Table 1 Program Summary (includes both CAL/APT and PPRC Programs)

Study	Type	Start	Complete	Objective(s)	Results	Reports
1. Fatigue performance of asphalt concrete mixes and its relationship to pavement performance in California.	Laboratory study, analyses	July 1994	Jan. 1996	• Evaluate effects of asphalt content and air-void content on fatigue response of a typical California asphalt concrete mix. • Demonstrate usefulness of SHRP-developed procedure for mix and pavement analysis and design to achieve improved fatigue performance.	• Used in interpretation of data obtained in Study 2. • Used in comparative analysis in Study 8. • Used in pay-factor Study 9. • Recommendation for use of "rich-bottom" design.	(1)
2. Accelerated loading on four full-scale pavements with untreated aggregate and asphalt-treated permeable bases. Goal 1*	Accelerated pavement tests with HVS, laboratory tests, analyses	June 1995	April 1999	*Primary objective:* Develop data to quantitatively verify existing Caltrans design methodologies for asphalt treated permeable base (ATPB) pavements and conventional aggregate base pavements with regard to failure under traffic at moderate temperatures. *Other objectives:* • Quantify effective elastic moduli of various pavement layers • Quantify stress dependence of materials in	• Importance of mix compaction conclusively demonstrated. • Recommendation for "tightening" Caltrans compaction requirements. • Comparison of measured and predicted results demonstrate the validity of the fatigue analysis and design system developed during the SHRP program and refined within the CAL/APT program. • The lack of bond	(3), (4), (5), (6), (7), (8), (9)

* Research goals that include HVS testing are assigned specific goal numbers; e.g. Goal 1, as noted above.

Study	Type	Start	Complete	Objective(s)	Results	Reports
				pavement layers • Determine failure mechanisms in various layers • Determine and compare fatigue lives of the two types of pavement structures	between compacted lifts of asphalt concrete observed in the HVS tests suggests re-examination by Caltrans of the use of a tack coat between lifts to improve the bond. • The subgrade strain criteria used by the Asphalt Institute can be used by Caltrans as a part of a mechanistic-empirical design procedure.	
3. Asphalt treated permeable base study (Phase of Goal 1)	Laboratory study, analyses	?	November 1997	• Measure effects of water on ATPB stiffness through laboratory testing. • Relate soaking performed in laboratory and its effects on ATPB stiffness to field conditions. • Provide “bridge” between HVS tests conducted with ATPB in dry state and in-situ performance with some likelihood of ATPB being saturated. • Evaluate design philosophy behind use of ATPB and its implementation to	• Improved compaction of the asphalt concrete layer and proper structural design based on results of Studies 1 and 2 as well as reduced permeability of asphalt concrete resulting from improved compaction would eliminate the need for the ATPB directly beneath the asphalt concrete layer. • Because of the susceptibility of ATPB to the action of water as currently specified, an	(10)

Study	Type	Start	Complete	Objective(s)	Results	Reports
				date. • From overall evaluation, provide recommendations pertaining to use of ATPB in California.	improved design is recommended using more asphalt and/or modified binders such as asphalt rubber. • To prevent clogging of the ATPB, if used, suitable filters should be incorporated in the structural section.	
4. Tire pressure study using 3-D stress sensor [Vehicle-Road Surface Pressure Transducer Array (VRSPTA)]	HVS loading with different tire types, pressures, tire configurations (single, dual)	Feb. 1997	June 1997	• Define stress distributions, both vertical and horizontal, exerted by a range in tire types, pressures, and configurations including bias-ply, radial, wide-base radial, used aircraft, radial (new and used), and wide-base (off-road) radial.	Tire pressure analysis used in finite element analysis to: • evaluate crack patterns observed in HVS tests. • provide confirmation of the results of layered elastic analysis of HVS tests. • provide a basis for the use of the simple shear test for permanent deformation evaluation of mixes.	(11)
5. Phase I: Mix rutting using accelerated loading at elevated pavement temperature(s) Goal 3	Accelerated pavement tests with HVS, laboratory tests, analyses	?	Jan. 2000	• Study mix rutting under radial, bias-ply, and wide-base tires at elevated temperatures.	• Test series on ten sections demonstrated the rapidity with which the influence of different tire types on asphalt concrete rutting can be evaluated.	(12)

Study	Type	Start	Complete	Objective(s)	Results	Reports
					• Results demonstrate the increased rutting which can result with wide base single tires as compared to dual tires for same total load and tire pressure under channelized traffic conditions. For this reason, Caltrans should monitor usage of this tire on California pavements. • The 2 to 1 equivalency for ARHM-GG as an overlay must be carefully applied to insure that rutting at the pavement surface from deformations in the untreated materials does not control performance.	
Phase II: Evaluation of in-service ARHM pavements.		?	Continuing	• Evaluate field performance of ARHM pavements at 3 sites in Contra Costa County. (PPRC joint study with Contra Costa County DPW)		

6. Accelerated loading on overlaid pavements Goal 3	Accelerated pavement tests with HVS, laboratory tests, analyses	March 1997	Dec. 2000	• The principal objective of this study (Goal 3 of the Program) was the evaluation of the performance of two rehabilitation strategies: 1. conventional DGAC overlay, and 2. ARHM-GG overlay at one-half the thickness of the DGAC	• The results of the study support the current Caltrans practice of the 2 to 1 thickness equivalency of ARHM-GG to DGAC for overlays on fatigue-cracked asphalt pavements • Reflection cracking rather than new fatigue cracking occurred in both overlay types; emphasizes importance of developing an improved overlay design methodology.	(13), (14), (15)
7. Accelerated loading of two full-scale pavements (including ARHM-GG overlay) with wet base conditions Goal 5	Accelerated pavement tests with HVS, laboratory tests, analyses	Nov. 1999	Continuing	• Evaluate the behavior of the drained and undrained pavement sections in the wet condition under HVS loading. • Additional testing of ATPB; for improved mix design. • Triaxial testing of granular materials in wet condition • In-situ testing to evaluate wet pavement conditions (GPR, FWD, hydroprobes, soil suction)	• Stripping of and intrusion of fines into ATPB; HVS test results support recommendations resulting from ATPB laboratory test study • Overlay performance on sections with untreated aggregate base demonstrate importance of improved compaction requirements over those currently required in Section 26 of Standard Specifications.	(16)

8. Comparison of AASHTO and Caltrans pavement design methods	Analyses	May 1997	Nov. 1997	• Quantify differences in pavement thicknesses by two methods. • Compare predicted performance for pavement designs considered equal within Caltrans procedure. • Evaluate effect of drainage conditions on pavement structures designed by AASHTO procedure. • Demonstrate the usefulness of mechanistic-empirical design procedure.	Provides additional evidence to Caltrans to make the transition from their current design procedure to a mechanistic-empirical procedure.	(17)
9. Phase I: Mix and structural pavement designs for LLPRS–Interstate 710, Long Beach, CA	Laboratory study, analysis, HVS test	June 1998	Sept. 2000	• Prepare mix and structural pavement designs for section of I-710 Freeway adjacent to the Port of Long Beach, CA	• Designs prepared for mixes containing PBA-6a* and AR8000 asphalt binders. Structural sections included: - full-depth asphalt section to be placed under overcrossings as replacements for existing PCC. - full-depth asphalt section as overlay on cracked and seated PCC. • HVS test on PBA-6a* mix provided	(18), (19)

					validation of mix design using the RSST-CH	
Phase II: QA Testing for Caltrans of Contractor's mixes		Jan. 2001	Continuing	• Perform quality assurance tests for Caltrans on contractor's mix designs	• Completed QA tests on contractor's mix for mix containing AR-8000 asphalt (same binder content and aggregate as used in design study)	Letter reports to Caltrans detailing test results
10. Pay-factor study	Analyses	Jan. 1997	Continuing	Use fatigue analysis/design system (calibrated with HVS tests and rut depth information from WesTrack) to develop pay-factors for compaction control (air-void content), asphalt content, asphalt concrete thickness, and aggregate gradation.	Recommended that Caltrans uses factors on a trial basis for selected QC/QA projects currently underway (shadow projects).	(20), (21), (22)
11. Effects of binder loss stiffness (SHRP PG binder specification) on fatigue performance of pavements	Analyses	July 1996	March 1997	Use fatigue analysis/design system (calibrated with HVS tests) to evaluate effects of binder loss modulus, $G^*sin\delta$, on pavement performance in fatigue.	Recommendation that $G^*sin\delta$ be eliminated from PG-specification for binders. [N.B. – Pacific Coast Conference on Asphalt Specifications is sponsoring a research endeavor at PPRC (~* 180,000)].	(23) (Note: paper served as report)

12. Accelerated loading of full-scale concrete pavements at the RFS and on State Route 14, Palmdale, CA Goal 4	Accelerated pavement tests with HVS, laboratory tests, and analyses	April 1998	Continuing (expected date of completion: Dec. 2002)	Construct a full-scale portland cement concrete (PCC) pavement test section at the RFS to evaluate instrumentation and data acquisition system in preparation for Palmdale experiment. On full-scale pavements at SR14 near Palmdale, CA: • identify potential problems in FSHCC construction • determine fatigue resistance of fast setting hydraulic cement concrete (FSHCC) pavements under HVS loading. • evaluate performance of concrete pavements with dowels, tied concrete shoulders, and widened traffic lanes under HVS loading and environmental stresses.	• Experience gained in installation of instrumentation and use of data acquisition system at RFS test permitted efficient operations at Palmdale. • Failure in the RFS PCC pavement stressed the importance of the use of non-erodable bases and dowels at transverse joints for heavy traffic loads. • *While the tests at Palmdale are still in progress*, it was observed that short term flexural strengths of the FSHCC did not meet specified strength requirements; field loading on the south tangent sections indicate the fatigue resistance of the FSHCC is similar to the fatigue resistance of PCC slabs tested in the laboratory	(24), (25), (26)

13. Long-term durability of concrete mixes used in LLPRS Program Goal 4	Laboratory study, analyses	April 1998	Continuing	• Evaluate the sulfate resistance of hydraulic cements in accelerated laboratory test as compared to conventional portland cements used in California (Type I/II). • Evaluate alkali-silica (ASR) susceptibility of hydraulic cements as compared to Type I/II portland cements	• Results showed that several hydraulic cements may be susceptible to sulfate attack • Recommendation that Caltrans enforce sulfate resistance guidelines for PCC and, for HCC, the contractor produce evidence that material is sulfate resistant. • Tests demonstrated that one hydraulic cement (calcium aluminate cement–CA) was highly resistant to ASR. • Recommendation that an improved ASR test be developed because of ambiguity in results for specimens containing three other cements including Type I/II portland cement.	(27), (28), (29)

14. Shrinkage and environmental effects on the performance of FSHCC pavements at Palmdale, CA Goal 4	Field and laboratory studies, analyses	April 1998	June 2000	Determine the influence of temperature gradients and drying shrinkage on the performance of FSHCC pavement slabs.	• High shrinkage hydraulic cement led to top-down premature cracking in longer slabs. Analysis indicated that shorter slab lengths will reduce the chance of premature failure if high shrinkage cement is used. In addition, to reduce the potential for this type of cracking, bases which are flexible under long-term and stiff under short-term loading are preferred. • Dowels and tie-bars were effective in restricting curling movements along transverse and longitudinal joints resulting from daily temperature changes.	(30), (31)

15. Evaluation of proposed LLPR strategies for rigid pavements; design and constructability considerations	Visual condition survey, analyses including that of historical Caltrans design and performance data			Evaluate adequacy of structural design options for concrete pavements under consideration by Caltrans for LLPR strategies.	• Faulting is the most prevalent form of distress in California concrete pavements. Transverse joint spacing should be made a function of climate. Non-erodable bases with low stiffness under long-time loading conditions desirable. • To minimize slab thickness, higher than current required flexural strengths and small coefficients of thermal expansion should be used. • For heavier truck traffic conditions, dowels should be used at transverse joints	(32), (33)

16. Constructability analyses for long life pavement rehabilitation a. Concrete	Analysis, computer program development, field study	Nov. 1998	May 2000	• Perform constructability analyses for LLPR-Rigid Program. • Validate program using I-10 reconstruction.	• Results of the analyses indicated that strategy to rebuild 6 lane-kilometers during 55 hour weekend closure has low probability of success. Existing pavement removal and new concrete supply were the major constraints. Construction productivity data obtained for rehabilitation operations on the I-10 freeway in Pomona provided validation for the approach.	(34), (35)
b. Asphalt	Analysis, computer program development, field study	Nov. 1998	Continuing	• Perform constructability analyses for LLPR-Flexible Program • Validate program using I-710 reconstruction	• Results of the analysis indicate that the current construction target for the I-710 project is feasible so long as no contingencies arise.	(36)
c. Productivity analysis products	Analysis, computer program development, validation	Jan. 2001	June 2004	• Combine efforts from Studies 16a, 16b, and 17 into software package for use by Caltrans and other agencies (N.B. This activity is being supported through the 4-states program).		

17. Computer program for determining pavement temperatures during AC placement (MultiCool)	Analysis, computer program development	?	?	• Develop computer program to determine pavement temperature profiles for multi-lift pavement construction throughout the duration of the paving operation.	• Computer program MultiCool with inputs including: AC lifts (up to 9); mix and underlying mat characteristics; and environment characteristics, e.g., ambient temperature, wind speed, etc. • Program available on PRC website www.its.berkeley.edu/pavementresearch/index.html	(37)

18. Mechanistic empirical pavement design and rehabilitation	Analysis, computer program development						
a. Layered elastic analysis for asphalt pavements		?	Oct. 1999	• Develop n-layer multilayer elastic analysis program including variable friction between layers and multiple loads with variable tire pressure conditions	• Multilayer elastic analysis computer program (LEAP)		(38), (39), (40)
b. Climate effect models		?	June 2002	• Develop climatic regions in California and procedures for prediction environmental conditions (temperature and moisture in pavement structures)	• Identification of seven climate regions in California (in terms of temperature and moisture) for materials selection and pavement design; • Computer program, CDIM under development (part of PPRC program with FHWA) for site specific weather conditions		(41)

c. Development of constitutive relationship for AC mix behavior at high temperatures		1999	Continuing; expected completion Dec. 2002	• Develop visco-elastic / plastic constitutive relationship for rutting estimates in AC mixes at high temperatures (> 40°C)			(42), (43)
d. Development of 3D finite element analysis for rigid pavements. Also part of Goals 4 and 7		June 2001	Aug. 2002	• Develop comprehensive 3D software for rigid pavement analysis and design (part of PPRC program with U. of Washington/ WSDOT)			
e. Calibration of procedures	Laboratory and field testing of analysis of HVS tests and in-service pavements	?	Continuing	• Obtain Caltrans, Ariz. and Washington State PMS databases for evaluation • Provide Caltrans with field test sections • Perform laboratory testing on field samples • Analyze data to calibrate models for specific distress modes	• Evaluation of state PMS databases • List of all known field test sections on state highway system to Caltrans		

19. Performance characteristics of compacted untreated granular materials Goal 5	Laboratory tests, HVS tests, analysis	Nov. 1999	Continuing	• Definition of the stiffness, strength and permeability characteristics of untreated granular materials for use in mechanistic-empirical design procedures and for QC/QA in construction	• Dry density and degree of saturation have significant impact on stiffness, strength, and permanent deformation resistance. • Recommendation that Caltrans change the method of compaction control for untreated granular materials from current procedure to Modified AASHTO Test (T-180)		(16), (44)
20. Nondestructive monitoring of water contents in untreated bases, subbases and subgrade soils of pavement structure and dowel bar location in concrete pavements (related to Goal 5) using ground penetrating radar (GPR)	Laboratory tests, in-situ tests on RFS HVS pavements, analysis			• Develop a reliable procedure to measure in-situ water contents of untreated materials in pavement sections • Evaluate feasibility of the use of GPR for deteremining dowel bar location in concrete pavement joints	• Preliminary results have demonstrated feasibility of this methodology to measure in-situ water contents in untreated materials in the pavement sections. • Preliminary results suggest that this methodology may not provide sufficient		(45), (45) The paper has served as a report on the project. See Reference ( )

					accuracy for use as an evaluation tool.		
21. Studies related to Caltrans pavement management system (PMS)	Analysis			• Evaluate data in California PMS to develop performance models for the various types of pavements used on the state highway system	• Recommendations for changes to *Caltrans Pavement Survey Manual* • Development of prioritized list of pavement test sections for inclusion in Caltrans condition survey network (N.B. Led to StanTec Contract) • Recommendations for modifications to the data base structure and to data collection methodology		(47), (48), (49)
22. CAL/APT database development	Analysis		Continuing (data entry as acquired)	• Develop CAL/APT database	• Database has been developed consisting of the following: 1. PRC Lab Database 2. HVS Asphalt Database 3. HVS PCC Database 4. Caltrans Database		(50)

					5. Westrack Database • Uses MS Access and Oracle as relational database management system		
23. Assessment of economic benefits from implementation of findings from CAL/APT Program	Analysis	Jan. 1998	March 2000	• Evaluate economic benefits of implementation by Caltrans of three changes in flexible pavement technology resulting from CAL/APT program: 1. increased AC compaction 2. use of tack coat between AC layers 3. use of "rich bottom layer" in think AC pavements	• Potential cost savings for use of these technology changes is substantial [approaching ~$590 million (1998 dollars)]		(51)
24. Verification of asphalt concrete long-life pavement strategies Goal 6	Analysis, laboratory testing, HVS tests, and field performance evaluation	Aug. 2000	Continuing	• Evaluate and verify effectiveness of long-life pavement rehabilitation alternatives using asphalt concrete long-life strategies	• HVS test on mix containing PBA-6a* binder validated mix design procedure using the RSST-CH methodology		(52)

				including but not limited to: - crack, seat, and overlay - full depth AC reconstruction including "rich-bottom" layer • Also includes evaluation of construction on performance			
25. Dowel bar retrofit of rigid pavements Goal 7 (N.B. U. of Washington and WSDOT are partners in this project)	Analysis, laboratory testing, HVS tests, and field performance evaluation	Nov. 2000	Continuing	• Compare performance of retrofitted joints and cracks with joints and cracks not retrofitted • Evaluate performance of different dowel types with respect to corrosion (Analysis of various conditions will be accomplished using the EVERFE program under development in Study 18d)	• HVS tests were completed on a section of U.S. 101 in Ukiah, CA; effectiveness of retrofitting both joints and cracks was demonstrated.		(53)
26. Moisture damage of asphalt-bound materials Goal 8	Analysis, laboratory studies, field performance evaluation (may include HVS testing as already done in Goal 5)	Dec. 2000	Continuing	• Determine causes of moisture damage in California pavements and develop database for moisture-related pavement			

				problems • Provide guidelines for improved mix design and construction methodology to mitigate moisture damage			
27. Improved rehabilitation designs for reflection cracking Goal 9	Analysis, laboratory testing, HVS tests, and field performance evaluation	Aug. 2001	Continuing	• Validate MB specifications through HVS tests on pavements at RFS and evaluation of performance of 12 in-service pavements • Develop improved models for reflection cracking • Use HVS test data to calibrate models (from Goals 3, 5, and 9) • Use models to develop effective strategies to mitigate reflection cracking	• Pavements for MB mix overlay constructed. (6 sections to be cracked by HVS plus 6 overlays for a total of 12 test sections) • Two (2) sections have been cracked by HVS loading in preparation for overlays • Field experiment have been planned in conjuction with the RACTG (Caltrans and Industry) for a total of 12 in-service sections		(54)

28. Validation of asphalt concrete QC/QA pay factors (future HVS goal)	Analysis, laboratory testing, shadowing of existing QC/QA projects, HVS tests at RFS on controlled sections	Feb. 2000	Continuing	• Validation of pay factors developed in Study 10. • HVS test sections will focus on overlays since earlier studies (Goal 1 and WesTrack) which served as the basis for the pay factors, were performed on "new" pavement sections.	• Same "shadowing" studies have been completed: 1) Caltrans, 2) contractor supplied contracts • Calculation spread sheet for calculation combined pay factors completed.		(21), (55) Diskette available.
29. Upgrade of HVS1 and HVS2	Equipment and computer upgrades	Nov. 2000	Sept. 2001	• Upgrade mechanical electrical and computer controls for both HVS units	• HVS units upgraded with replacement of power system, electrical wiring, some mechanical components, and new computer operating systems.		
30. Implementation projects	Analysis, laboratory and field testing, training						

a. Validation and calibration of HiperPav software		Jan. 2000	Continuing	• Perform sensitivity study of HiperPav system • Installation of instrumentation in new concrete pavements in District 8 to monitor potential for early age cracking			
b. Evaluation of concrete maturity meters		Jan. 2000	Continuing	• Provide to Caltrans information on calibration, accuracy, variance in results as a function of mix type, e.g. FSHCC			
c. Use of PCC grinding residue as base and subbase mineral admixture		Jan. 2000	Continuing	• Evaluate use of grinding residue as a mineral admixture to base and subbase aggregates			

d. Evaluation of asphalt concrete grindings (RAP) for stabilized or unbound bases and subbases		March 2000	Continuing	• Provide assistance to Caltrans Districts in implementing the use of recycled asphalt concrete as base/subbase in low and medium volume roads (Implementation of South African Technology)	• District 3 has used foamed asphalt for stabilizing existing recycled material as a base for a section of SR 20 West of I-5. • District 2 has used recycled material for a base on SR 299 northeast of Redding.		
e. Chip seal specifications (South Africa)		March 2000	Continuing	• Assist Caltrans Districts in using the type of chip seal technology developed in South Africa			

30. (cont'd) f. Dynamic core penetrometer		March 2000	Continuing	• Assist Caltrans Districts in using this equipment for evaluating existing pavements for rehabilitation particularly in providing a measure of stiffness of untreated materials in the pavement section (N.B. This equipment is also used in Goal 5.)	• District 3 has begun implementing this technology.		