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Caltrans

Test Plan for CAL/APT Goal 5

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1 INTRODUCTION

1.1 Background

Caltrans currently requires that all new flexible pavements include a 75mm thick layer of Asphalt Treated Permeable Base (ATPB) between the asphalt concrete (AC) and aggregate base layers (AB). Caltrans also requires that the ATPB layer be connected to an edge drain system. The purpose of the ATPB layer and drainage system are to intercept water entering the pavement either through cracks in the asphalt concrete or through high permeability asphalt concrete, and carry it out of the pavement before it reaches the unbound material layers. Water in the unbound layers can significantly reduce their strength and stiffness.

A "drained" structure is a flexible pavement structure that includes the ATPB layer and an edge drain system. An "undrained" structure does not contain the ATPB layer. CAL/APT Project Goal 1 evaluated the performance of drained and undrained pavement sections under "dry" conditions, in which no water was allowed to enter through the pavement surface. Water contents in the pavement could only change through capillary draw or lateral infiltration at the subbase and subgrade levels. Descriptions of the drained and undrained structures tested by the HVS at the UCB Richmond Field Station (RFS), and the results of the Goal 1 study are included in a series of CAL/APT reports (1, 2, 3, 4, 5, and 6).

CAL/APT project Goal 3 is currently underway, and is evaluating the performance of two overlay strategies, a dense graded asphalt concrete (DGAC) section and a gap graded asphalt-rubber hot mix (ARHM-GG) section. HVS testing is completed on the DGAC and ARHM-GG overlays on the drained and undrained pavement structures at RFS. The four sections that failed in Goal 1 were overlaid and tested for cracking performance at 20°C in Goal 3. Eight sections were tested at elevated temperatures for rutting performance. Three sites that have never been trafficked, but were overlaid, have been reserved for Goal 5.

Goal 5 is the comparison of the performance of drained and undrained flexible pavements under "wet" conditions. Wet conditions intend to simulate approximate surface infiltration rates that would occur along the northwest coast of California during a wet month, for a badly cracked asphalt concrete layer. The surface course in the test sections will be initially uncracked. It is assumed at this uncracked condition that water would only infiltrate from adjacent lanes. This will permit the evaluation of the performance of the drained and undrained structures and potential benefits of the drained pavement from the uncracked to the cracked condition. Surface water will be applied to the sections in addition to the lateral infiltration once cracks appear at the pavement surface, which should further accelerate pavement damage.

Two of the three sections that are available for HVS tests for Goal 5 are nearly replicates, except for the presence of the ATPB drainage layer in one of them. The two test sections, designated 543 RF and 544 RF, consist of the original Goal 1 pavements overlaid with approximately 38 mm of asphalt-rubber hot mix (ARHM-GG). The third test section, designated 545 RF, consists of the Goal 1 undrained pavement structure overlaid with about 75 mm of dense graded asphalt concrete. HVS testing on the third section may, or may not, be performed depending upon the time required to complete the first two tests, and the urgency of the next CAL/APT goal at RFS.

Included in Goal 5 are accelerated pavement testing, laboratory testing, and data analysis.

The accelerated pavement testing experiment will include four stages. Stage 1 will involve measurement of initial conditions and structural capacity before any water is introduced into the pavement. Water will be introduced into the pavement during Stage 2, and changes in water content in the pavement layers will be monitored. There will be no HVS loading during Stages 1 and 2. Stage 3 will consist of HVS loading on the drained and undrained test sections. Water contents, structural capacity, and damage mechanisms occurring in the pavement will be monitored. Stage 4 will consist of forensic testing, including deflection analysis, other non-destructive tests, and trenching of the test pavements to sample materials, take measurements, and make observations.

Laboratory testing will include the analysis of a more water stripping resistant mix for an asphalt treated permeable material, and evaluation of the effects of compaction and water content on the stiffness of the aggregate base and subbase layers.

The accelerated pavement and laboratory data will be analyzed using mechanistic-empirical procedures. The analyses will further provide validation and calibration of non-destructive pavement evaluation methods and mechanistic-empirical design procedures being developed for Caltrans by CAL/APT.

1.2 Conclusions and Recommendations of CAL/APT Goal 1 Regarding Drained and Undrained Pavements

Conclusions and recommendations regarding comparison of the drained and undrained structures under dry conditions from CAL/APT Goal 1 are as follows:

- The performance of the Caltrans drained (ATPB layer) and undrained (no ATPB layer) pavements under controlled conditions and HVS loading is different.
- Under dry conditions, the ATPB layer increases the fatigue cracking life of the pavement.
- Rutting performance in the unbound layers appears to be similar for both pavements.
- Surface deflections also appear to be similar.
- Based on the results, it is apparent that the Caltrans pavement design including the ATPB improves fatigue cracking performance, for the dry conditions simulated in the test enclosure at the Richmond Field Station. If the structural capacity of the ATPB can be maintained through the life of the pavement, it is apparent that the two design structures are not equal and the pavement containing ATPB has better performance. Indications that the ATPB has a tendency to strip and lose its structural capacity when saturated suggest that there may be a great deal of variance in the performance of the same drained structures in the field, depending upon the environment, the stripping potential of the ATPB mix, and maintenance practices that would reduce the time that the

ATPB remains saturated. It is recommended that the pavement used for this research be later subjected to HVS loading in combination with application of surface and/or subsurface water to evaluate their relative performance for wet conditions. (7)

Conclusions and recommendations regarding the mix design of Asphalt Treated Permeable Base (ATPB) and its use in Caltrans flexible pavement structures are as follows:

- The ATPB layer beneath the asphalt concrete layer can increase the structural capacity of Caltrans asphalt concrete pavements with respect to fatigue cracking and subgrade rutting, provided that the ATPB is resistant to stripping, loss of cohesion, and stiffness reduction from water damage.
- ATPB materials may be susceptible to stripping, loss of cohesion, and stiffness reduction from prolonged exposure to water as they are currently designed and constructed by Caltrans.
- The resistance of ATPB materials to water damage (stripping, loss of cohesion, and stiffness loss) can be significantly reduced by changes in the specifications for ATPB. The most likely variables for change are increased asphalt content and changes in binder specification including the use of asphalt-rubber. Any changes in the ATPB specification would need to ensure sufficient permeability and constructability comparable to materials currently in use.
- If ATPBs are to remain effective as drainage layers, it will be necessary to

insure that:

- adequate filter layers are provided adjacent to the ATPB to minimize the intrusion of fines;
- edge and transverse drains are maintained to prevent their filling with fines or becoming clogged.

The current practice of using a heavy prime coat on the aggregate base as the filter material should be evaluated to ascertain its effectiveness. Guidelines should be developed for proper design of filters using either soils or geotextiles. Recommended maintenance practices for edge and transverse drains should be established and distributed to the Districts, and adequate equipment and staffing to follow these practices should be provided.

If the above recommendations are followed to improve the resistance of ATPB to the action of water, then its gravel factor should be increased to a value of 2.0. (5)

1.3 Overview of Goal 5 Test Plan

Goal 5 is included in the CAL/APT Strategic Planning document prepared by the UCB Contract Team in 1998 (8). This test plan is intended to describe the objectives for CAL/APT Goal 5 and the details of the test plan to achieve those objectives. The test plan also includes a description of the anticipated benefits, and an implementation plan. The test plan includes components for Caltrans Heavy Vehicle Simulator (HVS) No. 1, other field measurements, laboratory experiments, and analysis.

2 TEST PLAN OBJECTIVES

2.1 Effects of Drainage Layer on Stiffness, Water Content and Performance Under Traffic

The Caltrans Highway Design Manual Section 600 (9) currently requires a drained pavement structure: an ATPB layer between the asphalt concrete and aggregate base, and edge drains for all new pavements. The cost effect of a drained structure rather than an undrained structure depends on the cost difference of constructing the two structures, and their respective long-term performance. The effectiveness of the ATPB layer in protecting the unbound layers from water infiltration has not been quantified or qualitatively evaluated yet. The impact of these drainage features on pavement performance has only been evaluated in terms of their effect on new, low volume pavements (5).

The *first objective* of Goal 5 is to measure the effectiveness of the drained pavement in preventing a decrease in stiffness and strength of the unbound layers (base, subbase and subgrade) due to an increase of water content produced by surface water infiltration.

The *second objective* of Goal 5 is to measure and compare the long-term performance of the drained and undrained pavement structures under wet conditions. Long-term performance is defined as fatigue cracking and rutting of the pavement structure. The ATPB asphalt binder stripping and the associated loss of stiffness and strength will also be evaluated.

2.2 Performance of ARHM-GG and DGAC Wearing Courses

Caltrans has published a guideline (9) allowing the use of reduced thickness of ARHM overlays in lieu of DGAC overlays, based primarily on the Ravendale field test results (10). A subsequent study by Shatnawi (11) has generally supported the guideline. These overlays are placed on flexible pavements that are in need of structural rehabilitation. HVS testing has been completed on four test sections to evaluate the performance of a 38 mm ARHM-GG overlay and a 75 mm conventional DGAC overlay on pavement structures originally designed for a Traffic Index of 9 and then cracked under HVS trafficking.

Caltrans is currently interested in considering the use of open-graded or gap-graded thin bituminous overlays of flexible and rigid pavements. These overlay are intended to provide wearing courses that reduce spray and skidding under wet conditions, help absorb noise, provide a smoother ride, and have good resistance to reflection cracking. Dense-graded or otherwise impermeable mixes are also being considered to help reduce water infiltration through joints and cracks, and provide a smoother ride. The use of rubberized binders to help obtain these properties has also been discussed.

The *third objective* of Goal 5 is to measure and compare the long-term performance of undrained structures with ARHM-GG and DGAC wearing courses under wet conditions. This objective will only be achieved if section 545 RF is tested.

2.3 Evaluation of Non-Destructive Pavement Evaluation Methods

Non-destructive methods for evaluating the structural condition of pavement sections are needed for modern mechanistic-empirical rehabilitation and reconstruction design methods, and for optimizing the use of available funds for rehabilitation and maintenance in pavement management systems. Current state-of-the-practice is to use deflection measurement equipment to determine material structural condition.

A key to the effective use of stiffness is the extrapolation of the results of one-time deflection measurement data to stiffnesses expected across the entire year. Primary factors affecting material stiffness are temperature (for asphalt bound materials), water content, and fatigue damage.

The *fourth objective* of Goal 5 is to evaluate the effectiveness of non-destructive and partially destructive methods of pavement structural condition. The non-destructive methods include ground penetrating radar (GPR) to measure water contents, and a Falling Weight Deflectometer (FWD) to measure the elastic stiffness of the pavement layers. Partially destructive methods include the hydroprobe to measure water content, and the soil suction gauge to measure soil suction. The interaction between water content, suction and stiffness obtained from non-destructive data will also be evaluated. The GPR and hydroprobe will provide independent measurements of water content that can be checked against each other. Destructive volumetric water contents will be taken at locations near the test sections before and after testing as a final independent check.

2.4 Development of Asphalt Treated Permeable Materials with Improved Stripping Resistance

The currently specified and designed Asphalt Treated Permeable Base (13) has a tendency to strip when exposed to soaking and loading while saturated (5, 12). Caltrans also currently uses an Open Graded Friction Course (OGFC) material as a wearing course. The current OGFC does not appear to have the stripping problems of the ATPB, although it is possible to improve the durability performance of OGFC.

Caltrans needs permeable materials that will provide adequate flow for use as drainage layers and not strip or lose stiffness and stability when subjected to soaking. Current and possible future applications of new Asphalt Treated Permeable Materials mix designs include:

- Permeable bases for rigid pavement reconstruction,
- Permeable surface wearing courses for rigid and flexible pavements, and
- Permeable subbases for interception of subsurface water in flexible and rigid pavements.

The flow capacity of the current ATPB material is much greater than needed for many applications. Several materials with different flow capacities and engineering properties specific to subsurface drainage layers and surface wearing courses that can be selected for different applications are needed for the "toolbox" of Caltrans pavement designers.

The *fifth objective* of Goal 5 is to develop improved asphalt treated permeable materials that have greater resistance to stripping.

2.5 Validation and Calibration of Mechanistic-Empirical Design Procedures

A long-term goal of the CAL/APT program is to help Caltrans develop mechanistic-empirical pavement design methods. A key to mechanistic-empirical design methods is calibration of mechanistic analyses with empirical performance data.

The *sixth objective* of Goal 5 is to develop calibration data for mechanistic analyses of the performance of the HVS test sections. The results of Goal 5 will provide data on flexible pavement performance under wet conditions, which will be used in conjunction with the data obtained in Goals 1 and 3 under "dry" conditions to validate and calibrate mechanistic predictions of fatigue and subgrade rutting performance.

2.6 Summary of Tasks to Complete Objectives

2.6.1 Accelerated Pavement Testing Tasks

Accelerated pavement testing will be performed using the Heavy Vehicle Simulator No. 1, the Goal 5 pavement test sections, pavement instrumentation, and various non-destructive, partially destructive, and destructive pavement performance monitoring equipment. The sequence of accelerated pavement testing tasks to complete the objectives of Goal 5 is shown in Table 1.

2.6.2 Laboratory Testing Tasks

Although the HVS and accelerated pavement testing often get the most attention, laboratory testing is essential for understanding and implementation of the accelerated pavement tests.

Table 1 Sequence of Accelerated Pavement Testing

Task	Brief Description of Activities and Outcomes
Stage 1 – Measurement of pavement properties before water infiltration	Water content measurements, FWD deflection testing, performed once.
Stage 2 – Surface water infiltration measurement	Water content measurements, FWD deflection testing, performed at various times during infiltration until water contents reach steady state.
Stage 3a – HVS test at moderate temperatures on drained/ARHM-GG pavement structure with continued water infiltration	Water content measurements, permanent and elastic deflection measurements, surface profile measurements, performed at various times during HVS trafficking.
Stage 3b – HVS test at moderate temperatures on undrained/ARHM-GG pavement structure with continued water infiltration	Water content measurements, permanent and elastic deflection measurements, surface profile measurements, performed at various times during HVS trafficking.
Stage 3c – HVS test at moderate temperatures on undrained/DGAC pavement structure with continued water infiltration (optional)	Water content measurements, permanent and elastic deflection measurements, surface profile measurements, performed at various times during HVS trafficking.
Stage 4 – Measurement of pavement properties after water infiltration and trafficking; in-depth observation of failure mechanisms	Water content measurements, FWD deflection testing, performed once. Trenching and sampling for laboratory testing.

- **APT test section characterization** is needed to place performance data in context with respect to pavements in the field, and to understand the distress mechanisms;
- **Validation of design models and technology** is the primary task of the APT. Design models and technology used in practice will primarily be dependent upon laboratory testing and analysis.

- **Interpolation and extrapolation of test section data** is necessary to apply the results from relatively few HVS test sections to the wide range of conditions encountered in practice in the field. This can only be done by means of relatively inexpensive and quick laboratory testing and analysis.

The sequence of laboratory testing tasks is shown in Table 2.

Table 2 Sequence of Laboratory Testing

Task	Brief Description of Activities and Outcomes
Water sensitivity of base, subbase and subgrade materials (in conjunction with similar effort to test Palmdale test section base, subbase and subgrade materials)	Triaxial and other testing to characterize stiffness, permanent deformation, and permeability of base, subbase and subgrade materials under different compaction efforts and water contents, and soaking exposures.
Mix design development for more stripping resistant asphalt treated permeable material (ATPM)	Triaxial testing of unconditioned and water conditioned ATPM alternatives, including changes in gradation, binder content, and binder types to identify greater stripping resistance.

2.6.3 Analysis Tasks and Reports

Analyses are required to make use of HVS test results and laboratory test results, and reports and technical documents are required to transmit those results to Caltrans. The sequence of analysis tasks and reports is shown in Table 3. Not shown are the presentations, graphics and short technical summaries that will be extracted from the reports to aid technology transfer to Caltrans, and that will be completed as part of Goal 5.

Table 3 Sequence of Analyses and Reports

Task	Brief Description of Activities
Analysis of Stage 1 and 2 water content changes and effects on stiffness	Technical memorandum on water content and stiffness changes in drained and undrained pavements; comparison of GPR, hydroprobe results
Analysis of Stage 3 HVS test results	Technical memorandum comparing performance under HVS loading of drained versus undrained pavements; comparison of ARHM-GG and DGAC surfaced flexible pavements under wet conditions
Analysis of Stage 4 forensic results	Technical memorandum incorporating trenching results; non-destructive post-HVS test results of stiffness, water content
Goal 5 Accelerated Pavement Testing Report	Preparation of report covering results of accelerated pavement testing Stages 1, 2, 3 and 4
Analysis of laboratory testing of water sensitivity of base, subbase and subgrade materials	Technical memorandum on effects on stiffness, permanent deformation, and permeability of base, subbase and subgrade materials of different compaction efforts and water contents, and soaking exposures
Goal 5 Report on Flexible Pavement Structures for Wet and Dry Climates in California	Preparation of report containing summary of Goal 5 APT and laboratory testing reports, extrapolation of APT results based on laboratory test results, and recommendations regarding flexible pavement structures for wet and dry climates, including results of Goal 1
Analysis of ATPM laboratory testing and mix design development	Report summarizing new mix design for ATPMs with more stripping resistance than the current ATPB material; recommendations for use in structural design; potential applications of results to development of more resistant thin, open-graded wearing courses for rigid and flexible pavements.

3 PAVEMENT STRUCTURES AND SECTION LAYOUTS

3.1 Section Numbers

Two studies are incorporated in the Goal 5 CAL/APT accelerated pavement testing:

- comparison of drained and undrained structures, both with ARHM-GG surface layers, and
- comparison of new flexible structures with DGAC and ARHM-GG surfaces, under wet conditions.

HVS test sections 543RF and 544RF will be used for the first study comparing the drained and undrained structures. Results from HVS test section 545RF will be compared with those of Section 544RF for the second study regarding DGAC and ARHM-GG surfaced pavements. A summary of the important HVS test conditions is included in Table 4.

Table 4 Summary of HVS Test Parameters

Test No.	Tire Wheel Type	Surface Type	Underlying Pavement	Load Pattern	Temp.	Wheel Load
543RF	Dual radial	Goal 3 ARHM-GG	Drained	1 m Wander	20 ^{0}C	40, 80, 100 kN
544RF	Dual radial	Goal 3 ARHM-GG	Undrained	1 m Wander	20 ^{0}C	40, 80, 100 kN
545RF	Dual radial	Goal 3 DGAC	Undrained	1 m Wander	20 ^{0}C	40, 80, 100 kN

(Note: all sections will be subjected to the same wetting procedure).

3.2 Pavement Structures

Goal 1pavement thickness designs were based on a subgrade R-value of 10 (4) and a traffic index (TI) of 9. Goal 3 overlay thicknesses were based on a TI of 9 and the deflection data on each failed Goal 1 test section (12). Figure 1 illustrates the layout of the Goal 5 test sections relative to the position of the Goal 1 sections. Table 5 summarizes the Goal 5 pavement structures of the test sections and their TI capacity. The thicknesses in Table 5 are assumed from previous cores and trenches nearby and will be adjusted from trenching and cores after testing is completed.

Table 5 Approximate Layer Thicknesses for HVS Test Sections.

Test Section	543RF	544RF	545RF
Overlay Type	ARHM-GG	ARHM-GG	DGAC
Overlay	50	40	75
Asphalt concrete	148	162	147
ATPB	76	-	-
Aggregate base	182	274	274
Aggr. subbase	215	305	215
Subgrade (SG)			
TI Capacity	10-11*	11-12*	10.5

* Low TI capacity is using ARHM-GG gravel factor (Gf) that is equal to DGAC Gf, high TI capacity is using ARHM-GG Gf that is double that of DGAC.

3.3 Materials

The materials in the test sections are described in the Goal 1 test plan (14), Goal 1 Interim Report (13), HVS Test Section reports (1, 2, 3, 4) and the Goal 3 Construction Report (17).

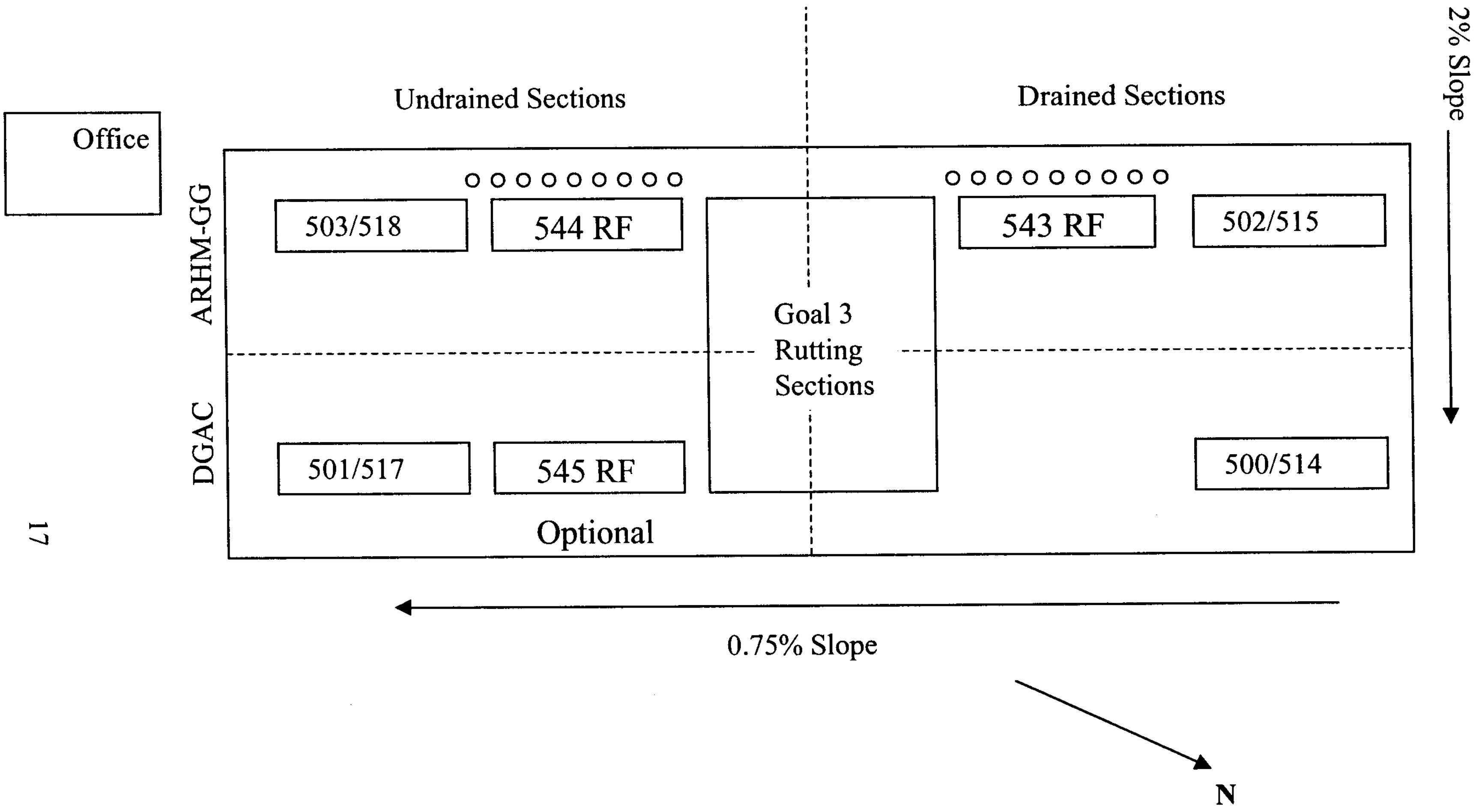


Figure 1. Relative Position of Goal 5 Test Section in Test Area

4 HVS SITE PREPARATION

The HVS test sites will be marked before any testing starts and Multi-depth deflectometers (MDDs) will be installed after the initial deflection testing (Stage 1). Hydro-probes and thermocouples will also be installed after the initial set of measurements is completed. There will be a water dripping system installed into the pavement to simulate the amount of rainfall that penetrates into the pavement.

4.1 Water Infiltration System

Pavement cracks is one of the several routes through which water enters into the pavement. In general, surface water (rainfall, snow, dew, and melting ice) infiltrates into the pavement through cracks, pavement shoulders, pavement side ditches, or ice melting. The amount of water infiltrating the pavement depends on the location. A two- inch rainfall per day in a 6-inch diameter area will result in an inflow of about 1 ml. per minute (15).

Rainfall data from two locations in Northern California have been selected to calculate pavement inflow. The first location is Sacramento with rainfall of 0.094m/peak month and 0.029m/peak week for an average of thirty-year data. The second location is Arcata (Northern Coast of California) with rainfall of 0.231m/peak month and 0.122m/peak week, which is more than triple of the amount of Sacramento.

Hassan and White (16) indicated based on the analysis of three asphalt pavement test sections that about 10-15% of rainfall water infiltrates into the pavement by cracks. The test section area was 7.4 m (two lane width) by 12 m (length of the test section + 2m edge on each side) long.

Each test section will have a separate system that drips water into the base through small holes drilled in the asphalt concrete. The holes are at 0.5-m intervals outside and upslope of the HVS test sections. The drip system consists of a twelve-meter long PVC pipe with twenty-five emitters attached at the end of dripping line. Each dripping system has a water filter that collects any dirt and deposits from the water line and an electronic valve and timer to control the amount of flow. The programmable dripping system can run 24 hours a day automatically.

4.2 Installation of MDDs

One stack of Multi Depth Deflectometers (MDDs) will be installed in each test section. The positions and depth locations of the LVDT modules are indicated on Figure 2. The MDDs will monitor both initial wetting phase and phase three (HVS Loading) of the test plan. MDDs are described in section 6.2.

4.3 Installation of Thermocouples

Thermocouples will be installed at various depths in the three wetted sections as indicated in Table 2. This is important for performance analysis of the HVS test sections, and its translation to field conditions. The temperature at a depth of 50 mm is critical for evaluating permanent deformation performance. This depth is in the zone of critical shear stresses occurring under typical in-situ loading (2). The temperatures on the underside of the asphalt concrete and overlay layers are important for the evaluation of fatigue cracking performance (*5*) since this is where the maximum value of tensile strain is assumed to occur.

Table 6 In-Depth position of thermocouples for fatigue study

SECTION	543 RF	544 RF	545 RF
Top of overlay	0	0	0
Bottom of overlay	38 mm	38 mm	75 mm
Critical position to evaluate permanent deformation	50 mm	50 mm	50 mm
Middle of AC Upper Lift	71 mm	71 mm	108 mm
Top of AC Lower Lift	140 mm	104 mm	141 mm
Bottom of AC lower lift	204 mm	170 mm	207 mm
Bottom of ATPB	245 mm	-	-

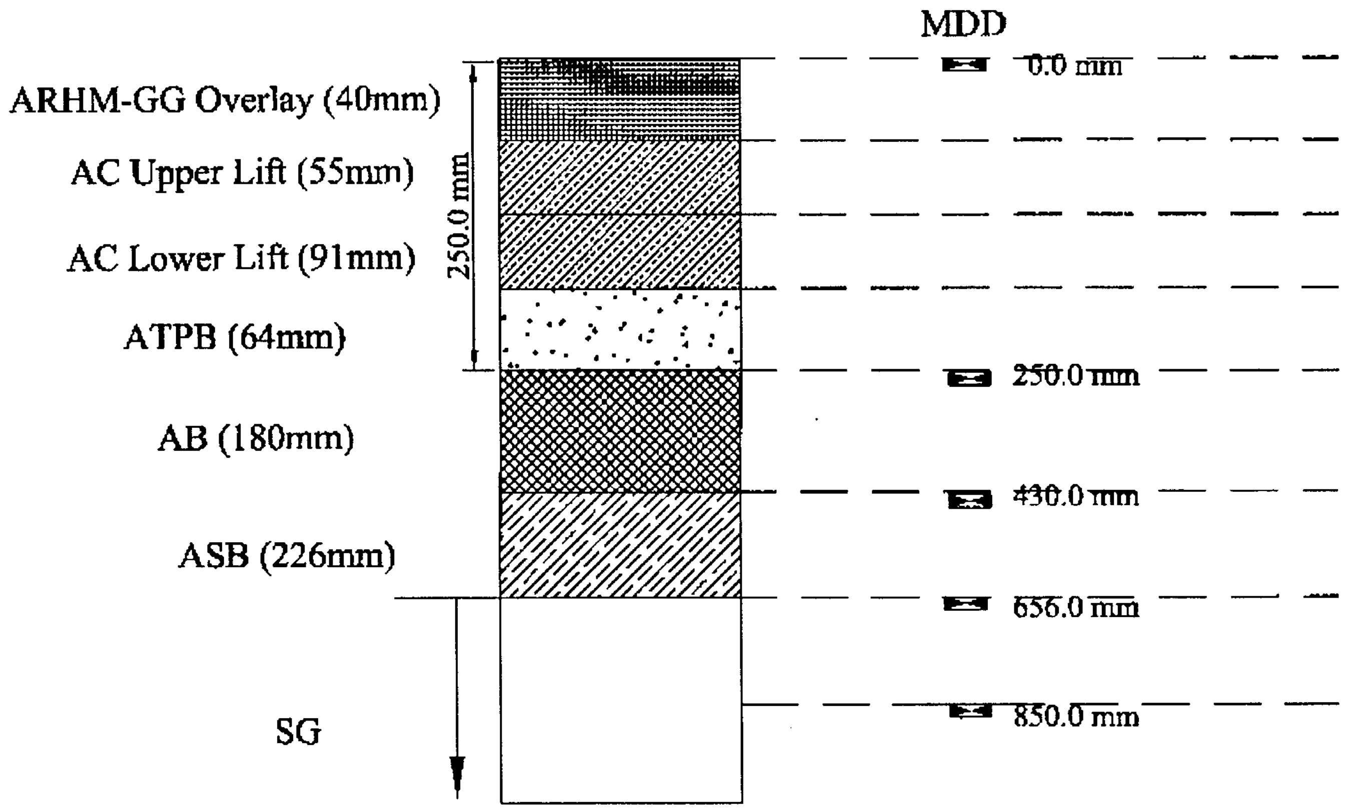


Figure 2 In-Depth Locations of MDDs in Section 543 RT

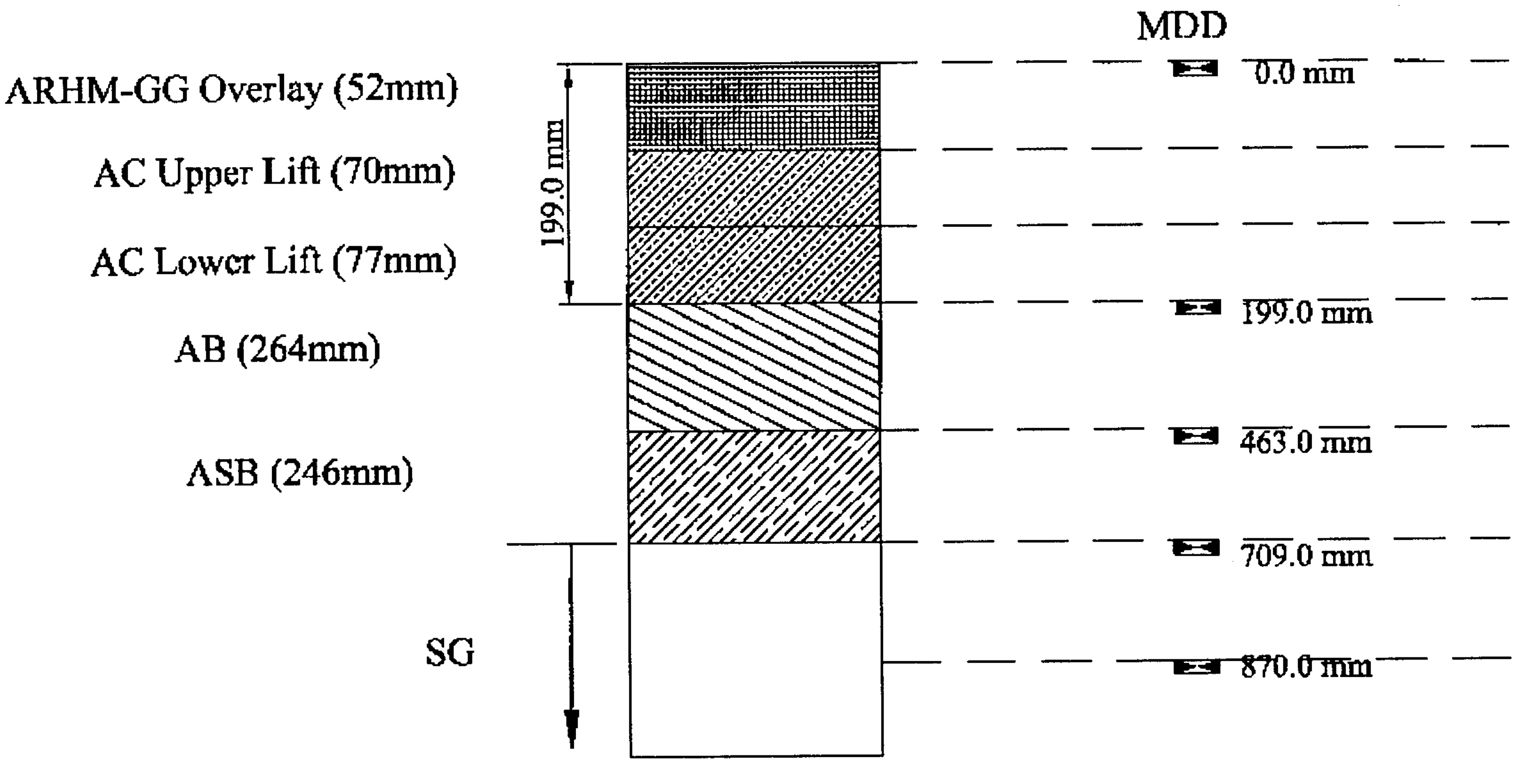


Figure 3 In-Depth Locations of MDDs in Section 544 RT

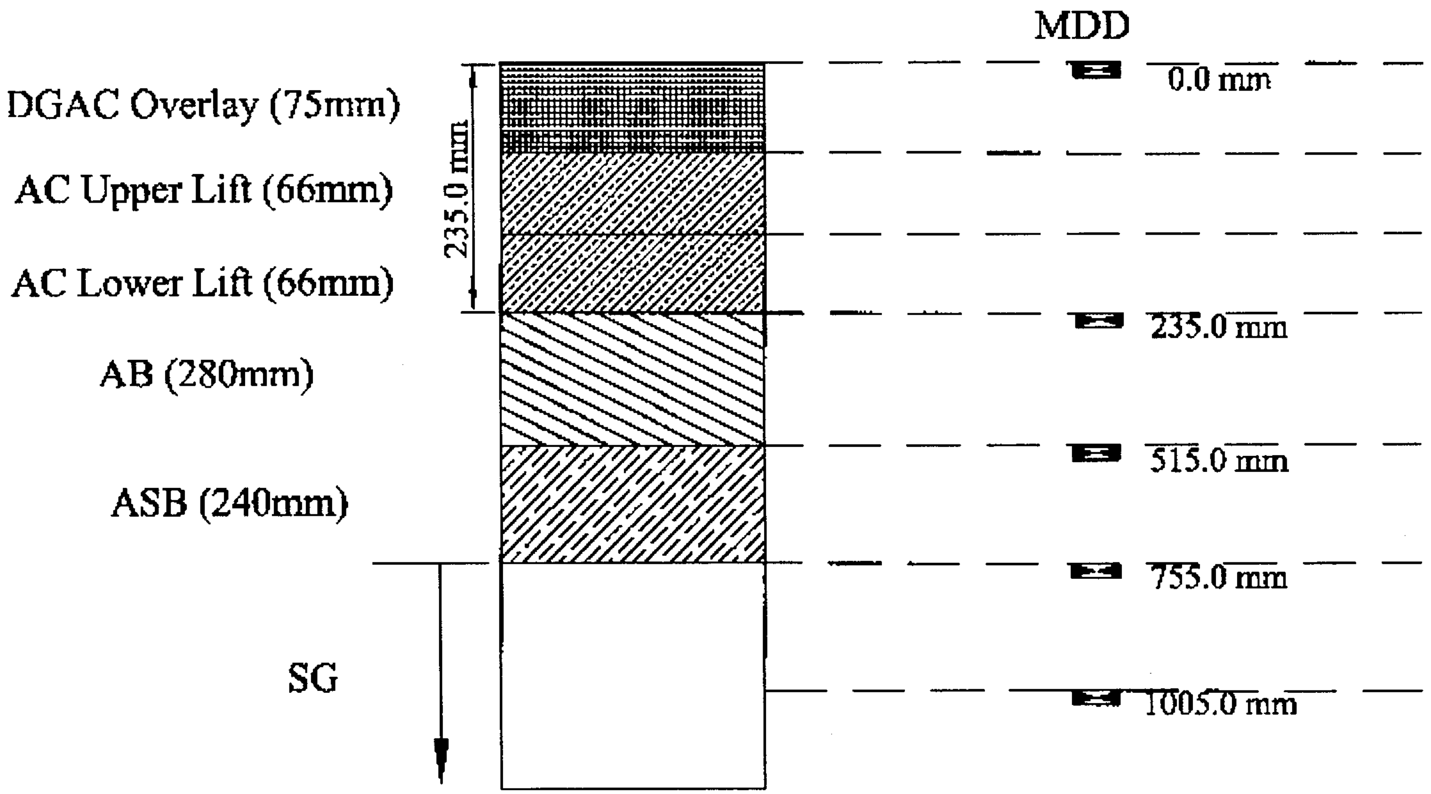


Figure 4 In-Depth Locations of MDDs in Section 545 RT (Optional)

5 TEST PROGRAM

5.1 Stage 1 – Evaluation of pavement structures in dry condition

The first set of measurements is scheduled to be completed before water is introduced into the pavement. This set of measurements includes HWD to measure surface deflection and estimate layer stiffness, GPR to check moisture content of the pavement layers, and Nuclear Density Gage to measure density of the pavement layers.

5.2 Stage 2 – Effects of water infiltration

Water content measurements and HWD testing will be conducted until water flow in the pavement reaches a steady state

5.3 Stage 3 – HVS TESTING OF WET PAVEMENT

5.3.1 Failure mechanisms

The failure mechanisms of wet pavements are very much similar to dry pavements. The main failure mechanism in the overlays is expected to be permanent deformation in the unbound layers. This is due to the relatively high applied load (100 kN). Cracking is another main failure mechanism. The temperature control at $20\,^{0}C \pm 4\,^{0}C$ and loss of stiffness and support in the unbound layers due to soaking should limit rutting in the asphalt concrete and accelerate fatigue damage. Lack of bonding between the bottom two asphalt concrete layers used in Goals 1 and 3 may also accelerate fatigue damage and rutting in the unbound layers

5.3.1.1 Fatigue damage

Two physical evidences of fatigue damage will be monitored:

- cracking, and
- elastic surface deflections.

The failure criteria will be based on a combination of the above. The suggested target failure for fatigue cracking of the DGAC and ARHM-GG pavements is the appearance of a significant amount of alligator cracking on the surface. As the amount of cracking constituting failure is subjective to some engineering judgment, the parameter of crack length per square meter of pavement will be used.

The Caltrans Test Method 356 "Test to Determine Overlay and Maintenance Requirements by Pavement Deflection Measurements" (17) is based on elastic surface deflections. Loss of stiffness due to fatigue can also be monitored using surface deflections and in-depth elastic deflections. Surface deflections will be monitored using falling weight deflectometer (FWD), Heavy Weight Deflectometer (HWD) and Road Surface Deflectometer (RSD) and in-depth deflections will be measured using MDDs.

5.3.1.2 Permanent deformation level on the surface

The functional failure limit for permanent surface deformation (rutting) of the test section will be an average maximum of 12.5 mm. This is a safety aspect to prevent water ponding on the surface that could result in vehicle skidding (i.e. hydroplaning).

The MDD and laser profilometer will be used to measure rutting on the surface and the MDDs will be used to measure in-depth permanent deformations.

5.3.2 Test program for individual HVS sections

5.3.2.1 Pavement condition prior to HVS testing

HWD testing will be conducted under several loads to measure non-linearity of the unbound layers

5.3.2.2 Loading conditions

The accelerated tests will begin with a 40 kN dual wheel load and a tire inflation pressure of 690 kPa. This load will be applied until the end of the "bedding-in" phase is reached. The bedding-in phase is defined as the initial compaction of the layer due to loading. It is expected that the end of this phase will be reached after approximately 75,000 load applications, after which rutting rate should reduce in the asphalt concrete. However, monitoring of the actual behavior is important to prevent the wheel load being changed before the bedding-in phase is completed.

The wheel load will be gradually increased to 60 kN, 80 KN and up to 100KN while the tire inflation pressure should remain constant at 690 kPa.

It is emphasized again that if the pavement performance (primarily rutting) is not constant during the initial loading, the test conditions should not change otherwise the effects of the changes cannot be adequately quantified. It is also advisable to change one test condition at a time to be able to relate the change in pavement performance to the change in that condition. This test plan should be constantly monitored to ensure that the required results are being observed and that any changes made at any stage will contribute to improve test results.

The test conditions and planned measurements are detailed in Appendix A. It should be noted that this is a proposed test plan and some adjustments may be necessary depending on pavement performance under the accelerated trafficking.

5.3.2.3 Traffic Conditions

The test wheel will traffic the length of the 8m section. Lateral wander over the 1m width of the test section is programmed as shown in Figure 5, to simulate traffic wander on a typical highway lane.

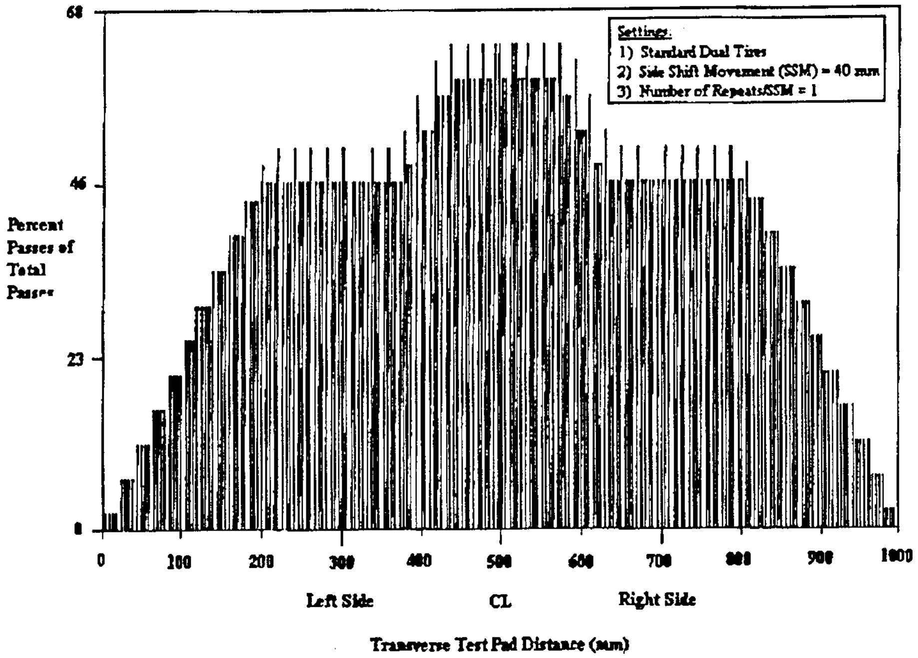


Figure 5 HVS Traffic Distribution for Goal 5

6 INSTRUMENTATION AND METHODS OF MONITORING

The following standard field instruments will be available to monitoring during the HVS testing.

- Road Surface Deflectometer (RSD)
- Multi-depth Deflectometer (MDD)
- Laser profilometer
- Thermocouples
- Visual inspections & crack growth monitoring

A brief discussion on the use of the instrumentation and the results obtained is included in section 6.2 of this test plan.

6.1 Water Content and Non-Destructive Structural Capacity Measurements

6.1.1 Tensiometer

Tensiometers are used to measure soil suction. A tensiometer consists of a tube of porous ceramic tip on the bottom, a vacuum gauge near the top, and a sealing cap.

6.1.2 Ground Penetrating Radar

Ground Penetration Radar system is based on fundamental electromagnetic principles designed for shallow subsurface site investigation. The GPR technology has been around since 1960's and is fairly new for transportation applications (since early 1970's). It has a significant contribution to the measuring process of all of the critical information needed on subsurface pavement conditions including pavement thickness, density, and water content in pavement layers. The GPR surveys provide more continuous contours than distinct measurements obtained with the hydroprobe. The GPR has been previously calibrated using a time domain reflectometer (TDR) and lab samples of base, subbase, and subgrade at known water contents.

6.1.3 Hydroprobe

The hydroprobe is an effective tool for monitoring moisture content in pavement layers at depths below the surface by nuclear methods. Each test section has six hydroprobe holes, three holes on each side. Data are collected once a day and gradually decrease to once a week.

6.1.4 Gravimetric

There are four cores in each test section to gravimetricly measure water content at different layers. Both dry and wet weights have been computed to calculate the water content. This was done to check initial water content of subsurface layers.

6.1.5 Heavyweight Deflectometer

The Heavyweight Deflectometer (HWD) collects deflection data for structural evaluation and back calculation of stiffness. The HWD will collect data every day for the first few weeks and then once a week thereafter.

HWD testing will be conducted during stages 1 and 2 and after HVS testing. The HWD does not fit under the HVS and; therefore, will not be used in stage 3.

6.2 Pavement monitoring during HVS loading

6.2.1 Road Surface Deflectometer (RSD)

The Road Surface Deflectometer measures the elastic surface deflection of a pavement under the action of a wheel load. The RSD is a modification of the Benkelman Beam. Output RSD data is elastic surface deflection basins that can be used to:

- characterize pavement behavior;

- backcalculate effective elastic moduli (stiffness);
- monitor changes in the stiffness of the pavement with number of load/stress repetitions over time, and
- determine stress dependency of pavement layers (non-linear elastic behavior)

During a HVS test, the RSD measuring points on the pavement are clearly marked to ensure that the deflection is measured at the same point each time. An adequate number of RSD readings should be taken to ensure that the behavior of the full test section is monitored.

6.2.2 Multi-depth Deflectometer (MDD)

A stack of MDDs will be installed in the centerline of each pavement section to obtain elastic deflection and permanent deformation at in-depth positions.

The MDD outputs are influence lines of deflection at the selected depths within the pavement and the pavement permanent deformation of the pavement with time, obtained by the permanent vertical movement of the various pavement layers as measured by the MDD modules. MDD measurements can be used to:

- characterize the behavior of the full pavement system;
- monitor changes in the stiffness of the various layers in the pavement with time;
- backcalculate effective E moduli (stiffness) of the various layers;
- determine stress dependency of pavement layers (non-linear elastic behavior), and

- determine the permanent deformation (compression) performance of all pavement layers

The installation depths of the MDDs are illustrated in Figures 2 to 4.

6.2.3 Laser profilometer

The laser profilometer is used to measure the surface profile of a test section surface. This output allows the determination of surface rut progression. The profilometer traverses the test section and the 17 points of measurement are clearly marked to ensure the same point is always measured at the different time intervals.

6.2.4 Thermocouples

Thermocouples are installed in the pavement to measure temperature at selected depths. This allows for the monitoring of temperature fluctuations within the test section. Table 6 presents the positions and depths of the thermocouples.

6.2.5 Visual inspection

Regular visual inspection of the test sections allows surface crack growth and bleeding progression to be monitored. These results can be compared to the Caltrans criteria of degree of cracking to warrant maintenance or rehabilitation. The above factors are measured at selected load repetitions (refer to Appendix A).

Crack monitoring will include visual inspection of the test pavement, direct measurement of crack length and photographic documentation of the cracking progress. Cracking images are digitalized and subjected to digital image analysis (18). The test section is marked with a lumber crayon and then photographed. The photographs are then digitized, adjusted to remove camera perspective and distortion, and then combined. The final product is a 2-dimensional image of the crack pattern over the entire test section. The cracks are traced and calibrated to real-life dimensions.

6.3 Trench

After completion of the tests, a trench will be dug across each test section to gain an understanding of the in-situ profile of the pavement. Material specimens for testing will also be obtained from the trench.

7 LABORATORY TEST PLAN FOR BASE, SUB-BASE AND SUBGRADE MATERIALS

The objectives of this laboratory test program are:

- provide laboratory data to study the main factors affecting resilient response, rutting, and permeability performance of granular materials and the subgrade,
- calibrate laboratory data to back-calculated HVS field data to permit extrapolation of laboratory results to the field,
- develop methodologies to select modulus inputs to mechanistic-based design procedures,
- establish design criteria for considering rutting in the unbound layers,
- compare Caltrans compaction specifications to others such as US Army Corps of Engineers, AASHTO, TX-DOT, MN-DOT, WS-DOT, AZ-DOT, Illinois-DOT, and South Africa-DOT,
- assess the effect of compaction effort (specifications) on fatigue (stiffness),

rutting (strength) and drainage performance.

- make recommendations regarding unbound materials specifications

Mechanistic analyses (linear and nonlinear as a minimum) will be used to investigate the failure mechanisms and validate analytical procedures for predicting pavement performance based on laboratory testing, such as:

- fatigue life based on maximum tensile strain at the asphalt layers (asphalt concrete fatigue data from Goals 1 and 3 will be used);
- rutting of unbound materials based on strains or stresses in the unbound layers.

7.1 Laboratory Testing

The following laboratory test will be performed:

1) Routine laboratory test
    a) Particle size analysis including fine material if any
    b) Standard and Modified AASHTO, and California Compaction Tests
    c) Strength Tests
        - Triaxial
        - Direct Shear (if time and equipment are available)
    d) Other strength tests:
        - R value Test results from Goal 1 will be used.
        - CBR (if needed to correlate with data from CSIR)
    e) Permeability Tests

2) Repeated Loading Tests
    a) Resilient Modulus: SHRP Protocol P-46
    b) Permanent Deformation Test

The testing will provide information on the properties of the unbound materials, and data to evaluate Caltrans specifications for construction and design.

Mechanistic analysis will be used 1) to investigate the response and performance, 2) provide modulus regression models for typical California materials, 3) provide data to develop concepts regarding rutting performance, 4) correlate laboratory data to HVS field data, and 5) permit extrapolation of HVS results to the field.

7.2 Sampling and Specimens

Aggregate base, aggregate subbase and subgrade materials were sampled before and during Goal 3 trenching.

150-mm diameter by 300-mm tall cylindrical specimens will be compacted in the laboratory to reproduce the target density and moisture conditions. For granular materials with less than 12 percent fines a vibratory hammer is recommended for compacting the soil samples. For fine-grained soils an impact hammer is recommended.

7.3 Test Descriptions

7.3.1 Shear Strength of unbound materials

Rutting in the unbound materials occurs if excessive high shear stresses are induced due to increased loads, stiffness reduction in upper layers, or strength reduction in the unbound materials.

Granular base rutting is controlled by establishing a minimum asphalt concrete thickness (conventional flexible pavements) to reduce the stress state in the base. Other procedures use vertical strain to control rutting. In general those factors that contribute to increase shear strength also contribute to reduce rutting. Factors influencing shear strength in the granular materials include gradation, density, plasticity index, particle geometric characteristics (shape, angularity, and surface texture), moisture content, and confining pressure.

Rutting in fine-grained subgrades is usually considered by limiting the strain or stress on the subgrade. As in the granular materials, those factors that contribute to increase shear strength or reduce the stress state in the subgrade also contribute to reduce subgrade rutting. Factors influencing shear strength in fine-grained soils include clay mineralogy, plasticity index, density, and moisture content.

Shear strength of unbound materials can be measured using a triaxial shear test. The Pavement Research Center at the UC-Berkeley is developing a triaxial shear apparatus for the testing unbound and bound materials. Triaxial shear tests on granular materials will be performed at various confining pressures under drained conditions. A rapid shear rate (>10%) is suggested to simulate highway conditions. Shear tests on cohesive soils will be performed under unconfined conditions.

Shear strength tests and rutting laboratory tests included in this test plan are intended to evaluate the rutting potential of the granular base, subbase, and cohesive subgrade materials.

7.3.2 Resilient Moduli of Unbound Materials

Resilient moduli are important material inputs to structural models such as elastic layer programs and finite element programs.

Granular materials stiffen (resilient modulus increases) as the cyclic stress state increases. The resilient moduli of granular materials display generic type behavior and are less variable than for fine-grained soils. Factors influencing the moduli of granular materials include gradation, particle geometric characteristics (shape, angularity, surface texture), and moisture content (in particular if high fine contents are present). The magnitude of the repeated stress state (represented by the first stress invariant or the bulk stress Theta) is the most dominant factor (19).

Fine-grained materials soften (resilient modulus decreases) as the stress state increases. Factors influencing the moduli of fine-grained soils include clay content, plasticity index, liquid limit, organic content, density, moisture content, and soil texture (19).

Resilient modulus tests will be conducted per SHRP P46 Protocol (20). Resilient modulus of cohesive soils can be conducted under unconfined conditions since at high saturation levels, confining pressure does not significantly influence the resilient response (21).

Data of the resilient modulus test program can be used in combination with back-calculated modulus from the HWD and HVS test data to develop procedures to characterize granular and subgrade materials for the mechanistic design of flexible pavements. These efforts can produce various procedures to estimate resilient moduli of unbound materials for pavement design.

7.3.3 Rutting of Unbound Materials

Rutting of unbound materials is significantly related to the applied stress and strength of the materials.

Rutting or permanent deformation tests on granular materials will be conducted in a triaxial apparatus at various confining pressures and applied deviator stresses under drained conditions. Confining pressures should correspond to the confining pressures used in the shear strength program. Repeated deviator stresses (σ_d) will be ratios (SR=stress ratios) to the deviator stress at shear failure (σ_f), i.e., $\sigma_d = SR^* \sigma_f$. The following stress ratios will be used: 0.3, 0.6, and 0.8.

Rutting or permanent deformation tests on cohesive soils will be conducted at various deviator stresses under unconfined conditions. The following repeated deviator stresses, as a ratio of the unconfined compressive strength will be used: 0.25, 0.50, 0.75 and 1.0.

Load duration and cycle will be those used in the resilient modulus test.

The total number of load applications will be 1000.

Shear strength tests and rutting laboratory tests included in this test plan are intended to evaluate the rutting potential of the granular base, subbase, and cohesive subgrade materials.

7.3.4 Permeability Tests

Permeability tests will be conducted to establish the hydraulic properties of the base and subbase materials. The coefficient of permeability is the critical aggregate property that influences the drainage performance of the base and subbase layers. The coefficient of permeability of the granular materials is influence by 1) gradation, 2) particle packing (density, void ratio, and porosity), and 3) degree of saturation.

Permeability tests will be conducted in the field to obtain the in-situ permeability of base and subbase layers. Several field permeability tests are available.

Laboratory permeability tests will be conducted on prepared specimens compacted to the anticipated field moisture and density conditions.

The laboratory results will be calibrated to the field test to estimate coefficient of permeability of Caltrans base and subbase layer materials.

The results will provide input for modelling moisture-soil states under different highway conditions using the ICM model and other models at UCB. These results will provide insight regarding pavement drainage requirements.

7.4 Tentative Test Program

The tentative test program for granular materials and the subgrade is presented in Table 7. Emphasis is on the effect of compaction on resilient modulus, strength, permanent deformation, and permeability.

Table 7 Tentative Test Program for Granular Materials

Test	Variables (2 replicates)		No. of Tests
Resilient Modulus	2 Compaction Levels	Caltrans USACE	2*2*2 + 2 = 10
	1 Moisture Content	To be specified	
	2 gradation	Caltrans base Caltrans subbase	
	2 Tests for Moisture Content Effects		
Strength	2 Compaction Levels	Caltrans USACE	2*2*3*2 + 2 = 26
	1 Moisture Content	To be specified	
	3 Confining Pressures	Low = 35kPa Medium= 70 kPa High= 105 kPa	
	2 Gradations	Caltrans base Caltrans subbase	
	2 Tests for Moisture Content Effects		
Permanent Deformation	2 Compaction Levels	Caltrans USACE	2*2*3*2 +2= 50
	1 Moisture Content	To be specified	
	2 Confining Pressures	45 kPa and 90 kPa	
	3 Repeated Stress Levels (ratio of deviator stress to failure)	0.30 0.60 0.80	
	2 Gradations	Caltrans base Caltrans subbase	
	2 Tests for Moisture Content Effects		
Permeability	2 Compaction Levels	Caltrans COE	2*2*2*2 = 16
	2 Moisture Contents	To be determined	
	2 Gradations	Caltrans base Caltrans subbase	
Total Number of Tests			102

Table 8 Tentative Test Program for a cohesive subgrade.

Test	Variables (2 replicates)		No. of Tests
Resilient Modulus	2 Compaction Levels	Caltrans COE	2*2*2 = 8
	2 Moisture Content	OMC OMC + 2%	
Strength	2 Compaction Levels	Caltrans COE	2*2*2 = 8
	2 Moisture Content	OMC OMC + 2%	
Permanent Deformation	2 Compaction Levels	Caltrans COE	2*2*2*4 = 32
	2 Moisture Content	OMC OMC + 2%	
	4 Repeated Stress Levels (ratio of deviator stress to failure)	0.25 0.50 0.75 1.0	
Total Number of Tests			48

A similar test plan can be produced for a sandier subgrade. The sandier subgrade has not been selected yet.

8 SCHEDULE

The planned schedule for all Goal 5 work is shown in Figure 6. The schedule for Goal 5, if HVS test section 545RF is included, is shown in Figure 7.

9 BENEFITS

Potential benefits to Caltrans and the public resulting from the implementation of the CAL/APT Strategic Plan Goal 5 include substantial cost savings, improvements in highway safety, and better understanding of the nature of some important pavement problems faced by Caltrans.

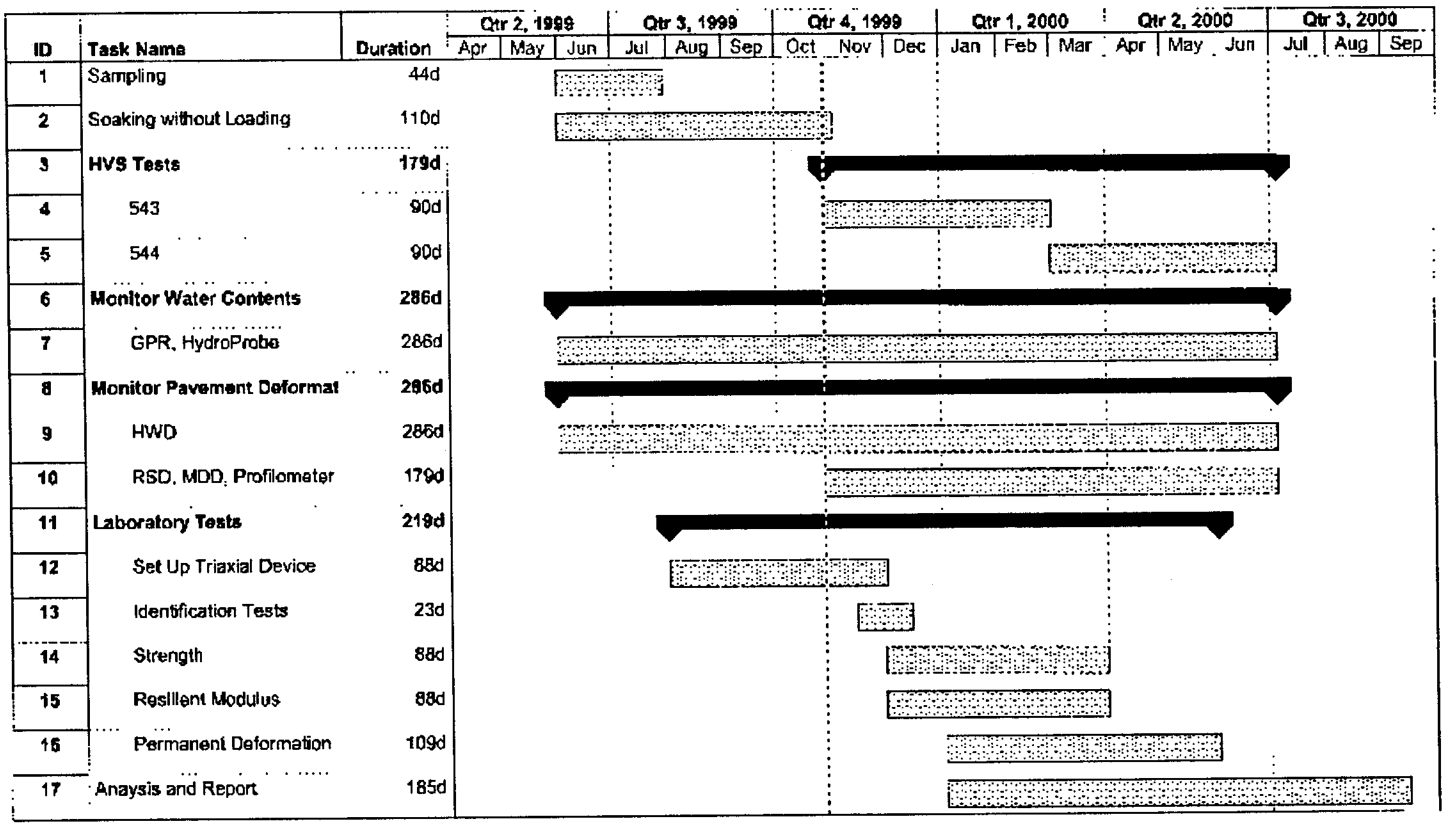
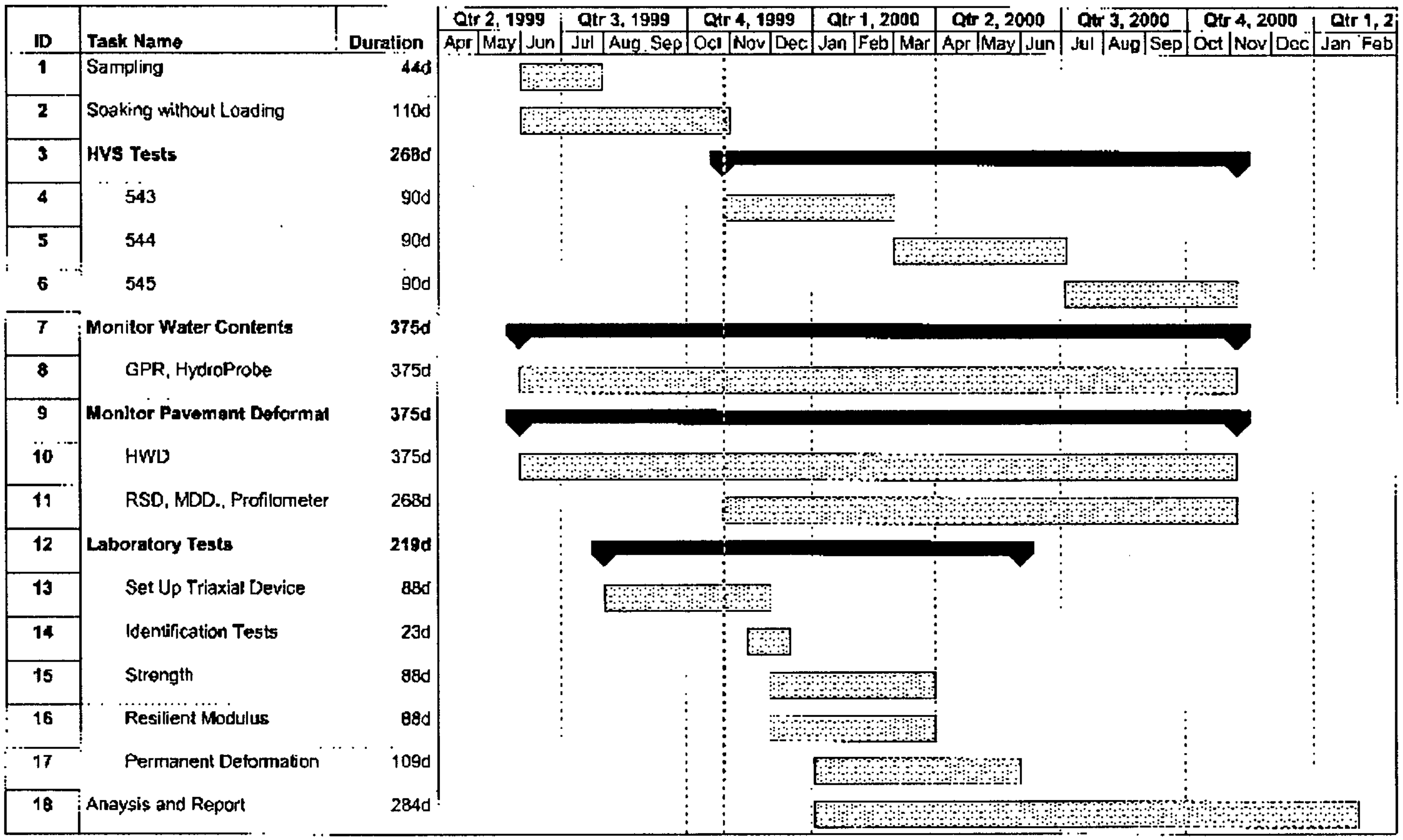


Figure 6 Schedule for Sections 543 RF and 544 RF



ID	Task Name	Duration
1	Sampling	44d
2	Soaking without Loading	110d
3	**HVS Tests**	**268d**
4	543	90d
5	544	90d
6	545	90d
7	**Monitor Water Contents**	**375d**
8	GPR, HydroProbe	375d
9	**Monitor Pavement Deformat**	**375d**
10	HWD	375d
11	RSD, MDD., Profilometer	268d
12	**Laboratory Tests**	**219d**
13	Set Up Triaxial Device	88d
14	Identification Tests	23d
15	Strength	88d
16	Resilient Modulus	88d
17	Permanent Deformation	109d
18	Anaysis and Report	284d

Figure 7 Schedule for Sections 543 RF, 544 RF, and 545 RF

Caltrans currently spends approximately 150 to 200 millions of dollars annually on maintenance and rehabilitation of the existing highway network. In the last five years, Caltrans has spent about 33 millions of dollars on AB and ASB and 4.5 millions of dollars on ATPB. Actual cost savings are difficult to quantify; however, the results will lead to a better structural capacity of the unbound layers and probably thickness reductions in the AB and ASB layers. The increase in structural capacity also represents long-life performance of reconstructed pavements resulting in savings in maintenance and rehabilitation. Significant saving can also be obtained in ATPB mix material in projects that do not require this drainage layer. A one-percent decrease in the annual cost of Caltrans maintenance and rehabilitation would be result in a benefit of about $ 2,000,000 *per year*. Specific benefits resulting from the implementation of the results of Goal 5 are summarized below:

- Rationalization of the need for drained pavements based on environmental region. Currently Caltrans requires a 75-mm ATPB layer in all new flexible pavements regardless of region. Significant savings of ATPB and drainage systems costs can be obtained by specifying drained pavements only for areas subjected to significant rainfall.
- Effects of compaction effort on the performance of granular and subgrade materials. The results will 1) quantify the improvement in pavement life by better compacting the unbound materials, 2) provide the development or refinement of pay factors for compaction, water content, and gradation of

unbound materials for QC/QA, and 3) provide guidelines for recommending specification changes.

- Development of material input to mechanistic-empirical design procedures. Material inputs (modulus and strength) are required to mechanistic-empirical design procedures. Modulus and strength input values will vary according to environmental locations. Comparison data for converting R-values to mechanistic material inputs will be developed to help for the transition from empirical to mechanistic based design procedures. The proper characterization of the paving materials will provide a better prediction of pavement performance producing significant cost savings.
- Quantifying the performance of flexible pavements for wet (Goal 5) and dry (Goal 1) environments. Results from Goal 5 and Goal 3 will provide support for the development and calibration of a mechanistic-based design procedure. Refined criteria for rutting and fatigue will be developed. The results will also provide inputs to pavement management systems.
- Provide information to improve the rutting resistance of Asphalt Treated Permeable Materials. This information will be applicable to treated permeable base materials and treated permeable materials used on the surface.

Actual cost savings are difficult to quantify but in general, the results are very important for the long-life performance of reconstructed flexible and rigid pavements.

10 IMPLEMENTATION

The accelerated test will help define the relation between laboratory tests and actual field performance. The results can be used to link laboratory data to expected pavement performance. Performance of these and other supplementary test sections will be used to validate present Caltrans design procedures and develop and validate new procedures and may result in modifications to the current Caltrans practices and specifications for pavement evaluation, design and construction.

The laboratory results may also result in changes to current Caltrans specifications for the structural design of pavements and the construction method used.

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APPENDIX A: TEST PLAN GOAL 5

Test Plan for Wet Sections (Data Collection prior to HVS traffic)
Project Location: Richmond Field Station
Test Start Date: 6/26/99

Date	GPR (Ground Penetration Radar)	HP (Hydro-Probe)	HWD (Heavy Weight Deflectometer) Temperature and Humidity	Temperature and Humidity	Water Input
4/14/99					
5/15/99					
6/25/99					
6/26/99					
6/27/99					
6/28/99					
6/29/99					
6/30/99					
7/1/99					
7/2/99					
7/3/99					
7/4/99					
7/5/99					
7/6/99					
7/7/99					
7/8/99					
7/9/99					
7/10/99					
7/11/99					
7/12/99					
7/13/99					
7/14/99					
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7/16/99					
7/17/99					
7/18/99					
7/19/99					
7/20/99					

HVS TEST PLAN FOR WET SECTIONS: Aug-99
Section Description:
Tire Pressure: 720 kPa (105 psi)
Traffic Load: 40 kN, 80kN, 100kN
Tire Type: Radial Dual
Temperature 16-24^{0}C (Aver. 20^0)

Section:
Authorizing Signature:
Version Date:

Thermocouple: One at the corner Depths: (Surface, 1st & 2nd Interface)
MDDs: One at the center Depths: (0,250,430,656,850)mm

Reps	Load (KN)	Temperature Hourly	Profilometer points (0-16)	MDD CL Point	RSD CL at Points(4,6,8,10,12)	RSD 200mm CS, 200mm TS at points(4,8,12	CAM	NDG on Surface	NDG in Depths	Hydro-Probe	Tensiometer	GPR (One Frequency)	Photo's
10	40	yes	yes	40	40	40		yes	yes				yes
15000 (Daily)	40	yes	yes	40	40								
30000	40	yes	yes	40	40								
45000	40	yes	yes	40	40								
60000	40	yes	yes	40	40								
90000	40	yes	yes	40	40								
120000	40	yes	yes	40	40								
150000	40	yes	yes	40	40								yes
170000	40 to 80	yes	yes	40	40	40							
205000	80	yes	yes	40	40	40							
225000	80	yes	yes	40	40								
260000	80	yes	yes	40	40								
317000	80 to 100	yes	yes	40,80,100	40,80,100	40,80,100		yes	yes				yes
353000	100	yes	yes	40,80,100	40,80,100	40,80,100							
400000	100	yes	yes	40,100	40,100	40,100							
450000	100	yes	yes	40,100	40,100	40,100							
500000	100	yes	yes	40,100	40,100	40,100							
If steady state phase has been reached weekly readings can be made, if not continue at 50000 intervals.													
Weekly until failure	100	Monthly	yes	40,100	40,100	40,100 every 2nd week		Monthly	Every 2nd Month				Every 2nd week until close to
Crack Initiation	100	Monthly	yes	40,80,100	40,80,100	40,80,100	yes	yes	yes				yes
Take complete set of readings after crack initiation and reduce interval between data collection to daily for 5 days.													
Failure	100	yes	40,80,100	40,80,100	yes	yes	yes						