Case Study of Urban Concrete Pavement Reconstruction on Interstate 10

Eul-Bum Lee[1]; Jeff Roesler[2]; John T. Harvey[3]; and C. William Ibbs[4]

Abstract: Many urban concrete pavements in California need to be reconstructed, as they have exceeded their design lives and require frequent maintenance and repair. Information is needed to determine which methodologies for pavement design, materials selection, traffic management, and reconstruction strategies are most suitable to achieve the objectives of California Department of Transportation's (Caltrans) long-life pavement rehabilitation strategies (LLPRS) program. To develop construction productivity information for several construction windows, a case study was performed on a Caltrans concrete rehabilitation demonstration project near Los Angeles on Interstate-10, where 20 lane-km was successfully rebuilt using fast setting hydraulic cement concrete (FSHCC) with one weekend closure for 2.8 lane-km and repeated 7- and 10-h nighttime closures for the remaining distance. The concrete delivery and discharge controlled the overall progress. In terms of the number of slabs replaced per hour, the 55-h weekend closure was 54% faster than the average nighttime closure. An excellent traffic management strategy helped to reduce the volume of traffic during the weekend closure and minimize the traffic delay through the construction zone.

DOI: 10.1061/(ASCE)0733-9364(2002)128:1(49)

CE Database keywords: Case reports; Urban areas; Concrete pavements; Reconstruction; California; Interstate high-ways.

Introduction

Most urban concrete pavements in California have exceeded their design lives and are in a state of deterioration requiring frequent maintenance and repair (Caltrans 1996). The reconstruction and rehabilitation of these urban concrete pavements is very important to the California Department of Transportation (Caltrans). In 1998, Caltrans launched the long-life pavement rehabilitation strategies (LLPRS) program to rebuild 3,000 lane-km of the state highway network over 10 years. Caltrans expects the concrete pavement to be constructed efficiently with minimal user disruption. When Caltrans launched LLPRS initially, they assumed that fast-track construction of long-life urban concrete pavements would result in a 30-year pavement design, increased safety for users and agency personnel during construction, and reduced user delay costs. To properly assist Caltrans in completing this task, contractors want to be reasonably confident that the project can be completed within the tight guidelines of fast-track construction with the added long-life pavement features specified by Caltrans.

Very little urban reconstruction of continuous truck lanes has been completed to date in California. Most previous work has consisted of replacement of individual slabs and did not include long-life pavement features such as dowels and tie bars. Caltrans needed to determine which pavement designs, materials, traffic management, and reconstruction strategies were most suitable to help achieve their objectives for long-life pavement and minimal traffic delay.

The main objective of the Univ. of California at Berkeley (UCB) research was to collect information during one weekend (55-h) and repeated nighttime (7- and 10-h) construction closures on Interstate-10 (I-10) in Pomona, Calif. The goal of the case study was to report an overview of the project, traffic management strategies utilized, the contractor's resource and scheduling plans, construction constraints, actual construction productivity and rehabilitation procedures, and a comparison of estimated versus actual productivities (Lee et al. 2000c).

Major Features of Pilot Project

Project Background

I-10 begins in Jacksonville, Florida and extends across the southern United States and terminates in Santa Monica, Calif. The segment running through Southern Calif., commonly called the "San Bernardino Freeway," was built in the early 1960s with a 20-year design life. It has a high concentration of deteriorated concrete pavement. Traffic volumes in this stretch of freeway are as high as 240,000 vehicles—average daily traffic (ADT)—with approximately 9% heavy trucks.

Caltrans selected a 5-km (3.3 mi) stretch from Route 57/210 to Garey Avenue in Pomona (Los Angeles County) as a pilot project for evaluating several of their long-life pavement strategies. Fast setting hydraulic cement concrete (FSHCC), dowels, and tie bars

[1]Postdoctoral Researcher, Construction Engineering and Management Program, Dept. of Civil and Environmental Engineering, Univ. of California Berkeley, Berkeley, CA 94720. E-mail: eblee@uclink4.berkeley.edu

[2]Assistant Professor, Dept. of Civil And Environmental Engineering, Univ. of Illinois at Urbana-Champaign, IL 61801.

[3]Associate Research Engineer, Pavement Research Center, Institute of Transportation Studies, Univ. of California Berkeley, Richmond, CA 94804.

[4]Professor, Construction Engineering and Management Program, Dept. of Civil and Environmental Engineering, Univ. of California Berkeley, Berkeley, CA 94720.

Note. Discussion open until July 1, 2002. Separate discussions must be submitted for individual papers. To extend the closing date by one month, a written request must be filed with the ASCE Managing Editor. The manuscript for this paper was submitted for review and possible publication on August 31, 2000; approved on April 23, 2001. This paper is part of the ***Journal of Construction Engineering and Management***, Vol. 128, No. 1, February 1, 2002. ©ASCE, ISSN 0733-9364/2002/1-49–56/$8.00+$.50 per page.

J. Constr. Eng. Manage., 2002, 128(1): 49-56

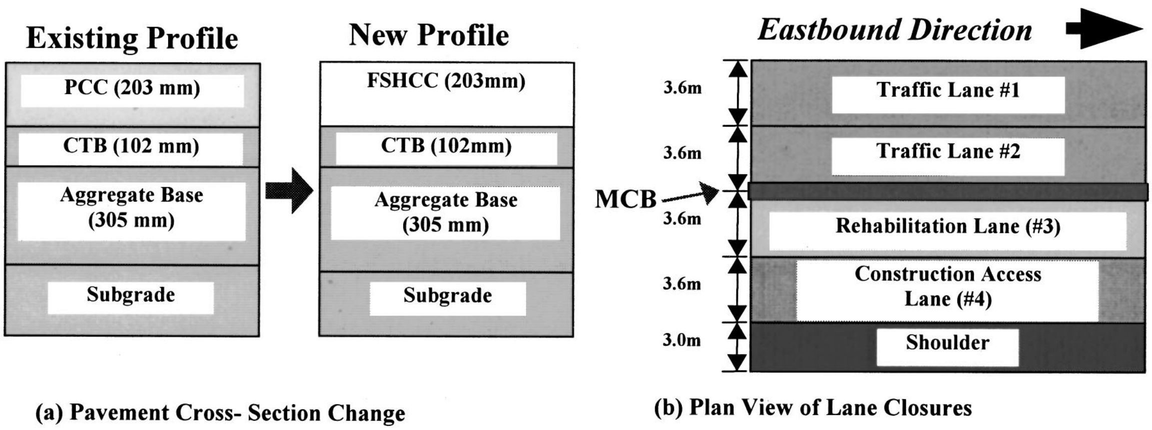

Fig. 1. Cross-sectional change and plan–view of lane closures

were included in the lane rehabilitation strategy. The purpose of the pilot project was to evaluate reconstruction of a truck lane with long-life pavement features and the use of FSHCC to minimize traffic delays during a 55-h weekend closure.

In early 1999, Caltrans awarded a $15.9 million contract to Morrison Knudsen Corporation (MK) of Highland, Calif. to complete the project. The total volume of FSHCC was estimated at 14,000 m^3 to rehabilitate about 20 lane-km of concrete pavement. This 20 lane-km consisted of 5 centerline-km of freeway for eastbound and westbound I-10 in the two truck lanes. The rehabilitation contract began in April 1999 and was completed in February 2000.

Scope of Pavement Rehabilitation

During the 55-h weekend closure, the main rehabilitation task was removal and replacement of the concrete slab without disturbing the cement treated base (CTB). In several locations where the CTB was badly deteriorated, both the slab and CTB were removed and replaced. The existing 230-mm Portland cement concrete (PCC) slab was replaced with the same thickness of FSHCC, as shown in Fig. 1(a). In a previous report to Caltrans on lane rehabilitation (Lee et al. 2000a, 2000b), replacement of the slab and CTB was found to be 50% less productive than replacement of the slab only.

Unique Features of I-10 Project

The I-10 rehabilitation project has several unique features as follows:

- Caltrans decided to use one 55-h weekend closure to check how many lane-km of existing PCC slab could be replaced with new FSHCC instead of repeated nighttime closures and how a weekend closure would impact traffic conditions.
- The contractor used a slab lift-out method for the concrete slab demolition operation. This method was intended to protect the underlying CTB from damage. Caltrans hoped this nonimpact method of demolition would expedite the demolition process and release the slab demolition activity from the potential constraints of the rehabilitation process.
- During the weekend closure, movable concrete barriers (MCBs) were used instead of rubber cones or K-rail between the traffic and rehabilitation lanes.
- Although the traditional low bid concept was used for the I-10 project, incentive and disincentive conditions were applied to the segment being built during the weekend closure to encourage the contractor to achieve the rehabilitation production objective (Herbsman et al. 1995). An incentive payment would be made to the contractor in the amount of $600 per lane-meter, for each lane-meter replaced in excess of 2,000 lane-m during the weekend closure (Caltrans 1998). Disincentive would be assessed in the amount of $250 per lane meter for each lane meter less than 2,000 lane-m. The incentives were capped at $500,000. A liquidated damage clause was provided in the contract to ensure the closure was open to traffic on Monday morning ($10,000 liquidated damages per each 10-min period).

7- and 10-Hour Nighttime Closures

The 20 lane-km of existing concrete pavement was to be rehabilitated with repeated nighttime closures except for a 2.8 lane-km stretch to be replaced during the 55-h weekend closure. Work completed in the nighttime closures consisted of replacing individual and/or multiple slabs in a row.

Two types of nighttime closure construction windows were implemented. Ten-hour nighttime closures (10 p.m.–8 a.m.) were implemented for the eastbound freeway and during weekend nights for westbound I-10. Seven-hour nighttime closures (9 p.m.–4 a.m.) were used for the westbound lanes during weekday nights due to the greater traffic volumes heading into downtown Los Angeles during the morning commute. Ten-hour closures covered approximately 64% of the nighttime closures while the 7-h closures covered 36%.

55-Hour Weekend Closure

Caltrans required two of the four lanes to remain open while rehabilitation work was underway. The asphalt concrete shoulder could not be used as a full access lane, because a sound wall limited the shoulder width to 2–3 m.

The 55-h weekend closure began at 10 p.m. on Friday, October 22, 1999, and the rehabilitated lanes were to be opened to traffic again at 5 a.m. on Monday, October 25, 1999. During the weekend closure, 2.8 lane-km were to be removed and replaced in Lane 3 with Lane 4 as the construction access in the eastbound direction as a plan view of the freeway in Fig. 1(b) shows the lane closure tactics utilized.

In the first kilometer of the project, two lanes were assigned for construction access—Lane 4 for main access and the shoulder

J. Constr. Eng. Manage., 2002, 128(1): 49-56

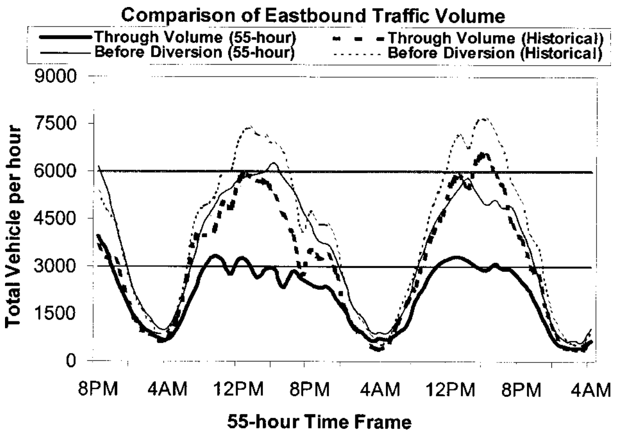

Fig. 2. Traffic levels before versus during construction

as an auxiliary access. For the remaining two-thirds of the project, only Lane 4 was assigned as the construction access because of the narrow shoulder and sound wall. The reduction in the number of access lanes significantly impacted the demolition operation, because trucks entering or exiting the demolition area were blocked by other trucks being loaded.

Traffic Management

Traffic Management Plan

Prior to the 55-h weekend closure, Caltrans and the contractor made a large effort to disseminate information about the I-10 project through media outlets. To control traffic and inform the public of detours during the weekend closure, approximately 100 message and signboards were installed on neighboring freeways, highways, and main arterials near the I-10 corridor.

The goal of the Caltrans traffic plan was to divert as many road users from the I-10 corridor onto alternative routes during the weekend closure. Caltrans advertised the I-10 project plan through sources such as newspapers, television, radio, and flyers for both nighttime and the 55-h weekend closure. Connector route entrances from other freeways as well as two entrance ramps and three exit ramps were closed to the public during the weekend construction but remained open to construction vehicles.

Impact of Weekend Closure to Road Users

With the assistance of Caltrans Traffic Management in District 7, traffic volume data were analyzed to understand the trends of road users during the weekend closure. The traffic data were compared with historical weekend traffic data. Fig. 2 shows that the total traffic volume on two lanes through the construction zone was reduced over historical volumes on four lanes. However, maximum capacity was reached for two lanes (1,500 vehicles/h/lane) during peak hours, similar to typical weekends when capacity was reached for all four lanes. This indicates traffic was still moving at the same level of service as on an average weekend, albeit in only two lanes.

During the weekend closure, the eastbound traffic volume passing through the project site at peak hours (Saturday and Sunday 9 a.m.–9 p.m.) was 30–60% less than peak traffic during typical weekends. The low traffic flow through the construction zone during the day resulted from more road users taking alternate routes than on typical weekends. The total eastbound traffic volume during the weekend closure was 5–35% less than typical weekend peak hours. Off-peak hour vehicles were not concerned about the weekend lane closures, so diversions during nighttime hours were only 5% less than historical volumes. The overall reduction in traffic volumes on I-10 during the peak hours indicates that road users were well informed. According to Caltrans traffic management, the calculated delay for the project was 19 min based on measured traffic flow data and assuming a maximum flow capacity per lane of 1,500 vehicles/h.

Fast Setting Hydraulic Cement Concrete (FSHCC)

Caltrans selected FSHCC to reduce the concrete curing time for opening to traffic. The cement utilized was Rapid Set, a proprietary cement from CTS Cement Manufacturing Company. The specification required a concrete flexural strength of 2.8 MPa (400 psi) after 4 h and 4.2 MPa (600 psi) within 28 days. The early age strength requirement eliminated PCC from consideration in this project.

FSHCC begins initial set after about 1 h and final set occurs after about 80 min. If the concrete is not discharged shortly after batching, then it begins to build up on the mixer fins in the drum. Traffic congestion on the way to the site, construction zone traffic jams, or a backup in discharging of the preceding mixer trucks may result in rejection of a load, increased buildup in the mixer drum, and/or the temporary loss of the mixer truck from service.

Productivity During 55-Hour Weekend Closure

Contractor's Initial Rehabilitation Plan

The prime contractor for the I-10 project was in charge of drilling holes for tie bars, installing dowel bars, placing the concrete, controlling traffic, and handling the MCB. All other activities, such as demolition, concrete production and delivery, and testing were subcontracted.

The CPM schedule showing the main activities of the rehabilitation with start times, finish times, and duration is summarized in Table 1. The contractor expected that the activities on the critical paths were mobilization, slab removal, FSHCC paving, clean up wash-out areas, apply pavement markers, cure FSHCC, pick up MCB, and open ramps and connectors. The contractor realized that if one activity lagged in production or a breakdown occurred, then the whole rehabilitation process could be delayed, which would jeopardize the targeted completion goal of 2.8 lane-km. For this reason, MK included redundancy in major equipment, including the batch plant, demolition trucks, excavators, paving screeds, and concrete delivery trucks.

In the initial demolition plan, seven end dump trucks were assigned to each demolition team. Three demolition crews could be used at the beginning, as two construction access lanes were initially available (Lane 4 and the shoulder). A 92 m^3/h capacity dry mix batch plant from a subcontractor was exclusively used for the project during the weekend closure. A standby batch plant was arranged with the same stock of materials for contingency. Two rotating concrete screeds were mobilized for concrete paving with one screed being used for backup. MK planned to mobilize approximately 35 people for coordination, paving, and traffic control.

Traffic Controls

The first step of the weekend rehabilitation process was traffic control. Traffic control activities were setting up traffic signs,

J. Constr. Eng. Manage., 2002, 128(1): 49-56

Table 1. Proposed Schedule versus Actual Schedule for Weekend Closure

Number	Work activity	Proposed Schedule Start	Proposed Schedule Finish	Proposed Schedule Duration (h)	Actual Schedule Start	Actual Schedule Finish	Actual Schedule Duration (h)
1	Set traffic control	−2.0	−1.0	1.0	−2.0	−1.0	1.0
2	Install moveable concrete barrier	0.0	1.0	1.0	0.0	2.0	2.0
3	Slab demolition	0.0	17.0	17.0	0.5	30.5	30.0
4	Cleaning subbase	0.0	17.0	17.0	1.0	31.0	30.0
5	Drill/tie bar install	0.0	26.0	26.0	2.0	40.0	38.0
6	Dowel baskets	0.0	26.0	26.0	3.0	41.0	38.0
7	Concrete paving	2.0	49.0	47.0	3.5	50.5	47.0
8	Concrete curing	49.0	53.0	4.0	50.5	55.0	4.5
9	Saw cut	4.0	51.0	47.0	6.0	52.5	46.5
10	Pavement marker	45.0	53.0	8.0	45.0	53.0	8.0

Note: Time 0 starts at 10 p.m. on Friday.

closing of entrance/exit ramps and connectors from other routes, and installing MCBs for the lane closure. The contractor began to set up traffic signs 2 h before the lane closure.

The MCB segments were already placed and lined up on the outside shoulder before the weekend closure and only needed to be shifted into place (between Lanes 2 and 3) by a transfer and transport machine. MCB installation for the whole 2.8 lane-km segment was performed within 30 min.

A few days prior to the weekend closure, Caltrans requested a contingency plan from the contractor to open the rehabilitated lane to traffic within 2 h of a notice by the resident engineer. Caltrans issued a letter to the contractor stating the demolition progress could not be more than 20 slabs ahead of the paving operation. The reason for this action was to avoid large delays to the road users traveling through the I-10 Pomona corridor. The contractor would be required to open the rehabilitated lanes to traffic if traffic backup on eastbound I-10 was 30 min longer than that of a normal weekend delay.

Demolition of PCC Slab

Impact and nonimpact demolition methods were used for the project. Most areas required only slab replacement (nonimpact demolition method), while a few areas needed the full-depth slab replacement (impact demolition). For the nonimpact demolition process, slabs were already longitudinally saw cut into three parts during previous nighttime closures.

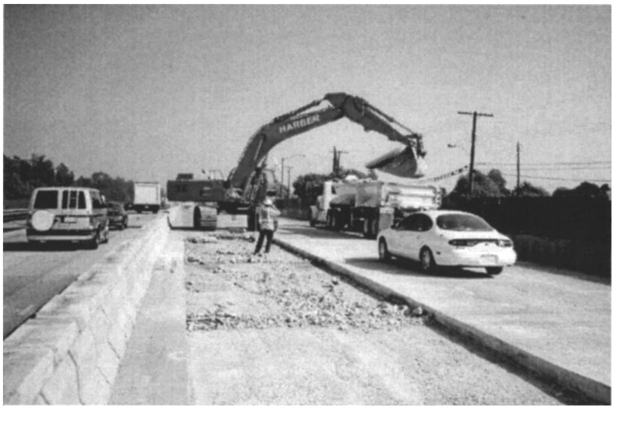

Fig. 3. Nonimpact demolition of existing Portland cement concrete slab

Slab Demolition Process

An excavator with a 1-m^3 bucket capacity and seven end dump trucks were initially assigned to each demolition team. With the nonimpact demolition method, the excavator sat in Lane 3 in front of the concrete that it was removing. The excavator then loaded the old concrete into the end dump truck sitting in Lane 4, as shown in Fig. 3. The loading rate of the slabs into the demolition trucks (nonimpact demolition method) was quicker than that of the rubblized slabs (impact demolition method), because the excavator could more easily remove a few large pieces than many smaller pieces. The dumping area was located about 8 km from the job site. Cleaning the base with a front-end loader followed right after the slab demolition.

Where the sound wall was adjacent to the outer shoulder, passage of an empty concrete mixer truck on the way back to the batch plant had top priority. The reason for this was that the concrete paving was the critical activity, and the contractor wanted to avoid buildup in the mixer drums.

As-Built Progress of Slab Demolition

The UCB research team recorded a total of 466 (Table 2) loaded end dump trucks exiting the site to haul out the 615 old concrete

Table 2. Performance of Slab Demolition and Concrete Delivery

Description	Demolition (End dump truck)	Concrete (Mixer truck)
(a) Performance data		
Total number of panels (1 panel = 3.6 m×4.5 m×0.23 m)	—[a]	—[a]
Activity duration (h)	30	47
Total number of deliveries	466	440
Average progression (slabs/h)	20	14
Average volume of delivery	10 t (4.2 m^3)	5.2 m^3
Capacity of truck	22 (9.0 m^3)	6.0 m^3
Efficiency of truck	47%	87%
(b) Statistics of demo/delivery trucks		
Average cycle time (min)	5.5	3.5
Average number of trucks per hour	9	10
Average turnaround (min)	64	74
Efficiency of operation (based on average cycle time)	82%	67%

[a]615.

J. Constr. Eng. Manage., 2002, 128(1): 49-56

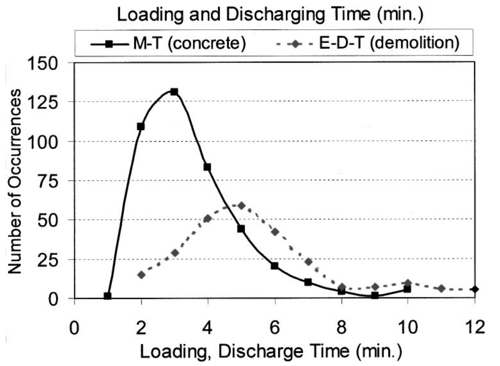

Fig. 4. Demoliton loading time and concrete discharging time

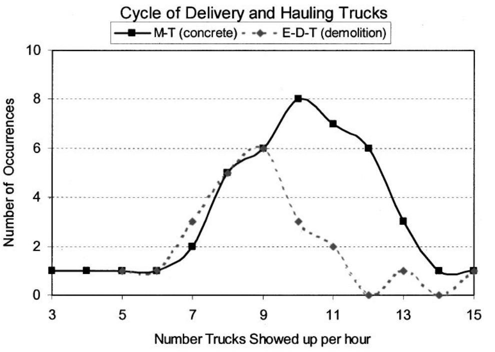

Fig. 5. Number of demolition and concrete trucks per hour

slabs. Although the 22-t capacity end dump trucks used for hauling had a 9-m^3 capacity (2.7 slabs), each end dump truck carried about 4.3 m^3 (1.3 slabs) on average. This meant that only 47% of the total carrying capacity of the end dump truck was utilized, due to the inefficient packing of the large panel pieces.

The average loading time per end dump truck was 5.5 min with a 0.9-min standard deviation, as the distribution of the loading time is shown in Fig. 4. Approximately 9 end dump trucks showed up per hour per crew for demolition with a 2.3 truck standard deviation, as shown in Fig. 5. For every demolition crew, an end dump truck arrived every 7 min. When three crews operated simultaneously, a demolition truck was entering and exiting the construction zone every 2.3 min., and this created construction traffic control problems.

The average turnaround of demolition trucks was measured as 64 min with a 5-min standard deviation, as shown in Fig. 6. Because the turnaround averaged more than 1 h, and the average number of demolition trucks per crew per hour was 9, total 32 demolition trucks had to be mobilized.

Installation of Steel Tie Bars, Bond Breaker, and Dowel Baskets

Tie bars were installed on both sides of Lane 3 during the weekend closure. The tie bars were 16 mm in diameter by 0.75 m in length and were placed at the middle of the slab thickness and spaced 0.75 m apart. The tie bar was inserted into the hole and secured by a fast-setting epoxy. A total of 6,150 holes were drilled in 38 h with two self-propelled gang drill units. The drilling productivity was approximately 80 holes/h/gang drill. This translated into an average progress rate of 72 lane-m/h for the drilling operation. As soon as the tie bar holes were drilled, a 0.15-mm polyethylene sheet was spread on the existing CTB to act as a bond breaker between the CTB and new concrete slab.

Dowel baskets were prefabricated with 10 epoxy coated dowel bars per joint with the steel dowel having a diameter of 38 mm and a length of 0.6 m. A chemical release agent was sprayed on the dowel bars to prevent bonding of the dowel bars to the concrete. Joint locations were chosen to match the existing joints on the adjacent lanes.

Concrete Production and Batch Plant Operation

Dry Mix Batch Plant

A dry mix concrete batch plant (92 m^3 capacity) was used for the project instead of central ready mix drum, because buildup on a central drum plant would occur and eventually slow the overall production of FSHCC. On Saturday around 11:30 a.m., the main concrete batch plant suspended its operation because of an electrical breakdown. The standby batch plant supplied only a limited amount of concrete. Approximately 4 h later, the primary batch plant was on-line and concrete delivery began once again. This temporary loss in concrete production ultimately prevented the contractor from finishing the project ahead of schedule.

Buildup of FSHCC in Mixer Trucks

The contractor took special precautions to prevent buildup by washing out every mixer drum with a high-pressure water jet after the truck had discharged its load. On average, the washout process typically took about 15 min per mixer truck out of 74 min of the average turnaround.

At the batch plant, a large scale was used to measure the weight of an empty mixer truck as soon as the mixer arrived back to the plant from its delivery. The amount of concrete buildup in the mix truck drum was obtained by finding the difference between the measured weight of the returning mixer truck and the empty, clean mixer truck weight. During the weekend project, 1 t of FSHCC buildup in the mixer drum was commonly acceptable, and the mixer was left in service until the amount of buildup accrued to 2～4 t. The buildup of FSHCC in the drum also reduced the effective fin length, which caused concern about the mixing effectiveness. Spare mixer trucks were used once trucks were taken out of service for chipping out the hardened concrete from inside the drum. That is why a total of 27 mixer trucks were mobilized but only 20 mixer trucks were in continuous operation.

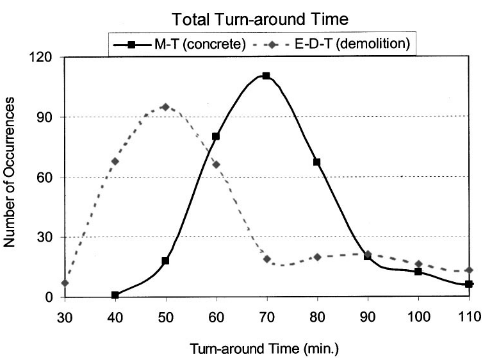

Fig. 6. Total turnaround of demolition and concrete trucks

J. Constr. Eng. Manage., 2002, 128(1): 49-56

Fig. 7. Concrete discharge and paving operation

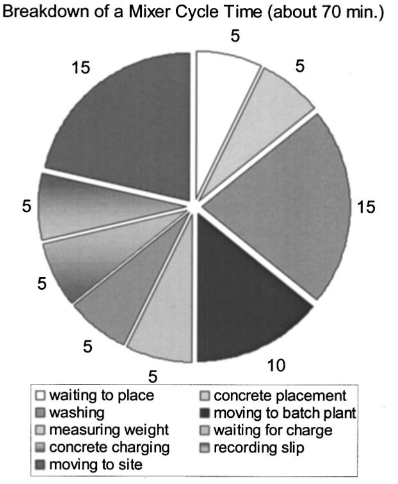

Fig. 8. Components of typical turnaround of mixer truck

Concrete Delivery

Although the batch plant was regarded as the resource most critical to the rehabilitation process, the concrete mixer trucks proved to be the resource most constraining to the project's production rate. Since agitation was required to prevent the FSHCC from setting up, ready mix trucks (rotating drum) had to be used rather than end dump trucks. Due to the potential for concrete buildup in the drums, only 6-m^3 loads were batched into each truck. This load was 20% less than the maximum capacity of the drum (7.5 m^3).

At the site, the mixer trucks were positioned on Lane 4 and discharged concrete into Lane 3 in front of the rotating concrete screed, as shown in Fig. 7. The mixer trucks leaving the site were almost always interrupted by the demolition operation in front of the paving operation.

As-Built Progress of Concrete Delivery

The UCB research team recorded concrete mixer truck delivery data throughout the entire 55-h weekend project. For the 55-h weekend, it took 440 concrete delivery trucks to complete 2.8 lane-km (615 slabs of 4.5-m length and 0.23-m thickness). This is equivalent to 1.4 concrete slabs (4.5 m by 3.66 m) per mixer truck delivery. The average efficiency of each mixer truck was 87%. On average, this meant only 5.2 m^3 out of each 6-m^3 batch from the concrete plant was discharged at the site. The remaining 0.8 m^3 of material lost per truck could be attributed to concrete buildup in the mixer truck, material washed out at the site, and trucks that did not discharge at the site due to other paving factors such as screed breakdown.

The average concrete discharge time per mixer truck was measured at 3.5 min with 0.7-min standard deviation, as shown in Fig. 4. This does not include waiting time and time to position the truck in the correct location. The average time for waiting, positioning, and discharging concrete was found to be 6 min.

On average, approximately 10 mixer trucks discharged concrete per hour with a 2.1-truck standard deviation (Fig. 5). The contractor expected the average turnaround of the mixer trucks to be between 45 and 60 min. The actual average turnaround for the mixer trucks was 74 min with a 4-min standard deviation (Fig. 6). Most likely, the contractor underestimated the time it took to wash out the mixer drum, which consisted of waiting in line, removing concrete chutes, and washing out with a high-pressure water jet. The power washing operation was delayed several times due to insufficient water for rinsing. Traffic during the weekend, particularly during the day, also played a role in increasing the turnaround time.

Breakdown of Concrete Mixer Truck Turnaround Cycle

Fig. 8 shows that 43% of the mixer truck's operational time is spent driving from the plant to the site and back to the plant. This transit time ends up costing the contractor and agency additional money, because more trucks have to be mobilized in order to meet the concrete volume required at the site.

Fig. 8 shows that the concrete production and placement with FSHCC helped to increase the turnaround for the mixer trucks. If the early strength requirements in the specification were relaxed, then PCC could have been used. Concrete batching could have been 50% faster with PCC, because a central mixing drum could have been used to batch the concrete and charge the trucks. The 5 min in the batch plant area for initial mixing could also have been eliminated, because a central drum plant would complete most or all of the mixing process. The washout process could have been reduced to 5 min or eliminated, because PCC does not build up as rapidly as FSHCC in the mixer drums, and weighing the drum for buildup could have been eliminated with PCC.

Based on these estimates, PCC would have decreased the turnaround for mixer trucks by about 30%. This means that an FSHCC operation probably requires 30% more mixer trucks to supply the same volume of concrete at the jobsite. This comparison suggests that there are ideal construction windows where FSHCC is the most efficient material to use for rehabilitation such as 7-h and 10-h nighttime closures, while longer construction windows make PCC the preferred material.

Concrete Paving and Finish Work

The FSHCC had a high slump, because it was being placed by hand. Finishing and texturing were completed by two laborers who floated, trowelled, and broomed the pavement surface behind the concrete screed. Curing compound was sprayed on the surface immediately after finishing and texturing. Approximately 2 h after the concrete was finished, a 44-mm deep saw cut was made for each transverse joint using a single saw team. The condition of the finished concrete pavement surface was rough, but the contractor had planned on diamond grinding the surface later, as part of the contract with Caltrans.

J. Constr. Eng. Manage., 2002, 128(1): 49-56

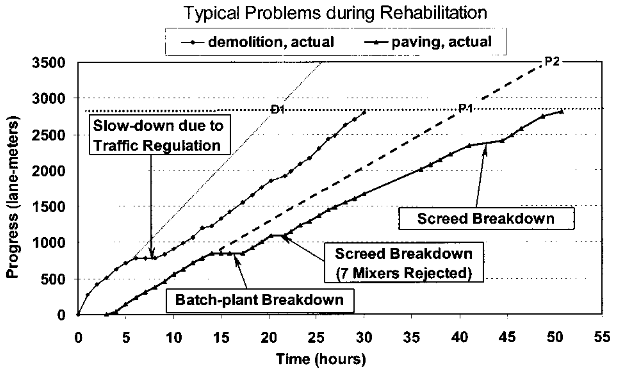

Fig. 9. Overall rehabilitation progress for demolition and concrete paving

Comparison of Actual Progress with Proposed Progress

Table 1 presents a comparison between the planned CPM and the as-built CPM schedule. Most of the activities progressed as planned, except for the existing slab demolition activity, which required an additional 13 h. One cause of the demolition slow down was the constraint placed on the contractor to open the construction site back to traffic within 2 h. During day 2 of the project, the narrow shoulder along with the presence of an adjacent soundwall caused access problems for the demolition operation, and thus it could not efficiently complete the task in the initial specified time.

The actual duration of the paving operation was the same as the contractor's original schedule. Four of the total paving operation hours were due to the batch plant breakdown, which meant the contractor actually had fewer net paving hours than originally planned.

Overall Progress of Rehabilitation

Fig. 9 shows that the planned and actual demolition rates were initially similar, but changed 5 h from the start, due to the reduction in the number of demolition crews to comply with Caltrans' contingency plan for opening the site back to traffic.

As shown in Fig. 9, the paving operation experienced several delays. The batch plant broke down for 4 h, and the paving screed broke down in two instances, temporarily suspending the operation. However, the contractor still achieved the rehabilitation goal within the 55-h weekend. Without the breakdown in the batch plant and the screeds, the contractor could have finished 6 h earlier.

The slope of the paving progress in Fig. 9 shows a gradual slowdown at the end of the operation relative to the initial production rate due to construction fatigue of the paving crew (for example, an average paving production of 77 m/h from hours 0 to 4, while 61 m/h of paving production from hours 24 to 41). The paving crew was observed to work continuously without major shifts or rests during the weekend project. Fig. 9 also indicates that paving productivity was the same for both daytime and nighttime operations.

Discussion of Demolition and Paving Productivity

Further conclusions can be drawn from Fig. 9:

- Based on the initial progress rate shown in Fig. 9, the fastest the concrete slab demolition could have been completed was 22 h based on a maximum of three crews as marked "D1" in Fig. 9. This would have saved the contractor 8 h of labor from the actual duration of 30 h.
- The paving operation could have been completed by hour 42 instead of hour 51 as marked by "P1" in Fig. 9, based in the initial paving rate. If paving could have progressed at this rate, then the rehabilitation project would have been completed in 46 h rather than 55 h.
- The maximum amount of concrete paved, based on the contractor's process, paving rate, and resources, would have been 3.5 lane-km, if the contractor had continued paving at full capacity without any work stoppages during the 55-h construction window. This ideal production of 3.5 lane-km can be read as point "P2" in Fig. 9. Based on the maximum allowable amount of paving, the efficiency of the contractor's paving operation can be calculated as 80% (2.8 lane-km/3.5 lane-km).

Production Comparison of Weekend Closure with Nighttime Closures

A detailed comparison of the slab replacement productivity for the two nighttime closures (7 and 10 h) and the 55-h weekend closure is summarized in Table 3 (Lee et al. 2000c). The definition of productivity used in Table 3 is based on the average number of slabs replaced per hour without consideration of the number of resources involved in the rehabilitation process.

Table 3. Comparison of Productivity for Different Construction Windows

	Nighttime Closure		Weekend Closure
	7-h closure	10-h closure	55-h closure
Closed time	9 p.m.–4 a.m.	10 p.m.–8 a.m.	10 p.m. (Friday)–5 a.m. (Monday)
Net working hours (concrete pouring)	2 h	5 h	43 h
Auxiliary hours (mobilization/curing/demobilization)	5 h	5 h	8 h
Typical production (slabs per closure)[a]	15	50	615
Productivity (slabs per hour)	7.5	10	14
Major resources	7 dump trucks;4 mixer trucks	7 dump trucks;8 mixer trucks	21 dump trucks;12 mixer trucks

[a]Typical panel size is 0.2-m thick×3.6-m width×4.5-m length.

J. Constr. Eng. Manage., 2002, 128(1): 49-56

Table 3 shows that the additional 3 h of work in the 10-h closure versus 7-h closure greatly enhanced the productivity of the nightly operation (50 slabs versus 15 slabs replaced). The 10-h nighttime closures were 33% more productive per hour than the 7-h closures because approximately 5 h were available for the actual slab replacement work versus 2 h for the 7-h closures. Five hours are needed in both types of nighttime closure for mobilization, demobilization, and curing. This can be further extrapolated to 55-h weekend closures, where mobilization, demobilization, and curing times became a smaller percentage of the total project length, and thus more productivity was achieved. In terms of the number of slabs replaced per hour, the 55-h weekend closure was 54% more productive than the average nighttime closure.

The amount of the rehabilitation work done over the 55-h extended closure would have normally taken approximately 16 days of nighttime lane closures to complete. From the road user's point view, when the total duration of lane closures for 16 days of nighttime closure is compared to one weekend closure, the duration of the 55-h weekend closure is only 38% of the 16 nighttime closure duration.

For nighttime closures, a 4-h opening strength material is required to achieve the proper concrete strength to open the lane back to traffic in a relatively short construction window. This is one reason for the use of FSHCC in nighttime closures. The benefits of FSHCC for a 55-h weekend closure may not outweigh its costs, and it may not be the most efficient material to use for weekend closures.

Case Study Conclusions

A 2.8 lane-km rehabilitation project on the I-10 near Los Angeles using fast setting hydraulic cement concrete (FSHCC) was successfully completed during a 55-h weekend closure. The rehabilitation project consisted of replacing the 230-mm concrete slab with new concrete, dowels, and tie bars. The contractor used a concurrent working method in which demolition and concrete paving occurred simultaneously and only a single lane was removed and replaced. Under the Caltrans incentives/disincentives clause in the contract, the contractor qualified for a $500,000 bonus payment for completion of the 2.8 lane-km stretch of rehabilitation over the weekend closure.

Slab demolition took 76% longer than the contractor's proposed schedule, but it did not slow the overall progress of the rehabilitation. The packing efficiency of the end dump trucks for demolition was found to be 47%.

Concrete delivery and discharge at the site were found to be the constraining factors. The average efficiency of the concrete delivery trucks was found to be 87%. FSHCC played a role in reducing the overall efficiency of the concrete mixer truck deliveries, primarily due to material buildup in the mixer drums.

During the weekend closure, an average of 14 slabs were paved per hour. The weekend closure was 54% more productive in terms of slabs replaced per hour compared with previous 7-h and 10-h nighttime closures by the contractor. The amount of the rehabilitation work performed over the 55-h extended closure would have normally taken 16.4 days of nighttime closures.

The estimated comparison of the cycle time of mixer trucks and batch plant for FSHCC and PCC suggests that the ideal construction windows for FSHCC are 7-h and 10-h nighttime closures, while PCC is the preferred material for longer construction windows.

During peak hours (Saturday and Sunday 9 a.m.–9 p.m.), traffic volumes through the construction were reduced by 30–60% compared with the peak traffic during typical weekends. Only two lanes were available instead of four, and traffic operated at capacity in those two lanes during peak hours. The percentage of traffic diverting to other routes doubled during the 55-h weekend closure during the daylight hours, but was only approximately 5% more than normal during the nighttime hours.

Acknowledgments

This paper is based upon work supported by the Innovative Pavement Research Foundation and Federal Highway Administration. Particular gratitude is extended to Morrison Knudsen Corporation and Caltrans Headquarter (Sacramento) and District 7 (Los Angeles) for cooperation with this study.

References

California Department of Transportation (Caltrans). (1996). *1995 state of the pavement*, Caltrans Maintenance Program, Pavement Management Information Branch, Sacramento, Calif.

California Department of Transportation (Caltrans). (1998). "Notice to contractors and special provisions for construction on state highway in Los Angeles County in Pomona from Route 210/57/10 interchange to Garey Avenue undercrossing." *Contract No. 07-181304*, Sacramento, Calif.

Herbsman, Z., Chen, W. T., and Epstein, W. C. (1995). "Time is money: Innovative contracting methods in highway construction." *J. Constr. Eng. Manage.*, 121(3), 273–281.

Lee, E. B., Roesler, J. R., Harvey, J. T., and Ibbs, C. W. (2000c). "Case study of urban concrete pavement reconstruction and traffic management for the I-10 (Pomona, Calif.) project." *Research Reports and Findings No: DTFH61-99-X-00008*, Innovative Pavement Research Foundation, Falls Church, Va.

Lee, E. B., Ibbs, C. W., Harvey, J. T., and Roesler, J. R. (2000a). "Constructability and productivity analysis for long life concrete pavement rehabilitation Strategies." *Final Rep. FHWA/CA/OR-2000/01*, Pavement Research Center, Univ. of California, Berkeley, Calif.

Lee, E. B., Ibbs, C. W., Roesler, J. R., and Harvey, J. T. (2000b). "Construction productivity and constraints for concrete pavement rehabilitation in urban corridors." *Transportation Research Record No. 1712*, Transportation Research Board, Washington, D.C., 13–22.

J. Constr. Eng. Manage., 2002, 128(1): 49-56