast concrete slabs under the incentive grant from FHWA's SHRP2, Round 6 Implementation Assistance Program. VDOT's Richmond District customized this special provision to fit its needs and used it to construct two roundabout projects with precast panels. The researchers analyzed construction challenges and experiences, and documented lessons learned. Some modifications and updates to the special provision were suggested based on the lessons learned in the areas of base preparation, slab placement, and grouting operations.

RESULTS AND DISCUSSION

Information on Selected Roundabouts

All the selected roundabouts were converted from existing three-way or four-way intersections to improve safety and traffic flow. Table 1 summarizes some of the geometrics on the selected roundabouts.

Table 1. Information on Selected Roundabouts

Roundabout	Truck Apron		Central Island		Circulatory Road
	Material	Width	Diameter	Material	
Laburnum Avenue (mini)	Precast concrete	57 ft (diameter)	Part of Truck Apron Precast Concrete		Asphalt
Hopkins Road	Precast concrete	11 ft	51 ft	Unpaved	Asphalt—16 ft
Maury Street	CIP concrete	12 ft	109 ft	Unpaved	Asphalt—16 ft
Fairground Road	CIP concrete	21 ft	28 ft	Unpaved	Asphalt—16 ft
Luray	CIP concrete	18 ft	29 ft	Paved—CIP	Asphalt—18 ft
Winterpock Road	CIP concrete	11 ft	66 ft	Unpaved	Asphalt—15–31 ft
Gum Spring	Asphalt with CIP concrete curb	21 ft	72 ft	Unpaved	Asphalt—18 ft

CIP = cast-in-place.

Construction Documentation

The following sections discuss the construction steps and challenges. Detailed information is presented for the two precast roundabouts that the research team visited. Brief highlights are provided for the other types of roundabouts.

Laburnum Avenue Roundabout

This roundabout's truck apron and central island were constructed using precast concrete panels during the third week of December 2020, at the height of the COVID-19 pandemic. This timing created some additional challenges for the construction team.

Precast Panel Construction and Trial Installation

Precast panels were cast at a plant in New York, and a complete fit of all the panels was attempted at the manufacturer's yard 1 week before construction in December 2020. Because of travel restrictions due to the pandemic, the complete trial installation process in New York was broadcast live to the construction team, VDOT personnel, and precast technology experts from FHWA. During this interactive video meeting, members of the construction team were able to ask questions during the trial fitting.

Twenty-three panels were fitted together to build the central island and the truck apron, with a diameter of 57 feet. Figure 9 shows the panel arrangement, dowel bars for load transfer, and tie bars between the lanes. The slabs were 9 inches thick, and most of them were trapezoidal, with approximate dimensions of 8 to 10 feet versus 12 to 16 feet. A red color tone and brick pattern were used for aesthetic appeal. The outer panels had beveled edges for easy truck climbing and enhanced safety.

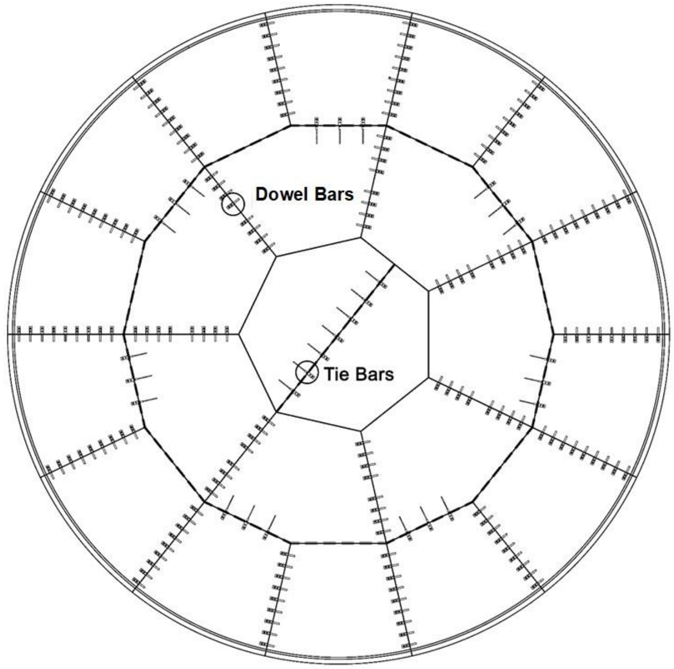

Figure 9. Panel Arrangement for Laburnum Avenue Precast Roundabout

During this trial installation, the construction team checked the complete fit of all 23 panels, and they passed for showing good fit. Because the actual panels were used during this trial fitting, no grouting or dowel bar and tie bar installations were performed. After the trial installation, all 23 panels, each weighing approximately 6 to 7 tons, were shipped by truck to Virginia for construction.

Site Preparation

The existing intersection was closed to traffic on Friday evening, December 18, 2020. To match the design grade (a 3-inch-raised central island), about 2 to 6 inches of the asphalt surface was milled off (Figure 10), leaving approximately 3 inches of asphalt as a base course on which to place the 9-inch precast slabs. All 23 slabs, after shipment, were stored on site (Figure 11).

Figure 10. Asphalt Surface Milling in Preparation for Slab Placement

Figure 11. Precast Slabs Stored on Site before Construction

Milling was completed on Friday night, and slab installation started on Saturday morning. Extensive surveying was used to achieve proper grade before slab placement. A sand-cement mixture (6:1 ratio) was spread over the milled surface (Figure 12), leveled, and sprayed with water.

Figure 12. Using a Sand-Cement Mixture to Achieve Final Grade before Panel Installation

Slab and Panel Installation

Installation started on Saturday morning of December 19, 2020, with the center panel (Figure 13). Installing all the panels took approximately 8 hours. The fit had no major issues, as demonstrated during the trial. However, achieving the desired grade was challenging, and substantial time was spent surveying and filling with a sand-cement mixture to accomplish the task. Because this installation was the first of its kind for the construction team, a panel manufacturer representative was present during the installation, which was very helpful.

Figure 13. Installing the Center Panel and Surveying to Set Proper Grade

Figure 14 illustrates the panel installation process. Screw-in tie bars were installed, dowel bars were coated with bond breaker, and joint filler blue polyethylene ribbon was glued to the panels before subsequent panel installation. Foam gaskets were already preglued under the slab to prevent leakage and grout loss.

Figure 14. Panel Installation Details for Laburnum Avenue: (a) Screw-in Tie Bar; (b) Blue Polyethylene Ribbon and Joint Filler; (c) Bond-Breaking Oil Spraying; (d) Foam Gasket to Prevent Grout Leak

At the end of the day on Saturday, the construction team completed panel placement and covered the panels with plastic sheeting (Figure 15) to protect them from the heavy rain forecasted for the next day. Heavy rain could have washed out the base materials because the joints were not sealed.

Figure 15. Panels Covered with Plastic Sheeting to Prevent Rain Damage

The panels fit together well for the most part, except for some minor gaps that occurred at a few places (Figure 16). Joints were sealed with silicon sealers (Figure 17).

Figure 16. Panel Fitting with Minor Gaps at Laburnum Avenue Precast

Figure 17. Joint Sealing with Silicon Sealer

Despite extensive surveying during installation, the panels needed elevation adjustment, which was conducted on Sunday morning. Each panel had four pre-installed, embedded leveling bolts to achieve the final surface profile. Figure 18 shows the vertical adjustment operation. The construction team emphasized the benefit of surveying to achieve the proper base grade during installation and expressed the opinion that using bolts alone would not be sufficient for the elevation adjustment because of the circular setup.

Figure 18. Surface Elevation Adjustment Using Leveling Bolts

To secure the slabs before opening the roundabout to traffic, dowel slots, tie bar slots, and underslabs were grouted. This grouting operation faced many challenges because of rain and cold weather, leading to delays and slower strength gain than expected. A hand-operated grout pump (Figure 19) was used to limit waste and spillage and preserve the surface color. A locally available grout was used instead of the slab manufacturer's recommended grout. Although dowel and underslab bedding grout requirements are usually different, the same grout was used at a different consistency because of time constraints and supply issues. The grouting operation was completed on Sunday night, but opening to traffic was delayed until Tuesday morning to ensure that the grouts achieved the proper strength. Although the low temperature did not affect the slab placement, it influenced the grouting operation.

Figure 19. Grouting Operation Using a Hand Pump

The foam gasket under the slab was supposed to prevent the grout from leaking, but some leakage was observed. A dense-graded base aggregate (VDOT No. 21-A) was placed around the perimeter of the truck apron to prevent leakage (Figure 20). The leakage was attributed to: (1) uneven grade resulting from difficulty operating the milling machine in a circular area with such a small radius and (2) the surface's sloping design, which was intended for drainage.

Figure 20. Dense-Graded Base Aggregate Placed around the Perimeter to Prevent Grout Leakage

The roundabout was scheduled to open to traffic on Tuesday morning, December 22, 2020, after placing the asphalt pavement around the precast circle (Figure 21). The opening, which had initially been planned for Monday morning, had to be postponed for 1 day because of construction disruptions from rain and low temperatures. The conversion of the standard intersection to a roundabout was successfully accomplished by using the precast panels during the weekend closure. A traditionally constructed roundabout usually takes months because one quadrant is constructed at a time. Moreover, the quality of the concrete was ensured because the panels were cast in a controlled environment at the precast plant. This precast roundabout was the first of its kind in the nation, and VDOT expects to monitor its long-term performance.

Figure 21. Completed Precast Laburnum Avenue Roundabout Opened to Traffic on December 22, 2020

Hopkins Road Roundabout

To create this roundabout, an existing four-way intersection was converted into a roundabout with an unpaved central island. The truck apron was constructed in July 2022, utilizing precast concrete panels. Unlike Laburnum Avenue, the central island was unpaved. This work was primarily completed in a weekend closure, but a second weekend closure was needed for extensive base preparation and drainage work. The grouting operation was delayed for a few days because of inexperienced crews but was completed under live traffic. The same contractor that worked on the Laburnum Avenue roundabout constructed the Hopkins Road roundabout and used the same precast panel manufacturer.

Precast Panel Construction and Trial Installation

Like the first precast construction, an interactive web-based meeting was arranged with the precast panel manufacturer at their yard in New York for a construction demonstration to check the complete fit of the actual panels before shipment. At the end of this trial installation, a large gap remained between the first and last panel that prevented proper closure of the circle. This problem was not a manufacturing issue rather a placement issue. All the panels had to be rearranged to accommodate and distribute this gap evenly among all panels. Despite having a large crane to facilitate easy movement of the panels, fixing this issue required 3 to 4 more hours of work. This experience was a valuable lesson for the construction team because well-surveyed reference points are important for proper installation.

Sixteen trapezoidal panels with nominal dimensions of 11 by 12 feet were fitted together to create the circle. All panels were connected by dowel bars. The central island had a diameter of 51 feet, with CIP internal curbs attached to the precast panels. Figure 22 shows the precast truck apron. These panels also had the red color tone, brick pattern, and beveled edge. All panels showed good fit after rearranging the panels during the trial installation. Panels were shipped to a nearby offsite location in Chesterfield, Virginia, a few days before construction.

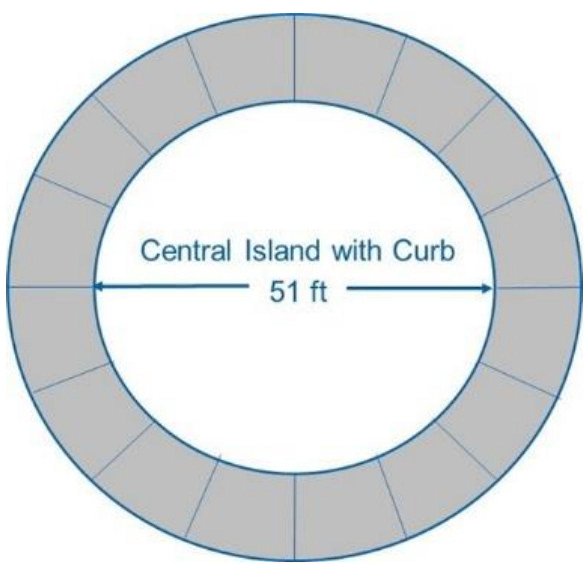

Figure 22. Hopkins Road Roundabout Panel Arrangement

Site Preparation

Significant site preparations, including removing pavement and adding drainage structures, were made. Because of drainage and grade issues, a part of the intersection was milled, and other parts needed to be built up with asphalt. Base preparation needed significant effort, but the contract and plan sheets provided minimum guidance. The precast panel installations require good accuracy in the grade preparation. Onsite storage of the precast panels was not possible because of space constraints. Therefore, the panels were stored in a nearby location and had to be hauled in for installation, which added some challenges and extra effort.

Panel Installation

Unlike the first precast roundabout project, an excavator was used to lift and place the panels instead of a big crane because of the presence of overhead electric power lines. Maneuvering such a heavy panel with an excavator was challenging, and proper placement was difficult. These challenges resulted in pinching and associated corner breakage in a few places. Figure 23 shows the panel placement.

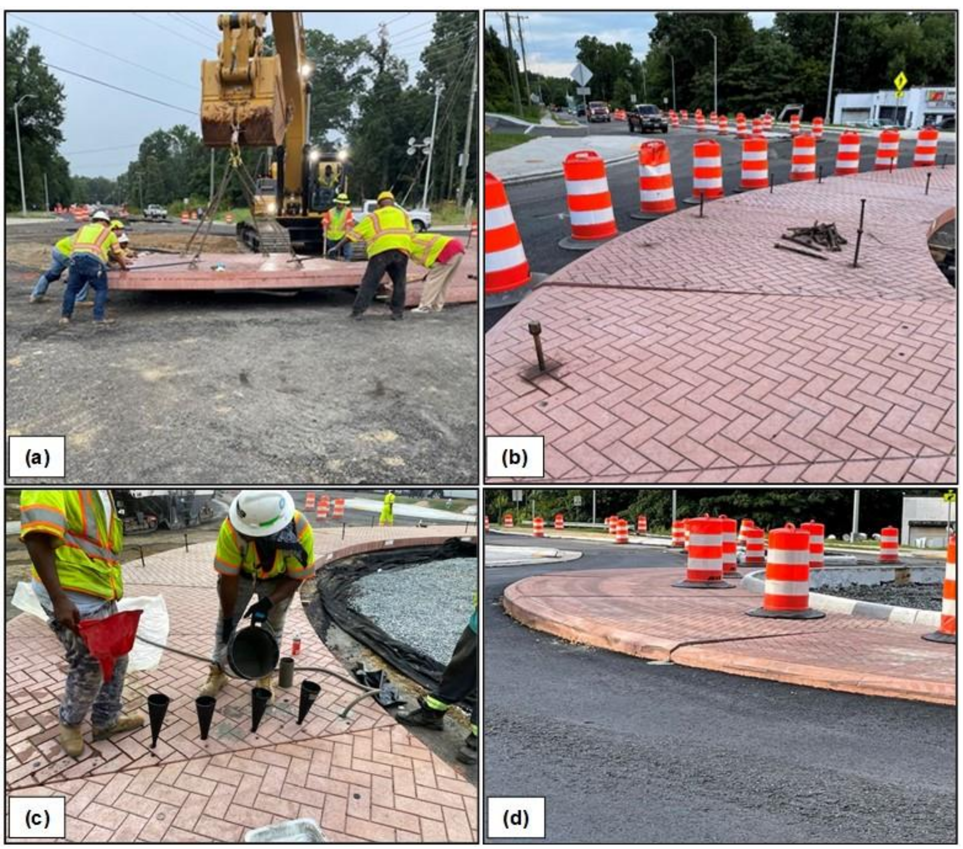

Figure 23: Construction Steps for Chesterfield, Virginia, Roundabout: (a) Excavator for Panel Installation; (b) Leveling Bolts to Correct Elevation; (c) Grouting Using Gravity Flow; (d) Final Surface after All Installation, Including Cast-in-Place Inner Curb

Extensive surveying was done to set the reference points to avoid a gap at the end. Despite these efforts, pinching and panel accommodation (setting with a uniform gap) was a common problem throughout the installation. Realigning the panels with the excavator was challenging. Leveling bolts were used to adjust the elevation of successive panels at the end of the panel placement. A few locations had issues with misalignments and gaps.

The grouting operation also faced some challenges. Instead of a hand pump or mechanical pump, gravity flow with funnels was used. In addition to the flow issues, grout leakage was observed. Base aggregate was used along the outer perimeter, and spray foam was used along the inside perimeter to prevent grout leakage. The same grout was used for both dowel slot and base support for convenience. The lack of an experienced grouting technician and use of gravity flow caused significant delay in the operation. Elevation differences were noticeable between panels in several locations, and grinding was done to correct the surface irregularities.

Although one weekend of full lane closure was needed for the panel installation, several days, including another weekend closure, were needed to finish other tasks such as leveling, grouting, joint sealing, and working on the central island, including inside curb and drainage structures. After 3 years of service, this roundabout is performing satisfactorily.

Maury Street Roundabout

The construction of this roundabout with a CIP concrete truck apron was completed in early 2022. The one-lane truck apron used colored concrete and had contraction joints at every 20 feet and extension joints at every 100 feet. The central island was unpaved and had a diameter of 109 feet. The truck apron was inscribed by two concrete curbs at the inner and outer circles. These curbs were tied to the CIP slab with J-bars. VDOT A-4 concrete was used for the truck apron, and A-3 concrete was used for the curbs. The truck apron had welded wire mesh reinforcement at the mid-depth without any transverse load transfer devices (dowel rods).

The Richmond District construction team provided the construction pictures in Figure 24. Stamping the stone-paver block pattern was usually accomplished after finishing the surface, while the concrete was still plastic. Sometimes stamping involved spraying a retarder on the surface to facilitate the stamping operation. Construction of this roundabout took approximately 5 days, 3 days for the truck apron and 2 days for the curbs. The usual construction practice involves one quadrant at a time. Normal construction time was under live traffic from 8:00 a.m. to 4:00 p.m., with a flagging operation and occasional detours. A few nighttime works occurred, specifically during paving. This roundabout appears to be performing satisfactorily after 2 years of traffic.

Figure 24. Maury Street Roundabout Construction: (a) Concrete Delivery and Wire Mesh Reinforcement; (b) Slab Tied to the Curb with a J-Bar and Construction under Live Traffic; (c) Concrete Stamping; (d) Final Stamped Surface (Courtesy of VDOT's Richmond District)

Fairground Road Roundabout

This roundabout is a two-lane truck apron with a 28-foot-diameter unpaved central island in Goochland, Virginia. This CIP truck apron used regular VDOT A-3 concrete but without any color tone or pattern, unlike Maury Street. It was an existing three-way intersection converted into a roundabout with an extension of the fourth roadway construction. The construction project took more than 8 months in several phases. The roundabout circle was constructed under live traffic because isolating the area with cones was not possible. Although full traffic closure was not needed, detouring trucks was possible as needed. This roundabout is jointed concrete at every 14 feet of spacing, with dowel bars for load transfer.

Luray Roundabout

This 7-inch CIP concrete truck apron was constructed under live traffic with some road closure on North Cott Drive and a truck traffic detour for West Main Street. The first half of the circle was constructed with traffic coned off (Figure 25). High early strength concrete, which attained 3,000 psi within 24 hours, was used in some areas. The truck apron was inscribed by two circular curbs. Constructing the truck apron took about 4 days to complete. The truck apron has expansion joints at every 22 feet of spacing. Although the original plan called for an unpaved central island, the city decided to use paved concrete for the central island to reduce future maintenance needs.

Figure 25. Luray Roundabout Construction on Business Route 211 in Page County, Virginia (Courtesy of VDOT)

Winterpock Road Roundabout

This roundabout has a CIP concrete truck apron with red color tone and a design pattern. Construction was ongoing during the research study, enabling discussions with the construction team for comparison with the precast construction process. This roundabout was a locally administrated project, so the research team had discussions with the contractor’s project management team. The truck apron was 8-inch, wire-mesh-reinforced concrete, type VDOT A-3. Completing the roundabout, including base preparation, rebar, wire mesh, and concrete placement, took about 1 week.

A rapid-setting cement could not be used to expedite construction because a 5-hour setting time was needed to complete delivery, placement, and concrete stamping in the fresh state. Early stiffening of the concrete during the stamping process caused cracks that had to be sealed. In an ideal condition with enough resources, concrete placement could be finished in 3 to 4 days. However, problems with concrete and truck availability, rejection potential and disposing of colored concrete, and labor force availability could delay CIP operations.

Gum Spring Roundabout

This roundabout was the first project discussed during the precast workshop, mentioned earlier, for the possible use of precast concrete panels. It was planned with alternate bid options using either an asphalt or precast concrete truck apron. An asphalt roundabout, with a CIP concrete curb for truck climbing, was the lowest bid and awarded for construction. Rapid-setting cement was selected for the CIP curb as part of the value engineering. The Culpeper District construction team provided the photographs of the construction steps in Figures 26 and 27. The central portion of the roundabout was completed in about 4 weeks, and an additional 2 weeks was required for the outside (splitter) islands. To minimize traffic interruptions, work was allowed only between 8:00 a.m. and 4:00 p.m. CIP concrete curb was cast in four quadrants, with traffic diversion using a flagging operation. Complete closure was not needed. Limited traffic interruptions occurred when the concrete was delivered.

Figure 26. Gum Spring Roundabout Construction: (a) Form Work for the Outer Curb; (b) Concrete with Rapid-Setting Cement in the Curb; (c) Glue Application on the Asphalt Truck Apron; (d) Installation of Red Thermoplastic Sheets (Courtesy of VDOT's Culpeper District)

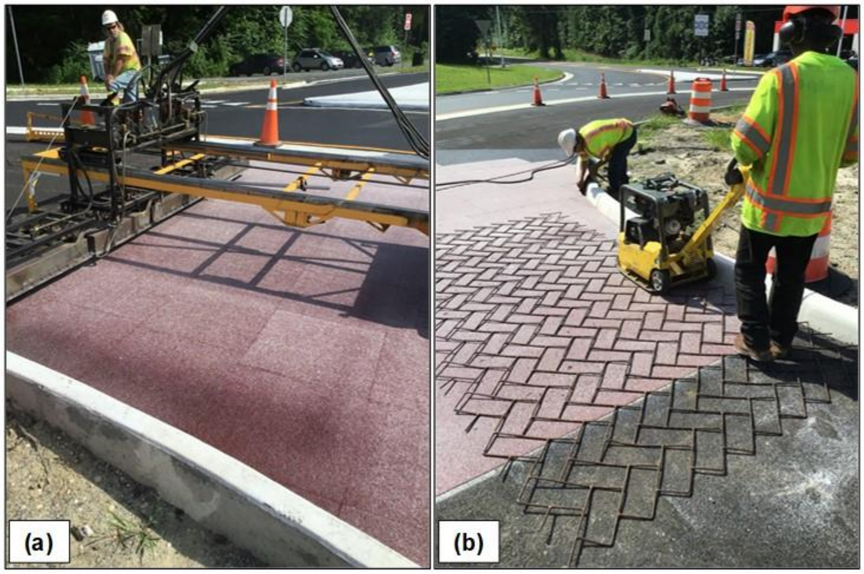

Figure 27. Gum Spring Roundabout Construction: (a) Using Heat to Attach Thermoplastic Sheet; (b) Heat Application to Stamp Brick Pattern on Thermoplastic

The installation was successful and satisfactory. Four outside corners of the existing intersection were built up to accommodate traffic before inner circle construction started. The inner circle was formed with cones, such that the intersection could be used as a roundabout. The CIP curb for the truck apron was done in four quadrants, one at a time. Each quadrant was cast with 1 day of traffic control, from 8:00 a.m. to 4:00 p.m. Rapid-setting cement was used, and the concrete was prepared in a mobile mixer. The outside ring (curb) was 3 feet wide and 10 inches deep. Asphalt was milled the day before to prepare the trench for the outer curb but left in place for traffic. The following day, millings were removed, formwork was installed, and concrete was placed. By the end of the day at 4 p.m., the concrete had achieved enough strength (3,000 psi) and was opened to traffic. Temporary asphalt edges were used along the curb for easy traffic movement. Joints were cut at 10-foot spacing at about a third of the depth. No dowel bars were present, but two No. 4 bars were used at the construction joints after each day's work. Construction of the inner curb and central island was executed simultaneously. The asphalt layers on the truck apron were constructed after the completion of the outer curb. Red-colored thermoplastic sheets were glued to the asphalt layer at the very end. The brick pattern was achieved by applying a heated template on the thermoplastic. This thermoplastic installation took about 2 weeks to complete.

Performance Evaluation

Visual Observations

Within the limited exposure to the traffic, none of the roundabouts in this study showed any discernable surface distresses. The precast roundabout on Laburnum Avenue has been in service for more than 3 years. The surface exhibited no signs of distress in a recent visual survey. Figure 28 shows the surface condition. It had only one defect, which seemed to be a broken-off signpost. The extensive tire marks indicated a considerable amount of truck apron usage.

Figure 28. Surface Condition of Laburnum Avenue Precast Mini-Roundabout in 2023

The second precast roundabout at Hopkins Road in Chesterfield, Virginia, is also performing satisfactorily. It has a few corner breaks and uneven joints. These defects happened during installation and were present before opening to traffic in July 2022. Figure 29 shows surface conditions in 2023. As discussed in the Hopkins Road Roundabout’s Panel Installation section, the panels were placed using an excavator, which made maneuvering the panels for correct placement difficult. Corner breaks occurred at a few places. A big crane was not used because of overhead electric lines. The grouting operation and base preparation had some challenges and resulted in uneven panels at the joint. A few panels were ground at the joints to eliminate uneven surfaces.

Figure 29. Hopkins Road Precast Roundabout Surface Condition in 2023: (a) Completed Truck Apron; (b) Ground Panel to Match Elevation; (c) Panel Drop-off in One Location; (d) A Few Cracks Near a Joint

The research team also visited a few CIP concrete roundabouts. In general, no discernable distresses were apparent in any of these roundabouts. Figure 30 shows some of the surface conditions. Most of the roundabouts had only been in service for 1 to 2 years and had tire marks on them, indicating truck traffic use, as expected.

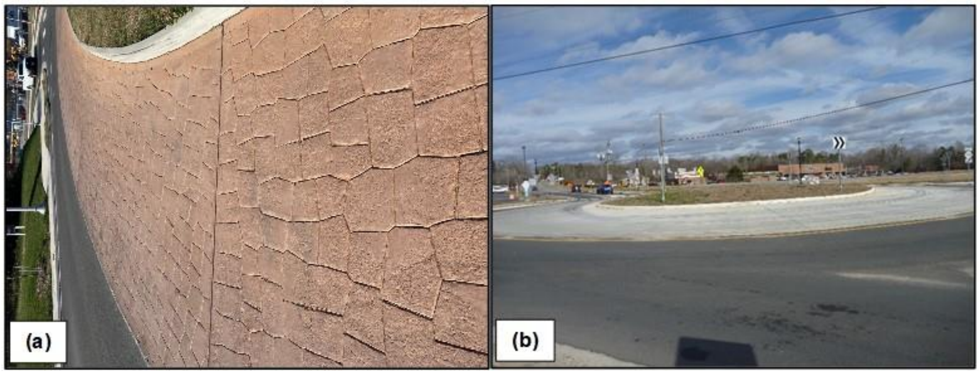

Figure 30. Cast-in-Place Concrete Roundabout Surface Condition in 2023: (a) Maury Street; (b) Fairground Road

Figure 31 shows the surface condition of the roundabout in Gum Spring in early 2024, after more than a year of service. Field observations revealed minor distresses, the thermoplastic surface worn off or damaged in a few places, a small area at one side of the roundabout with some sign of settlement at the edge, and a minor crack on the outer curb in one place. The CIP concrete with rapid-setting cement used for the outer curb enabled early opening to traffic—in less than 8 hours.

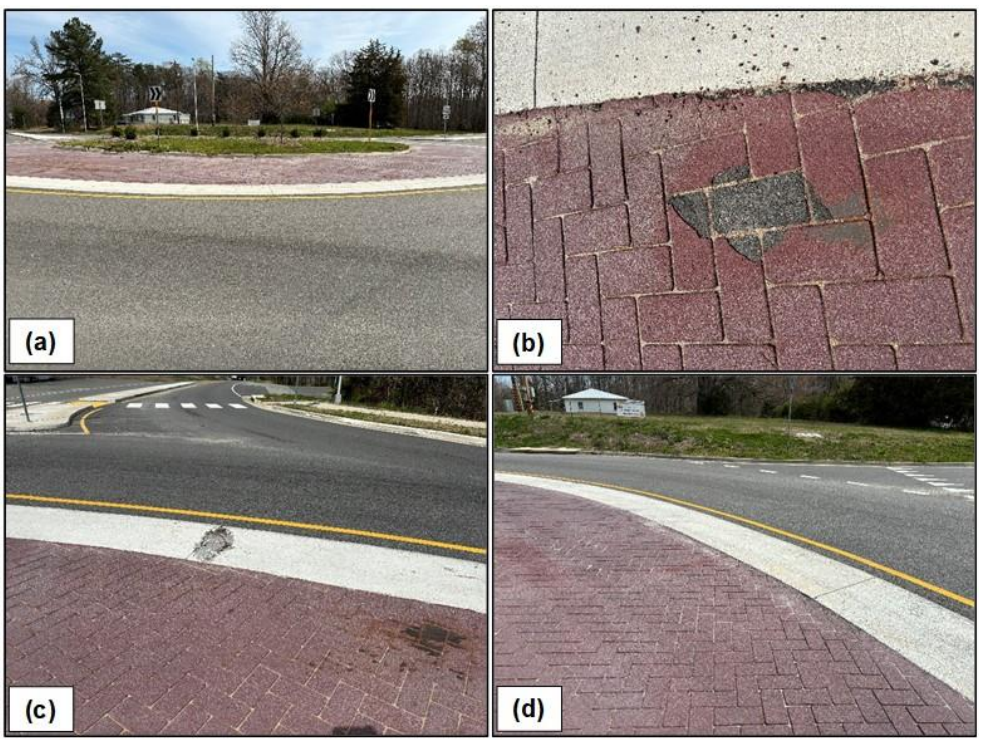

Figure 31. Gum Spring Roundabout Surface Condition in 2024: (a) Seemingly Accidental Damage to Roundabout; (b) Thermoplastic Surface Worn off; (c) One Crack on Rapid-Setting Cement Concrete Curb; (d) Some Settlement at the Thermoplastic Edge

Falling Weight Deflectometer Testing

In addition to visual observation, the condition of the joints was assessed using FWD, which can provide LTEs along a joint as the wheel load passes over it. Joints are one of the first places to show deterioration because water intrusion can happen through a broken joint seal and cause damage to the underlaying base course. Although trucks passing over the apron may not always traverse perpendicular to the joints, this LTE measure can provide an early sign of deterioration. Because of difficulty in traffic control and the unavailability of equipment, LTE using FWD was measured only for two roundabouts: (1) precast concrete at Hopkins Road and (2) CIP at Fairground Road. Table 2 summarizes the LTEs for all the transverse joints on the precast roundabout at Hopkins Road.

Table 2. Falling Weight Deflectometer Data at Truck Apron Transverse Joints for Hopkins Road Precast Roundabout

Joint No.	Drop Load on Approach Side of Traffic				Drop Load on Leave Side of Traffic			
	9-Kip Drop Load		16-Kip Drop Load		9-Kip Drop Load		16-Kip Drop Load	
	D_0 (mils)[a]	LTE (%)	D_0 (mils)	LTE (%)	D_0 (mils)	LTE (%)	D_0 (mils)	LTE (%)
1	2.22	81.5	4.13	82.3	2.31	77.9	4.29	79.5
2	2.65	81.5	4.89	80.4	2.94	74.5	5.50	74.5
3	1.60	91.9	3.03	87.5	3.15	76.8	5.80	78.4
4	1.46	81.5	2.65	78.5	2.44	75.8	4.56	77.2
5	1.43	77.6	2.55	76.9	2.75	78.9	5.03	80.7
6	1.60	76.3	2.68	78.4	3.5	92.3	6.68	89.1
7	1.56	85.3	2.90	84.1	2.37	80.6	4.35	82.3
8	2.00	73.0	3.67	75.5	2.34	73.5	4.35	74.5
9	2.39	75.7	4.46	75.1	1.98	71.2	3.69	72.4
10	2.29	83.4	4.25	84.0	1.62	83.3	3.07	79.8
11	3.41	85.9	6.35	83.8	1.63	66.3	3.13	62.3
12	2.95	72.5	5.46	74.5	1.47	80.3	2.57	80.5
13	2.54	72.8	4.85	73.2	1.27	89.0	2.42	82.2
14	3.07	82.1	5.82	82.1	1.61	86.3	2.98	83.9
15	2.58	81.8	4.80	82.3	2.28	82.9	4.67	75.2
16	2.38	76.5	4.50	76.2	2.14	76.6	4.03	78.7

D_0 = deflection under load; LTE = load transfer efficiency.
[a] Deflection across the joint is not presented here. Joints are numbered counterclockwise. The location of the first joint is at the middle of Hopkins Road facing north.

LTEs on the precast truck apron were mostly above 70% except for two that scored 62 and 66%. According to the specification, 80% LTE is recommended in a jointed precast panel. About 50% of the joints satisfied this criterion. In a previous VDOT project on I-66, LTEs were mostly above 80% immediately following construction, with a few between 70 and 80% (Hossain and Ozyildirim, 2012). The difficulty in the grouting operation in this Hopkins Road roundabout might have contributed to the lower values. Deflections under 9- and 16-kip loads are mostly less than 5 mils and are reasonable for a 9-inch concrete pavement. For comparison, LTEs were also measured for a CIP-jointed concrete roundabout at Fairground Road (Table 3).

LTEs are similar to the precast panels, about 40% measurements were below 80%. Unlike precast, some of the low values were as low as 25%, and some deflections were very high, in the range of 10 mils under a 16-kip drop load.

Table 3. Falling Weight Deflectometer Data at the Truck Apron Transverse Joints for Fairground Road Cast-in-Place Roundabout

Joint No.	Drop Load on Approach Side of Traffic				Drop Load on Leave Side of Traffic			
	9-Kip Drop Load		16-Kip Drop Load		9-Kip Drop Load		16-Kip Drop Load	
	D_0 (mils)[a]	LTE (%)	D_0 (mils)	LTE (%)	D_0 (mils)	LTE (%)	D_0 (mils)	LTE (%)
Outer Circle (Outside Lane)								
1	3.99	93.7	7.1	92.5	3.04	30.3	4.88	33.6
2	5.04	90.7	9.05	90.8	0.79	101.3	1.64	85.4
3	5.38	69.7	9.73	70.1	0.95	78.9	1.6	83.8
4	3.74	91.7	6.73	90.5	0.88	84.1	1.51	84.1
5	2.20	82.3	3.80	84.7	1.09	69.7	2.00	69.0
6	1.70	67.1	3.07	69.1	0.78	76.9	1.35	74.8
7	0.93	79.6	1.63	79.8	0.80	65.0	1.40	62.9
8	1.03	52.4	1.82	50.0	0.91	81.3	1.56	82.1
9	0.75	81.3	1.39	74.1	1.34	82.8	2.44	82.0
11	1.09	71.6	1.88	75.0	1.81	97.2	3.17	99.1
12	0.85	78.8	1.52	79.6	3.78	91.0	6.66	91.4
13	0.97	78.4	1.65	83.0	5.61	66.5	10.22	67.4
14	1.00	85.0	1.60	89.4	4.83	90.1	8.61	90.1
Inner Circle (Inside Lane)								
1	5.67	86.6	10.17	86.3	3.56	25.8	5.76	28.3
2	6.46	92.3	11.43	92.9	1.03	85.4	1.81	85.1
3	6.59	85.7	11.72	86.5	0.85	80.0	1.52	78.3
4	3.26	86.2	5.74	87.1	0.88	79.5	1.52	80.9
5	1.21	88.4	2.20	85.9	1.35	69.6	2.47	67.6
6	2.09	56.0	3.67	56.4	0.93	80.6	1.67	77.8
7	1.13	83.2	1.94	85.1	0.93	72.0	1.65	69.7
8	1.28	62.5	2.25	58.2	1.06	90.6	1.91	88.0
9	1.13	71.7	2.03	68.0	1.79	64.8	3.20	65.0
10	1.19	80.7	2.06	80.6	1.19	86.6	2.00	91.5
11	1.07	83.2	1.87	82.4	2.92	94.2	5.21	93.7
12	0.89	85.4	1.65	80.0	5.91	90.7	10.85	89.7
13	0.94	86.2	1.72	83.1	6.20	88.2	11.11	88.3
14	1.5	60.0	2.59	61.8	5.29	92.1	9.83	89.3

D_0 = deflection under load; LTE = load transfer efficiency.
[a] Deflection across the joint is not presented here. Joints are numbered counterclockwise. No readings were taken on joints at both sides of the manhole. Location of first joint is on the right side of the fourth extension road facing west or the second joint counterclockwise after the manhole.

Benefit Assessment

Using any precast concrete element can provide high-quality concrete because precast concrete is produced in a controlled environment at offsite locations. Because precast concrete does not need to cure for a long time on site, it can expedite construction. However, in most cases, using precast panels in pavement construction is expensive. The following sections discuss expedited construction and cost aspects. Some of the benefits may include the following:

- High-quality concrete.
- Expedited construction.
- Easier maintenance of traffic during construction.
- Construction with rigid elements is possible even if fresh concrete is not easily available.
- Special color and texture can be achieved easily.
- Experienced concrete contractor is not essential.
- Easy maintenance by replacing one panel at a time if damaged.

Expedited Construction

In addition to having a quality product, using precast cement is supposed to expedite the construction process. Both precast projects, Laburnum Avenue and Hopkins Road, were constructed during weekend lane closures. Regular traffic detours or lane closures during the weekdays were not practical for these locations.

The Laburnum Avenue truck apron construction was completed during a weekend closure plus one extra day because of rain and cold temperatures as low as 27 to 42ºF. The grout took extra time to gain strength. The closure started on Friday night, and the roadway reopened to traffic on Tuesday morning. Many additional tasks and care were needed to complete the construction successfully, such as submittal review, fine base grading, continuous surveyor help throughout the installation, appropriate grouting and associated equipment (pump), and a skilled grouting operator.

The Hopkins Road precast roundabout construction took a little extra time. Although one weekend closure was needed to install the precast truck apron, an extra weekend closure was required for additional base preparation and a drainage structure in the unpaved central island. The grading needed asphalt buildup on one side, and the other side needed significant asphalt milling. The leveling and grouting operation for the precast panels took a few additional days, but traffic was allowed around the roundabout with traffic barriers around the central area. Additional base preparation and lack of a skilled grouting crew made this installation a little challenging and delayed the operation.

CIP construction may require a few extra days, but the challenges with the base preparation and grouting operation can be avoided. Most of the CIP roundabouts considered in this study had the benefit of detours for truck traffic if not for all traffic. Construction was possible under live traffic with flaggers during the daytime. Some occasional short closure was needed. Actual truck apron construction took 4 to 5 days. In some places, high early strength concrete was used. However, opening to traffic immediately was not essential in most cases, so regular A-3 concrete was sufficient.

Bid Cost Comparison

In this study, a small part of the roundabout construction was considered—the central island, truck apron, and curbs. Bid documents were collected to compare the bid prices. All the roundabout projects considered in the study were intersection improvement projects, with many other components, such as road extension or widening and drainage retrofit or enhancement. The total cost varied from 1.5 to 4 million dollars. Table 4 summarizes some of the bid prices. Mobilization and regular excavation are some of the high-price items in all bids. CIP concrete costs are usually less than precast but vary significantly. For 16-inch CIP reinforced concrete, the bid price was $160 per square yard in one project, whereas the bid price was $275 per square yard for 8-inch reinforced concrete in another project. On the other hand, precast concrete panel costs were $315 and $850 per square yard for two projects. Both precast concretes were manufactured in a New York plant and shipped to Virginia. Notably, the same manufacturer and contractor were involved in both cases. Therefore, these bid prices may not be the best indicator of the cost. Overall, cost always dictates a project. A new product or technology may suffer from overpricing because of the lack of familiarity, lack of support structure for efficient production, uncertainty, and associated risks.

Table 4. Bid Price Comparison

Roundabout	Days to Complete Construction[a]	Total Project Cost (millions)	Mobilization Cost	Concrete		
				Type	Quantity (SY)	Unit Price
Laburnum Avenue	228	$1.45	$150,000	Precast (9”)	284	$315
Hopkins Road	509	$2.28	$200,000	Precast (9”)	239	$850
Maury Street	511	$4.18	$190,000	Reinforced CIP Concrete (16”)	706	$160
Fairground Road	481	$3.38	$168,000	Reinforced CIP Concrete (8”)	565	$275
Luray	242	$1.65	$54,000	CIP Plain Concrete (7”)	485	$90
Winterpock Road	—	—	—	Reinforced CIP Concrete (8”)	(60 CY)	($470/ CY)
Gum Spring	438	$1.95	$68,000	—	—	—

— = data not available; CIP = cast-in-place; CY = cubic yard; SY = square yard.
[a] Construction start and end dates were based on VDOT C-5 form. The price for Winterpock Road includes only concrete in cubic yards.

The two precast truck apron projects had five and six bidders, and the precast truck apron in a third project had one bidder, with alternate bidding at Gum Spring (Table 5). Table 6 lists all bid prices for precast truck aprons. Most prices varied from $700 to $1,100 per square yard for a 9-inch precast panel except for two at two extremes: $315 and $2,830. Only one successful bidder for the Laburnum Avenue project bid $315 per square yard, which is similar to a 2009 project on I-66 in Northern Virginia (Hossain and Ozyildirim, 2012). The panels were made locally in Virginia in 2009 and did not require additional shipping, which could have added significant cost to the system.

Table 5. Bid Prices for Precast Truck Aprons[a]

Project	Quantity, SY	Bidder	Unit Price, $/SY
Laburnum Avenue (Letting Date: May 2020)	284	1	315
		2	910
		3	1,066
		4	1,056
		5	1,106
		6	2,830
Hopkins Road (Letting Date: March 2021)	239	1	850
		2	896
		3	1,078
		4	1,019
		5	700
Gum Spring (Letting Date: June 2021)	694	4	1,030

SY = square yard.
[a] All truck aprons were 9-inch-thick slabs. The Gum Spring project had only one bidder with an alternate precast option.

Table 6. Alternate Bid Prices for Gum Spring Roundabout[a]

Bidder	Total Bid Price (Millions)	Truck Apron Bid Price	
		Alternate 1: Asphalt	Alternate 2: Precast
1	$1.95	$328,800	N/A
2	$2.07	$301,490	N/A
3	$2.12	$193,900	N/A
4	$2.56	N/A	$754,500
5	$2.85	$489,950	N/A

N/A = not available.
[a] Total truck apron area is 239 square yards with 9-inch depth.

The Gum Spring roundabout had an alternative bid option to use precast concrete. Five bids were submitted, with estimated costs in the millions: $1.95, $2.07, $2.12, $2.56, and $2.85. All bidders preferred to use the asphalt option except the fourth bidder, who had precast concrete, which was 30% more expensive than the lowest bid but was not the highest bid. The precast panels alone had a high cost, but the differences were low enough in the total project cost to make the precast option competitive and feasible with more system familiarity. Also, adverse weather conditions and concrete availability, especially in congested areas, can make precast concrete desirable.

Lessons Learned and Updating the Special Provision

The roundabouts investigated in this study provided some comparisons and lessons learned, which facilitated updating the precast construction specifications. The lessons learned and the specification changes were mainly in three areas: base preparation, panel installation (maneuvering), and grouting operation. Precast roundabouts require careful planning and scheduling. A mockup installation with actual panels was very helpful and should always be practiced. Because the panels are cast ahead of time, their storage and subsequent handling should be given consid eration during the planning phase of preconstruction meetings. If the panels are produced out of state, proper inspection needs to be arranged.

Base Preparation

Detailed instructions for base preparation in the specification or special provision would be helpful for both the precast and CIP systems. Some of the key areas of base preparation in the current special provision for the precast system that might need attention include the following:

- If the existing stabilized base or the unbound aggregate requires less than 1 inch of raising, sand-cement bedding should be used. Sand-cement bedding involves the 6:1 sand to cement ratio, mixed and cast dry, followed by misting with water.
- If the grade needs more than 1 inch of raising, in the case of:
  - Unbound base: Follow section 309 of VDOT specifications (VDOT, 2020).
  - Stabilized base: The same stabilized materials should be used, or follow the Engineer's directions.
- In any case, the final base surface should be compacted, smooth, and free of debris. Finished grade elevation should be within plus or minus 0.04 feet of the elevation indicated in the plan, provided the actual cross slope does not vary more than 0.20% from the design cross slope indicated in the plan—similar to VDOT specification section 315.07 (b) (VDOT, 2020).
- Using leveling bolts helps achieve the final grade for the precast slabs. However, the slabs in a circular area have more limitations than a straight portion, so fine grading is needed before leveling with bolts. Therefore, a base preparation is needed with stricter tolerance, such as in the asphalt pavement construction, according to section 315.07 (VDOT, 2020).

Panel Installation

Proper placement of the heavy panels, which weigh at least 6 tons, requires heavy equipment for easy maneuvering. Using a big crane at the Laburnum Avenue roundabout made the placement efficient. However, the Hopkins Road project used an excavator because of limited overhead clearance due to electric cables near the intersection and faced many challenges. The following are a few notes for successful placement:

- A contractor-provided surveyor should be required to lay lines and corners for panel placement. Reference points should be required when precast slabs are installed around an unpaved central island.
- A crane capable of lifting 1.5 times the minimum weight of the panel or at least a 10-ton capacity should be used for placement. The contractor should have enough crews to maneuver the moving panels and ensure proper placement without damaging the base and the panels. This activity becomes more critical when a big crane is not available, and an excavator or front-end loader is used, requiring more crews for the installation.
- The respective horizontal and vertical tolerances of 1/4 inch and 3/16 inch should be followed as required by the plans.

Grouting

The grouting operation was challenging in both precast projects. Crews should be specifically trained in the grouting operation, and it is best to use appropriate preapproved grout, as the precast panel manufacturer recommends or as the special provision (or specification) specifies. The presence of a panel manufacturer's representative during the grouting operation seemed to be helpful. Guidelines for grouting should satisfy the recommendations from both the precast panel and grout manufacturers and as a minimum should include the following:

- The sequence should be applying grout to the underslab first by hand or mechanical pump as recommended by the precast panel and grout manufacturers. The grout should have enough flowability, as specified in the special provision (or specification) and by the grout manufacturer, to facilitate complete coverage.
- Next, the dowel grout should be placed following both precast panel and grout manufacturers recommendations in the dowel ports (or opening), for complete grouting to the surface level. The gravity flow should not be permitted unless specifically permitted by the grout manufacturer because grout consistency may hinder complete coverage of dowel slot or voids underneath the slab.
- In case the foam seal or gasket at the outer edges of the slab does not stop grout leakage, preventive measures such as backer rod and spray foam may be used. A dense-graded aggregate can be used at the perimeter, but care should be taken for easy removal after the installation.
- Grout material can be the same for both the underslab and the dowel slot. However, their consistency will be different, as required by the need for flow and strength specified in the special provision or specification.
  - Dowel grout strength should be 2,500 psi before opening to traffic.
  - Underslab grout strength should be 500 psi before opening to traffic.
  - Grout should remain fluid and maintain uniform consistency until installed.

CONCLUSIONS

- *Roundabout truck aprons were constructed successfully with precast panels, or CIP concrete, or asphalt with a concrete curb at the outside edge.*

- *It was possible to install precast concrete panels to build a truck apron during a single weekend lane closure.*

- *A contractor with minimum experience was able to install precast panels with guidance from the concrete panel manufacturer.*

- *Special planning and scheduling are needed to use the precast panels successfully. Base preparation, panel installation, and grouting need special attention.* Base preparation must meet stricter tolerance than regular base construction, panel installation requires a crane for heavy lifting, and grouting operations need experienced crews.

RECOMMENDATIONS

1. *VDOT's Materials Division and districts should consider using precast concrete panels for the roundabout truck apron where traffic closure is limited to only weekends and where fresh concrete for CIP use is not readily available.*

2. *VDOT's Materials Division should incorporate the suggested changes, as mentioned in the "Lessons Learned and Updating the Special Provision" section of this report, regarding base preparation, panel installation, and grouting operations into the current special provision.*

3. *VDOT's Materials Division should develop an approved list of grouts for precast panel installation.*

IMPLEMENTATION AND BENEFITS

Researchers and the technical review panel (listed in the Acknowledgments) for the project collaborate to craft a plan to implement the study recommendations and determine the benefits of doing so. This process is to ensure that the implementation plan is developed and approved with the participation and support of those involved with VDOT operations. The implementation plan and the accompanying benefits are provided here.

Implementation

With regard to Recommendation 1, VDOT's Materials Division, districts, and VTRC will continue to promote precast concrete panels for truck aprons in roundabouts through different venues, such as the Virginia Concrete Conference, District Materials Engineers' meetings, and the Materials Division's Pavement Forum focusing on reduced traffic disruption.

With regard to Recommendation 2, VDOT's Materials Division will review the language and make necessary changes in the current VDOT special provision, if any, based on the findings and recommendations of this investigation by June 2028.

With regard to Recommendation 3, VDOT's Materials Division will initiate and develop an approved list of grouts satisfying the requirements in the VDOT special provision by June 2028.

Benefits

Generally, precast concrete is of high quality because it is produced in a controlled environment. Using precast concrete panels facilitates expedited construction and enables easy repairs by replacing one panel at a time. Some of the benefits could include as follows:

- High-quality concrete.
- Expedited construction.

- Maintenance of traffic during construction is improved.
- Special colors and textures can be achieved easily.
- Experienced concrete contractors are not essential.
- Easy maintenance is possible by replacing one panel at a time if damaged.
- An alternative option for construction when fresh concrete is not easily available.

Precast construction can be conducted during a weekend closure, whereas CIP concrete construction is usually preferred during weekdays because of difficulties procuring concrete and hauling drivers during the weekend. Although it may be possible to complete truck apron construction in weekday operations, using early strength concrete will be necessary if opening to traffic is immediately needed, raising concerns with the concrete's durability, especially when portland cements are used. With the CIP option, delivery delays may occur because of urban congestion that could further delay the construction.

Another concern for CIP is load rejection and disposal, especially for the colored concrete. If stamping is needed in CIP construction, the pattern's success depends on properly timing the stamping. If stamping is not done when the concrete is still plastic, unintended cracks may develop and may require additional surface sealing. To keep the concrete plastic longer, a retarder may be used, which will extend the construction time. Also, the small amount of concrete needed for truck apron construction may make finding a suitable supplier challenging. In addition, finding skilled laborers for concrete operations can be more challenging than finding laborers for precast fabrication.

Precast concrete construction is expected to reduce traffic interruptions because traffic volume during the weekend is usually less than during weekdays, as the following scenarios depict. The CIP truck apron construction is completed during weekdays, Monday through Friday, with a working window from 8:00 a.m. to 4:00 p.m. compared with construction with precast concrete panels during a weekend closure from 8:00 p.m. Friday night to 6:00 a.m. Monday morning. The research team gathered variations in traffic distribution among different days of the week and hourly volume profiles from the *Urban Mobility Report* published by the Texas A&M Transportation Institute (Schrank et al., 2021). Table 7 presents the weekly traffic distribution for annual average daily traffic (AADT) of 1,000, which is typical, assuming a nationwide average volume profile on an arterial road with equal speeds in both the a.m. and p.m. hours. The total number of vehicles passing the intersection during 5 weekdays of construction is 2,423, but it is 1,936 during the weekend construction period, resulting in a difference of 487 vehicles. The difference in the total number of vehicles passing the construction zone, or intersection, during the two construction scenarios is about one-half of AADT. When AADT is 1,000, approximately 500 fewer vehicles will pass through the intersection during weekend construction. Thus, weekend construction will create less disruption and inconvenience for travelers.

Table 7. Distribution of Traffic during Construction

Day of the Week	AADT Factor[a]	No. of Vehicles per 1,000 AADT	Construction Time	Traffic Volume Ratio[a]	No. of Vehicles Affected by Construction	
					Weekday	Weekend
Monday	1.05	1,050	8 a.m. to 4 p.m.	0.4573	480	—
	1.05	1,050	12 a.m. to 6 a.m.	0.0864	—	91

Day of the Week	AADT Factor[a]	No. of Vehicles per 1,000 AADT	Construction Time	Traffic Volume Ratio[a]	No. of Vehicles Affected by Construction	
					Weekday	Weekend
Tuesday	1.05	1,050	8 a.m. to 4 p.m.	0.4573	480	—
Wednesday	1.05	1,050	8 a.m. to 4 p.m.	0.4573	480	—
Thursday	1.05	1,050	8 a.m. to 4 p.m.	0.4573	480	—
Friday	1.10	1,100	8 a.m. to 4 p.m.	0.4573	480	—
	1.10	1,100	8 p.m. to 12 a.m.	0.1314	—	145
Saturday	0.90	900	All day	1	—	900
Sunday	0.80	800	All day	1	—	800
Total					2,423	1,936

— = not applicable. AADT = annual average daily traffic.
[a] AADT factor and traffic volume ratio were obtained from Schrank et al. (2021).

During either construction scenario, traffic delays are expected. On a complete traffic closure during the weekend, vehicles must use a detour. The amount of delay depends on the length of the detour and vehicular speed. For example, a 1-mile detour will produce a1-minute delay if vehicular speed is 60 mph. On the other hand, weekday construction will also face delays when using flagging operations for the safe passage of vehicles. For example, if the flagging operation cycle is 2 minutes, and each vehicle takes one cycle to pass through, the delay per vehicle is 2 minutes. To compare the delay cost, assume for simplicity that the maintenance of traffic is designed in such a way that delay per vehicle in both scenarios is equal. Lan et al. (2021) calculated average delay cost per vehicle in a recent VTRC study 22-R15 and found this cost was expected to be \$45 per hour for a passenger vehicle and \$80 per hour for a truck. Therefore, the difference in cost for a 1-minute delay when AADT is 1,000, with 10% trucks, is \$404 (= 500 × {0.9 × 45 + 0.1 × 80}/60). Figure 32 presents the difference in delay cost for weekdays versus weekend construction, with varying AADTs and delay times. As Figure 32 shows, the difference in delay cost can be significant, depending on the traffic level and amount of expected delay. The respective estimated AADT for the two Laburnum Avenue and Hopkins Road precast roundabouts were 42,000 and 12,500. Therefore, the estimated delay cost difference for Laburnum Avenue could have been \$86,000 for weekday versus weekend construction for a 5-minute per vehicle delay during the truck apron construction.

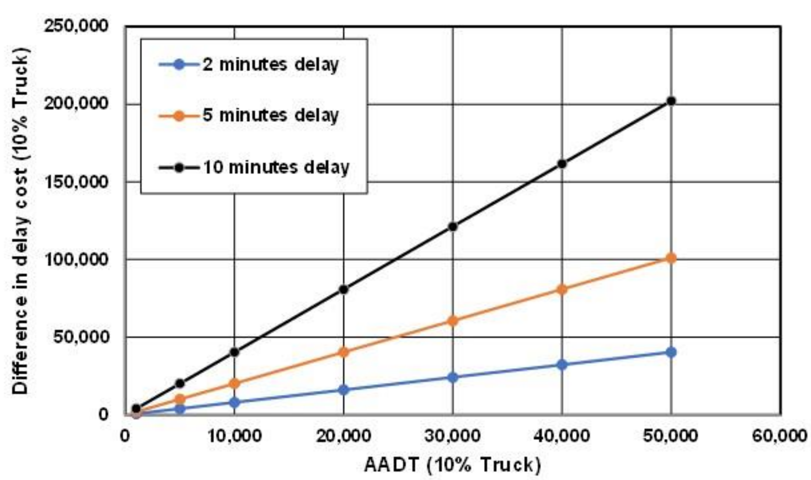

Figure 32. Difference in Delay Cost for Weekday versus Weekend Construction. AADT = annual average daily traffic.

Tables 4 and 5 show that precast panels are expected to cost more than CIP options. However, when considering the total cost of the project, the differences are small, as evidenced by one of the projects for which alternate bidding was sought. The precast option was high—30% more than the lowest asphalt bid—but not the highest among the bids. With further precast panel installation and use familiarity, cost is expected to reduce, making the precast option competitive with CIP placement. Also, improvements in grouting materials and applications will help reduce the precast panel installation times of future projects. If expedited construction and durability are considered, the precast option is already an effective alternative option to existing CIP systems. Thus, the introduction of this innovative roundabout construction using precast panels provides VDOT and contractors a beneficial option, especially when adverse weather conditions are expected, availability of concrete is restricted, and traffic disruptions are limited.

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