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Accelerated construction of urban intersections with Portland Cement Concrete Pavement (PCCP)

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ABSTRACT

The frequent maintenance required on asphalt concrete (AC) pavement sections has made reconstruction with portland cement concrete pavement (PCCP) a feasible alternative. However, many constructability issues need to be addressed in order to realize the full potential of this alternative. Accelerated paving encompasses three classes of activities: methods to accelerate the rate of strength gain, methods to minimize the construction time, and traffic control strategies to minimize user delay. In this paper a case study will be presented in which an AC intersection was reconstructed with portland cement concrete pavement. The entire reconstruction of the intersection, including demolition of the AC pavement and its replacement with PCCP, took place over a period of three days, starting on Thursday evening and opening the intersection to the traffic on Sunday afternoon. This paper documents this effort in order to provide practitioners additional options for rapid reconstruction of urban intersections and includes documentation of the construction process, traffic management strategies, and an analysis of the costs. The results of this investigation can be used to educate pavement construction professionals and the academic community on the use of PCCP for accelerated reconstruction of major urban intersections with minimal user and traffic disruption, using innovative construction techniques and traffic management optimization principles. This investigation produced valuable information to demonstrate that concrete pavements can be constructed efficiently and quickly.

1. Introduction

Traditional pavement construction, repair, or replacement practices are no longer acceptable due to increasing public impatience with traffic interruption. However, public works agencies must continue to repair or replace deteriorated pavements while maintaining traffic on these roadways. Construction of these roadways is especially difficult in urban areas where traffic congestion is significant.

Intersections pose major construction staging and traffic interruption challenges because they affect two or more streets [4,12]. Where it is feasible to close the entire intersection for a short time, a contractor can use accelerated paving techniques to complete reconstruction over a weekend. Accelerated techniques for concrete paving allow transportation officials to

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consider concrete for projects that might not otherwise be feasible due to misperception about concrete curing requirements [3,13]. Specifications often require lengthy cure periods for conventional concrete mixtures. The result is that portland cement concrete pavement (PCCP) reconstruction for urban intersections is frequently not considered due to perceived constructability problems, especially at locations with high traffic flow. With accelerated paving construction techniques using PCCP, concrete can meet opening strengths in less than 12 hours, providing quick public access to a high-quality, long-lasting pavement. Accelerated construction techniques are suitable for new construction, reconstruction, or resurfacing projects.

The most efficient method of construction is to completely close the roadway. Complete closures allow the contractor to remove and replace the roadway in a continuous and safe operation. Interaction with traffic is avoided, as complicated work zone lane configurations are eliminated. However, a major urban arterial is often not an option, particularly when detours are not available. Another concern is that complete closures restrict access to businesses that are adjacent to the intersection, therefore they are unpopular.

In an effort to produce pavements that are safer, more durable and more cost effective, three urban intersections constructed with asphalt concrete (AC) in Eastern Washington were replaced with portland cement concrete pavement (PCCP). Traffic volume passing through these intersections are as high as 30,000 Average Daily Traffic (ADT), with twenty percent heavy trucks. Fig. 1 shows the general vicinity where these activities were taken place.

2. Project background

Asphalt pavement has long been a popular road construction material. In areas where traffic becomes concentrated, such as urban intersections, flexible pavement may be prone to rutting over time. In areas with seasonal temperature extremes, the ruts can quickly become severe. Several of the flexible pavement intersections had been suffering from severe rutting caused by slow moving heavy vehicles, exasperated by high temperatures during the summer months.

Severe ruts, as much as 2–4 inches (5–10 cm) or more could be observed in these intersections. Despite routine maintenance, minor ruts reappeared after a few months with severe ruts within a year after rehabilitation.

Fig. 2 depicts the level of severity of pavement rutting at the intersection of Kennewick Avenue and SR 395 intersection.

The Washington State Department of Transportation (WSDOT) has been using PCCP as a long-term pavement solution at urban intersections since 1994. The purpose of this reconstruction was to provide a quality long-life pavement with minimal user disruption which will result in safety improvements and a significant reduction in user costs.

3. Research objectives

Traditionally, reconstruction of intersections with PCCP requires several weeks and complex traffic management plans, which can cause significant user delays. However, the use of PCCP can result in lower long-term maintenance and user costs due to the reduction in overlay frequency. The major disadvantage to the use of PCCP for intersection reconstruction is that initial construction costs are typically higher. Despite the lower initial cost of AC pavements, life cycle cost analysis (LCCA) indicates that PCCP may be more cost effective under certain circumstances [1]. According to American Concrete Pavement Association (ACPA) LCCA, concrete alternate will cost an agency just 40 % of the comparable asphalt alternate (in inflated or actual dollars) over 50 years if future asphalt and concrete costs inflate as they have for the past 54 years; the diff ;erence will be even larger if user costs are included [2]. The use of techniques to reduce construction time and user impacts can make the use of PCCP even more cost effective and provide a viable alternative to AC rehabilitation.

4. Planning process

The three-day complete intersection closure idea, from Thursday evening at 6:00 PM to Monday morning at 6:00 AM, evolved because of the past problems on a previous PCCP intersection project. The goal was to reduce the construction period and minimize traffic disruption. All the parties involved benefitted from this technique because meeting this goal reduced public complaints, business impacts, user-delay costs, traffic control costs, increasing employee and public safety and reducing the time resources committed to the project. The contractor also benefited by increasing productivity.

There needs to be an effective public relations campaign prior to the 3-day closures. Numerous public meetings were held during the design phase for public input. Businesses were contacted a week and then just days prior to the start of construction. Flyers were handed out explaining the process and reminding the businesses that there would be detour routes. Weekly meetings were held by the project engineer to update the local media. These activities were aimed at making the closures as organized and painless as possible for the public.

Media coverage was essential to the success of this project and it started a week ahead of the actual construction. This ensured that the public was well informed of the closures. Newspapers provided coverage as well.

Informed local drivers avoided the area entirely, reducing traffic delays. As a result, complaints from the public were reduced by over 70 % compared to the projects constructed before.

Fig. 1. Map of the project area.

Fig. 2. Severity of pavement rutting at the intersection of W. Kennewick Avenue and SR 395.

5. Traffic management

Traffic management and construction staging is typically the primary issue associated with the construction of PCCP intersections. An important consideration during design is to obtain input from any party that will be affected by the intersection reconstruction. These parties include, but are not limited to, local governments, emergency services, business owners, and private citizens.

Local traffic was detoured to adjacent streets, while state highway traffic was detoured over nearby interstate highway. A multi-staged, detour plan was implemented that provided local access, access to commercial sites, and special routes for heavy trucks passing through the area. It was this plan that made it possible for the contractor to modify the reconstruction of the intersection approaches and complete this work in the week prior to the intersection closure.

Flaggers were placed at all key locations to keep the car traffic flowing. Truck traffic utilized signing placed on the state highways. Traffic flowed well through the weekend. Isolated backups and detour problems were resolved as soon as possible.

6. Concrete materials

The primary concern with accelerated pavement construction is determining when traffic can begin to use the new pavement. The basis for this decision should be made on the concrete strength and not arbitrarily on the time from placement. Strength directly relates to load-carrying capacity and provides certainty that the pavement is ready to accept loads by construction or public traffic.

For concrete pavement applications, flexural strength is the most direct indicator of load capacity. Flexural strength values indicate the tensile strength at the bottom of the slab where wheel loads induce tensile stresses.

For the intersection to be opened to traffic, the PCCP compressive strength of 2,500 psi (17.2 MPa) must be achieved, which was determined from the maturity meters. The specification called for a design flexural strength of 650 psi (4.5 MPa) at 14 days and 2,500 psi (17.2 MPa) compressive strength for opening to traffic. Typically, this is obtained in 3–7 days. For this project, the concrete mix design was critical in maintaining the accelerated schedule. The contractor's schedule required a

Table 1
Concrete Mix Design.

Material	Type	Quantity	
Cement	ASTM C150 Type III	705 lbs/yd^3	418 kg/m^3
Aggregate	1 $^1/_2$" (3.8 cm)	940 lbs/yd^3	558 kg/m^3
	$^3/_4$" (1.9 cm)	799 lbs/yd^3	474 kg/m^3
	3/8" (9.5 mm) Pea Gravel	140 lbs/yd^3	83 kg/m^3
Sand	Coarse	590 lbs/yd^3	590 kg/m^3
	Fine	481 lbs/yd^3	285 kg/m^3
Water	–	254 lbs/yd^3	151 kg/m^3
Air-entraining admixture	ASTM C260	11 oz/yd^3	408 g/m^3
Water-reducing admixture	ASTM C494	30.3 oz/yd^3	1224 g/m^3
Set-retarding admixture	ASTM C494 / Delvo	17.6 oz/yd^3	653 g/m^3

Table 2
Concrete characteristics.

Characteristic	Quantity
Slump	3 $^1/_4$ in. (8.3 cm)
w/c ratio	0.36
Air Content	6.3 %
Unit Weight	149.8 pcf (2,400 kg/m^3)
Concrete temperature	85 °F (29.4 °C)
Air Temperature	82 °F (27.8 °C)

Table 3
Concrete compressive strength gain.

Time at Test, Hours	Compressive Strength, f'_c, psi (MPa)
6	2,050 (14.1)
12	3,290 (22.7)
18	3,770 (26.0)
24	4,015 (27.7)
30	4,200 (29.0)
36	4,225 (29.1)
42	4,140 (28.5)
48	4,245 (29.3)
54	4,245 (29.3)
60	4,495 (31.0)
66	4,685 (32.3)
72	4,690 (32.3)

mix which would allow for opening to traffic within 24 h. In order to determine the strength of concrete, maturity meters were utilized [6].

Air-entraining admixtures meeting the American Society for Testing and Materials (ASTM) C260 [8] requirements were used to entrain microscopic air bubbles in concrete. Entrained air improves concrete durability by reducing the adverse effects of freezing and thawing. Most accelerated paving mixtures have entrained air and a relatively low water content that improves strength and decreases chloride permeability. Freeze-thaw deterioration can occur if water freezes and expands within a concrete binder with a poor air-void distribution or if the concrete contains poor-quality aggregates. Properly cured concrete with an adequate air-void distribution resists water penetration and relieves pressures that develop in the cement paste. Air-entrained concrete pavement is resistant to freeze-thaw deterioration even in the presence of deicing chemicals. The concrete used for this project had 6.3 % total air content.

Finely ground cement increases surface area and allows more cement contact with mixing water and, consequently, the cement hydrates faster. In this project ASTM C150 [5] Type III portland cement was used. Type III cement, which is much finer than other types of portland cements, usually develops strength quickly.

A low water-cementitious material ratio (w/c) contributes to low permeability and improved durability. A w/c ratio between 0.40 and 0.50 provides moderate chloride permeability for concrete made from conventional materials. A w/c ratio below 0.40 typically provides low chloride permeability. The concrete used in this project had a w/c ratio of 0.36.

Water-reducing admixtures reduce the quantity of water necessary in a concrete mixture or improve workability at a given water content [7]. Water-reducing admixtures increase early strength in accelerated concrete paving mixtures by

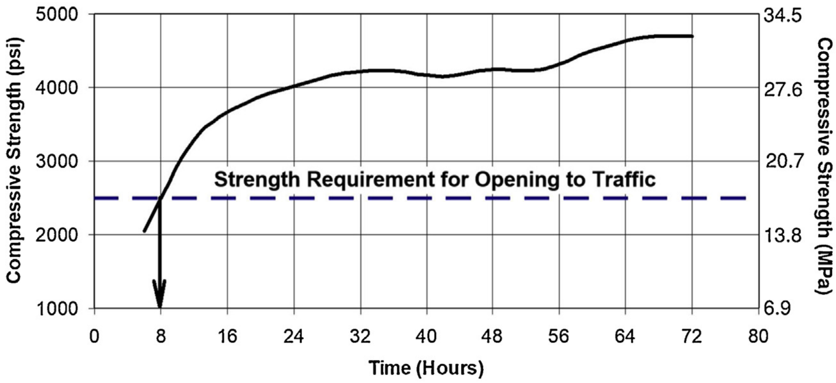


Fig. 3. Compressive strength gain vs. time.

Fig. 4. (a) Concrete sampling from mixer truck; (b) Air content measurement.

Table 4
The results of the Kennewick intersection testing.

Cylinder No.	Unit Weight lbs/ft^3 (kg/m^3)	W/C Ratio	% Air	Compressive Strength, f'_c psi (MPa)
25A	148.6 (2380)	0.38	4.5	4,926 (34.0)
25B	148.6 (2380)	0.38	4.5	4,978 (34.3)
26A	151.1 (2420)	0.39	3.4	5,207 (35.9)
26B	150.5 (2410)	0.39	3.4	5,407 (37.3)

lowering the quantity of water required for appropriate concrete placement and finishing techniques. Water reducers disperse the cement, reducing the number of cement agglomerations. More efficient and effective cement hydration occurs, thus increasing strength at all ages.

In order to prevent premature set of concrete during transportation from the mix plant to the job site or while the truck is being queued before delivery, set-retarding admixture (Delvo) was used in this project [7].

7. Concrete mix proportioning considerations

Rapid strength gain is one of the requirements for reducing facility closure time. While many methods exist to do this, the contractor was determined to keep the mix as simple as possible and limit the number of variables to a minimum. The batch

Table 5
The results of the Kennewick intersection core testing.

Core Location	Core Density lbs/ft^3 (kg/m^3)	Core Depth in (mm)	Core Depth Specification in (mm)
North Approach on SR 395	148.02 (2371)	12.28 (312)	11.81 (300)
South Approach on SR 395	150.08 (2404)	12.20 (310)	

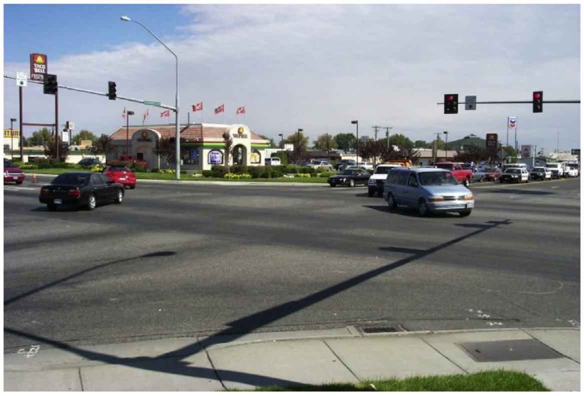


Fig. 5. The Intersection of SR 395 and Kennewick Avenue prior to construction.

plant was located 20–25 min away from the job site and the construction crew needed 45 min to 1 h to place the concrete without rapid setting. Table 1 shows the concrete mix design used for the intersections in Kennewick. Table 2 shows the characteristics of the concrete delivered to the site.

8. Concrete testing

Acceptance testing for the PCCP was done by statistical acceptance according to Washington State Department of Transportation (WSDOT) Standard Specification 1-06.2(2)D. WSDOT's statistical acceptance accounts for the air content and the 28-day compressive strength. The lower quality limits for air content is 3.0 percent. The upper quality limit for air content is 7.0 percent. The lower quality limit for compressive strength is 1,000 psi (6.9 MPa) less than that established in the mix design as the arithmetic mean of the five sets of 28 day compressive strength cylinders or 3,000 psi (20.7 MPa), whichever is greater. These compressive strength cylinders were cast at the same time as the flexural beams that were used to pre-qualify the mix design. There is no upper quality limit for compressive strength.

WSDOT Standard Specifications allows for both statistical and non-statistical acceptance. Typically, statistical acceptance in not done on projects where the concrete quantities are small, such as intersections.

The frequency of testing provided, as required in the specifications, is one test per a maximum of 500 cubic yards (400 m^3) with a minimum of three tests. For smaller projects, WSDOT recommends increasing the testing frequency to increase the number of samples for the statistical analysis and reduce any potential penalty to the contractor should a particular sublot yield poor results.

In this project, the ready mix supplier provided quality control personnel for every concrete placement on the project. This was essential to avoid penalties. Table 3 shows the results of the compressive strength testing conducted in developing the strength-maturity relationship for this mix. This mix is capable of reaching the opening strength requirements in about 8 h after placement. The strength gain data shown in Table 3 is plotted in Fig. 3. Fig. 4a and b show concrete sampling from the concrete mix truck and air content measurement. Tests were conducted on each concrete truck delivery. These tests included unit weight measurement, slump test (to measure flowability and consistency), and air content measurements. Table 4 shows the results of the Kennewick intersection testing on 6 in. × 12 in. (15.2cm × 30.5cm) cylinders. Table 5 shows the results of the Kennewick intersection core testing.

9. Construction

Fig. 5 shows the Intersection of SR 395 and Kennewick Avenue prior to reconstruction of that intersection (Stage 0). The 3-day closure rebuilt the intersection square (radius return to radius return). The approach legs were rebuilt in the days prior to

Stage 1: Construction of the left hand turn lane

Stage 2: Construction of the northern approach with traffic pushed to the south

Stage 3: Construction of the southern approach with traffic pushed to the north

Stage 4: Construction of the intersection square (radius return to radius return)

Fig. 6. Construction sequence of the approach legs in SR 395.

the complete intersection closure. The reconstruction of the approach legs for Kennewick Avenue intersection were staged as follows and depicted in Fig. 6.

Stage 1: Construction of the left hand turn lane with traffic on both sides of the turn lane. Traffic reduced to one lane in each direction.

Stage 2: Construction of the northern approaches with traffic (one lane in each direction) pushed to the south.

Stage 3: Construction of the southern approaches with traffic (one lane in each direction) pushed to the north. Finally, after the approach legs were completed,

Stage 4: Construction of the intersection square (radius return to radius return).

The contractor had to prepare and execute an hourly progress schedule during the intersection closure. This was critical to the contractor since the contractor set the liquidated damages at $2,400 per hour for each hour that public was denied the full use of the intersection after 6:00 AM on Monday. The intersections were shut down by 7:00 PM on Thursday evening and construction started by 8:00 PM. The contractor maintained a “milestone” schedule whereby certain activities had to occur by a certain time.

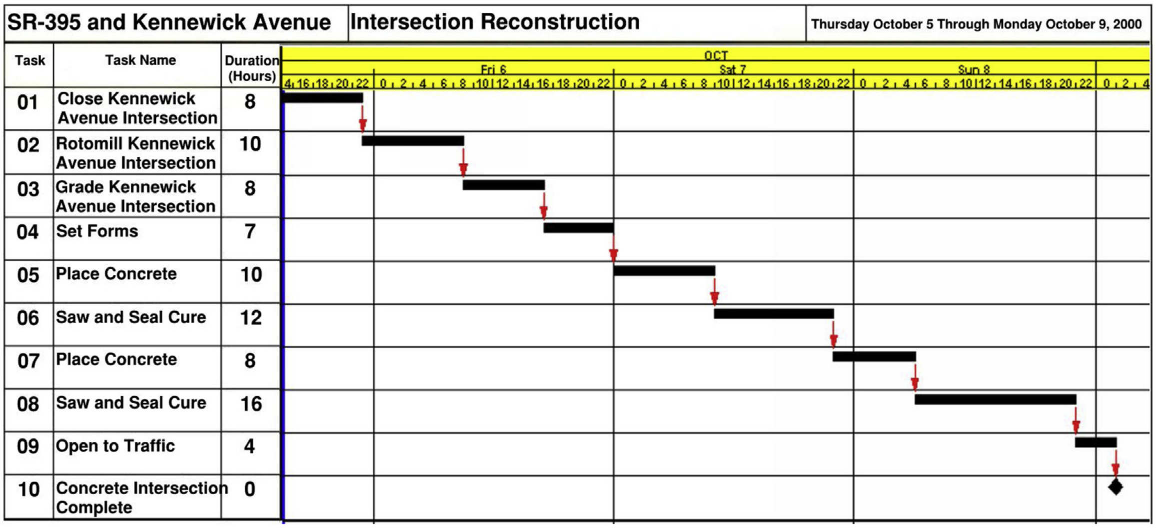


Fig. 7. Contractor's CPM schedule.

Table 6
Contractor's estimated CPM schedule for Kennewick Avenue intersection weekend closure.

Sequence	Work Activity	Start	Finish	Duration (Hours)
1	Close Kennewick Ave. Intersection	Thurs 3 PM	Thurs 11 PM	8
2	Rotomill Kennewick Ave. Intersection	Thurs 11 PM	Fri 9 AM	10
3	Grade Kennewick Ave. Intersection	Fri 4 AM	Fri 12 PM	8
4	Set up Forms	Fri 7 AM	Fri 3 PM	8
5	Place Concrete	Fri 11 AM	Fri 9 PM	10
6	Saw and Seal Cure	Fri 9 PM	Sat 9 AM	12
7	Set up Forms	Sat 7 AM	Sat 10 AM	3
8	Place Concrete	Sat 10 AM	Sat 6 PM	8
9	Saw and Seal Cure	Sat 6 PM	Mon 10 AM	16
10	Open to Traffic	Mon 10 AM	Mon 2 PM	4
	Concrete Intersection Complete	Thurs 3 PM	Mon 2 PM	71

The schedule used by the contractor was as follows:

- Thursday evening to Friday morning – Excavate the existing roadway and prepare the grade for concrete.
- Friday at 10:00 AM to early evening – Form and place concrete.
- Saturday at 8:00 AM to late evening – Form and place concrete.
- Sunday – Prepare roadway for opening to traffic

The intersections were opened on Sunday between 4:00 PM and 6:00 PM, well ahead of the 6:00 AM Monday morning opening. Fig. 7 shows the contractor's CPM schedule. The CPM schedule was straight forward, as most activities have "start-to-start" or "start-to-finish" relationships.

Table 6 is a summary of the CPM schedule showing the main activities of the construction with start times, finish times, and duration. The contractor's actual CPM schedule is shown in Table 7. The breakdown of the time actually spent on each

Table 7
Contractor's actual CPM schedule for Kennewick Avenue intersection weekend closure.

Sequence	Work Activity	Start	Finish	Duration (Hours)
1	Close Kennewick Ave. Intersection	Thurs 3:00 PM	Thurs 7:00 PM	4:00
2	Rotomill Kennewick Ave. Intersection	Thurs 8:07 PM	Fri 3:10 AM	7:03
3	Grade Kennewick Ave. Intersection	Fri 3:30 AM	Fri 11:30 AM	8:00
4	Set up Forms	Fri 7 AM	Fri 3 PM	8
5	Place Concrete	Fri 11:40 AM	Fri 9:00 PM	9:20
6	Saw and Seal Cure	Fri 3:00 PM	Sat 6:30 AM	15:30
7	Set up Forms	Sat 7 AM	Sat 10 AM	3
8	Place Concrete	Sat 8:00 AM	Sat 4:15 PM	8:15
9	Saw and Seal Cure	Sat 6:00 PM	Mon 11:30 AM	17:30
10	Open to Traffic	Mon 9:00 AM	Mon 4:45 PM	7:45
	Concrete Intersection Complete	Thurs 3 PM	Mon 2 PM	73:45

activity during the reconstruction of the Kennewick Avenue intersection is listed in Table 8. Fig. 8 is a pie chart of the activities shown in Table 8. Special equipment is not necessary for rapid construction of concrete pavement. Because the time for placement can be shorter than with conventional paving, however, accelerated paving requires well-planned construction sequencing [10,11].

The construction began at 7:00 PM on Thursday October 5th. The construction sequence from removal of the existing pavement to opening to traffic on Sunday, October 8th is outlined in the following sections.

Fig. 9a shows an aerial photo of the construction of the SR 395 and West Kennewick Avenue on the Friday of the three-day closure.

10. Removal of the existing AC pavement

Removal of the existing pavement and preparation of the grade to support the new material is critical in the reconstruction process. A rotomill was used to remove the existing pavement and base to a depth of 12 in. (30.5 cm) in a single pass (Fig. 9b). To ensure that the schedule was maintained, the contractor had a second rotomill standing by. The total amount of the existing AC pavement removed was 998 Tons. During removal of the existing pavement, electrical conduit was encountered in two locations (Fig. 9c). This required a change order to relocate these conduits and replace the wiring. This emphasizes the necessity to have decision makers onsite to address unexpected problems. WSDOT and the contractor immediately agreed to relocate the utility and address the change order when possible.

Table 8
Breakdown of time consumed by each activity during the reconstruction of the intersection of SR 395 and Kennewick Avenue.

Activity	Time (Minutes)
Closing Roadway	60
Excavation	395
Grading	260
Conduit Repair	60
Form and Place Concrete	1290
Sawcutting	570
Cure Concrete	720
Clean Joints	240
Joint Seal	240
Clean Roadway	60
Prep Roadway for Opening to Traffic	165
Delay	95
Total	4155 Min. ≅ 70 h

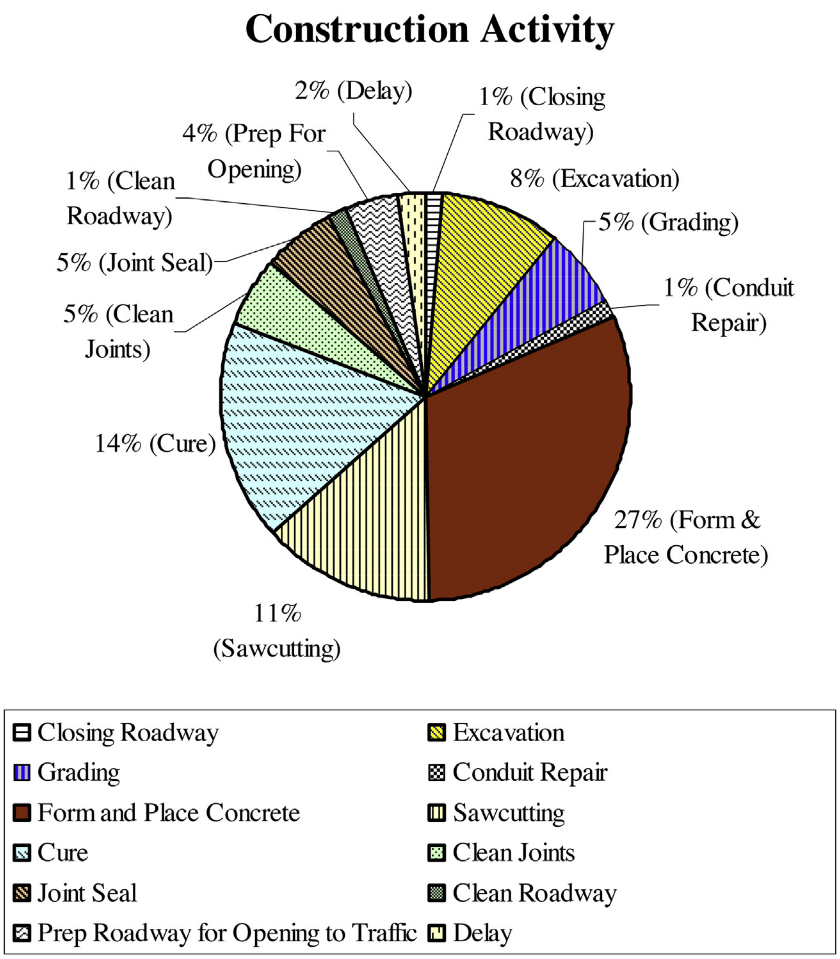


Fig. 8. Components of typical turn-around time for a PCCP intersection reconstruction.

11. Grade preparation

In an intersection, while the surface area to be graded is not large, it can still be a difficult job due to the size of the equipment and the confined working area. Obtaining uniform support demands the same construction practices and attention to detail that any newly constructed roadway requires. A poorly compacted base layer will lead to pavement performance problems, such as settlement and cracking. Fig. 9d through f show some of the grading operations at the Kennewick Avenue intersection. Attention must be paid to the compaction around all utility installations. They are especially vulnerable to soft spots, which lead to excess settling and jeopardize the useful life of the intersection.

12. Setting forms, dowel bar baskets and tie bars

Construction of PCCP intersections requires some type of fixed-form construction to accommodate short paving segments, varying paving widths, and curved paving areas. The forms were placed to allow placement of the PCCP with roller screeds. Fig. 9g shows the erection of forms. Dowel bar baskets were pre-fabricated with ten epoxy coated dowel bars per joint. Fig. 9h shows the dowel bar baskets placed between the forms. The dowel bar baskets were placed at the proper transverse joint locations according to the design plan.

Tie bars for longitudinal construction joints and dowel bars for construction joints were inserted into holes along the sides of the fixed forms. The dowel baskets for transverse joints were clearly referenced before concrete placement. Dowel and tie bars were properly aligned within WSDOT specifications and tolerances. The dowel bar baskets were not anchored to the base, however, the contractor placed concrete directly on them to prevent movement during other placing operations. All dowel and tie bars were epoxy coated and the dowels were coated with non-bonding agent for their entire length to prevent bonding with PCCP.

Fig. 9. (a) Aerial photo of Kennewick intersection ready for concrete placement; (b) Wirtgen W2200 Rotomill; (c) Replacing broken electric conduit; (d) Grade preparation; (e) Rolling grade; (f) Subgrade compaction; (g) Setting forms; (h) Installation of dowel bar baskets.

13. Placing the concrete

Concrete was placed in alternate sections (Fig. 10) to eliminate the use of forms for the interim sections. The alternate Sections 1 through 4 were placed on Friday. With the alternate sections in place (Sections 1 through 4), on Saturday, the interim sections (Sections 5 through 7) were placed, which did not require use of forms, since the sides of the newly placed pavement act as forms. This way a significant amount of time was saved by not erecting and removing side forms (Fig. 11).

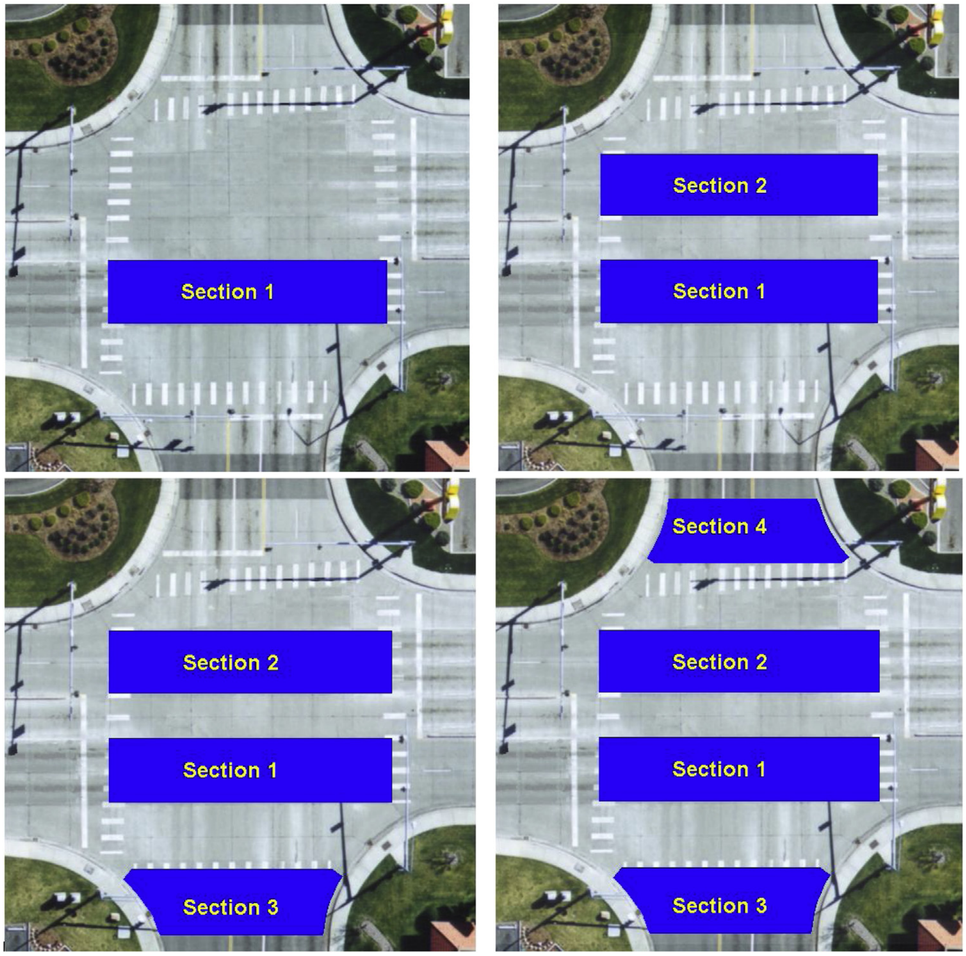


Fig. 10. Concrete placement in alternate sections.

Concrete was delivered to the site in ready-mix trucks (Fig. 12a and b). Then, a roller screed and a Whiteman screed were used for finishing (Fig. 12c through e). Vibration was used to consolidate the concrete mix (Fig. 12f).

14. Use of maturity meter

Determination of the strength of in-place concrete is obviously important to contractors. Decisions such as when to strip forms and when to open the pavement to traffic are based on reaching a minimum level of concrete strength. Waiting too long to perform these operations is expensive, but acting prematurely may cause the structure to crack or collapse. The maturity method is the technique that was used to estimate the strength of in-place concrete in this project. The maturity method is simply a technique for predicting concrete strength based on the temperature history of the concrete. Maturity testing provides strength evaluation through monitoring of internal concrete temperature in the field [6]. The temperature history is used to calculate a maturity index that accounts for the combined effects of time and temperature. The basis of maturity testing is that each concrete mixture has a unique relationship of strength to maturity index. Strength increases as cement hydrates and the amount of cement hydrated depends on curing time and temperature. Maturity is a measure of how far hydration has progressed. The time-temperature numbers for the concrete mix used in this project were determined in the laboratory prior to placement.

As soon as practicable after concrete placement, temperature sensors were embedded into the fresh concrete. Sensors were connected to maturity instruments and the recording device was activated. Using the strength-maturity relationship developed in the laboratory, the value of compressive strength corresponding to the measured maturity index could be read from the instrument.

Maturity meters were used to determine form removal and time of opening to traffic. Fig. 12g shows a commercial maturity meter and Fig. 12h shows maturity meter sensors imbedded in fresh concrete and recording the internal

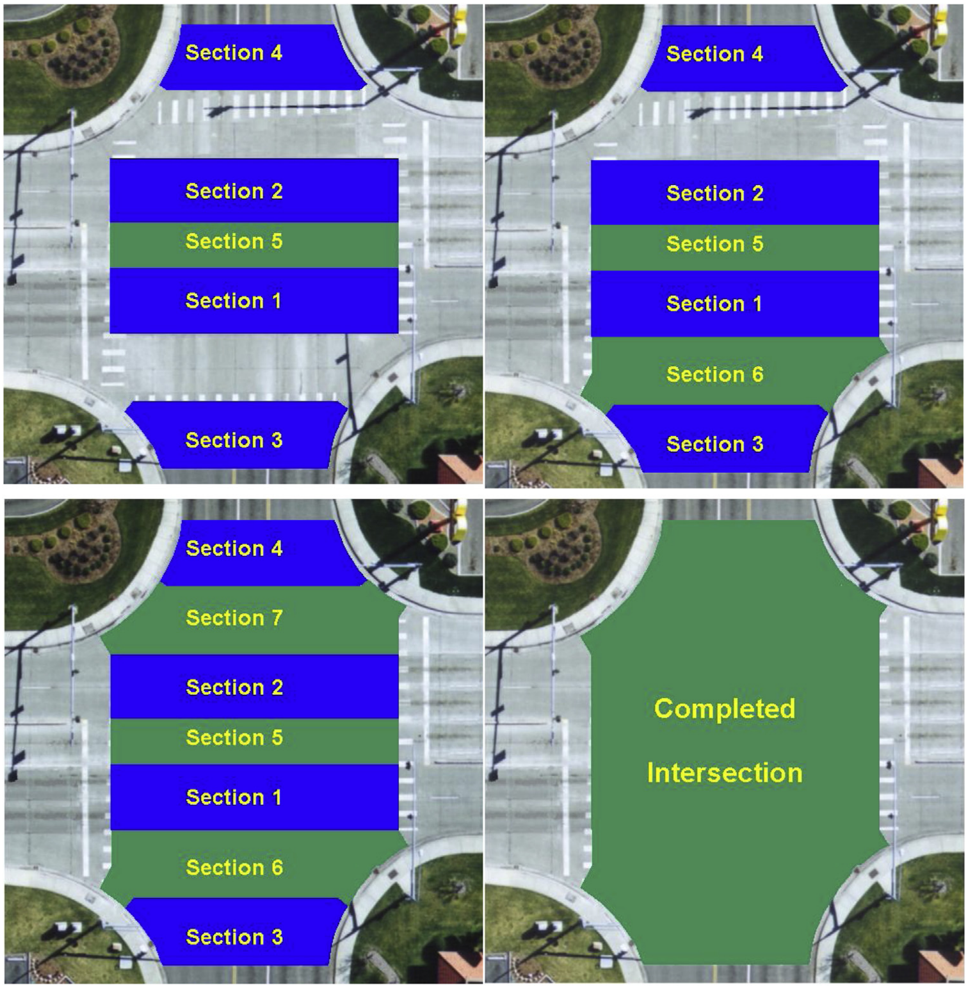


Fig. 11. Concrete placement in interim Sections.

temperature. Figs. 13 and 14 show the maturity (time temperature factor) versus compressive and flexural strengths for a mix used by the contractor. The dash lines indicate WSDOT compressive and flexural strengths requirements. Fig. 15 shows concrete compressive and flexural strength gain versus time.

15. Finishing and texturing of concrete

Hand finishing was kept to a minimum through proper operation of the Whiteman and roller screeds. Where hand finishing was necessary, it was accomplished with standard hand tools. Fig. 16a and b show finishing, and Fig. 16c and d show floating operations. Tines were used to texture the surface of freshly placed PCCP. Fig. 16e and f show the texturing operation and a textured concrete surface.

16. Curing of concrete

Proper curing is necessary to maintain a satisfactory moisture condition in the concrete to ensure a proper hydration. Internal concrete moisture directly influences both early and ultimate concrete properties. Therefore, initiating curing immediately after placing and finishing activities is important. Even more so than with standard concrete, curing is necessary to retain the moisture necessary for hydration during the early strength gain of accelerated concrete pavement.

In this project a liquid membrane curing compound was utilized which met ASTM C309 [9] material requirements. This compound was a white-pigmented compound applied to the surface and exposed edges of the concrete pavement at a rate of one gallon per 150 ft^2. The curing compound creates a seal that limits evaporation of mixing water and contributes to thorough cement hydration. The white color also reflects solar radiation during bright days to prevent excessive heat buildup

Fig. 12. (a) Two Trucks delivering concrete; (b) Concrete discharge and paving operation; (c) Roller screed; (d) Placement with roller screed; (e) Whiteman screed; (f) Vibrating concrete; (g) Maturity meter; (h) Maturity meter sensors imbedded in concrete.

in the concrete surface. Class A liquid curing compounds used in this project are sufficient for accelerated-concrete paving under normal placement conditions when the application rate is sufficient.

Curing compound was sprayed on the surface immediately after finishing and texturing. Curing compound was applied in two passes at 90 degrees to each other, to ensure complete coverage and offset wind effects. Fig. 16g shows application of the curing compound.

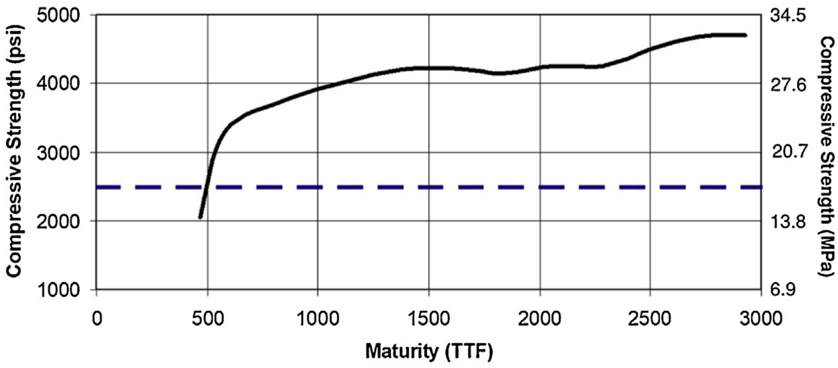


Fig. 13. Maturity vs. concrete compressive strength.

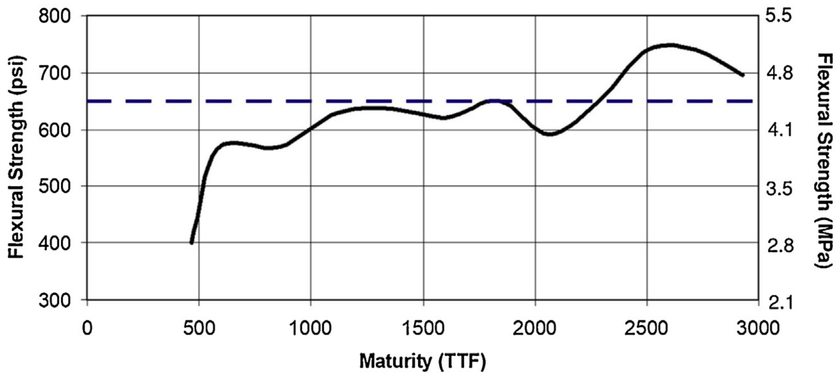


Fig. 14. Maturity vs. concrete flexural strength.

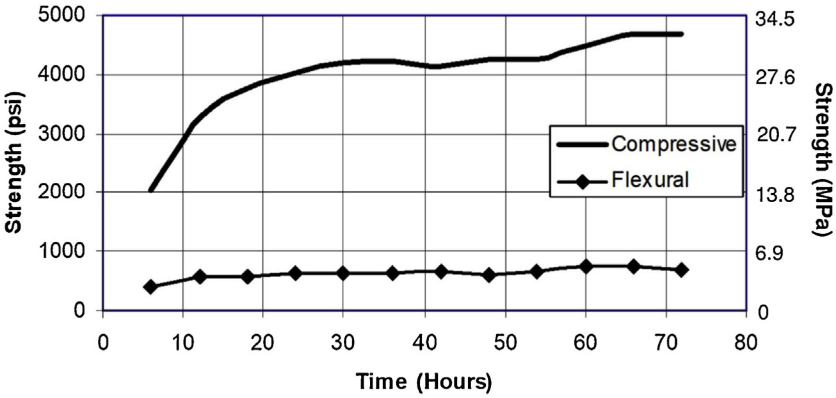


Fig. 15. Concrete compressive and flexural strength gain vs. time.

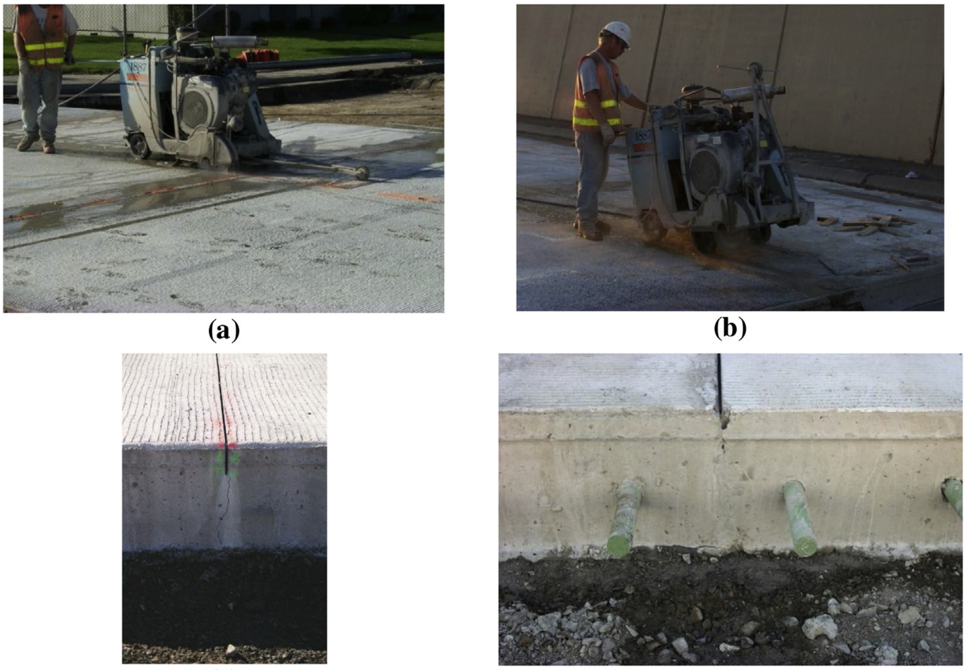
17. Sawing and sealing joints

After paving and curing of concrete, control joint must be sawn into the new pavement. Monitoring heat development in concrete enables the contractor to adjust curing measures to influence the rate of strength development, the window for sawcutting, and the potential for uncontrolled cracking. Maturity testing allows field measurement of concrete temperature and correlation to concrete strength.

Fig. 16. (a) Finishing concrete; (b) Finishing concrete; (c) Floating behind Whiteman screed; (d) Floating; (e) Manual texturing of the pavement; (f) Tines of freshly placed concrete; (g) Curing compound being applied manually.

The sawing window is a short period of time after placement when the concrete can be cut successfully or crack. The windows opens when the pavement can be sawn without producing excessive raveling along the sawcut. It ends when shrinkage stresses exceed the tensile strength of the concrete and uncontrolled cracking begins.

There are many factors which can affect the length of the sawing window. These include the rate of concrete hydration, base type, and weather conditions. While experience is the most important factor in deciding when to saw, the surface hardness and concrete temperature can also be used to monitor the sawing window. Sawing should be completed before the pavement temperature drops significantly. The sawcutting at the Kennewick Avenue intersection typically began within 6 h of concrete placing. Fig. 17a through d show sawcutting operations.



(a) (b) (c) (d)

Fig. 17. (a) and (b) Sawcutting freshly placed PCCP; (c) Traverse crack at form edge; (d) Joint at PCCP.

The joint sealing in this intersection was in accordance with standard WSDOT specifications which require that sawed contraction joints be from 3/16" to 5/16" in width and 1/3 the depth of placement. The joints are then cleaned, dried, and sealed with a hot-poured asphaltic joint filler. Fig. 18a through e show joint cleaning and sealing operations.

18. Bond breakers between PCCP and existing concrete and isolating utilities

In order to prevent transverse cracking in newly placed PCCP caused by existing concrete surfaces, it is important to isolate two structures. In this project a 30 lb. roofing felt was attached to the face of the existing curb and gutter to provide this isolation. Without this isolation, the freshly placed concrete can bond to existing surfaces. Excessive cracking can then be developed from the stresses created in the new concrete from its inability to expand and contract and from developing a mechanical bond to the existing concrete. Fig. 19 shows the roofing paper placed on the interface of the old and new material.

Manholes and other utilities should be isolated in order to prevent uncontrolled cracking around these utilities. The utilities were encased in a box out, effectively isolating them from the main concrete slab to minimize the impact of differential movement. The box out was left imbedded in the concrete slab. As the result of this operation, no visible cracks were observed around these utilities after concrete was cured and hardened. Fig. 20a through d show details of this operation.

19. Placing asphalt concrete adjacent to new PCCP

The final step to completing the intersection is to place the asphalt concrete pavement (ACP) adjacent to the concrete approach, leave legs, and the ends of the PCCP intersection. The area adjacent to the newly placed PCCP was excavated 2–3 feet and the excavated area was replaced with concrete to the level of the inlay that abuts the PCCP. ACP is then placed above the new concrete to the level to the PCCP. Fig. 21a through c show placement of concrete for backfill and Fig. 21d shows paving with ACP over concrete backfill.

20. Surface preparation and opening to traffic

Before opening to traffic, the intersection was thoroughly cleaned using a water truck, as shown in Fig. 22a. Fig. 22b shows the cleaned intersection. Cores were taken from the newly paved intersection for depth measurement (Fig. 23). The next step was to place striping prior to opening to traffic. Figs. 24 and 25 shows this operation.

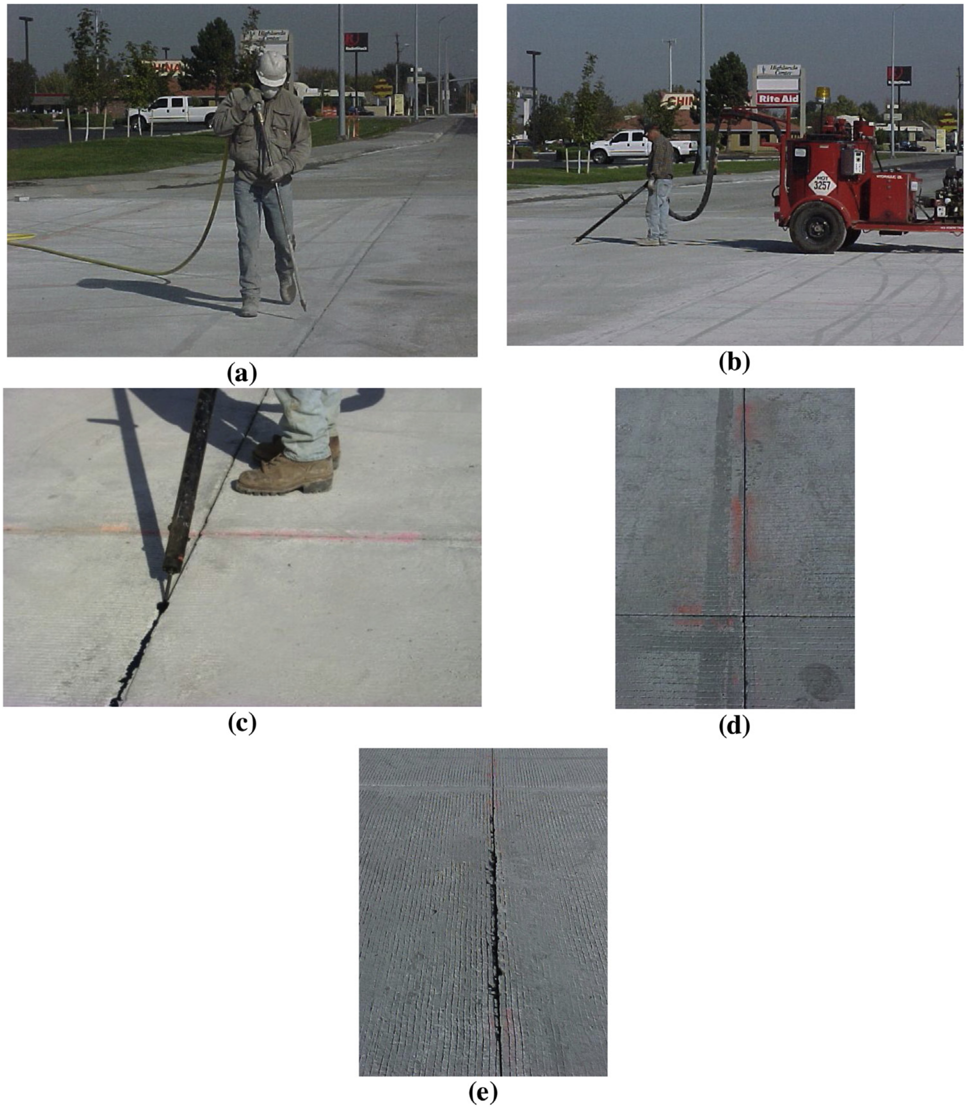


Fig. 18. (a) Cleaning the joint reservoir; (b) Joint sealing of sawed construction joint; (c) Joint sealing; (d) Example of proper sawcut and sealing; (e) Example of poor sawcut and sealing.

Fig. 19. Placement of roofing paper sheet as a bond breaker between existing curbing and new concrete slab.

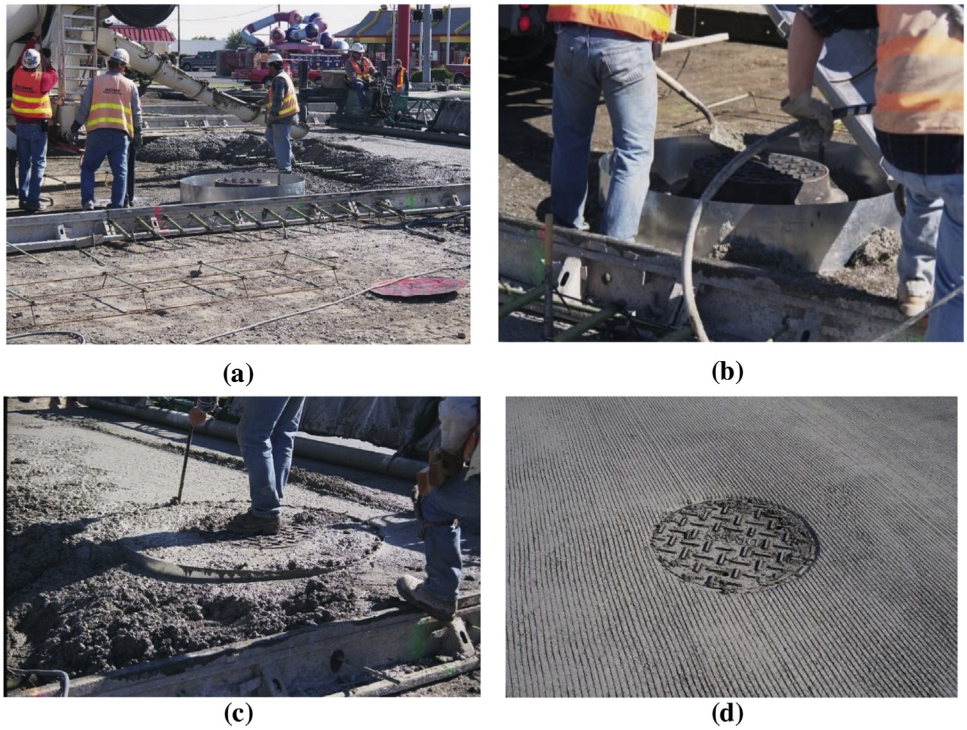


Fig. 20. (a) Encasing existing utility; (b) Boxed out manhole; (c) Placing concrete inside and outside of the box out; (d) Finished surface with imbedded encasement.

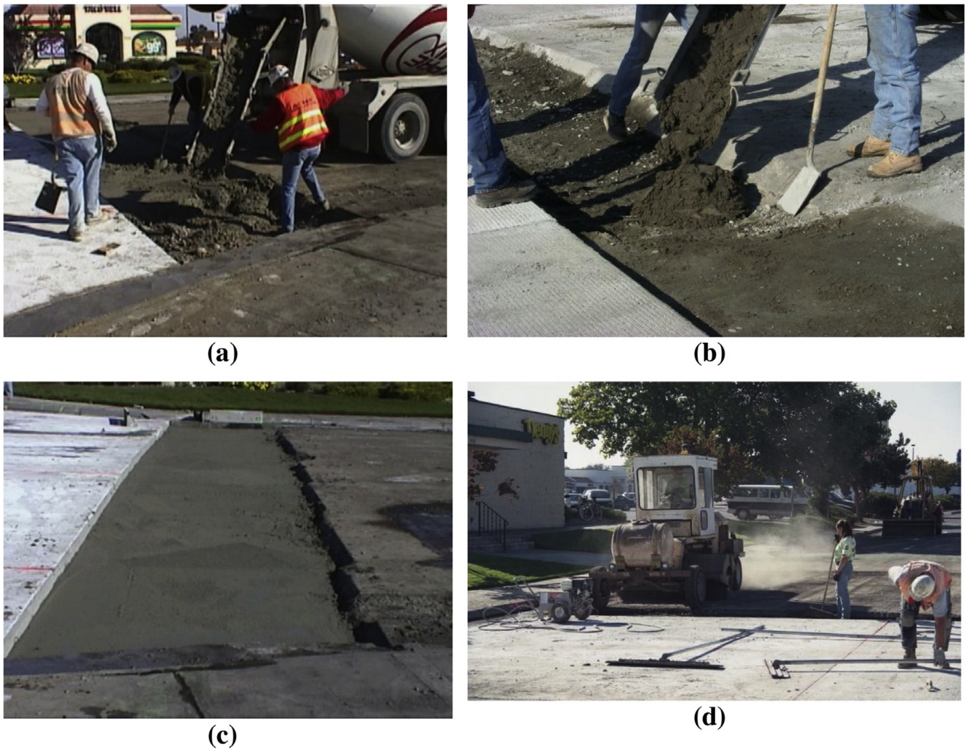


Fig. 21. (a) Placing concrete for backfill; (b) Placing concrete at pourback area; (c) Completed concrete backfill; (d) Brooming preparation for ACP.

(a) (b)

Fig. 22. (a) Cleaning the roadway with water truck; (b) Cleaned intersection.

Fig. 23. Coring concrete.

Fig. 24. Placing striping.

21. Construction costs

Full-depth PCCP reconstruction at urban intersections costs approximately 25–30 percent more than full-depth ACP construction [1]. According to the Federal Highway Administration (FHWA), PCCP has an average life of 30–35 years, requires less annual maintenance, and therefore, less time is lost in traffic jams caused by road repairs. Life-cycle cost analysis is a tool that brings together all of the information needed to make an educated choice: initial investment, anticipated service life, overlay and maintenance costs over the roadway's life, the value of money saved as well as spent. The 40-year annualized costs for intersections with and without user delay costs show that full-depth PCCP intersection reconstruction typically costs less than full-depth ACP reconstruction with future ACP inlays when intersection reconstruction is necessary.

Fig. 25. Placing stop bar and lane striping.

22. Summary and conclusions

1 The reconstruction of the intersection at SR 395 and Kennewick Avenue using accelerated construction techniques and complete weekend closure was completed successfully. In fact, the intersection was opened to traffic 16 hours ahead of the scheduled opening time. As contractors become more familiar with intersection reconstruction, the construction time and cost per unit volume should decrease.
2 The closure of state highways is possible. Once people are well informed of the closure details they are more willing to accept it. The customer focused construction comments show that the overall effect is negative (that is, the inconvenience and loss of sales). However, with the alternative of extending construction the public would much rather be inconvenienced for a short period as long as the work gets done.
3 Weekend closures allow the public to see constant production. Concrete is placed daily and completion can be seen. The long term service life of concrete pavement out ways the one-time inconvenience to the public.
4 Weekend closures allow more efficiency for the contractor and their operations. Because the contractor had control of the entire intersection, and because the approaches were completed prior to the weekend closure, it was possible to move efficiently and place the concrete in the intersection.
5 The complete closure of the intersections allows a safe environment for state and construction workers.
6 With the appropriate planning and preparation, and the use of an experienced crew, placement of the paving material became routine. The batch plant was able to easily meet the production demands of the contractor's schedule. This, combined with the contractor's experience, resulted in a smooth and continuous operation.
7 The concrete mix design was critical in maintaining the accelerated schedule. Placing, consolidation, and finishing operations were consistent with typical paving operations, and in accordance with standard WSDOT requirements. Maturity meters were used to verify adequate strength prior to opening the intersections to traffic.
8 A detour plan was implemented that provided local access, access to commercial sites, and special routes for heavy trucks passing through the area. The detour plan made it possible to modify the reconstruction of the intersection approaches and complete this work in the week prior to the intersection closure.
9 Many individuals, especially business owners in the affected areas, were contacted personally by Washington State DOT personnel. Pre-construction meetings were held with the City Council and the public to encourage active involvement of all the affected parties.
10 Public information served a vital role in the success of the project. The media was utilized to alert the public to the upcoming construction and to keep them up to date on the schedule. Informed local drivers avoided the area entirely, reducing traffic delays. As a result, complaints from the public were reduced by over 70 % compared to the project constructed two years before.
11 The contractor's schedule required a concrete mix design that would allow for opening to traffic within 24 hours. The contractor believed that the project goals could have been accomplished using Type I/II cement for the approach and departure legs. However, the use of Type III cement may be necessary for rapid strength gain during the closure period.

Data availability statement

All data, models, and code generated or used during the study appear in the submitted article.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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