Fast-Track Urban Freeway Rehabilitation with

55-hour Weekend Closures: I-710 Long Beach Case Study

Technical Memorandum Prepared for

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By

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EXECUTIVE SUMMARY

In June 2003, The California Department of Transportation successfully completed reconstruction of a 4.4-km stretch of Interstate 710 in Long Beach, the most heavily truck loaded route in the state. The work was a part of a long-life asphalt concrete (AC) pavement rehabilitation project constructed during repeated 55-hour weekend closures with fast-track construction and 24-hour operations. This report presents the overall rehabilitation process and productivity based on construction data monitored at three of the eight weekend closures. Production rates of demolition, aggregate base placement, and AC paving operations received special focus, particularly in terms of variations due to 1) time of day, 2) AC mix design and number of layers, and 3) paving methods. Noticeable effects on productivity related to the learning curve of the construction crew were observed as the weekend closures were repeated.

In addition, a traffic measurement study utilizing various traffic surveillance tools was implemented to quantify the impact of construction closures on network traffic delay. This case study will be useful for transportation agencies and contractors in developing integrated construction and traffic management plans for highway rehabilitation projects that maximize construction productivity and minimize traffic delay in high volume situations.

TABLE OF CONTENTS

LIST OF FIGURES

1.0 INTRODUCTION

More than 95 percent of the 78,000 lane-km California state highway system was built between 1955 and 1970. Not only have pavements on these highways exceeded their original 20-year design lives, many of them reached their design traffic lives sooner than 20 years after their construction because of heavier traffic volumes and loads than originally anticipated.(*1*) The combination of age and continuously increasing traffic demand has resulted in faster rates of pavement deterioration than originally anticipated and has adversely affected road user safety, ride quality, vehicle operating costs and the cost of highway maintenance and rehabilitation.

In 1998, responding to the increased need for highway maintenance and rehabilitation, the California Department of Transportation (Caltrans) launched the Long-Life Pavement Rehabilitation Strategies (LLPRS) program to rebuild approximately 2,800 lane-km of deteriorated urban freeways over the subsequent 10 years. The program represented an estimated extra $1 billion investment over the regular budget of the State Highway Operation and Protection (SHOP) budget.(*2*) LLPRS candidate projects were selected based on criteria of poor pavement structural condition and ride quality and minimum 150,000 Average Daily Traffic (ADT) or 15,000 Average Daily Truck Traffic. Most of the candidate freeways were Portland cement concrete (PCC) interstates in the Los Angeles Basin (80 percent) and the San Francisco Bay Area (15 percent).

The goals of the Caltrans LLPRS program were to 1) provide 30+ years design life instead of traditional 20 years with minimal maintenance, and 2) achieve a production of 6 lane-km during a 55-hour weekend closure (i.e., 10 P.M. Friday to 5 A.M. Monday). This weekend closure with 24-hour operations was selected to minimize traffic delay and inconvenience to the traveling public during construction, since many urban freeways in California carry relatively little weekend traffic.

The first LLPRS concrete project was on Interstate 10 in Pomona, CA, where 2.8 lane-km of PCC pavement were successfully rebuilt using fast-setting hydraulic cement concrete (FSHCC) in one 55-hour weekend closure. A series of 7- and 10-hour weekday nighttime closures were also performed as part of this project. The 55-hour weekend closure included in the project was about 40 percent more productive than the traditional nighttime closures.(*3*)

Caltrans recently implemented the first LLPRS asphalt project on Interstate 710 in Long Beach. A 4.4-km stretch of existing PCC pavement was rehabilitated/reconstructed with long-life asphalt concrete (AC) in only eight 55-hour weekend closures.

The study presented in this report monitored the fast-track rehabilitation progress and contractor production rates over three of the eight 55-hour weekend closures. A traffic monitoring study was conducted simultaneously to evaluate the impact of the 55-hour weekend closures on network traffic delay. Collecting the construction data and the contractor's learning curve for repeated 55-hour weekend closures allows Caltrans to begin to develop a construction database that can be used for future LLPRS construction management planning.(*4*) The main objective of the traffic study was to measure changes in traffic statistics (volume, speed, and time) by comparing "before-construction" and "during-construction" weekends. Due to space limits, only a summary of the traffic study is presented in this report. Details are discussed in the project report.(*5*)

This case study will be useful for transportation agencies in developing integrated construction and traffic management plans for highway rehabilitation projects that maximize construction productivity and minimize traffic delay in high volume situations, and contractors in developing plans that account for learning effect across repeated short, intense work periods.

2.0 I-710 PROJECT OVERVIEW

First opened in 1952 as the Long Beach Freeway, I-710 is the primary access route to the City of Long Beach and to the Ports of Long Beach and Los Angeles. The I-710 corridor carries an average daily traffic (ADT) volume of more than 164,000 vehicles per day (vpd), 13 percent of which is heavy trucks during weekdays. The weekend ADTs drop to about 122,000 vpd.(*5*) Because of this heavy truck traffic volume and its 50 years of service, the Long Beach corridor had become one of the most deteriorated urban freeways in Southern California, with severe faulting, various types of cracks (transverse, longitudinal, and corner) and very rough ride quality.

2.1 55-hour Extended Weekend Closures

Caltrans decided to implement the pavement rehabilitation through 55-hour weekend closures rather than weekday closures since weekend peak hourly volume (4,300 vehicles per hour [vphr]) for one direction is less than weekday peak hourly volume (5,400 vphr). Traditionally, urban California freeway rehabilitation uses short nighttime closures (7-hour or 10-hour). However, these conventional nighttime closures did not seem appropriate for this LLPRS project due to the need to rebuild all three lanes in each direction and concern about the relatively short pavement expected life as results of the designs, materials, and construction quality possible in such short closures. The variable quality control (QC) achieved and the limitations on designs and materials that can be used during nighttime closures can potentially reduce pavement life to 10 to 15 years. Moreover, the volumes of materials to be demolished and paved for the LLPRS project were too large to be handled efficiently within conventional nighttime closures.

2.2 Project Rehabilitation Scope

The I-710 project scope was to rehabilitate about 4.4 centerline-km (26.4 lane-km) of the Long Beach Freeway between the Pacific Coast Highway (PCH) intersection and the San Diego Freeway (I-405) system interchange during a series of 55-hour weekend closures. The original plan in the contract called for 10 consecutive weekend closures, with incentives if fewer closures were actually used. The project scope included rehabilitation of all three lanes in each direction. The project intersects four freeway overpasses: PCH, Willow Street, Wardlow Road, and I- 405.

As illustrated in Figure 1, the project had four Full-Depth AC Replacement (FDAC) sections (1.6 km in total), located under the four overpasses, where the existing PCC pavement was removed and replaced with AC. The rest of the project consisted of two Crack, Seat and Overlay (CSOL) sections (2.8 km total), located between the FDAC sections. In these sections, the existing PCC pavement was cracked, seated, and overlaid with AC.

The project, awarded to Excel Paving Company for $16.7 million, started in April 2001 with a completion date set in December 2002. A number of complications and resulting change

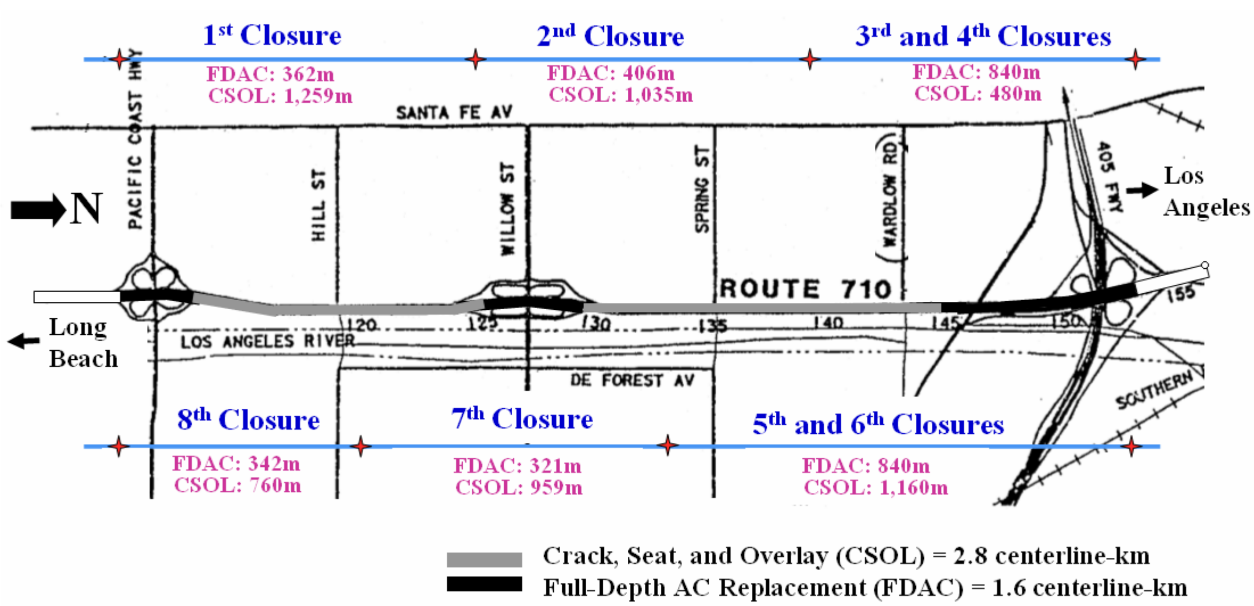


Figure 1. Contractor's revised construction staging plan.

orders and claims including an AC mix design problem, roadway alignment discrepancies, and poor subgrade soil conditions, delayed completion by about one year and caused the costs to overrun to about $19 million.

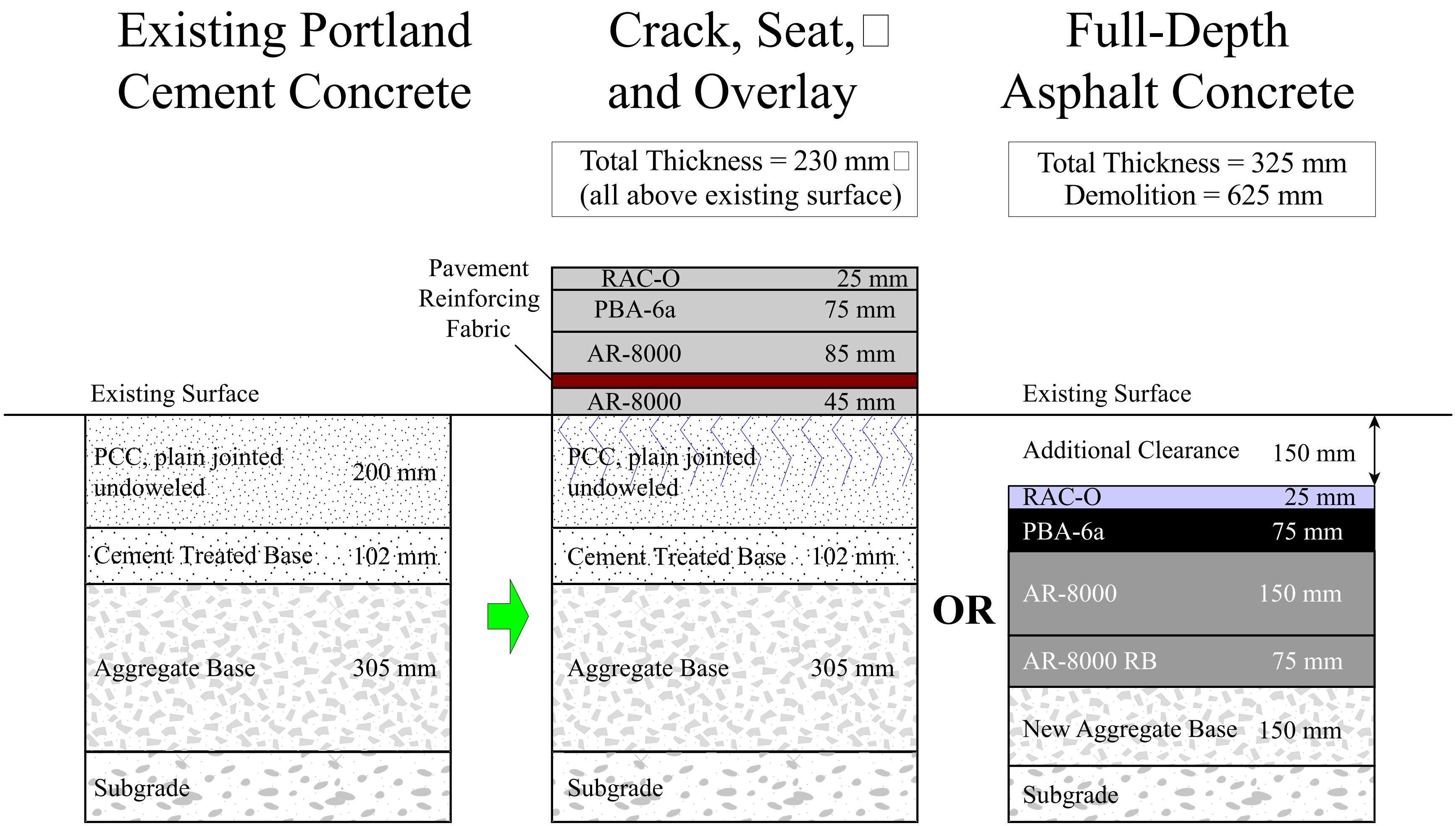
2.3 Pavement Cross-section Changes

The CSOL sections received a total of 230 mm AC overlay, including conventional AR-8000 and polymer-modified PBA-6a binders placed on top of the cracked and seated PCC pavement (Figure 2). The CSOL design included a pavement reinforcing fabric to slow the rate of reflection cracking from the bottom.

For the FDAC sections, also shown in Figure 2, the contract required excavation of the existing pavement structure to a depth of 625 mm. The replacement section included 150 mm of new aggregate base (AB) and 325 mm of AC, providing an additional 150 mm to meet the new interstate bridge clearance requirements set by the Federal Highway Administration (FHWA). The FDAC pavement design incorporated the same materials as specified for the CSOL pavement design, plus a rich bottom layer with 0.5 percent additional binder and less than 3 percent air-void content to provide increased stiffness and fatigue resistance.(*6*)

Special provisions (SP) for the project required AC compaction in terms of the theoretical maximum density (TMD) as follows:

- Minimum compaction requirement for layers containing PBA-6a and AR-8000 binders with 4.7 percent binder contents by mass of aggregate was 93 percent of TMD, i.e., a maximum air-void content of 7 percent.
- Minimum compaction requirement for the AR-8000 rich bottom was 97 percent of TMD, i.e., a maximum air-void content of 3 percent.



RAC-O: Rubberized Asphalt Concrete-Open graded
PBA-6a: Dense graded asphalt concrete with polymer-modified binder
AR-8000: Dense graded asphalt concrete with conventional binder
AR-8000 RB: Rich bottom dense graded asphalt concrete with conventional binder

Figure 2. Pavement cross-section changes.

The CSOL and FDAC pavement designs both included 25 mm of rubberized asphalt concrete open-graded friction course (RAC-O) to reduce hydroplaning potential, tire spray, and tire noise. The RAC-O also serves as a sacrificial layer for top-down cracking in addition to its contributions to noise reduction and safety and will probably be replaced every 10 to 12 years.(*6*) Both sections were designed using mechanistic-empirical methodologies to accommodate 200 million Equivalent Single Axle Loads (ESALs) for a design period of 30 years. Prior to the project, rutting resistance of the PBA-6a mix designs was verified using the Heavy Vehicle Simulator.(*7*)

2.4 Construction Staging Plan

The I-710 project was performed in six construction stages. During the first stage the median shoulder was reconstructed and widened, and old guardrails were upgraded with new concrete barriers. The second stage included excavating, widening, and paving the outside shoulders up to the existing pavement surface elevation. The majority of the work for the stages one and two took place during weekday nights, with partial traffic closures for typically 7 hours. The remaining four stages involved the main lanes rehabilitation for the four FDAC sections under the overpasses and the two CSOL sections. A total of 10 consecutive 55-hour weekend closures were scheduled for completion of these last four stages in the initial Caltrans plan.

2.5 Incentives and Disincentives Provision

The contract included an incentives and disincentives provision relative to the number of 55-hour weekend closures. The contractor was eligible for a $100,000 incentive payment per weekend closure if the main rehabilitation work was completed in fewer than the Caltrans initial plan of ten weekend closures. Similarly, he would be subjected to a disincentive of $100,000 per weekend closure for more than ten weekend closures. The total incentive or disincentive was limited to $500,000. Encouraged by the incentives, the contractor deployed additional resources, revised the Caltrans initial staging plan, finished the main rehabilitation work in eight consecutive weekend closures (as shown in Figure 1), and got awarded $200,000 of the incentives. Basically, each segment consisted of one CSOL section and one FDAC section rehabilitated simultaneously during one weekend closure.

2.6 Traffic Control during Construction

According to the Caltrans transportation management plan (TMP) for the project, a serious traffic delay could be expected if traffic demand during the weekend closure was not reduced from 4,300 vphr to about 3,000 vphr, which was the expected capacity of the construction work zone (CWZ). The strategy was to use neighboring freeways and arterials as detours for traffic re-routing. A traffic control plan was required to minimize adverse impacts to the network during weekend closures.

During weekend construction, Caltrans applied a “counter-flow traffic” plan in which one side of the freeway was entirely closed for the construction work zone (CWZ), as illustrated in Figure 3. Traffic was diverted to a temporary traffic roadbed on the other side of the CWZ using traffic crossovers. The outside shoulder was temporarily converted to a main traffic lane to provide the “two-by-two lanes” configuration on the traffic roadbed because this section of the freeway has only three lanes for each direction. At the beginning of each weekend closure, the freeway was completely closed in both directions for about 7 to 8 hours with traffic being detoured to local arterial roads. During this full closure, moveable concrete barrier (MCB) was installed on the traffic roadbed as a safety divider and re-striping was performed. Meanwhile, the main rehabilitation operation was performed around the clock from 10 P.M. Friday through 5

Figure 3. I-710 rehabilitation and traffic control during the weekend closure.

A.M. Monday. At the end of the weekend closure, both directions of the freeway were closed completely one more time for 6 to 7 hours to relocate the MCB and restore the striping and markers before the 5 A.M. Monday freeway re-opening.

2.7 Rehabilitation Process

The breakdown of the major CSOL and FDAC rehabilitation activities implemented during a typical 55-hour weekend closure is:

1. Traffic Full Closure

- Set up CWZ signs and close both directions of the freeway.
- Remove existing striping and markers on temporary traffic roadbed.
- Setup MCB and place temporary striping and markers.

- Open counter-flow traffic on the traffic roadbed.

2. CSOL Rehabilitation

- Crack and seat existing PCC pavement.
- Place 45 mm AR-8000 leveling course.
- Install pavement reinforcing fabric.
- Place 85 mm AR-8000 and 75 mm PBA-6a.

3. FDAC Rehabilitation

- Fracture (rubblize or so-called “stomp”) and remove existing PCC pavement.
- Excavate roadway and cut subgrade.
- Place 50 mm AR-8000 working platform or 150 mm new aggregate base.
- Place 75 mm AR-8000 rich bottom, 150 mm AR-8000, and 75 mm PBA-6a.

4. Traffic Opening

- Place striping and markers on new pavement.
- Close both directions of the freeway again.
- Remove temporary striping and markers on the traffic roadbed.
- Relocate MCB to the median and restore striping and markers.
- Remove CWZ signs.
- Re-open both directions of the freeway.

Figure 4 shows the contractor’s overall CPM schedule submitted for a typical 55-hour weekend closure. Because of extreme time, space, and resource constraints, many activities were scheduled to be performed concurrently. Large amounts of schedule float were assigned to riskier demolition activities at the FDAC section. PCC cracking at the CSOL section and PCC fracturing at FDAC section were scheduled to begin shortly after the full traffic closure was

Activity	Duration (Hours)	Early Start	Early Finish
Traffic Closure	8	FR 23:00	SA 06:59
CSOL Section			
Crack PCC	8	SA 01:00	SA 08:59
Seat PCC	8	SA 03:00	SA 10:59
AC Overlay	21	SA 05:00	SU 01:59
Paving Fabric	9	SA 11:00	SA 19:59
FDAC Section			
PCC Solids Removal	6	SA 01:00	SA 06:59
Roadway Excavation	14	SA 07:00	SA 20:59
Cut Subgrade and AB Placement	12	SA 14:00	SU 01:59
AC Paving	15	SU 02:00	SU 16:59
Striping and Clean-up	4	SU 17:00	SU 20:59
Traffic Opening	5	SU 19:00	SU 23:59

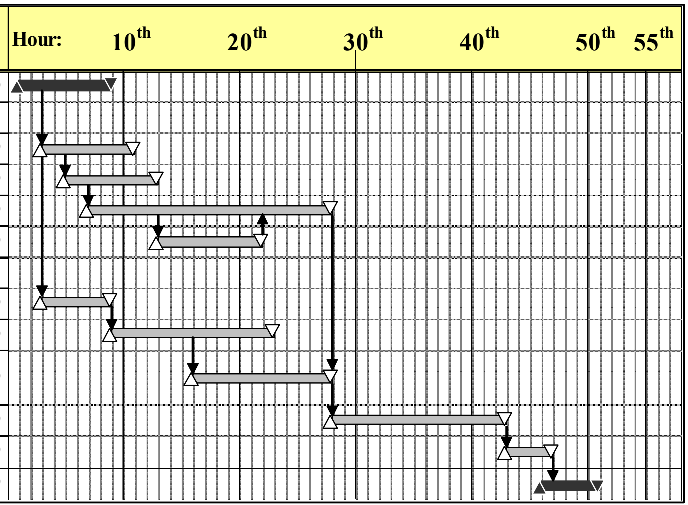


Figure 4. Typical CPM schedule for a 55-hour weekend closure (2nd weekend closure).

implemented. AC placement was planned to finish at the CSOL section first and proceed to the FDAC section.

At each weekend closure, median and outside shoulders were completely overlaid and/or replaced with AC, together with three main traffic lanes, in four strips (pulls), each approximately 4.3 m wide. An alternating strip paving sequence was utilized to avoid potential paving suspension due to AC cooling time. This paving sequence enabled Hot Mix Asphalt (HMA) delivery trucks to reach the discharging location without driving on the hot AC, eliminating material pickup by truck tires. When the planned schedule did not provide enough time for placing the 75 mm PBA-6a at the FDAC section, it was often placed in the following weekend closure. The 25 mm RAC-O was placed during weekday nighttime closures, after completion of all weekend closures.

3.0 CONSTRUCTION MONITORING STUDY

The contractor started the first 55-hour weekend closure on March 28–31, 2003 and completed all the major rehabilitation work by the eighth weekend closure on June 20–23, 2003, excluding the weekend of the Long Beach Grand Prix, Easter and Memorial Day weekends, and two bad-weather weekends. The research team selected the first, second, and seventh weekend closures for both construction and traffic monitoring studies because their work scope was relatively similar. This enabled analysis of the contractor's learning effects in production and the changes in traffic demand through the CWZ over the three weekend closures. The sections observed in earlier and later closures were selected to have similar situations to minimize the influence of different conditions on the learning effect analysis. For example, the second weekend closure for the Southbound rehabilitation of the 1.0-km CSOL section between the Willow St. and Wardlow Rd. overpasses and the 0.4-km FDAC section under the Willow St. overpass was similar to the seventh closure on the opposite side (Northbound).

During each monitored weekend, the team of 10 to 12 researchers recorded the contractor's as-built process and progress. To keep track of production, all trucks mobilized, (i.e., HMA delivery, new AB materials delivery, and demolition hauling trucks) were individually numbered with temporary reflective magnetic placards. The contractor's station benchmarks placed along the outside shoulders were referenced to track the rehabilitation progress. During each closure the following data were collected:

- Rehabilitation sequence and process
- Schedule variances

- Contractor's resources, especially trucking information: total number of trucks mobilized, truck arrival and departure times, average truckloads or discharges per hour, and truck cycle and turnaround times
- Typical hourly production rates for major rehabilitation activities (demolition, AB placement and AC paving)
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4.0 REHABILITATION PRODUCTION ANALYSIS

Being a fast-track construction project, the contractor maintained around-the-clock operations in two alternating shifts of about 40 personnel for the concurrent rehabilitation of the CSOL and FDAC sections during each 55-hour weekend closure. Each shift consisted of one AC paving crew, two demolition crews, one pavement reinforcing fabric placement crew, and one cracking and seating PCC crew. Major demolition equipment included two excavators, three front loaders, two motor graders, one milling machine, four mechanical breakers ("stompers"), and two guillotine breakers. Paving equipment included two self-propelled asphalt pavers (one with a hopper and the other with an asphalt pick-up machine), two pneumatic-tired rollers, three vibratory steel rollers, and one tack coat truck. Additional backup equipment was on standby near the project site. On average, a total of 35 demolition hauling and 42 HMA delivery trucks were mobilized at each weekend closure.

The crew's progress of the major rehabilitation activities is summarized in the following section. Unless otherwise noted, the average hourly production rates can be compared against each other because the resource configuration was similar for all three weekend closures.

4.1 CSOL Paving Production

During the three weekend closures monitored, the paving crew placed approximately 21,630 tons of HMA (about 850 truckloads). The AC overlay paving operation was completed as scheduled, often ahead of schedule. At each weekend closure, the paving crew placed an average of 7,210 tons of HMA (284 truckloads) in 18.3 hours, 13 percent faster than the contractor's planned 20.7 hours. Paving production ranged from 643.6 tons/hour and 50.0 tons/hour with an average hourly rate of 395.7 tons and a standard deviation of 112.6 tons/hour. On average, 15.7 double bottom-dump semi-tractor trailers (semi-bottom dump trucks [SBT]) arrived at the job site per hour and discharged the HMA windrows with about 4 minutes discharge cycle time per truck. The batch plant was located about 50 km from the project site, and the average turnaround time of HMA delivery trucks was 2 hours and 13 minutes.

The paving crew placed approximately 8 percent more HMA during the daytime (7:00 A.M.–7:00 P.M.) with the average hourly rate of 403 tons as compared to the nighttime (7:00 P.M.–7:00 A.M.) rate of 374 tons. The average production rate of 45 mm AR-8000 leveling course was about 11 percent less than that of the subsequent layers combined, probably due to the fact that it was the first layer being placed with the least thickness. AR-8000 and PBA-6a were placed at a similar rate of about 400 tons per hour.

During the first weekend closure, the paving crew overlaid the HMA at the rate of 380.1 tons per hour. Production increased 13 percent to 430.9 tons/hour in the second closure, but decreased 11 percent to 384.7 tons/hour in the seventh closure. Apparently, the contractor was ahead of schedule by the seventh closure and decided not to push the CSOL paving operation any faster because it was proven as a non-critical activity.

4.2 FDAC Demolition and Excavation Productions

Throughout the three weekend closures monitored, the two demolition and excavation crews (which were deployed simultaneously) removed approximately 10,340 m^3 of PCC solids and road base materials including the crumbled CTB, AB, and part of the subgrade soil (about 1,380 truckloads). PCC solids removal (demolition) operation was completed as scheduled, but the excavation operation (including subgrade cutting and compacting) took longer than planned, especially during the first weekend closure.

The accepted reason is that the contractor encountered unexpectedly unstable subgrade soil, which was difficult to compact to the required density. If such unfavorable subgrade conditions were encountered, the contractor was supposed to excavate another 150 mm of the poor subgrade and replace it with new AB. Unfortunately, at the time of the first closure, Caltrans and the contractor could not agree on a written contingency plan for the AB remediation procedure. Because of time constraints, the parties decided to move ahead without replacing the poor subgrade soils with AB and to place the 50 mm AR-8000 working platform on top of the poor subgrade. From the second weekend closure, any unstable subgrade was replaced with new AB. Consequently, the excavation quantity increased significantly compared to the initial plan. Some standby equipment was deployed to accommodate these additional material volumes.

At each weekend closure, the demolition and excavation crews hauled away an average of 3,452 m^3 (459 truckloads) of PCC solids and road base materials in 19.2 hours versus the planned 20 hours. The dumping area was located about 4 km from the project site. On average, 24.7 hauling trucks were loaded each hour by the two crews with about 5 minutes loading cycle time per truck. The average turnaround time for the hauling trucks was 46 minutes.

During the first closure, the demolition and excavation crews removed an average of 138.5 m^3 of the PCC and road base materials per hour. Production increased 44 percent to 199.5

m^3/hour in the second closure and another 8 percent to 214.5 m^3/hour by the seventh closure. During the first closure, an average of 16.9 hauling trucks were loaded each hour. This increased 59 percent to 26.8 trucks/hour in the second closure and by 14 percent to 30.5 trucks/hour in the seventh closure.

4.3 FDAC AB Placement Production

During the second and seventh closures, the crew placed approximately 4,800 tons of AB (about 270 truckloads). At each weekend closure, the crew placed an average of 2,399 tons of new aggregate (135 truckloads) in 8.4 hours, as scheduled by the contractor. On average, 16.3 hauling trucks unloaded the new aggregate per hour with the turnaround time of 1 hour and 3 minutes. The placement of new AB (recycled from PCC slabs removed at the previous closure) was carried out concurrently with the subgrade cutting operation. By performing both operations simultaneously, the contractor managed to incorporate this added activity into his 55-hour work schedule without making any significant changes, except that the additional work hours for new AB placement required PBA-6a paving for the FDAC section to be scheduled in the following weekend closure.

During the second closure, 258.2 tons of aggregate were typically placed per hour. Production increased 25 percent to 322.1 ton/hour in the seventh closure. During the second closure, 14.8 hauling trucks unloaded the new aggregate in a typical hour compared to 17.8 trucks in the seventh closure.

4.4 FDAC Paving Production

During the three weekend closures monitored, the paving crew placed approximately 15,700 tons of HMA (about 620 truckloads). An average of 5,234 tons (206 truckloads) of HMA was placed in 18.4 hours at each weekend closure, 17 percent slower than the contractor's planned 15.3 hours. The production varied between 550 tons/hour and 77.4 tons/hour (average hourly rate of 293.3 tons and standard deviation of 121.6 tons/hour). On average, 11.5 HMA delivery trucks discharged the HMA per hour with about 5 minutes discharge cycle time per truck. The average turn-around time for the HMA delivery trucks was 2 hours and 26 minutes.

On average, the hourly paving production rate at the FDAC sections was 26 percent lower than the CSOL paving production rate. The unstable subgrade condition was one of the main reasons for this sharp decrease in paving crew performance. For example, during the first closure the asphalt paver got stuck in the weak subgrade while placing the 50-mm AR-8000 working platform, and motor graders bladed out the HMA instead. During compaction, fine sands from the subgrade pumped through the AC layers at certain locations. These sands had to be manually shoveled, causing further delay. The relative short distance of the FDAC sections also contributed to the paving slowdown as the relative amount or frequency of paving stoppage (while bringing the asphalt paver back to the original starting point after finishing each pull) increased. The paving crew also experienced difficulty in accommodating changes in pavement alignment within such short distance.

The decision to use double end-dump trucks for delivery of the AR-8000 working platform and AR-8000 rich bottom (during the first and second closures only) on the FDAC sections also led to the paving slowdown. Compared to a typical AC overlay paving operation where multiple SBTs discharge HMA continuously in a windrow and an asphalt paver equipped with an asphalt pick-up machine ("ant-eater") places HMA windrows, the paving progress was noticeably slower because each end-dump truck had to unload the HMA into the hopper one-by-one. The double end-dump trucks required a significant set-up time to separately discharge the loads in the truck bed and in the attached trailer. However, use of less productive end-dump trucks seemed to be unavoidable since the first two layers involved AC paving over the loosely bound and uneven subgrade.

Similar to the CSOL sections, the daytime paving operation was about 11 percent more productive than the nighttime operation at the FDAC sections. The average daytime paving production was 312.2 tons/hour whereas the average nighttime production was 280.9 tons/hour. The average production rate of the first layer of 50 mm AR-8000 and/or 75mm AR-8000 rich bottom (using the hopper) was 25 percent less than that of the subsequent layers which were placed using the pick-up machine with the windrow paving process.

During the first closure, the paving crew placed HMA at the rate of 243.2 tons per hour. Production increased 18 percent to 285.8 tons per hour in the second closure and another 24 percent to 353.5 tons per hour in the seventh closure. During the first closure, 9.5 HMA delivery trucks arrived per hour on average. The number of trucks/hour increased 18 percent to 11.2 trucks/hour in the second closure and another 26 percent to 14.2 trucks/hour in the seventh closure.

4.5 Contractor's Learning Effect

As summarized in Figure 5, a noticeable learning effect was observed in the contractor production rates on this project, especially in demolition (including excavation) and paving operations. The contractor's records revealed that the production rates during the five weekend closures that were not monitored by the research team corresponded fairly well with the rates approximated by the learning curve. In particular, the crew's demolition learning effect was most apparent. This is probably because the contractor realized that demolition was the most critical

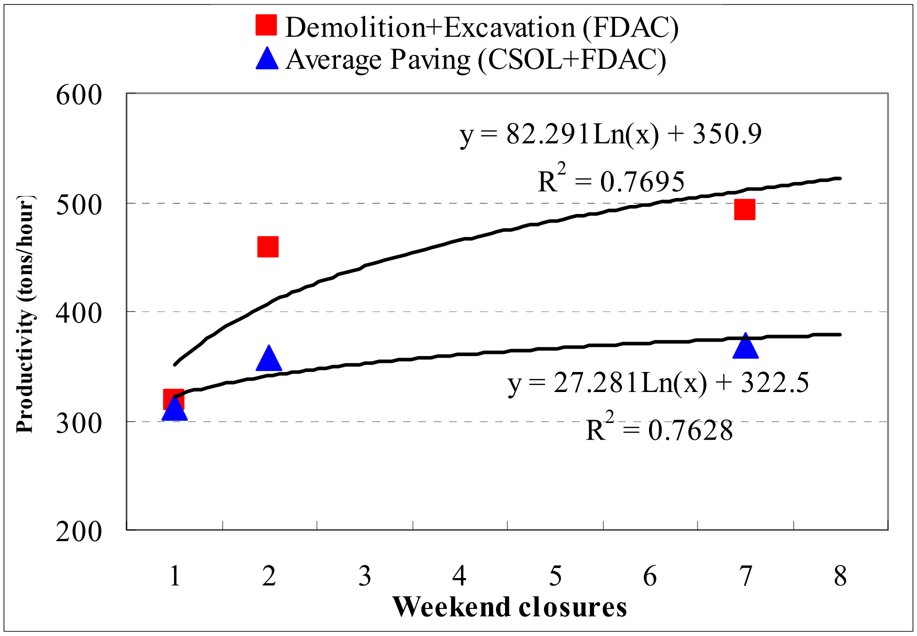

Figure 5. Contractor's learning curve over the repeated weekend closures.

activity, and thus made an extra commitment from both the resource and scheduling standpoints to ensure the timely completion.

Comparing the seventh and first closures, demolition production improved about 55 percent while the combined production rate for the AC paving (average of CSOL and FDAC paving) improved about 19 percent. By the seventh closure, the production rate flattened at about 550 tons (240 m^3) per hour for demolition and 375 tons (164 m^3) per hour for paving, which were recognized as the maximum achievable production rates on average in this type of fast-track urban freeway rehabilitation in California.

The following factors seemed to have contributed in various degrees to the overall improvement in the contractor's production across the closures:

- Knowledge and experience of the Caltrans staff and contractor's work forces (project engineers, superintendents, and especially crew)

- Improved resource planning and work zone space management
- Decreases in equipment down time and crew and equipment idle time
- Concurrent operations with multiple crews and equipments (for demolition, excavation, new aggregate base placement on the FDAC section)
- More realistic and attainable production goals
- Schedule-based contract incentives which stimulate the contractor into more production
- The contractor's decision to start demolition early with partial traffic closures

5.0 TRAFFIC IMPACTS OF WEEKEND CLOSURES

5.1 Traffic Monitoring Study Overview

The traffic monitoring study evaluated traffic impact of the 55-hour weekend closures on network delay by measuring changes in the traffic performance (volume, speed, and time) between before- and during-construction weekends. The traffic impact was measured at three different geographical sections of the traffic network: the I-710 corridor through the CWZ, adjacent freeway network, and detour arterials.

Various traffic surveillance tools were used for the measurement including the California freeway Performance Measurement System (PeMS) based on loop detectors and Weigh in Motion (WIM) for freeways, Remote Traffic Microwave Sensor (RTMS) on the CWZ, and rubber tubes for ramps and local arterials. Tach run vehicles were driven to measure travel time and speed. The results of the traffic measurement analysis were then compared with the predictions of the I-710 project TMP in terms of traffic reduction and number of detoured trips during construction. The study also examined the dynamic changes in traffic peak demand through the CWZ as the weekend closures were repeated.

5.2 Traffic Measurements Results

Despite concerns over potential delays, the traffic measurement study showed that the impact of the 55-hour weekend closures on traffic was tolerable mainly because the TMP induced a significant traffic demand reduction through the CWZ, as illustrated in Figure 6. There was no significant congestion and traffic was in free-flow speed condition throughout the whole network, especially at the I-710 corridor and detour arterials during the weekend construction.

Compared to historical (before-construction) weekend traffic volume, the average I-710 Northbound (NB) daily traffic through the CWZ was reduced by 37 percent, whereas Southbound (SB) traffic volume was reduced by 26 percent. The large reduction in the NB traffic

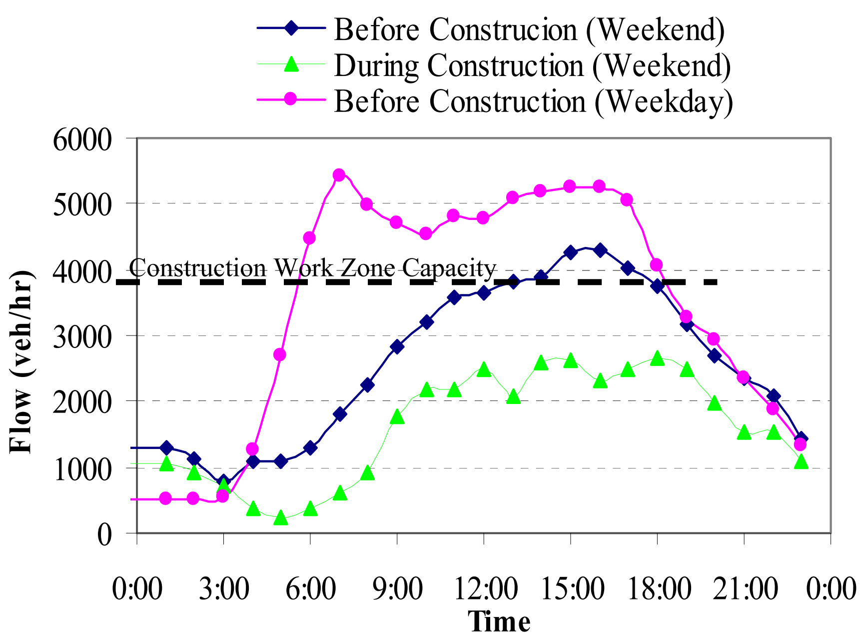

Figure 6. Comparison of traffic flow before and during construction on I-710 Northbound.

through the CWZ resulted from more drivers taking alternate routes while the SB direction drivers were less inclined to detour, possibly because they were near their destination (Long Beach). The measurements showed that the Caltrans TMP, developed during the planning stage, somewhat overestimated these traffic reductions. The TMP expected the peak hour traffic reductions during the closure would be 35 and 45 percent for the NB and SB directions, respectively, compared with the 37 and 11 percent measured peak hour reductions.

The peak hourly traffic flow through the CWZ at the first weekend closure was 1,350 vehicle/lane/hour. Traffic measurement over the 6 weekend closures revealed that this peak volume increased gradually as the closures were repeated, and finally stabilized at around 1,500 vehicle/lane/hour, which is believed to be the maximum CWZ capacity with the lane closure constraint of “two-by-two lane” on typical California urban freeway. This convergence in peak traffic volume through the CWZ appears to show the driver’s learning effect as a result of their original anticipation of delay, followed by observation of little delay in the first closure.

On neighboring freeways connecting to I-710, there was no significant change in traffic flow during the weekend closures except at the Harbor Freeway (I-110, parallel to I-710) where traffic increased about 7 percent, mainly due to drivers re-routing around the CWZ. On arterial roads, significantly more traffic was observed during the weekend closure as a result of detours. For example, a daily traffic volume at the intersection of Pacific Ave. and Wardlow Road, increased by about 156 percent from the historical weekend traffic. Traffic volume of all 20 measured detour intersections increased more than 14 percent over historical weekends.

Overall, the total traffic demand reduction (“no-show” traffic) across the network study area (about 20 km × 20 km boundary) was only about 1 percent, compared to the 10 percent estimated by the TMP. Total traffic flow measured in the before-construction weekend and the during-construction weekend were 743,543 and 735,854 vehicles per day, respectively. This indicated that the detoured drivers from the CWZ re-entered the freeway for their destination after utilizing alternate arterial roads around the CWZ.

6.0 FINDINGS AND LESSONS LEARNED

Overall, the construction productivity data collected during the case study indicated that the Caltrans and contractor rehabilitation plans were reasonably accurate and reliable. All rehabilitation activities were completed as scheduled, except for the PBA-6a paving during the first weekend, and the freeway was reopened to the public by 5 A.M. Monday for all of the weekend closures monitored, as well as the other 5 unmonitored weekends.

Contractor operations showed noticeable improvements and a learning effect evidenced by production gains as the weekend closures were repeated. By the seventh closure, demolition and paving production rates reached near the maximum production rates typically achievable in fast-track urban freeway rehabilitation in California.

The poor subgrade condition caused significant bottlenecks at the FDAC section. Consequently, grading, aggregate placement and compaction activities took more time than planned and thus constrained the overall project progress. Having backup equipment in the contingency plan allowed the contractor to mitigate some of the unexpected problems. If an agreement for a remediation measure for the unstable subgrade had been in effect prior to the start of the weekend closure, the contractor could have completed the PBA-6a paving on time in the first closure. Due to the poor subgrade, AC paving at the FDAC section took longer than planned while AC overlay paving at the CSOL section was completed on or ahead of schedule. At the FDAC section, the paving crew was not only less productive, but their production rates fluctuated greatly because of the mixed use of windrow and non-windrow (hopper) paving processes and difficulty in accommodating the alignment changes within the relative short distance.

The daytime paving production was slightly faster and more stable than the nighttime paving at both the CSOL and FDAC sections. No noticeable difference in the paving production rates was observed between the AC mix types except that the production rate of the first AC layer was considerably less than those of the subsequent layers. This may be due to the difficulty in starting up paving for the first layer, and is likely due in part to the extra compaction required for the rich bottom. On some occasions, contractor production rates slowed toward the end of the operation. It was not clear if these decreases in productivity were attributable to crew fatigue, resource constraints, rectification of non-conformances from the prior operation (such as errors or mistakes in elevation), intentional slowdowns, or some combination of these factors.

Sometimes a long queue of up to 20 HMA delivery trucks was observed while other times the paving crew could not make progress due to HMA delivery delays. If the AC production and paving were coordinated and synchronized more efficiently, both the HMA delivery and paving production rates could have improved. The adverse effect of faster and repeated production on quality was observed from time to time. For example, an increasing frequency of HMA segregation (pockets of coarse or fine material) after the placement and compaction was noticed especially during the seventh closure.

The impact of 55-hour weekend closures on traffic was tolerable, mainly due to the well-developed TMP, the agency's comprehensive public outreach campaign publicizing the construction project and potential impacts on traffic, and the compliance of traveling drivers to the Caltrans outreach campaign. There was no traffic congestion, and traffic was at free-flow speed during the weekend construction. Overall, the traffic measurement data were consistent with those estimated by the TMP. The CWZ traffic volume increased as the weekend closures were repeated and almost reached the CWZ capacity, probably showing the drivers' learning curve from experience gained from successive closures and their decision making with regard to route choice to detours or through the CWZ.

7.0 CONCLUSIONS

The existing PCC pavement along the 4.4-km stretch of Interstate 710 in Long Beach, California was rehabilitated successfully with long-life asphalt concrete in eight 55-hour weekend closures, two weekends earlier than the initial Caltrans contract plan. The project proved that asphalt concrete is viable with respect to construction productivity when designed to meet long-life pavement rehabilitation design criteria, even on the most heavily truck loaded route in the state.

The traffic monitoring study revealed that no congestion occurred during the 55-hour weekend closures, thus maintaining free flow speed on the whole network during construction. The results clearly showed a significant traffic reduction through the CWZ, increased traffic on neighboring freeways and detour re-routing to arterials during the weekend closures. The study results also provided some useful information about patterns of driver re-routing through the CWZ during the weekend closures and the associated learning effect.

It is anticipated that the rehabilitation scheme and lane closure tactics adopted for this project, (i.e., repeated 55-hour extended weekend with counter-flow traffic) will be utilized on future LLPRS projects on urban freeways in California. The results of this study will be useful for transportation agencies and contractors trying to maintain a balance between maximization of construction productivity and minimization of traffic delay in developing construction and traffic management plans for highway rehabilitation with high traffic volume.

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