Long-Life Rehabilitation Design and Construction
I-710 Freeway, Long Beach, California

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This paper briefly describes the methodologies used for the mix and structural pavement section designs for the rehabilitation of the Interstate 710 (I-710) freeway adjacent to the Port of Long Beach, California, which include asphalt concrete (AC) replacement structures in the vicinity of three overcrossings and AC overlays on the broken and seated existing portland cement concrete pavement sections. Both structural pavement sections have been designed to accommodate estimated traffic of 200 million equivalent single-axle loads.

Critical to the successful performance of these pavement structures in this heavily trafficked section of the I-710 are the construction quality control and quality assurance and mix design requirements. Important aspects of the construction requirements are also discussed, which include strict controls on the aggregate and binder contents as well as the compaction of the mixes utilized in the pavement sections.

Staging of construction including considerations relating to construction management to meet the 55-h weekend closures planned for the freeway are also described. Finally, the paper emphasizes the importance of the partnered effort between the California Department of Transportation, the Asphalt Industry in California, and the University of California at Berkeley, in developing the requisite design and construction requirements for this project.

Interstate 710 (I-710) is located in Southern California, in Los Angeles County. Rehabilitation is scheduled for Spring 2001 and the project has been selected for a long-life pavement design, with a design life of 30 to 40 years. The freeway is a heavily trafficked route and carries traffic in and out of the Port of Long Beach. The specific section of Interstate Route 710 selected for this project is between the Pacific Coast Highway and the I-405 Freeway (Figure 1).

The existing pavement structural section consists of 200 mm (8 in.) of portland cement concrete (PCC), 100 mm (4 in.) of cement treated subbase, 100 mm (4 in.) of aggregate base and 200 mm (8 in.) of imported subbase material. Two rehabilitation strategies have been selected, one for the majority of the section and the other for under the structures. On the sections where the overhead clearance is acceptable, the existing PCC will be cracked and seated and overlaid

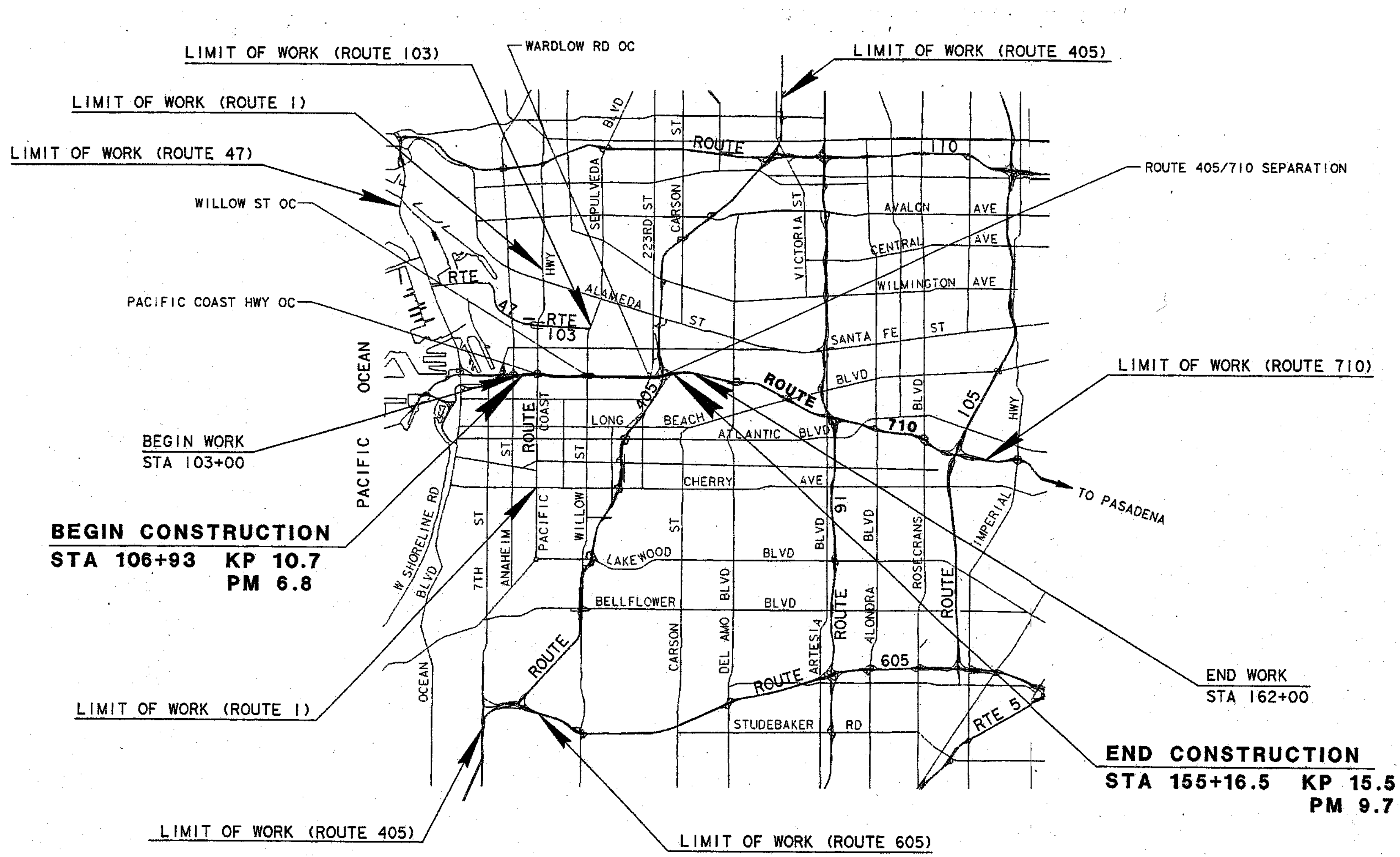

FIGURE 1 Portion of I-710 scheduled for rehabilitation (OC = overcrossing, STA = station, KP = kilometer post, PM = post mile).

with asphalt concrete (AC). Under the structures where minimum clearance requirements do not allow an overlay, full depth AC sections will be utilized and the freeway grade will be reconstructed and lowered to improve the clearance.

This paper briefly summarizes the results of an investigation to design both a suitable AC mix and a full-depth AC structural section containing the mix, or mixes for this segment of the I-710. In addition, included is a brief summary of some of the specification requirements for the mixes to be used for both sections as well as mix compaction requirements and considerations of constructability of the sections within time constraints associated with weekend freeway closure for rehabilitation and reconstruction.

MIX AND STRUCTURAL PAVEMENT DESIGNS

Strategic Highway Research Program (SHRP) mix evaluation technology, enhanced by research resulting from the Caltrans Accelerated Pavement Testing (CAL/APT) Program, was used in preparing both the mix and pavement designs. Binder contents for mixes containing a PBA-6a* polymer modified binder with additional elastomeric components (AASHTO MP-1 designation, PG64-40) and an AR-8000 asphalt cement (AASHTO MP-1 designation, PG64-16) were selected based on the results of the SHRP-developed repeated load simple shear test at constant height (RSST-CH) (*1*). Structural section designs were prepared using mix fatigue test data obtained with the SHRP-developed flexural fatigue test (*2*).

Mix Designs

Laboratory tests were performed on mixes with materials that will be used in construction. The aggregate, an all-crushed San Gabriel material, and the binders were supplied by members of the California asphalt industry, i.e., Vulcan/CalMat and Huntway Refining. The aggregate requirements for the project were changed to 100 percent crushed with the coarse aggregate containing two crushed faces. This is in contrast to current standards for the coarse aggregate which are 90 percent crushed and one crushed face (*3*).

Results of the RSST-CH obtained at 50°C (122°F) were used to select the binder contents for the two mixes. Essentially, the mix design consisted of selecting the highest binder content which permits the mix to accommodate the design traffic at the critical temperature [in this case 50°C (122°F)] without exceeding a limiting rut depth of 12.5 mm (0.5 in.) (*4*). Results of the RSST-CH tests are shown in Figure 2 together with associated traffic repetitions at 50°C (122°F) converted to equivalent laboratory repetitions. Because of its greater resistance to permanent deformation, the mix containing the PBA-6a* binder is planned for use as the surface course. A design binder content of 4.7 percent (by weight of aggregate) was selected for the estimated laboratory equivalent of 660,000 repetitions. Because of structural considerations, the AR-8000 mix was selected for the rest of the pavement section. Since it would likely be subjected to trafficking prior to placement of the PBA-6a* mix, a binder content of 4.7 percent was also selected to preclude premature rutting. The 146,000 repetitions shown in Figure 2 were the maximum equivalent laboratory repetitions that the AR-8000 mix would be expected to sustain prior to placement of the PBA-6a* mix.

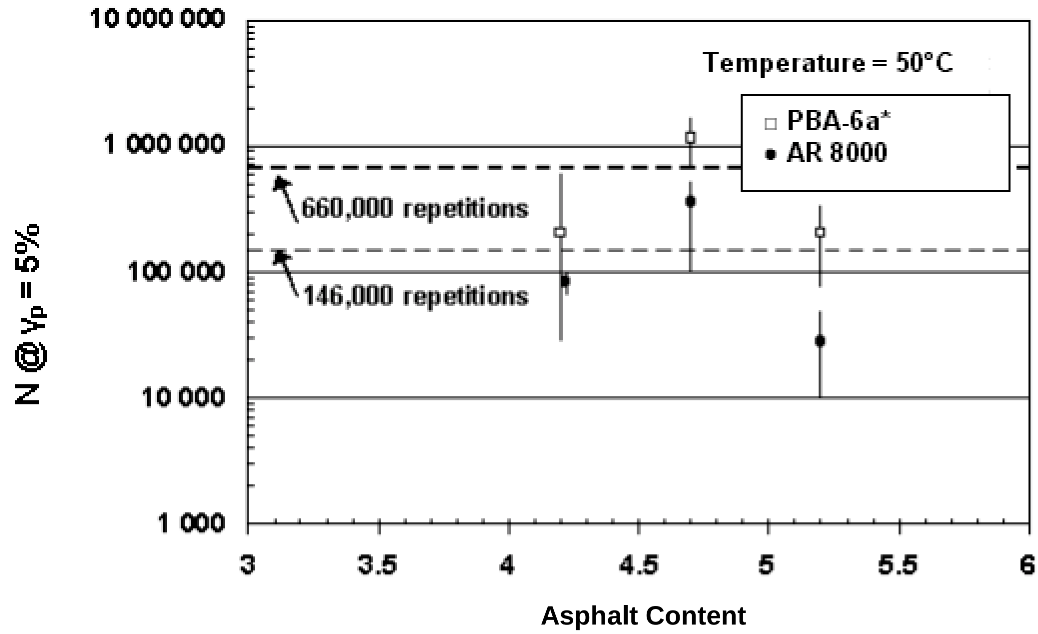

FIGURE 2 RSST-CH repetitions to 5 percent permanent shear strain versus binder content (percent by weight of aggregate).

Structural Section Designs

Underneath the overcrossing, it is not possible to place an overlay and maintain the vertical clearance; therefore, a full depth asphalt concrete section was designed to replace the existing PCC structural section. This design will be used at three locations, 305 m (1000 ft) in length at each location. Over the remainder of the project, an asphalt concrete overlay will be placed on broken and seated PCC.

The full depth AC was designed using multilayer elastic analysis. The procedure requires determination of the principal tensile strain on the underside of the AC pavement to mitigate bottom-up fatigue cracking; and determination of the vertical compressive strain at the subgrade surface to minimize the contribution of the layers below the AC to surface rutting. Fatigue resistance and stiffness of the mixes were determined using the SHRP-developed flexural fatigue test, which permits determination of a relationship between the applied tensile strain and the load repetitions to cracking.

The full-depth structural section includes the use of a rich-bottom design for the lower portion of the full-depth AC (*5*); the binder content is 0.5 percent higher than the design binder content. Increasing the binder content facilitates greater compaction, which improves the fatigue resistance of the mix. Rutting resistance of the pavement is not compromised because this layer is at the bottom of the AC.

The recommended structural section resulting from the analyses is shown in Figure 3*a*. The section consists of mixes containing the AR-8000 mix (because of its higher stiffness) and the PBA-6a* mix (because of its higher rut resistance). Use of both mixes gave the thinnest pavement section while ensuring the required fatigue and rutting performance. In addition, an open-graded friction course with an asphalt-rubber binder will be used as the wearing course. Its purpose is to reduce tire splash and spray, hydroplaning potential, and tire noise, and to serve as a layer that reduces the potential for aging in the PBA-6a* mix and that can be replaced periodically.

For the overlay section, a finite element analysis was performed to select the total thickness above the cracked and seated existing PCC pavement. The resulting section is shown in Figure 3*b*. As seen in this schematic, the same materials as used in the full-depth replacement sections

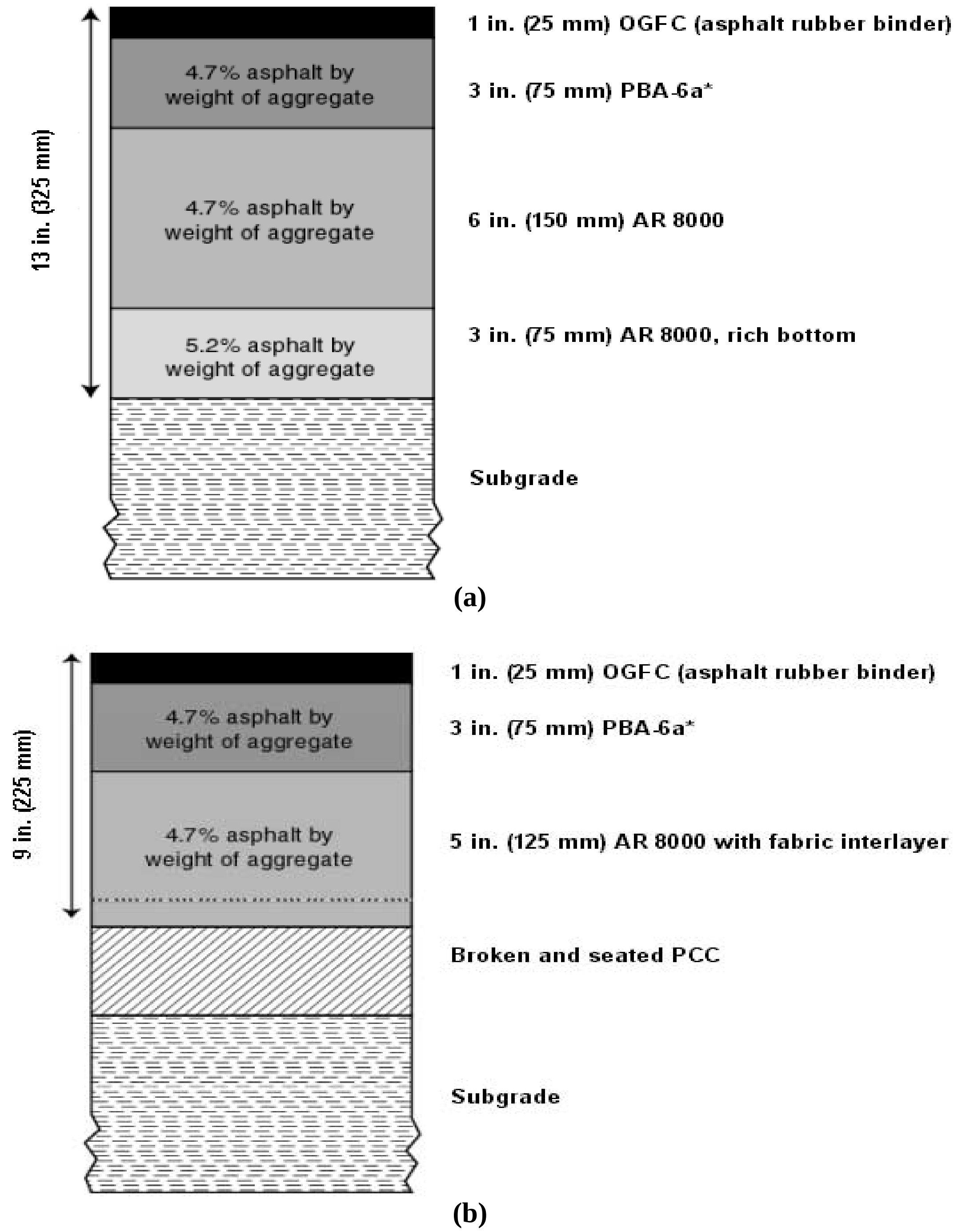

FIGURE 3 Proposed design for Interstate 710 rehabilitation: (a) replacement section and (b) overlay section.

are incorporated. Also, the California Department of Transportation (Caltrans) practice of using an asphalt-saturated fabric interlayer has been recommended to reduce the potential for reflection cracking.

Heavy Vehicle Simulator Test

To evaluate the mix design prior to rehabilitation construction, an overlay was constructed on an existing jointed PCC pavement at the Richmond Field Station (RFS) of University of California, Berkeley (UC Berkeley). The overlay consisted of 75 mm (3 in.) of the mix with the PBA-6a* binder over 75 mm (3 in.) of the AR-8000 mix, both at 4.7 percent binder content.

The California asphalt industry shipped aggregate representative of the type likely to be used on the project from Southern California. Industry representatives also supplied the binders (Huntway Refinery), prepared the mixes at a central batch plant (operated by Dumbarton Quarries), and placed the mixes at the RFS site (O. C. Jones Engineering and Construction). Both layers were compacted to about 6 percent air-void content.

Following construction, the heavy vehicle simulator (HVS) shown in Figure 4 was used to load the PBA-6a* mix with about 10,000 repetitions per day of a 40 kN (9,000 lb) load on dual tires with a cold inflation tire pressure of 690 kPa (100 psi). The temperature of the pavement was maintained at the critical temperature, 50°C (122°F), at a 50 mm (2 in.) depth. [A description of HVS and its use in pavement evaluation is included in *Caltrans Accelerated Pavement Test Program* (*6*).]

Results of the accelerated loading on the PBA-6a* mix carried to about 170,000 channelized repetitions are shown in Figure 5. Also shown in the figure are results obtained from an earlier study using both a dense-graded AC with AR-4000 asphalt cement (Stabilometer "S" value = 43) and an asphalt rubber gap-graded hot mix (Stabilometer "*S*" value = 23). It will be noted that the PBA-6a* mix performed significantly better in terms of rutting than the other two mixes (*6*).

FIGURE 4 Heavy vehicle simulator.

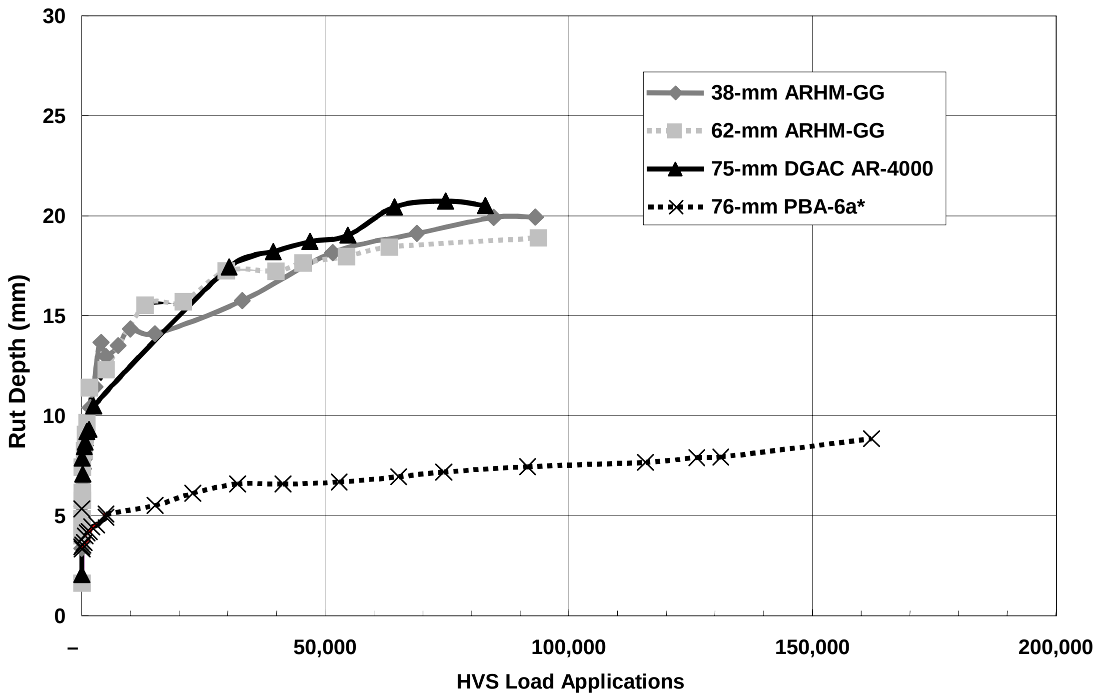

FIGURE 5 Rut depth versus HVS load applications with 40 kN load on dual tires at 50°C.

Construction Considerations

For successful performance of these pavement structures, strict attention to pavement construction will be required. This necessitates careful control both of the mix components and mix compaction.

Prior to construction, shear and fatigue test data must be submitted by the contractor to Caltrans for mix approval. This requirement has been incorporated in the project specifications to insure that the mixes to be used by the contractor meet the performance characteristics shown in Table 1 (*7*). These characteristics correspond to those used in the mix and pavement design processes. In addition, prior to construction, materials must be submitted to Caltrans for verification of these mix characteristics.

During mix production the contractor is required to provide the minimum process control requirements shown in Table 2 (*7*).

Compaction and other quality control requirements are summarized in Table 3 (*7*). The mixes containing the PBA-6a* mix and the AR-8000 at a binder content of 4.7 percent should be compacted to an air void content of about 6 percent [93 to 97 percent of theoretical maximum density (ASTM D 2041)], whereas the rich-bottom mix should be compacted to an air-void content of not more than 3 percent. It should be emphasized that this project, which uses ASTM D 2041 as the basis for compaction control, is a departure from the current Caltrans procedure (*4*).

Current Caltrans practice does not require a tack coat between lifts for multiple lift construction; the decision to use a tack coat is made on a case-by-case basis by the resident construction engineer. For the I-710 project, this practice has been changed and a tack coat will be required between each lift. This change in practice is based upon an evaluation of the performance of HVS test sections as a part of the CAL/APT program.

TABLE 1 Asphalt Concrete Mixture Performance Requirements (*7*, Table 39-3A)

Design Parameters		Test Method	Minimum Requirement
Permanent Deformation	PBA-6a* (modified)[2]	AASHTO TP7-94 modified[1]	660,000 stress repetitions[3,4]
	AR-8000[2]	AASHTO TP7-94 modified[1]	132,000 stress repetitions[3,4]
Fatigue	PBA-6a* (modified)[5,6]	AASHTO TP8-94 modified[1]	7,000,000 repetitions[4,8] 60,000,000 repetitions[4,9]
	AR-8000[5,7]	AASHTO TP8-94 modified[1]	300,000 repetitions[4,8] 15,000,000 repetitions[4,9]

NOTES: [1] Included in the testing guide provided upon request.
[2] At proposed asphalt binder content and with mix compacted to 3±0.3% air-void content.
[3] In repeated simple shear test at constant height (RSST-CH) at a temperature of 50°C.
[4] Mean of 3 specimens.
[5] At proposed asphalt binder content and with mix compacted to 6±0.3% air voids [determined using AASHTO 209 (Method A)].
[6] At proposed asphalt binder content, minimum stiffness at 20°C and a 10 Hz load frequency must be equal to or greater than 150,000 psi (1000 MPa). At proposed asphalt binder content, minimum stiffness at 30°C and a 10 Hz load frequency must be equal to or greater than 45,000 psi (300 MPa).
[7] At proposed asphalt binder content and 6±0.3% laboratory air voids [determined using AASHTO 209 (Method A)], minimum stiffness at 20°C and a 10 Hz load frequency must be equal to or greater than 900,000 psi (6200 MPa). At proposed asphalt binder content plus 0.5 percent and 3±0.3% laboratory air voids [determined using AASHTO 209 (Method A)], minimum stiffness at 20°C and a 10 Hz load frequency must be equal to or greater than 990,000 psi (6800 MPa).
[8] At 300×10^{-6} mm/mm. Results shall be reported for this strain level but may be obtained by extrapolation. Minimum number of repetitions required prior to extrapolation defined within test procedure.
[9] At 150×10^{-6} mm/mm. Results shall be reported for this strain level but may be obtained by extrapolation. Minimum number of repetitions required prior to extrapolation defined within test procedure.

CONSTRUCTIBILITY CONSIDERATIONS

The project specifications have been written to allow the Contractor to overlay and reconstruct from 10 p.m. Friday to 5 a.m. Monday. A construction window of 55 h has been provided with the anticipation that the project will completed during 10 or fewer weekend closures. A total of about 4.8 km (3 mi.) of the freeway will be rehabilitated, including 2.8 km (1.8 mi.) of the break, seat, and overlay alternative (BSOL), shown in Figure 3b, and 2.0 km (1.2 mi.) of the full depth asphalt concrete (AC), shown in Figure 3a. For the full depth alternative, some excavation is required of the cement treated base and aggregate subbase so that the clearance under the structures can be increased by 100 mm (4 in.).

The project schedule is shown in Figure 6. Median and shoulder reconstruction will be done during nighttime closures whereas the BSOL and full-depth AC will be constructed during weekend closures, as noted above.

Stage construction will be done by splitting the 4.8-km (3.0-mi.) project into two equally divided segments in each direction, a total of four segments as seen in Figures 7 and 8. Three lanes in one direction will be closed and traffic switched to the other side, as shown in Figure 8. As seen in this figure, the use of a movable median barrier and crossovers result in counterflow on one roadway during construction. Two or three weekend closures are planned for each segment as noted in Figure 8.

TABLE 2 Minimum Process Control Requirements (*7*, Table 39-4)

Quality Characteristic		Action Limit (Min.)	Test	Min. Sampling and Testing Frequency	Point of Sampling	Reporting Time Allowance
Data Used for Specifications						
Sand Equivalent		47	CT 217[1]	One sample per 2000 tonnes. Not less than one sample per day	Batch Plant from hot bins or Drum Plant from cold feed	24 h
Percent of Crushed Particles	Coarse Aggregate	100%	CT 205	Not less than one sample per day		24 h
	Fine Aggregate (Passing 4.75-mm, Retained on 2.36-mm)	100%				
Hveem Stabilometer	PBA-6a* (modified)	TV_{S1}[2] TV_{S2}[3]	CT 366 See 1,3,4,6,7,8	Sample at least once per 500 tonnes. See [9] for minimum testing schedule	Mat behind paver	36 h
	AR-8000	TV_{S3}[2] TV_{S4}[3]				
Data for Report Only						
Hveem Stabilometer	AR-8000 (rich bottom)	TV_{S5}[2] TV_{S6}[3]	CT 366 See 1,3,4,6,7,8	Sample at least once per 500 tonnes. See [9] for minimum testing schedule	Mat behind paver	36 h
Laboratory Percent Air-Void Content	PBA-6a* (modified)	TV_{AV1}	CT 367 See [1,4,10]	See [9] for minimum testing schedule	Mat behind paver	36 h
	AR-8000	TV_{AV2}				
	AR-8000 (rich bottom)	TV_{AV3}				

NOTES: Min. = minimum; CT = California test method

[1] Reported value shall be average of 3 test results. Samples used for the 3 tests shall be from a single split sample.

[2] Do not modify CT 304.

[3] Perform CT 304, and then apply an additional 500 tamping blows at 500 psi (3400 kPa) at 140°F (60°C).

[4] Sets of 3 briquettes must be prepared and tested to meet conditions of Note 3 and 4 separately.

[5] Limited reheat for sample preparation to 2 h. Do not place sample or briquette in oven for 15-h curve.

[6] Briquettes shall be fabricated from a single, combined sample obtained from at least 4 locations across the mat behind the paver in conformance with the requirements of CT 125.

[7] If the range of stability for the three briquettes is more than 12 points, the samples shall be discarded and new samples shall be obtained before the end of the following shift of paving and tests per Table 39-3.

[8] During production start-up evaluation, a correlation factor for cured versus uncured specimens shall be established in conformance with the requirements of Section 39-10.01A, "Production Start-Up Evaluation."

[9] AC will be sampled each 500 tonnes. Each type of AC shall be tested each day the first 5 days (or at least per 2,000 tonnes of production) and testing may be decreased to one per 5,000 tonnes thereafter unless stability falls below the action limit. Samples shall be retained to define limits of problem areas should the stability fall below the action limit. When stability falls below the action limit, testing will be increased to one test for each of the first 2,000 tonnes and may be decreased to one per each 5,000 tons thereafter. Each AC type being produced and placed shall be sampled and tested at least once per 55-h window if the quantity is less than 2,000 or 5,000 tonnes as it applies to the interval. The sequence of the first 5 test results shall not be broken by more than 7 days of non-production.

[10] Use CT 308A for determination of bulk specific gravity and AASHTO T209 (Method A) for maximum theoretical specific gravity.

TABLE 3 Minimum Quality Control Requirements (*7*, Table 39-9)

Index (i)[5]	Quality Characteristic		Specification Limits	Weighting Factor (w)	Test Method	Minimum Sampling and Testing Frequency	Point of Sampling
1	Asphalt Content		TV[1]±0.3%	0.30	CT 379 or CT 382	One sample per 500 tonnes or part thereof Not less than one sample per day	Mat behind paver
	Gradation	25.4 mm			CT 202	One sample per 500 tonnes or part thereof Not less than one sample per day	Batch plant from hot bins or Drum Plant from cold feed
2		19 mm	TV±5%	0.01			
3		12.5 mm	TV±5%	0.02			
4		9.5 mm	TV±6%	0.02			
5		4.75 mm	TV±7%	0.02			
6		2.36 mm	TV±5%	0.04			
7		600µm	TV±4%	0.05			
8		300µm	TV±4%	0.07			
9		75µm[2]	TV±2%	0.07			
10	Percent of Maximum Theoretical Density for given binder	PBA-6a* (modified)	93–97%	0.40	CT 375	One sample per 500 tonnes or part thereof Not less than one sample per day	Finished mat after final rolling
		AR-8000	93–97%				
		AR-8000 (rich bottom)	97–100%				
		AR-8000 (working platform)	91–97%				
	Maximum Theoretical Density[3] % Air Voids[4]				CT 308 AASHTO T209 (Method A) AASHTO T269		Mat behind the paver
11	Mix Moisture Content		≤1%		CT 370	One sample for 1,000 tons but not less than one sample per day	Mat behind the paver
12	Asphalt and Mix Temperature		120°C to 190°C (Asphalt) ≤ 165°C (Mix)			Continuous using an automated recording device	Plant

NOTES: [1] TV = Target Value from Contractor's Mix Design Proposal
[2] The percent passing the 75-µm sieve shall be reported to the first decimal place (tenths).
[3] California Test (CT) 375, "Density of Asphalt Concrete Using a Nuclear Gage" modified to use maximum theoretical density in accordance with ASTM D 2041 (Rice Method) in lieu of test maximum density as provided in Part 5, "Determining Test Maximum Density."
[4] Report only.
[5] Quality characteristics 1 and 10 are defined as critical quality characteristics.

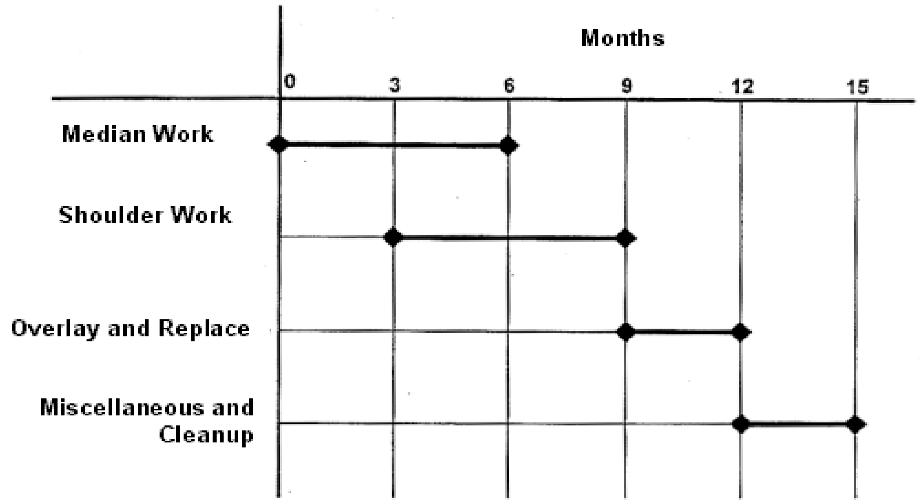

FIGURE 6 Staged rehabilitation construction schedule for I-710 project. (Source: 4th Meeting for Long-Life AC Pavement Rehabilitation Strategies with Caltrans and Southern California Asphalt Paving Association, June 11, 1999.)

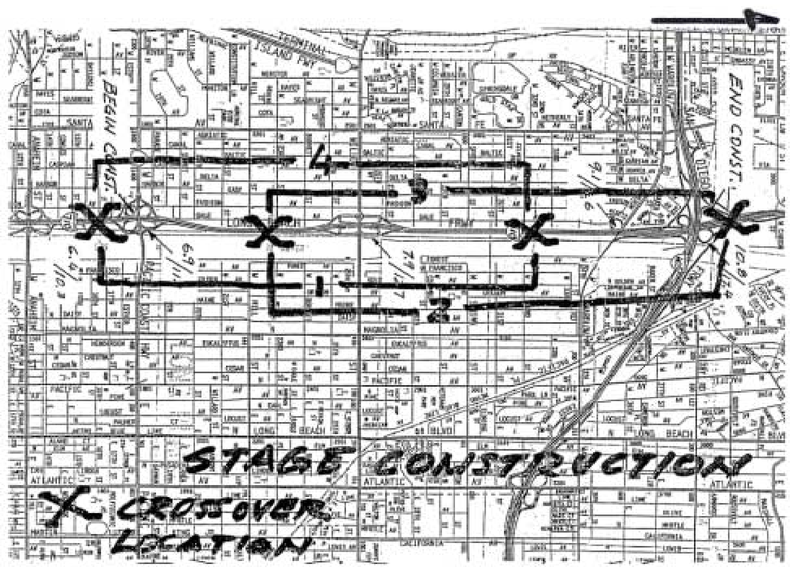

FIGURE 7 Site layout of the asphalt pavement project for I-710. (Source: 4th Meeting for Long-Life AC Pavement Rehabilitation Strategies with Caltrans and Southern California Asphalt Paving Association, June 11, 1999.)

An analysis has been made of the feasibility of one construction plan using the project management procedure described in Lee's Ph.D. dissertation at the University of California–Berkely (UC Berkeley) (*8*). This plan assumes that the BSOL section will be constructed in four lifts while the full-depth AC section will be constructed in five lifts. To assist in the analysis, the computer program CalCool (*9*), developed as a part of the CAL/APT program, was used to estimate pavement temperatures. According to Caltrans requirements the underlying layer in multi-lift construction must have cooled to 74°C (165°F) prior to placing the next lift. Since the paving sequence assumed single lane paving (3.7 m or 12 ft.) for three lanes, the program indicated that for the specific environment the lift cooling requirement would not slow construction. Figure 9 illustrates schematically the elements of the constructability analysis.

Comparison of the prediction using the procedure described by Lee (*8*) with that estimated by Caltrans is shown in Table 4. It would appear that the Caltrans estimate for the BSOL part of the construction can be completed as anticipated. On the other hand, the full-depth AC construction expectations of Caltrans may not be attainable.

A construction alternative under consideration and differing from that assumed in the analysis described herein is placing the pavement sections to the top of the second lift for the BSOL and the top of the third lift for the full-depth AC (i.e., to the top of the layer containing the AR-8000 mix). This alternative would then be opened to traffic and the PBA-6a* mix and open-graded mix would be placed in a continuous paving operation subsequently. An analysis of traffic effects on pavement performance for this approach was included in the original design considerations as noted earlier. Preliminary calculations suggest that this alternative may increase the likelihood that the full-depth AC construction would be completed in the planned time frame as compared to that shown in Table 4.

Comparison of the forecasted progress with that actually achieved during construction should provide data for improved construction guidelines for future projects. A demonstration of the potential usefulness of the program has already been accomplished during concrete reconstruction of a portion of the I-10 Freeway in Pomona, California (*10*).

SUMMARY

The I-710 project has provided an opportunity to implement approaches for mix and pavement design developed during the SHRP program (*1, 2*) and improved upon in the CAL/APT program, particularly the use of the shear test for permanent deformation evaluation and use of the flexural fatigue test and mechanistic-empirical design concepts as a part of structural thickness determination (*6*).

Results of the CAL/APT program have been incorporated in the design and construction requirements for the pavement section including improved AC compaction, the use of the "rich bottom" concept, and the incorporation of a tack coat between succeeding layers of multiple lift AC construction (*6*).

Finally, it must be emphasized that the process in arriving at the designs as well as the construction requirements was a "partnered" effort between Caltrans, the Asphalt Industry in California, and academia through UC Berkeley. This partnering provided an excellent opportunity to successfully implement new ideas and research results on this challenging project for which some of the traditional approaches were insufficient. Hopefully such working together can continue in the future to the benefit of California's traveling public.

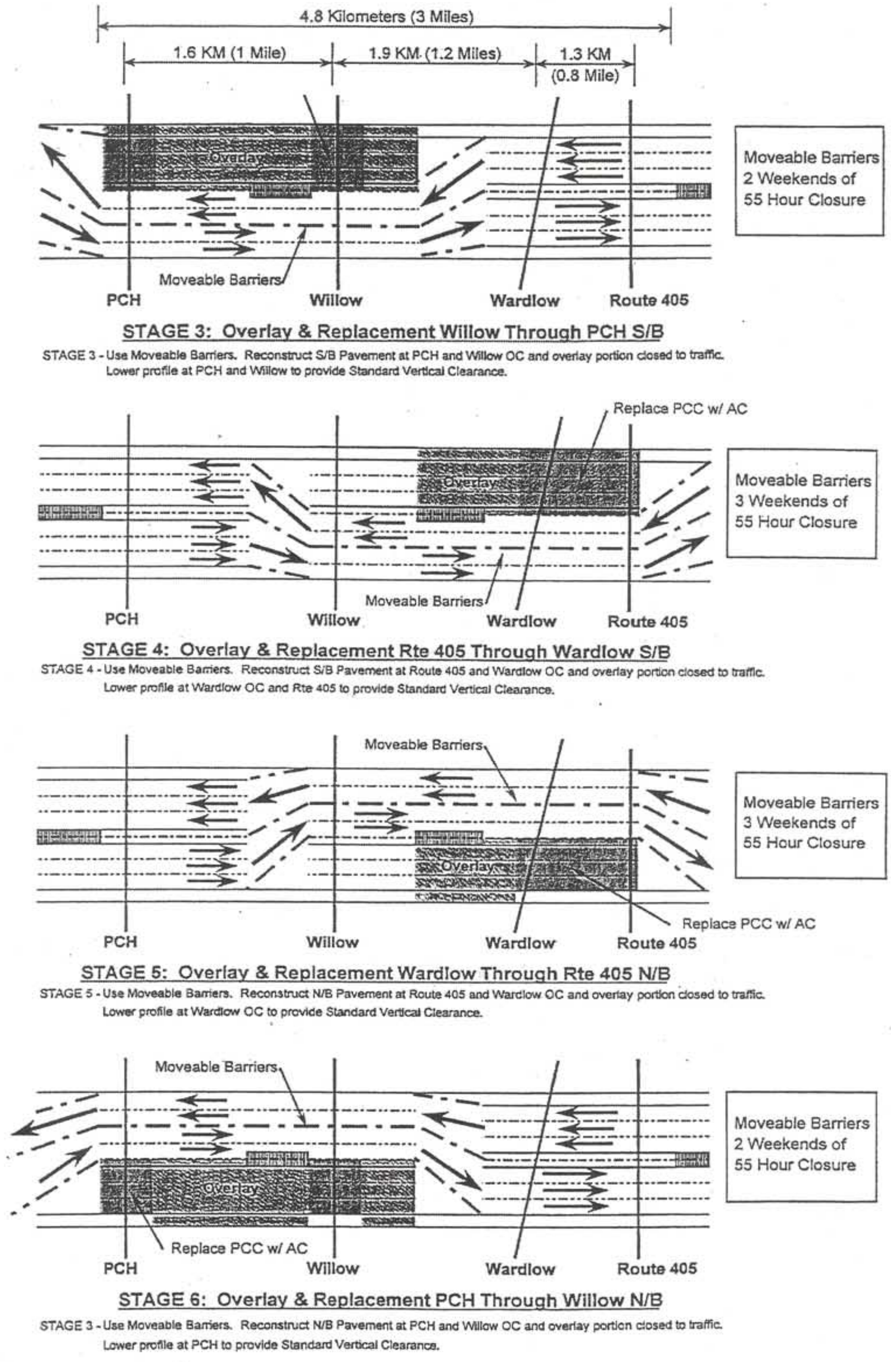

FIGURE 8 Schematic of the stage construction for the I-710 project. (Source: 4th Meeting for Long-Life AC Pavement Rehabilitation Strategies with Caltrans and Southern California Asphalt Paving Association on June 11, 1999.)

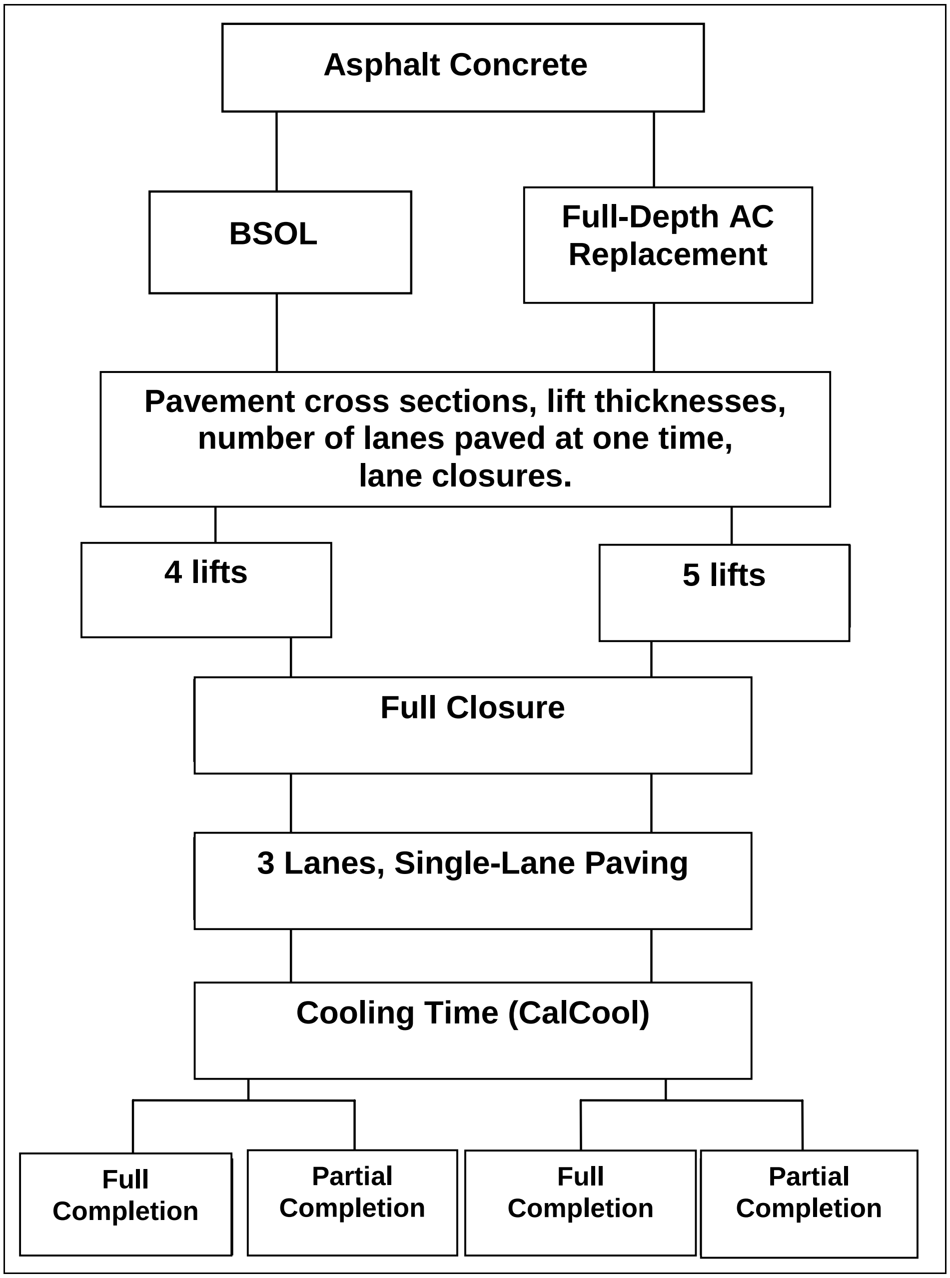

FIGURE 9 Analysis considerations, 55-hour closure constructibility program (summarized in Table 4).

TABLE 4 Productivity Estimates, I-710: Caltrans Versus University of California–Berkeley Model

Pavement Section	Section Length	Caltrans Plan (km per stage)		UC Berkeley Model (km)	Feasibility of Caltrans Plan[1]
		Stages 3, 6	Stages 4, 5		
BSOL	Centerline—km	1.60	1.10	1.55	can be achieved
	Total lane—km	4.80	3.30	4.83	can be achieved
Full Depth	Centerline—km	0.80	0.65	0.50	likely will not be achieved
	Total lane—km	2.40	2.00	1.50	likely will not be achieved

NOTE: BSOL = break, seat, and overlay. Model procedure validated for concrete pavement construction in *Case Study of Urban Concrete Pavement Reconstruction and Traffic Management for the I-10 (Pomona, Calif.) Project* (*10*).
[1] Based on model estimates (*8*).

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