Fast-Track Urban Freeway Rehabilitation with 55-H Weekend Closures: I-710 Long Beach Case Study

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Abstract: As an asphalt concrete demonstration project implemented under the California Department of Transportation's Long-Life Pavement Rehabilitation Strategies program, a 4.4 km stretch of Interstate-710 (I-710) in Long Beach was successfully rehabilitated during eight repeated 55-h extended weekend closures using around-the-clock construction operations and counterflow traffic. This case study documented the accelerated rehabilitation process, assessed traffic impacts, and compared collected productivity data. Compared to the productivity rates of traditional nighttime closures, the 55-h weekend closures effectively reduced the construction duration and the overall traffic inconvenience. Noticeable improvement ("learning-curve effect") in the contractor's production rates was observed as the weekend closures were repeated. As a result of a significant (38%) traffic demand reduction through the work zone, the traffic impact of construction closures was tolerable to the extent that traffic was in free-flow condition throughout the highway network. This case study will be useful for transportation agencies and contractors in developing integrated construction and traffic management plans for urban freeway rehabilitation projects to maximize pavement life expectancy and construction productivity while minimizing agency and road user costs.

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Introduction

Need for Highway Rehabilitation in California

Rehabilitation of urban freeways is a critical issue confronting the California Department of Transportation (Caltrans) as more than 90% of the 78,000 lane/km of the state highway system have exceeded their original 20 year design lives and show extensive signs of distress requiring immediate rehabilitation and reconstruction (Caltrans 1998). In response to ever-increasing maintenance and rehabilitation backlogs and continual shrinkage in the available budget, Caltrans decided to introduce long-life pavements for rehabilitation of deteriorated urban freeways. It was expected that the savings over the life of the pavements, in terms of reduced maintenance and rehabilitation requirements, decreased numbers of traffic delays, and reductions in accident exposures for freeway users, would offset the initial premium cost of long-life pavements.

In 1998, Caltrans launched the Long-life Pavement Rehabilitation Strategies (LLPRS) program with an estimated $1 billion investment plan for rebuilding approximately 2,800 lane/km of severely distressed urban freeways over the next 10 years (Caltrans 1998). Most of candidate segments were concrete paved interstates in the urban highway networks of the Los Angeles (80%) and the San Francisco Bay, Calif. (15%) areas. For these candidate segments under high traffic volumes, Caltrans' goal was to provide pavements with design lives of 30 plus years while: (1) minimizing traffic disruptions and road user cost; (2) providing a safe work environment for construction workers and freeway users; and (3) reducing impacts on the neighboring business community and the environment.

Since the launch of the LLPRS program, Caltrans has completed two demonstration projects utilizing 55-h weekend closures (from 10 p.m. Friday to 5 a.m. Monday) with the around-the-clock construction operations. The first project was on Interstate I-10 (I-10) near the city of Pomona where a 2.8 lane/km segment of a deteriorated concrete truck lane was rebuilt with fast-setting hydraulic cement concrete in one 55-h weekend closure in the fall of 1999 (Lee et al. 2002). The second was the I-710 Long Beach project, as introduced in this paper, where a 4.4 km stretch of badly damaged concrete pavement was rehabilitated with long-life asphalt concrete (AC) pavements during eight 55-h weekend closures in the spring of 2003.

Study Objectives and Methodology

This case study summarized the state-of-practice strategies used to accelerate construction and minimize traffic impacts on the

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I-710 Long Beach project, fast-track urban freeway rehabilitation in California. The construction study monitored the as-built process and progress over three of eight 55-h weekend closures, paying particular attention to the hourly progress of major operations in conjunction with truck cycle times allowed by repeated weekend closures.

Beginning with construction data from the first LLPRS demonstration on I-10 Pomona, Calif., Caltrans has been developing a contractor's production rate database that can be used for future LLPRS construction management planning documentation. The collected construction progress data is stored in the reference database of the construction analysis for pavement rehabilitation strategies (CA4PRS) software, which was designed to estimate the minimum duration of LLPRS projects under a given set of project constraints, including schedule interfaces, pavement design, construction logistics, and traffic operations (Lee and Ibbs 2005).

The study also evaluated the contractor's "learning-curve effect" in achieving the project's monetary incentive compensation goal, comparing production rate changes, as the weekend closures were repeated, on similar rehabilitation processes in accelerated construction under schedule pressure. Similarly, the construction case study quantitatively compared production rates from the perspective of different operation variables, such as delivery methods, surface conditions, and pavement designs.

A traffic monitoring study was conducted simultaneously to evaluate the traffic delay impact of the weekend closures on a highway network under high traffic volumes. The traffic impact was assessed and quantified with the measurement of changes in traffic statistics (volume, speed, and travel time) by comparing "before-construction" (historical) and "during-construction" weekends.

This study, based on collected construction data, traffic data, and lessons learned, was designed to help Caltrans engineers and other transportation agencies assess and refine construction and traffic management plans for future high volume urban freeway rehabilitation to maximize construction productivity and minimize traffic delay. The study will be useful for contractors in developing accelerated construction staging plans that account for the effects of the learning curve across repeated, short, intense work periods.

Unique Features of I-710 Project

Project Overview

The I-710 Long Beach project was to rebuild, with long-life AC, about 4.4 centerline km (total of 26.3 lane/km) of the six-lane concrete segment (including median and outside shoulders) of I-710 near the Port of Long Beach. The main rehabilitation work was completed in eight 55-h weekend closures. First opened to the public in the early 1950s, the freeway segment is a heavily congested commuter/truck route, carrying an average daily traffic (ADT) of more then 164,000 vehicles during weekdays with heavy trucks accounting for close to 13% of the total traffic (Caltrans 2003). Having been in service for more than 50 years without a major rehabilitation, and subjected to the heavy axle loads by the high percentage of truck traffic, the existing concrete pavements were severely deteriorated with excessive cracking and faulting contributing to poor ride quality.

Two rehabilitation strategies were implemented for the existing pavements consisting of 203 mm Portland cement concrete (PCC) slabs on top of cement treated base (CTB) and aggregate base (AB) layers. For most of the segment (2.8 km total length), the PCC slabs were cracked, seated, and overlaid (CSOL) with AC. Under four overpass structures (1.6 km total length), where minimum clearance requirements did not allow an AC overlay, full-depth asphalt concrete (FDAC) reconstruction replaced the old PCC slab, CTB, and AB, with additional excavation to comply with the Federal Highway Administration interstate bridge clearance requirements.

In the project's special provisions (SP), a total of ten consecutive 55-h weekend closures were allowed for the main rehabilitation work of CSOL AC overlay and FDAC reconstruction operations. An unlimited number of 7-h nighttime closures (from 9 p.m. to 4 a.m.) were permitted for the preparatory works, including widening and upgrading of median and outside shoulders and replacement of the old median metal guardrails with new concrete barriers. The placement of the final surfacing layer (25 mm rubberized AC layer) was carried out during the subsequent 7 h nighttime closures after completion of the weekend closures for the main rehabilitation work.

The SP included a monetary incentive/disincentive clause to encourage earlier project completion and on time reopening of the freeway. The contractor was entitled to an incentive amount of \$100,000/weekend closure if the main rehabilitation work was completed in fewer than ten weekend closures. Conversely, the contractor was subjected to a disincentive penalty of \$100,000 if more than ten weekends were required for the designated work. The total amount of incentive or disincentive was limited to \$500,000.

The preparatory works in the median started in April 2001 with an initial total contract amount of \$16.7 million. A number of unexpected problems, such as hazardous asbestos in the median, roadway alignment discrepancies between the plan and actual surveys, and delay in finalizing AC mix binder contents, were encountered, but these problems did not cause any substantial traffic delay impact. They did push the start of weekend closures back about 1 year to March 2003. Encouraged by the incentive award, the contractor was however able to complete all the main rehabilitation work by the eighth weekend closure in June 2003, two weekends ahead of the initial Caltrans plan. The final construction cost, including additional compensations for contract change orders to address the above-mentioned adverse issues, increased to about \$20 million at the end.

Long-Life Pavement Design

Fig. 1 shows the 230 mm AC overlay design specified for the CSOL sections. It includes four AC layers containing either AR-8000 (PG64-16) or PBA-6a (PG64-40) binders on top of cracked and seated PCC pavement. The use of both binders (i.e., conventional AR-8000 with high stiffness and polymer modified PBA-6a with larger rut resistance) was intended to reduce the pavement section thickness while ensuring adequate fatigue and rutting performances. The pavement reinforcing fabric between the first two AC lifts was to serve as a stress-absorbing interlayer to slow down reflection cracking from the bottom. The rubberized AC open-graded friction course (OGFC) was intended to serve as a sacrificial top layer for top-down cracking and to reduce tire splash and spray, hydroplaning potential, and tire noise

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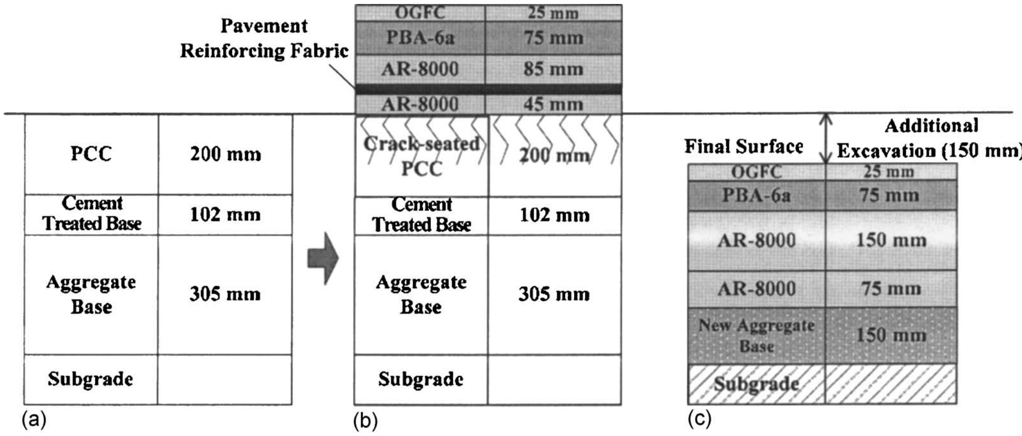

Fig. 1. Typical pavement cross-section changes: (a) existing pavement; (b) CSOL [crack, seat, and AC overlay (230 mm)]; and (c) FDAC (full-depth AC replacement (325 mm)]

as well. It was intended that this OGFC would be periodically (about every 10–12 years) removed and replaced during the service life of the pavement.

As also shown in Fig. 1, the pavement design for the FDAC sections consists of 325 mm AC layers on top of 150 mm of new AB layer. The FDAC pavement design incorporated the same AC materials as specified in the CSOL pavement design, except for the first AR-8000 rich bottom layer, to provide additional stiffness and fatigue resistance.

The asphalt mix designs for the project were obtained using mix design/analysis technology developed through the Strategic Highway Research Program (St. Martin et al. 2001). The CSOL and FDAC pavement sections were designed using mechanistic-empirical design methodologies to accommodate 200 million equivalent single axle loads for a life of 30 plus years. Prior to the start of the project, the rutting resistance of PBA-6a mix designs was verified through heavy vehicle simulator testing (Deacon et al. 2002).

55-h Extended Weekend Closure

I-710 Long Beach was Caltrans' first major LLPRS urban freeway rehabilitation project to incorporate a series of 55-h weekend closures. The 55-h weekend closure alternative was implemented for this project because peak hourly traffic volumes through the I-710 Long Beach area are significantly lower on weekends than on weekdays: 4,300 versus 5,400 vehicles/h. It was anticipated that the weekend schedule would produce far fewer traffic delays.

The decision was also based upon experience with the previous I-10 Pomona LLPRS project. There hourly rehabilitation progress during a 55-h weekend closure, utilizing around-the-clock construction operations, was observed to be nearly 40% greater than the hourly progress achieved using 7- or 10-h nighttime closures (Lee et al. 2002). The large difference in the rates of progress was mainly due to the portion of time nighttime closure crews spent on mobilization/demobilization and traffic control, or "nonworking" activities. This suggested that nighttime closures in the urban highway network would result in longer overall closure time, therefore higher construction and traffic handling costs, and potentially greater traffic delay costs for freeway users.

Of key importance to the goals of the LLPRS program, 55-h weekend closures generally allow a focus on creating long-life pavements that 7- and 10-h nighttime closures do not. In the past, rehabilitation of urban freeways in California was done during 7- or 10-h nighttime closures. However, the types of pavement structures that can be constructed during short-term nighttime closures are limited to types with service lives of no more than 10–15 years, far short of the 30 plus year design lives envisioned for LLPRS projects. The 55-h closures were also expected to ensure better surface conditions, while pavement structures designed for nighttime closures are generally expected to have relatively inferior surface condition and ride quality, in part due to the limitations on construction quality control imposed by tight time constraints. Finally, the estimated volume of materials to be hauled away and brought into the site for LLPRS projects was too large to be handled efficiently within such a short time frame.

Traffic Control and Management

In order to maintain traffic flow while ensuring a safe environment for both construction workers and freeway users, Caltrans applied "counterflow traffic," wherein both directions of traffic were temporarily aligned to the traffic roadbed on the other side of the construction roadbed through predetermined openings in the median, called "traffic crossovers." The outside shoulder on the traffic roadbed was temporarily converted to a main traffic lane to provide two traffic lanes in each direction and movable concrete barriers (MCBs) were installed as a safety divider between the two directions of traffic (Fig. 2). At the beginning and end of each weekend closure, both directions of the freeway were completely closed for about 6–8 h for installation/removal of the MCB and pavement striping while traffic was being detoured to the local arterial roads.

During the project's design stage, a microscopic simulation study was conducted to estimate the impact of weekend closures on the traffic network (Lee et al. 2004). The simulation estimated that with a traffic handling capacity through the construction work zone (CWZ) of 3,000 vehicles/h (with two lanes open for each direction), well below the weekend peak demand of 4,300 vehicles/h, weekend peak hour delays of as much as 220 min would likely occur. In order to encourage diversion to arterial roads and neighboring freeways and induce a reduction in traffic demand through "no-shows," several methods of informing the freeway users of potential delays and alternate routes were included in the Caltrans' traffic management plan (TMP). These included public awareness campaigns, portable and permanent changeable message signs (PCMSs), and highway advisory radio

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Fig. 2. Around-clock construction operations and counterflow traffic with MCB

messages. In total, 230 roadway guide signs and 26 PCMSs were installed on the traffic network during each weekend closure.

Accelerated Rehabilitation Construction

Fig. 3 shows the contractor's critical path method (CPM) schedule during a typical 55-h weekend closure. Because of extreme time, space, and resource constraints, the CSOL overlay and FDAC replacement operations were performed around the clock with activities being planned concurrently. Considerable amounts of schedule float were assigned to the FDAC replacement activities against the possible adverse subgrade condition. The following are the major rehabilitation activities performed during the typical weekend closure:

1. Traffic closure:
   - Set up CWZ signs and close both directions of the freeway temporarily;
   - Set up MCB and place temporary striping and markers on the traffic roadbed; and
   - Open counterflow traffic through the traffic roadbed.
2. CSOL rehabilitation:
   - Crack and seat existing PCC pavement;
   - Place 45 mm of AR-8000 leveling course;
   - Install pavement reinforcing fabric; and
   - Place 85 mm of AR-8000 and 75 mm of PBA-6a.
3. FDAC reconstruction:
   - Fracture (rubblize) and remove existing PCC pavement;
   - Excavate CTB and AB layers and cut subgrade;
   - Place 150 mm of new AB layer; and
   - Place 75 mm of AR-8000 rich bottom, 150 mm of AR-8000, and 75 mm of PBA-6a.
4. Traffic opening:
   - Place striping and markers on new pavement;
   - Close both directions of the freeway again;
   - Relocate MCB to the median and restore the original striping and markers; and
   - Remove CWZ signs and reopen both directions of the freeway.

During each weekend closure, the paving crew started with the CSOL AC overlay operation, then proceeded to the FDAC AC paving once the compaction on new AB was completed. The median and outside shoulder were completely overlaid or replaced with AC along with three main traffic lanes, in four strips (pulls), each approximately 4.3 m in width. An alternating strip paving sequence between the lanes was used to avoid potential paving stoppages due to AC cooling time required.

Contractor Quality Control

The project's SP included a contractor quality control requirement that held the contractor responsible for the final AC pavement quality. The contractor was required to submit shear and fatigue test results on his AC materials for mix design approval and field performance test results on three AC quality characteristics: (1) asphalt content; (2) gradation; and (3) percent of maximum theoretical density. Payment to the contractor for AC was adjusted based upon a combination of pay factors determined for the three quality characteristics with weighting factors of 0.3 for asphalt content, 0.3 for gradation, and 0.4 for percent of maximum theoretical density. The maximum achievable compensation adjustment factor was 1.05 with a minimum acceptable factor of 0.90. The inclusion of the pay factor clause effectively encouraged quality awareness and quality workmanship on the part of the contractor.

Activity	Duration (Hours)	Early Start	Early Finish
Traffic Full Closure	8	FR 23:00	SA 06:59
CSOL Rehabilitation			
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 Reconstruction			
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

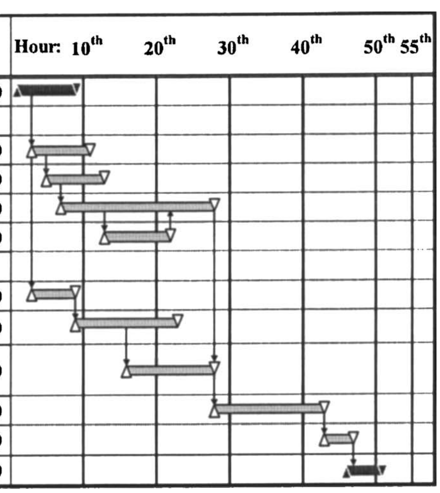

Fig. 3. Typical CPM schedule for 55-h extended weekend closure (second weekend closure)

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Table 1. Production Summary of 55-h Extended Weekend Closures

Periods	Activities	Unit	Estimated quantity	Duration (h)	Average trucks per hour	Average hourly production rate
First weekend closure	CSOL AC overlay	t	7,595	22.2	14.9	341.6
	FDAC demolition/excavation	m^3	3,342	20.8	18.4	161.1
	FDAC AC paving	t	4,204	18.5	10.1	227.9
Second weekend closure	CSOL AC overlay	t	4,846	12.4	17.8	393.0
	FDAC demolition/excavation	m^3	4,939	24.0	25.6	205.8
	FDAC AB placement	m^3	1,059	10.1	14.5	104.5
	FDAC AC paving	t	6,208	24.2	11.5	256.6
Seventh weekend closure	CSOL AC overlay	t	7,089	20.0	15.8	355.3
	FDAC demolition/excavation	m^3	3,200	13.9	30.5	231.0
	FDAC AB placement	m^3	1,100	7.9	15.0	139.5
	FDAC AC paving	t	3,877	12.3	13.9	314.4

Productivity Monitoring

Monitoring Method

The contractor started the first weekend closure on March 28–31, 2003 and completed all the designated main 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 weekends with bad weather. The research team monitored the contractor's as-built process and progress during the first, second, and seventh weekend closures as the planned work scope and resource configurations were relatively similar to each other during these periods.

Initially, a global positioning system (GPS) was to be used for tracking rehabilitation progress and cycle times for hauling and delivery trucks. Tracking measurements were eventually done manually when the accuracy of available GPS devices was deemed to be inadequate. During each weekend closure, 10–12 monitoring staffs were stationed around the CWZ for recording the planned and actual activity durations, material quantities, truck cycle times, and hourly production rates of the major rehabilitation activities. This was more comprehensive monitoring than that which was done for the study on the I-10 Pomona reconstruction (Lee et al. 2002). The contractor's station benchmarks, placed along the outside shoulders, were referenced to keep track of the hourly activity progress, and all the trucks mobilized for the major activities were individually marked with reflective magnetic placards for recording hourly truck discharges and turnaround cycles. Table 1 summarizes the contractor's as-built progress of the major rehabilitation activities over the three monitored weekend closures.

Utilized Resources

During each 55-h extended weekend closure, the contractor maintained two alternating shifts of about 40 site personnel for the around-the-clock rehabilitation operations. Each shift consisted of one AC paving crew, two demolition/excavation crews, one pavement reinforcing fabric placement crew, and one PCC cracking/seating crew. Major demolition equipment included two excavators, three front loaders, two motor graders, one milling machine, four mechanical breakers (also known as "stompers") for rubblizing PCC slabs, and two guillotine breakers for PCC slab cracking. Paving equipment included two self-propelled asphalt pavers (one with a hopper only and the other with a hopper and a windrow elevator), two pneumatic-tired rollers, three vibratory steel rollers, one water tank truck and one tack coating truck. Additional backup equipment was on standby near the work site with stockpile materials at the backup batch plant. On average, a total of 35 demolition hauling and 42 hot mix asphalt (HMA) delivery trucks were mobilized at each weekend closure.

Demolition and Base Placement Productivities

Two concurrently working demolition/excavation crews removed an average of 3,827 m^3 of PCC solids and road base materials in 19.6 h during each weekend closure, similar to the contractor's planned 19.3 h. The average hourly truck loads hauled away by the two crews was 24.2 with about 5 min loading time per truck. The dumping yard was located approximately 4 km from the project site near the Port of Long Beach and the average turnaround time of the hauling trucks was 42 min.

The PCC removal (demolition) was completed as scheduled, but the roadway excavation (including subgrade cutting and compaction) took longer than planned, especially during the first weekend closure when the operation was abruptly stopped for hours due to the unstable subgrade lacking CTB and AB layers above as indicated in the contract drawings. The equipment workability on the compacted subgrade materials was extremely low as they contained an excessive amount of salt, making it difficult to compact to the required density.

If such unfavorable subgrade soils were encountered, the contractor was supposed to excavate another 150 mm of the poor subgrade and replace it with new aggregates. Unfortunately, at the time of the first weekend closure, Caltrans and the contractor could not agree on a contingency procedure for the subgrade remediation due to a discrepancy in each party's unit cost for aggregate base. Because of time constraints and lack of aggregate stockpiles on hand at the first weekend closure, it was decided to place a 50 mm AR-8000 working platform on top of the poor subgrade without replacing it with new aggregates. In the subsequent extended weekend closures, all unstable subgrade was replaced with new aggregates. Consequently, the excavation quantity increased significantly compared to the initial plan and standby equipment was deployed to handle the additional quantity within the limited time slot.

The placement of new AB was concurrently carried out with the subgrade excavation. During the second and seventh closures, the two demolition/excavation crews placed an average of 1,080 m^3 of new aggregates in 9.0 h as scheduled by the contractor. On average, 14.7 truckloads of aggregates (recycled

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from PCC slabs removed at the previous weekend closure) were placed onto the subgrade soils with an average truck turnaround time of 1 h and 3 min. By performing both operations simultaneously, the contractor managed to incorporate this activity into the 55-h work schedule without making significant changes.

AC Paving Productivities

CSOL AC Overlay

During each weekend closure, the CSOL paving crew placed an average of 6,523 t of HMA in 18.2 h, 12% faster than the planned 20.7 h. Hourly paving rate ranged between 112.9 and 542.0 t/h with the average rate of 358.4 t/h. The windrow paving process allowed continuous paving operation with minimized truck waiting time. On average, 16.0 double-dump semitractor trailers [also known as semibottom dump trucks (SBTs)] arrived at the paving site per hour and discharged HMA windrows at a rate of about 4 min/truck. With the distance to the batch plant being close to 50 km from the project site, the average turnaround time of HMA delivery trucks was 2 h and 13 min.

FDAC AC Paving

The FDAC paving crew, who finished the CSOL AC overlay at first, placed an average of 4,763 t of HMA in 18.3 h during each weekend closure, 20% slower than the planned 15.3 h. The hourly paving rate varied between 33.3 and 472.9 t/h with the average rate of 259.8 t/h. On average, 11.6 truckloads of HMA were placed per hour with about 5 min discharging time per truck. The average turnaround time of the HMA delivery trucks was 2 h and 26 min.

The average hourly paving rate at the FDAC sections was about 28% less than that observed at the CSOL sections. The unstable subgrade condition was one of the main reasons for this sharp decrease in the FDAC paving crew performance. For instance, during the first weekend closure, motor graders had to be used to place the AR-8000 working platform and AR-8000 rich bottom course as the paver got stuck repeatedly in the weak subgrade. During AC compaction, subgrade soils were pumped out at some locations and these soils had to be removed manually, causing further delay in progress. The relatively short length (about 400 m) of the FDAC sections also contributed to the paving slowdown as the frequency of paving stoppage (while bringing the paver back to the original starting point after finishing each pull) increased. The FDAC paving crew also experienced difficulty in accommodating changes in pavement alignment within such a short distance.

Use of double end-dump trucks for the delivery of the AR-8000 working platform and AR-8000 rich bottom lift (during the first and second closures only) also contributed to the loss in the FDAC paving productivity. Compared to the CSOL AC overlay operation (i.e., windrow paving process), where multiple SBTs simultaneously laid down HMA windrows, the paving progress was noticeably slower as each end-dump truck had to individually unload the HMA into the paver's hopper. The double end-dump trucks also required a significant amount of setup time to separately unload the HMA in the truck bed and the attached trailer. Based upon its experiences, the contractor expected that use of nonwindrow paving process (with less productive double end-dump trucks) was more appropriate as the two AC lifts would be placed over loosely bound and uneven surface. Starting from the third weekend closure, all AC lifts including AR-8000 rich bottom were placed using the windrow paving process.

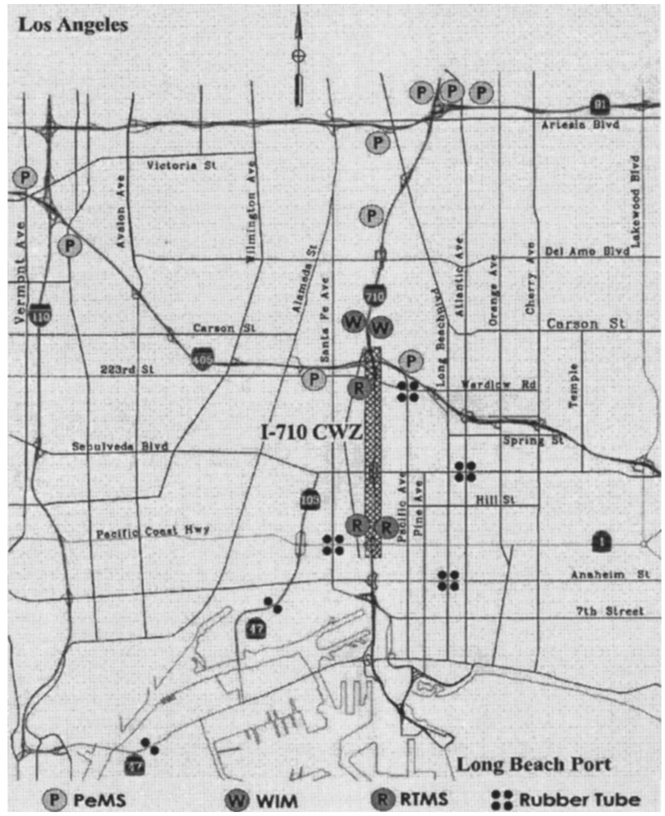

Fig. 4. Traffic study area showing locations of traffic monitoring devices

Traffic Impact Measurement

Monitoring Devices

The traffic impact of 55-h weekend closures was monitored by measuring changes in the traffic network performance (volume, speed, and time) between weekends before and during construction. Traffic measurements were performed throughout all eight weekend closures over the network study area of about 20 km×20 km in size (Fig. 4) to find out any changes in traffic pattern as the weekend closures went on. Traffic surveillance devices utilized included:

1. Loop detectors on the California Freeway Performance Measurement System and weigh-in-motion on the I-710 corridor and neighboring detour freeways;
2. Remote traffic microwave sensors, radar detection devices installed roadside along the CWZ;
3. Rubber tubes to measure a traffic demand change at ramps and intersections on detour arterials; and
4. Tach-run vehicles to measure real-time travel time and speed along the CWZ.

Traffic Study Summary

The results showed a significant reduction in traffic demand (volume) through the CWZ throughout the weekend closures, similar to what was estimated in the TMP. Compared to the historical (before-construction weekends) average rates, 39% decrease in the ADT volume and 37% decrease in the peak hour traffic volume were observed as the freeway users rerouted to local arterials and neighboring freeways (Table 2). During the

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Table 2. Comparison of Traffic Flows between Before- and During-Construction Weekends

Period	Traffic measurements	Northbound	Southbound
Weekends before construction	Average daily traffic (vehicles/day)	61,255	61,044
	Peak hour traffic (vehicles/h)	4,299	3,900
Weekends during construction	Average daily traffic (vehicles/day)	38,667	35,544
	Peak hour traffic (vehicles/h)	2,733	3,498
Traffic demand reduction (%)	Average daily traffic	36.9	41.7
	Peak hour traffic	37.2	35.8

weekend closures, the traffic volume on the parallel arterial roads, which were designated as detours in the TMP, increased about 14% on average. However, there was no significant change in traffic volume on the neighboring freeways, except on the parallel Harbor Freeway (Interstate-110) where traffic increased about 7%. Overall, the total traffic demand reduction across the network study area was only about 1%, compared to 5% estimated in the TMP, indicating that the detoured drivers re-entered the freeway via the detour arterial roads around the CWZ.

The results also showed a steady traffic demand increase through the CWZ as the weekend closures were repeated. During the first weekend closure, the peak hour traffic volume was 1,350 vehicles/lane/h. This peak hourly rate gradually increased in the succeeding weekend closures and finally stabilized at around 1,500 vehicles/lane/h, which was believed to be near the maximum traffic capacity under the counterflow configuration with two lanes in each direction. The CWZ traffic increase appeared to reflect the drivers' dynamic response and learning curve as, during the first weekend closure, they observed that delays were not going to be as significant as they had anticipated. Overall, the traffic measurements suggested that the impact of the weekend closures was tolerable as there was no significant congestion and traffic was in free-flow condition throughout the traffic network, including the I-710 corridor, neighboring freeways, and detour arterials.

Lessons Learned and Conclusions

Lessons Learned

Being fast-track construction, the I-710 project emphasized the need for having a comprehensive contingency plan in place against all possible adverse events. The unstable subgrade encountered during the first weekend closure caused a temporary suspension and difficulty in schedule control for the rehabilitation operations at the FDAC section. However, the contractor was able to mitigate some of the geotechnical problems by deploying the backup equipment that was on standby near the site. Prior agreement on the contingency procedures in the event of unstable subgrade could have prevented the loss of productivity at the FDAC sections and helped the contractor to stay on schedule during the first weekend closure.

Use of repeated weekend closures for similar types of rehabilitation operations led to significant improvements in the contractor's production rates (learning-curve effect), especially in the demolition/excavation and paving operations. Between the first and seventh weekend closures, the contractor's demolition/excavation production rate improved about 43%, while the combined production rate for paving (i.e., average of CSOL and FDAC paving) increased by about 18%.

The notable increase in the demolition/excavation production rate occurred as the contractor made an extra commitment in terms of resources and scheduling after realizing that this operation was the most critical, constraining overall project progress under the unstable subgrade condition. According to the postconstruction interviews with Caltrans construction engineers and the contractor, and comparison with the productivity data collected from the I-10 Pomona and I-15 Devore LLPRS projects, the demolition and paving production rates observed during the seventh weekend closure were believed to be near the maximums possible for fast-track urban freeway rehabilitation in California with the currently available equipment and methods.

The average nighttime paving rate (from 7 p.m. to 7 a.m.) was slightly slower (about 10%) than the average daytime rate at both CSOL and FDAC sections. No noticeable difference in the paving rate was observed between the AR-8000 and PBA-6a asphalt mixes being placed with the windrow paving process. Sometimes, long queues of up to 20 HMA delivery trucks were observed while at other times, the paving crew could not make any progress due to delivery delays. The HMA delivery and paving synchronization problems were mostly caused by lack of coordination between the site and the batch plant rather than traffic congestion on the delivery routes. More efficient coordination between HMA production and paving could have resulted in consistent paving progress and improved the overall paving production rate.

The comprehensive TMP and extensive public awareness campaigns enabled the contractor to have efficient access to the site and minimized the turnaround time of demolition hauling and HMA delivery trucks. The results obtained from implementation of the TMP were considered a complete success as it induced a significant traffic demand reduction through the CWZ, as much as 38% during the weekend peak hours, thus allowing traffic to flow safely without any significant congestion on one side of the freeway while intensive construction progressed on the other side. The project won the 2003 Roadway Workzone Safety Awareness Award in the category of "Innovations in Technology (Methodology—Large Projects)," sponsored by American Road and Builders Association and the National Safety Council. Caltrans utilized the monitored construction and traffic data together with their lessons learned from this I-710 project as a reference in developing construction staging and traffic management plans for the first large-scale LLPRS implementation project on I-15 in Devore (Lee et al. 2005).

The monetary incentives/disincentives proved to be effective in this fast-track rehabilitation project as it inspired creativity and ingenuity on the part of the contractor in reducing the number of

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extended weekend closures. The contractor was awarded an incentive amount of $200,000 for the two weekends early completion and was compensated about $70,000 extra for exceeding the minimum AC quality control requirements.

Summary and Conclusions

This paper presented the fast-track rehabilitation process and progress that were monitored during the first long-life asphalt concrete pavement rehabilitation project in California. Though there was some schedule delay and cost overrun in the initial preparation phase, the project proved that 55-h weekend closures with counterflow traffic and around-the-clock construction operations is a viable option that can drastically shorten overall construction time and thus lessen traffic inconvenience in urban areas. With completion of the major rehabilitation work two weekends ahead of schedule, it is estimated that millions of dollars were saved in the end from fewer traffic delays and accident exposures for freeway users.

Overall, the productivity monitoring results indicated that the contractor's staging plans for the main rehabilitation work were generally accurate and reliable. Almost all the planned activities were completed during each weekend closure and the freeway was reopened to the public by Monday 5 a.m. after every weekend closure. Use of repeated weekend closures for similar types of rehabilitation operations led to a noticeable improvement in the contractor's production rates in the succeeding weekend closures and enabled the contractor to complete the main rehabilitation work ahead of schedule.

The traffic monitoring results revealed that the comprehensive TMP with proactive public outreach was successful as it induced a significant traffic demand (volume) reduction at the CWZ and the traffic maintained the free flow speed throughout the network study area. The monetary incentive and pay factor proved to be effective as they encouraged the contractor to expedite site operations while ensuring quality workmanship in the accelerated rehabilitation. As fast-track construction, this project emphasized the need for a comprehensive contingency plan in place against all possible adverse events. It is expected that the repeated extended closures with counterflow traffic scheme will be continuously utilized in future long-life urban freeway rehabilitation projects in California.

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