SELECTION AND EVALUATION OF METHODS AND TREATMENTS FOR ACCEPTABLE FATIGUE LIFE OF MOISTURE-SUSCEPTIBLE DENSE-GRADED ASPHALT CONCRETE

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SOUTHERN IDAHO AGGREGATES

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TO

IDAHO TRANSPORTATION DEPARTMENT
BOISE, IDAHO

ITD FC Register #82-036

FROM
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ACKNOWLEDGMENTS

The evaluation of moisture damage susceptibility of four predominant aggregate sources in southern Idaho was accomplished under the cooperation of Idaho Transportation Department (ITD). The ITD materials and research staff selected and obtained aggregates for this study. The central laboratory of ITD in Boise made asphalt concrete test specimens from the aggregate for testing at the University of Idaho. Cores from four older pavements, which incorporated the aggregates, were drilled by ITD and sent to University of Idaho for testing. The Boise central laboratory also performed some tests on the mix specimens for comparison to the University results. The ITD Districts provided performance data and estimated life of the four pavements as well as aggregate source and related information.

Initiation of the study was accomplished by Chuck Humphrey (materials supervisor) and Jim Hill (research supervisor). Completion of the study was also carried out with the cooperation of Kay Montgomery (laboratory research engineer), Dave Cole (bituminous mix supervisor) and his staff, Jim Hill (research supervisor) and Phil Marsh (materials supervisor). Their cooperation and assistance are gratefully acknowledged.

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OBJECTIVE AND SCOPE

The objective of the study was to evaluate four aggregate sources in southern Idaho from the basis of moisture damage susceptibility when the aggregate is incorporated into dense-graded asphalt concrete mixes. Field cores and performance information from four representative pavements were used with the laboratory test information obtained from laboratory specimens.

Laboratory mechanical indicator tests that were used to reflect the moisture damage susceptibility were: splitting tensile strength, resilient modulus and repeated stress diametral fatigue. These tests were performed on dry, vacuum saturated and accelerated conditioned laboratory specimens and cores. Three of the four aggregate source mixes were evaluated both in untreated and treated conditions.

Pavement lives were predicted by two calculation methods using both the splitting tensile strength ratios and the fatigue lines.

A discussion of the results follows. Appendix A and Appendix B contain the predicted pavement life procedures, Appendix C contains the tensile strength and modulus test data, and Appendix D contains the fatigue lines obtained on the cores and laboratory specimens.

AGGREGATE SOURCES

Four aggregate sources used in this study were: AD-53, BK-142s, GD-56 and CS-147. A constant asphalt cement (AC-11) was used for the laboratory specimens.

Asphalt concrete mix performance as based on moisture damage susceptibility has been ranked by ITD as follows:

AD-53	Good
GD-56	Fair-Good
CS-147	Poor
BK-142s	Poor

Records from the older road pavements made with these aggregates, especially in the sections from which cores were drilled for this study, indicated that all field mixes were untreated except for GD-56. The GD-56 mix contained 1% hydrated lime powder as an antistrip.

RESULTS OF MECHANICAL INDICATOR TESTS

The mechanical indicator tests used were stripping tensile strength (STS), resilient modulus (M_R) and repeated stress diametral fatigue at 55°F. The data obtained are shown in Appendix C and Appendix D.

Specimen vs. Core Comparisons

A comparison of test data (ratios) between laboratory specimens matched to field cores is shown in Table 1. If there is a good match between specimens and cores, then the accel. cond. ratio of specimens should not be higher than the vac. sat. ratio of cores from the pavements. In all four cases, this is true for STS ratio, which implies that the potential field moisture damage has not been reached to date because of lower moisture entry to the pavement. But the field core STS vac. sat. ratio is generally below the lab specimen STS vac. sat. ratio, which implies that field moisture damage has occurred beyond the stage of vac. saturation effects. Similar M_R ratio comparisons are not evident probably because of differences in oxidation-hardening effects for the field cores vs. lab specimens.

A comparison of STS and M_R ratio magnitudes between cores and specimens per aggregate source shows there are some similarities, but the matching is not exact. The similarities are probably due to matching aggregate source, but the differences are probably due to using a current asphalt in specimens rather than using the original asphalt in the pavement mixes. The use of current asphalt is a practical necessity in this case.

Overall, the aggregate source mixes can be ranked from best to worst using the ratio magnitudes as follows:

TABLE 1. COMPARISON OF RATIOS BETWEEN FIELD CORES AND MATCHED LABORATORY SPECIMENS

Mix Type by Aggr. Source	Ratios					
	Splitting Tensile Strength		Resilient Modulus		Fatigue Stress at 1 X 10^6 reps	Fatigue Strain at 1 X 10^6 reps
	vac sat	accel cond	vac sat	accel conc	accel cond	accel cond
AD-53 Cores[1]	.91	.58	.90	.75	.59	.71
AD-53 specimens	.91	.74	.78	.65	.55	.83
BK-142s Cores[1]	.61	.45	.56	.31	.48	.82
BK-142 Specimens	.85	.54	.86	.62	.54	.75
GD-56 Cores[2]	.95	.90	1.06	1.06	.87	.83
GD-56 Specimens	.86	.95	.83	.98	1.06	1.03
CS-147 Cores[1]	.83	.72	.89	.75	.81	.89
CS-147 Specimens	.99	.59	.94	.54	.38	.65

Notes: 1. Untreated mix for cores and specimens.

2. 1% hydrated lime treated mix for cores and specimens.

Cores GD-56, CS-147, AD-53 and BK-142s

Specimens GD-56, AD-53, CS-147 and BK-142s

The GD-56 mix, containing 1% lime, shows that it is top-rated by ratio. The BK-142s mix is bottom-rated. The AD-53 and CS-147 mixes are in between.

The fatigue stress and strain ratios ($=\frac{\text{stress or strain wet}}{\text{stress or strain dry}}$ at 1×10^6 reps.) show that the GD-56 mix is again top-rated. The rest of the aggregate source mix rating is difficult to assess because of the general fatigue mismatch between cores and specimens. If fatigue ratios are not considered but, rather, the high position of the strain fatigue lines, then the AD-53 mix is top rated overall (See Appendix D, Figure D-2).

Although the match between specimens and cores is not what one would hope, the overall comparison based on ratios shows that lab specimen ratio indicator tests after performing accelerated moisture condition do a reasonable job of predicting aggregate source mix performance based on ITD field observations.

If the same pavement thicknesses are to be compared, then the mix which has the highest STS ratios should perform the best in the field under a given traffic volume, soil support and climate providing the basic fatigue life and strength is adequate. The Appendix D fatigue lines for the dry mixes appear to be high enough to provide from one to ten million or so repetitions before fatigue cracking, which seems to be minimal but adequate for all the four aggregate sources. However, since the four pavement sections have different thicknesses, the ratio comparison is not always sufficient to predict pavement life. This will be discussed in a later section.

Effects of Additives

One of the objectives was to determine the sensitivity of antistrip treatment to moisture damage. The BK-142s, GD-56 and CS-147 aggregate source lab-specimen mixes were treated with 1% hydrated lime powder or 0.50% liquid antistrip, or both. Table 2 shows the ratios for the untreated and treated lab mixes.

The AD-53 aggregate source mix was not treated. The STS, M_R and fatigue strain ratios appear to be minimally satisfactory; the stress fatigue ratio is too low but the strain fatigue ratio is satisfactory.

The GD-56 mix ratios are satisfactory for the untreated condition. Although the field pavement mix was treated with lime, the current lab specimen ratios show that treatment is not needed. However, lime treatment does show a benefit; most of the ratios increase to about 1.0 with the addition of lime. The liquid antistrip in the GD-56 mix appears to produce no ratio increases when compared to the untreated mix.

The BD-142s and CS-147 mixes perform better when treated with the liquid antistrip. The low, unacceptable ratios for the untreated mixes rise to generally minimal acceptable levels when treated. The greatest improvement is observed with the CS-147 aggregate source; a much lesser improvement is observed with the BD-142s aggregate source, except for strain fatigue ratio where the ratio becomes quite large. Therefore, the liquid antistrip additive has the greatest "benefit-cost" indicator values for the CS-147 aggregate for all ratios, is ineffective in the case of GD-56 and, to a certain extent, questionable for BK-142s aggregate except for fatigue ratios. It appears that the performance of this liquid antistrip is related to aggregate source when using 0.5% dosage and the same lab asphalt.

TABLE 2. EFFECTS OF ADDITIVES ON RATIOS OF LABORATORY SPECIMENS

Mix Type by Aggregate Source	Ratios after Accelerated Conditioning			
	Splitting Tensile Strength	Resilient Modulus	Fatigue Stress at 1 X 10^6 reps	Fatigue Strain at 1 X 10^6 reps
AD-53 Untreated	.74	.65	.55	.83
BK-142s Untreated	.54	.62*	.54	.75
BK-142s 0.5% liquid antistrip	.65*	.61	.74*	1.26*
GD-56 Untreated	.86	.80	.93	1.21*
GD-56 1% hydrated lime	.95*	.98*	1.06*	1.03
GD-56 0.5% liquid antistrip	.82	.78	.92	1.08
CS-147 Untreated	.59	.54	.38	.65
CS-147 0.5% liquid antistrip	.82*	.73*	.70*	.96*

*Note: *Denotes highest magnitudes (not necesarily ratios) of respective mechanical property after accelerated conditioning per aggregate source mix.

Comparison of STS Ratios: Boise Central Lab (ITD) vs. Univ. of Idaho

ITD's Boise Central Lab obtained STS ratios of laboratory specimens for each aggregate source mix. These results are compared to the Univ. of Idaho STS ratios for specimens sent to Univ. of Idaho in Table 3.

In 3 out of the 7 comparisons shown, the ratios are different enough to indicate a cross-check on test method detail is warranted. For instance, the ratio for the AD-53 aggregate source mix shows a low ratio (.42) for the ITD test and a minimum acceptable ratio (.74) for the Univ. of Idaho test. For another comparison, the liquid antistrip treatment shows up more favorably for the BK-142s aggregate source mix with the ITD results as compared to the Univ. of Idaho results. In the first case, there is enough difference in ratios obtained for the AD-53 mix such that one agency would call the mix unacceptable while the other agency would probably give approval to the mix. In the second case, one agency would conclude that the 0.5% liquid antistrip in the BK-142s source mix would be benefit-cost acceptable, while the other agency would not conclude that the liquid antistrip is benefit-cost acceptable. So, it is suggested that the STS test method steps be cross-checked between the two agencies before further testing and study continuation takes place.

On the other hand, both agency STS ratios show general agreement between untreated and treated ratio levels for the BK-142s, GD-56 and CS-147 aggregate source mixes. The untreated GD-56 mix has high ratios and both agencies show that the effect of 0.5% liquid antistrip is not effective. Also, both agencies show that the untreated BK-142s and CS-147 mixes are moisture sensitive and require treatment.

TABLE 3. COMPARISON OF SPLITTING TENSILE STRENGTH RATIOS BETWEEN ITD AND U of I

Mix Design by Agg. Source	Splitting Tensile Strength Ratios for Laboratory Speicmens[1]			
	Untreated		Treated[2]	
	ITD	UI	ITD	UI
AD-53	.42	.74	-	-
BK-142s	.61	.54	.85	.65
GD-56	.95	.86	.85	.82
CS-147	.76	.59	.85	.82

Notes: 1. Ratios obtained after accelerated conditioning.

2. 0.5% liquid antistripping additive.

RESULTS OF PAVEMENT LIFE PREDICTIONS

When assessing the aggregate source mixes by fatigue life using pavement variables, the life methods and other variables are superimposed upon the mechanical indicator test results. What might be a good ratio by the mechanical indicator tests may not look so good in life performance when the variables of pavement thickness and traffic volume are included, and vice versa. Each of the four pavements (and aggregate source mixes) have different thicknesses, traffic volume and soil support. Although the mechanical indicator test ratios are indicative of the asphalt concrete performance for consistent field pavement variables, the variety of the four pavement sections can show a different arrangement of aggregate source performance.

Table 4 lists the pavement thicknesses for the four aggregate source field pavements used in this study. Three out of the four pavements incorporate the .4 ft. PMS and .4 ft. ATB top layers used in the Idaho interstate, with varying aggregate base and granular borrow thicknesses.

The ITD Flexible Pavement Method is based on the reduction of asphalt concrete's cohesion using STS ratio from which the reduced gravel equivalency is calculated. The ITD pavement thickness-traffic method is used to calculate the reduced allowable traffic index and thus, the reduced allowable fatigue life wheel load repetitions based on a 20-year design period. The reductions are field prorated with STS ratio using 2 yrs. dry + 8 yrs. vac. sat. + remaining yrs. accel. cond. for laboratory specimens. For pavement cores

TABLE 4. PAVEMENTS AND THICKNESSES

Pavement Designation	Layer Thicknesses, ft.			
	Plant Mix	ATB	Agg. Base	Granular Borrow
I-84 AD-53	.4	.4	.3	1.5
I-15 BK-142s agg.	.4	-	1.1	1.0
I-84 CS-147 agg.	.4	.4	.9	-
I-84 GD-56 agg.	.4	.4	.7	-

representing the older pavements, the vac. sat. STS ratio is used for the PMS: the life of the PMS is added on to the estimated life of the ATB. Appendix A describes the procedure.

The Fatigue (First Cracking Life) Method uses the fatigue lines (Appendix D) and the Chevron 5L computer program for obtaining stresses and strains under the 5,000 lb. wheel load in the PMS and ATB. The procedure is described in Appendix B. For laboratory specimens, the ATB first crack life is calculated and the the remaining (added) first crack life increment for the PMS is calculated. The first crack life is prorated using basic fatigue lives for 2 yrs. dry + 8 yrs. vac. sat. + remaining yrs. accel. cond. The lives are usually less than the total life of the pavement due to fatigue cracking because the time for surface crack propagation is not known and therefore not added to the first crack life. But the first crack life may serve as a relative measure of the aggregate source mix in the pavements. For field cores, the ATB life is estimated and the remaining life increment of the PMS is added using the vac. sat. fatigue line.

The traffic volumes (TI) used for the fatigue method are shown in Table 5. Note that the I-84 pavement thicknesses are sufficiently thick such that the TI are very high and are not in correspondence with the ITD pavement thickness method. Therefore, if the TI was over 12, a TI = 12 was assigned in the dry stage for the asphalt concrete. The fatigue first crack method uses the estimated field TI, which is more realistic.

The pavement life predictions by both methods are shown in Table 6 with the ITD field estimated life. The ITD field rank, from highest to lowest life, is AD-53, GD-56, CS-147 and BK-142s. The ITD flexible pavement thickness

TABLE 5. TRAFFIC INDEX FOR CALCULATION OF PAVEMENT LIVES[1]

Pavement and Aggregate Source	ITD Flex. Pavt. Method w/STS Ratios[2]			Fatigue Mechanistic Method[3]
	Dry	Vac. Sat.	Accel. Cond.	
I-84 AD-53	12.0	11.9	11.6	10.2
I-15 BK-142s	9.7	9.5	9.3	9.5
I-84 GD-56	12.0	11.8	11.6	11.0
I-84 CS-147	12.0	11.8	11.6	8.5

Notes: 1. Total 5 k EWL's = $\frac{5 \text{ k EWL}}{\text{yr}}$ X yrs. of Pav't Life

where TI = 1.3 (total 5 k EWL)$^{.12}$ for a 20-yr. period

and $\frac{\text{Total 5 k EWL}}{\text{20 yr}}$ = ave. $\frac{\text{5 k EWL}}{\text{yr}}$

2. TI calculated from pavement section gravel equivalency for STS ratios of asphalt treated layers. TI max. = 12.0 (dry)

3. Average field estimated TI (past and future traffic) by ITD field engineers.

TABLE 6. COMPARISON OF FIELD LIFE CALCULATIONS

Pavement and Agg. Source	Pavement Age as of Spring 1982 (yrs)	ITD Field Estimated First Cracking by Wheel Loads (yrs)		Calculated First Cracking of Plant Mix Surface from Lab Fatigue Tests (yrs)		Calculated Overall Pavement Life by ITD Flex. Pavt. Thickness Method (yrs)		ITD Field Estimated Overall Pavt Life (yrs)
		ATB	Plant Mix Surface	Lab Specimens Stress/ Strain	Field Cores (Spring 1982) Stress/Str.	Lab Spec. (20 yr max design life basis	Field Cores (Spring 1982	
I-84 AD-53 (MP 61 WBL)	19	15±	19	16.0/32.0*	16/50+	17.0*	33.5	25
I-15 BK-142s (MP 65 N-SBL)	17	no ATB	2.5	0.2/4.9* 0.2/5.4***	2.0/2.5	16.0* 16.6***	16.5	17-
I-84 CS-147 (MP 253 WBL)	12	3±	4.5	13.6/18.3* 9.8/17.6***	35/50+	13.4* 15.4***	18	17
I-84 GD-56 (MP 160 EBL)	9.5	6±	8.5	1.2/4.1* 2.1/5.6** 4.1/14.6***	6.3/14	16.7* 16.7** 14.9***	24	19-20

Notes:
* Untreated Mix
** 1% hyd. lime treated mix
*** 0.5% liquid antistrip treated mix

method ranks AD-53 highest and CS-147 lowest using lab specimens, and AD-53 highest and BK-142s lowest using pavement cores. Again, there is some mismatch (due to STS ratios) between cores and specimens. But this method using cores shows the same life proportional ranking as the ITD field estimated life. The lab specimen rating is not as good but perhaps generally reasonable considering that 20-yrs. life is maximum in the method when using specimens for predictions. The fatigue first cracking life method does not give reasonable ranking at first glance, but the AD-53 is rated the highest and the BK-142s is rated the lowest, both for predictions based on specimens and cores. The CS-147 mix is rated better than the GD-56 mix. The basic fatigue lines of mixes with hydrated lime (i.e. GD-56 mix) tend to be lower (or greater slope), thus giving rise to less life when employing fatigue life methods.

Additives seem to be only "benefit-cost" effective in the GD-56 and CS-147 mixes. The 0.5% liquid additive is very effective in the GD-56 mix for the strain fatigue first crack life method and moderately effective in the CS-147 mix for the ITD flexible pavement thickness method. The hydrated lime in the GD-56 mix did not show improved life by either method. The liquid additive did not produce a significant life increase in the BK-142s mix by either method, which was also previously indicated by STS and M_R ratios of the BK-142s mix in Table 2.

The results indicate that the ITD flexible pavement thickness method gives pavement life ranking that corresponds to the STS ratios. This method appears to be the most practical method at the present time for evaluating additives and aggregate sources through laboratory specimen STS ratios and pavement variables. However, it should be noted that a smaller difference in predicted pavement lives results from this method as compared to the strain fatigue life method. The implications of the strain fatigue life

method is discussed next.

If the lab specimens could ever match field cores, which is practically not completely achievable in the near future, then the strain fatigue first crack life method would give good predictions for overall pavement life ranking. Even with the superposition of pavement variables, there is some resemblance to predicting aggregate source mix overall pavement ranking by mechanical indicator tests and by strain fatigue life using laboratory specimens. For instance, the AD-53 mix is top rated and the BK-142s is bottom rated. However, the GD-56 mix is lower rated than the CS-147, the reverse of the mechanical indicator tests. This appears to be the only "switch" due to pavement variables. Therefore, the strain fatigue first crack life method using laboratory specimens, appears to hold promise as the better method for predicting overall ranking of aggregate sources in pavements.

CONCLUSIONS AND RECOMMENDATIONS

1. Laboratory specimen ratios from STS tests appear to be good indicators of aggregate source mix moisture damage susceptibility and for evaluation of additive treatments. However, it also appears that the STS ratio evaluation is applicable to a consistent set of field pavement variables. Changes of thickness, traffic volume and soil support can be factors in the overall evaluation of mixes using STS ratios when the aggregate source mix is incorporated as structural asphalt concrete (see 2. below).
2. STS ratios from laboratory specimens can easily be employed in the current ITD flexible thickness-life method to predict the aggregate source mix's performance as a structural layer in the pavement. This appears to be a good method for relating STS ratios to pavement variables using aggregate source mixes that are untreated and treated. However, the life differences tend to be attenuated by the 20 yr. design limit. (A past study, in connection with NCHRP 4-8(3)/1, shows that this method can be used to determine STS cut-off ratios in the laboratory for untreated specimens and to determine benefit-cost ratios if additive treatments are used). Fatigue tests, modulus tests, and the Chevron 5L computer program are not used in this method.
3. The use of laboratory specimen fatigue and modulus tests for the aggregate source mixes and the Chevron 5L computer program for determining the pavement <u>strain</u> first crack life show promise as a good method for predicting <u>overall</u> field pavement life ranking using pavement variables. Pavement life differences for aggregate sources are larger than the ITD method. However, this is a time-consuming method because fatigue tests consume a lot of lab time. The basic positions of the fatigue lines are

used for the wet and dry condition of mixes; ratios are not used. This method is applicable for future years. (The University of Idaho is developing a method for reducing the fatigue testing time).

4. In reference to 1., 2., and 3. above, the above tests and methods seem to rank the aggregate source mixes according to field pavement performance. The AD-53 and GD-56 aggregate source mixes show higher performance than the CS-147 and BK-142s aggregate source mixes. The University of Idaho tests show that the CS-147 mix's performance would be increased by liquid additive treatment; the additive treatment would not be as effective in the BK-142s mix at 0.5% dosage. (Lime treatment was not evaluated in these two mixes). The GD-56 mix had a small improvement in performance with the use of 1% lime, but the untreated mix showed satisfactory performance also. Fatigue tests showed the strain fatigue life for the liquid additive treated mix was much better than the life for the lime additive treated mix, implying that pavement variables affect the outcome of additives in the GD-56 mix, rather than STS ratios by themselves.

5. The fatigue lines for the four dry aggregate source mixes appear to be positioned high enough to withstand 1 million to 10 million 5,000 lb. equiv. wheel loads for "thick" pavements where the bending strain of 100×10^{-6} is not exceeded. If the CS-147 and BK-142s mixes could be made less moisture susceptible, these mixes would have equivalent life to the AD-53 and GD-56 mixes.

6. Continuation of evaluation of aggregate sources in Idaho appears advisable since field pavement performance is directly related to the mechanical indicator tests used and to certain portions of the fatigue life-pavement variable methods used (see 1., 2., 3. above).

7. A procedural cross-check needs to be performed between ITD and Univ. of Idaho before further STS ratio testing is performed. This would provide for better matching of ratios for aggregate source mixes between the two agencies.

APPENDIX A

USE OF STS RATIO TO CALCULATE PAVEMENT LIFE BY ITD FLEXIBLE PAVEMENT METHOD

I. Determination of Life Expectancy for an Existing Pavement Using Field Cores

1. Obtain the in place pavement layer thicknesses, full-value substitution ratios, soil support (R-value), and regional factor. Calculate the in-place gravel equivalent and divide by the regional factor to obtain the unadjusted gravel equivalent.

2. For a 20 year "dry" design life calculate the traffic index for the dry stage using the following equation.

$$TI = \frac{C^{0.2}\ T}{.0058\ (100-R)}$$

Where

T = thickness in feet (from step 1)

R = resistance value (soil support from Step 1)

C = cohesiometer value (normally taken as 20)

3. From laboratory tests, obtain the STS ratio of the asphalt concrete in the vacuum saturated stage.

4. Using substitution ratio = 1.3 for 100% stripped asphalt concrete plant mix and 1.1 for 100% stripped ATB, and a substitution ratio of 2.0 for 0% stripped (dry) asphalt concrete plant mix and 1.75 for 0% stripped (dry) ATB, calculate the substitution ratios for the asphalt-treated layers (plant mix and ATB) in the vacuum saturated stage using STS ratio for vacuum saturation with interpolation to obtain the amount of cohesion lost due to moisture damage (stripping).

5. Using the in-place pavement thickness, the substitution ratios for vacuum saturation, soil support and regional factor, calculate the in-place gravel equivalent representing the vacuum saturated condition. Divide by the regional factor to obtain the unadjusted gravel equivalent.

6. Using the equation in Step 2 and the gravel equivalent thickness from Step 5, calculate the Traffic Index for the vacuum saturated condition.

Note: If the TI from Step 2 is greater than 12, let $TI_{dry} = 12.0$ with TI_{vs} proportionately smaller.

7. With the following equations calculate the traffic rates in both the dry and vacuum saturated stages.

$$\frac{5kEWL}{yr} = \frac{1}{20}\left(\frac{TI}{1.3}\right)^{8.3333}$$

$$\frac{\text{Commercials}}{yr} = 8.928 \times 10^{-4}\,(TI)^{8.34934}$$

8. Calculate the extended life (yrs.) in the vacuum saturated condition using the following equation.

$$\frac{(20)\ (\text{yearly dry rate})}{(\text{yearly vac. sat. ratio})} = Y_{ext.}$$

9. Estimate age of pavement, Y_{ATB}, when the asphalt concrete underlayer, i.e. ATB, is fully cracked but plant mix is not, or obtain this information from field engineers.

10. Total life to pavement failure (high roughness) of the plant mix is the sum of the pavement age from Step 9 and Y_{ext} from Step 8, i.e. $Y_{total} = Y_{ATB} + Y_{ext}$

11. Total repetitions are obtained by multiplying the dry condition traffic rate by the total life. For example:

$$\text{Total 5kEWL} = \left(\frac{5\text{kEWL}_{dry}}{yr}\right)\left(Y_{total}\right)$$

$$\text{Total Commercials} = \left(\frac{\text{Commercials Dry}}{yr}\right)\left(Y_{total}\right)$$

II. Estimation of Pavement Life Expectancy using Laboratory Specimens

1. Obtain in-place pavement layer thicknesses, full value substitution values, soil support (R-value), and regional factor. Calculate in-place gravel equivalent, divide by the regional factor and obtain the unadjusted gravel equivalent.

2. For a 20 year design life calculate the Traffic Index for the dry stage using the following equation.

$$TI = \frac{C^{0.2}\ T}{0.0058\ (100-R)}$$

Where

T = thickness, in feet (from step 1)

R = resistance value (soil support from Step 1)

C = cohesiometer value (normally taken as 20)

3. From laboratory tests, obtain the vacuum saturated and accelerated conditioned STS ratios for the asphalt concrete.

4. Using substitution ratio = 1.3 for 100% stripped asphalt concrete plant mix, and 1.1 for 100% stripped ATB along with a substitution ratio of 2.0 for 0% stripped (dry) asphalt concrete plant mix and 1.75 for 0% stripped (dry) ATB, calculate the substitution ratios for the asphalt treated layers (plant mix and ATB) for vacuum saturation and for wet accelerated condition. Use the STS ratios to determine the amount of cohesion lost due to stripping.

5. Using the place pavement thickness, the substitution ratios for the vacuum saturation and for wet accelerated condition, soil support and regional factor, calculate the in-place gravel equivalencies for

vacuum saturation and the wet accelerated condition. Divide by the regional factor to get the unadjusted gravel equivalent for each of the two moisture stages.

6. Using the equation in Step 2 and the thicknesses from Step 5, calculate Traffic Indices for each of the two moisture stages (vacuum saturated and wet accelerated conditioned).

Note: If any of the TIs (dry, vac. sat. or accel. cond.) are greater than 12.0 let $TI_{dry} = 12.0$ with TI_{vs} and TI_{AC} proportionately less.

7. Using the following equations calculate the traffic rates for dry, vacuum saturated and wet accelerated conditioned stages.

$$\frac{5kEWL}{yr} = \frac{1}{20} \left(\frac{TI}{1.3}\right)^{8.3333}$$

$$\frac{\text{Commercials}}{yr} = 8.928 \times 10^{-4} \, (TI)^{8,34934}$$

9. (a) Assuming that the pavement is in a dry stage for 2 years, a vacuum saturated stage for the next 8 years and an accelerated conditioned stage after that, solve the following cumulative damage equation for Y_{ac}, where Y_{ac} = years in accel. cond. stage.

$$1 = \frac{(2)\ \text{Dry Rate}}{(20)\ \text{Dry Rate}} + \frac{(8)\ \text{Dry Rate}}{(20)\ \text{Vac. Sat. Rate}} + \frac{(Y_{ac})\ \text{Dry Rate}}{(20)\ \text{Accel. Cond. Rate}}$$

(b) Calculate Y_{total} = 2 yrs. + 8 yrs. + Y_{ac}

Note: If Y_{ac} in Step 9 is negative this indicates that the pavement fails before it reaches the accelerated conditioned stage. In this case solve the following cumulative damage equation for Y_{vs}, i.e. substitute Y_{vs} for 8 yrs. and let $Y_{ac} = 0$ such that

$$\frac{(2)\ \text{Dry Rate}}{(20)\ \text{Dry Rate}} + \frac{Y_{vs}\ (\text{Dry Rate})}{20\ \text{Vac. Sat. Rate}} = 1$$

$$Y_{total} = 2 + Y_{vs}$$

10. The total number of repetitions to roughness failure are found by multiplying the dry yearly rate by the total life in years. For example:

$$\text{Total 5kEWL} = \left(\frac{5\text{kEWL}_{Dry}}{yr}\right)(Y_{total})$$

$$\text{Total Commercials} = \left(\frac{\text{Commercials}_{Dry}}{Yr}\right)(Y_{total})$$

APPENDIX B

USE OF FATIGUE TEST DATA TO CALCULATE PAVEMENT LIFE BY MECHANISTIC METHODS

I. Determination of Life Expectancy for an Existing Pavement Using Field Cores.

1. From laboratory tests obtain the resilient modulus (M_R) values for the asphalt concrete in the vacuum saturated stage.
2. Obtain pavement cross sectional profiles.
3. The vac. sat. M_R is used with the appropriate values from the table below in the Chevron 5L computer program to solve for radial stresses and strains at the bottom of the plant mix for the 5 kip equivalent wheel load.

Layer	M_R (psi)	Poissons Ratio
Plant Mix	(as tested)	.30
ATB	70,000	.35
AGG Base	20,000	.35
Granular Borrow	14,000	.35
Subgrade	14,000	.40

4. From laboratory fatigue test data on vac. sat. cores, construct the fatigue lines - log life (repetitions) vs. log stress (strain).
5. Using the vacuum saturated stresses (strains) from the Chevron 5L program, enter the fatigue lines and obtain the corresponding lives.

6. Obtain estimates of past and future Traffic Indices. From these, calculate the past and future yearly traffic rates for 5 kip equivalent wheel loads and commercial vehicles using the following equations.

$$\frac{5kEWL}{yr} = \frac{1}{20}\left(\frac{TI}{1.3}\right)^{8.3333}$$

$$\frac{Commercials}{Yr} = 8.928 \times 10^{-4}\ (TI)^{8.34934}$$

7. The extended life in the vacuum saturated stage is then calculated by dividing the vacuum saturated life (from fatigue graph) by the future yearly traffic rate.

$$Y_{ext} = \frac{\text{Life vs}}{\text{vac. sat. rate}}$$

8. Estimate the age of the pavement, Y_{ATB}, when the asphalt concrete under layer (i.e. ATB) is cracked, but the plant mix is not, or obtain this information from field dynaflect measurement increase.

9. Total life to first cracking of the plant mix is the sum of Y_{ATB} from step 8 and Y_{ext} from step 7.

$$Y_{total} = Y_{ATB} + Y_{ext}.$$

10. Total repetitions are obtained by multiplying Y_{ATB} by the past yearly traffic rate and adding this to Y_{ext} multiplied by the future yearly traffic rate:

$$\text{Total 5kEWL} = Y_{ATB}\ \frac{5kEWL\ (past)}{yr} + \frac{Y_{ext}\ 5kEWL\ (Future)}{yr}$$

$$\text{Total Commercials} = Y_{ATB}\ \frac{Comm\ (past)}{yr} + \frac{Y_{ext}\ Comm\ (Future)}{yr}$$

II. Estimation of Pavement Life Expectancy Using Laboratory Specimens

1. From laboratory tests obtain the resilient modulus (M_R) values for the asphalt concrete in the dry, vacuum saturated and wet accelerated conditioned stages. Also obtain thicknesses of the pavement and base courses from the pavement profile.

2. Using the Chevron 5L Computer program, obtain the radial bending stresses and strains at the bottom of the ATB and plant mix layers. Since both stress and strain are dependent upon the modulus, three different values of stress and strain must be calculated corresponding to the dry, vacuum saturated and accelerated conditioned M_R values obtained from lab testing.

   In computing the stress (strain) at the bottom of the ATB the M_R of the ATB itself is unknown. For estimation, the M_R of the ATB is equal to one half of the M_R of the plant mix. When calculating the stress (strain) at the bottom of the plant mix when the ATB is cracked, then the M_R of the ATB is reduced to 70,000.

   The table below summarizes the M_R and Poisson's ratio values used.

Layer	M_R (psi)	Poisson's Ratio
Plant Mix	From lab test Dry. vac. sat. accel. cond.	.30
ATB (not cracked)	1/2 lab M_R	.35
ATB (cracked)	70,000	.35
Agg. Base	20,000	.35
Granular Borrow	14,000	.35
Subgrade	14,000	.40

3. With the fatigue life data obtained from the lab tests, construct a graph of log stress (strain) vs. log life (repetitions) for the dry, vacuum saturated and accelerated conditioned stages. (Note: the vacuum saturated fatigue line may be interpolated between the dry and accelerated conditioned lives using STS ratios for stress fatigue and M_R ratios for strain fatigue).

4. Using the stresses (or strains) from the Chevron 5L program (Step 2) enter the fatigue lines and obtain the lives (repetitions) for the dry, vacuum saturated, and accelerated conditioned stages.

5. Obtain field estimates of past and future Traffic Indices along with the future predicted life (yrs.). Using this information calculate the mean observed TI (TI ave.) using the following equation.

$$TI_{ave.} = \frac{(\text{Present Age})(\text{Past TI}) + (\text{Predicted Life})(\text{Future TI})}{\text{Present Age} + \text{Predicted Life}}$$

6. Using $TI_{ave.}$, the traffic rates for 5 kip equivalent wheel loads and commercial vehicles are calculated for heavy traffic:

$$\frac{5kEWL}{yr} = \frac{1}{20}\left(\frac{TI}{1.3}\right)^{8.3333}$$

$$\frac{\text{Commercials}}{yr} = 8.928 \times 10^{-4}\ (TI)^{8.34934}$$

7. Assuming that the ATB will remain dry for 2 years, then be in the vacuum saturated stage for the next 8 years, then be in the accelerated conditioned stage after that, solve the cumulative damage equation for Y_{ac} :
ATB

$$\frac{(2)(\text{Rate})}{\text{Life}_{\substack{\text{Dry}\\\text{ATB}}}} \quad \frac{(8)(\text{Rate})}{\text{Life}_{\substack{\text{vs}\\\text{ATB}}}} \quad \frac{(Y_{ac})(\text{Rate})}{\text{Life}_{\substack{ac\\\text{ATB}}}} = 1$$

Where - $Y_{\substack{ac\\\text{ATB}}}$ is the number of years in the accelerated conditioned stage.

- Rate is from Step 6

- Lives are from Step 4

$$Y_{ATB} = 2 + 8 + Y_{\substack{ac\\\text{ATB}}}$$

<u>Note</u>: If you're only considering the life of the plant mix, Step 7 will be omitted and the cumulative damage equation will be:

$$\frac{(2)(\text{Rate})}{\text{Life}_{\substack{\text{Dry}\\\text{PM}}}} \quad \frac{(8)(\text{Rate})}{\text{Life}_{\substack{\text{vs}\\\text{PM}}}} \quad \frac{(Y_{\substack{ac\\\text{DM}}})(\text{Rate})}{\text{Life}_{\substack{ac\\\text{PM}}}} = 1$$

8. Solve for the extended life of the plant mix, $Y_{\substack{ac\\\text{PM}}}$, using the following cumulative damage equation.

$$\frac{(Y_{\substack{ac\\\text{PM}}})(\text{Rate})}{\text{Life}_{\substack{ac\\\text{PM}}}} = 1$$

$$Y_{DM} = Y_{\substack{ac\\\text{DM}}}$$

<u>Note</u>: If $Y_{\substack{ac\\\text{ATB}}}$ from Step 7 is negative, first cracking occurs during the vacuum stage and the cumulative damage equations are:

$$\frac{(2)(\text{Rate})}{\text{Life}_{\substack{\text{Dry}\\\text{ATB}}}} + \frac{Y_{\substack{ac\\\text{ATB}}}(\text{Rate})}{\text{Life}_{\substack{\text{vs}\\\text{ATB}}}} = 1$$

$$Y_{ATB} = 2 + Y_{\substack{vs \\ ATB}}$$

$$\frac{Y_{\substack{vs \\ PM}} \text{ (Rate)}}{\text{Life}_{\substack{vs \\ PM}}} = 1$$

$$Y_{PM} = Y_{\substack{vs \\ DM}}$$

9. Total predicted life is Y_{total}

$$Y_{total} = Y_{ATB} + Y_{PM}$$

10. The total number of repetitions is calculated by multiplying Y_{total} by the rate.

Total 5KEWL (Y_{total}) (5kEWL Rate)

Total Commericals = (Y_{total}) (Commercial Rate)

APPENDIX C

MECHANICAL PROPERTIES FROM SPLITTING TENSILE STRENGTH AND RESILIENT MODULUS TESTS

AD-53

Pavement

I-84. Source AD-53. MP ≈ 61. Cores drilled from shoulder in spring 1982. Pavement constructed in 1963. Mix was untreated.

Laboratory Specimens

Laboratory specimens fabricated by Boise Lab, ITD June 1982 from fresh materials.

Mechanical Properties from Indicator Tests

Test Specimen Type	Voids (%)	Splitting Tensile Strength at 55°F (psi)[1]					Resilient Modulus at 55°F (1000 psi)[2]				
		Dry	Vac. Sat.	Accel Cond.[3]	Ratios Vac. Sat.	Ratios Accel. Cond.	Dry	Vac. Sat.	Accel. Cond.	Ratios Vac. Sat.	Ratios Accel. Cond.
Pavement Cores (untreated)	5.2	129	109	74	.84	.58	726	653	547	.90	.75
Laboratory Specimens (untreated)	4.2	96	88	71	.91	.74	809	631	549	.78	.65

Notes: [1]Splitting tensile strength deformation rate = .065 in. per min.
[2]Resilient modulus load rate cycle = .1 sec. load, 1.9 sec. no load.
[3]Light stripping in cores; moderate stripping in lab specimens.

BK-142 s

Pavement

I-15. Source BK-142's. MP ≈ 65. Cores drilled in spring 1982. Pavement constructed in 1965. Mix was untreated.

Laboratory Specimens

Laboratory specimens fabricated by Boise Lab, ITD, July 1982 from fresh materials. 0.5% liquid antistrip (Acra 500) used for treated mix.

Mechanical Properties from Indicator Tests

Test Specimen Type	Voids (%)	Splitting Tensile Strength at 55°F (psi)[1]					Resilient Modulus at 55°F (1000) psi)[2]				
		Dry	Vac. Sat.	Accel Cond.[3]	Ratios Vac. Sat.	Ratios Accel Cond.	Dry	Vac. Sat.	Accel Cond.	Ratios Vac. Sat.	Ratios Accel Cond.
Pavement Cores (untreated)	3.7	95	58	42	.61	.45	1,211	675	370	.56	.31
Laboratory Specimens (untreated)	4.4	105	89	56	.85	.54	805	691	502	.86	.62
Laboratory Specimens (liq. antistrip)	4.1	99	84	64	.85	.65	770	693	471	.90	.61

Notes: [1]Splitting tensile strength deformation rate = 0.65 in. per min.

[2]Resilient modulus load rate cycle = .1 sec. load, 1.9 sec. no load.

[3]Heavy stripping in cores; heavy stripping in untreated lab specimens; light stripping in liq. antistrip treated specimens.

GD-56

Pavement

I-84. Source GD-56. MP ≈ 160. Cores drilled from east bound lane in spring 1982. Pavement is 9.5 years old. Mix was treated with 1% hydrated lime.

Laboratory Specimens

Laboratory specimens were fabricated by Boise Lab, ITD, September-October 1982 from fresh materials. One set was untreated; one set was treated with lime at 1% to match the cores; and the third set was treated with 0.50% liquid antistrip (Acra 500).

Mechanical Properties from Indicator Tests

Test Specimen Type	Voids (%)	Splitting Tensile Strength at 55°F (psi)[1]					Resilient Modulus at 55°F (1000 psi)[2]				
		Dry	Vac. Sat.	Accel Cond.[3]	Ratios Vac. Sat.	Ratios Accel Cond.	Dry	Vac. Sat.	Accel Cond.	Ratios Vac. Sat.	Ratios Accel Cond.
Pavement Cores (treated)	0.8	178	169	161	.95	.90	1174	1247	1245	1.06	1.06
Lab Specimens (untreated)	4.8	114	107	98	.94	.86	1015	888	808	.87	.80
Lab Specimens (Lime)	4.3	118	101	112	.86	.95	1007	839	991	.83	.98
Lab Specimens (liq. antistrip)	5.2	120	101	98	.84	.82	1053	835	818	.79	.78

Notes: [1]Splitting tensile strength deformation rate = .065 in. per minutes.
[2]Resilient modulus load rate cycle = .1 sec. load, 1.9 sec. no load.
[3]No stripping in cores; no stripping in lab specimens, but some aggregate fracture.

CS-147

Pavement

I-84. Source CS-147. MP ≈ 253. Cores drilled from west bound lane in spring 1982. Pavement is 12 years old. Mix was untreated.

Laboratory Specimens

Laboratory specimens were fabricated by Boise Lab, ITD, November-December 1982 from fresh materials. One set was untreated; one set was treated with 0.50% liquid antistrip (Acra 500).

Mechanical Properties from Indicator Tests

Test Specimen Type	Voids (%)	Splitting Tensile Strength at 55°F (psi)[1]					Resilient Modulus at 55°F (1000 psi)[2]				
		Dry	Vac. Sat.	Accel Cond.[3]	Ratios Vac. Sat.	Ratios Accel Cond.	Dry	Vac. Sat.	Accel Cond.	Ratios Vac. Sat.	Ratios Accel. Cond.
Pavement Cores (untreated)	3.2	166	130	120	.83	.72	1656	1482	1246	.89	.75
Lab Specimens (untreated)	3.7	115	114	68	.99	.59	936	880	503	.94	.54
Lab Specimens (liq. antistrip)	6.9	106	98	87	.92	.82	885	726	646	.82	.73

Notes: [1]Splitting tensile strength deformation rate = .065 in. per minute.
[2]Resilient modulus load rate cycle = .1 sec. load, 1.9 sec. no load.
[3]Extremely light stripping in cores; moderate stripping in nontreated lab specimens; some aggregate fracture.
Extremely light stripping in treated lab specimens; some aggregate fracture.

APPENDIX D

FATIGUE LINES FOR PAVEMENT CORES AND LABORATORY SPECIMENS AT 55°F

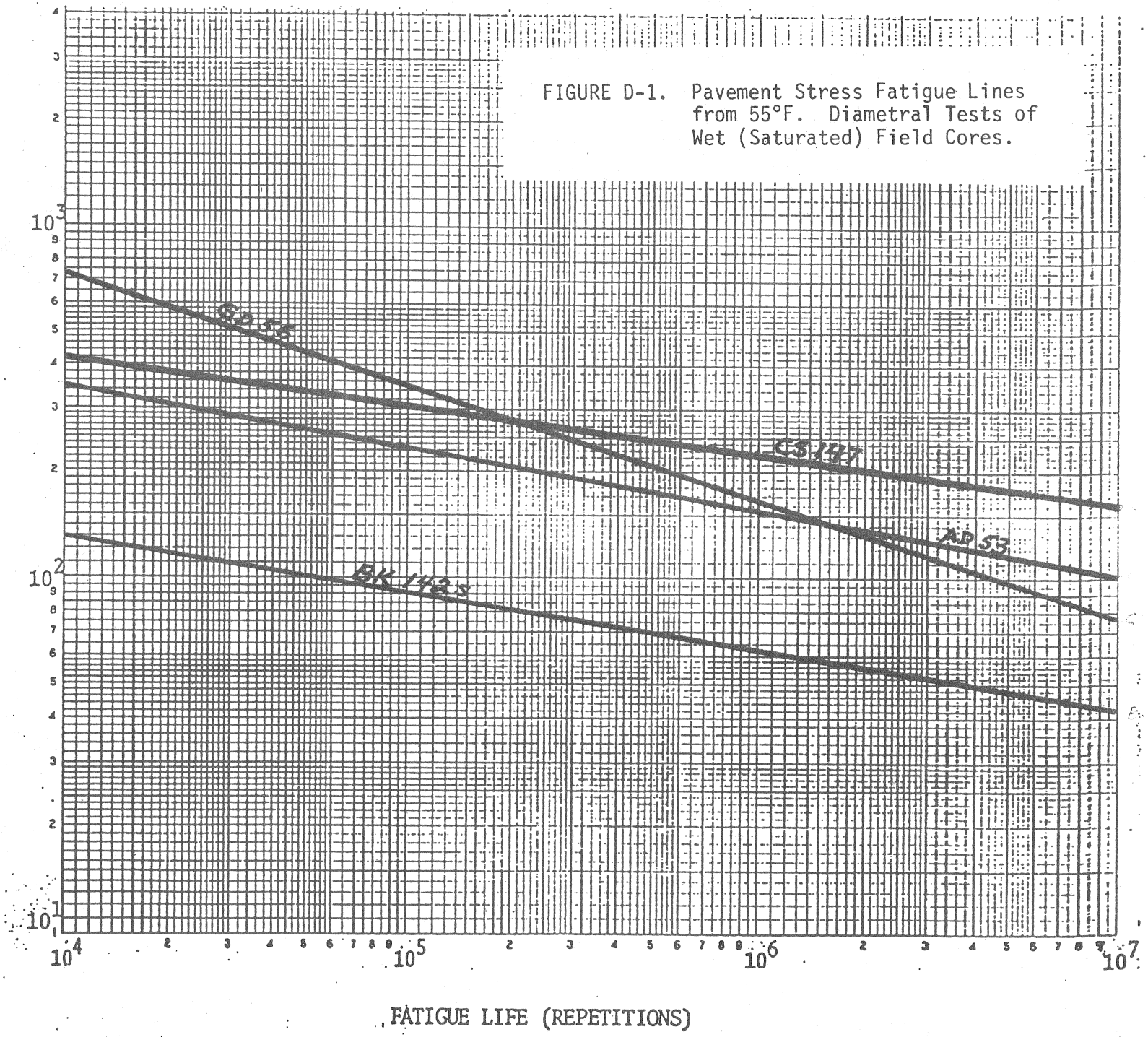

FIGURE D-1. Pavement Stress Fatigue Lines from 55°F. Diametral Tests of Wet (Saturated) Field Cores.

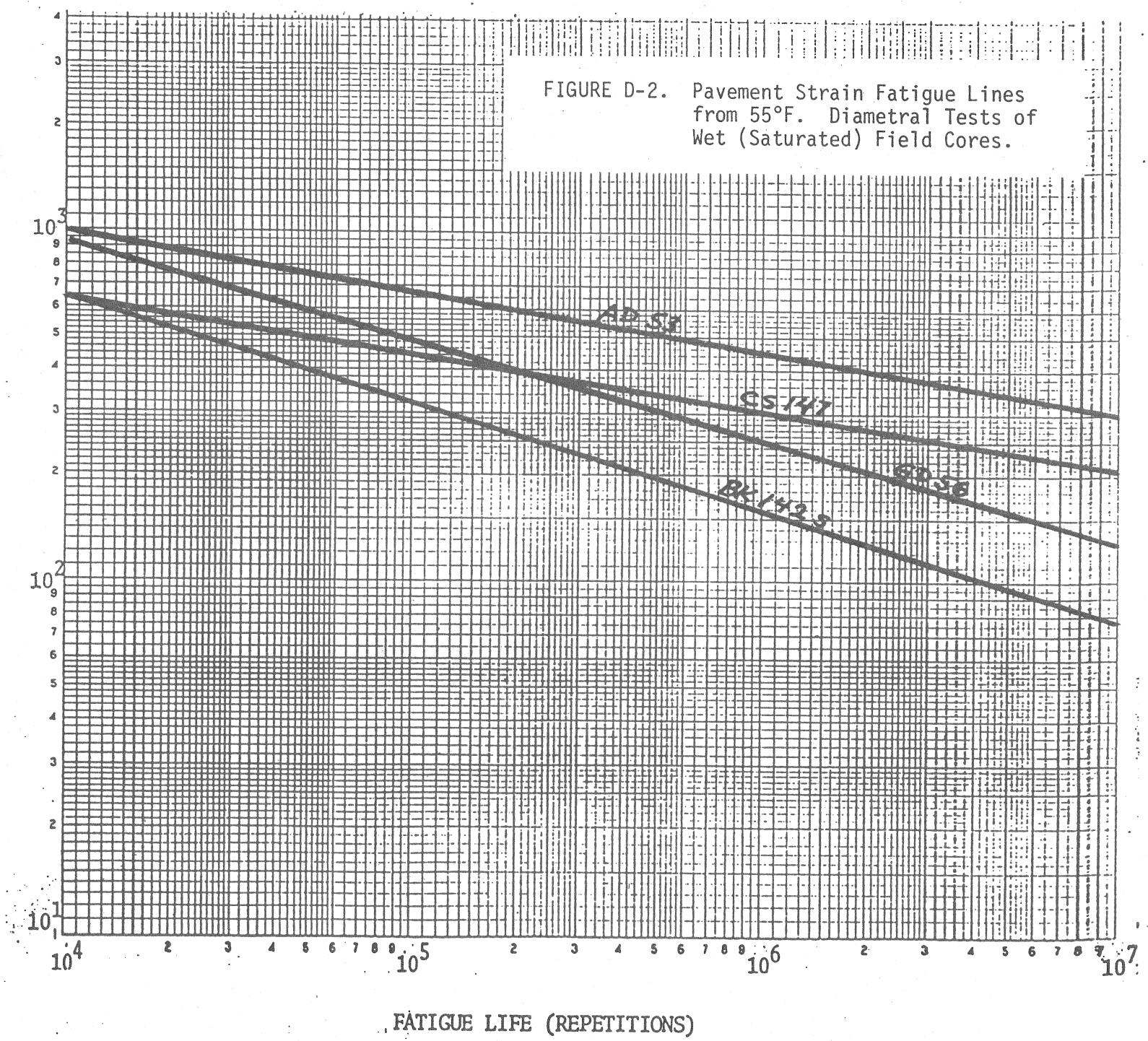

FIGURE D-2. Pavement Strain Fatigue Lines from 55°F. Diametral Tests of Wet (Saturated) Field Cores.

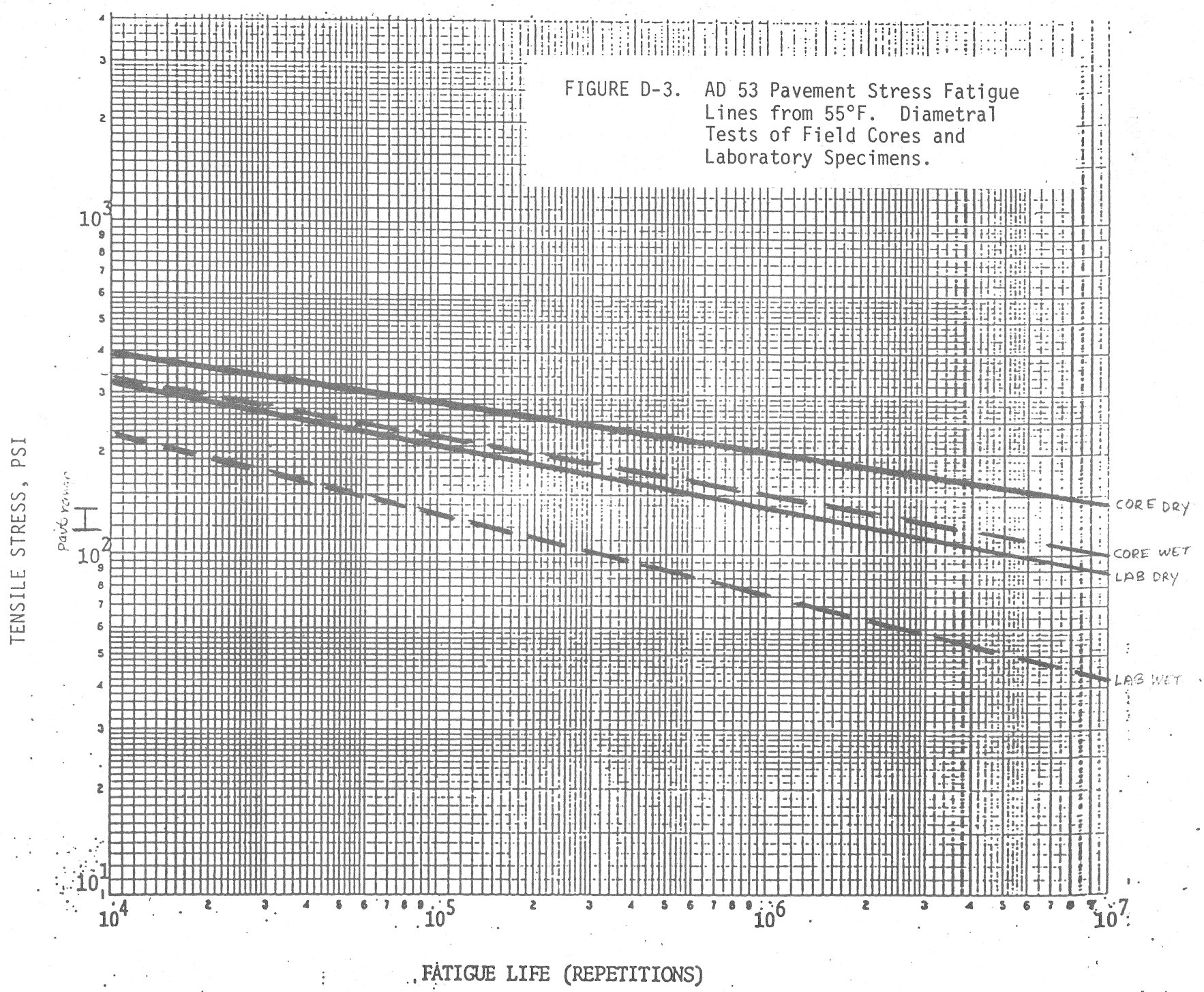

FIGURE D-3. AD 53 Pavement Stress Fatigue Lines from 55°F. Diametral Tests of Field Cores and Laboratory Specimens.

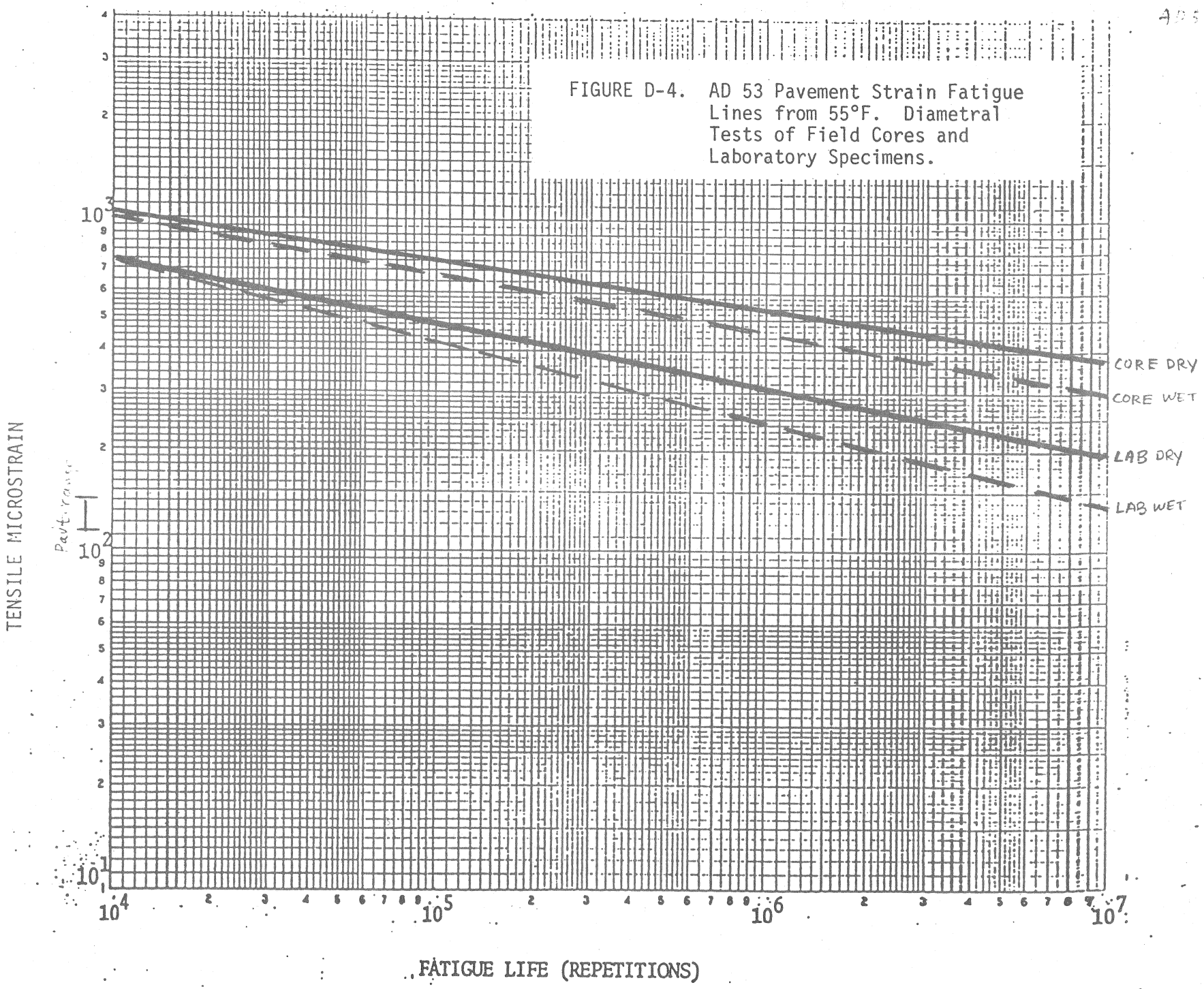

FIGURE D-4. AD 53 Pavement Strain Fatigue Lines from 55°F. Diametral Tests of Field Cores and Laboratory Specimens.

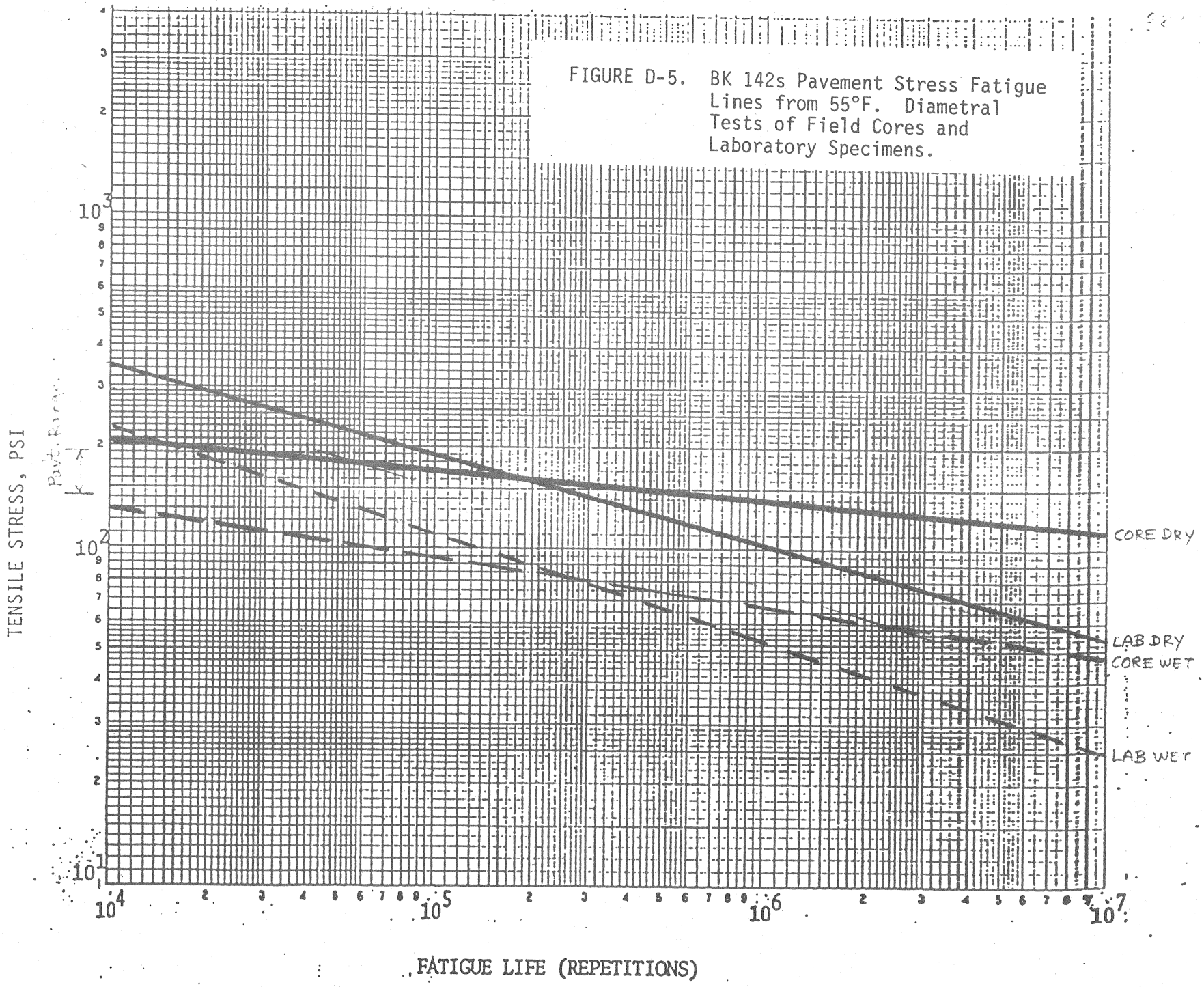

FIGURE D-5. BK 142s Pavement Stress Fatigue Lines from 55°F. Diametral Tests of Field Cores and Laboratory Specimens.

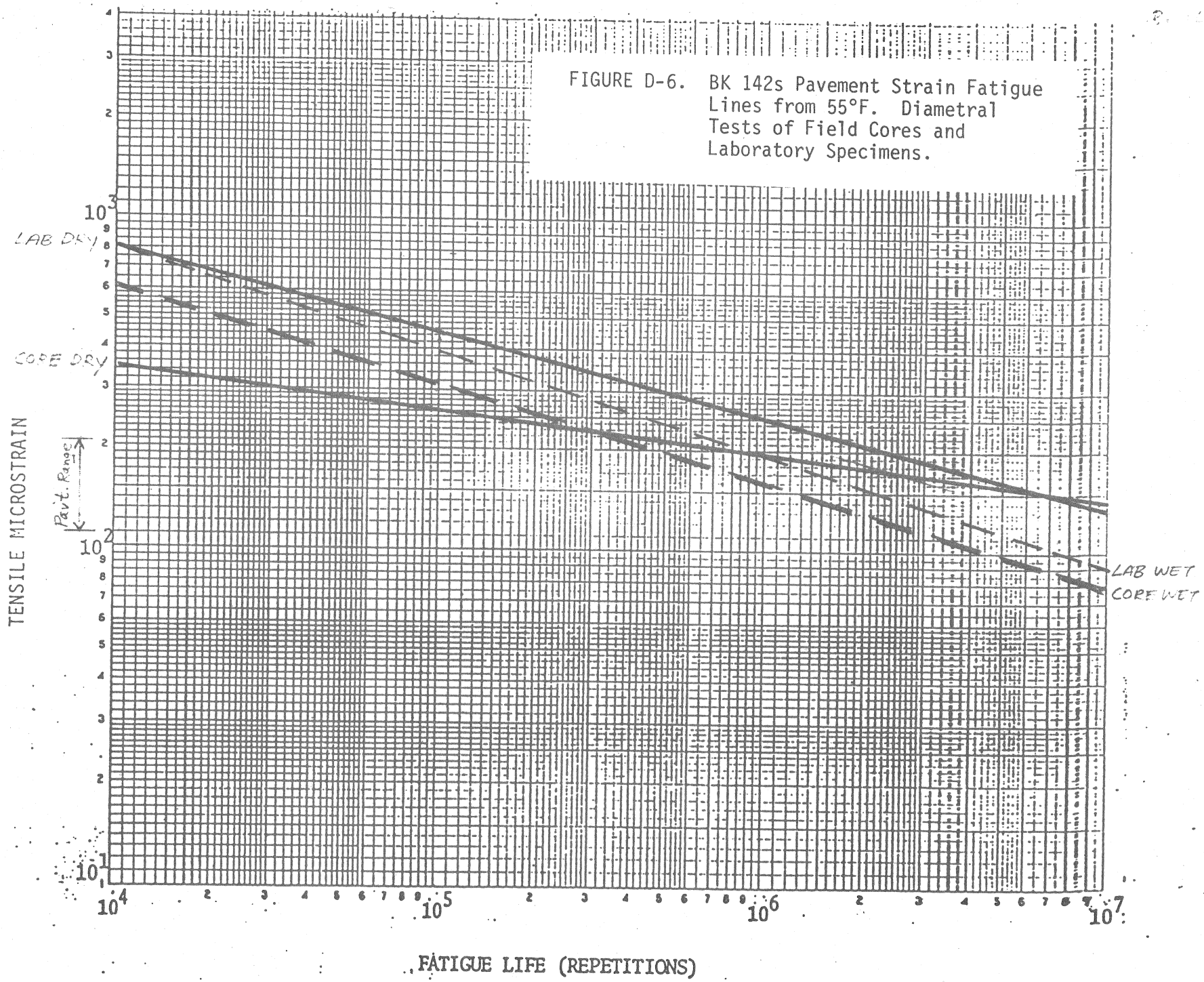

FIGURE D-6. BK 142s Pavement Strain Fatigue Lines from 55°F. Diametral Tests of Field Cores and Laboratory Specimens.

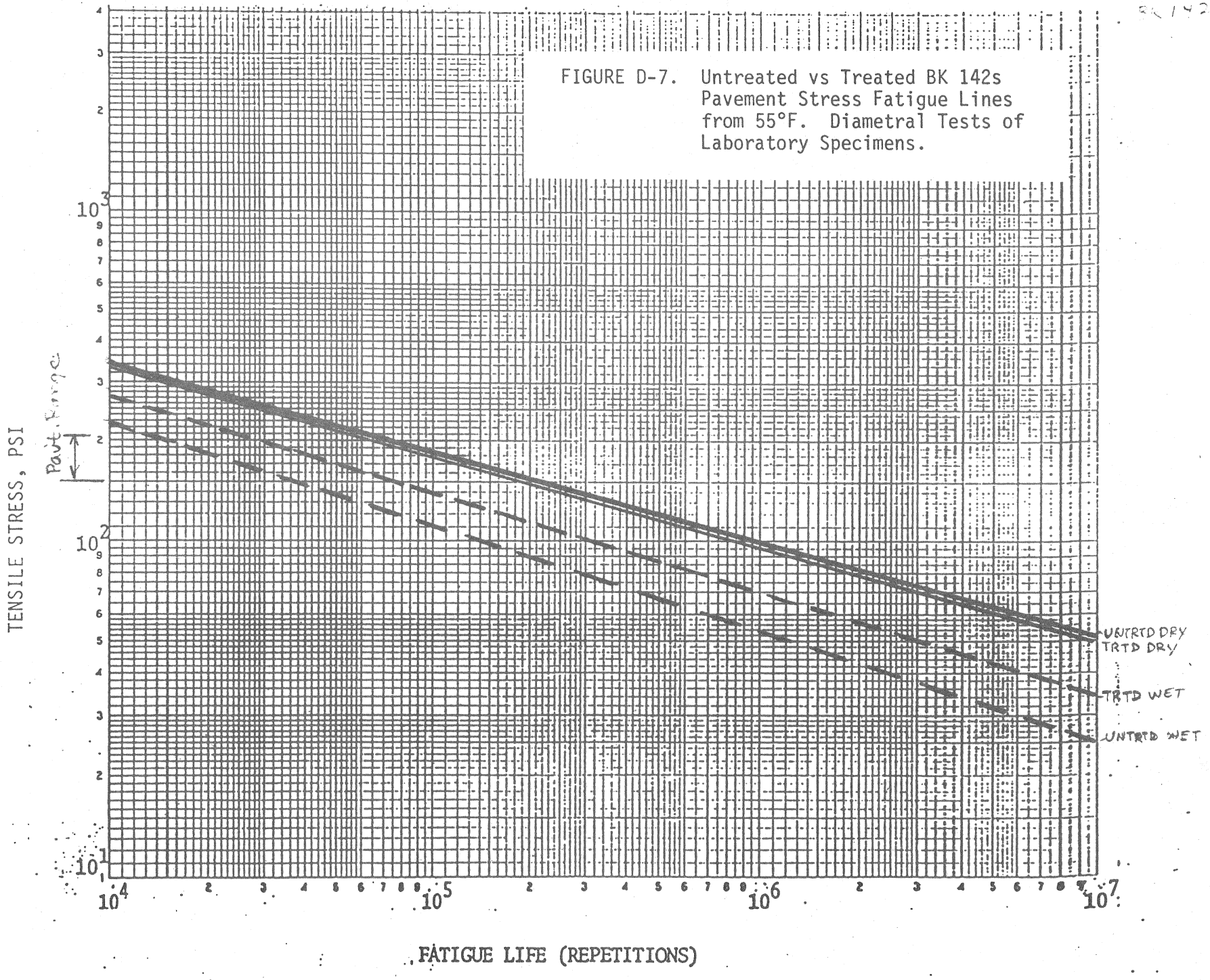

FIGURE D-7. Untreated vs Treated BK 142s Pavement Stress Fatigue Lines from 55°F. Diametral Tests of Laboratory Specimens.

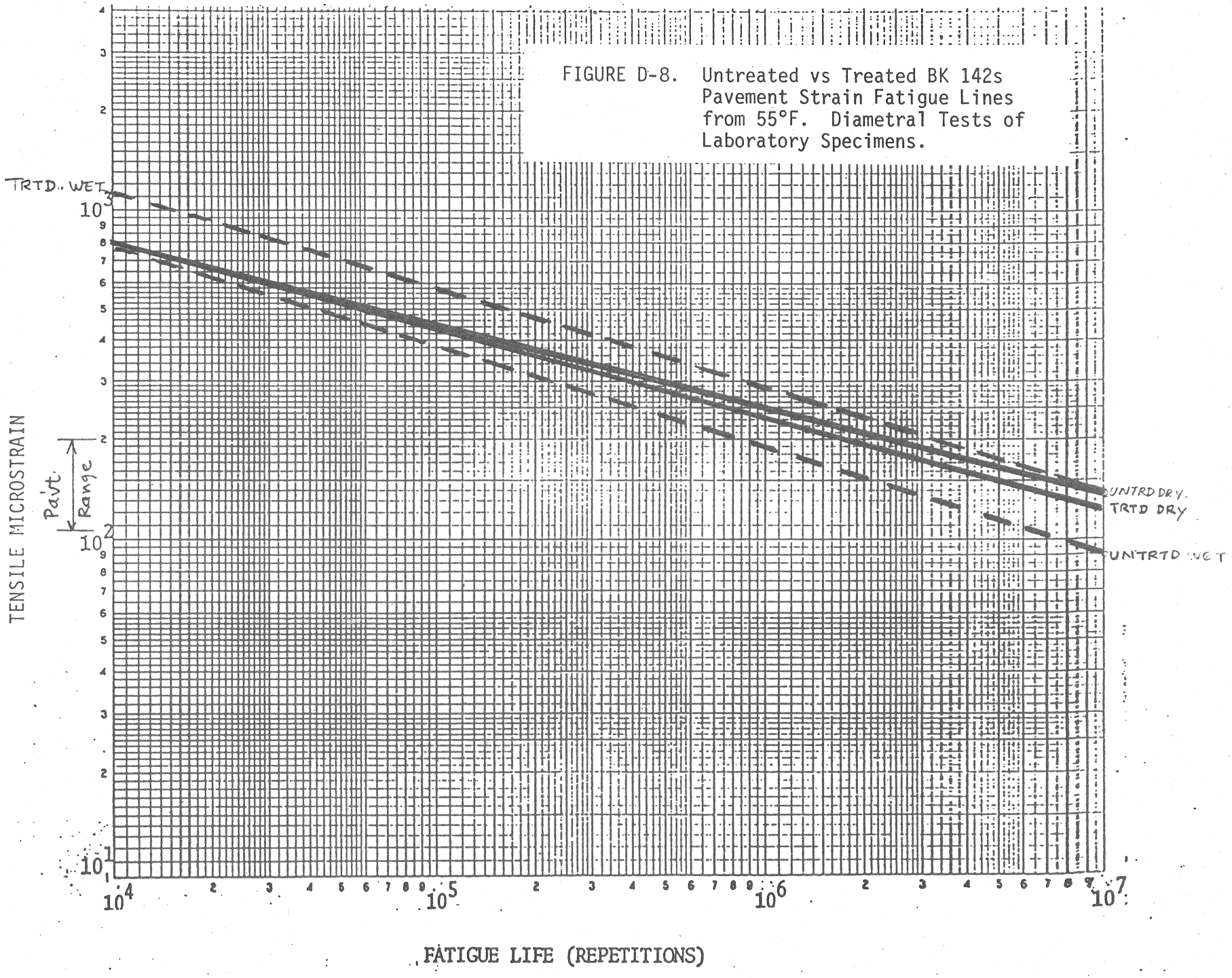

FIGURE D-8. Untreated vs Treated BK 142s Pavement Strain Fatigue Lines from 55°F. Diametral Tests of Laboratory Specimens.

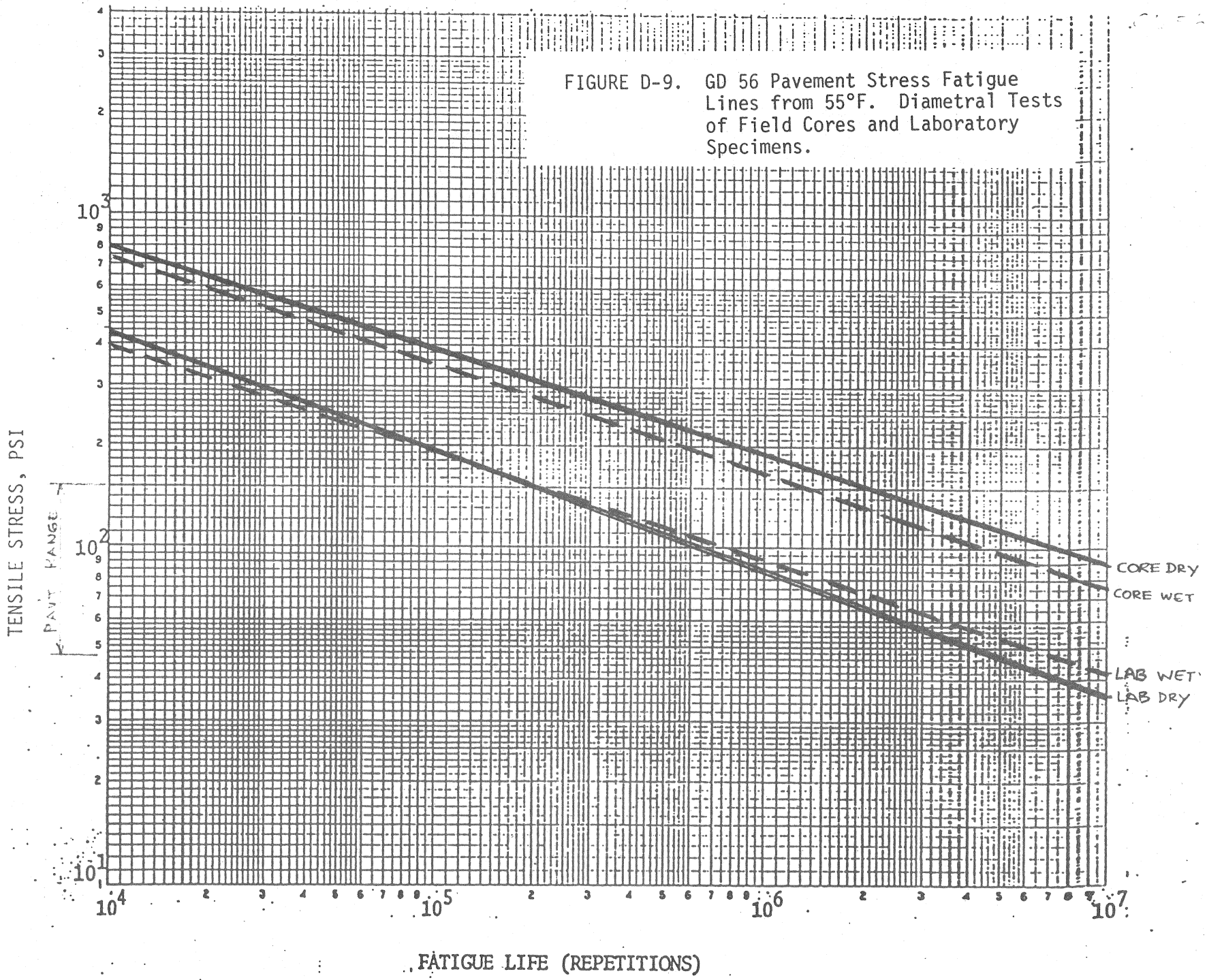

FIGURE D-9. GD 56 Pavement Stress Fatigue Lines from 55°F. Diametral Tests of Field Cores and Laboratory Specimens.

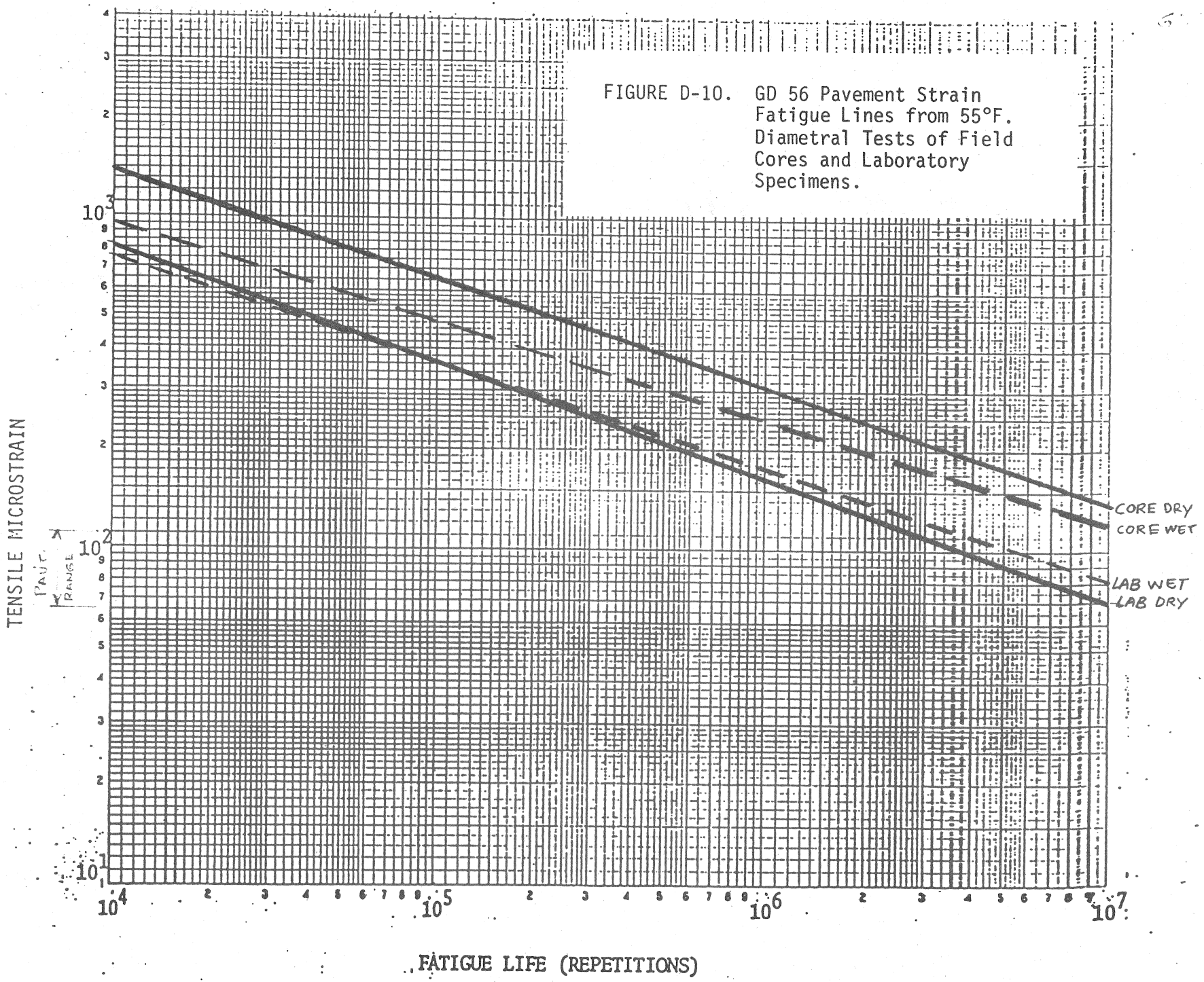

FIGURE D-10. GD 56 Pavement Strain Fatigue Lines from 55°F. Diametral Tests of Field Cores and Laboratory Specimens.

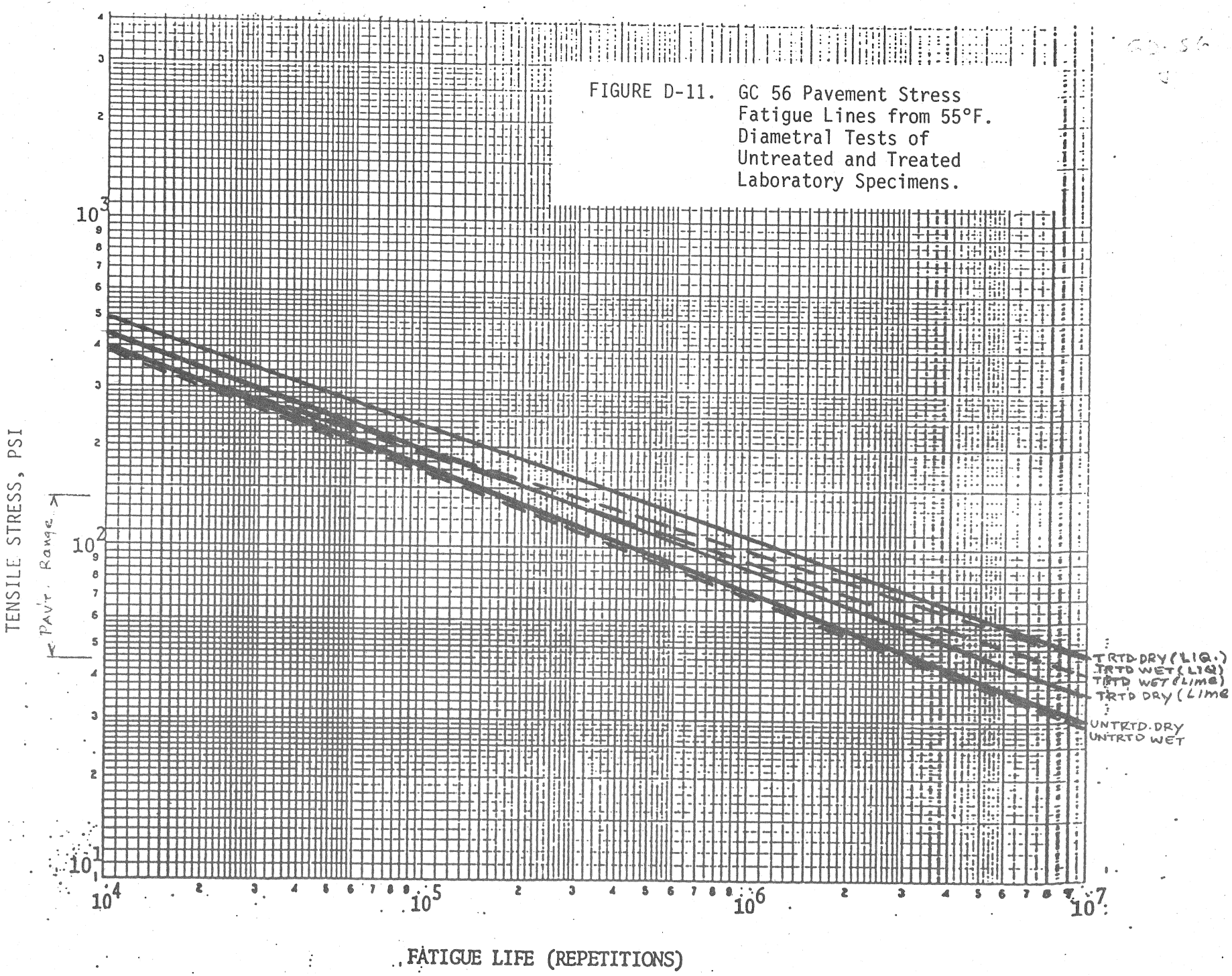

FIGURE D-11. GC 56 Pavement Stress Fatigue Lines from 55°F. Diametral Tests of Untreated and Treated Laboratory Specimens.

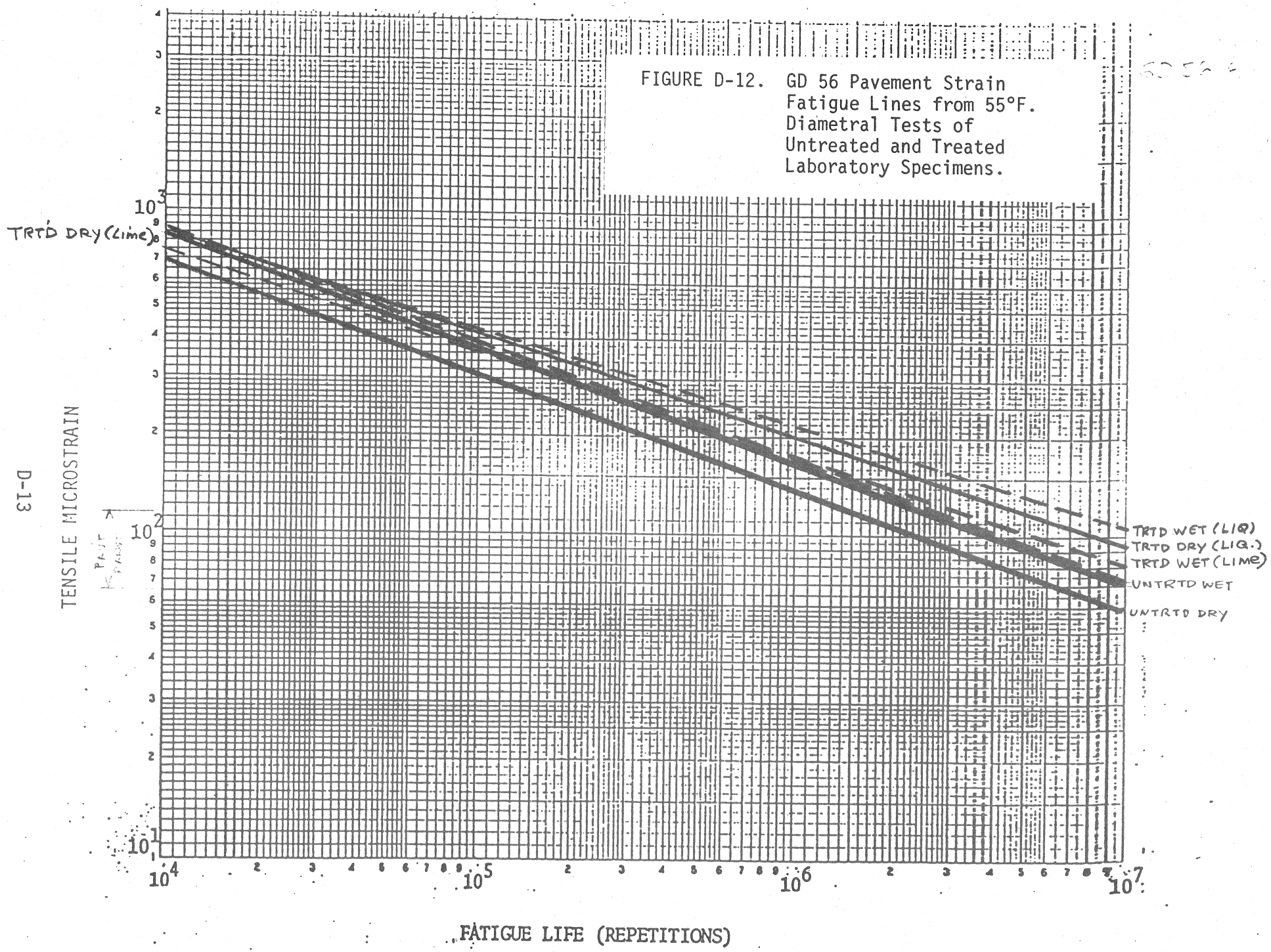

FIGURE D-12. GD 56 Pavement Strain Fatigue Lines from 55°F. Diametral Tests of Untreated and Treated Laboratory Specimens.

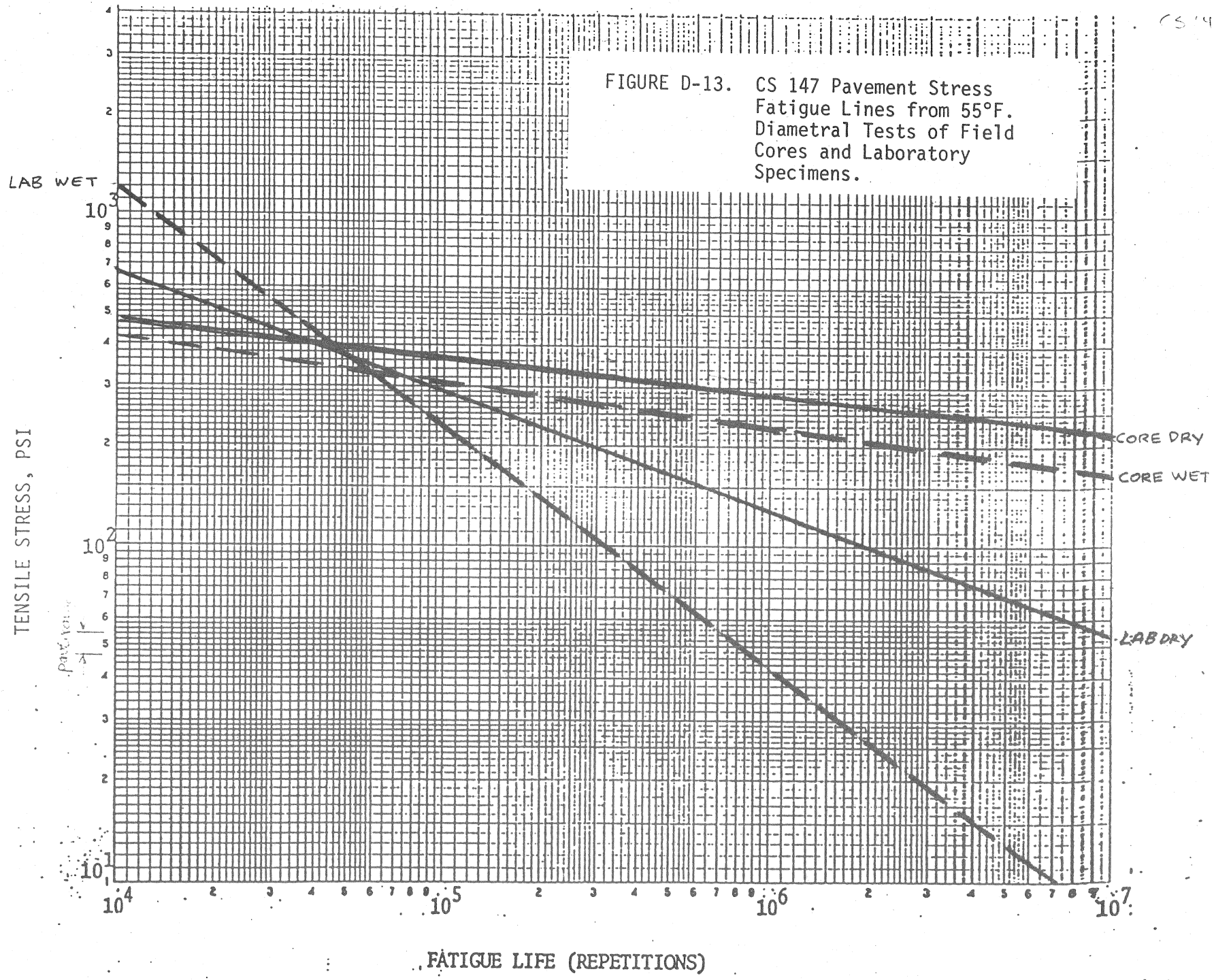

FIGURE D-13. CS 147 Pavement Stress Fatigue Lines from 55°F. Diametral Tests of Field Cores and Laboratory Specimens.

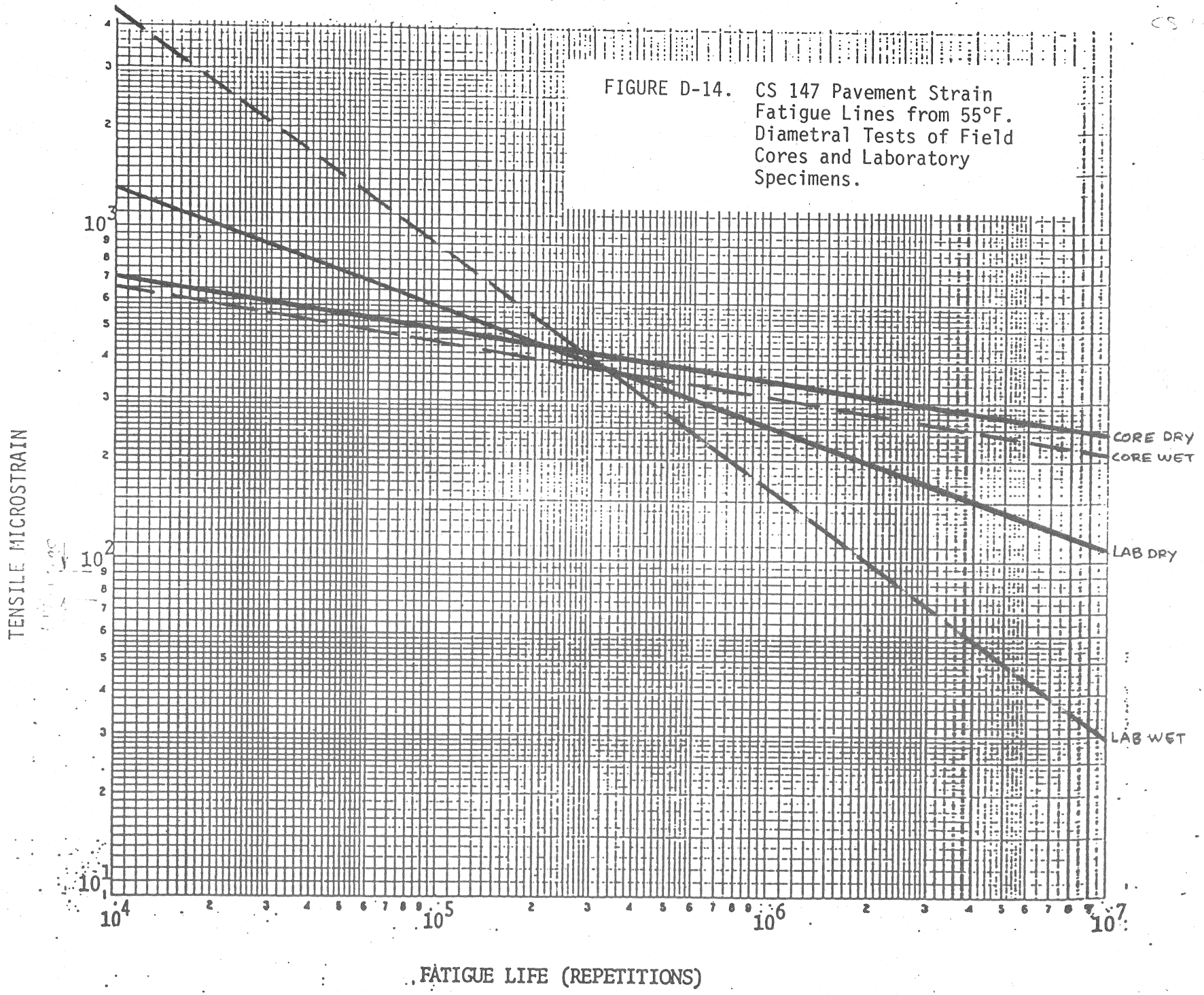

FIGURE D-14. CS 147 Pavement Strain Fatigue Lines from 55°F. Diametral Tests of Field Cores and Laboratory Specimens.

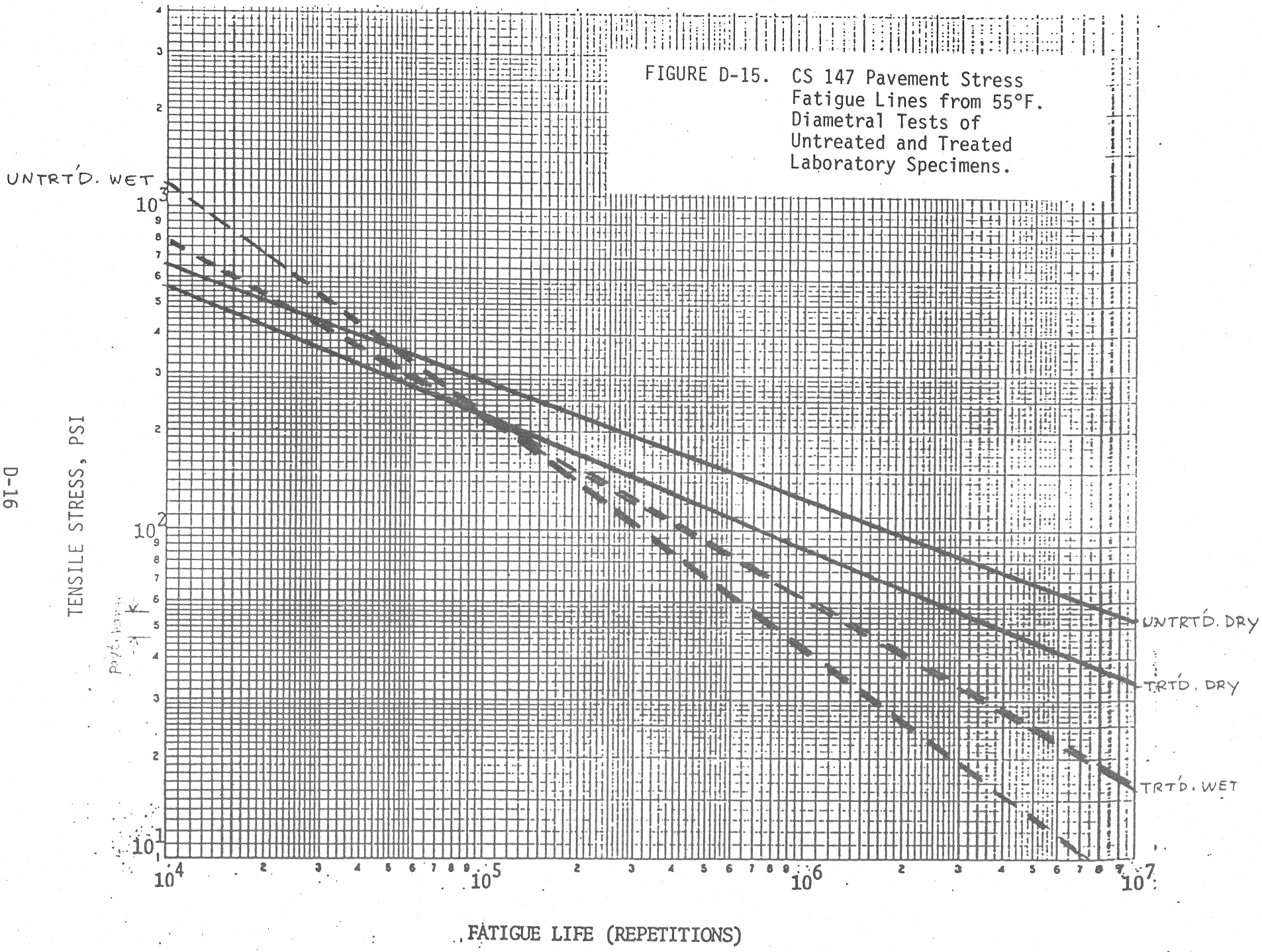

FIGURE D-15. CS 147 Pavement Stress Fatigue Lines from 55°F. Diametral Tests of Untreated and Treated Laboratory Specimens.

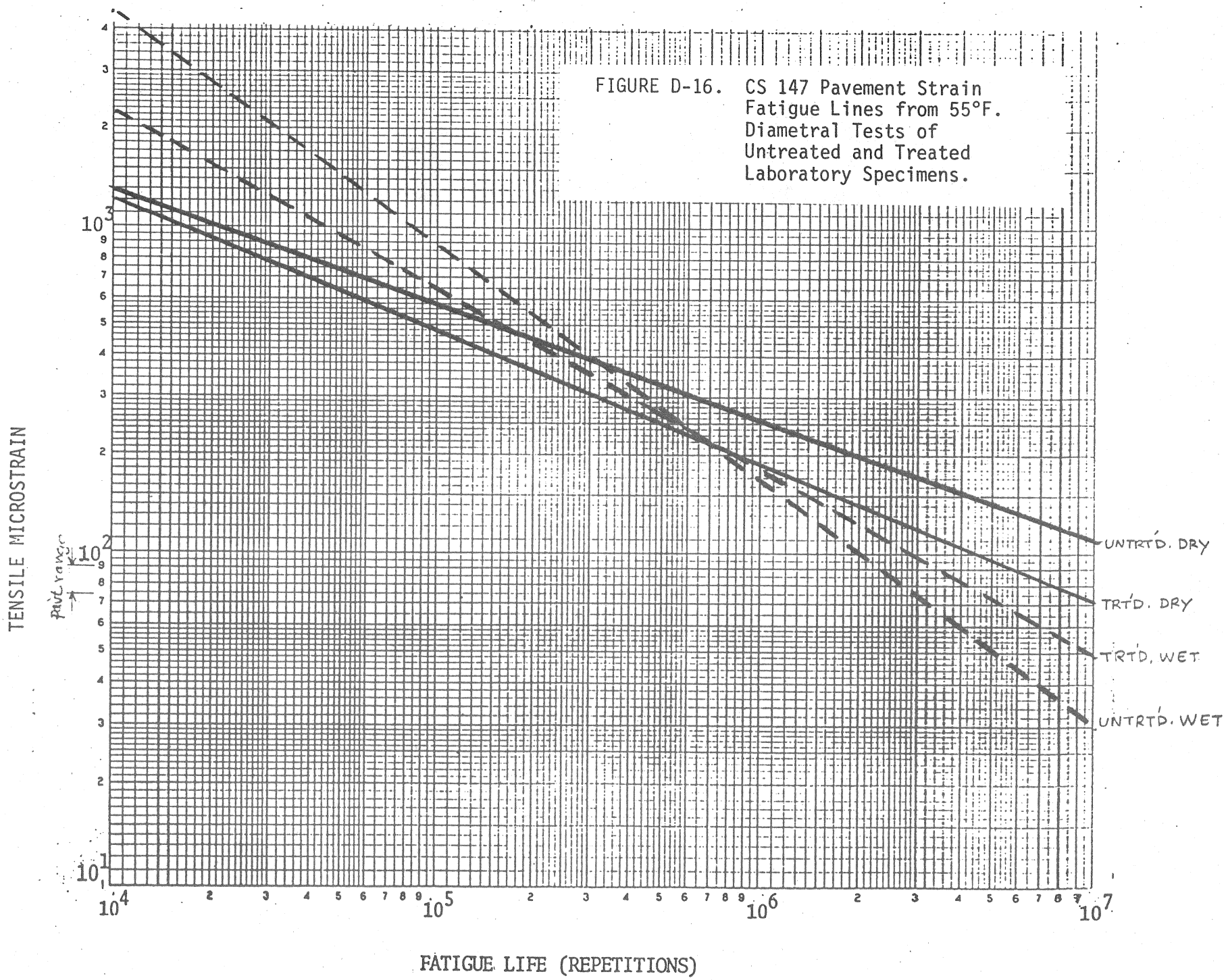

FIGURE D-16. CS 147 Pavement Strain Fatigue Lines from 55°F. Diametral Tests of Untreated and Treated Laboratory Specimens.