REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE 8.Sep.00	3. REPORT TYPE AND DATES COVERED THESIS

4. TITLE AND SUBTITLE
LABORATORY AND FIELD TESTS ON AGGREGATE BASE MATERIAL FOR CALTRANS ACCELERATED PAVEMENT TESTING GOAL 5

5. FUNDING NUMBERS

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
UNIVERSITY OF CALIFORNIA AT BERKELEY

8. PERFORMING ORGANIZATION REPORT NUMBER
CY00372

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
THE DEPARTMENT OF THE AIR FORCE
AFIT/CIA, BLDG 125
2950 P STREET
WPAFB OH 45433

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT
Unlimited distribution
In Accordance With AFI 35-205/AFIT Sup 1

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

14. SUBJECT TERMS

15. NUMBER OF PAGES
42

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT

Abstract for
Laboratory and Field Tests on Aggregate Base Material for Caltrans Accelerated Pavement Testing Goal 5

Prepared by: Capt Mark A Russo
21 Jul 00

In partial fulfillment of the requirements for the degree of
Master of Engineering in Geotechnical Engineering
at the University of California, Berkeley

This report evaluates the effect of aggregate base density and permeability on in-situ moisture content, assesses the effectiveness of asphalt treated permeable base (ATPB) courses and recommends future testing. This report characterizes the aggregate base material used for California Department of Transportation (Caltrans) Accelerated Pavement Testing (APT) Goal 5. Laboratory and field tests were performed on aggregate base material used in the construction of the Heavy Vehicle Simulator (HVS) test sections at the University of California's Richmond Field Station.

Excess water accumulating in untreated granular base layers may cause damage through four mechanisms: weakening, buoyancy, expansive soils, and frost heave.[1] To prevent and mitigate water damage, drainage structures are often incorporated into pavement design. Presently, Caltrans design for flexible pavements includes an asphalt treated permeable base (ATPB) layer between the traffic-bearing asphalt concrete layer and the aggregate base layer. This report summarizes the laboratory and field evaluation of typical Caltrans aggregate base course density and permeability relationships.

The original aggregate base material used in the HVS test section met the Caltrans gradation standards and was compacted according to the Caltrans specifications. The testing for this report confirmed the aggregate base material still meets Caltrans specifications. As expected, the permeability decreased with increasing density and increasing water content (once past the optimum water content). Density curves and permeability analyses were completed and details can be found in the appendices.

Drainage has been identified as a crucial design feature of pavement structures. Increasing aggregate compaction is known to reduce permeability and improve the structure's resistance to water infiltration. Current Caltrans specifications allow a compaction effort of 95% relative density, according to the Caltrans method (California Test 216). An increase in compaction of a few percent will greatly decrease the permeability of aggregate bases and, in turn, increase the life of future constructed

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[1] *Drainage of Asphalt Pavement Structures*, The Asphalt Institute Manual Series No. 15 (MS-15), 1984.

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pavements. Increased density will also reduce pavement permanent deformations and improve fatigue performance.[2]

Tests to determine the permeability of the aggregate base materials were performed according to AASHTO, ASTM, and Caltrans compaction and permeability standards. A compaction spacer disk, a permeability insert, and a top permeability cap were designed and fabricated to conduct compaction and permeability tests in a six-inch CBR (California Bearing Ratio) mold.

Field percolation tests were performed. Permeability in the field followed general trends that agree with the laboratory results. Traffic loading of a pavement causes a decrease in permeability of the ATPB and the aggregate base (AB) below it. Conclusions from the field testing: 1) the ATPB reduces the added compaction benefits to the AB layer during construction of the top layers and 2) ATPB will not perform as a drainage layer when trafficked to fatigue failure. These results support the following recommendations for Caltrans flexible pavement designs: 1) eliminate the ATPB layer and 2) increase the Caltrans specification for compaction of AB from 95% to 97% relative density.

These recommendations will significantly reduce permeability, and strength and stiffness will increase. Therefore asphalt concrete fatigue life will increase with reduced pavement rutting -- yielding pavements with lower maintenance costs and longer life. Longer life pavement structures will also lead to significant economic savings because of reduced lane closures and fewer traffic delays (a major concern for busy California freeways).

Some tests were performed on slightly asphalt-contaminated aggregate base material. Results were surprising. Sieve analysis and compaction results appeared similar to uncontaminated samples. However, permeability results indicate a trend for the contaminated material to be much more permeable. Reclaimed aggregate material, commonly used in rehabilitation and other projects, is often slightly contaminated with asphalt. Recommendations for future testing are established.

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[2] H.B.Seed; Chan, C.K. and Lee,C.E. Resilience Characteristics of Subgrade Soils and Their Relation to Fatigue Failures in Asphalt Pavements. Proceedings: *International Conference on the Structural Design of Asphalt Pavements*. University of Michigan, August 20-24, 1962.

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Excess water accumulating in untreated granular base layers may cause damage through four mechanisms: weakening, buoyancy, expansive soils, and frost heave.[1] To prevent and mitigate water damage, drainage structures are often incorporated into pavement design. Presently, Caltrans design for flexible pavements includes an asphalt treated permeable base (ATPB) layer between the traffic-bearing asphalt concrete layer and the aggregate base layer. This report summarizes the laboratory and field evaluation of typical Caltrans aggregate base course density and permeability relationships.

The original aggregate base material used in the HVS test section met the Caltrans gradation standards and was compacted according to the Caltrans specifications. The testing for this report confirmed the aggregate base material still meets Caltrans specifications. As expected, the permeability decreased with increasing density and increasing water content (once past the optimum water content). Density curves and permeability analyses were completed and details can be found in the appendices.

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Laboratory and Field Tests on Aggregate Base Material for Caltrans Accelerated Pavement Testing Goal 5

21 July, 2000

Prepared for: Dr John Harvey

Prepared by: Mark Russo

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1 INTRODUCTION

This report characterizes the aggregate base material used for Caltrans Accelerated Pavement Testing (APT) Goal 5. Laboratory and field tests were performed on aggregate base material used in the construction of the Heavy Vehicle Simulator (HVS) test sections at the University of California's Richmond Field Station.

Excess water accumulating in untreated granular base layers may cause damage through four mechanisms: weakening, buoyancy, expansive soils, and frost heave.[1] To prevent and mitigate water damage, drainage structures are often incorporated into pavement design. Presently, California Department of Transportation (Caltrans) design for flexible pavements includes an asphalt treated permeable base (ATPB) layer between the traffic-bearing asphalt concrete layer and the aggregate base layer. This report summarizes the laboratory and field evaluation of typical Caltrans aggregate base course density and permeability relationships.

Tests to determine the permeability of aggregate base materials were performed according to AASHTO, ASTM, and Caltrans compaction and permeability standards.

This report gives a description and results from tests performed on the aggregates used in the construction of an aggregate base course for the Caltrans Accelerated Pavement Testing at the Richmond Field Station.[2] The aggregate base material met the Caltrans gradation standards and was compacted according to the Caltrans specifications. This report evaluates the effect of aggregate base density and permeability on in-situ moisture content, assess the effectiveness of asphalt treated permeable base (ATPB) courses and recommends future testing.

1.1 Summary of Results

The testing for this report confirmed the aggregate base material still meets Caltrans specifications. As expected, the permeability decreased with increasing density and increasing water content (once past the optimum water content). Density curves and permeability analyses were completed and details can be found in the attached appendices.

Drainage has been identified as a crucial design feature of pavement structures. Increasing aggregate compaction is known to reduce permeability and improve the structure's resistance to water infiltration. Current Caltrans specifications allow a compaction effort of 95% relative density, according to the Caltrans method (California Test 216). An increase in compaction of a few percent

1

will greatly decrease the permeability of aggregate bases and, in turn, increase the life of future constructed pavements. Increased density will also reduce pavement permanent deformations and improve fatigue performance.[3]

2 AGGREGATE TESTS

2.1 Scope and purpose of laboratory investigation

The scope and purpose of this portion of the laboratory investigation was to test the aggregate base material and to compare the test results with the Caltrans specifications. The following test was performed:

- Gradation (dry and wet/dry sieve tests) on split samples

Basic descriptions of the various test methods are provided in the next section.

Previous characterization testing was performed on the material during the construction of the test sections and it was found that the material is non-plastic (no plastic limit).[4]

2.2 Test methods

Samples were taken from three APT test pits at the Richmond Field Station. The aggregate base material came from sections 517/518 and 500/514 in building 280. All test pits were dug in March and May 2000, after APT section testing was completed.

Barrels of the material were split into sample sizes following California Test 201 (1978) to ensure representative samples. The gradation of the split aggregate was determined using test methods ASTM C117-95 and ASTM C136-96a which provide a method to calculate the percentage material passing the 75 μm (#200) sieve as well as the particle size distribution of the larger aggregates.

2.3 Summary of test results

Full results from the tests on the aggregates are presented in Appendix A.

Table 1 gives the average gradation for the aggregate along with the Caltrans specification for Type 2 aggregate bases with a maximum particle size of 19 mm. Figure 1 illustrates the results.

Sieve size		Percentage passing by mass						Average Meets Specification
(US)	(mm)	Sample 1	Sample 2	Sample 3	Average	Upper limit	Lower limit	
2"	50.8	98.9	100	100	99.6			
1"	25	98.1	100	100	99.4	100	100	No
3/4"	19	89.4	100	99.8	96.4	100	87	Yes
1/2"	12.5	81.0	91.6	87.9	86.8			
3/8"	9.5	62.5	83.4	77.4	74.5			
#4	4.75	48.8	65.6	56.7	57.1	65	30	Yes
#8	2.36	39.2	50.7	42.0	44.0			
#16	1.18	31.2	40.4	31.9	34.5			
#30	0.6	23.9	32.1	22.5	26.1	35	5	Yes
#50	0.3	17.8	25.0	13.4	18.7			
#100	0.15	14.1	18.9	5.6	12.9			
#200	0.075	13.4	15.2	0.8	9.8	12	0	Yes

Table 1: Aggregate and Specification Gradations
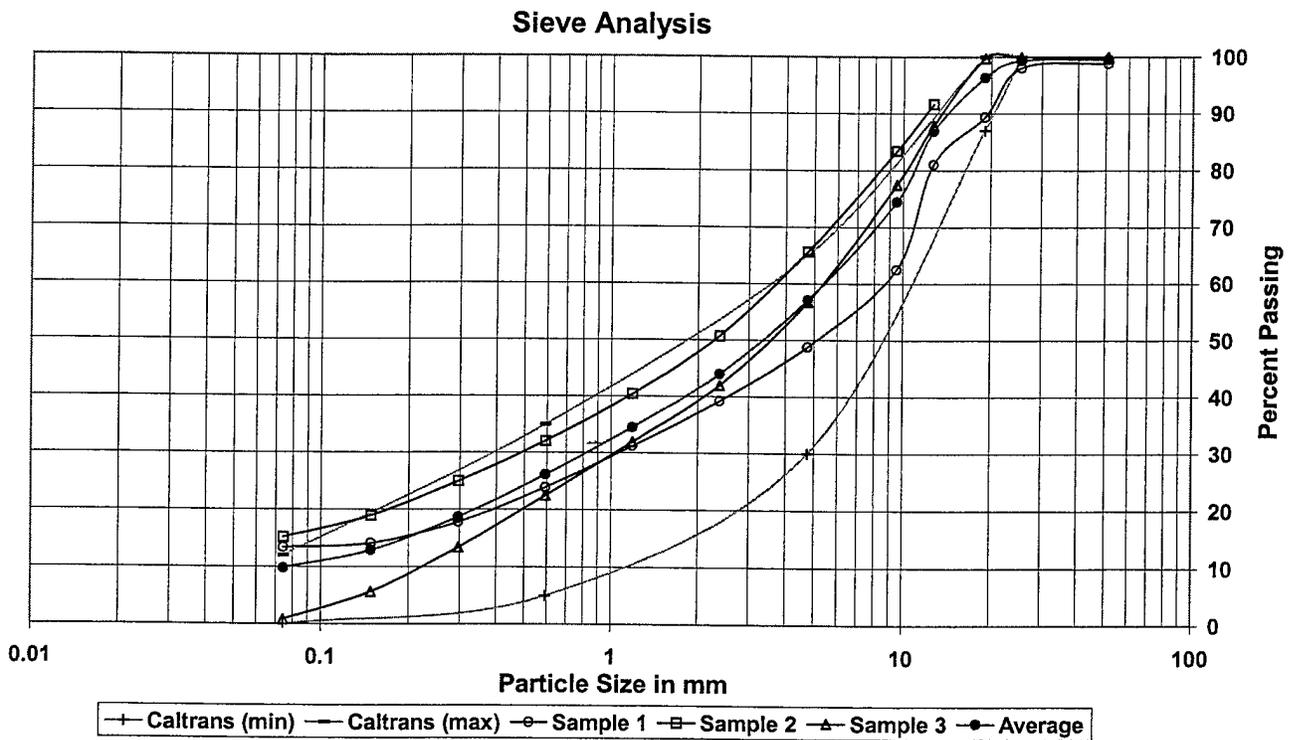
Figure 1: Aggregate and Specification Gradation

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From Table 1 and Figure 1, the average gradation meets the Caltrans specification. One sample did not meet the 25 mm specification but this was most likely a sampling or testing error. Two of the samples are slightly higher than the specification for the percentage material passing the #200 sieve. The aggregate base material originally met Caltrans specifications during the construction of the pavement test area. An increase in fines in any individual sample may be a result of breakdown or segregation during field compaction of this material, under HVS testing or during sampling. Since the #200 value is only slightly above the specification (and the rest of the values fall within the specification), it was decided to proceed with the compaction and permeability tests using this gradation.

From the aggregate distribution, the sample is classified as a GM material according to the Unified Soil Classification System (USCS). GM material requires 3 hours of standing time when water is mixed in to reach a desired water content.

3 COMPACTION TESTS

3.1 Scope and purpose of laboratory investigation

The scope and purpose of this portion of the laboratory investigation was to compact AB samples to known densities at different water contents and prepare them for permeability testing. The following compaction tests were performed:
- ASTM D698-91, Standard effort
- ASTM D1557-91, Modified effort
- California Test 216, Part II

Descriptions of the various test methods are provided in the following sections. Standard and Modified compaction tests employed a free-fall tamper and not a struck, or firmly rammed tamper as in Proctor tests.

3.2 Preparation of samples

Barrels of the aggregate were passed through a 19 mm sieve and the oversize material discarded. The aggregate was then split into samples of approximately 6 kg. A chemical analysis of the sample material was not conducted. As a precaution to prevent possible clay particle chemistry changes, no oven drying of aggregate samples was allowed. Varying compaction moisture contents were used, assuming an initial moisture content of 1 to 2%, based on experience with the material. For standard

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and modified compaction tests, water contents were calculated with the remaining sample material after a compacted specimen was prepared. For Caltrans compaction tests, material was also retrieved from the split mold after the compaction test and water contents were determined. This value was double checked against the water content of the remaining sample material not used in the test.

3.3 Test methods

Both Standard and Modified compaction tests require a 6 inch diameter compaction mold due to the ½ inch maximum size aggregate. In order to perform permeability tests on as-compacted samples that meet ASTM D698 and D1557 specifications, a standard 6" CBR mold was used as a compaction mold with a spacer at the bottom. A compaction spacer disk was designed and is shown in Figure 2. The spacer disk fits snugly in the base of the CBR mold.

Compaction Insert
Material: steel

152mm (5.990 in.) diam.

102-12.7mm
(4-1/2")
diam. pipe

61.4mm (2.416") (height to make CBR
mold meet compaction spec.s)

9.52m
m
(3/8")

6.35mm (1/4")
fillet weld (typ.)

9.52m
m
(3/8")

152.1mm (5.990") diam. (fits snugly
inside 152.4mm (6") nom. CBR mold)
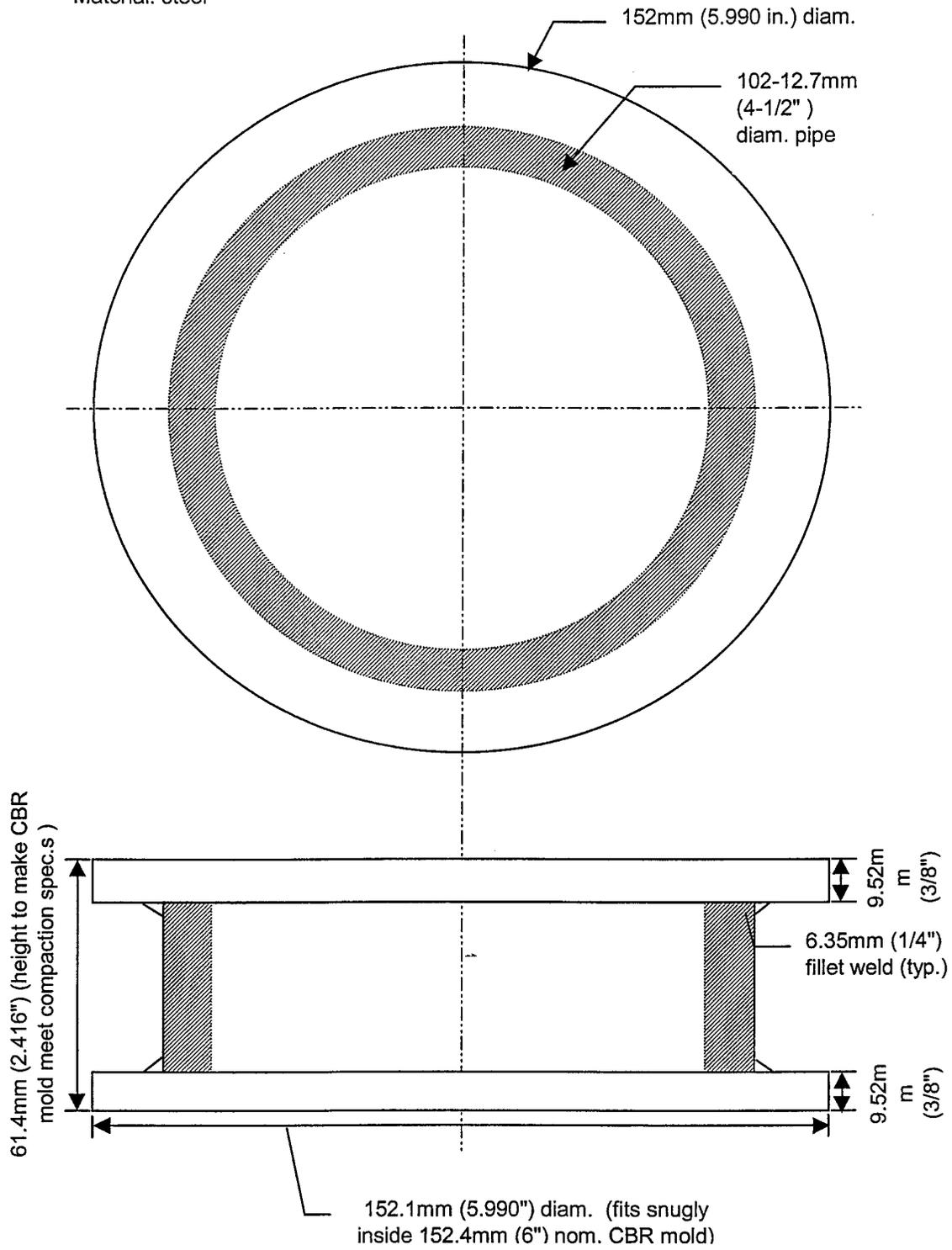
Figure 2: Compaction Spacer Disk for CBR Mold

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3.4 Summary of test results

The moisture contents given are the gravimetric moisture contents. The full test results are presented in Appendix B.

Figure 3 summarizes the results of the compaction tests. The lowest curve is not a standard compaction effort, but demonstrates the effect if ½ the energy of a Standard compaction test is used.
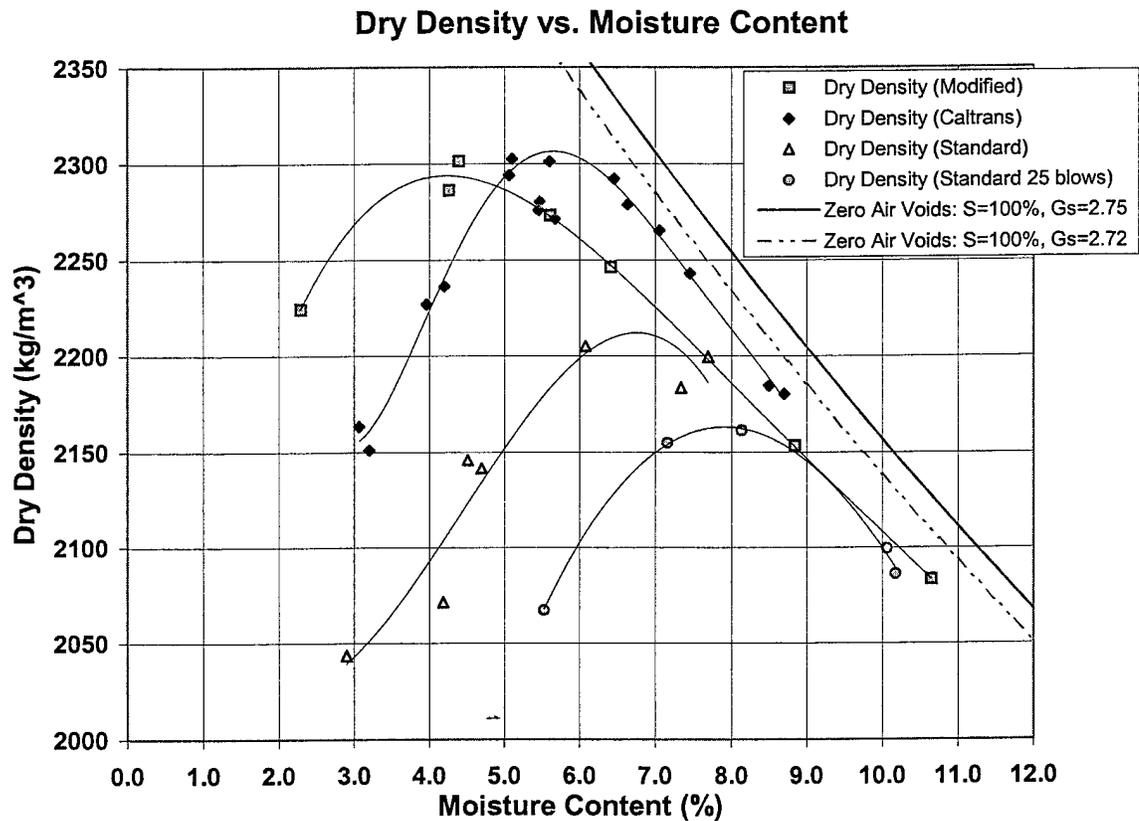
Figure 3: Water Content vs Density at Differing Compaction Efforts

3.5 Discussion of results

All standard and modified compaction tests are sensitive to technician experience and control as some aggregate is used to fill in any depressions left after trimming off the last layer. The amount of

aggregate used may influence the density by approximately one percent. Therefore the same technician performed all the tests for each compaction effort in order to ensure consistency. The Caltrans test methodology does not rely on technician expertise, and consequently it is easier to get reproducible results much faster.

The curves are best fit polynomials calculated with Microsoft Excel. Three points from Caltrans testing (near the Modified compaction curve at 5.5% water content) were not used for the Caltrans curve. Those tests are not included in the analysis due to excessive lost moisture at the base of the split mold leading to a lower actual compaction water content. Subsequent Caltrans compaction tests at water contents above optimum were performed with plastic wrap at the base of the split mold. This technique kept the moisture in the bottom layer from squeezing out during compaction.

The Caltrans tests were grouped in sets of two using soil from a sample mixed to a specified water content. Results varied slightly due to the variable nature of aggregate base material, imperfect mixing of added water, slight drying during compaction, and moisture remaining on the inside of the Caltrans split mold compaction device.

The zero air void line is estimated to be between the Gs=2.75 and Gs=2.72 lines.

Current Caltrans specifications allow a compaction effort of 95% relative density. Figure 4 shows this minimum compaction level, 2195 kg/m^3 (95% of the maximum Caltrans laboratory density of 2310 kg/m^3), comparing it to the 100% Standard compaction curve.

While the Caltrans method uses less compaction effort than the Modified AASHO compaction tests, the density at respective optimum water contents is approximately the same. The Caltrans method uses a 3 inch diameter split mold which induces higher confining stresses during compaction. The amount of induced shearing is also higher. Moving away from the optimum water content, the Caltrans test method gives a less dense material. The steeper compaction curve that results indicates a different soil fabric, caused by the different shearing action and confinement. The field compaction of the aggregate base is probably closer to the Standard and Modified compaction method with less shear. Permeability testing was performed on the samples compacted using the Standard and Modified methods.

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Dry Density vs. Moisture Content
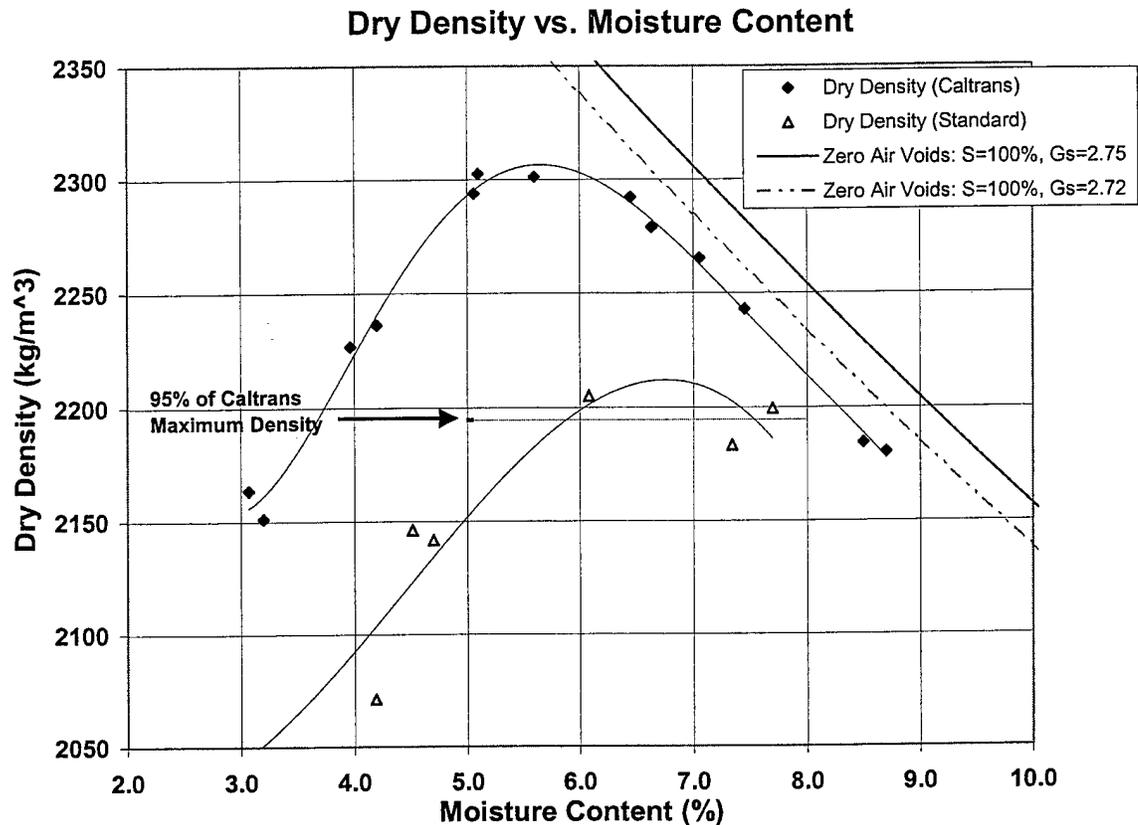
Figure 4: Moisture-Density Curves and Caltrans 95% Relative Density

4   LAB PERMEABILITY TESTS

4.1   Scope and purpose of laboratory investigation

The scope and purpose of this portion of the laboratory investigation was to test the permeability of the as-compacted aggregate base. The following tests were performed:

   - ASTM D2434-68 (1993), Constant Head Permeability Test

   - ASTM D5856-95, Permeability Measured with a Compaction-Mold Permeameter

Descriptions of these test methods are provided in Section 4.3.

4.2   Identification of samples

The aggregate used for the permeability tests was that described in the previous sections.

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4.3   Test methods

All samples for the testing were prepared according to ASTM D5856-95 which covers the preparation and permeability testing of aggregate material.

The compaction spacer disk (illustrated in Figure 1) was gently removed and replaced with a permeability insert (Figure 5). This new set up was placed on a rubber membrane on top of a modified CBR soaking base plate. The rubber membrane has a hole in the middle and the base plate has a tapped hole through the bottom to channel the water through. A top cap was placed above the mold and another rubber membrane was used to seal the gap between the top cap and the top of the CBR mold. Figure 6 details the top cap design. A constant hydraulic head was maintained during testing.

Typically, 24 to 48 hours were required to ensure complete saturation of each sample and laminar flow of the permeant. Future designs of the permeability insert will be of a solid material to allow for a vacuum to be pulled on the top cap, and speed the saturation process. A vacuum used with the present insert will first draw air into the sample from the void space of the insert, greatly increasing time to complete saturation.

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Bottom Permeability Insert
Material: steel

152mm (5.990 in.) diam.

102-12.7mm (4-1/2")
diam. pipe

106mm (4.175") diam.
(fit porous stone)

106mm (4.175") diam.
(fit porous stone)

12.7mm

19.0mm
(3/4")

61.4mm (2.416") (height to make CBR
mold meet compaction spec.s)

4.44mm (1/8")
fillet weld (typ.)

19.0mm (3/4")
diam pipe

6.35mm (1/4")
fillet weld

9.52mm
(3/8")

152.1mm (5.990") diam. (fits snugly
inside 152.4mm (6") nom. CBR mold)
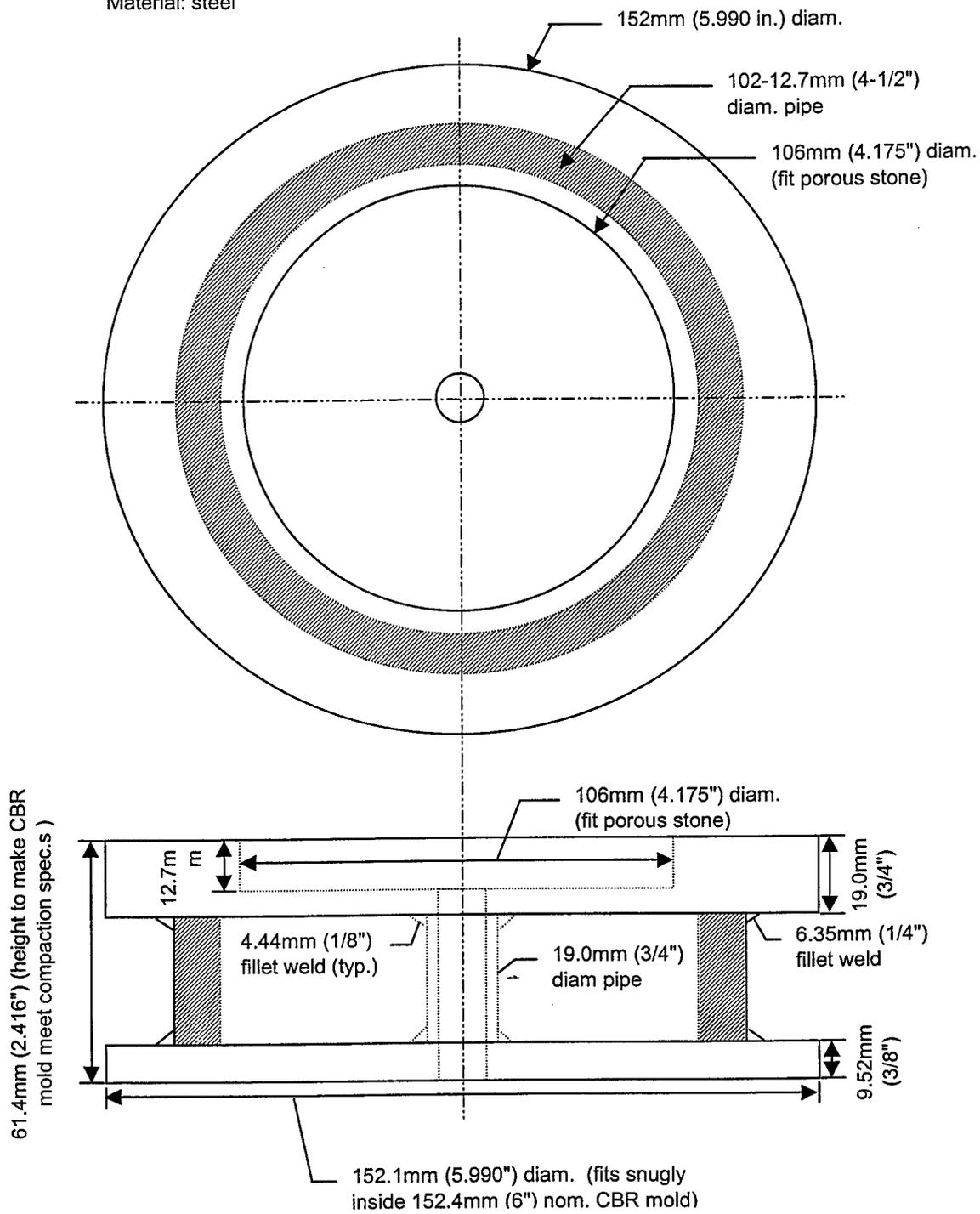
-insert into CBR mold after compaction for permeability test

Figure 5: Permeability Insert

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Top Permeability Cap
Material: Aluminum plate

threaded, 12.7mm (1/2"-NC)

12.7mm (1/2") (fits porous stone)

25.4mm (1.0")

12.7mm (1/2") diam. (typical)

Bottom of top cap

203mm (8") square

134mm (5.275") diam. (fit porous stone)

12.7mm (1/2") diam. (typical)
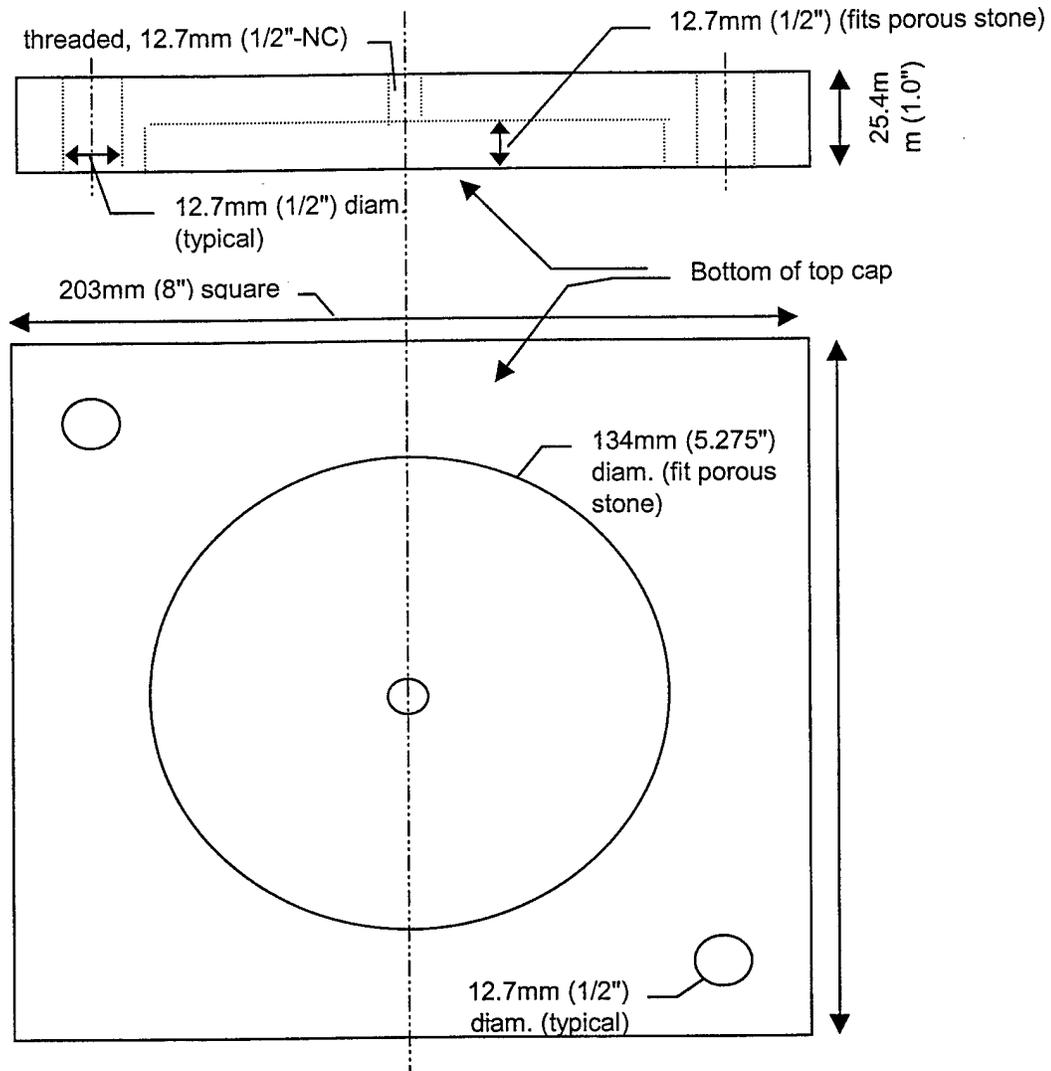
Figure 6: Top Permeability Cap

4.4   Summary of test results

A summary of the results of the permeability tests is shown in Figure 7 below. The full results are presented in Appendix C. The permeability results are given in cm/day as these units can be visualized easier than cm/s. 1 cm/s = 0.864 e5 | 1 e5 cm/day.
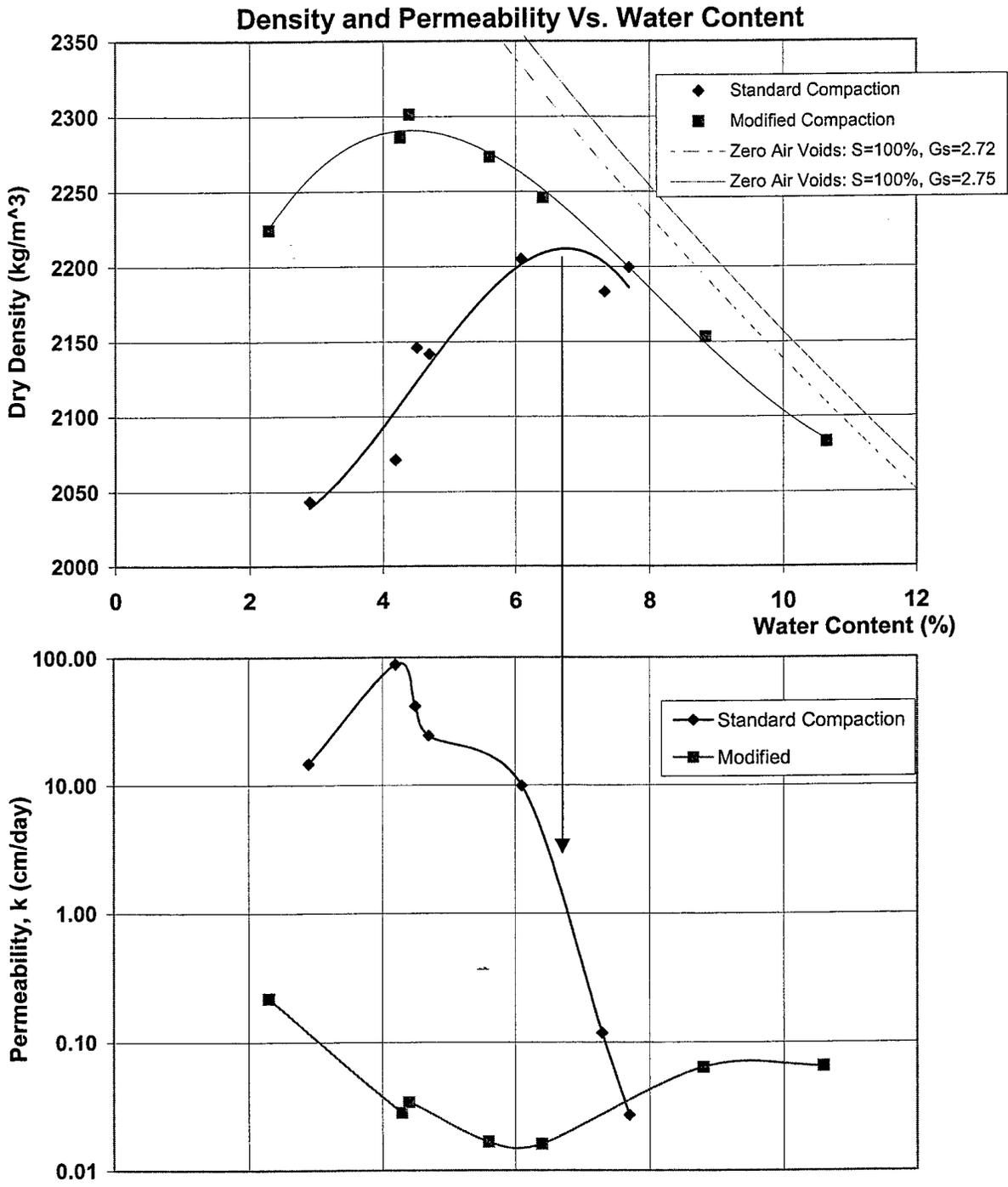
Figure 7: Density and Permeability Vs Water Content

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4.5 Discussion of results

In general and as expected, permeability decreased as the material increased in density and when compacted wet of optimum. These findings follow similar results from other studies including the seminal work of Seed and Chan.[5] Results from modified compaction slightly wet of optimum show the least permeable structure. Those points almost meet the Environmental Protection Agency's strict permeability requirements for clay liners (1e-6 cm/sec). All Modified compaction samples have low permeability structures, regardless of water content.

Permeability results for samples compacted using the standard effort dry and near optimum water content indicate up to 3 orders of magnitude higher permeability. Pavement layers compacted to this degree will readily absorb excess water, possibly leading to premature pavement failure. An aggregate base with 95% relative density using this material (and thus meeting current Caltrans specifications) may have the density *and permeability* similar to the Standard compaction effort. This is likely in construction when the density is reached by adding water, which is less expensive for the contractor, than increasing the compaction effort.

There is presently no Caltrans permeability specification for aggregate base courses. The lower the permeability, the less excess water will be allowed to flow through a layer. Drainage layers below the pavement, such as ATPB, may not be necessary in arid areas, or if the aggregate base is sufficiently protected from damage and is compacted to resist water absorption. Temporary standing water on the pavement or along the road side will choose the path of least resistance. Aggregate bases compacted to 1e-6 cm/sec (~0.1 cm/day) will not be a preferred pathway.

Another option to initiating a permeability specification would be to raise the compaction standard for the bases. A permeability specification could result in field compaction at water contents above optimum. Material compacted wet of optimum would have a lower permeability than those compacted at or below optimum, but would have a lower stiffness due to a flocculated fabric, leading to increased surface deflections and lower asphalt concrete fatigue life. Increased density would benefit in two ways, by decreasing permeability and increasing asphalt concrete fatigue life.

Lab testing should be performed on the aggregate source used for the pavement project to verify the established minimum compaction standards will reach the desired permeability levels. Some aggregate sources will not meet permeability requirements, and this should be considered in the design.

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5　Field Percolation Tests

5.1　Scope and purpose of field investigation

Field percolation tests were conducted in the area where the laboratory sample material was retrieved. An empirical correlation between field and laboratory values for AB permeability is desired. Too few data points were obtained to develop an accurate correlation. However, the trend between laboratory and field values is consistent, indicating a correlation could be established.

5.2　Test methods

Cores (150mm) were drilled and the AC and ATPB removed in the trafficked and untrafficked areas of the APT testing area at the Richmond Field Station. Because of the coring method, the holes were approximately 160mm in diameter. The AB was hand dug approximately 150 mm below the ATPB or AC, so that the bottom of the hole is approximately 50 mm above the ASB. The holes were filled with water to the base of the ATPB or top of the AC, and allowed to percolate through the AB for 24 hours. This waiting period allowed the AB to saturate. After 24 hours, the water level was increased to the top of the AB and testing began. Care was taken to ensure the water level was below the top of the AB during testing, thereby preventing water from running between layer interfaces.

The monitoring plan was scheduled to record the water level at 30 minute intervals for the first 4 to 6 hours, then every hour.

The percolation rate was calculated as the drop in head per hour.

5.3　Summary of test results

All field locations for percolation tests are in AB originally compacted to Caltrans specification and is characterized in Harvey et al.[6] After construction the area was divided into test sections and all traffick was recorded. Figure 8 summarizes the percolation rates for AB that has undergone various levels of compaction. Figure 9 summarizes the percolation rates for ATPB under various levels of compaction.

AB Percolation rate
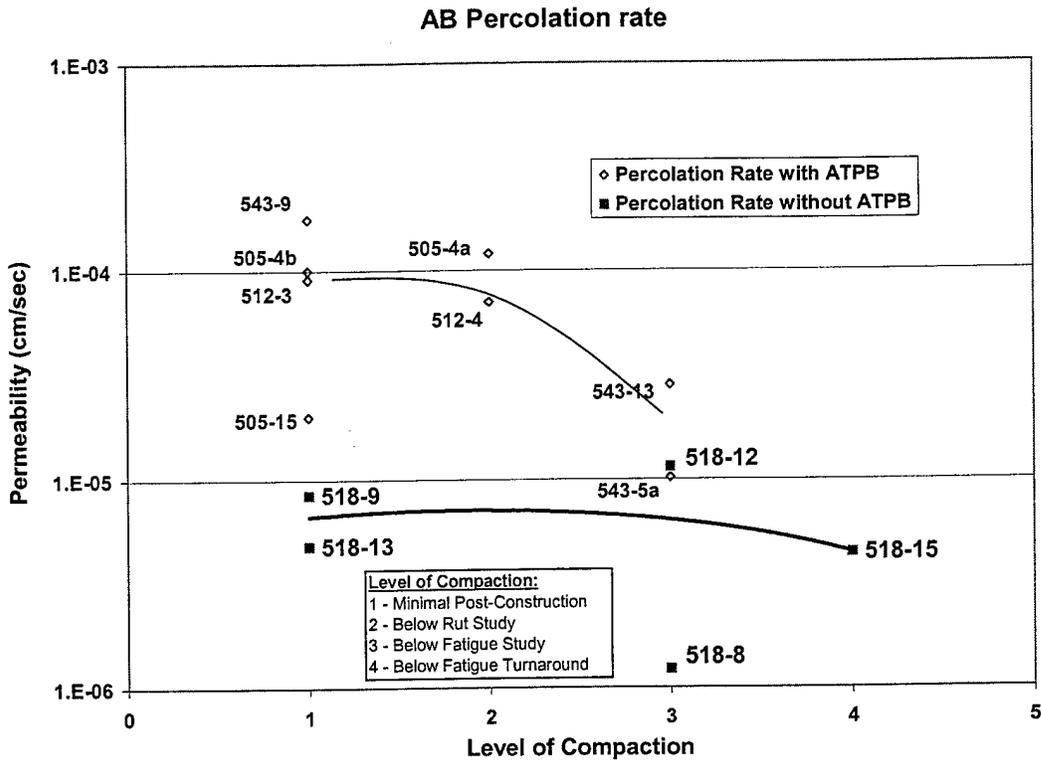
Figure 8: Aggregate Base Percolation Rates

ATPB Percolation rate
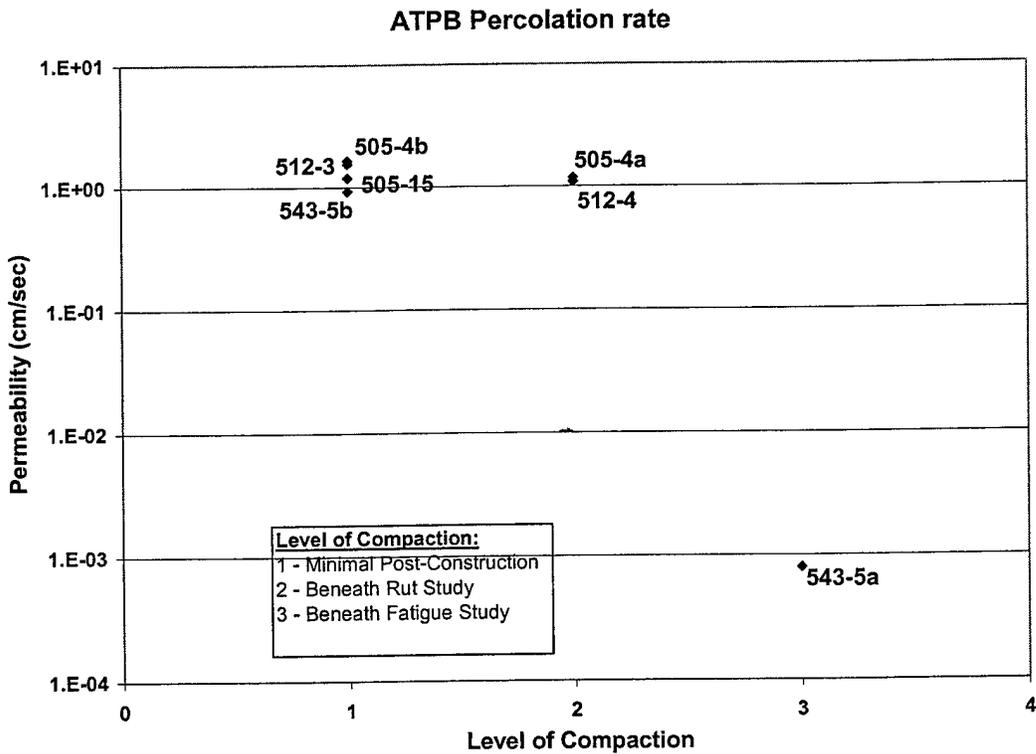
Figure 9: Asphalt Treated Permeable Base Percolation Rates

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5.4 Discussion of results

Permeability in the field followed general trends that agree with the laboratory results. Presuming all of the AB was compacted to the same density initially, further compaction occurred as the top layers were placed and the finished pavement was trafficked. As the AB undergoes further compaction, its permeability will drop. The degree or level of compaction was grouped based on the relative number of passes for the particular HVS tests. Figure 8 shows a contrast between AB beneath ATPB and without ATPB. This is probably due to the ATPB acting like a sponge and absorbing some of the compaction energy that would otherwise be imparted to further consolidate the AB layer, both during construction and later during trafficking.

Figure 9 shows the dramatic difference between the expected ATPB drainage capability, and the permeability of ATPB under a moderately trafficked section where fatigue failure was initiating. The ATPB beneath section 543 was completely crushed and filled with material from the AB layer, decreasing its effectiveness as a drainage layer.

From these test results, one can conclude ATPB:
1) reduces the added compaction benefits to the AB layer during construction of the top layers, and
2) will not perform as a drainage layer when trafficked to fatigue failure.

6 Tests with Asphalt-Contaminated Aggregate Base Material

6.1 Discussion of results

During the course of testing, a batch of contaminated aggregate was tested. The initial visual inspection noted minimal asphalt-coated particles mixed in the aggregate. The amount of asphalt-coated particles was estimated at 2% of the total by mass. The visual inspection regarded the sample batch as acceptable and testing proceeded. Sieve analysis yielded the gradation in Figure 10.

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Sieve Analysis (Contaminated)
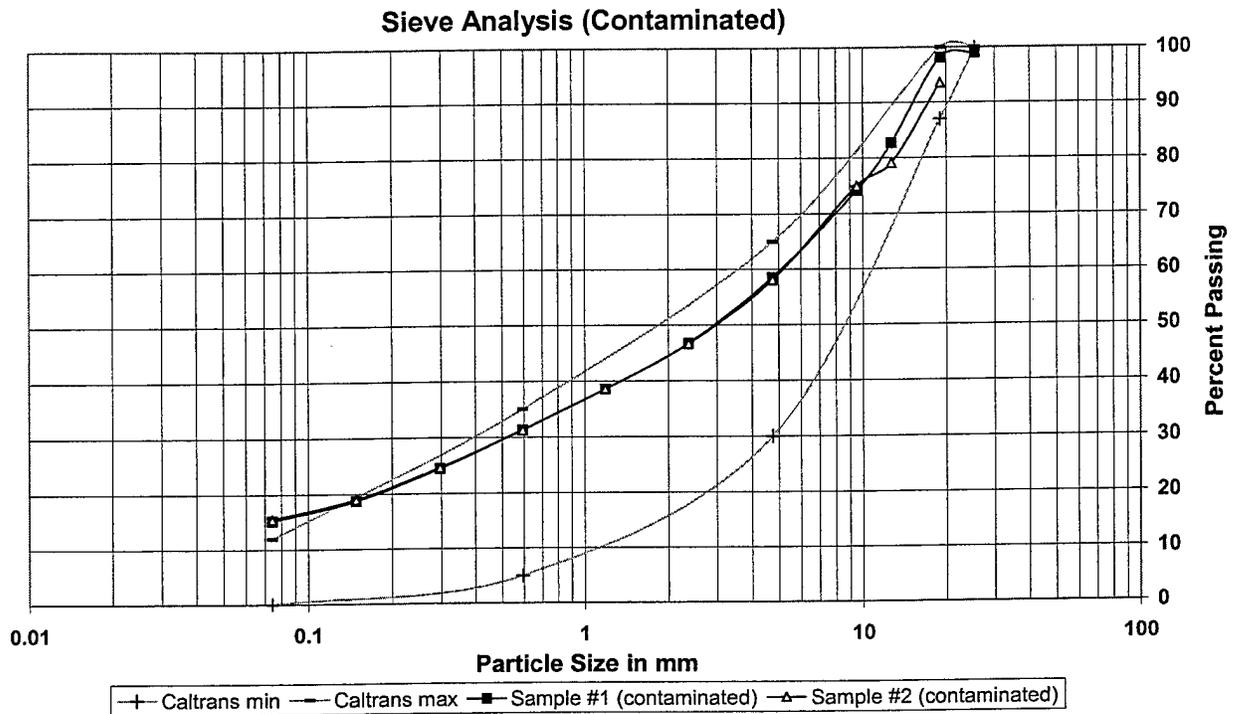
Figure 10: Contaminated Aggregate and Specification Gradation

As Figure 10 shows, the gradation was essentially the same as the uncontaminated samples (Figure 1). Testing proceeded to compaction. Figure 11 illustrates the moisture-density curves for the standard effort on the contaminated and uncontaminated aggregate samples.

Density vs. Moisture Content
(Standard Compaction: Contaminated and Clean)
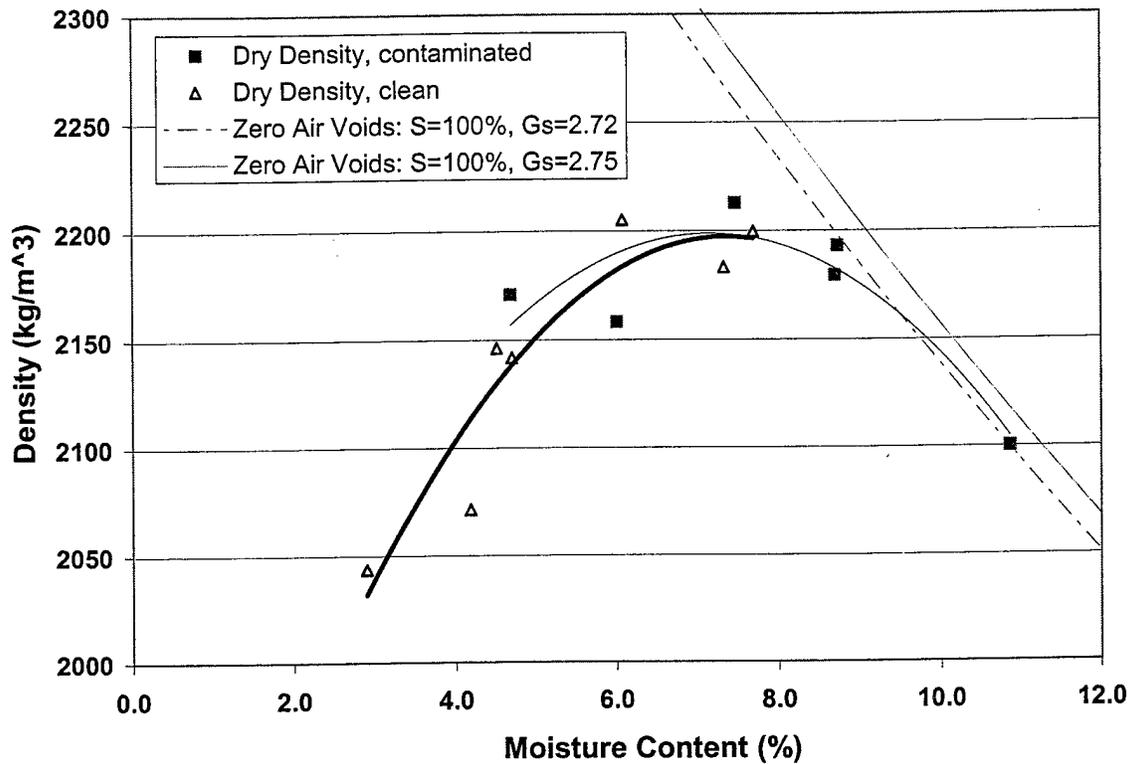
Figure 11: Standard Compaction of Contaminated Aggregate and Clean Aggregate

The standard compaction results of the contaminated aggregate appeared similar to the uncontaminated samples (Figure 11). From the gradation and density tests, there is little difference between the two samples. Permeability testing was then initiated. Tests were performed on high water content samples first, working back toward the optimum. The third data point was two orders of magnitude more permeable than expected. Figure 12 compares the contaminated aggregate permeability results with the clean aggregate results.

Permeability Vs. Water Content
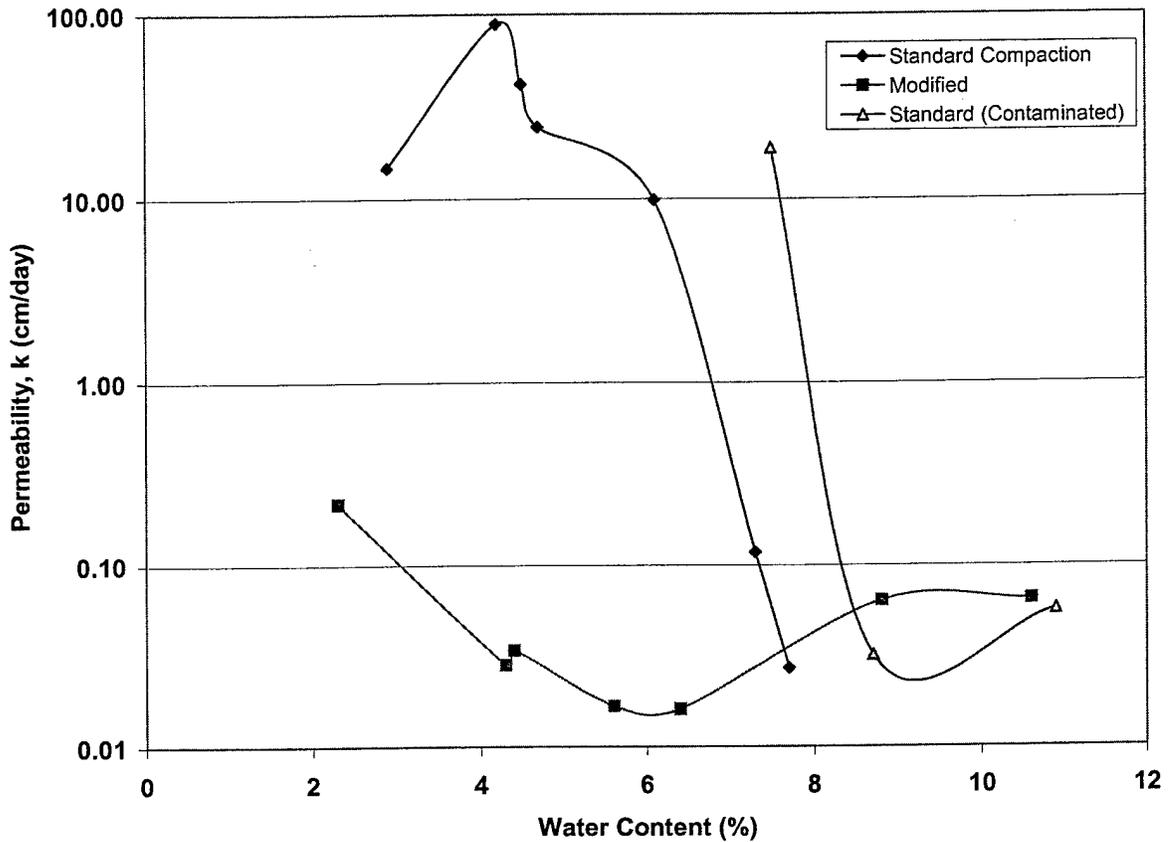
Figure 12: Permeability of Contaminated Aggregate and Clean Aggregate

Verifying the source of the material, we confirmed the aggregate was from a waste pile intended for trash. No further testing on this batch was performed. The values for the permeability were different for the contaminated and uncontaminated samples possibly because the chemical composition of the samples were different, which can have a large effect on permeability. It is important to note it was only after permeability testing that the contaminated batch was identified as different material — with poor permeability characteristics.

Figure 13 shows the predicted permeability of samples contaminated with the same amount of asphalt-coated aggregate over a wider range of water contents. It is recommended that further testing be performed to verify these trends.

Permeability Vs. Water Content
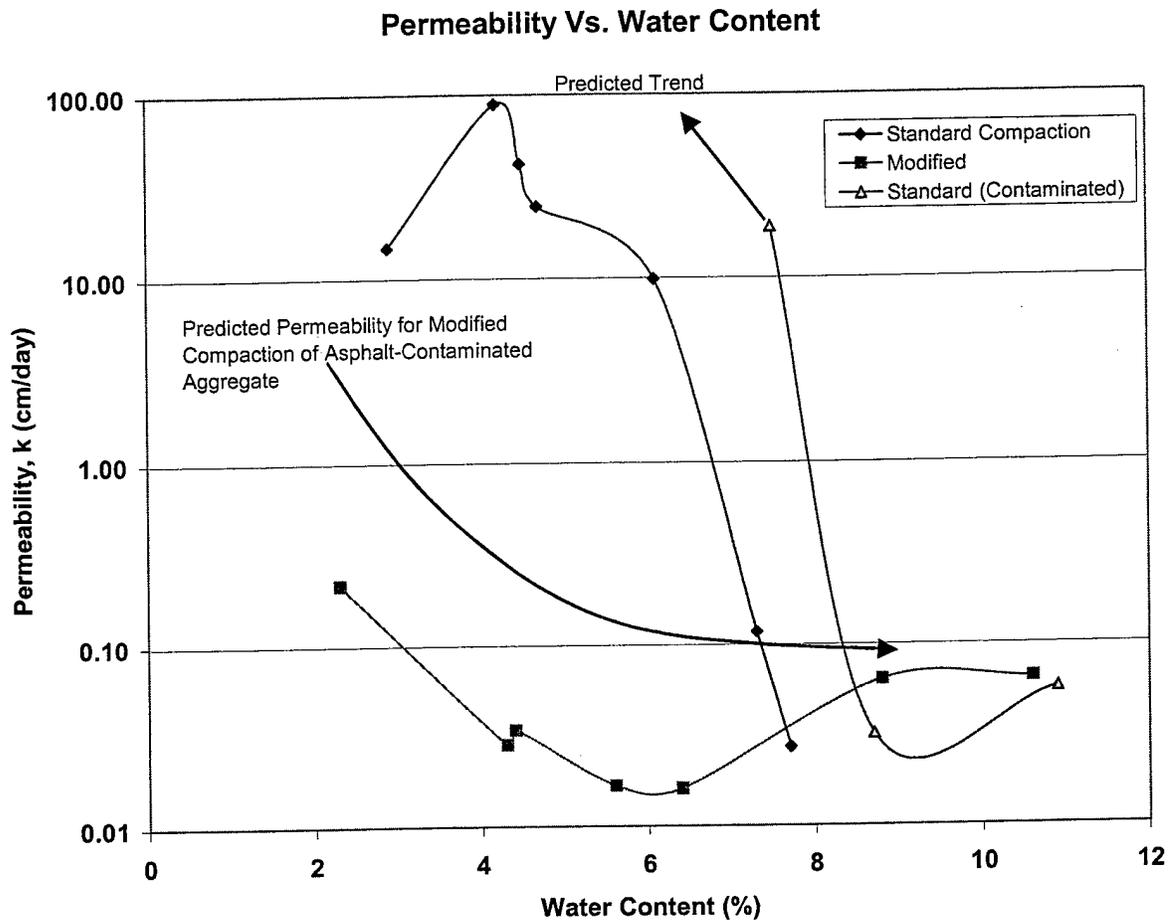
Figure 13: Predicted Trend for Permeability of Similarly Contaminated Aggregate

The asphalt-contaminated aggregate is similar to reclaimed aggregate materials with small portions of old AC or ATPB layer material. Many pavement projects contain reclaimed materials in subgrade layers. Follow-up studies should evaluate the permeability of reclaimed materials at standard and modified compaction.

7 Conclusions

This report details the laboratory and field analysis of the aggregate base material used in the construction of the Caltrans Accelerated Pavement Testing test sections at the University of California's Richmond Field Station. The aggregate base material met Caltrans specifications at construction and this was confirmed during the testing for this report. As expected, the permeability

decreased with increasing density and increasing water content (once past the optimum water content). Density curves and permeability analyses were completed and details can be found in the attached appendices.

Drainage has been identified as a crucial design feature of pavement structures. Increasing aggregate compaction is known to reduce permeability and improve the structure's resistance to water infiltration. Current Caltrans specifications allow a compaction effort of 95% relative density, according to the Caltrans method (California Test 216). An increase in compaction of a few percent will greatly decrease the permeability of aggregate bases and, in turn, increase the life of future constructed pavements. Increased density will also reduce pavement permanent deformations and improve fatigue performance.[7]

If slightly contaminated aggregate were the only material available, the field engineer or supervisor should assess the potential impact of the contaminated material on permeability. The resulting AB layer may impact the design and cause a premature failure due to higher than expected permeability.

A follow-up study should be conducted to analyze the effect on permeability of reclaimed aggregate material that is contaminated with asphalt-coated aggregate. The test plan should include testing with a range of asphalt-coated aggregate that could be expected in typical construction.

APPENDIX A: AGGREGATE TEST RESULTS

Gradation - Clean

Sample #1 Particle Size in mm	Particle Size	% Passing	Average of Samples #1-3 % Passing
50.8	2"	98.9	99.6
25.4	1"	98.1	99.4
19.05	3/4"	89.4	96.4
12.7	1/2"	81	86.8
9.51	3/8"	62.5	74.5
4.75	#4	48.8	57.1
2.38	#8	39.2	44.0
1.19	#16	31.2	34.5
0.59	#30	23.9	26.1
0.30	#50	17.8	18.7
0.15	#100	14.1	12.9
0.07	#200	13.4	9.8

Sample #2 Particle Size in mm	Particle Size	Weight Retained	% Retained (Cum)	% Passing (cum)
50.8	2"			100.0
25.4	1"			100.0
19.05	3/4"			100.0
12.7	1/2"	214.3	8	91.6
9.51	3/8"	210.5	17	83.4
4.75	#4	455.9	34	65.6
2.38	#8	382.6	49	50.7
1.19	#16	263.7	60	40.4
0.59	#30	214.3	68	32.1
0.30	#50	182	75	25.0
0.15	#100	154.2	81	18.9
0.07	#200	97	85	15.2
	pan	388.7	100	0.0
	total weight	2563.2		

Sample 3 Particle Size in mm	Particle Size	Weight Retained	% Retained (Cum)	% Passing (cum)
50.8	2"			100.0
25.4	1"			100.0
19.05	3/4"	10.2	0	99.8
12.7	1/2"	529.9	12	87.9
9.51	3/8"	466.9	23	77.4
4.75	#4	922.7	43	56.7
2.38	#8	658.6	58	42.0
1.19	#16	449.6	68	31.9
0.59	#30	420.2	78	22.5
0.30	#50	405.5	87	13.4
0.15	#100	346.2	94	5.6
0.07	#200	214.6	99	0.8
	pan	46.7	100	0.0
	total weight	4460.9		

Caltrans Specifications Min	Max		
100	100	25.4	1"
87	100	19.05	3/4"
30	65	4.75	#4
5	35	0.59	#30
0	12	0.07	#200

Sieve Analysis

Percent Passing by mass

Particle Size in mm

— Caltrans (min)   —+— Caltrans (max)   —o— Sample 1   —□— Sample 2   —△— Sample 3   —●— Average
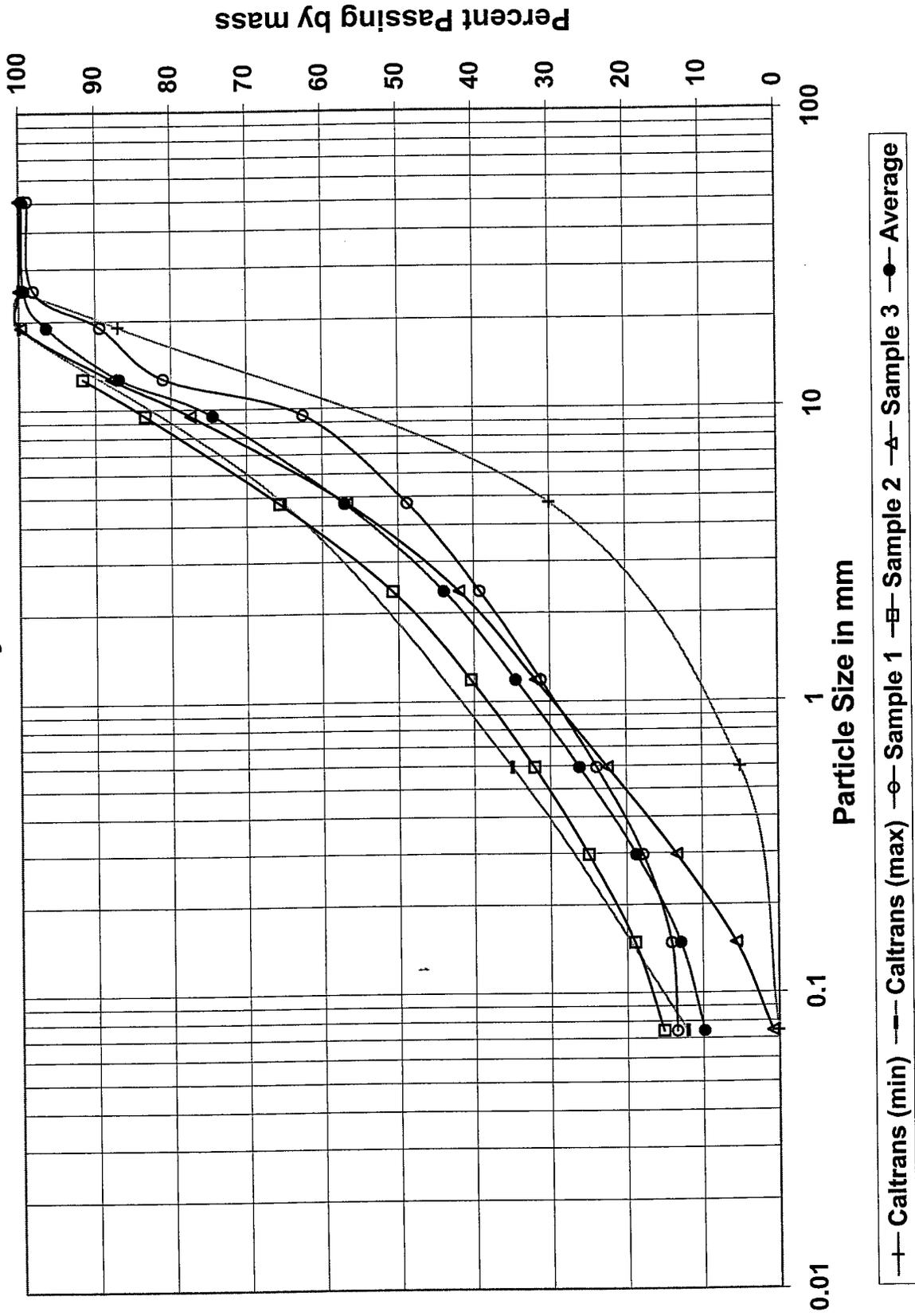
APPENDIX B: COMPACTION TEST RESULTS

Results

The following compaction data sheets are in english units and then a series in metric units follow.

Data Form-Laboratory Compaction Test

Modified Compaction

Sample No.	5	2	1	6	3	4	7
A-Initial Moisture Content	1.8	1.8	1.8	1.8	1.8	1.8	3.01
B-Sample Weight (g)	7233.1	7131.0	7103.2	7477.7	7084.7	6963.8	7238.8
C-Solids Weight (g)	7105.2	7004.9	6977.6	7345.5	6959.4	6840.7	7027.3
D-Moisture Weight (g)	127.9	126.1	125.6	132.2	125.3	123.1	211.5
E-Desired Moisture Content	11.0	5.0	3.0	7.0	7.0	9.0	13.0
F-Water to add (g)	653.7	224.2	83.7	382.0	361.9	492.5	702.0
G-Water to add (ml)	653.7	224.2	83.7	382.0	361.9	492.5	702.0

Laboratory Compaction Test Procedure							
H-Weight Mold+Soil (g)	14830.1	15086.9	15129.2	15100.5	15100.8	14979.1	14919.8
I-Weight Mold (g)	9998.2	10025	10027.1	10002	10025.0	10002	10024.2
J-Weight Compacted Soil (g)	4831.9	5061.9	5102.1	5098.5	5075.8	4977.1	4895.6
K-Wet Density(g/ft^3)	64425	67492	68028	67980	67677	66361	65275
Wet Density(lb/ft^3)	142.0	148.8	150.0	149.9	149.2	146.3	143.9
L-Moisture Content (%)	2.3	4.3	4.4	5.6	6.4	8.8	10.6
M-Dry Density (g/ft^3)	62984	64734	65165	64370	63601	60973	58993
Dry Density(lb/ft^3)	138.9	142.7	143.7	141.9	140.2	134.4	130.1

Pan Weight	949.1	341.8	949.3	341.7	948.1	220.4	949
Pan+Soil Wet	3058.7	2605.8	2956.8	2899.1	3288.9	2554.1	3390.9
Pan+Soil Dry	3011.5	2513.3	2872.3	2763.3	3147.9	2364.6	3155.9
water content	2.29	4.26	4.39	5.61	6.41	8.84	10.65

[(weight of soil wet-weight of soil dry)/weight of soil dry]*100

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CalTrans Test

Sample No.	1	2	3	4	5	6	7	8
A-Initial Moisture Content	1.8	1.8	1.8	1.8	1.8	1.4	1.4	1.4
B-Sample Weight (g)	5277.0	5570.9	5661.8	5379.0	4848.0	6078.0	6701.0	6901.0
C-Solids Weight (g)	5183.7	5472.4	5561.7	5283.9	4762.3	5994.1	6608.5	6805.7
D-Moisture Weight (g)	93.3	98.5	100.1	95.1	85.7	83.9	92.5	95.3
E-Desired Moisture Content	3.3	4.2	5.2	6.2	7.3	6.5	7.0	8.0
F-Water to add (g)	77.8	131.3	189.1	232.5	261.9	305.7	370.1	449.2
G-Water to add (ml)	77.8	131.3	189.1	232.5	261.9	305.7	370.1	449.2

Laboratory Compaction Test Procedure   * CalTrans Test 216

Weight of wet sample, grams	2610	2690	2650	2700	2700	2700	2640	2670
J value	11.1	11.5	10.85	11	10.6	10.55	10.3	10.65
K value* (Table 1, g/cm^3)	2.23	2.22	2.315	2.33	2.41	2.42	2.43	2.37
Wet Density(g/ft^3)	63147	62863	65554	65978	68244	68527	68810	67111
Wet Density(lb/ft^3)	139.2	138.6	144.5	145.5	150.5	151.1	151.7	148.0
Moisture Content (%)	3.1	3.2	4.0	4.2	5.1	5.1	5.6	8.5
Dry Density (g/ft^3)	61265	60914	63052	63319	64955	65202	65161	61854
Dry Density(lb/ft^3)	135.1	134.3	139.0	139.6	143.2	143.7	143.7	136.4

* CalTrans Test 216	1a	1b	2a	2b	4a	4b	5b	9
Pan Weight	946.9	359.4	240.5	351.0	952.9	351.3	346.3	947.6
Pan+Soil Wet	3551.6	3041.0	2887.4	3400.0	3646.8	3251	2987.1	3613.3
Pan+Soil Dry	3474.0	2957.5	2786.4	3276.4	3517	3110.2	2849	3404.5
water content	3.07	3.21	3.97	4.23	5.06	5.10	5.52	8.50
Measured Pan+Soil Wet		3047.1		3408.6		3255.8		
Measured Water Content		3.45		4.52		5.28		

Modified to reflect testing conditions. The water content samples included some material that remained in a container, protected from drying during the compaction testing.

CalTrans Test   (continued)

Sample No.	
A-Initial Moisture Content	
B-Sample Weight (g)	
C-Solids Weight (g)	
D-Moisture Weight (g)	
E-Desired Moisture Content	
F-Water to add (g)	
G-Water to add (ml)	

Laboratory Compaction Test Procedure   * CalTrans Test 216

Weight of wet sample, grams		2650	2700	2700	2700	not used	not used	2650	2700	2400
J value	10.65	10.35	10.5	10.6	10.55	to test	to test	10.45	10.65	9.375
K value* (Table 1, g/cm^3)	2.37	2.43	2.44	2.41	2.425			2.405	2.4	2.4
Wet Density(g/ft^3)	67111	68810	69093	68244	68668			68102	67960	67960
Wet Density(lb/ft^3)	148.0	151.7	152.3	150.5	151.4			150.1	149.8	149.8
Moisture Content (%)	8.7	6.6	6.5	7.5	7.1			5.5	5.5	5.7
Dry Density (g/ft^3)	61740	64526	64904	63510	64143			64570	64445	64312
Dry Density(lb/ft^3)	136.1	142.3	143.1	140.0	141.4			142.4	142.1	141.8

* CalTrans Test 216	9b	6a	6b	7a	7b	6c	7c	3a	3b	5a
Pan Weight	351.2	352.2	345.2	339.8	346.9	362.2	343.8	347.0	352.1	240.5
Pan+Soil Wet	5031	2996	3040.3	3034.1	3040.5	1356.9	2014.5	2992.1	3553.5	2634
Pan+Soil Dry	4656	2831.4	2876.9	2847.2	2863	1292.5	1905.1	2854.9	3387.9	2505.5
water content	8.71	6.64	6.45	7.45	7.05	6.92	7.01	5.47	5.45	5.67

Measured Pan+Soil Wet	5056.4
Measured Water Content	9.30

Modified to reflect testing conditions. The water content samples included some material that remained in a container, protected from drying during the compaction testing.

Standard Compaction

Sample No.	1	2	3	4	5	6	7	8
A-Initial Moisture Content	2	2	2	2	2	2	2	2
B-Sample Weight (g)	7001.0	6967.1	7599.7	6991.6	8486.1	8329.0	8902.4	7809.1
C-Solids Weight (g)	6863.7	6830.5	7450.7	6854.5	8319.7	8165.7	8727.8	7656.0
D-Moisture Weight (g)	137.3	136.6	149.0	137.1	166.4	163.3	174.6	153.1
E-Desired Moisture Content	2.5	6.0	7.0	9.0	5.0	3.5	6.0	5.25
F-Water to add (g)	34.3	273.2	372.5	479.8	249.6	122.5	349.1	248.8
G-Water to add (ml)	34.3	273.2	372.5	479.8	249.6	122.5	349.1	248.8
Laboratory Compaction Test Procedure								
H-Weight Mold+Soil (g)	14487.7	15000	15054		14760	14580	14964.1	14785
I-Weight Mold (g)	10022.1	10022.8	10023.3		9996.5	9996.8	9996.4	10022.8
J-Weight Compacted Soil (g)	4465.6	4977.2	5030.7	0	4763.5	4583.2	4967.7	4762.2
K-Wet Density(g/ft^3)	59541	66363	67076	0	63513	61109	66236	63496
Wet Density(lb/ft^3)	131.3	146.3	147.9		140.0	134.7	146.0	140.0
L-Moisture Content (%)	2.9	7.3	7.7		4.5	4.2	6.1	4.7
M-Dry Density (g/ft^3)	57863	61826	62283	0	60769	58653	62438	60646
Dry Density(lb/ft^3)	127.6	136.3	137.3		134.0	129.3	137.7	133.7

Pan Weight	644.0	408.1	240.8		644.0	409.6	948.4	238.6
Pan+Soil Wet	3116.8	2586	2982.2		4273.3	4137.1	4952.7	2773.7
Pan+Soil Dry	3047.1	2437.1	2786.3		4116.5	3987.3	4723.1	2659.9
water content	2.9	7.3	7.7	#DIV/0!	4.5	4.2	6.1	4.7

[(weight of soil wet-weight of soil dry)/weight of soil dry]*100

	17-May	18-May	14-May		16-May	17-May	19-May	19-May

Zero Air Voids: S=100%, Gs=2.72

Water content (percent)	5	6	7	8	9	10	11	12
Dry density (g/cc, kg/liter)	2.394	2.338	2.285	2.234	2.185	2.138	2.094	2.051
Dry density (pcf)	149.5	146.0	142.6	139.5	136.4	133.5	130.7	128.0

Zero Air Voids: S=100%, Gs=2.75

Water content (percent)	5	6	7	8	9	10	11	12
Dry density (g/cc, kg/liter)	2.418	2.361	2.306	2.254	2.204	2.157	2.111	2.068
Dry density (pcf)	150.9	147.4	144.0	140.7	137.6	134.6	131.8	129.1

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Standard Test (with 25 blows -- too little)

Sample No.					
A-Initial Moisture Content	2.5	1.8	3.01	3.01	2.5
B-Sample Weight (g)	6758	7365.6	6998.8	7087.3	7636
C-Solids Weight (g)	6593.2	7235.4	6794.3	6880.2	7449.8
D-Moisture Weight (g)	164.8	130.2	204.5	207.1	186.2
E-Desired Moisture Content	6	7.0	9.0	11.0	9
F-Water to add (g)	230.8	376.2	407.0	549.7	484.2
G-Water to add (ml)	230.8	376.2	407.0	549.7	484.2

Laboratory Compaction Test Procedure

H-Weight Mold+Soil (g)	14656.0	14987.9	14825.9	14883.3	14930.3
I-Weight Mold (g)	10023.0	10024.1	9921.6	10002.0	10023.0
J-Weight Compacted Soil (g)	4633.0	4963.8	4904.3	4881.3	4907.3
K-Wet Density(g/ft^3)	61773.3	66184.0	65390.7	65084.0	65430.7
Wet Density(lb/ft^3)	136.2	145.9	144.2	143.5	144.2
L-Moisture Content (%)	5.5	8.1	7.2	10.2	10.1
M-Dry Density (g/ft^3)	58537	61225	61020	59072	59449
Dry Density (lb/ft^3)	129.1	135.0	134.5	130.2	131.1

Pan Weight	304.2	220.5	121.5	121.5	236.2
Pan+Soil Wet	2046.9	2679.2	2419.7	2673.3	3255.0
Pan+Soil Dry	1955.6	2494.2	2266.1	2437.6	2979.0
water content	5.53	8.14	7.16	10.18	10.06
	25-Apr	13-Apr	7-Apr	7-Apr	25-Apr

Dry Density vs. Moisture Content
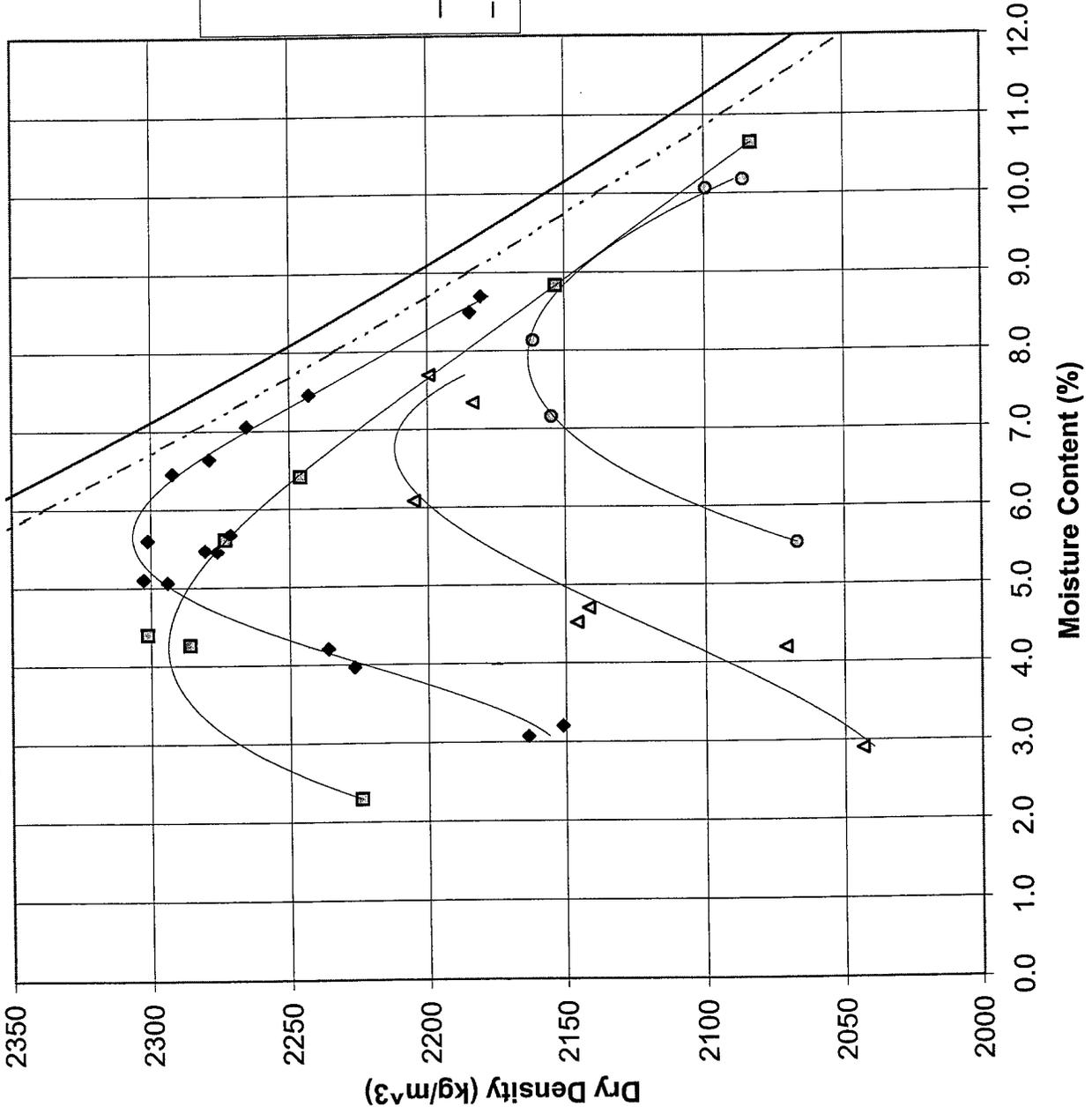
Legend:
- ■ Dry Density (Modified)
- ◆ Dry Density (Caltrans)
- △ Dry Density (Standard)
- ○ Dry Density (Standard 25 blows)
- —— Zero Air Voids: S=100%, Gs=2.75
- —·— Zero Air Voids: S=100%, Gs=2.72

Y-axis: Dry Density (kg/m^3)

X-axis: Moisture Content (%)

Dry Density vs. Moisture Content

Legend:
- ▣ Dry Density (Modified)
- ◆ Dry Density (Caltrans)
- △ Dry Density (Standard)
- ⊙ Dry Density (Standard 25 blows)
- —— Zero Air Voids: S=100%, Gs=2.75
- —·— Zero Air Voids: S=100%, Gs=2.72

X-axis: Moisture Content (%) — 0.0, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0, 11.0, 12.0

Y-axis: Dry Density (kg/m^3) — 2000, 2050, 2100, 2150, 2200, 2250, 2300, 2350
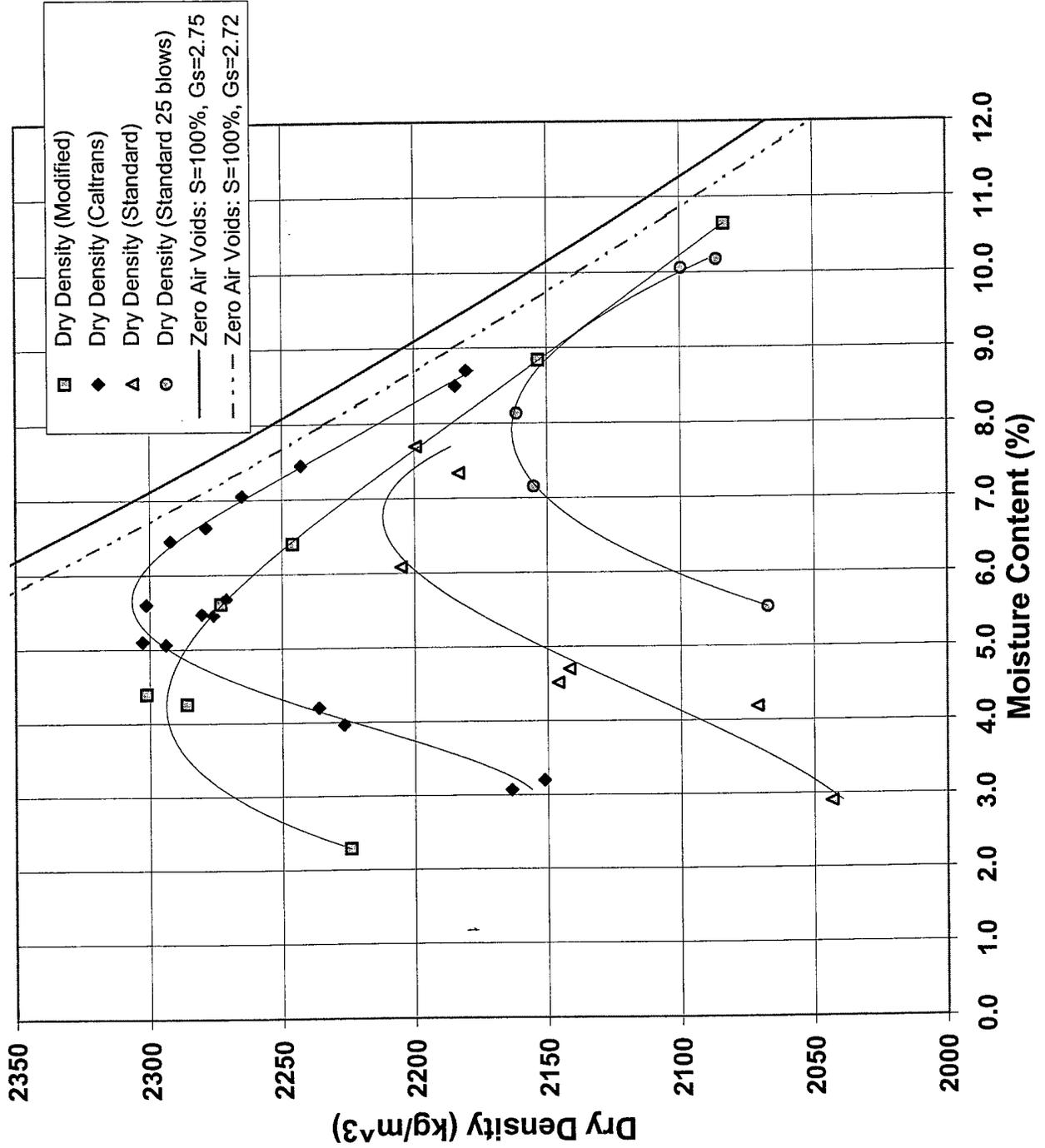
Dry Density vs. Moisture Content
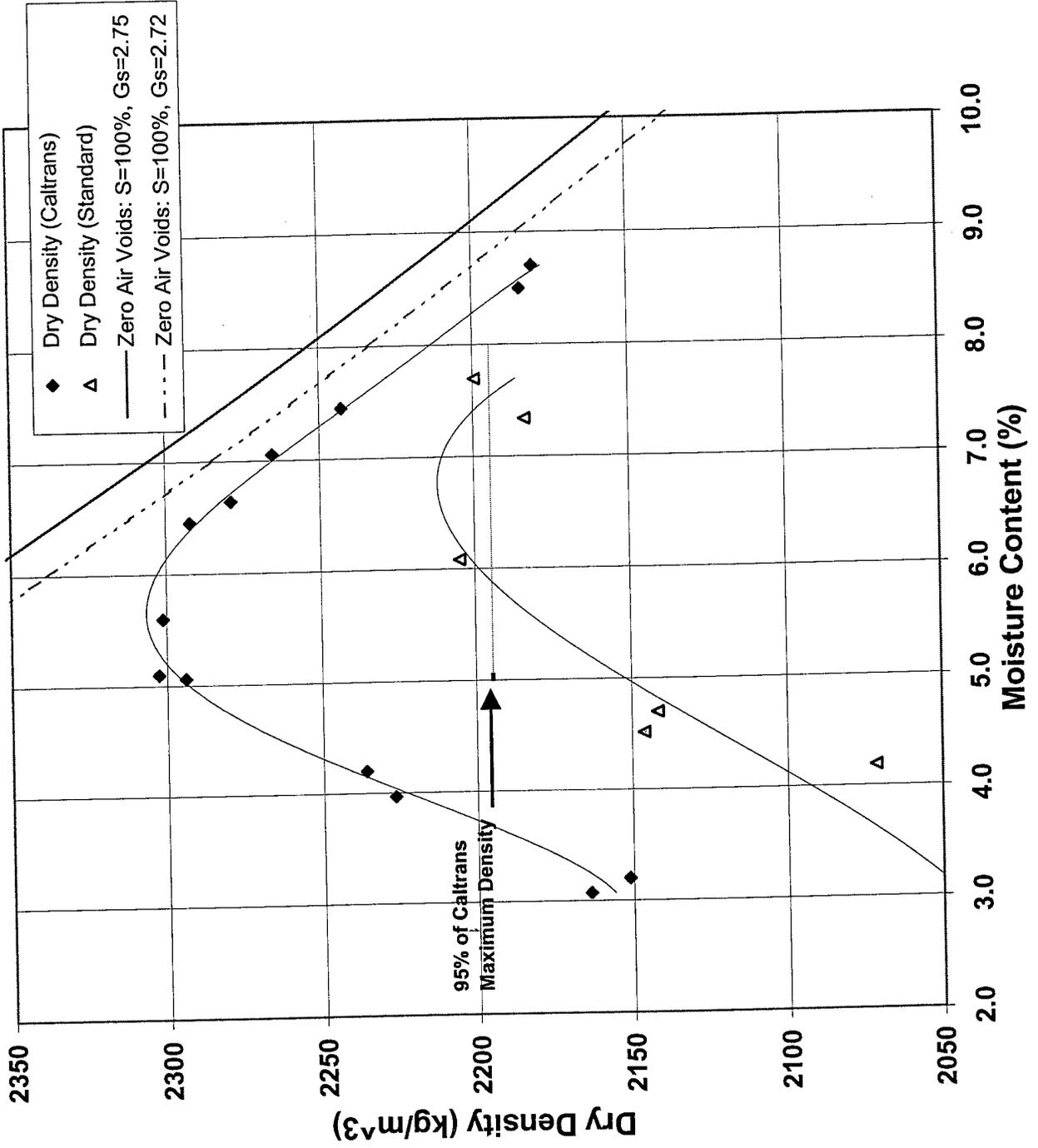
APPENDIX C: LAB PERMEABILITY TEST RESULTS

Results

Permeability Data

Constant Head Test $\qquad$ k=QL/(Aht)

$\qquad\qquad$ L =4.58 in= $\qquad$ 11.64 cm

$\qquad\qquad$ A=(pi)/4 * D^2= $\qquad$ 182.4 cm^2

	Test #	Avg Flow, Q (cm^3)	Collection Time t (sec)	Head Difference (inches)	h (cm)	k (cm/sec)	H2O Temp (Celsius)
Standard	1	100	462	27.5	69.9	0.00020	
6.1%	2	100	1302	27.5	69.9	0.00007	
	3	100	1240	27.5	69.9	0.00007	
Standard	1	100	207	27.5	69.9	0.00044	
4.7%	2	100	246	27.5	69.9	0.00037	
	3	100	372	27.5	69.9	0.00025	
	4	100	406	27.5	69.9	0.00023	
	5	100	331	27.5	69.9	0.00028	
	6	100	390	27.5	69.9	0.00023	
	7	1020	4080	27	68.6	0.00023	
	8	1040	4200	27	68.6	0.00023	
	9	100	387	27.5	69.9	0.00024	
	10	100	337	27.5	69.9	0.00027	
	11	100	347	27.5	69.9	0.00026	
	12	100	356	27.5	69.9	0.00026	
	13	100	265	27.5	69.9	0.00034	
	14	100	271	27.5	69.9	0.00034	
	15	100	275	27.5	69.9	0.00033	
	16	100	279	27.5	69.9	0.00033	
	17	1520	5040	27	68.6	0.00028	
	18	1680	6120	27	68.6	0.00026	
	19	100	367	27.5	69.9	0.00025	
	20	100	335	27.5	69.9	0.00027	
	21	100	344	27.5	69.9	0.00027	
Standard	1	100	250	21.5	54.6	0.00047	17.8
4.5%	2	100	250	21.5	54.6	0.00047	
	3	100	255	21.5	54.6	0.00046	
	4	100	185	27	68.6	0.00050	
	5	100	189	27	68.6	0.00049	
	6	100	191	27	68.6	0.00049	
	7	100	184	27	68.6	0.00051	
	8	100	190	27	68.6	0.00049	

Standard	1	100	480	27	68.6	0.00019	
2.9%	2	100	476	27	68.6	0.00020	
	3	100	605	27	68.6	0.00015	
	4	100	680	27	68.6	0.00014	
Standard	1	100	64	27	68.6	0.00145	
4.2%	2	100	78	27	68.6	0.00119	
	3	100	85	27	68.6	0.00109	
	4	100	82	27	68.6	0.00114	
	5	100	94	27	68.6	0.00099	
	6	100	89	27	68.6	0.00105	
	7	100	137	21.5	54.6	0.00085	
	8	100	133	21.5	54.6	0.00088	
	9	100	131	21.5	54.6	0.00089	
	10	100	135	21.5	54.6	0.00087	
	11	100	135	21.5	54.6	0.00087	
Standard 7.3%	1	5.5	3600	28.25	71.8	0.0000014	
Standard	1	28	77400	30	76.2	0.00000030	
7.7%	2	27	75600	28	71.1	0.00000032	
Standard (25B) (25Blows - #2)	1	75	86400	50	127	0.00000044	
Standard (25B)	1	100	630	24	60.96	0.000166	17.8
(25Blows - #3)	2	100	630	24	60.96	0.000166	17.6
	3	100	660	24	60.96	0.000159	17.6
Standard (25B)	1	115	2700	40	101.6	0.000027	20.8
(25Blows - #4)	2	15	1800	40	101.6	0.000005	21
Modified #1	1	11	21600	32.5	82.55	0.00000039	
Modified #2	1	30	72000	32	81.28	0.00000033	
Modified #3	1	10	54000	25	63.5	0.00000019	
Modified	1	120	64800	50	127	0.00000093	
#4	2	60	86400	32	81.28	0.00000055	
Modified #1s(old) -- #6	1	8	32400	32	81.28	0.00000019	

Falling Head Test $k=2.303*VL / [(h1-h2)At)] * \log h1/h2$

Length of specimen = 11.64 cm
Area of specimen = 182.4 cm^2

	Test #	Volume, V (cm^3)	Test Duration t (sec)	Head Difference h1 (cm)	Head Difference h2 (cm)	k (cm/sec)
Standard	1	28	77400	76.2	75.5	0.000000304
7.7%	2	27	75600	71.1	70.6	0.000000322
Modified	1	210	61200	82.55	78.4225	0.000002722
#5	2	128	43200	82.55	80.3275	0.000002323
Modified	1	73	75600	82.55	81.28	0.000000753
#7 -- old #5s						

Info for plots!	**Standard Compaction**			**Modified**		
Sample Number	Water Content	k (cm/sec)	Sample #	Water Content	k	
1	2.9	0.00017	5	2.3	0.00000252	
2	4.2	0.00102	2	4.3	0.00000033	
3	4.5	0.00048	1	4.4	0.00000039	
4	4.7	0.00028	6	5.6	0.00000019	
5	6.1	0.00011	3	6.4	0.00000019	
6	7.3	0.0000014	4	8.8	0.00000074	
7	7.7	0.0000003	7	10.6	0.00000075	

Info for plots!	**Standard Compaction**				**Modified**			
Sample Number	Water Content	k (cm/day)	k (in/day)	Sample #	Water Content	k (cm/day)	k (in/day)	
1	2.9	14.691	5.784	5	2.3	0.218	0.086	
2	4.2	88.514	34.848	2	4.3	0.028	0.011	
3	4.5	41.817	16.463	1	4.4	0.034	0.013	
4	4.7	24.480	9.638	6	5.6	0.017	0.007	
5	6.1	9.840	3.874	3	6.4	0.016	0.006	
6	7.3	0.117	0.046	4	8.8	0.064	0.025	
7	7.7	0.027	0.011	7	10.6	0.065	0.026	

Permeability Vs. Water Content

Permeability Vs. Water Content

Standard Compaction
Modified
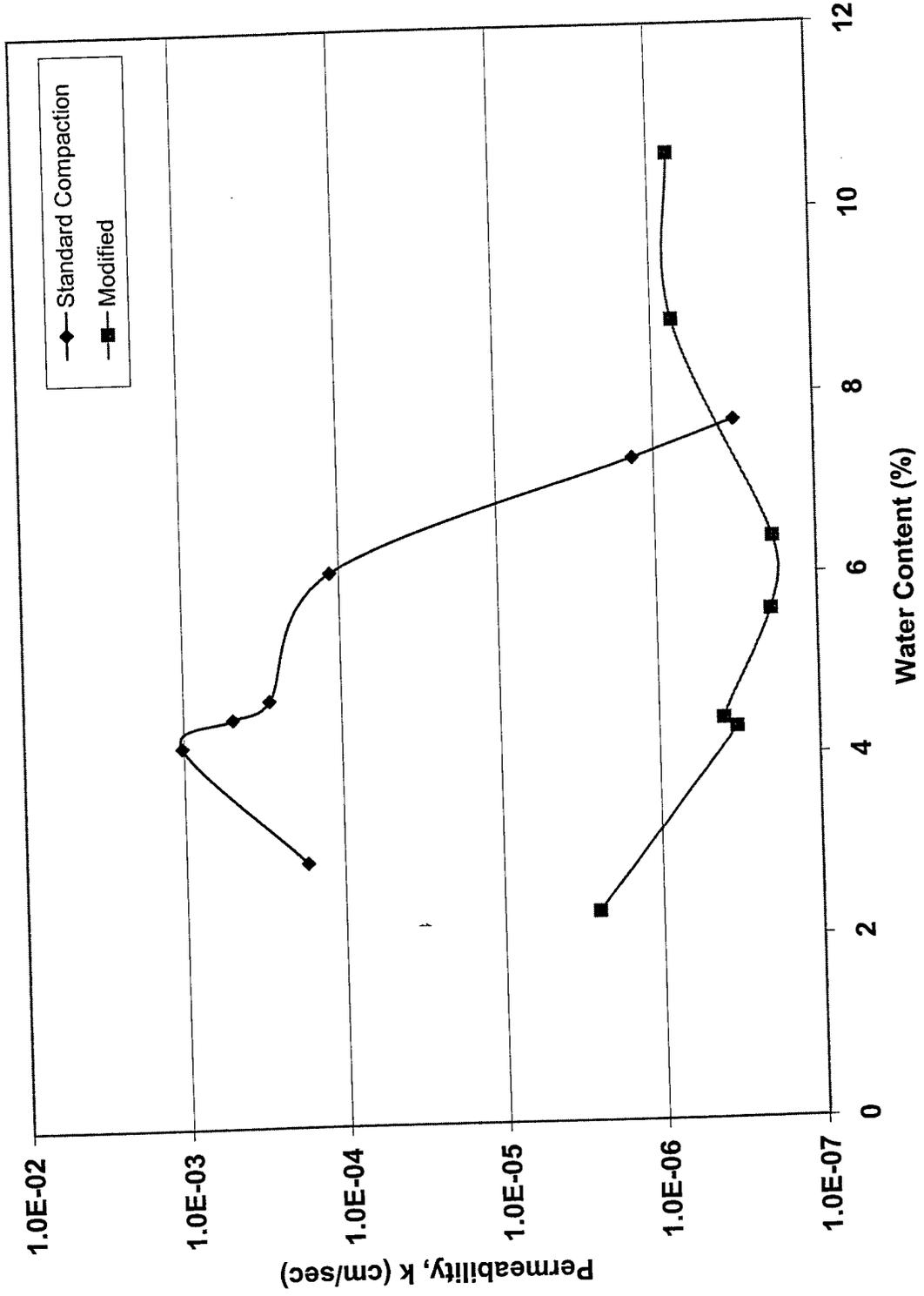
Water Content (%)

Permeability, k (cm/day)
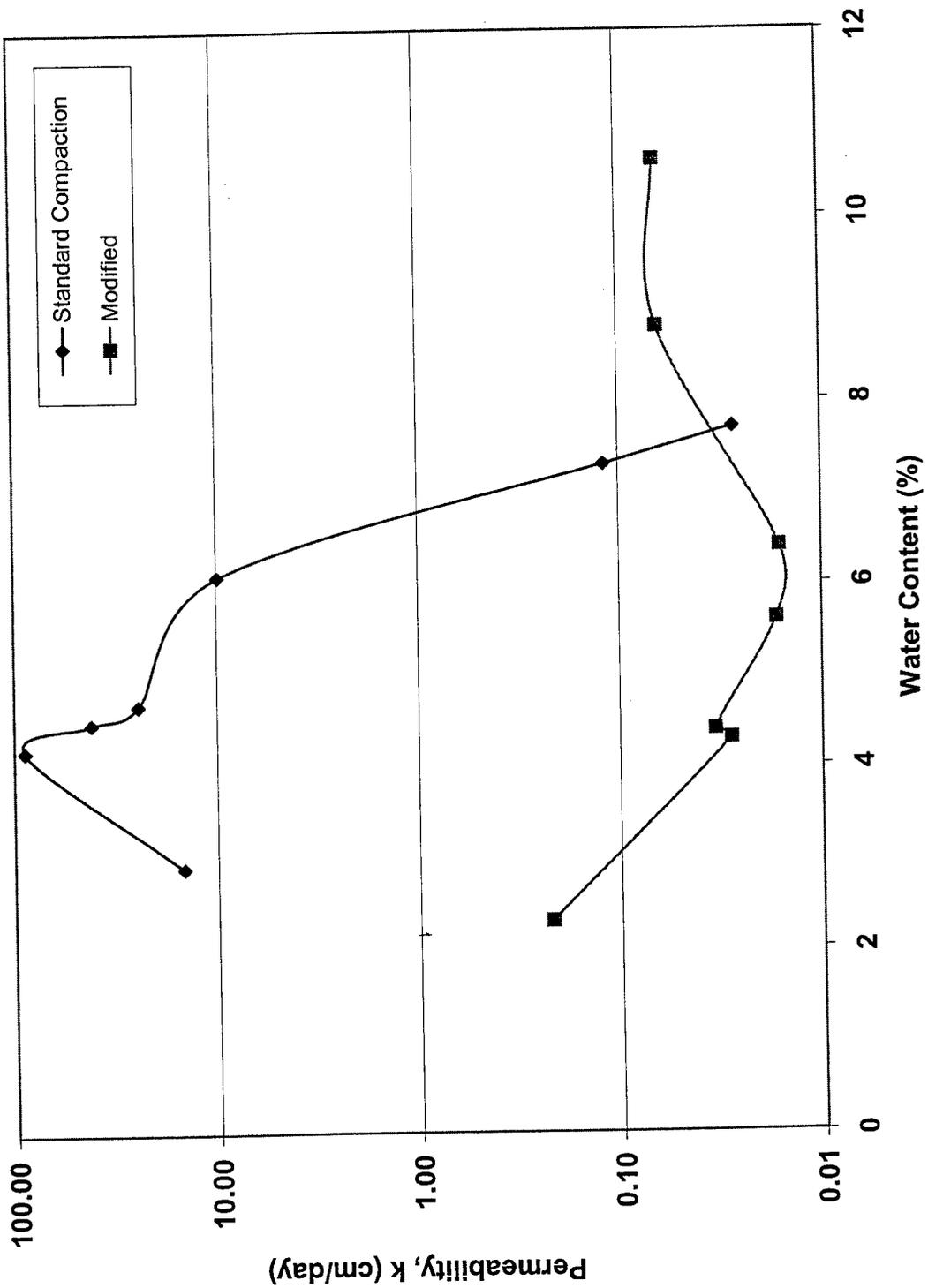
Density and Permeability Vs. Water Content
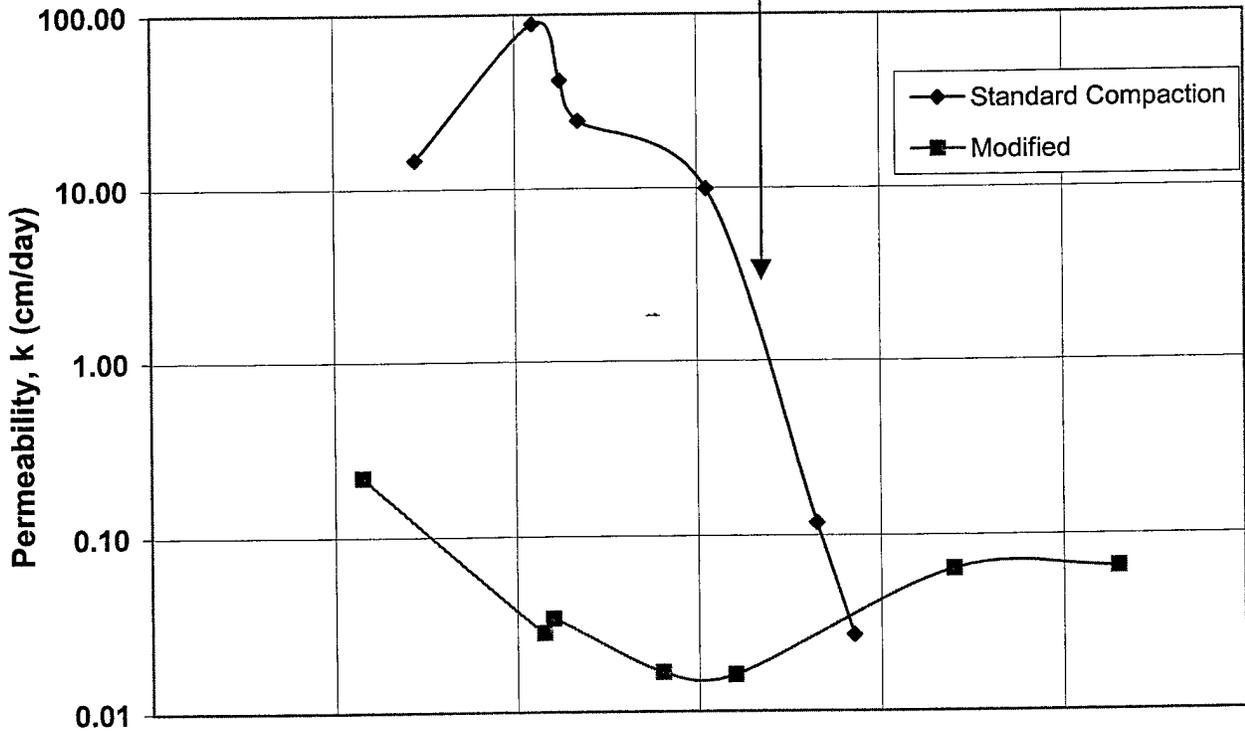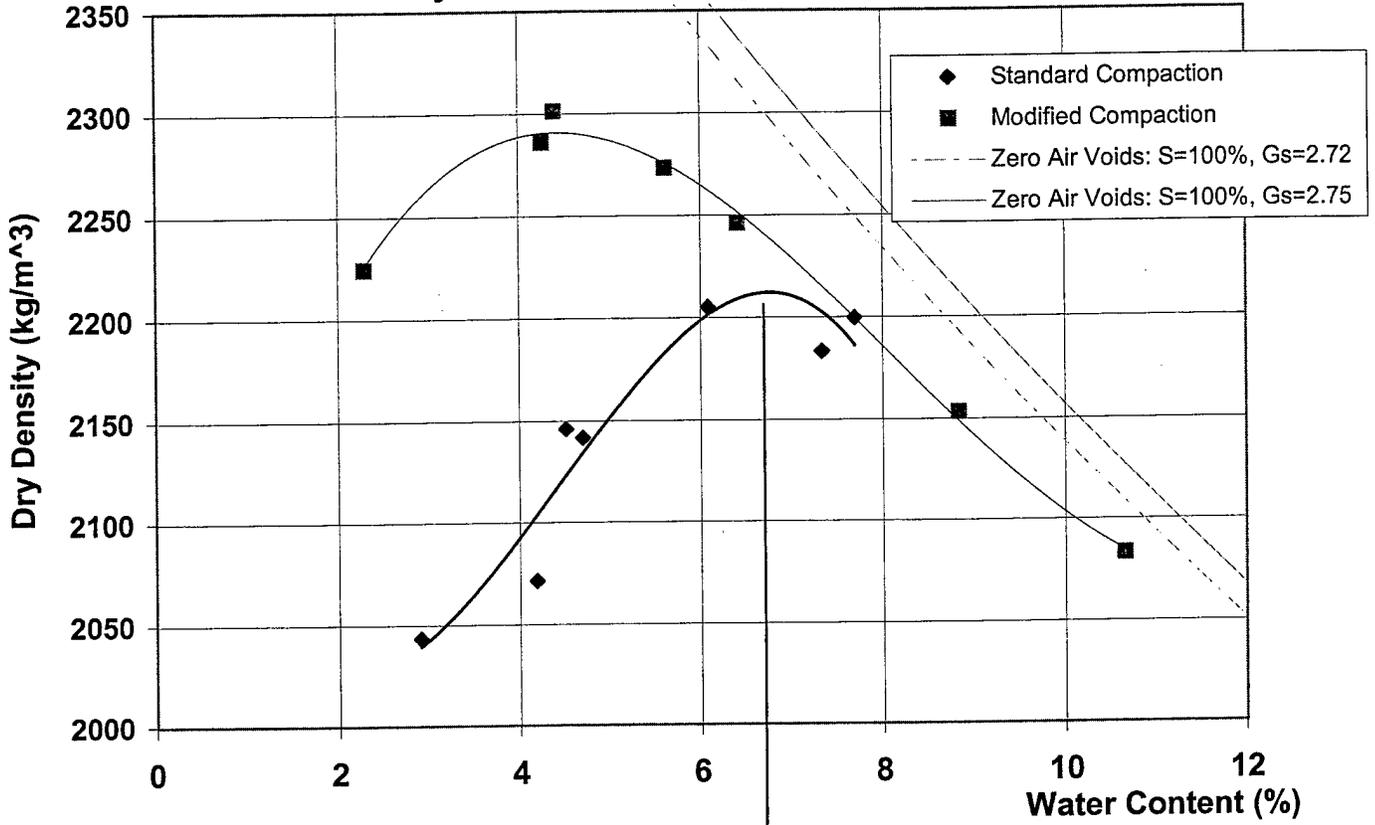
APPENDIX D: FIELD PERCOLATION TEST RESULTS

Percolation field tests were conducted on AB and ATPB in multiple locations within building 280 on the Richmond Field Station. Following the field data is a diagram of these locations.

Percolation Field Tests
Aggregate Base
Building 280, Richmond Field Station, B280

    150mm cores removed (holes ~160mm) then hand dig in AB.
    Holes dug ~6 inches below ATPB -- bottom is 1 to 2 inches above the ASB.
    Water filled to base of ATPB, allowed to percolate through AB for 24 hours.
    Water topped off and test begun.

DGAC (505-15): NOT trafficked, approx. station 15, section 505,
    between dual and super single ruts (if extended)

Section 543, Station 9: 165cm from outside edge, NOT trafficked
Station 13: 20cm from edge to center of core, Trafficked

Station 5: 20cm from edge to center of core, Trafficked

		Water level (inches)	
	Time	Station 9 (543-9)	Station 13 (543-13)
4/20/00	1505	6.25	6.625
	1540	6.625	6.625
	1610	6.75	6.75
	1640	6.875	6.875
	1710	7	6.875
	1740	7.125	6.875
	1810	7.25	6.875
	1840	7.25	6.875
	1910	7.375	6.875
	1940	7.5	6.875
	2010	7.625	6.875
	2040	7.75	6.875
	2110	7.875	6.875
	2140	8	6.875
	2210	8.125	7
	2240	8.25	7
	2300	8.25	7.125
4/21/00	0000	8.5	7.25
	0100	8.875	7.375
	0200	9	7.375
	0300	9.25	7.5
	0400	9.125	7.5
	0500	9.375	7.5
	0600	9.625	7.625

Percolation rate (in/hr)	
0.25	0.04
	= ~1 in/day

		Water level (inches)	
	Time	DGAC section (505-15)	Station 5 (543-5a)
4/25/00	1535	6.125	5.625
	1600	6.125	5.625
	1630	6.25	5.625
	1700	6.25	5.625
	1730	6.25	5.625
	1800	6.25	5.625
	1830	6.25	5.625
	1900	6.25	5.625
	1930	6.25	5.625
	2000	6.375	5.625
	2030	6.375	5.625
	2100	6.375	5.625
	2130	6.375	5.75
	2200	6.375	5.75
	2230	6.375	5.75
	2300	6.375	5.75
4/26/00	0500	6.375	5.75
	0600	6.5	5.75
	0700	6.5	5.875
	1035	6.625	5.9375

	Percolation rate (in/hr)	
	0.021	0.016
	0.036	0.013
avg:	0.028	0.014

Percolation Field Tests
ATPB

Core holes drilled to top of AB. All asphalted material removed.
Chalk lines drawn in core holes 6 inches in depth apart.
Water filled to top of hole, allowed to drain through ATPB.
Pictures taken 25 Apr 2000, @ 1430

Station 5 (543-5a): 20cm from edge, Trafficked
| 1 inch in 53 minutes = | 1.13 in/hr

Station 5 (543-5b): 7.5cm from outside edge, NOT trafficked
| 6 inches in 16.5 seconds | 1309.1 in/hr
(As seen in the pictures, the two core holes above
are 27.5 cm apart -- Dramatic difference!)

DGAC (505-15): NOT trafficked
| 6 inches in 12.8 seconds | 1687.5 in/hr

Second set of tests run the first week of June. ATPB tests done then AB (data to the right)
ATPB Permeability (6" water drop):

Location	Date	Time (sec)	Description of pavement at test location
512-4	mid May	14.09	middle of super single rut study, Section 512,
	~6/1/2000	13.1	between station 4 and 5
	~6/1/2000	14.9	
	avg:	14.03	1539.6 in/hr
512-3	mid May	10.06	
	~6/1/2000	9.7	untrafficked middle of dual and super single
			areas, between stations 3 and 4 of section 505
	avg:	9.88	2186.2 in/hr
505-4a	mid May	13.62	station 4 of section 505, middle of one rut of
	~6/1/2000	12.4	dual (rut closest to section 512)
	avg:	13.01	1660.3 in/hr
505-4b	mid May	7.69	
	~6/1/2000	10.8	~2 feet from edge of dual, section 505 station
			4, between dual study and k-rail, untrafficked
	avg:	9.245	2336.4 in/hr

Percolation Field Tests
Aggregate Base

		Water level (inches)			
		Section 512		Section 505	
	Time	4	3	4a	4b
6/1/00	1630	5.125	5.25	5.25	6.125
	1700	5.75	5.75	5.75	6.75
	1730	5.75	5.875	5.875	6.875
	1800	5.625	5.875	5.75	6.75
	1830	5.625	5.75	5.75	6.875
	1900	5.625	5.875	5.75	6.875
	1930	5.5	5.75	5.875	7
	2000	5.625	5.875	5.875	7.125
	2030	5.5	5.875	5.875	7.25
	2100	5.5	5.875	5.875	7.25
	2200	5.5	6	6.25	7.375
	2300	5.625	6.25	6.25	7.5
6/2/00	0000	5.625	6.375	6.375	7.75
	0100	5.625	6.5	6.625	8
	0200	5.875	6.625	6.75	8
	0300	5.875	6.75	7	8.125
	0400	5.875	6.875	7.125	8.25
	0500	5.875	7	7.375	8.375
	0620	6	7.25	7.625	8.5
	0700	6	7.375	7.875	8.625

Percolation rate (in/hr)

0.10	0.13	0.17	0.15
	0.12	0.17	0.14
	0.14		0.13
avg: 0.10	0.13	0.17	0.14

Conversion:	1/8 inch	3/8	5/8	7/8
	0.125	0.375	0.625	0.875

Percolation Field Tests
Aggregate Base

Section 518, Station 8: 50cm from edge to center of core, Trafficked
Station 9: 38cm from outside edge, NOT trafficked
Station 12: 53cm from edge, Trafficked
Station 13: 34cm from outside edge, NOT trafficked
Station 15: 55cm from edge, Trafficked

	Time	Water level (inches)				
		1 (518-8)	2 (518-9)	3 (518-13)	4 (518-15)	5 (518-12)
7/14/00	1600	5.5	5.125	18	5.375	6.5
	1635	5.5	5.25	18	5.375	6.5
	1705	5.5	5.375	18	5.375	6.5
	1740	5.5	5.375	18	5.375	6.625
	1810	5.625	5.375	18	5.375	6.625
	1830	5.75	5.5	18	5.375	6.625
	1940	5.75	5.5	18	5.375	6.5
	2010	5.75	5.5	18	5.375	6.625
	2100	5.75	5.5	18	5.375	6.625
	2230	5.5	5.875	18	5.375	6.625
	2330	5.5	5.875	18	5.375	6.625
7/15/00	0030	5.5	5.875	18.125	5.375	6.625
	0130	5.625	6	18.125	5.375	6.625
	0230	5.625	6	18.125	5.375	6.625
	0330	5.625	6	18.125	5.375	6.625
	0430	5.625	6	18.125	5.5	6.625
	0530	5.625	6	18.125	5.5	6.625
	0630	5.625	6	18.125	5.5	6.625
	0730	5.625	6	18.125	5.5	6.625
7/17/00	1210	6	6.5625	18.75	5.75	7
	1540	6	6.625	18.75	5.75	7
	2035	6	6.625	18.75	5.8125	7
Percolation rate (in/hr)						
		0.008	0.011	0.010	0.006	0.006

Erratic test results in hole 1; someone bumped ruler.

Percolation rate was very low. Followup testing was performed to confirm original values.

	Time	Water level (inches)		
		3 (518-13)	4 (518-15)	5 (518-12)
7/17/00	2050	18.125	5.25	6.1875
	2155	18.1875	5.25	6.1875
	2305	18.25	5.25	6.1875
7/18/00	0010	18.25	5.25	6.1875
	0100	18.25	5.25	6.1875
	0210	18.25	5.375	6.1875
	0305	18.25	5.375	6.25
	0410	18.375	5.375	6.25
	0505	18.375	5.25	6.25
	0610	18.375	5.25	6.25
	1315	18.5	5.375	6.3125
		0.022	0.007	0.006

		Water level (inches)			
		1 (518-8)			2 (518-9)
7/18/00	1715	5.375	7/20/00	0946	6.9375
	1815	5.4375		1039	6.9375
	1915	5.4375		1147	6.9375
	2015	5.4375		1246	6.9375
	2115	5.4375		1341	7
	2215	5.4375		1440	7
	2300	5.4375		1543	7
7/19/00	0015	5.4375		1637	7
	0115	5.4375		1730	7
	0215	5.375			
	0315	5.375			
	0355	5.375			
	0455	5.4375			
	0555	5.4375			
	0655	5.4375			
	0759	5.4375			
	0904	5.4375			
	1000	5.4375			
	1100	5.4375			
	1200	5.4375			
7/20/00	0930	5.5			
		0.0017			0.013

Percolation Field Tests - Summary

Aggregate Base

Location	Percolation rate in/hr	cm/sec	Trafficked?	Level of Compaction	Field Density (Nuclear) g/cc	pcf
543-9	0.25	1.8E-04	no	1		
505-15	0.028	2.0E-05	no	1		
543-13	0.04	2.8E-05	yes	3		
543-5a	0.014	1.0E-05	yes	3	2.23	139.1
512-4	0.10	7.1E-05	yes	2		
512-3	0.13	9.1E-05	no	1		
505-4a	0.17	1.2E-04	yes	2		
505-4b	0.14	1.0E-04	no	1		
518-8	0.002	1.2E-06	yes	3		
518-9	0.012	8.5E-06	no	1		
518-12	0.016	1.1E-05	yes	3		
518-13	0.007	4.8E-06	no	1		
518-15	0.006	4.4E-06	yes	4		

ATPB

Location	Percolation rate in/hr	cm/sec	Trafficked?	Level of Compaction
543-5a	1.132	8.0E-04	yes	3
543-5b	1309	9.2E-01	no	1
505-15	1688	1.2E+00	no	1
512-4	1540	1.1E+00	yes	2
512-3	2186	1.5E+00	no	1
505-4a	1660	1.2E+00	yes	2
505-4b	2336	1.6E+00	no	1

AB Percolation rate

Legend:
- ◆ Percolation Rate with ATPB
- ☐ Percolation Rate without ATPB

Data points:
- 543-9
- 505-4b
- 505-4a
- 512-3
- 512-4
- 543-13
- 505-15
- 518-12
- 543-5a
- 518-9
- 518-13
- 518-15
- 518-8

Level of Compaction:
1 - Minimal Post-Construction
2 - Below Rut Study
3 - Below Fatigue Study
4 - Below Fatigue Turnaround

X-axis: Level of Compaction
Y-axis: Permeability (cm/sec)

ATPB Percolation rate

Data points:
- 512-3
- 505-4b
- 505-15
- 543-5b
- 505-4a
- 512-4
- 543-5a

Level of Compaction:
1 - Minimal Post-Construction
2 - Beneath Rut Study
3 - Beneath Fatigue Study

X-axis: Level of Compaction
Y-axis: Permeability (cm/sec)

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AB Percolation rate

◇ Percolation Rate with ATPB
■ Percolation Rate without ATPB

Level of Compaction:
1 - Minimal Post-Construction
2 - Below Rut Study
3 - Below Fatigue Study
4 - Below Fatigue Turnaround

543-9
505-4b
512-3
505-15
518-9
518-13
505-4a
512-4
543-13
518-12
543-5a
518-15
518-8

Permeability (cm/sec)

1.E-03
1.E-04
1.E-05
1.E-06

Level of Compaction

0   1   2   3   4   5

ATPB Percolation rate

Level of Compaction

Permeability (cm/sec)

Level of Compaction:
1 - Minimal Post-Construction
2 - Beneath Rut Study
3 - Beneath Fatigue Study

512-3 505-4b 505-15 505-4a 512-4 543-5b 543-5a

Percolation Field Tests

GOAL 1 PLAN VIEW

DRAINED

502CT-DB

500RF-DB

UNDRAINED

504RF-DB

503RF-DB

501RF-DB

ARHM-GG
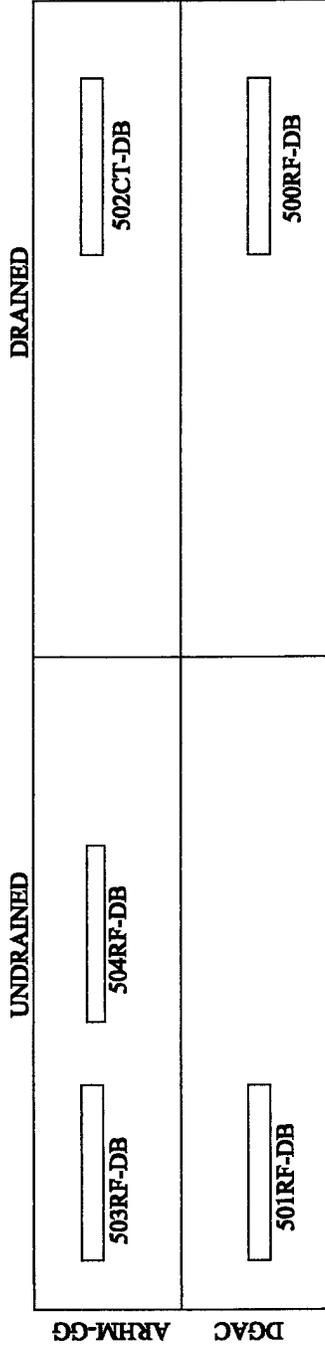
DGAC

Test Areas

GOAL 3 PLAN VIEW

DRAINED

515RF

514RF

511RF
510RF

512RF
505RF

508RF
509RF

513RF

507RF

506RF

UNDRAINED

518RF

517RF

ARHM-GG

GDAC

18.3 0+15 0+20 0+25

0+00 0+05 0+10 0+15 0+20 0+25 0+30 0+35 0+40 0+45 0+50 0+55 0+60 0+64

61m

0+00 0+00 0+00 0+00 0+00 0+00 0+00 0+00 0+00 0+00 0+00 0+00
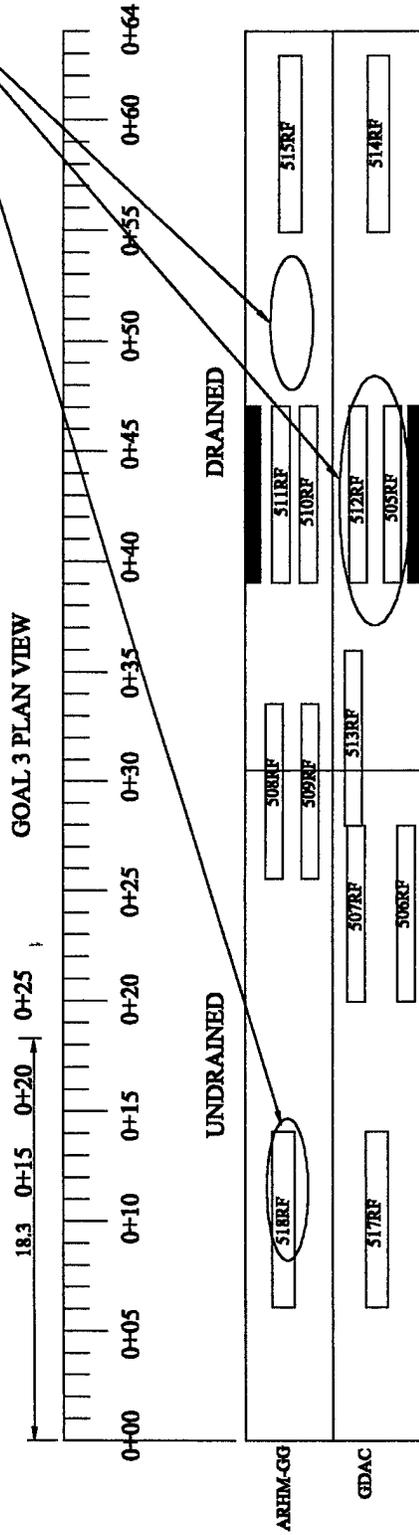
University of California Berkeley	
Building 280, RFS	Percolation Tests
Drawn By: Mark Russo	6/20/00

Percolation Field Tests

Test Areas
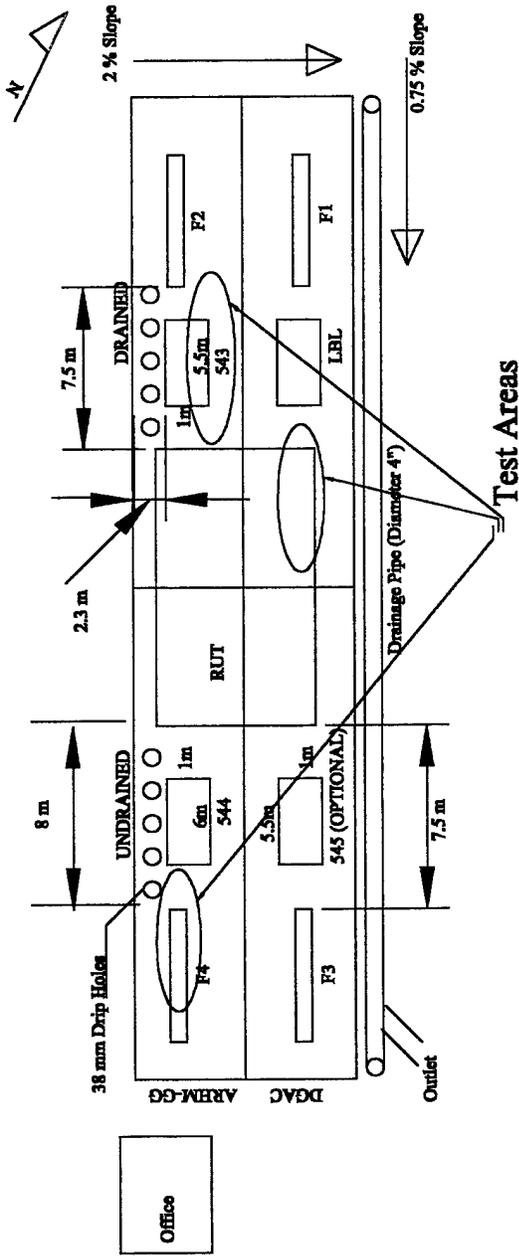
| Cross-section (left)	Cross-section (right)
ARHM-GG/DGAC Overlays (38mm/75mm)	ARHM-GG Overlay (38mm)
AC UPPER LIFT (66mm)	AC UPPER LIFT (66mm)
AC LOWER LIFT (66mm)	AC LOWER LIFT (66mm)
	ATPB (75mm)
AB (272mm)	AB (183mm)
ASB (214mm)	ASB (214mm)
SG	SG

Sites of Field Percolation Tests

Richmond Field Station, Bldg 280

Undrained | Drained

ARHM-GG

518 | 543

DGAC

512

505

N

Section 543

Trafficked area for fatigue study

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

Section 512

Trafficked area for rut study, super single

16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0

Section 505

Trafficked area for rut study, dual

Section 518

Trafficked area for fatigue study

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
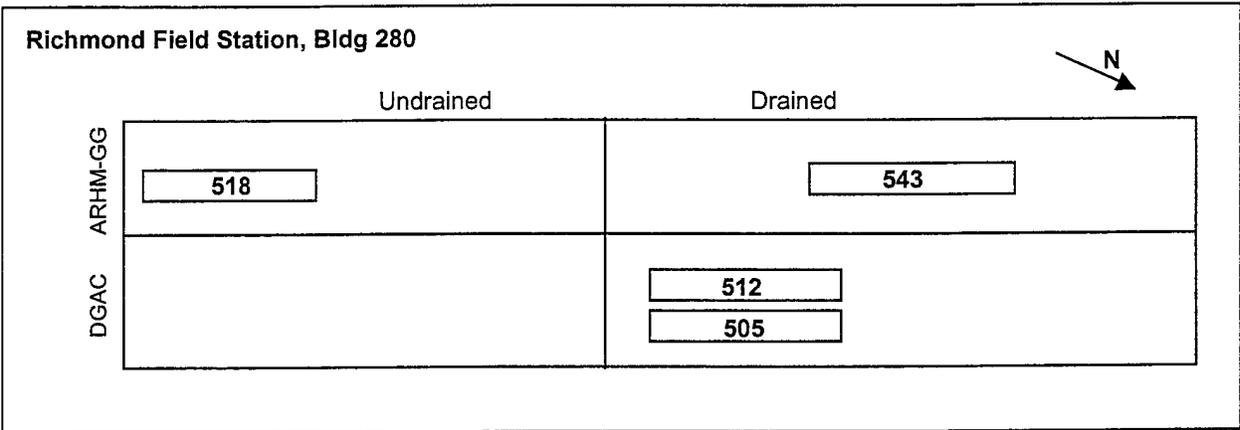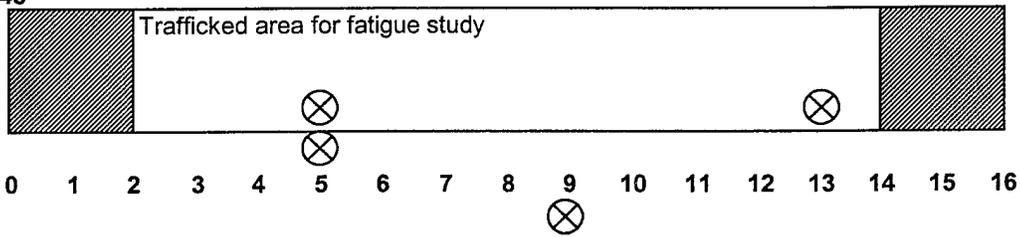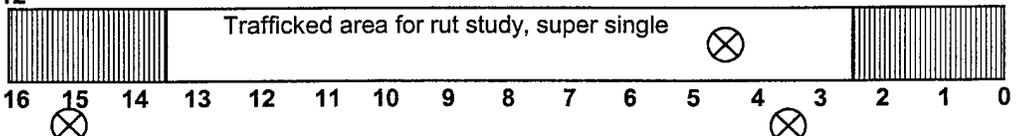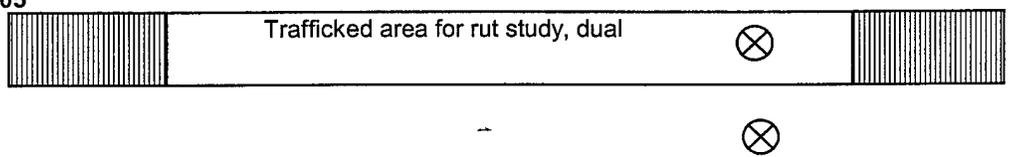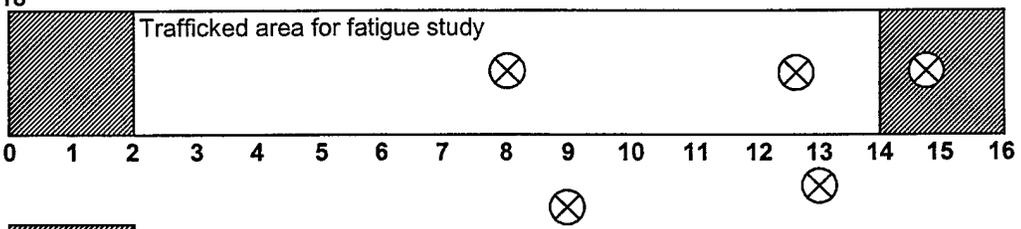
Turnaround areas
Turnaround areas with ramps

APPENDIX E: ASPHALT-CONTAMINATED TEST RESULTS

Gradation - Contaminated

Sample #1 (contaminated)

% Passing	Particle Size in mm	Particle Size	Caltrans Specifications	
			Min	Max
	50.8	2"		
99	25.4	1"	100	100
98.12	19.05	3/4"	87	100
82.71	12.7	1/2"		
74.17	9.51	3/8"		
58.54	4.75	#4	30	65
46.71	2.38	#8		
38.56	1.19	#16		
31.29	0.59	#30	5	35
24.49	0.30	#50		
18.75	0.15	#100		
15.24	0.07	#200	0	12
	25.4	1"	100	100
	19.05	3/4"	87	100
	4.75	#4	30	65
	0.59	#30	5	35
	0.07	#200	0	12

Sample #2 (contaminated)

Sieve Size	Weight Retained	% Retained	% Passing
3/4"	190.3	0.064807247	93.51928
1/2"	424	0.209201744	79.07983
3/8"	120.4	0.250204332	74.97957
#4	495.4	0.418914317	58.10857
#8	337	0.533680697	46.63193
#16	237.7	0.614630159	38.53698
#30	212.4	0.686963629	31.30364
#50	196.5	0.753882305	24.61177
#100	165.8	0.810346002	18.9654
#200	102.3	0.84518458	15.48154
Pan	454.6	1	0
Total WT	2936.4		

Sieve Analysis (Contaminated)

Percent Passing

Particle Size in mm
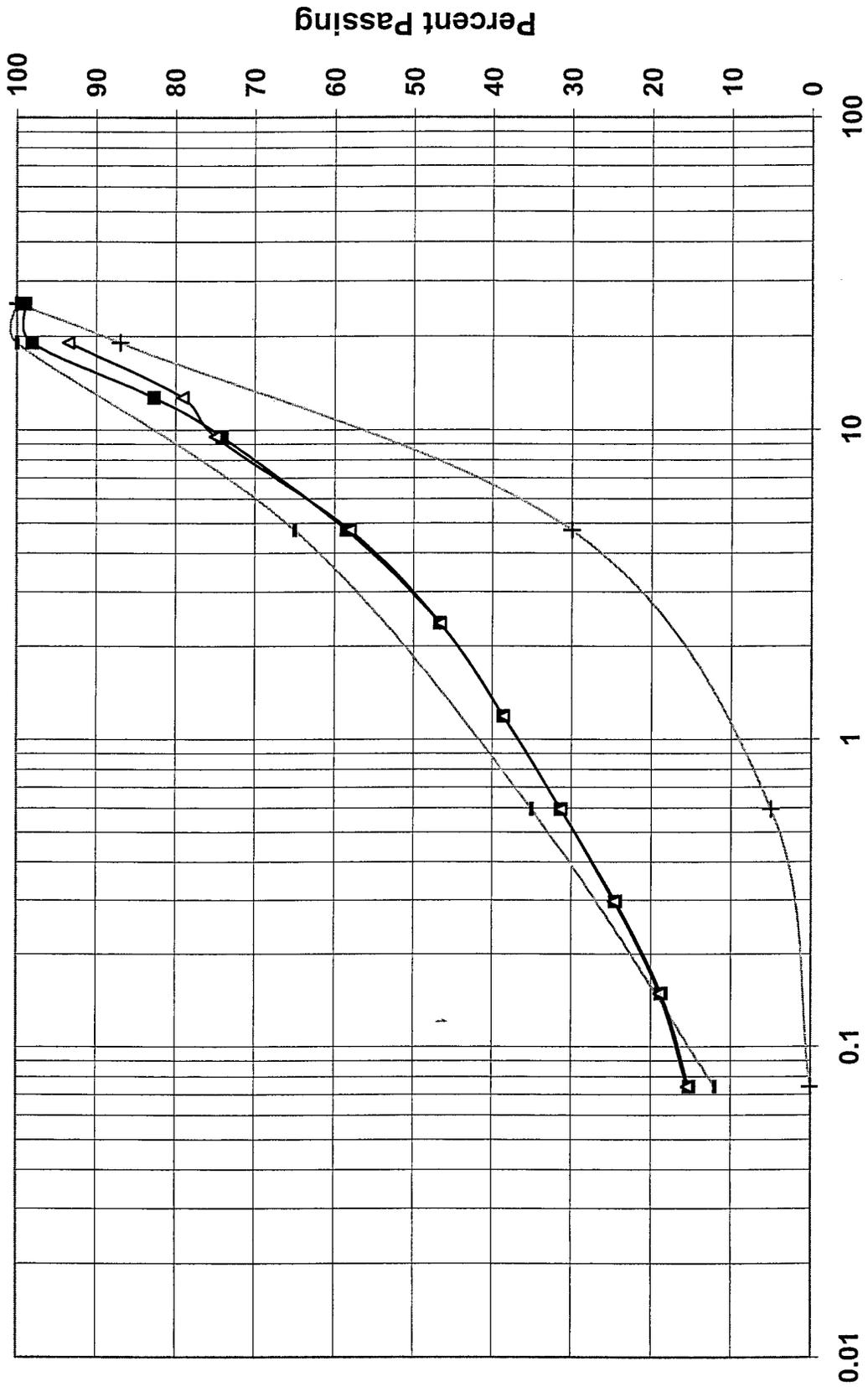
—+— Caltrans min   —■— Caltrans max   —■— Sample #1 (contaminated)   —△— Sample #2 (contaminated)

Data Form-Laboratory Compaction Test

Standard (Contaminated)

Sample No.	1	2	3	4	5	6
A-Initial Moisture Content	3.5	3.5	3.5	3.5	3.5	3.5
B-Sample Weight (g)	7773.2	8221.3	6917.3	6778.7	8590.6	7057.6
C-Solids Weight (g)	7510.3	7943.3	6683.4	6549.5	8300.1	6818.9
D-Moisture Weight (g)	262.9	278.0	233.9	229.2	290.5	238.7
E-Desired Moisture Content	5	7.0	9.0	11.0	8	6.0
F-Water to add (g)	112.7	278.0	367.6	491.2	373.5	170.5
G-Water to add (ml)	112.7	278.0	367.6	491.2	373.5	170.5
Laboratory Compaction Test Procedure						
H-Weight Mold+Soil (g)	14849.3	15048.9	15086.4	14942.0	15032.9	14882
I-Weight Mold (g)	10023.1	9998.5	10022.8	9997.7	10002	10023.2
J-Weight Compacted Soil (g)	4826.2	5050.4	5063.6	4944.3	5030.9	4858.8
K-Wet Density(g/cm^3)	2.27	2.38	2.38	2.33	2.37	2.29
Wet Density(kg/m^3)	2272	2378	2384	2328	2369	2288
L-Moisture Content (%)	4.7	7.5	8.7	10.9	8.7	6.0
M-Dry Density (g/cm^3)	2.17	2.21	2.19	2.10	2.18	2.16
Dry Density (kg/m^3)	2171	2213	2193	2100	2179	2158

Pan Weight	232.1	236.1	111.6	121.7	111.7	121.9
Pan+Soil Wet	3244.7	2369.7	2166.0	2033.0	2748.7	2886.7
Pan+Soil Dry	3110.0	2221.3	2001.1	1845.7	2537.8	2730
water content	4.7	7.5	8.7	10.9	8.7	6.0

[(weight of soil wet-weight of soil dry)/weight of soil dry]*100

	9-May	3-May	1-May	27-Apr	21-Apr	28-Apr
					* added 5/16	

Density vs. Moisture Content
(Standard Compaction: Contaminated and Clean)

Legend:
■ Dry Density, contaminated
△ Dry Density, clean
— · — Zero Air Voids: S=100%, Gs=2.72
——— Zero Air Voids: S=100%, Gs=2.75

Moisture Content (%)

Density (kg/m^3)
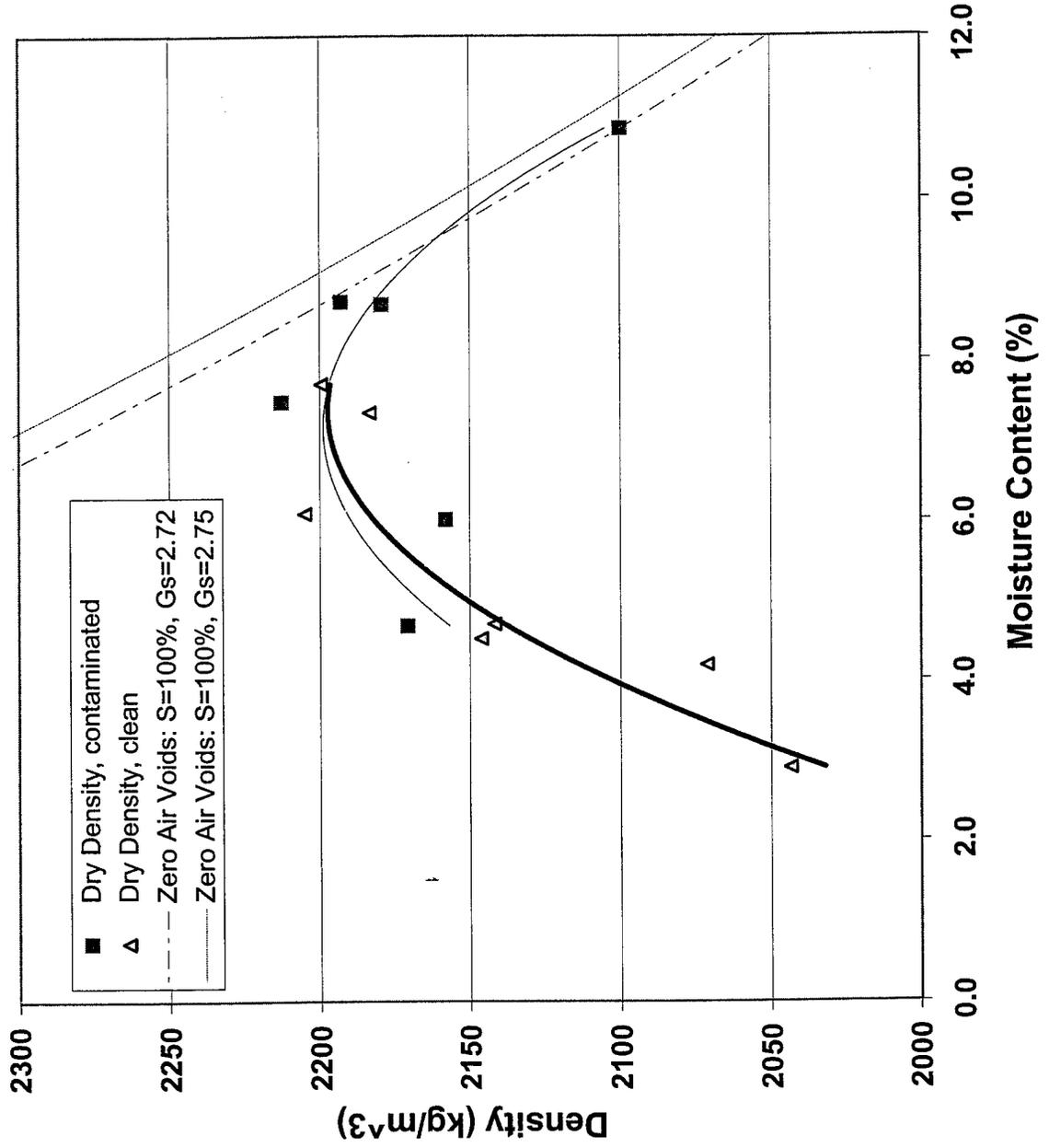
Permeability Data - Contaminated Soil

Constant Head Test

L = 4.58 in = 11.64 cm $k = QL/(Aht)$

$A = (pi)/4 * D^2 =$ 182.4 cm^2

Test #	Avg Flow, Q (cm^3)	Collection Time t (sec)	Head Difference (inches)	h (cm)	k (cm/sec)	H2O Temp (Celsius)
Standard #2 7.5%						
1	100	720	16.5	41.9	0.00021	
2	100	690	16.5	41.9	0.00022	
3	100	690	16.5	41.9	0.00022	
Standard #3 8.7%						
1	44	93600	32.5	82.6	0.00000036	
2	25	57600	32.5	82.6	0.00000034	
3	40	75600	32.5	82.6	0.00000041	
Standard #4 10.9%						
1	100	111600	32.5	82.6	0.00000069	
2	47	57600	32.5	82.6	0.00000063	

Sample #	2	3	4
Pan Weight	236.1	111.6	121.7
Pan+Soil Wet	2369.7	2166.0	2033.0
Pan+Soil Dry	2221.3	2001.1	1845.7
water content	7.5	8.7	10.9
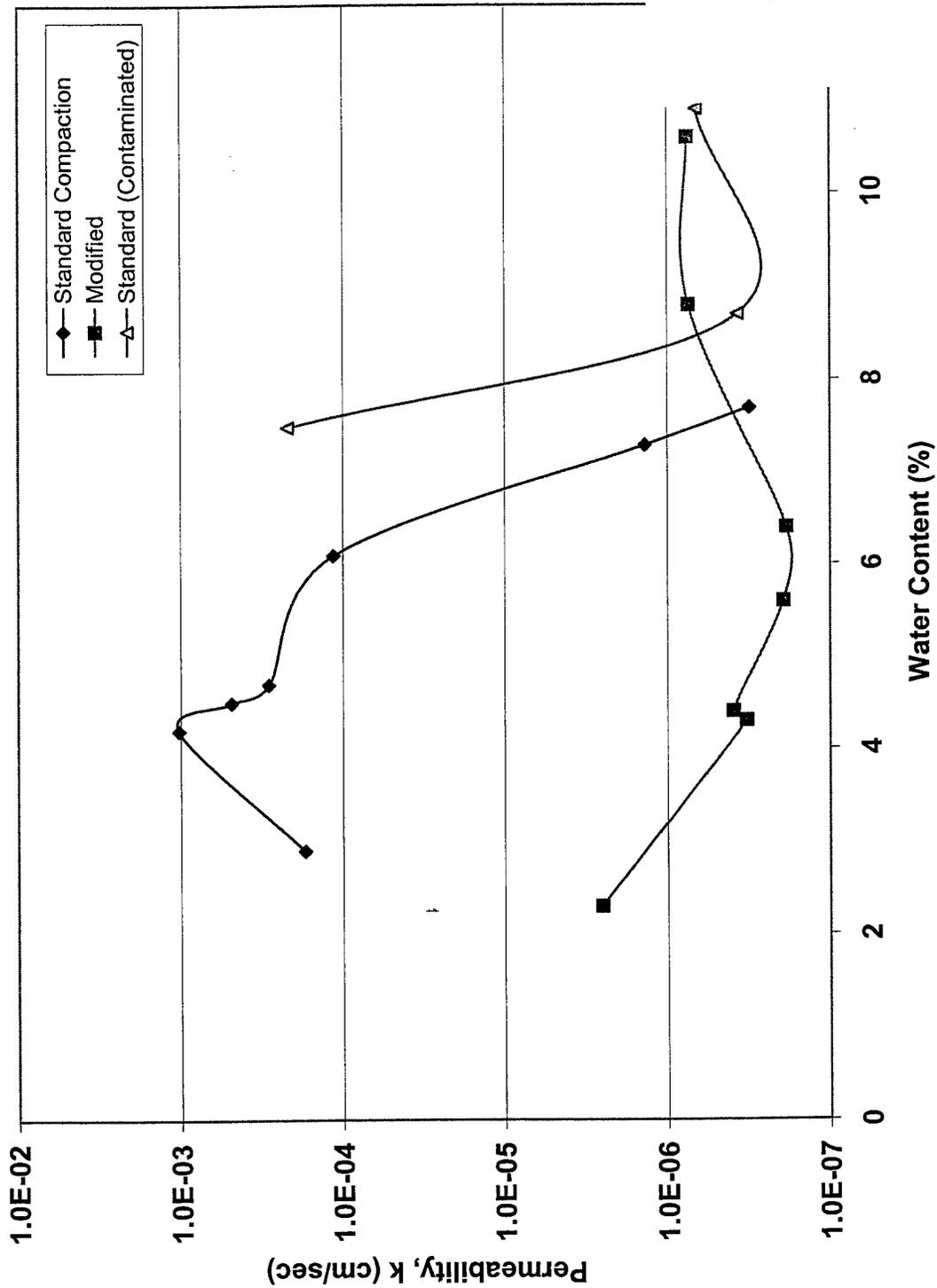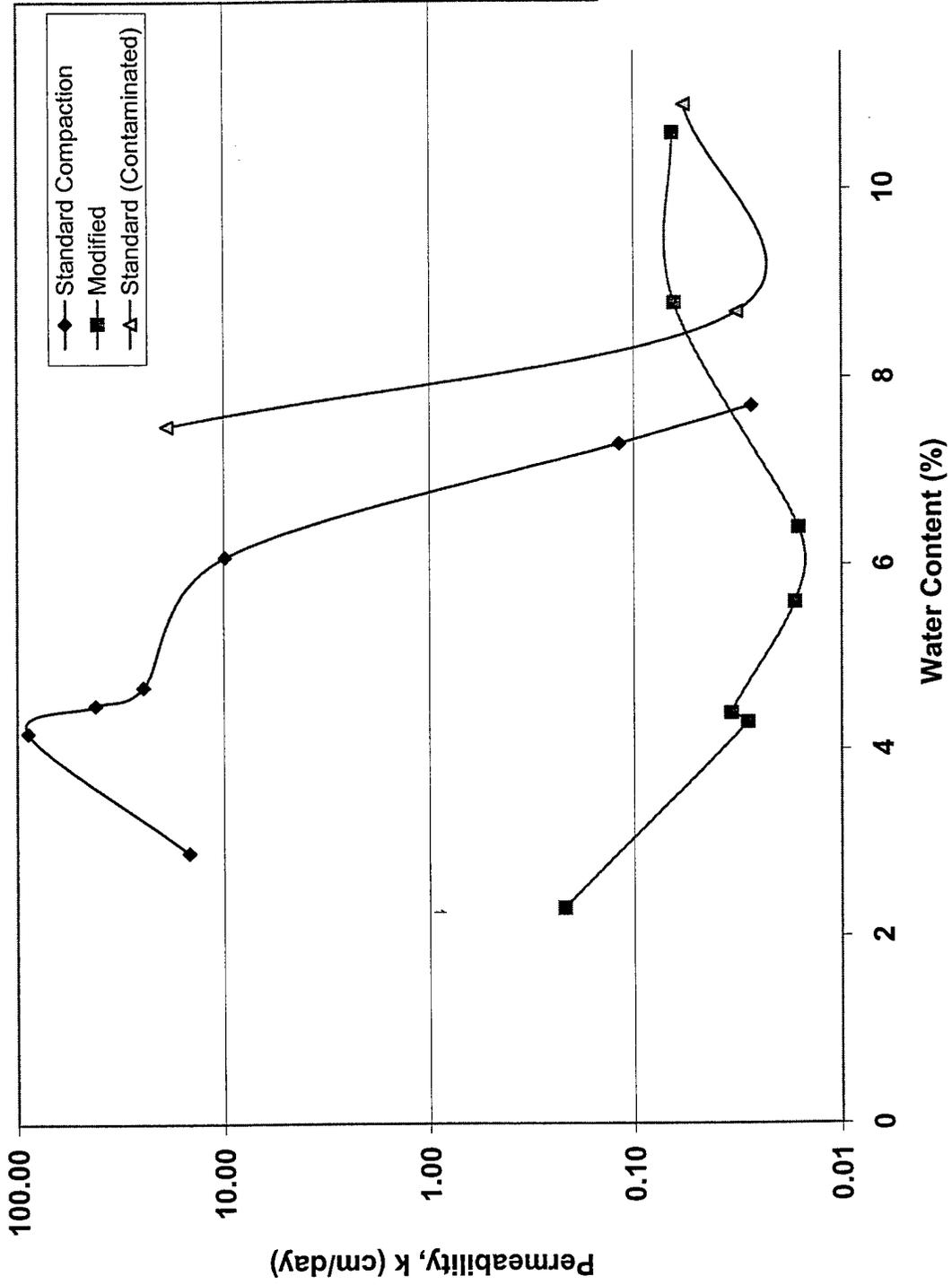
Standard (Contaminated)

Info for plots!	Standard Compaction	
Sample Number	Water Content	k (cm/sec)
2	7.5	0.0002177
3	8.7	0.000000369
4	10.9	0.0000007

| Info for plots!	Standard Compaction		
Sample Number	Water Content	k (cm/day)	k (in/day)
2	7.5	18.806	7.404
3	8.7	0.032	0.013
4	10.9	0.057	0.023

Permeability Vs. Water Content

cm/sec

Permeability Vs. Water Content

cm/day

Density and Permeability Vs. Water Content

Permeability Vs. Water Content

Predicted Trend

Predicted Permeability for Modified
Compaction of Asphalt-Contaminated
Aggregate

Legend:
- Standard Compaction
- Modified
- Standard (Contaminated)
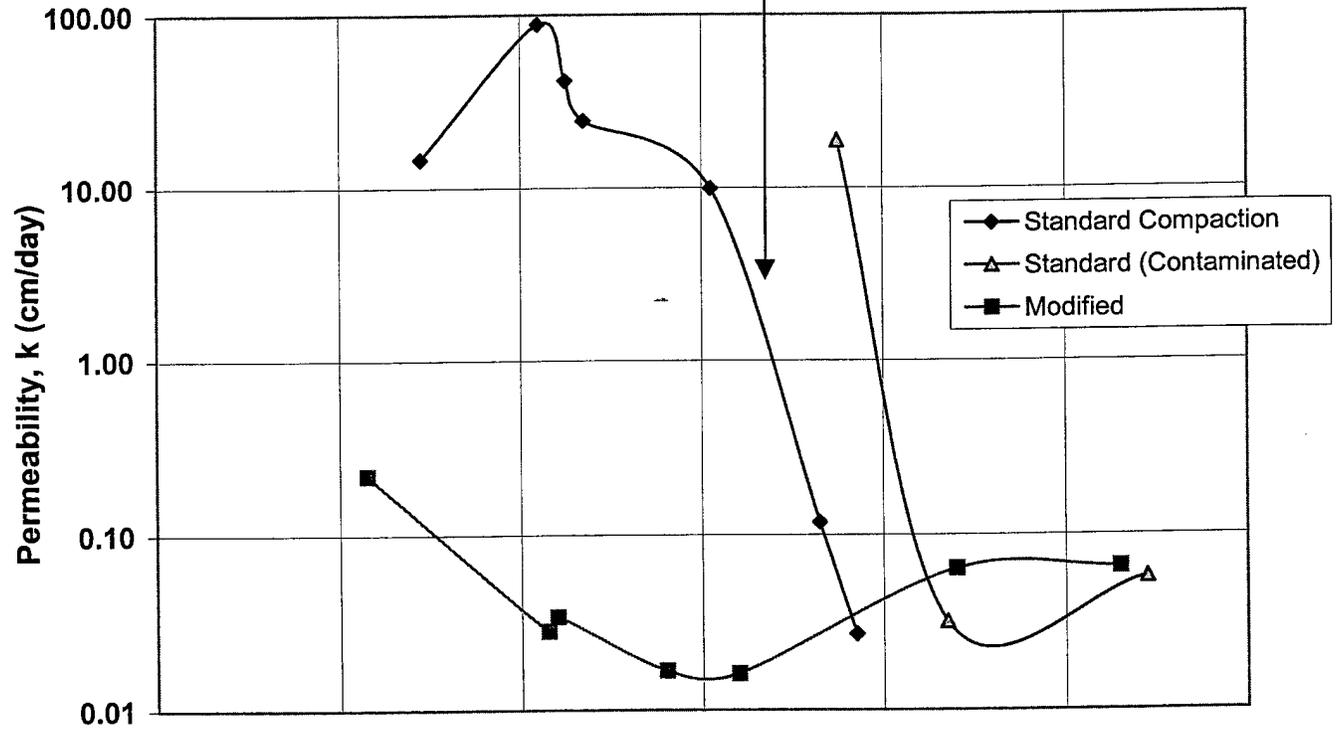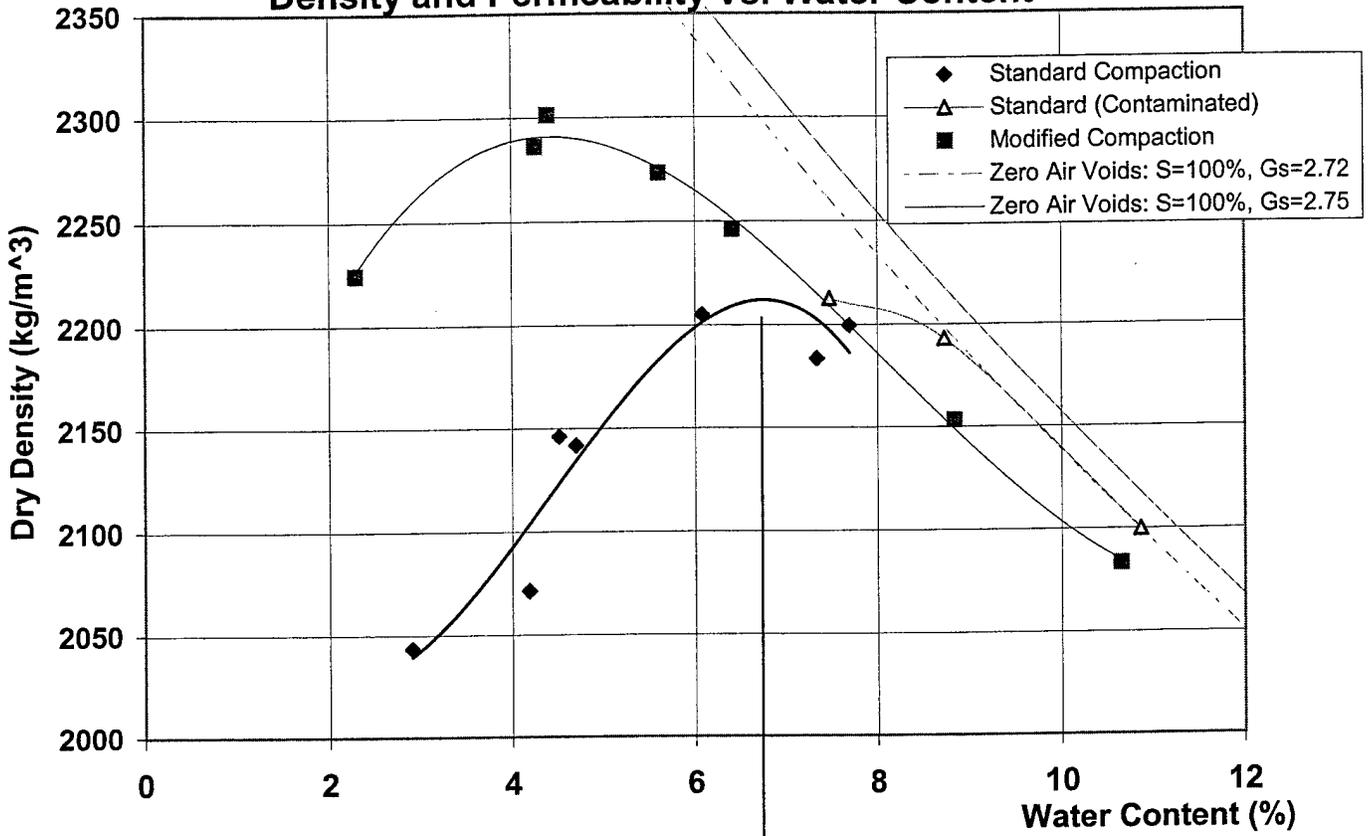
Water Content (%)

Permeability, k (cm/day)
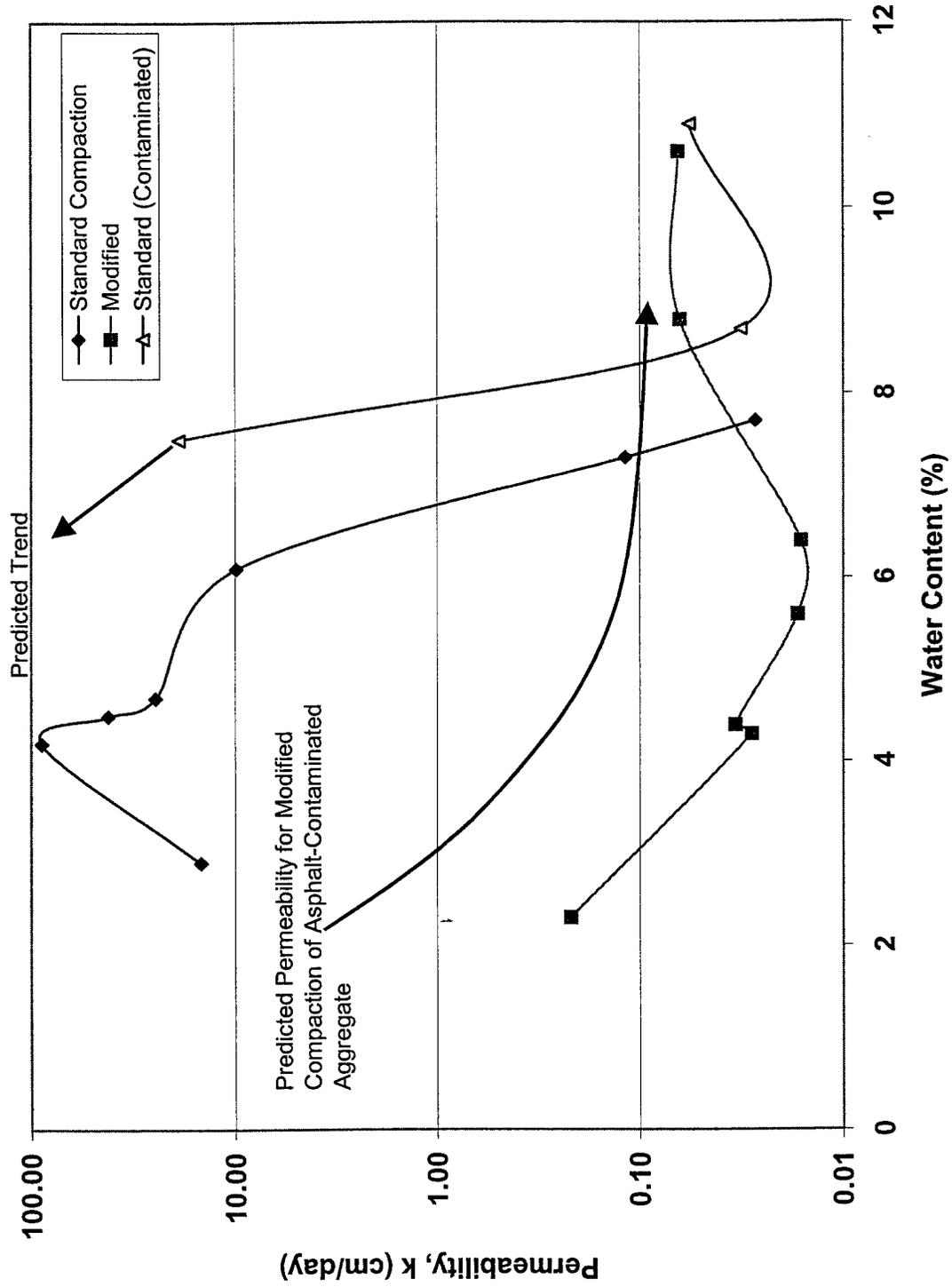
[1] *Drainage of Asphalt Pavement Structures*, The Asphalt Institute Manual Series No. 15 (MS-15), 1984.

[2] J.T. Harvey; du Plessis, L; Long, F.M.; Shatnawi, S.; Scheffy, C.W.; Tsai, B-W.; Guada, I.M.; Hung, D.; Coetzee, N.; Riemer, M. and Monismith, C.L. *Initial Cal/Apt Program: Site Information, Test Pavements Construction, Pavement Materials Characterizations, Initial CAL/HVS Test Results, And Performance Estimates.* Initial Report : Institute For Transportation Studies, University Of California, Berkeley, June, 1996.

[3] H.B. Seed; Chan, C.K. and Lee, C.E. Resilience Characteristics of Subgrade Soils and Their Relation to Fatigue Failures in Asphalt Pavements. Proceedings : *International Conference on the Structural Design of Asphalt Pavements.* University of Michigan, August 20-24, 1962.

[4] Harvey, et al., 1996. (see endnote 2)

[5] Seed, et al., 1962. (see endnote 3)

[6] Harvey, et al., 1996. (see endnote 2)

[7] Seed, et al., 1962. (see endnote 3)