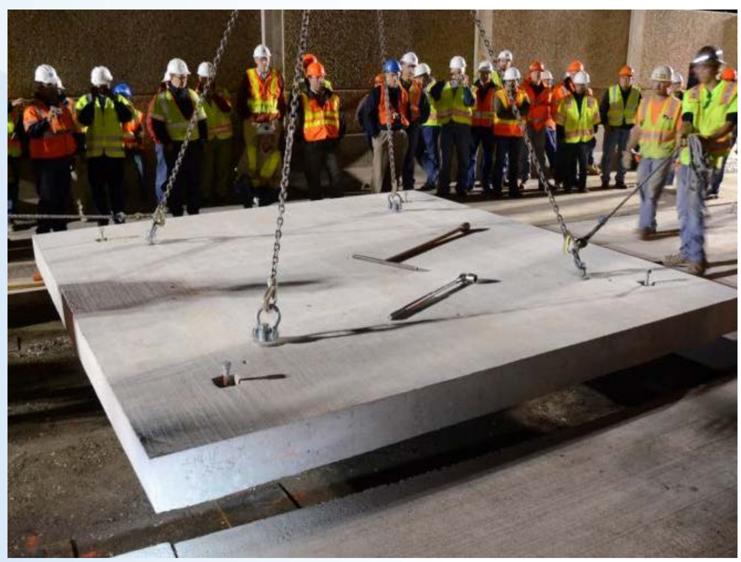
Utah Demonstration Project: Precast Concrete Pavement System on I-215

Final Report
June 2013

HIGHWAYS FOR LIFE
Accelerating Innovation for the American Driving Experience.



U.S.Department of Transportation
Federal Highway Administration

FOREWORD

The purpose of the Highways for LIFE (HfL) pilot program is to accelerate the use of innovations that improve highway safety and quality while reducing congestion caused by construction. **LIFE** is an acronym for **L**onger-lasting highway infrastructure using **I**nnovations to accomplish the **F**ast construction of **E**fficient and safe highways and bridges.

Specifically, HfL focuses on speeding up the widespread adoption of proven innovations in the highway community. Such "innovations" encompass technologies, materials, tools, equipment, procedures, specifications, methodologies, processes, and practices used to finance, design, or construct highways. HfL is based on the recognition that innovations are available that, if widely and rapidly implemented, would result in significant benefits to road users and highway agencies.

Although innovations themselves are important, HfL is as much about changing the highway community's culture from one that considers innovation something that only adds to the workload, delays projects, raises costs, or increases risk to one that sees it as an opportunity to provide better highway transportation service. HfL is also an effort to change the way highway community decisionmakers and participants perceive their jobs and the service they provide.

The HfL pilot program, described in Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) Section 1502, includes funding for demonstration construction projects. By providing incentives for projects, HfL promotes improvements in safety, construction-related congestion, and quality that can be achieved through the use of performance goals and innovations. This report documents one such HfL demonstration project.

Additional information on the HfL program is at www.fhwa.dot.gov/hfl.

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16. Abstract

As part of a national initiative sponsored by the Federal Highway Administration under the Highways for LIFE program, the Utah Department of Transportation (UDOT) was awarded a $750,000 grant to demonstrate the use of proven, innovative precast concrete pavement system (PCPS) technology to deliver this project in less time and with less impact on motorists than conventional construction.

This report details the PCPS innovations used to replace the existing deteriorated concrete pavement during 7- to 10-hour nighttime lane closures. Traditional construction practices of cast-in-place full-depth repairs would have required closures of 7 to 10 days, greatly impacting traffic during peak hours on this urban belt route. Traditional construction practices would have resulted in delays of 3,608 vehicle-hours with one-lane closure and 122,704 vehicle-hours with two-lane closures per day on Monday through Thursday and 1,255 vehicle-hours with one-lane closure and 106,820 vehicle-hours with two-lane closures on Friday. Using PCPS and nighttime construction reduced vehicle-hours of delay to zero.

UDOT learned several valuable lessons on rehabilitation using PCPS. The project was completed with minimal disruption to the traveling public, improved worker and work zone safety, and substantial reduction in construction time that affected traffic. The experience gained on this successful project will help UDOT refine its accelerated pavement construction processes and use them in other situations where traffic impacts are a major concern.

17. Key Words	18. Distribution Statement
Highways for LIFE, precast concrete pavement system (PCPS), accelerated pavement construction (APC), pavement rehabilitation, rigid pavements, prefabricated elements	No restriction. This document is available to the public through the Highways for LIFE website: http://www.fhwa.dot.gov/hfl/

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Unclassified	Unclassified	49	

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SI* (MODERN METRIC) CONVERSION FACTORS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
(none)	mil	25.4	micrometers	µm
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	millimeters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela per square meter	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	Newtons	N
lbf/in^2 (psi)	poundforce per square inch	6.89	kiloPascals	kPa
k/in^2 (ksi)	kips per square inch	6.89	megaPascals	MPa
		DENSITY		
lb/ft^3 (pcf)	pounds per cubic foot	16.02	kilograms per cubic meter	kg/m^3

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
µm	micrometers	0.039	mil	(none)
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela per square meter	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	Newtons	0.225	poundforce	lbf
kPA	kiloPascals	0.145	poundforce per square inch	lbf/in^2 (psi)
MPa	megaPascals	0.145	kips per square inch	k/in^2 (ksi)

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

ACKNOWLEDGMENTS

The project team would like to acknowledge the invaluable insights and guidance of Federal Highway Administration (FHWA) Highways for LIFE Team Leader Byron Lord and Program Coordinators Mary Huie and Kathleen Bergeron, who served as the technical panel on this demonstration project. Their vast knowledge and experience with the various aspects of construction, technology deployment, and technology transfer helped immensely in developing both the approach and the technical matter for this document. The team also is indebted to Utah Department of Transportation Engineer John Montoya and FHWA Engineer Russell Robertson for their advice and assistance during this project.

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ABBREVIATIONS AND SYMBOLS

APC	accelerated pavement construction
dB(A)	A-weighted decibels
DOT	department of transportation
FHWA	Federal Highway Administration
HfL	Highways for LIFE
HMA	hot-mix asphalt
IRI	International Roughness Index
OBSI	onboard sound intensity
PCPS	precast concrete pavement system
PCC	portland cement concrete
SI	sound intensity
SRTT	standard reference test tire
UDOT	Utah Department of Transportation
vpd	vehicles per day

INTRODUCTION

HIGHWAYS FOR LIFE DEMONSTRATION PROJECTS

The Highways for LIFE (HfL) pilot program, the Federal Highway Administration (FHWA) initiative to accelerate innovation in the highway community, provides incentive funding for demonstration construction projects. Through these projects, the HfL program promotes and documents improvements in safety, construction-related congestion, and quality that can be achieved by setting performance goals and adopting innovations.

The HfL program—described in the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU)—may provide incentives to a maximum of 15 demonstration projects a year. The funding amount may total up to 20 percent of the project cost, but not more than $5 million. Also, the Federal share for an HfL project may be up to 100 percent, thus waiving the typical State-match portion. At the State's request, a combination of funding and waived match may be applied to a project.

To be considered for HfL funding, a project must involve constructing, reconstructing, or rehabilitating a route or connection on an eligible Federal-aid highway. It must use innovative technologies, manufacturing processes, financing, or contracting methods that improve safety, reduce construction congestion, and enhance quality and user satisfaction. To provide a target for each of these areas, HfL has established demonstration project performance goals.

The performance goals emphasize the needs of highway users and reinforce the importance of addressing safety, congestion, user satisfaction, and quality in every project. The goals define the desired result while encouraging innovative solutions, raising the bar in highway transportation service and safety. User-based performance goals also serve as a new business model for how highway agencies can manage the project delivery process.

HfL project promotion involves showing the highway community and the public how demonstration projects are designed and built and how they perform. Broadly promoting successes encourages more widespread application of performance goals and innovations in the future.

Project Solicitation, Evaluation, and Selection

FHWA issued open solicitations for HfL project applications in fiscal years 2006, 2007, 2008, 2009, 2010, 2011, and 2012. State highway agencies submitted applications through FHWA Divisions. The HfL team reviewed each application for completeness and clarity and then contacted applicants to discuss technical issues and obtain commitments on project issues. Documentation of these questions and comments was sent to applicants, who responded in writing.

The project selection panel consisted of representatives of the FHWA offices of Infrastructure, Safety, and Operations; the Resource Center Construction and Project Management team; the Division offices; and the HfL team. After evaluating and rating the applications and supplemental information, panel members convened to reach a consensus on the projects to recommend for approval. The panel gave priority to projects that accomplish the following:

- Address the HfL performance goals for safety, construction congestion, quality, and user satisfaction.
- Use innovative technologies, manufacturing processes, financing, contracting practices, and performance measures that demonstrate substantial improvements in safety, congestion, quality, and cost-effectiveness. An innovation must be one the applicant State has never or rarely used, even if it is standard practice in other States.
- Include innovations that will change administration of the State's highway program to more quickly build long-lasting, high-quality, cost-effective projects that improve safety and reduce congestion.
- Will be ready for construction within 1 year of approval of the project application. For the HfL program, FHWA considers a project ready for construction when the FHWA Division authorizes it.
- Demonstrate the willingness of the applicant department of transportation (DOT) to participate in technology transfer and information dissemination activities associated with the project.

HfL Project Performance Goals

The HfL performance goals focus on the expressed needs and wants of highway users. They are set at a level that represents the best of what the highway community can do, not just the average of what has been done. States are encouraged to use all applicable goals on a project:

- **Safety**
    - Work zone safety during construction—Work zone crash rate equal to or less than the preconstruction rate at the project location.
    - Worker safety during construction—Incident rate for worker injuries of less than 4.0, based on incidents reported on Occupational Safety and Health Administration (OSHA) Form 300.
    - Facility safety after construction—Twenty percent reduction in fatalities and injuries in 3-year average crash rates, using preconstruction rates as the baseline.
- **Construction Congestion**
    - Faster construction—Fifty percent reduction in the time highway users are impacted, compared to traditional methods.
    - Trip time during construction—Less than 10 percent increase in trip time compared to the average preconstruction speed, using 100 percent sampling.
    - Queue length during construction—A moving queue length of less than 0.5 miles (mi) in a rural area or less than 1.5 mi in an urban area (in both cases at a travel speed 20 percent less than the posted speed).
- **Quality**
    - Smoothness—International Roughness Index (IRI) measurement of less than 48 inches per mile (in/mi).

    - Noise—Tire-pavement noise measurement of less than 96.0 A-weighted decibels (dB(A)), using the onboard sound intensity (OBSI) test method.

- **User Satisfaction**—An assessment of how satisfied users are with the new facility compared to its previous condition and with the approach used to minimize disruption during construction. The goal is a measurement of 4 or more on a 7-point Likert scale.

REPORT SCOPE AND ORGANIZATION

This report documents the Utah Department of Transportation's (UDOT) HfL demonstration project featuring innovative precast concrete pavement system (PCPS) technology to replace deteriorated portland cement concrete (PCC) pavement on Interstate 215. The report presents project details relevant to the HfL program, including panel replacement and construction highlights, PCPS methods and materials, and HfL performance metrics measurement. Technology transfer activities that took place during the project and lessons learned are also discussed.

PROJECT OVERVIEW AND LESSONS LEARNED

PROJECT OVERVIEW

This demonstration project consisted of rehabilitating a 4-mi section of concrete pavement on southbound I-215 in Salt Lake County, UT. The limits of the project are Milepost 22.78 to Milepost 26.94. This section of I-215 is next to Salt Lake City International Airport and is used by both truck and commuter drivers. The section is predominantly three lanes per direction and typically serves about 68,000 vehicles per day (vpd), or about 34,000 vpd in the southbound (SB) direction. To reduce the impact of construction, UDOT wanted to use accelerated pavement construction (APC) technologies.

The primary purpose of the project was to rehabilitate the existing concrete pavement. Deficiencies included the following:

- The existing concrete pavement was constructed in 1976 and was well beyond its 20- to 30-year design life.
- Pavement repairs had not been made since original construction.
- The existing concrete pavement showed signs of surface polishing and cracking.
- The skid resistance of the pavement needed to be improved.
- About 1,500 square yards of the pavement required full-depth replacement.
- The IRI pavement rating suggested that the pavement was in fair condition.
- Joints had debris and missing materials that contributed to cracking.

This section of road required full-depth panel repairs and introduced local designers and contractors to the use of APC. Central to the APC approach on this project was use of a PCPS consisting of precast concrete panels leveled with urethane grout and dowel bars retrofitted across the joints to enhance load transfer.

HFL PERFORMANCE GOALS

Safety, construction congestion, quality, and user satisfaction data were collected before, during, and after construction to demonstrate that innovations can be an integral part of a project while simultaneously meeting the HfL performance goals in these areas.

- **Safety**
  - Work zone safety during construction—No incidents occurred during the construction period, including the closure period, which met the HfL goal of achieving a work zone crash rate equal to or less than the preconstruction rate.
  - Worker safety during construction—No workers were injured on the project, so the contractor achieved a score of 0 on OSHA Form 300, meeting the HfL goal of less than 4.0.
  - Facility safety after construction—Both pre and post construction crash rates were low for this facility. No crash event was recorded in a 17 month period after construction.

- **Construction Congestion**
  - Faster construction—The APC approach shortened construction-related lane closures from 7 to 10 days, which could have affect large numbers of vehicles during daytime peak hours, to 7- to 10-hour overnight closures with minimal impact on traffic, meeting the HfL goal of a 50 percent reduction in the time traffic is impacted compared to traditional construction methods.
  - Trip time—Although no actual travel time studies were conducted, a review of spot speeds each night at several sensor locations verified that the project had little, if any, impact on traffic, meeting the HfL goal of no more than a 10 percent increase in trip time compared to the average preconstruction conditions.
  - Queue length during construction—No traffic backups occurred, so the project met the HfL goal of less than a 1.5-mi queue length in a urban areas.

- **Quality**
  - Smoothness—IRI was reduced from 150 in/mi before construction to 130 in/mi after construction. Motorists will notice a somewhat smoother ride, but the road remains rough and does not meet the HfL goal for IRI of 48 in/mi.
  - Noise—SI data showed a noticeable noise decrease of 7.7 dB(A). The SI value dropped from 108.1 dB(A) before construction to 100.4 dB(A) after rehabilitation, which does not meet the HfL requirement of 96.0 dB(A) or less.

LESSONS LEARNED

Through this project, UDOT gained valuable insights into using innovative techniques and materials—both those that were successful and those that need improvement in future project deliveries. The following are some of the lessons learned:

- A solid, well-compacted base is needed to control displacement when the panel load is transferred to the leveling bolt plates. Using a thinner layer of material and denser materials with high fine content is recommended. Proper base work must be performed and subgrade disturbance should be minimized for a successful installation.
- Use wide leveling plates for better weight distribution of the leveling bolts.
- Both urethane and cement grout flow and cover voids extremely well. Urethane sets in 20 minutes, which allows for opening the road sooner. However, because it sets so fast, it has the potential to lift the panel before the injection is completed and can cause uneven load bearing. Cement grout sets in 1 to 3 hours and shows no signs of setting up between injections or lifting the panel, but injections and slow setting time may delay opening the road.
- Setting and spacing of panels are critical. An exact layout or jig should be used for panel placement spacing, or a concrete saw should be onsite for field modifications.
- Longitudinal joints need to be saw cut because of the jagged edges.
- Over-width cutting of the existing roadway creates the need for some type of forming or control to avoid waste of grout or urethane and the need for repairing the overcut.
- Curvature of the roadway cannot be ignored. The curvature should be cast into the panels or saw cut for proper fit.

- Panels are not perfect and vary to some degree. Tighter tolerances may need to be specified during prefabrication.
- Work in multiple lanes can be done simultaneously and can proceed from multiple directions.
- A hot-mix asphalt (HMA) plug is used at the end of the work area to allow for opening to traffic the next day. To minimize delay times before opening to traffic, the HMA mix should be prepared and ready to use ahead of time.
- The scheduling sequence of subcontractors and suppliers is critical for the timely completion of the project.

CONCLUSIONS

UDOT gained valuable insights into PCPS use and the improvements needed to make this process a more viable tool. UDOT evaluated PCPS with a goal to minimize traffic impacts by performing concrete curing offsite to improve the cure environment, construction zone safety, and overall construction time, all of which were achieved on this project. The ride quality of the rehabilitated panels did not meet the HfL performance goals.

PROJECT DETAILS

BACKGROUND

I-215 is a busy interstate belt route southeast of Salt Lake City. The HfL project was conducted on the SB lanes of I-215 in the vicinity of the entry ramp from 3900 South. The general project location is shown in Figure 1. Here, the SB direction of I-215 has three lanes, and a shoulder, as seen in Figure 2. A portion of the project also includes a merge area, as seen in Figure 2.

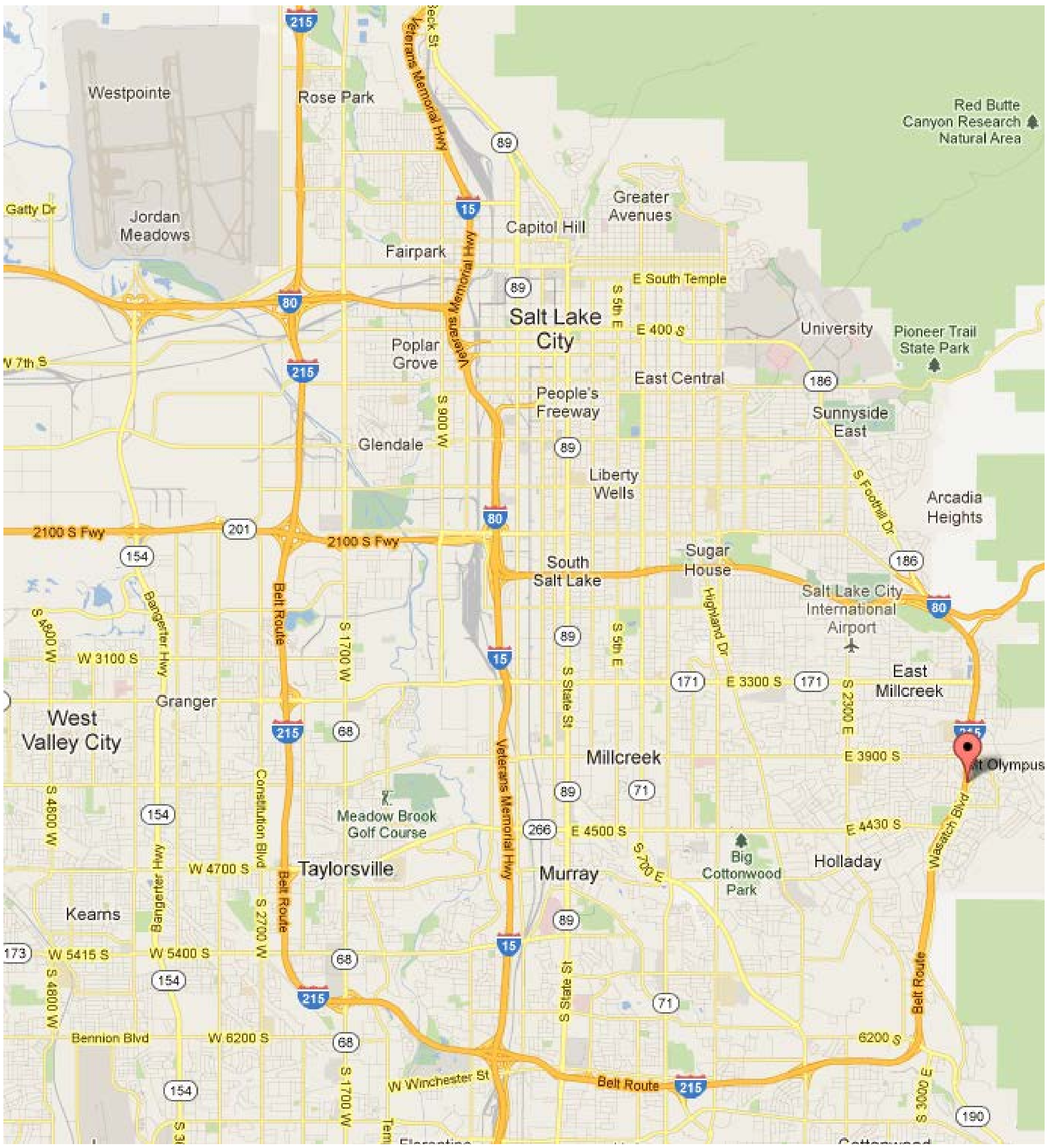


Figure 1. Location of project on I-215 southeast of Salt Lake City.

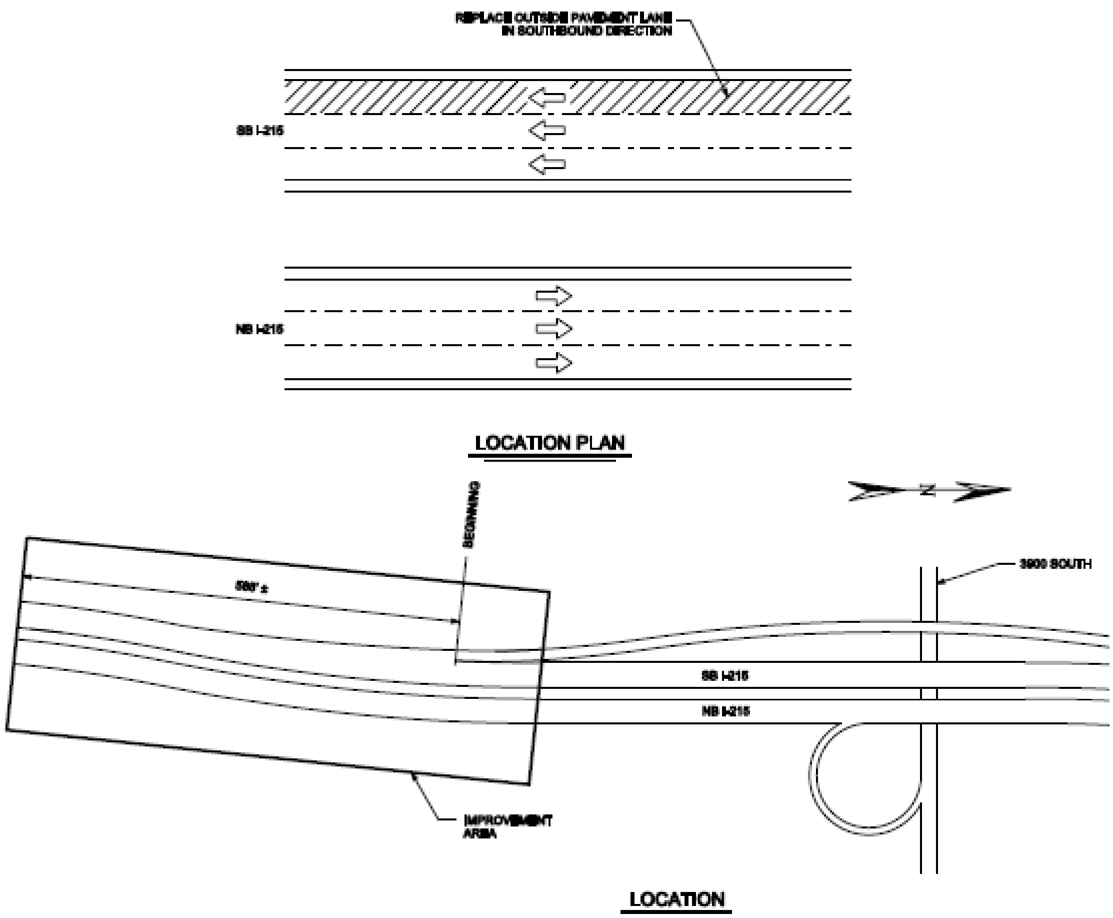


Figure 2. Project location and plan on southbound I-215.

Figure 3. Southbound project view showing three lanes, merge area, and shoulder.

The 2009 average daily traffic for this section was 68,000 (in two directions), which includes a mix of commuter and truck traffic. The a.m. hourly peak was close to 4,500 vehicles, and the p.m. hourly peak was close to 2,500 vehicles in the SB direction alone. This is also a major route to Salt Lake City International Airport and a major truck route for SB traffic from I-80 to I-15. The relatively high peak hour urban traffic volumes make long-term lane closures highly disruptive, so UDOT sought to minimize the impact of construction on traffic.

The pavement was in poor condition when measured in 2008. The existing nondoweled concrete pavement was constructed in 1976 and was well beyond its 20- to 30-year design life. Pavement repairs had not been made since original construction. The existing concrete pavement also showed signs of surface polishing and cracking and corresponding reduction in skid resistance. UDOT estimated that about 1,500 square yards required full-depth replacement, which would cause enormous disruptions to traffic if performed traditionally. The pavement condition was assessed as fair. Pavement joints had debris and missing materials, which also contributed to cracking and spalling. Figures 3 through 7 show the pavement condition in May 2011.

Figure 4. Shattered slabs with longitudinal and transverse cracking on I-215.

Figure 5. High-severity spalling and polishing of PCC surface on I-215.

Figure 6. High-severity cracks and spalls on the on-ramp slabs on I-215.

Figure 7. Severely deteriorated cracks and spalls filled with HMA on I-215.

PROJECT DESCRIPTION

The innovation on this project was the use of APC techniques, specifically PCPS. UDOT chose to use precast pavement panels with a placement time of 7 to 10 hours. Using precast pavements allowed for offsite construction with a better cure environment and offpeak construction, compared to traditional cast-in-place construction with a minimum 7- to 10-day cure time and limited control of the cure environment.

UDOT's goals for using APC were the following:

- Minimize traffic impacts by performing concrete curing offsite.
- Use an improved cure environment with greater control of temperature, moisture, and cure time.
- Reduce traffic disruptions from 7 to 10 days per panel to 7 to 10 hours.
- Allow for offpeak construction with normal operations during normal traffic.
- Minimize traffic impacts by reducing the overall construction schedule.
- Improve construction zone safety by minimizing exposure time for workers and the traveling public.
- Make the pavement replacement more constructible by working around difficult constraints.
- Enhance the design quality by reducing dependence on weather and increasing the control of the quality of elements and systems.
- Reduce traffic control costs by minimizing construction time.
- Maximize the functional use of this vital corridor.

Using APC to address the pavement deficiencies and the knowledge and abilities of the contractor and designer, UDOT hoped to achieve best-value improvements. UDOT considered the use of PCPS for rapid repair because it is a technology that could improve safety, reduce congestion, and improve pavement performance, all of which are key elements of the HfL program.

- **Safety**: UDOT expected that APC use would improve work zone safety primarily because of the reduction in construction time and exposure of workers and motorists to work zone hazards. In addition, APC use would allow for offpeak construction when traffic volumes are lower, which was also expected to reduce the potential for crashes.
- **Construction congestion**: Normal construction would require phasing traffic with cure times of 7 to 10 days. The use of APC was expected to reduce this to 7 to 10 hours per panel, leading to a 90 percent reduction in construction time. With the use of precast panels, it was expected that the majority of work could be performed at night during offpeak hours. Once the panels were placed, the road would be opened to traffic the next day. Thus, the use of precast pavement panels with nighttime construction would allow all traffic lanes to be open during daytime, particularly peak, hours because of the absence of traditional cure times.
- **Quality**: The project performance goal was to meet or exceed the more restrictive requirement of either the IRI or UDOT's standards. The project also included diamond grinding of the existing concrete pavement, which was expected to reduce tire-pavement noise. However, this reduction would not be because of APC use, but the grinding itself.
- **User satisfaction:** UDOT performs a pre-, mid- and postconstruction survey using a 1 to 7 scale to measure user satisfaction on major elements affecting stakeholders at various intervals during any major project. On this project, UDOT's goal was to receive an average score of 4-plus on the postconstruction survey on how satisfied the user is with the new facility compared with its previous condition and how satisfied the user is with the approach used to construct the new facility in terms of minimizing disruption. UDOT used the mid- and preconstruction surveys as indicators of where and how to do a better job for stakeholders to reach the goal of 4-plus on the postconstruction survey.

UDOT's goal for the project was to demonstrate how APC technologies can be used to reduce construction impacts while improving safety and durability. UDOT planned to use APC with other programs, such as accelerated bridge construction. HfL's promotion of PCPS as a Vanguard Technology encouraged UDOT to submit an HfL project application.

Design Decisions

The design for the project began with a scanning study of other States with experience using PCPS, followed by a lessons-learned report. A brainstorming meeting was held with UDOT engineers, fabricators, consultants, and contractors to discuss lessons learned from the scanning study. Based on the lessons learned and the meeting, the concept plans and work approach were developed. Six test panels were placed in fall 2010 for evaluation over the winter. Lessons learned from placement of the test panels were used to modify and improve plans for placement of the I-215 panels. Key design challenges included the following:

- Geometry and fit
- Lifting of panels (weight, devices, etc.)
- Leveling of panels, base preparation, and profile
- Grout materials
- Load distribution and transfer between panels

Geometry and Fit

Geometry and fit were important technical issues that needed to be resolved, particularly with a curved horizontal alignment. Curved horizontal alignment creates potential for fit issues with an estimated calculated chord offset as high as 0.25 in. A key question was whether to use curved or straight panels. The decision was made to use 12-foot (ft) straight panels rather than curved panels, vary the joint width, and saw cut and grout as needed. This was done with a goal to develop standardized sizes and shapes and to have flexibility for starting and stopping points of the project. Another issue considered during design was that the existing longitudinal joint would be irregular after removal of the old PCC, creating potential fit problems. The decision was made to saw cut the existing longitudinal joint to improve the fit between the lane 2 pavement and the new lane 3 panels. During construction, some of the new panels were also saw cut to improve fit.

Lifting of Panels

Key decisions needed to be made to reduce stresses and potential cracking of the panels during transportation, lifting, and placement. The panels were reinforced with #4 deformed steel bars to support panel weight during lifting. Reusable swivel lifting devices used for heavy loads were specified. These lifting devices have angular load capacity because of the swivel, and a smaller hole is needed for the swivel lifting devices compared to conventional lifting bolts.

Grade Preparation and Profile Leveling

Decisions on grade preparation and profile leveling were made with a goal to minimize the time spent preparing the grade and placing panels because of the short nighttime timeframe (7- to 10-hour closures) to remove and replace the existing pavement. Decisions were made to adjust the panel elevation using leveling screws, eliminate the sand bed, and use urethane or concrete grout injection under the panels to provide uniform support to the panels.

Grout Materials

Grout was specified to be pumped in the grout ports of the panels to flow between the panel and the base material, filling voids and providing uniform support to the panels. Prototype tests showed 100 percent coverage for both urethane and concrete grout options. Field tests showed that both materials performed well over the winter. The decision made was that both materials were acceptable. However, urethane was chosen for this project because of its shorter cure time.

Load Transfer Devices

The existing pavement does not have load transfer at the joints. A key design question was whether load transfer devices (dowel bars) were needed and whether they would damage the adjacent panels. The decision made was to use 1.5-in × 18-in dowel bars at transverse joints (six for the 12-ft × 12-ft slabs and three for the 6-ft × 12-ft slabs) and to saw cut the dowel bar slots and joint sealant reservoir after placement of the panels for better alignment and to avoid fit problems.

Design Details

Figure 8 is a typical cross-section showing the transverse view and the side view of the PCPS slab. As shown in the figure, two sizes of panels (49 12 ft × 12 ft and seven 6 ft × 12 ft) were used on this project. The 12-ft × 12-ft panel was used on lane 3, while both 12-ft × 12-ft and 6-ft × 12-ft panels were used in the merge area of the on-ramp to SB I-215.

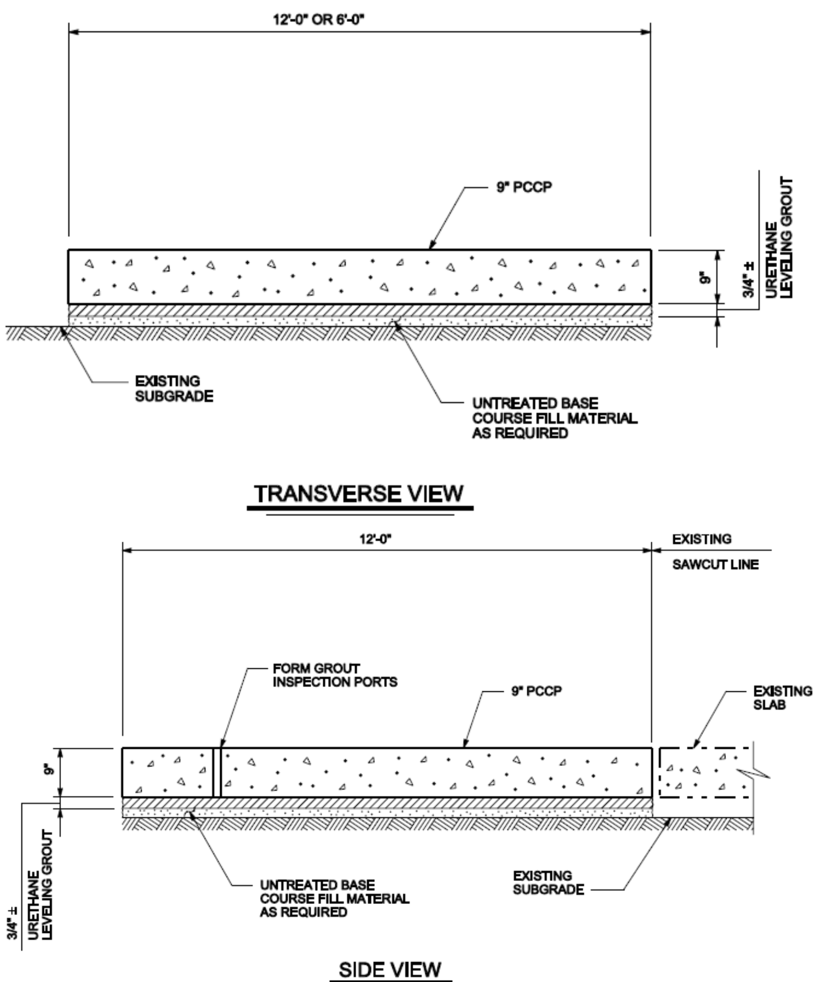


Figure 8. Transverse view and side view showing the PCPS slab panels to be placed.

Figure 9 and Figure 10 show the typical plan views and section views for the 12-ft × 12-ft panels and the 6-ft × 12-ft panels, respectively. The key features of the PCPS panels are summarized as follows:

- The 9-in thick panels are placed on untreated base course fill material with as-required thickness, which is placed directly over the existing subgrade.
- A urethane leveling grout is pumped in through nine grout injection holes in the 12-ft × 12-ft panels and three grout injection holes in the 6-ft × 12-ft panels. The leveling grout levels the PCPS panels above the base course fill material. The thickness of the leveling grout varies depending on the amount of grout needed for leveling. A preformed strip seal is used on all sides to prevent the grout from seeping out.
- The 12-ft × 12-ft panels consist of six dowel bar slots (three in each wheelpath), as shown in Figure 9, and the 6-ft × 12-ft panels consist of three dowel bar slots, as shown in Figure 10. Details of the dowel slots and load transfer device (dowel bar) placement are shown in Figure 11. The figure shows that the slots from two adjacent panels are aligned for placement of the 18-in long, 1.5-in diameter smooth dowel bar. The dowel bars are supported by the rebar chairs (0.5 in high), which are placed directly in the bottom of the slot. The rebar chairs ensure that the dowels rest horizontally and parallel to the centerline of the pavement at the desired depth. Expansion caps are placed at both ends of the dowel to allow for any joint closure after installation of the dowel. The length of the dowel bar slot is 1 ft in each of the panels corresponding to a total slot length of 2 ft, which provides for a 3-in clearance on both sides of the dowel bar. Each slot is 3 in wide and 4.5 in deep. After the dowel bar is placed, the slot in each panel is filled with load transfer grout, which completely encompasses the bar on each side of the transverse joint. A filler board or expanded polystyrene foam material is placed at the midlength of the dowel to help form the joint in the slot and prevent intrusion of the grout into the joint between the two panels.
- Four lift points are used for each panel at the four corners of the panels. Each lift point is 2 ft from the longitudinal edge and 2 ft from the transverse edge of the panel. A Dayton Superior T-26 lifting swivel with B-14 coil and T-1 insert was specified to be used for lifting. Detail of the T-26 lifting swivel is shown in Figure 12.
- The panels include four holes for leveling bolts at the four corners. Each hole is 1.5 ft from the longitudinal edge and 1.5 ft from the transverse edge of the panel. Details of the leveling bolt are shown in Figure 13. Each leveling bolt is placed on top of 6-in × 6-in × 0.25-in leveling plates. The 1-in diameter coil rod bolt screws into the coil rod nut and 4-in × 4-in × 0.25-in washer that is cast in the panel. The action of screwing and unscrewing the coil rod bolt onto the surface of the leveling plate raises and lowers the corresponding panel corner. Leveling gauges on the panel surface are used to ensure that the panels are level. Once a panel is level, it is grouted to the base to fill all voids and ensure even support. The coil rod bolt is removed and the bolt holes grouted after urethane grout is set.
- The panels are constructed with steel reinforcement (#4 bars spaced at 12 in) placed with 2-in clearance from the bottom of the panels. The purpose of the steel reinforcement is to prevent breaking of the slab during transportation, lifting, and installation.

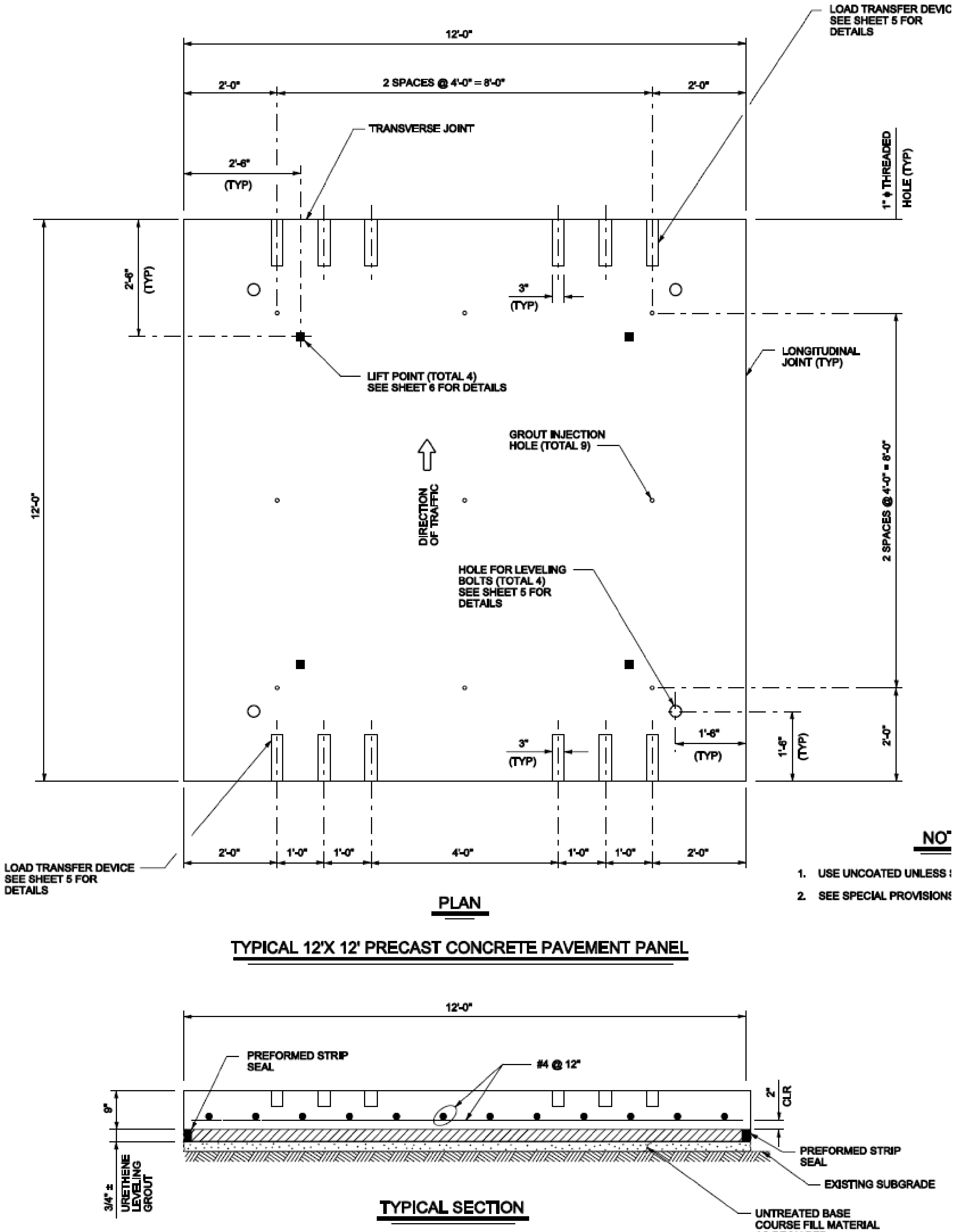


Figure 9. Typical plan view and section view for 12-ft × 12-ft panels.

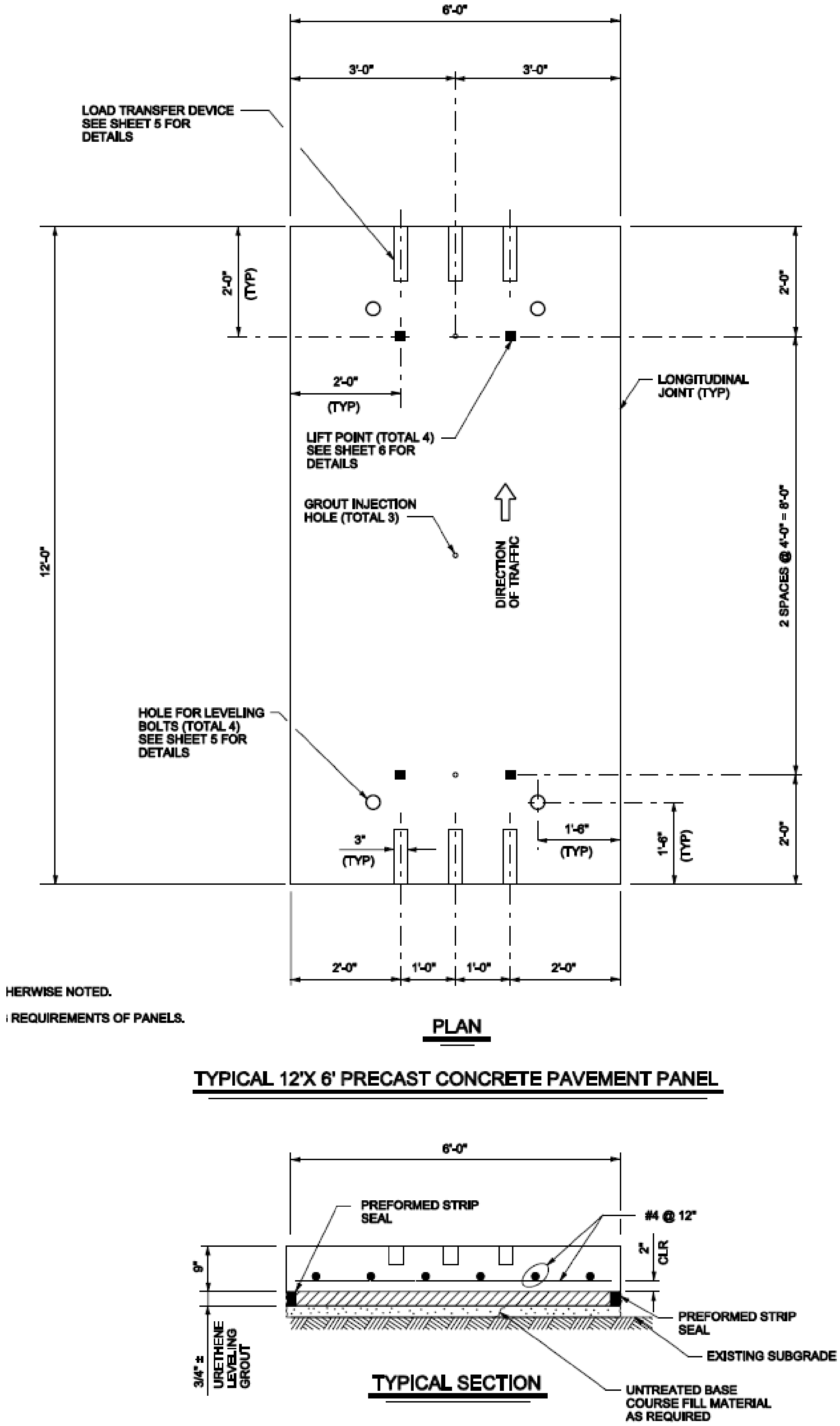


Figure 10. Typical plan view and section view for 6-ft × 12-ft panels.

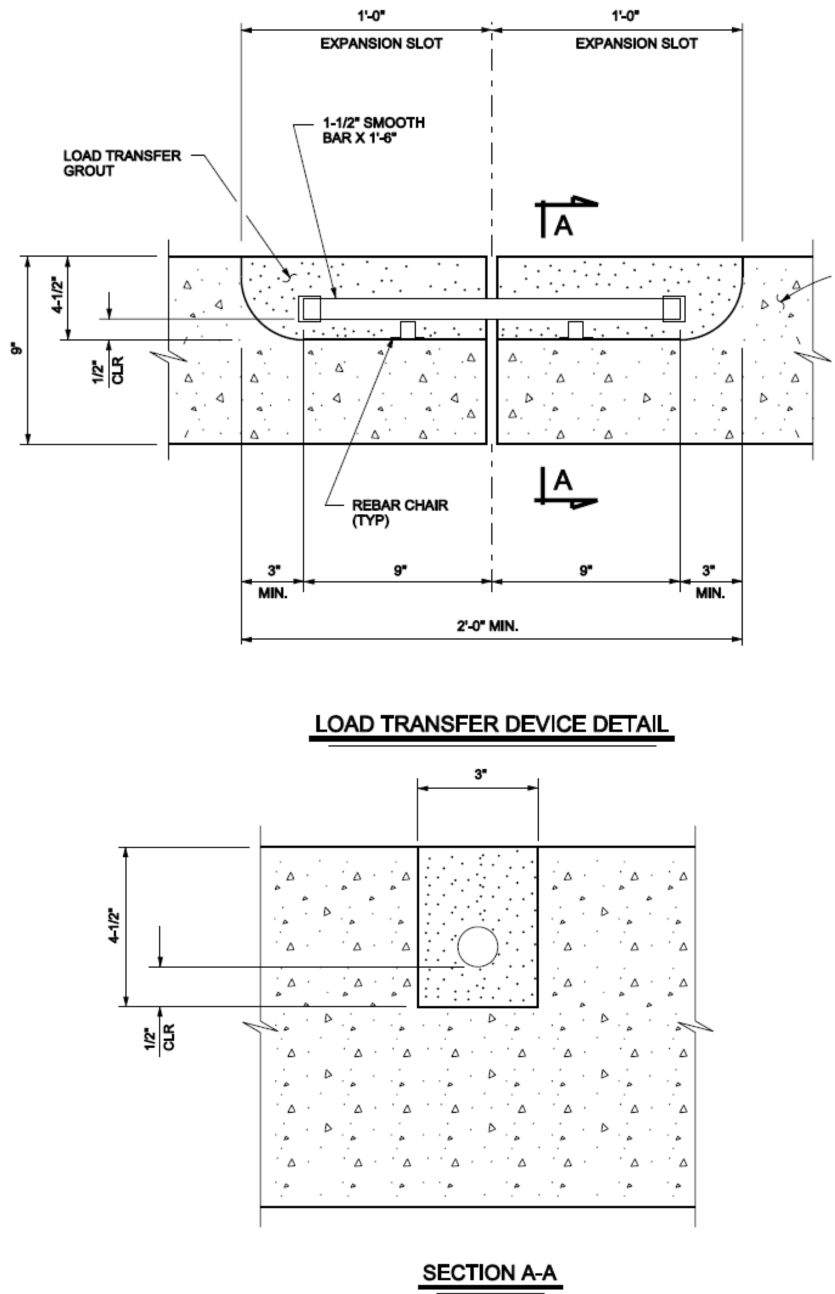


Figure 11. Load transfer device details.

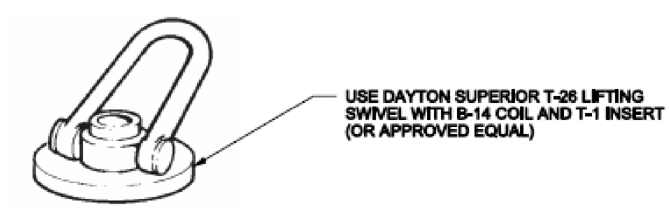


Figure 12. Lifting device details.

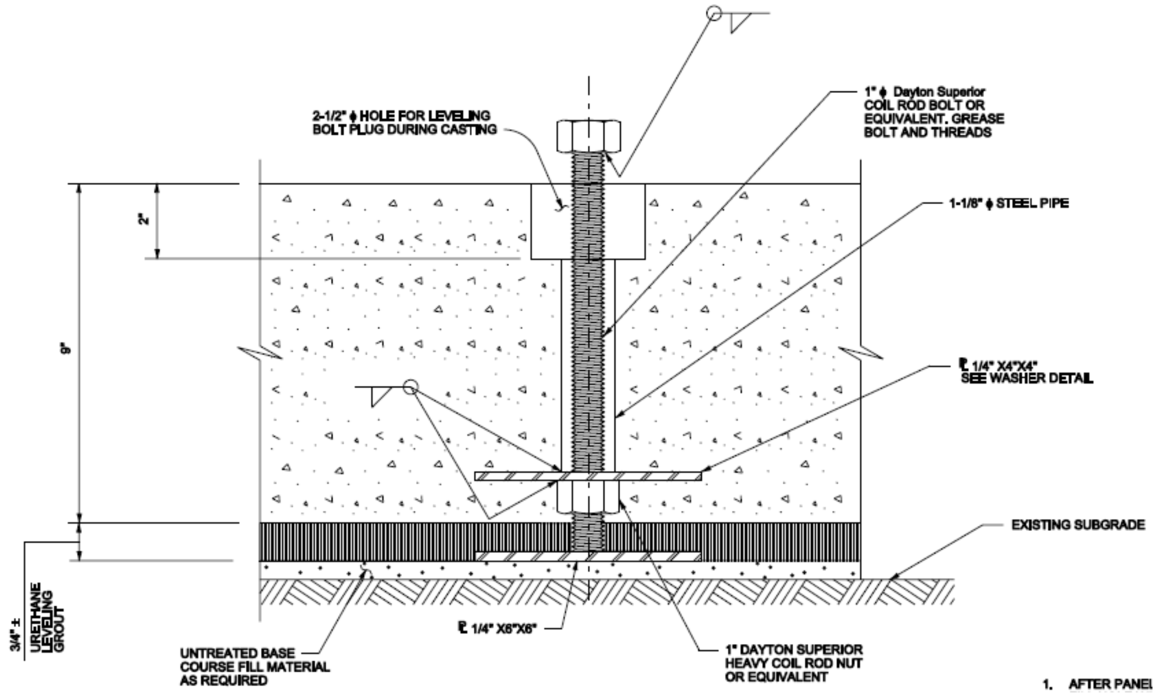


Figure 13. Leveling bolt detail.

Construction

The construction project was awarded to Kilgore Contracting and the precast panels were made by Harper Precast. The I-215 construction project included replacing distressed pavement slabs with precast concrete pavement panels. Figures 14 through 17 show the casting of the precast panels at Harper Precast. The panels were placed during a 7- to 10-hour nighttime window with closure of the rehabilitated lane and the adjacent lane. The third lane (lane 1) was open to traffic throughout the construction. All lanes were open to traffic during daytime hours. Special provisions required the following:

1. No work will be allowed before May 1, 2011.
2. All paving operations must be completed by May 31, 2011 (this deadline was changed allowing for work in June).
3. Temporary HMA asphalt paving may be used at the end of each day's work to transition concrete panel replacement with existing pavement.
4. The contractor will be required to obtain noise and other permits and perform work within those limitations.
5. Traffic control setup will be allowed to start at 7:30 p.m. daily (Monday through Sunday).
6. A single lane closure will be allowed daily (Monday through Sunday) beginning at 8 p.m.
7. Two lanes will be allowed for closure daily (Monday through Sunday) beginning at 10 p.m.
8. Two lanes of traffic must be open by 6 a.m. on weekdays (Monday through Friday).

9. All three lanes of traffic must be open by 6:30 a.m. on weekdays (Monday through Friday).
10. Two lanes of traffic must be open by 7 a.m. on weekend days (Saturday and Sunday).
11. All three lanes of traffic must be open by 9 a.m. on weekend days (Saturday and Sunday).
12. Conduct work to minimize lane closures. Maintain communication with UDOT Traffic Operations Center during lane closures.
13. Lane closures beyond allowable timeframes will result in a lane rental charge of $15,000 per lane per hour.

Table 1 shows the contractor's nightly activity schedule.

Table 1. Nightly activity schedule.

Approximate Time	Activity
7–7:30 p.m.	Close ramp and lane 3; place barrier.
7:30–9 p.m.	Remove existing panels.
8:30–10 p.m.	Prepare grade.
9:30 p.m.–3 a.m.	Set panels.
10:30 p.m.–3:30 a.m.	Inject urethane.
3:30–6 a.m.	Stripe, clean up, and remove barrier.
6 a.m.	Open travel lane.

After lane closures, barrier placement, mobilization, and preparation, the project started with removal and hauling of the existing pavement (lane 3), as shown in Figure 18 and Figure 19. Note the jagged longitudinal edge of the existing pavement (lane 2) in Figure 18. These longitudinal edges were saw cut for better panel fitting and grout containment, as shown in Figure 19. Per specifications, the existing base material was excavated, repaired, regraded, and compacted with a vibrating plate compactor, as shown in Figure 20. The base was specified to be finished with plus or minus 0.5 in of the desired profile. Sand bedding material was used to fill void areas as needed. The leveling plates were placed directly on the prepared compacted base, as shown in Figure 21. The panels were moved into place using a crane and supported at four points using lifting swivels, as shown in Figure 22 and Figure 23. A field decision was made to taper cut some of the panels (Figure 24) by 1 to 1.5 in to account for the horizontal curvature of the existing roadway.

Once the panels were placed on the prepared base, they were leveled using leveling bolts to within final grade tolerance of 0.25 in, as shown in Figure 25 and Figure 26. Preformed strip seal was used to seal the longitudinal joint and prevent grout from flowing out of these joints, as shown in Figure 27. Urethane leveling grout was injected through the grout injection hole, as shown in Figure 28 and Figure 29, to fill voids and support the panels. The urethane grout was specified to develop 90 percent of its full compressive strength of 90 pounds per square inch within 30 minutes of injection at 40° F or greater. The leveling bolts were specified to be removed or field cut at a minimum of 1 in below the top surface of the panel. Lifting block-outs, grout ports, and leveling bolt hardware block-outs were repaired using specified cement grout. Longitudinal or transverse joints in excess of 0.5 in were filled with specified encasement grout.

Dowel slots were cut in at the transverse joints to retrofit the panels with dowel bars, as shown in Figure 30 and Figure 31. The final constructed project is shown in Figure 32.

Figure 14. Completed form ready for concrete pour.

Figure 15. Pouring concrete in form to precast the panel.

Figure 16. Removal of grout tube and bolt locator jigs.

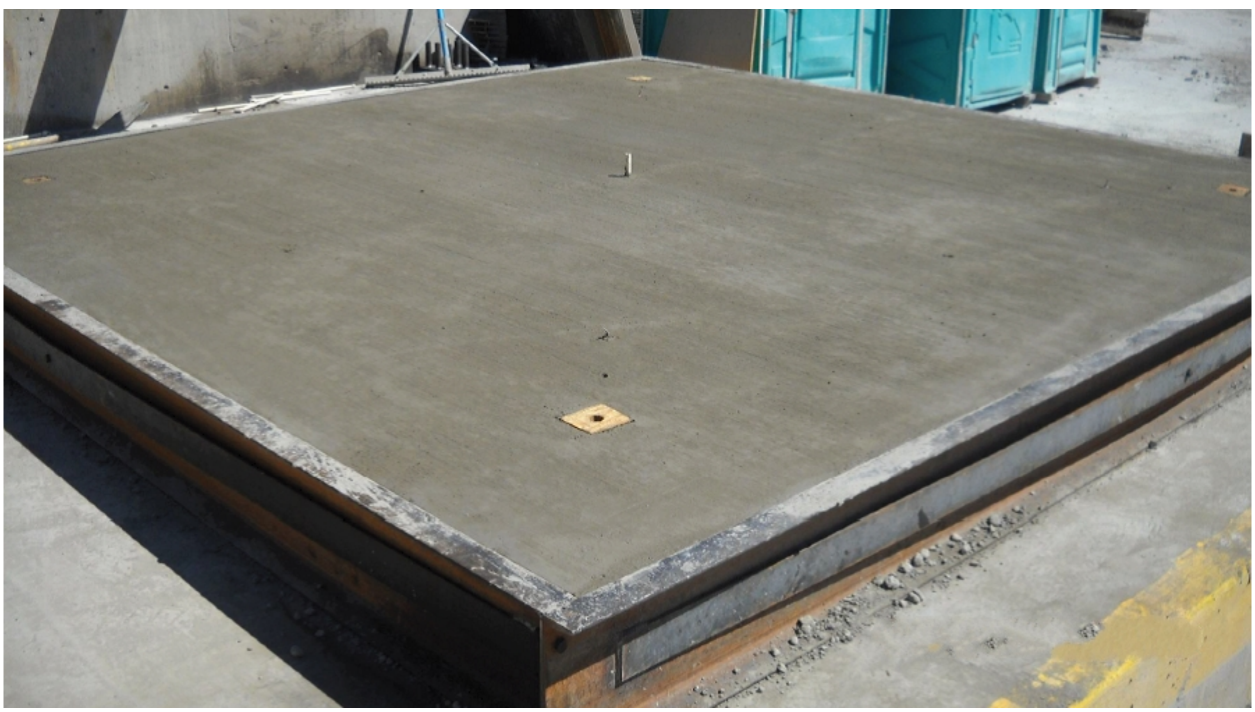


Figure 17. Finished top of precast panel ready for curing.

Figure 18. Removal of existing deteriorated pavement (lane 3).

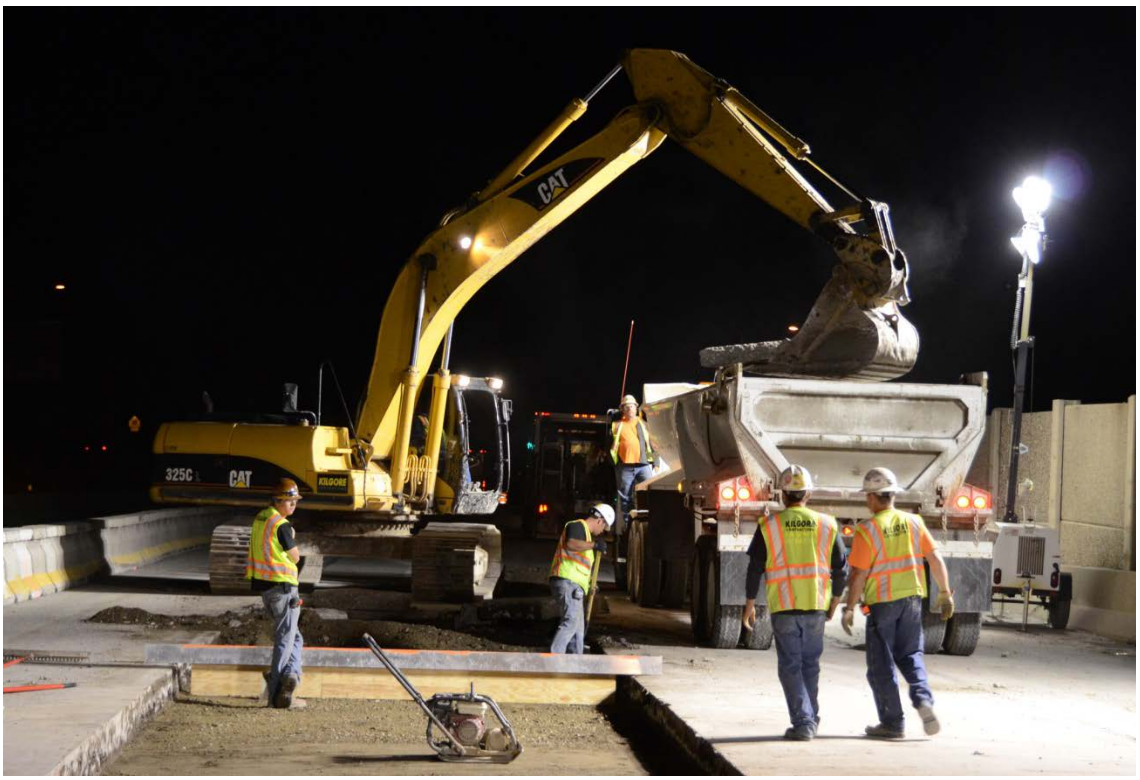


Figure 19. Hauling of existing pavement (lane 3).

Figure 20. Placing and compacting the base course fill material.

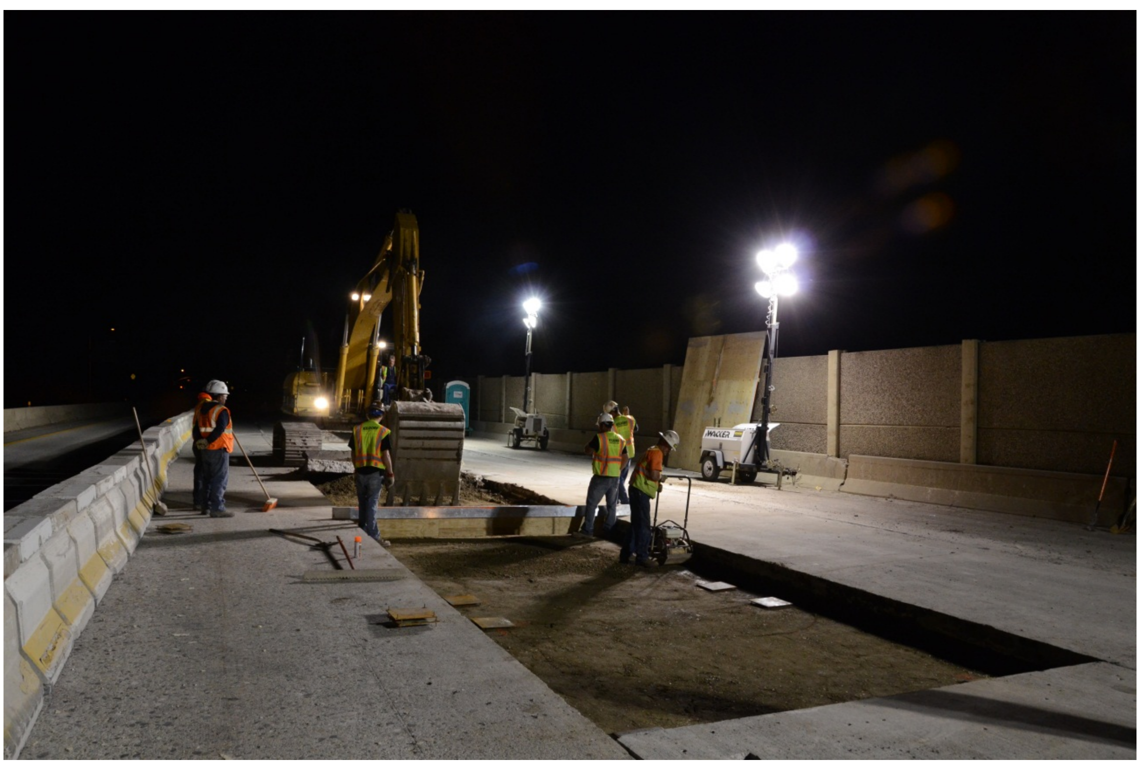


Figure 21. Leveling plates placed directly on top of the compacted base.

Figure 22. Placement of precast panel on the prepared base.

Figure 23. Steering precast panel into place onto the prepared base.

Figure 24. Cutting panels to 1- to 1.5-in taper to account for horizontal curvature of existing roadway.

Figure 25. Leveling bolts used to level the panels on the leveling plates.

Figure 26. Panels leveled using leveling bolts to within final grade tolerance of 0.25 in.

Figure 27. Placing preformed strip seal to contain grout.

Figure 28. Urethane grout injected through the grout injection hole.

Figure 29. Urethane grout injection closeup.

Figure 30. Placement of dowel bars into dowel slot.

Figure 31. Transverse joint with grout-filled dowel bar slots.

Figure 32. Placed panels and project open to traffic before diamond grinding for ride quality.

DATA ACQUISITION AND ANALYSIS

Data on traffic flow and quality before, during, and after construction were collected to determine if this project met the HfL performance goals. The primary objective of acquiring these types of data was to quantify project performance and provide an objective basis from which to determine the feasibility of the project innovations and to demonstrate that the innovations can be used to do the following:

- Reduce construction time and minimize traffic interruptions.
- Produce a high-quality project.

This section discusses how well the UDOT project met the HfL performance goals related to these areas.

SAFETY

The safety performance of the facility after construction was evaluated using pre and post construction crash data shown in tables 2 and 3, respectively. As indicated in these tables, the crash frequencies were extremely low for both pre and post construction periods. No crash was recorded in the post construction period from August 2011 through December 2012. Due to the extremely low crash rates, there is no need to evaluate the safety performance of the facility.

Table 2. Preconstruction crash data

Period	Fatalities	Injuries	PDO
2008	0	1	0
2009	0	1	1
2010	0	0	0
2011 (Jan – May)	0	0	0
Total	0	2	1

Table 3. Post construction crash statistics.

Period	Fatalities	Injuries	PDO	ADT
2011 (Aug – Dec)	0	0	0	67688
2012	0	0	0	68213
Total	0	0	0	

CONSTRUCTION CONGESTION AND TRAVEL TIME

No actual travel time studies were performed during this project. Instead, UDOT has a transportation management system on major routes throughout Salt Lake City and its suburbs. Consequently, spot speed and flow data during the project dates were available along the study section at about 0.5-mi spacing. Detailed (5-minute average) speed data aggregated across all travel lanes for the majority of sensor locations within the project section were extracted from UDOT's performance measurement system. Any significant drop in speeds at a sensor location was then extrapolated over a freeway section representative of that sensor to estimate delay over the segment, and delays over multiple segments were totaled to provide an overall estimate of traveler delay.

Hourly traffic flow data at a representative sensor location in the project segment were also extracted to assess the possible delays that would have occurred had a more traditional slab replacement approach (such as cast-in-place full-depth repairs) been used. Such an approach would involve the long-term closure of one or two lanes over multiple days to allow removal of existing concrete, placement of reinforcing bars and concrete, curing, and installation of pavement markings.

UDOT project personnel anticipated that the use of nighttime lane closures would minimize traffic disruptions, and staff comments after the project was completed suggested that those expectations were met. A review of spot speeds each night at several sensor locations verified that the project itself had little, if any, impact on traffic. As indicated in Figures 33 through 37, speeds at each sensor location throughout each night were at or near free-flow speeds (60 to 70 miles per hour). Thus, the project generated no significant delays within the project limits on any of the nights it was active.

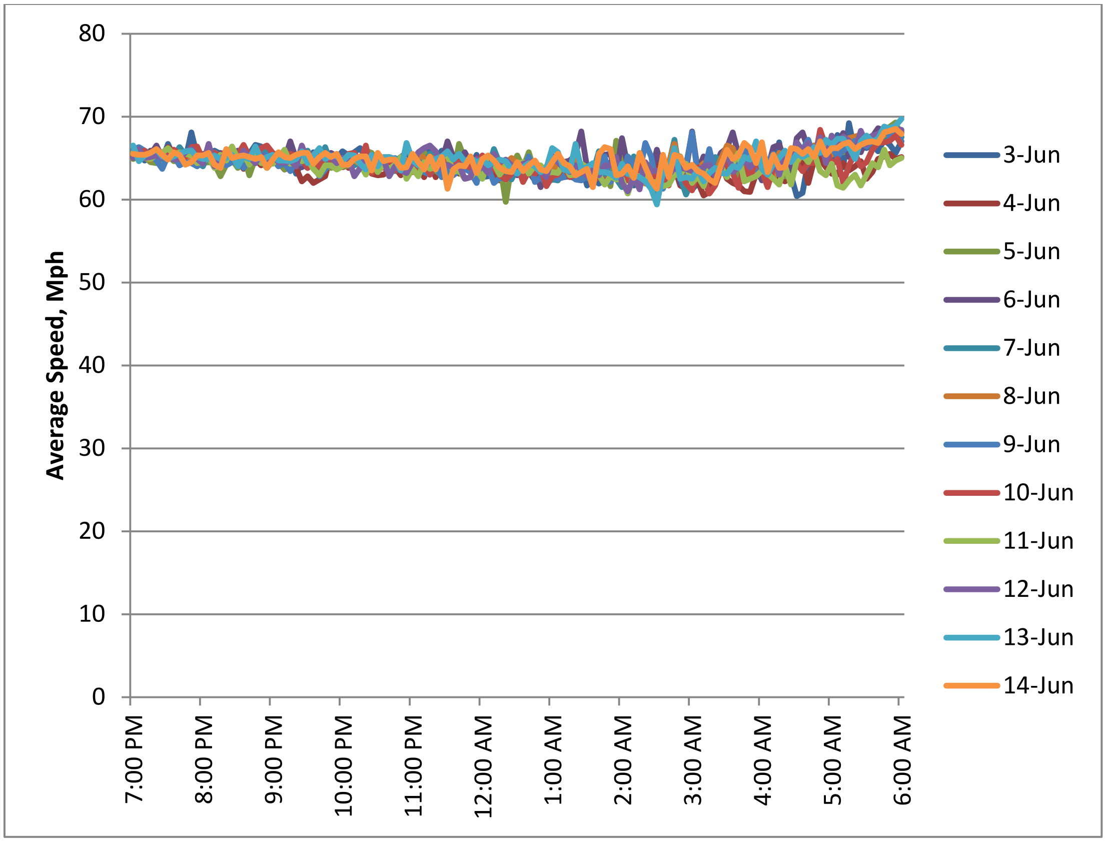


Figure 33. Average speeds southbound at sensor station 105, milepost 26.8.

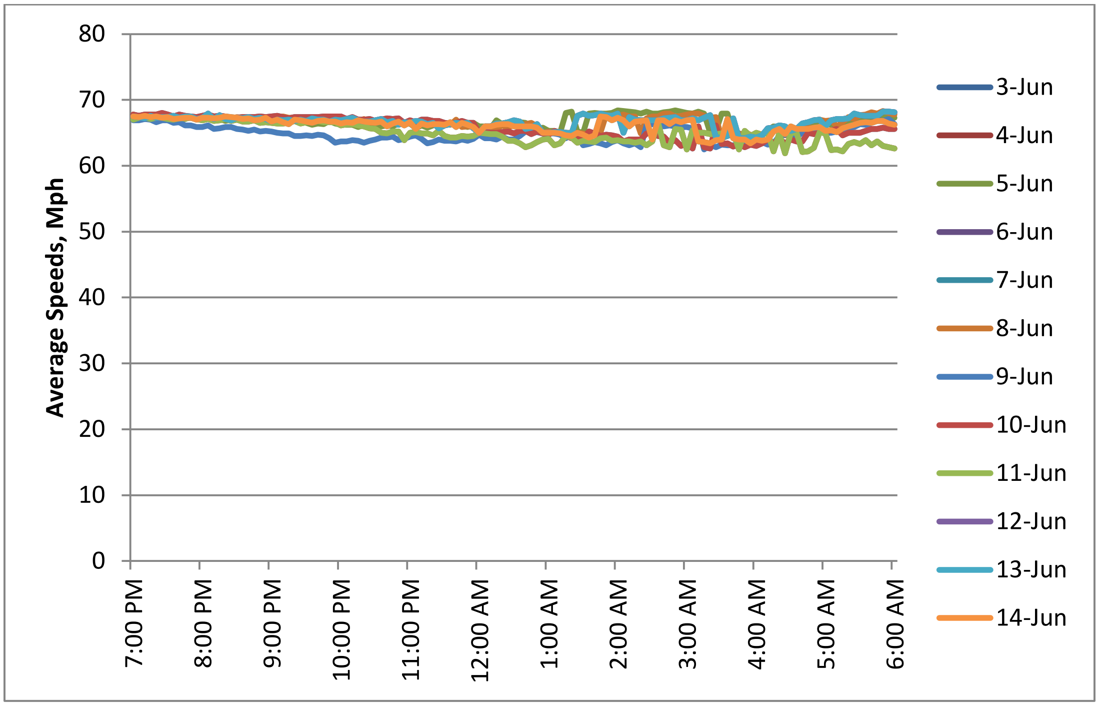


Figure 34. Average speeds southbound at sensor station 108, milepost 25.8.

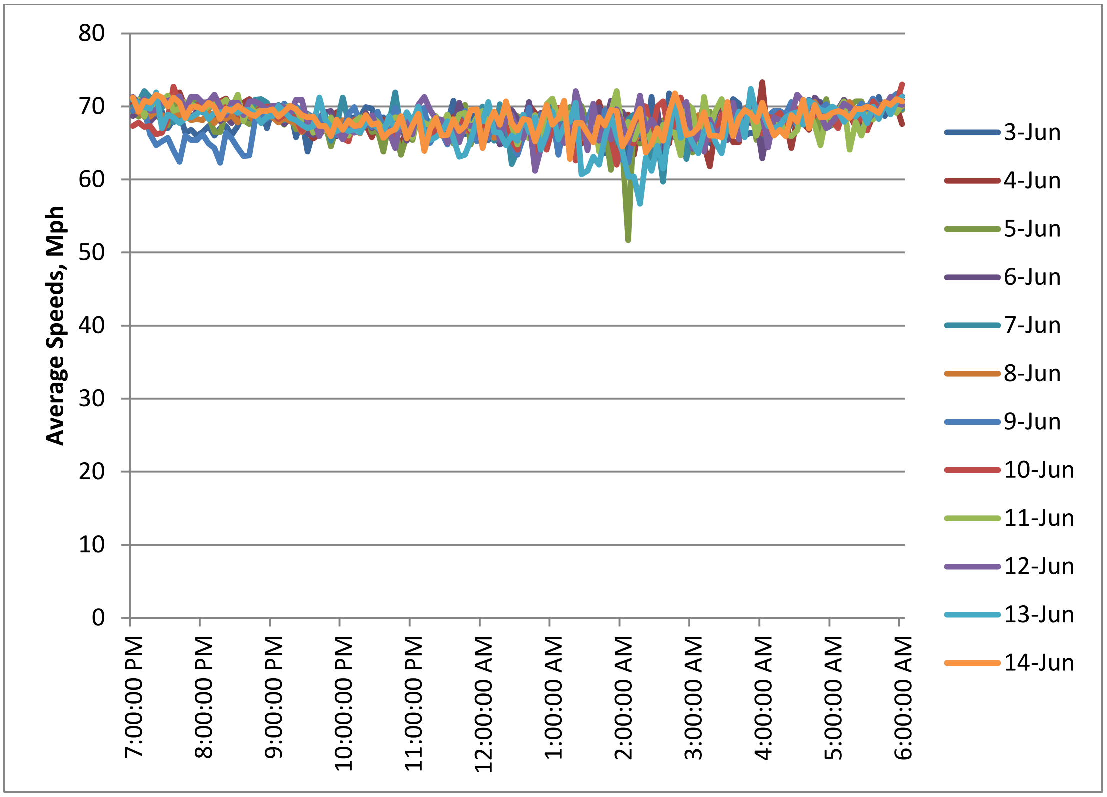


Figure 35. Average speeds southbound at sensor station 112, milepost 24.4.

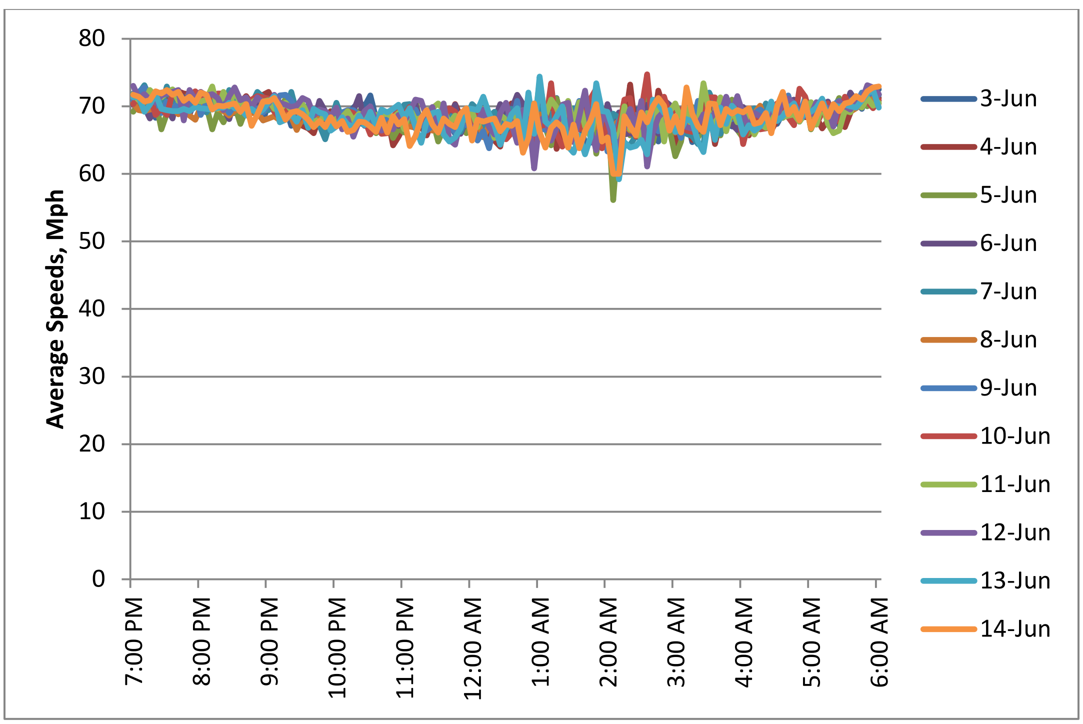


Figure 36. Average speeds southbound at sensor station 115, milepost 23.5.

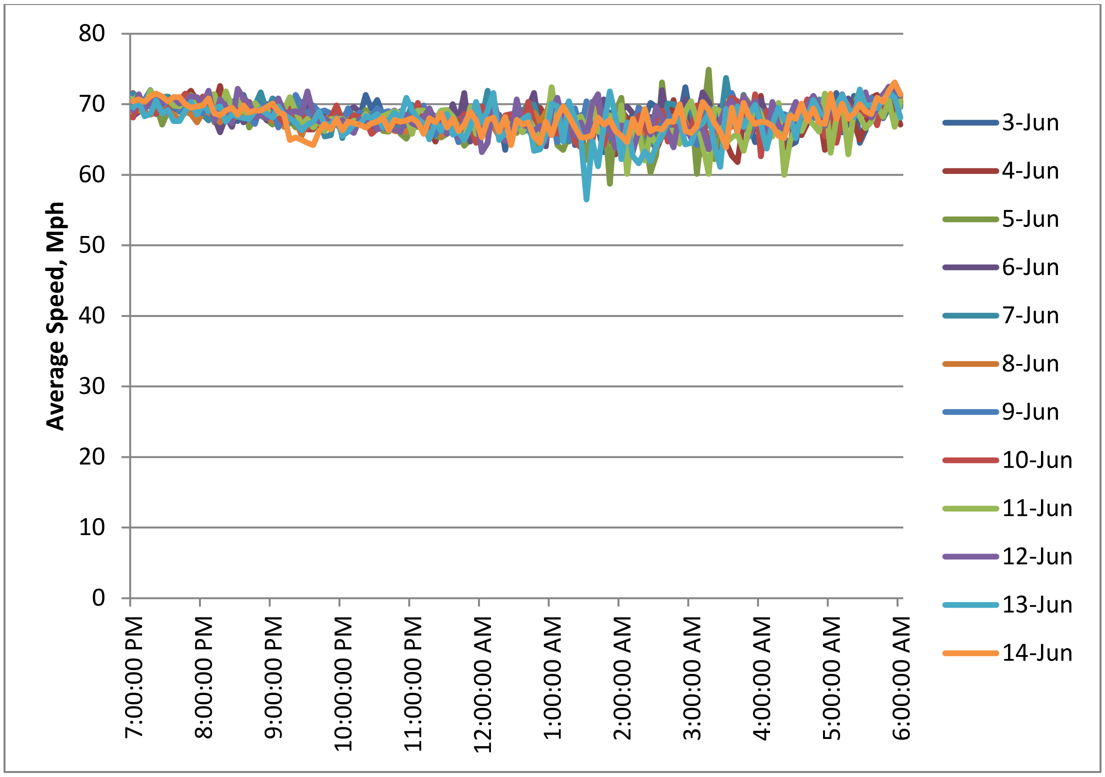


Figure 37. Average speeds southbound at sensor station 119, milepost 22.8.

The use of precast concrete panels allowed work to be completed as a series of short-term nighttime lane closures. If this technology had not been used, a more traditional rehabilitation scheme would have been required, typically a long-term closure of one or two lanes over several days. For comparison purposes, Figure 38 illustrates the typical hourly flow rates on I-215 on weekdays and highlights what capacity would have been if this traditional method of slab replacement had been used. Note that a single long-term lane closure on this section would have resulted in overcapacity conditions each weekday morning from about 6 until 8 or 9. If two lanes would have been closed on a long-term basis, oversaturation would have existed during most of the daytime hours, leading to long delays and queues. This latter point is illustrated in Figure 39, which shows average per-vehicle delay that would have resulted daily from long-term lane closures.

Further analysis of these data provides a summary of the total vehicle-hours of delay per day expected had the traditional method of slab replacement been used, shown in Table 4. The two-lane values are slightly conservative because the delays at midnight in Figure 39 would have had to dissipate in the early morning hours before the a.m. peak and contributed to the delay total. With these numbers, it is possible to estimate the total delay costs avoided by estimating the total number of days it would have taken to replace the slabs via traditional methods and multiplying that estimate by these daily delay values and a unit value of delay time per vehicle.

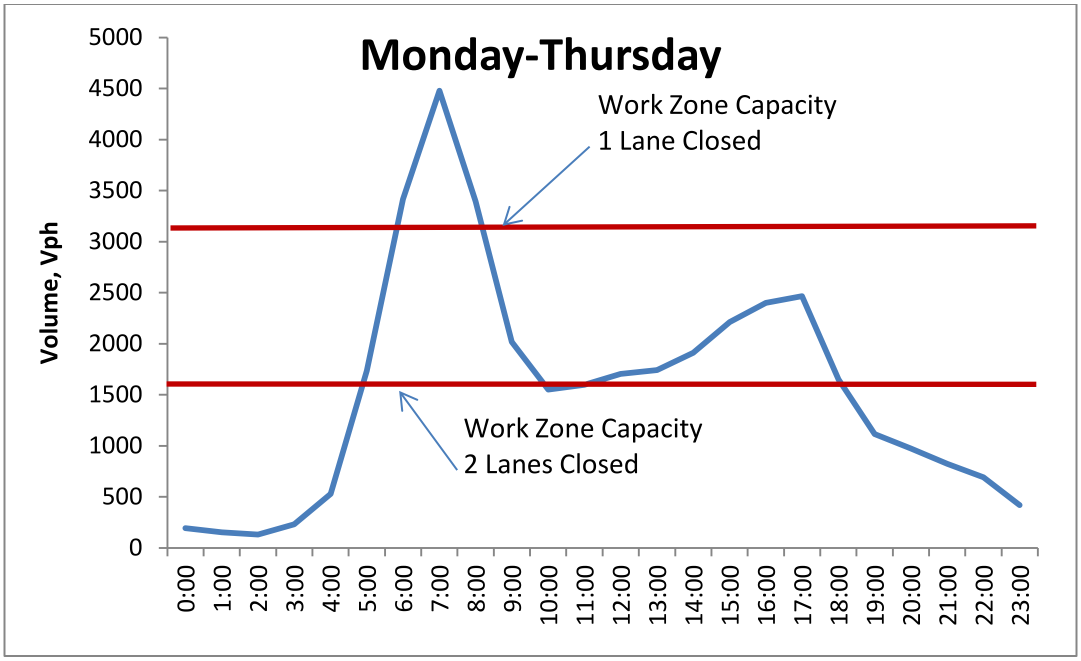


Figure 38. Hourly volumes southbound on I-215, weekdays.

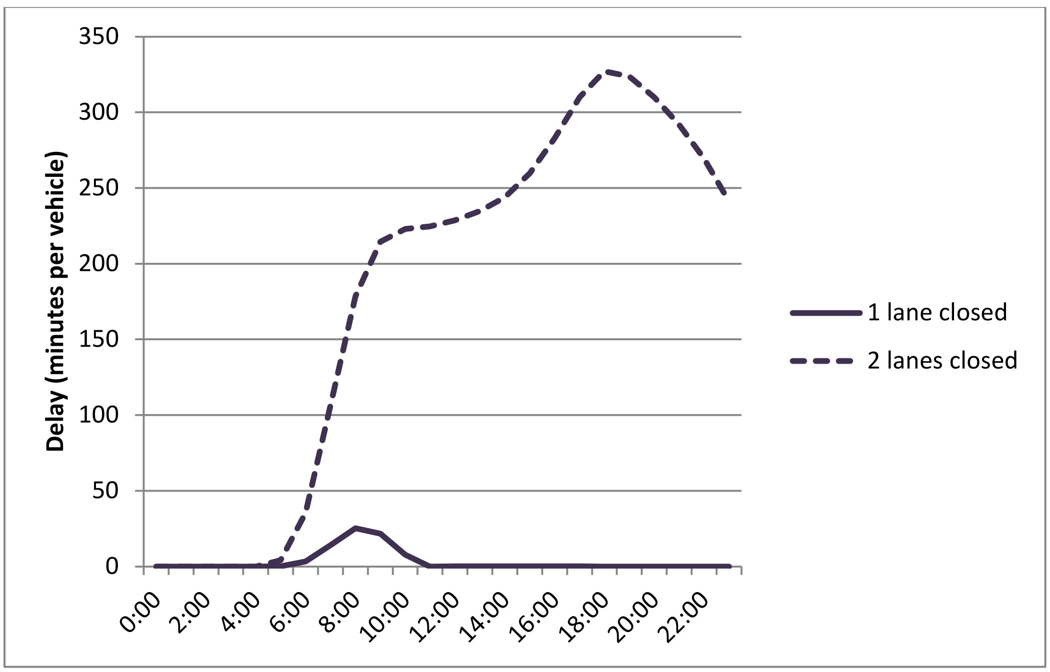


Figure 39. Average per-vehicle delays that would have resulted from long-term lane closures on I-215.

Table 4. Potential daily vehicle delays during long-term lane closures, I-215 southbound.

Days	One Lane Closed	Two Lanes Closed
Monday–Thursday	3,608 vehicle-hours	122,704 vehicle-hours
Friday	1,255 vehicle-hours	106,820 vehicle-hours
Saturday and Sunday	0	0

QUALITY

Pavement Test Site

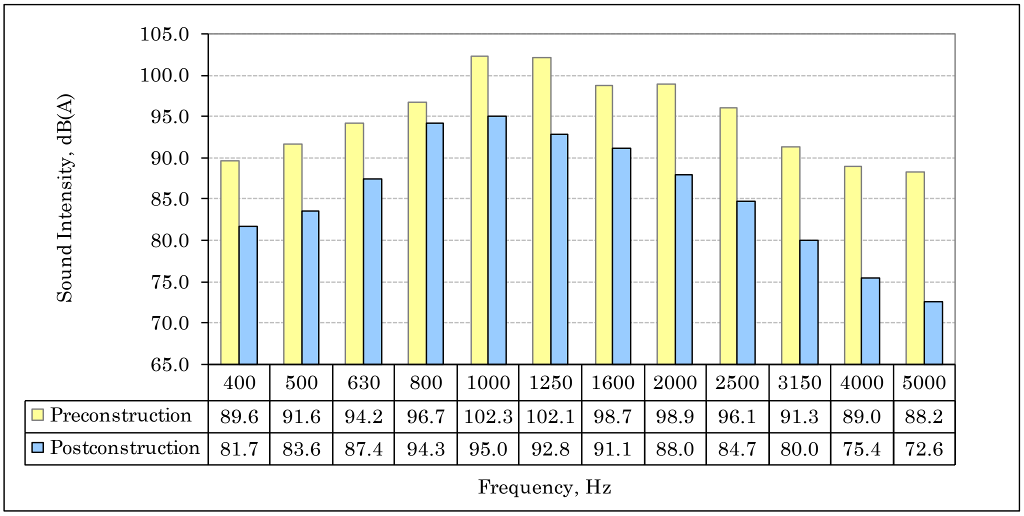
Sound intensity (SI) and smoothness test data were analyzed from a 300-ft tangent section of the project pavement. Comparing these data before and after construction provides a measure of the quality of the finished pavement.

Sound Intensity Testing

SI measurements were made using the current accepted OBSI technique AASHTO TP 76-10, which includes dual vertical SI probes and an ASTM recommended standard reference test tire (SRTT). Data were collected before construction on May 7, 2010, and on the new pavement surface on August 9, 2011, after it was opened to traffic. The SI measurements were recorded and analyzed using an onboard computer and data collection system. Multiple runs were made in the right wheelpath with two microphone probes simultaneously capturing noise data from the leading and trailing tire-pavement contact areas. Figure 40 shows the dual-probe instrumentation and the tread pattern of the SRTT.

Figure 40. OBSI dual probe system and the SRTT.

The average of the front and rear SI values was computed to produce a global SI value. Raw noise data were normalized for the ambient air temperature and barometric pressure at the time of testing. The resulting mean SI levels are A-weighted to produce the SI frequency spectra in one-third octave bands, as shown in Figure 41.



	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
Preconstruction	89.6	91.6	94.2	96.7	102.3	102.1	98.7	98.9	96.1	91.3	89.0	88.2
Postconstruction	81.7	83.6	87.4	94.3	95.0	92.8	91.1	88.0	84.7	80.0	75.4	72.6

Figure 41. Mean A-weighted sound intensity frequency spectra before and after construction.

SI levels were calculated using logarithmic addition of the one-third octave band frequencies across the spectra. The global SI value for the existing pavement was 108.1 dB(A) and 100.4 dB(A) for the new pavement. While not meeting the HfL goal of 96.0 dB(A), the 7.7 dB(A) drop in SI is a significant improvement. Overall, each frequency was reduced and no single frequency spiked, indicating the absence of the distinct tone or whine common to concrete pavement with a transverse or aggressive surface texture.

Smoothness Measurement

Smoothness testing was done in conjunction with SI testing using a high-speed inertial profiler integrated with the test vehicle. The smoothness or profile data were collected from both wheelpaths and averaged to produce an IRI value. Low values are an indication of higher ride quality (i.e., smoother road). Figure 42 shows the test vehicle with the profiler positioned in line with the right rear wheel. Figure 43 graphically presents the IRI values for the preconstruction and newly constructed pavement. The existing distressed pavement had a value of 150 in/mi, and the new pavement was 130 in/mi. Motorists may notice a somewhat smoother ride, but the rehabilitated pavement did not meet the HfL goal of 48 in/mi.

Figure 42. High-speed inertial profiler mounted behind the test vehicle.

Figure 43. Mean IRI values before and after construction.

USER SATISFACTION

The HfL requirement for user satisfaction includes a performance goal of 4-plus on a Likert scale of 1 to 7 (in other words, 57 percent or more participants showing favorable response) for the following two questions:

- How satisfied is the user with the new facility compared with its previous condition?
- How satisfied is the user with the approach (APC) used to construct the new facility in terms of minimizing disruption?

Overall, the response to the questions exceeded the HfL goal of 4 out of 7 (the majority of the respondents) or more showing favorable response.

TECHNOLOGY TRANSFER

On June 7, 2011, a showcase was held to introduce the innovations used on the project, followed by an onsite construction observation in the evening. The showcase held at UDOT District 2 was attended by 103 participants from across the United States representing State highway agencies, FHWA, consultants, and paving contractors. The showcase agenda is in the appendix. UDOT Region 2 Deputy Director Tim Rose introduced the project. FHWA Utah Division Administrator James Christian presented an overview of the HfL program. Sam Tyson of FHWA and Shiraz Tayabji of Fugro Consultants provided background and national perspectives on PCPS.

Presentations from the project team followed. Matt Zundel, UDOT project manager, presented an overview of the project, while David Eixenberger of TY Lin discussed design issues faced during the planning stages. Dave Gilley of Harper Precast presented details on panel fabrication, while John Montoya of UDOT and Sam Donaldson of Kilgore Contracting provided an overview of the field construction. The presentations were followed by a question-and-answer session and the showcase concluded with a visit to the project site.

APPENDIX: SHOWCASE AGENDA

UDOT-FHWA Precast Pavement Panel Showcase
UDOT Region 2, Hurley Conference Room
June 7, 2011

2–2:15 p.m.	**Introduction** Welcome Introductions UDOT Perspective **Tim Rose** Deputy Director UDOT Region 2
2:15–2:30 p.m.	**Highways for LIFE Overview (video)** **James Christian** Division Administrator FHWA
2:30–3 p.m.	**National Perspective** **Sam Tyson** Concrete Pavement Engineer FHWA **Shiraz Tayabji** Fugro Consultants, Inc.
3–5 p.m.	**I-215 East 3900 South Project Presentation** 1. Project Overview—Matt Zundel, UDOT 2. Design—David Eixenberger, TY Lin 3. Precast Panels—Dave Gilley, Harper Precast 4. Construction Overview—John Montoya, UDOT, and Sam Donaldson, Kilgore
5–5:15 p.m.	**Break**
5:15–5:45 p.m.	**Question-and-Answer Session** **Amalia Deslis** Moderator
5:45–6 p.m.	**Safety Discussion** Preparation for evening field visit **Kilgore Contracting**