A COMPARISON OF THE IDAHO AND CALIFORNIA METHODS OF EVALUATING AGGREGATE DEGRADATION

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Moscow Laboratory
and
Districts No. 2, 4, 5 and 6

State of Idaho
DEPARTMENT OF HIGHWAYS
Boise, Idaho

ACKNOWLEDGEMENTS

This study was initiated by the Research Engineer in cooperation with the Materials Engineer to compare the results of the Idaho degradation test with those of the California degradation test.

The samples were obtained from the different districts under the direction of the respective District Materials Engineers. Mr. Martin A. Hill, Engineering Aide, performed the tests on the samples in the Moscow Laboratory under the supervision of Mr. Dick O. Sanchez, Engineering Technician VIII. The report was prepared by Mr. Terry R. Howard, Engineering Aide, reviewed initially by Mr. H. L. Day, P.E., Materials Engineer, edited by Mr. William A. Sylvies, P.E., Associate Materials Engineer, and approved by Mr. L. F. Erickson, P.E., Research and Materials Engineer.

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A COMPARISON OF THE IDAHO AND CALIFORNIA METHODS OF EVALUATING AGGREGATE DEGRADATION

INTRODUCTION

At the present time the Idaho Department of Highways does not have a standard specification governing potential degradation of aggregate to be used in highway construction. Aggregates are tested using the Idaho degradation test and the results are plotted on the chart shown in Appendix "F". Zones "A" and "C" of the chart indicate undesirable material while Zone "B" depicts material acceptable for use.

It has thus been proposed that a numerical value be assigned to the results of the Idaho degradation test. Such a number would facilitate interpretation of test results and permit publication of a definite specification controlling potential degradation. It would be particularly valuable during consideration of source change applications because a numerical value representing the degradation test results of the proposed aggregate source could easily be compared with the test value from the original aggregate source.

Twenty aggregate sources throughout the State having degradation potentials ranging from "acceptable" to "undesirable" were selected for evaluation by the Materials Engineer and the Research Engineer. Samples were obtained from each source and sent to the Moscow Laboratory for analysis during the summer of 1965.

Each sample was tested using the California degradation test, the Idaho degradation test with washed aggregate, and the Idaho degradation test with unwashed aggregate to determine whether the tests gave the same final results for the same aggregate sample. If such was the case, then consideration could be given to revising the Idaho degradation test to give a finite numerical value or to substituting the California degradation test in its place.

SUMMARY

Ratings of "good" and "poor" were used to denote material acceptable for use and undesirable material, respectively. The correlation between the ratings of "good" and "poor" as assigned by the two different tests was only fair. There is a wide spread between the values for D_c and D_f for the California test which indicates that the California test needs modification to be applicable to Idaho aggregate.

The majority of the test results seem to provide irrational patterns when compared to the service histories of the sources. The best correlation with service history is that for the decrease in fineness modulus for both the washed and the unwashed Idaho tests. Fairly good correlation was obtained by plotting the California test final minus #200 against the unwashed Idaho test final sand equivalent and also against the washed Idaho test final minus #200 and final sand equivalent. The comparison of

the different fineness moduli, surface areas, sand equivalents, and minus #200 as such for the three tests indicates no particular trend.

Method 1 in Appendix "J" for mathematically computing a numerical value reflecting potential degradation has definite promise in providing interim numerical specification limits. It is especially attractive because of its simplicity, and tables would expedite its use in both the field and the laboratory.

CONCLUSIONS

1. There is little or no connection between the irrational pattern of many of the test results and the amount of crushed material used to make up the test specimens.
2. The California degradation test is much easier to run than the Idaho degradation test.
3. There is only fair correlation between the ratings of "good" or "poor" as assigned by the California degradation test and the corresponding ratings made from the unwashed Idaho degradation test.
4. The California degradation test in its present form is not applicable to Idaho aggregate.
5. If further consideration is to be given to the use of the California degradation test, it should be modified to reflect the degradation potential of Idaho's principal rock types.

6. There is no recognizable trend from the comparison of the different fineness moduli, surface areas, sand equivalents, and minus #200 as such for the three tests.

7. The decrease in fineness modulus for both the washed and unwashed Idaho degradation tests shows the best correlation with the service record history when the "good" and "acceptable" sources are grouped into the single category of aggregate suitable for use.

8. Fairly good correlation of test results with service record history is also obtained by plotting the California test final minus #200 against the washed Idaho test final minus #200, against the washed Idaho test final sand equivalent, and against the unwashed Idaho test final sand equivalent.

9. Of the three methods in Appendix "J" for mathematically computing a numerical rating value, Method 1 is the best method to use in providing a numerical set of specification limits for potential degradation of aggregate.

RECOMMENDATIONS

1. A study needs to be made of past unwashed Idaho degradation test results for as many different sources as is practical.

The average decrease in test fineness modulus for each source could be compared to the service record history of the source to determine what type of correlation exists between the two on a statewide basis. This would either substantiate or invalidate the correlation discovered with the limited data of this investigation.

2. A yearly evaluation needs to be made of the amassed data from which the Idaho Degradation Chart has been developed. The new data being made available each year may indicate that the zone limits need to be revised from time to time.

3. Since the California degradation test is easier to run than the Idaho degradation test, a winter research project should be set up to modify the California test to reflect the degradation potential of Idaho's principal rock types. This would involve establishing a possible new minimum value of D_c or D_f and the revision of the formula for D_c to give a value approximately equal to that for D_f.

4. Method 1 in Appendix "J" should be used to develop a numerical rating system for potential degradation as an interim measure until such time as a new method of determining degradation is developed and approved for use. Tables need to be developed showing the specification limits for each set

of original minus #200 and original sand equivalent values based upon the corresponding set of values for final minus #200 and final sand equivalent, respectively.

TEST METHODS

The Idaho degradation test and the California degradation test were used as contained in Idaho Test Method T-15 and Test Method No. California 229-C, respectively. Appendix "B" gives the test procedure used for this project as compiled from those two test methods. Certain modifications were made in the test procedures and calculations so the results could easily be compared and additonal information obtained.

The modifications were:

1. A manual sand equivalent shaker was used for both tests.
2. A No. 16 sieve was used in the sieve analysis.
3. The Idaho degradation test was performed on a washed sample as well as on a standard unwashed sample.

Appendix "C" contains all the test data including screen sizes, gradations, sand equivalents, surface areas, fineness moduli, and values for D_c and D_f. Three tests were performed on each sample submitted for each of the three methods to provide an average test value for each method. The results of the three tests are given in Appendix "D" together with the average value for each set.

RESULTS OF INVESTIGATION

Appendix "A" shows that four of the five sources with good service records consist of quarry rock while three of the seven sources with poor service records also consist of quarry rock. Furthermore, the four remaining sources with poor service records all required over fifty per cent of crushed oversize material to meet the gradation specifications. Of the eight sources with acceptable service records, four required forty per cent or more of crushed oversize material to meet the gradation specifications. It is thus believed that there is little or no connection between the irrational pattern of many of the test results and the amount of crushed material used to make up the test sample.

In Appendix "E" seven of the twenty ratings of "good" or "poor" as assigned by the California degradation test differ from the corresponding rating made from the unwashed Idaho degradation test. This provides a comparable rating of only sixty-five per cent. This percentage could be raised to eighty per cent if a minimum value of 35 were used for D_c or D_f for the California test. (California standard specifications specify a minimum value of 35 for Class II and Class III bases.) Shifting the lines between Zones A, B, and C of the Idaho Degradation Chart slightly would not help to increase the percentage since as many "borderline" Idaho test values would be changed from "good" to "poor" as would be changed from "poor" to "good".

No "good" or "poor" ratings were given to the washed Idaho test results because there is no criteria from which a rating can be made.

It is very noticeable that there is a wide spread between the values for D_c and D_f for the California degradation test. The formula for determining D_c [$D_c = 30.3 + 20.8$ ctn $(0.29 + 0.15 H)$] was derived to give a value of D_c approximately equal to D_f. Differences between California and Idaho rock types could be the reason for this discrepancy. It would be necessary to derive a formula for D_c which is commensurate with Idaho's common rock types if the California degradation test is to be used in the future. Statistical analysis would be invaluable in the development of a new formula.

The comparison of fineness modulus and surface area for the three tests as made in Appendix "G" shows no discernable trend. In some cases the average values for the three groups (good, acceptable, poor) show either an increasing or a decreasing direction. However, the individual values within the group have such a wide variation that no valid conclusions can be drawn regarding a possible trend.

In Appendix "H" Column 15, Decrease in Fineness Modulus for Washed Idaho Degradation Test, and Column 20, Decrease in Fineness Modulus for Unwashed Idaho Degradation Test, show the best correlation with the service record history when the "Good" and

"Acceptable" sources are grouped into the single category of aggregate suitable for use. Column 10, Final Minus #200 for California Degradation, also shows fair correlation under the same conditions. The remaining columns have fair to poor correlation.

Plotting the final minus #200 for the California test against the final minus #200 for the washed Idaho test as shown in Figure 1 of Appendix "H" again provides fairly good correlation of test results with service record history. The dashed line shows one possible criteria for separating sources into acceptable and undesirable categories.

A high statistical correlation coefficient ($r = 0.9136$) was obtained by plotting D_f of the California test against the final sand equivalent for the washed Idaho test as shown in Figure 2. This is to be expected since the two tests so closely approximate each other in procedure. Plotting D_f against the final sand equivalent for the unwashed Idaho test provided a lower correlation coefficient ($r = 0.7768$). This is also to be expected since a washed test result is being compared with an unwashed test result. There is, however, fair to poor correlation of those test results with service record history when the same plots are made with the individual sources being identified as is shown in Figures 3 and 4, respectively.

Fairly good correlation is obtained when the California test final minus #200 is plotted against the washed Idaho test final sand equivalent as shown in Figure 5 and good correlation is obtained when it is plotted against the unwashed Idaho test final sand equivalent as shown in Figure 6. The dashed line in both graphs shows a possible criteria for separating sources into acceptable and undesirable categories.

Appendix "J" contains three methods for mathematically computing a numerical value from which an acceptable or undesirable rating can be assigned to the test results. These methods were developed from the Idaho Degradation Chart (Appendix "F") as contained in the article by H. L. Day (1) and show great promise in providing a numerical set of specification limits for potential degradation of aggregate. This conclusion is strongly supported by the results obtained from plotting the original sand equivalent against the final sand equivalent and the original minus #200 against the final minus #200 of the unwashed Idaho test as shown in Figure 9. The high correlation coefficients indicate a good linear relationship between the plotted values.

Method 1 is especially attractive because of its simplicity and tables could easily be developed to expedite its use in both the field and the laboratory.

REFERENCES

1. Day, H. L. , Idaho Department of Highways. "A Progress Report on Studies of Degrading Basalt Aggregate Bases," Highway Research Board Bulletin 344, (1962), 8-16.

APPENDIX A

Appendix "A" shows how the original sample submitted from each source was prepared to meet the gradation specifications. The gradation specified was for a 3/4 inch Maximum Type "B" Aggregate Base Course which is identical to that for a Class "E" Plant Mix Surface Course. The service record indicated is a compilation of the opinions of the District Materials Engineers together with the Materials and Research Engineer concerning the service histories of the named sources.

Column 1 indicates the condition of the sample as submitted. All quarry rock was crushed to 3/4 inch minus material as indicated in Column 2. Column 3 shows the actual per cent of original 3/4 inch minus material contained in the pit run samples as submitted while Column 4 indicates the actual per cent of original pit run 3/4 inch minus material used to prepare the test sample. Column 5 shows the per cent of original oversize (3/4 inch plus) material that was crushed while Column 6 indicates the actual per cent of crushed original oversize (3/4 inch plus) material used to prepare the test sample. The per cent of original minus #4 material that had to be wasted in order to meet the gradation specifications is shown in Column 7.

Sample Preparation Required to Meet Gradation Specifications

Source	Service Record	Col. 1 Original Material	Col. 2 All Original Material Crushed to 3/4" Minus	Col. 3 Original 3/4" Minus Material (Per Cent)	Col. 4 Original 3/4" Minus Material Used (Per Cent)	Col. 5 Original Oversize 3/4" Plus Material Crushed (Per Cent)	Col. 6 Original Oversize 3/4" Plus Crushed Material Used (Per Cent)	Col. 7 Original Minus #4 Material Wasted (Per Cent)
Bl-94 & 94 A	G	Pit Run	No	66	66	34	34	0
Bu-58	A	Pit Run	No	71	71	29	29	0
Cs-57	A	Pit Run	No	74	74	26	26	0
Cs-84 A	A	Pit Run	No	93	93	7	7	0
Cu-39	A	Pit Run	No	59	59	41	41	0
Jr-2	P	Pit Run	No	43	43	57	57	0
Jr-38	P	Pit Run	No	41	33	59	67	50
TF-63	P	Pit Run	No	49	49	51	51	0
TF-66	A	Pit Run	No	64	64	36	36	0
TF-67	P	Pit Run	No	41	35	59	65	50
Id-93	P	Quarry Rock	Yes	-	-	-	-	-
Lt-102	P	Quarry Rock	Yes	-	-	-	-	-
Lt-126	P	Quarry Rock	Yes	-	-	-	-	-
NP-11	G	Quarry Rock	Yes	-	-	-	-	-
NP-32	G	Quarry Rock	Yes	-	-	-	-	-
NP-96	G	Quarry Rock	Yes	-	-	-	-	-
Kt-1	G	Quarry Rock	Yes	-	-	-	-	-
Bn-33 s	A	Pit Run	No	43	43	57	57	0
Cl-56 s	A	Pit Run	No	60	60	40	40	0
Fr-33 s	A	Pit Run	No	51	51	49	49	0

Note: A = Acceptable G = Good P = Poor

APPENDIX B

TEST PROCEDURE FOR EACH SAMPLE

I. Gradation, Make up, and Preparation of Aggregate.

A. Gradation

1. Grade the original sample (crushing when necessary) into 1/2", 3/8", #4, #6, #8, #16, #20, #30, #40, #50, #100, and #200 material.

a) Obtain a gradation for both the crushed and the uncrushed portions of the aggregate.

b) Combine the crushed and the uncrushed portions to meet the specifications for 3/4" maximum surfacing.

B. Make up.

1. Coarse aggregate.

a) Make up the California degradation test sample as follows:

(1) If the weight of each size (1/2", 3/8", or #4) is 10% or more of the total weight of the coarse aggregate, make up two identical samples as follows:

1/2" - 1050 gms.
3/8" - 550 gms.
#4 - 900 gms.
Total - 2500 gms.

(2) If the weight of any size (or sizes) is less than 10% of the weight of the total coarse aggregate, use that percentage of the weight of the total

coarse aggregate times 2500 gms. for that size and propertionally increase the weight of the other sizes so the total sample weighs 2500 gms.

b) Make up the unwashed Idaho degradation test sample as follows: (Hand fit the aggregate through the sieves.)

1/2" - 184 gms.

3/8" - 182 gms.

#4 - 184 gms.

-#4 (to be added later) - 550 gms.

Total - 1100 gms.

c) Make up the original material for the washed Idaho degradation test sample as follows: (Additional weight is to allow for washing.)

1/2" - 250 gms.

3/8" - 250 gms.

#4 - 250 gms.

-#4 - 650 gms. of unwashed material to be added later.

2. Fine Aggregate (Using the proper proportion of crushed and uncrushed material)

a) Make up a sand equivalent sample from the original material for comparison with the unwashed Idaho degradation test sample.

b) Make up the fine aggregate for the California degradation test sample using enough -#4 to make an oven dry sample of 500 gms.

c) Make up the fine aggregate for the unwashed Idaho degradation test sample to obtain a 550 gm. oven dry sample and add it to its respective coarse aggregate sample.

d) Make up the fine aggregate for the washed Idaho degradation test sample to obtain a 650 gm. sample (add 100 gms. to the 550 gms. to allow for washing) but do not add the fine aggregate to its respective coarse aggregate sample.

3. Place all material in the proper oven:

a) Place all coarse and fine aggregate for the California degradation test in the 230° F. oven.

b) Place the unwashed Idaho degradation test aggregate in the 140° F. oven.

c) Wash the coarse and fine aggregate for the washed Idaho degradation test thoroughly and place it in the 140° F. oven separately.

C. Preparation of Aggregate.

1. Preparation of California degradation test samples.

a) Coarse aggregrate

(1) Place the oven dried samples, one at a time, into the mechanical washing vessel (washing vessel as shown in California Materials Manual, Test Method No. 229-C) with 1000 ml. of distilled water.

(2) Let the vessel stand for one minute.

(3) Agitate the vessel for two minutes.

(4) Pour the contents of the vessel over a #4 sieve (be sure to rinse any remaining fines through the sieve) and wash all -#4 through the sieve. Discard the -#4.

(5) Repeat the washing procedure for the second sample.

(6) Oven dry the samples in the 230° F. oven.

(7) Grade each preliminary sample into 1/2", 3/8", & #4 material, discarding all -#4 material.

(8) Prepare the samples for the washed test.

(a) If the preliminary samples were made up from a sample having each size (1/2", 3/8", #4) of the coarse aggregate equal to 10% or

more of the total weight of the coarse aggregate, make up the washed sample from the material of the two preliminary samples as follows:

1/2"	-	1050 gms.
3/8"	-	550 gms.
#4	-	900 gms.
Total	-	2500 gms.

(b) If the preliminary samples were made up from a sample having a deficient size (or sizes), make up the washed sample from the material of the two preliminary samples as follows: Use all of the material representing the deficient size (or sizes) and proportionally increase the weight of the other sizes to make a total sample weight of 2500 gms.

b) Fine Aggregate.

(1) Oven dry the sample and adjust the weight to 500 gms.

(2) Place the sample into the washing vessel with 1000 ml. of distilled water.

(3) Let the vessel stand for 10 minutes.

(4) Agitate the vessel for two minutes.

(5) Pour the contents of the vessel over a #200 sieve (be sure to rinse any remaining fines through the sieve) and wash the material until the water passing

through the sieve looks clear. Discard the -#200 material.

(6) Oven dry the sample in the 230° F. oven.

(7) Grade the sample into #6, #8, #16, #20, #30, #40, #50, #100, and #200 sizes, catching all -#200 material. Shake the sample for 20 minutes.

(8) Recombine all the fine aggregate for the test, including the -#200 materials obtained from sieving.

2. Preparation of unwashed Idaho degradation test samples.

a) Adjust the weight of the oven dried material to 1100 gms.

b) Soak the material in a glass jar for at least 16 hours.

3. Preparation of washed Idaho degradation test samples.

a) Coarse aggregate.

(1) Grade the sample into 1/2", 3/8", & #4 sizes, discarding any -#4 material.

(2) Make up the sample as follows:

1/2"	-	184 gms.	(Hand fit aggregate through
3/8"	-	182 gms.	sieves.)
#4	-	184 gms.	

b) Fine aggregate.

(1) Add a representative 550 gms. of the 650 gm. sample of washed fine material to the coarse aggregate.

c) Place the total 1100 gm. washed Idaho degradation test

sample in a glass jar and allow the sample to soak at least 16 hours.

II. Test Procedure.

A. California Degradation Test.

1. Coarse aggregate.

a) Place the prepared aggregate sample into the washing vessel with 1000 ml. of distilled water.

b) Let the vessel stand for one minute.

c) Agitate the vessel for 10 minutes.

d) Pour the contents of the vessel (be sure to keep the fines in suspension) over a #8, #200 sieve nest (the #8 sieve is to protect the #200 sieve) and collect the -#200 material.

e) Add enough distilled water to the -#200 wash water to bring the volume to 1000 ml.

f) Place 7 ml. of stock sand equivalent solution into a sand equivalent cylinder and pour the dirty wash water into the cylinder to the level of 15 inches (be sure to keep the fines in suspension).

g) Mix the contents of the cylinder by alternately turning the cylinders upside down and right side up allowing the bubble to completely traverse the length of the cylinder 20 times in approximately 35 seconds.

h) Allow the cylinder to stand undisturbed for 20 minutes.

i) Read the column height in the cylinder to the nearest 0.1 inch; this is the reading "H".

j) Retain all the material and oven dry it at 230° F.

k) Grade the material for comparison with the washed Idaho degradation test final gradation.

2. Fine aggregate.

a) Wet the sample to the fluff point and let it soak for two hours.

b) Obtain two 3 oz. samples by the following method: Roll the wetted material on a canvas to a pile in the center of the canvas. Place one hand on one side of the pile and push the 3 oz. cup through the pile from the other side. Consolidate the material in the cup by tapping it on the table and then strike off the excess material. Re-roll the material and repeat the procedure for the second cup. (California method calls for the method of quartering to be used in this step.)

c) Pour the sand equivalent working solution to the level of 4 inches in two sand equivalent cylinders.

d) Pour each 3 oz. sample into a cylinder.

e) Let the cylinders stand for 10 minutes.

f) Shake the cylinders for 10 minutes using the Idaho mechanical sand equivalent shaker.

g) Let the cylinders stand undisturbed for 20 minutes.

h) Read the level of the clay and of the sand in the cylinder.

$$\frac{\text{Sand}}{\text{Clay}} \times 100 = D_f$$

i) Retain all of the material from the sand equivalent cylinder and oven dry it at 230° F.

j) Grade the material for comparison with the unwashed Idaho degradation test final gradation.

B. Washed and Unwashed Idaho Degradation Tests.

a) Place the jar in the Deval machine which is to be set to stop at 1850 revolutions and start the machine.

b) After the 1850 revolutions have been completed, pour the sample over a #4 sieve and catch all the -#4 material.

c) Oven dry the coarse material at 140° F. and grade it accurately into 1/2", 3/8", and #4 aggregate, adding the -#4 material to the -#4 material of part b. Record the gradation.

d) Allow the -#4 portion to stand until all of the fines have settled and then siphon off the water.

e) Oven dry the -#4 portion at 140° F. to the fluff point and run a sand equivalent on it.

f) Retain the sand equivalent material and return it to the total -#4 portion.

g) Wash the total -#4 portion.

h) Compute the gradation of the entire sample using the 3/4" to #200 sieves.

III. Calculations and Reporting

A. California Degradation Test.

1. Coarse aggregate: Durability Factor = D_c

$D_c = 30.3 + 20.8 \text{ ctn } (0.29 + 0.15 H)$

(A table exists in the California Materials Manual, Test Method No. 229-C, page 9, which tabulates D_c for values of H)

2. Fine Aggregate: Durability Factor = D_f

$D_f = \frac{\text{Sand}}{\text{Clay}} \times 100$

(Values of the durability factors are listed in the California Materials Specifications).

B. Unwashed Idaho Degradation Test.

1. The final sand equivalent and the final per cent passing the #200 sieve are to be compared with the original sand equivalent and the original per cent passing the #200 sieve. These values are plotted on the comparison graph shown in

Fig. 1, page 11, of the Highway Research Board Bulletin 344, Degradation of Aggregates Used In Highway Base Construction. Appendix F

C. Washed Idaho degradation Test.

1. Values for the sand equivalent and the gradation are to be compared with the unwashed Idaho degradation test and the California degradation test.

APPENDIX C

Appendix "C" is a summary of all test data obtained from Research Project No. 29.

The column labeled "Original Gradation" shows the actual gradation of the total test sample. The amount of crushed and uncrushed material in each test sample is shown in Appendix "A".

The column "Unwashed Idaho Deg. Original Gradation" shows the made-up coarse aggregate for the Idaho degradation test (184 gm 1/2", 182 gm 3/8", and 184 gm #4) with the minus #4 part proportioned to 50 per cent passing the #4 sieve.

The column "Washed Idaho Deg. Original Gradation" shows the same made-up coarse aggregate as for the unwashed Idaho degradation test but with a fine gradation recalculated to zero per cent passing the #200 sieve. In order to recalculate this gradation, the original gradation had to be changed. The weight passing the #200 sieve was subtracted from the weight passing each sieve and a new gradation was calculated using the new weights. This gradation was then proportioned to 50 per cent passing the #4 sieve.

The columns "Unwashed Idaho Deg. After Test" and "Washed Idaho Deg After Test" are the actual gradations of each test after the specified test was performed.

The California degradation test was performed in two parts so that the coarse and fine portions are completely separate. The column "California Deg. Before Test Gradation" shows the gradation of the material in the test specimen before the test was performed. The coarse aggregate gradation is a made-up gradation (see Appendix B, Part I-B) but the fine portion is a calculated gradation showing zero per cent passing the #200 sieve. The California test procedure requires a gradation after the fine portion is washed so that gradation was calculated using the weight on the #200 sieve as the total weight. The column "California Deg. After Test Gradation" is the actual gradation of the specimen after testing.

The last column "California Deg. After Test Gradation for Surface Area" is the actual test gradation of the California degradation test proportioned to 50 per cent passing the #4 sieve. This column was used to calculate a surface area and fineness modulus comparable to the values for the original washed Idaho degradation test gradation.

Because of the two part method used for the California degradation test, the fineness modulus for each gradation was calculated omitting the value for the 3/8" sieve.

The original gradation and its respective values for surface area and fineness modulus are for reference only and cannot be compared directly to any other values. The original gradation for the unwashed Idaho degradation test along with the values for the surface area, sand equivalent, and fineness modulus are for comparison with the final gradation of the unwashed Idaho degradation test and the corresponding

surface area, sand equivalent, and fineness modulus. The original gradation, surface area, sand equivalent, and fineness modulus for the washed Idaho degradation test can be compared with the after test values for the washed Idaho degradation test and also with the after test proportioned gradation to 50 per cent passing the #4 sieve, the surface area, and the fineness modulus for the California degradation test.

~~B1-94 & 94-A~~

B1-94 & 94A

~~APPENDIX B~~

Sieve Size	Orig. Grad.	Unwashed Idaho Deg. Orig. Grad.	Unwashed Idaho Deg. After Test.	Washed Idaho Deg. Orig. Grad.	Washed Idaho Deg. After Test	Calif. Deg. Before Test Grad. Coarse	Calif. Deg. After Test Grad. Coarse	Calif. Deg. After Test Grad. for Surface Area (Based upon 50% Passing - No. 4)
3/4"	100	100	100	100	100	100	100	
1/2"	82	83	83	83	83	58	59	
3/8"	71	67	67	67	67	36	37	
No. 4	55	50	51	50	51	0	1	50
						Fine	Fine	
No. 6	50	45	47	46	46	91	91	46
No. 8	46	42	43	42	42	82	83	42
No. 16	36	33	34	31	33	62	65	33
No. 20	32	29	31	27	29	54	57	29
No. 30	24	22	25	20	23	40	45	23
No. 40	15	14	18	11	16	23	30	15
No. 50	10	9	14	6	11	13	21	11
No. 100	6	5	9	2	6	3	13	7
No. 200	4	4	7	0	4	0	9	5
Surface Area	24.81	23.15	32.25	13.84	24.62			26.56
F.M.	4.23	4.39	4.24	4.49	4.34			4.34
S.E.	71	71	53		64			
D_c							80	
D_f							47	

Bu-58

~~Bu-58~~

~~APPENDIX B~~

Sieve Size	Orig. Grad.	Unwashed Idaho Deg. Orig. Grad.	Unwashed Idaho Deg. After Test	Washed Idaho Deg. Orig. Grad.	Washed Idaho Deg. After Test	Calif. Deg. Before Test Grad. Coarse	Calif. Deg. After Test Grad. Coarse	Calif. Deg. After Test Grad. for Surface Area (Based upon 50% Passing - No. 4)
3/4"	100	100	100	100	100	100	100	
1/2"	88	83	83	83	83	58	59	
3/8"	74	67	67	67	67	36	37	
No. 4	55	50	51	50	51	0	1	50
						Fine	Fine	
No. 6	46	42	44	42	43	83	86	43
No. 8	39	35	38	34	37	71	73	37
No. 16	29	26	29	25	27	52	55	28
No. 20	26	24	27	22	24	45	50	25
No. 30	23	21	24	19	21	38	42	21
No. 40	19	17	21	15	18	31	37	19
No. 50	14	13	18	10	14	22	29	15
No. 100	6	5	11	2	8	4	16	8
No. 200	4	4	8	0	5	0	11	6
Surface Area	25.20	23.52	35.62	14.24	27.34			29.27
F.M.	4.34	4.50	4.29	4.60	4.42			4.41
S.E.	65	65	40		58			
D_c							78	
D_f							33	

Cs-57

~~APPENDIX B~~

~~Cs-57~~

Sieve Size	Orig. Grad.	Unwashed Idaho Deg. Orig. Grad.	Unwashed Idaho Deg. After Test	Washed Idaho Deg. Orig. Grad.	Washed Idaho Deg. After Test	Calif. Deg. Before Test Grad. Coarse	Calif. Deg. After Test Grad. Coarse	Calif. Deg. After Test Grad. for Surface Area (Based upon 50% Passing - No. 4)
3/4"	100	100	100	100	100	100	100	
1/2"	92	83	83	83	83	58	59	
3/8"	82	67	67	67	67	36	37	
No. 4	64	50	51	50	51	0	1	50
						Fine	Fine	
No. 6	55	42	44	42	43	85	88	44
No. 8	46	36	38	35	36	70	75	38
No. 16	29	23	26	21	23	43	49	25
No. 20	23	18	21	16	19	34	40	20
No. 30	17	13	17	11	15	24	31	16
No. 40	13	10	14	7	11	16	23	12
No. 50	9	7	12	5	9	10	18	9
No. 100	5	4	9	2	6	3	12	6
No. 200	4	3	7 ✓	0	4 ✓	0	10	5
Surface Area	22.71	18.22	29.69	11.24	21.81			23.71
F.M.	4.30	4.67	4.47	4.76	4.60			4.56
S.E.	67	67 ✓	50 ✓		67 ✓			
D_c							78 ✓	
D_f							53 ✓	

Cs-84A

~~APPENDIX B~~

~~Cs-84 A~~

Sieve Size	Orig. Grad.	Unwashed Idaho Deg. Orig. Grad.	Unwashed Idaho Deg. After Test	Washed Idaho Deg. Orig. Grad.	Washed Idaho Deg. After Test	Calif. Deg. Before Test Grad. Coarse	Calif. Deg. After Test Grad. Coarse	Calif. Deg. After Test Grad. for Surface Area (Based upon 50% Passing - No. 4)
3/4"	100	100	100	100	100	100	100	
1/2"	96	83	84	83	83	71	72	
3/8"	87	67	68	67	67	44	38	
No. 4	55	50	50	50	50	0	3	50
						Fine	Fine	
No. 6	35	32	36	30	32	60	66	33
No. 8	26	24	30	22	24	42	49	25
No. 16	17	15	23	12	16	24	34	17
No. 20	16	15	22	11	15	21	31	16
No. 30	14	13	21	9	14	18	29	15
No. 40	12	11	20	8	12	14	26	13
No. 50	10	9	19	6	11	11	24	12
No. 100	6	5	15	2	8	3	19	10
No. 200	4	4	14 ✓	0	6 ✓	0	16	8
Surface Area	21.23	20.01	46.29	10.26	25.57			30.42
F.M.	4.72	4.84	4.42	4.99	4.77			4.71
S.E.	55 ✓	55	29 ✓		49 ✓			
D_c							67 ✓	
D_f							42 ✓	

Cu-39

~~Cu-39~~

~~APPENDIX B~~

Sieve Size	Orig. Grad.	Unwashed Idaho Deg. Orig. Grad.	Unwashed Idaho Deg. After Test	Washed Idaho Deg. Orig. Grad.	Washed Idaho Deg. After Test	Calif. Deg. Before Test Grad. Coarse	Calif. Deg. After Test Grad. Coarse	Calif. Deg. After Test Grad. for Surface Area (Based upon 50% Passing - No. 4)
3/4"	100	100	100	100	100	100	100	
1/2"	82	83	83	83	84	58	60	
3/8"	70	67	68	67	67	36	37	
No. 4	55	50	51	50	50	0	2	50
						Fine	Fine	
No. 6	48	44	44	43	44	85	87	44
No. 8	41	37	39	37	38	74	76	38
No. 16	31	28	31	27	30	55	59	30
No. 20	27	25	27	23	26	48	51	26
No. 30	21	19	23	18	21	35	41	21
No. 40	14	13	17	10	15	22	29	15
No. 50	9	8	14	6	12	13	21	11
No. 100	5	5	10	2	7	3	13	7
No. 200	3	3	8 ✓	0	6 ✓	0	11	6
Surface Area	21.41	20.42	31.21	12.99	27.72			27.48
F.M.	4.38	4.53	4.32	4.70	4.42			4.43
S.E.	63 ✓	63 ✓	39 ✓		53 ✓			
D_c							73 ✓	
D_f							39 ✓	

~~Jr-2~~

Jr - 2

~~APPENDIX B~~

Sieve Size	Orig. Grad.	Unwashed Idaho Deg. Orig. Grad.	Unwashed Idaho Deg. After Test	Washed Idaho Deg. Orig. Grad.	Washed Idaho Deg. After Test	Calif. Deg. Before Test Grad. Coarse	Calif. Deg. After Test Grad. Coarse	Calif. Deg. After Test Grad. For Surface Area (Based upon 50% Passing - No. 4)
3/4"	100	100	100	100	100	100	100	
1/2"	82	83	83	83	84	58	59	
3/8"	69	67	68	67	68	38	37	
No. 4	55	50	51	50	51	0	3	50
						Fine	Fine	
No. 6	49	45	47	43	46	90	93	47
No. 8	42	38	41	36	41	76	82	41
No. 16	26	24	30	21	28	44	56	28
No. 20	20	18	26	14	23	32	46	23
No. 30	15	14	22	10	20	22	39	20
No. 40	12	11	20	8	17	16	33	17
No. 50	10	9	19	6	15	12	30	15
No. 100	7	6	16	2	12	4	24	12
No. 200	5	5	13 ✓	0	9 ✓	0	19	10
Surface Area	24.80	23.30	46.39	11.40	36.17			37.70
F.M.	4.45	4.59	4.21	4.75	4.33			4.34
S.E.	62 ✓	62 ✓	35 ✓		45 ✓			
D_c							73 ✓	
D_f							27 ✓	

Jr-38

~~Jr-38~~

~~APPENDIX B~~

Sieve Size	Orig. Grad.	Unwashed Idaho Deg. Orig. Grad.	Unwashed Idaho Deg. After Test	Washed Idaho Deg. Orig. Grad.	Washed Idaho Deg. After Test	Calif. Deg. Before Test Grad. Coarse	Calif. Deg. After Test Grad. Coarse	Calif. Deg. After Test Grad. for Surface Area (Based upon 50% Passing - No. 4)
3/4"	100	100	100	100	100	100	100	
1/2"	87	83	84	83	84	58	60	
3/8"	70	67	68	67	69	36	39	
No. 4	43	50	51	50	51	0	5	50
						Fine	Fine	
No. 6	38	44	46	42	45	84	89	45
No. 8	33	38	41	34	38	69	77	39
No. 16	25	29	33	22	28	45	56	28
No. 20	22	26	31	18	25	38	51	26
No. 30	20	23	29	16	23	31	45	23
No. 40	18	21	28	13	22	25	41	21
No. 50	16	19	26	11	20	21	38	19
No. 100	13	15	22	5	16	10	30	15
No. 200	9	10	18	0	10	0	21	11
Surface Area	36.39	41.12	61.12	15.55	42.00			42.73
F.M.	4.50	4.26	3.98	4.62	4.24			4.26
S.E.	42	42	25		62			
D_c							72	
D_f							53	

~~TF-63~~ TF - 63

~~APPENDIX B~~

Sieve Size	Orig. Grad.	Unwashed Idaho Deg. Orig. Grad.	Unwashed Idaho Deg. After Test	Washed Idaho Deg. Orig. Grad.	Washed Idaho Deg. After Test	Calif. Deg. Before Test Grad. Coarse	Calif. Deg. After Test Grad. Coarse	Calif. Deg. After Test Grad. for Surface Area (Based upon 50% Passing - No. 4)
3/4"	100	100	100	100	100	100	100	
1/2"	83	83	83	83	84	58	59	
3/8"	71	67	68	67	68	36	38	
No. 4	55	50	52	50	51	0	2	50
						Fine	Fine	
No. 6	45	41	44	40	44	81	87	44
No. 8	37	34	38	32	36	65	73	37
No. 16	23	21	25	19	23	37	49	25
No. 20	18	16	22	14	19	28	39	20
No. 30	14	13	18	10	16	20	31	16
No. 40	11	10	16	6	13	14	25	13
No. 50	8	7	14	5	11	9	22	11
No. 100	5	5	11	2	8	3	18	9
No. 200	4	4	9	0	6	0	15	8
Surface Area	20.95	20.11	34.23	10.74	26.86			30.67
F.M.	4.58	4.70	4.42	4.82	4.55			4.52
S.E.	62	62	44		59			
D_c							67	
D_f							41	

~~TF-66~~ TF-66

~~APPENDIX B~~

Sieve Size	Orig. Grad.	Unwashed Idaho Deg. Orig. Grad.	Unwashed Idaho Deg. After Test	Washed Idaho Deg. Orig. Grad.	Washed Idaho Deg. After Test	Calif. Deg. Before Test Grad. Coarse	Calif. Deg. After Test Grad. Coarse	Calif. Deg. After Test Grad. for Surface Area (Based upon 50% Passing - No. 4)
3/4"	100	100	100	100	100	100	100	
1/2"	87	83	83	83	83	58	56	
3/8"	76	67	67	67	67	36	36	
No. 4	55	50	51	50	50	0	1	50
						Fine	Fine	
No. 6	50	45	46	44	46	91	91	46
No. 8	44	40	41	40	41	81	82	41
No. 16	32	29	31	28	30	56	60	30
No. 20	26	24	26	22	25	47	50	25
No. 30	19	17	20	16	18	33	36	18
No. 40	11	10	14	7	12	17	22	11
No. 50	7	6	11	5	8	9	15	8
No. 100	4	4	7	2	5	2	8	4
No. 200	3	3	6 ~	0	4 ~	0	7	4
Surface Area	19.63	19.00	27.50	12.41	22.03			21.34
F.M.	4.39	4.54	4.39	4.59	4.48			4.49
S.E.	70	70 ~	50 ~		65 ~			
D_c							80 ~	
D_f							65 ~	

~~TF-67~~

TF-67

~~APPENDIX B~~

Sieve Size	Orig. Grad.	Unwashed Idaho Deg. Orig. Grad.	Unwashed Idaho Deg. After Test	Washed Idaho Deg. Orig. Grad.	Washed Idaho Deg. After Test	Calif. Deg. Before Test Grad. Coarse	Calif. Deg. After Test Grad. Coarse	Calif. Deg. After Test Grad. for Surface Area (Based upon 50% Passing - No. 4)
3/4"	100	100	100	100	100	100	100	
1/2"	82	83	83	83	84	58	60	
3/8"	67	67	68	67	68	36	39	
No. 4	50	50	53	50	52	0	5	50
						Fine	Fine	
No. 6	41	41	46	39	44	80	88	44
No. 8	34	34	40	31	37	64	74	37
No. 16	24	24	31	19	26	38	52	26
No. 20	21	21	28	14	23	30	45	23
No. 30	19	19	26	12	20	24	40	20
No. 40	17	17	25	9	18	19	37	19
No. 50	15	15	24	8	17	15	35	18
No. 100	12	12	21	3	14	8	31	16
No. 200	9	9	18 ✓	0	11 ✓	0	26	13
Surface Area	35.50	35.50	59.27	12.45	40.82			45.41
F.M.	4.46	4.46	4.05	4.77	4.34			4.33
S.E.	43 ✓	43 ✓	26 ✓		42 ✓			
D_c							55 ✓	
D_f							25 ✓	

~~Id-93~~

Id-93

~~APPENDIX B~~

Sieve Size	Orig. Grad.	Unwashed Idaho Deg. Orig. Grad.	Unwashed Idaho Deg. After Test	Washed Idaho Deg. Orig. Grad.	Washed Idaho Deg. After Test	Calif. Deg. Before Test Grad. Coarse	Calif. Deg. After Test Grad. Coarse	Calif. Deg. After Test Grad. for Surface Area (Based upon 50% Passing - No. 4)
3/4"	100	100	100	100	100	100	100	
1/2"	81	83	84	83	84	58	61	
3/8"	67	67	68	67	68	36	39	
No. 4	53	50	53	50	51	0	5	50
						Fine	Fine	
No. 6	41	39	43	37	41	74	85	43
No. 8	33	31	36	28	32	56	70	35
No. 16	21	20	25	15	20	29	46	23
No. 20	18	17	22	11	17	22	39	20
No. 30	15	14	20	9	15	17	34	17
No. 40	13	12	19	6	14	12	30	15
No. 50	12	11	18	5	13	9	28	14
No. 100	9	8	16	2	11	4	25	13
No. 200	7	7	14 ✓	0	9 ✓	0	23	12
Surface Area	28.95	27.68	46.89	10.20	33.41			40.41
F.M.	4.57	4.66	4.32	4.91	4.58			4.48
S.E.	58 ✓	58 ✓	33 ✓		53 ✓			
D_c							59 ✓	
D_f							32 ✓	

~~Lt-102~~

Lt-102

~~APPENDIX B~~

Sieve Size	Orig. Grad.	Unwashed Idaho Deg. Orig. Grad.	Unwashed Idaho Deg. After Test	Washed Idaho Deg. Orig. Grad.	Washed Idaho Deg. After Test	Calif. Deg. Before Test Grad. Coarse	Calif. Deg. After Test Grad. Coarse	Calif. Deg. After Test Grad. for Surface Area (Based upon 50% Passing - No. 4)
3/4"	100	100	100	100	100	100	100	
1/2"	82	83	84	83	85	58	61	
3/8"	71	67	68	67	69	36	38	
No. 4	56	50	52	50	52	0	5	50
						Fine	Fine	
No. 6	43	38	42	36	40	75	84	42
No. 8	33	30	34	27	31	55	67	34
No. 16	19	17	22	13	18	28	41	21
No. 20	15	13	20	9	15	20	35	18
No. 30	12	11	17	6	13	15	29	15
No. 40	19	9	15	5	11	10	26	13
No. 50	9	8	14	4	10	7	24	12
No. 100	7	6	13	1	8	3	21	11
No. 200	5	4	12	0	7	0	20	10
Surface Area	23.24	20.23	40.18	8.80	27.16			34.80
F.M.	4.64	4.78	4.48	4.99	4.68			4.57
S.E.	72	72	45		59			
D_c							62	
D_f							38	

~~Lt-126~~

Lt-126

~~APPENDIX B~~

Sieve Size	Orig. Grad.	Unwashed Idaho Deg. Orig. Grad.	Unwashed Idaho Deg. After Test	Washed Idaho Deg. Orig. Grad.	Washed Idaho Deg. After Test	Calif. Deg. Before Test Grad. Coarse	Calif. Deg. After Test Grad. Coarse	Calif. Deg. After Test Grad. for Surface Area (Based upon 50% Passing - No. 4)
3/4"	100	100	100	100	100	100	100	
1/2"	78	83	84	83	83	58	60	
3/8"	66	67	69	67	67	36	38	
No. 4	55	50	52	50	51	0	3	50
						Fine	Fine	
No. 6	47	43	45	37	44	81	88	44
No. 8	41	37	39	35	37	66	75	38
No. 16	31	28	29	25	26	41	53	27
No. 20	27	25	26	21	23	33	46	23
No. 30	23	21	24	17	19	26	39	20
No. 40	19	17	21	13	17	19	32	16
No. 50	16	15	19	9	14	14	29	15
No. 100	11	10	15	4	10	6	21	11
No. 200	8	7	12	0	7	0	16	8
Surface Area	35.07	31.84	44.41	14.83	31.30			33.73
F.M.	4.23	4.39	4.22	4.60	4.43			4.39
S.E.	70	70	53		67			
D_c							78	
D_f							58	

~~NP-11~~

NP-11

~~APPENDIX B~~

Sieve Size	Orig. Grad.	Unwashed Idaho Deg. Orig. Grad.	Unwashed Idaho Deg. After Test	Washed Idaho Deg. Orig. Grad.	Washed Idaho Deg. After Test	Calif. Deg. Before Test Grad. Coarse	Calif. Deg. After Test Grad. Coarse	Calif. Deg. After Test Grad. for Surface Area (Based upon 50% Passing - No. 4)
3/4"	100	100	100	100	100	100	100	
1/2"	79	83	83	83	83	58	59	
3/8"	68	67	67	67	67	36	37	
No. 4	55	50	51	50	50	0	3	50
						Fine	Fine	
No. 6	42	38	41	37	40	77	82	41
No. 8	32	29	32	28	30	57	65	33
No. 16	17	15	20	14	17	29	38	19
No. 20	14	13	16	10	14	22	31	16
No. 30	11	10	14	7	11	15	25	13
No. 40	8	7	12	5	9	11	21	11
No. 50	7	6	10	4	8	8	18	9
No. 100	5	5	8	2	5	3	14	7
No. 200	3	3	7	0	4	0	11	6
Surface Area	17.77	17.27	27.45	9.62	19.70			24.92
F.M.	4.73	4.85	4.65	4.95	4.79			4.69
S.E.	85	85	67		77			
D_c							80	
D_f							59	

~~NP-32~~

NP-32

~~APPENDIX B~~

Sieve Size	Orig. Grad.	Unwashed Idaho Deg. Orig. Grad.	Unwashed Idaho Deg. After Test	Washed Idaho Deg. Orig. Grad.	Washed Idaho Deg. After Test	Calif. Deg. Before Test Grad. Coarse	Calif. Deg. After Test Grad. Coarse	Calif. Deg. After Test Grad. for Surface Area (Based upon 50% Passing - No. 4)
3/4"	100	100	100	100	100	100	100	
1/2"	80	83	83	83	84	58	59	
3/8"	71	67	67	67	67	36	37	
No. 4	54	50	51	50	51	0	2	50
						Fine	Fine	
No. 6	43	40	41	39	40	76	82	41
No. 8	33	31	32	28	30	57	62	31
No. 16	18	17	18	14	16	27	34	17
No. 20	14	13	15	10	12	20	26	13
No. 30	11	10	12	8	9	14	20	10
No. 40	8	7	10	5	7	9	16	8
No. 50	7	6	8	4	6	6	13	7
No. 100	4	4	6	1	4	2	10	5
No. 200	3	3	5 ✓	0	3 ✓	0	8	4
Surface Area	17.21	16.79	22.24	9.11	16.59			19.27
F.M.	4.73	4.82	4.73	4.95	4.84			4.80
S.E.	88 ✓	88 ✓	80 ✓		88 ✓			
D_c							85 ✓	
D_f							77 ✓	

~~NP-96~~

NP-96

~~APPENDIX B~~

Sieve Size	Orig. Grad.	Unwashed Idaho Deg. Orig. Grad.	Unwashed Idaho Deg. After Test	Washed Idaho Deg. Orig. Grad.	Washed Idaho Deg. After Test	Calif. Deg. Before Test Grad. Coarse	Calif. Deg. After Test Grad. Coarse	Calif. Deg. After Test Grad. for Surface Area (Based upon 50% Passing - No. 4)
3/4"	100	100	100	100	100	100	100	
1/2"	83	83	84	83	84	58	59	
3/8"	72	67	68	67	67	36	37	
No. 4	56	50	51	50	51	0	2	50
						Fine	Fine	
No. 6	45	40	41	39	41	79	85	44
No. 8	36	32	33	30	32	60	69	35
No. 16	21	19	22	15	19	31	43	22
No. 20	17	15	19	11	16	23	35	18
No. 30	14	13	17	8	13	16	29	15
No. 40	11	10	15	6	11	11	25	13
No. 50	10	9	14	4	9	8	22	11
No. 100	8	7	13	2	8	3	19	10
No. 200	6	5	12	0	7	0	18	9
Surface Area	26.22	23.15	39.97	9.99	27.03			32.47
F.M.	4.55	4.70	4.50	4.91	4.68			4.57
S.E.	74	74	53		70			
D_c							74	
D_f							57	

~~Kt-1~~

Kt - 1

~~APPENDIX B~~

Sieve Size	Orig. Grad.	Unwashed Idaho Deg. Orig. Grad.	Unwashed Idaho Deg. After Test	Washed Idaho Deg. Orig. Grad.	Washed Idaho Deg. After Test	Calif. Deg. Before Test Grad. Coarse	Calif. Deg. After Test Grad. Coarse	Calif. Deg. After Test Grad. for Surface Area (Based upon 50% Passing - No. 4)
3/4"	100	100	100	100	100	100	100	
1/2"	81	83	84	83	84	58	59	
3/8"	68	67	68	67	67	36	37	
No. 4	55	50	51	50	50	0	3	50
						Fine	Fine	
No. 6	45	41	43	40	42	79	84	42
No. 8	35	32	36	30	33	60	68	34
No. 16	22	20	25	17	22	34	44	22
No. 20	18	16	22	13	18	27	38	19
No. 30	15	14	19	10	16	20	31	16
No. 40	12	11	17	8	13	15	26	13
No. 50	10	9	15	6	11	11	23	12
No. 100	7	6	12	2	8	4	17	9
No. 200	4	4	9	0	6	0	14	7
Surface Area	22.69	21.25	35.71	10.97	29.59			29.11
F.M.	4.56	4.69	4.42	4.85	4.60			4.57
S.E.	82	82	67		76			
D_c							85	
D_f							70	

~~Bn-33-s~~

Bn-33s

~~APPENDIX B~~

Sieve Size	Orig. Grad.	Unwashed Idaho Deg. Orig. Grad.	Unwashed Idaho Deg. After Test	Washed Idaho Deg. Orig. Grad.	Washed Idaho Deg. After Test	Calif. Deg. Before Test Grad. Coarse	Calif. Deg. After Test Grad. Coarse	Calif. Deg. After Test Grad. for Surface Area (Based upon 50% Passing - No. 4)
3/4"	100	100	100	100	100	100	100	
1/2"	80	83	83	83	84	58	58	
3/8"	67	67	67	67	67	36	36	
No. 4	54	50	50	50	50	0	2	50
						Fine	Fine	
No. 6	45	42	43	40	42	83	86	43
No. 8	39	36	37	34	36	68	72	36
No. 16	30	28	30	25	27	50	56	28
No. 20	28	26	28	22	25	45	52	26
No. 30	26	24	27	21	24	41	48	24
No. 40	24	22	26	19	23	37	46	23
No. 50	23	21	25	17	21	34	44	22
No. 100	12	11	17	6	13	13	29	15
No. 200	7	6	11 ✓	0	6 ✓	0	16	8
Surface Area	36.45	33.06	46.20	18.86	34.28			38.89
F.M.	4.16	4.30	4.14	4.47	4.29			4.25
S.E.	54 ✓	54 ✓	35 ✓		56 ✓			
D_c							87 ✓	
D_f							39 ✓	

~~C1-56 s~~

C1-56s

~~APPENDIX B~~

Sieve Size	Orig. Grad.	Unwashed Idaho Deg. Orig. Grad.	Unwashed Idaho Deg. After Test	Washed Idaho Deg. Orig. Grad.	Washed Idaho Deg. After Test	Calif. Deg. Before Test Grad. Coarse	Calif. Deg. After Test Grad. Coarse	Calif. Deg. After Test Grad. for Surface Area (Based upon 50% Passing - No. 4)
3/4"	100	100	100	100	100	100	100	
1/2"	82	83	83	83	83	58	59	
3/8"	70	67	67	67	67	36	37	
No. 4	54	50	51	50	51	0	1	50
						Fine	Fine	
No. 6	43	40	42	38	41	81	84	42
No. 8	35	32	36	31	34	65	69	35
No. 16	23	21	26	19	24	42	47	24
No. 20	20	19	23	16	21	36	41	21
No. 30	17	16	21	13	18	29	36	18
No. 40	14	13	19	11	16	23	31	16
No. 50	12	11	16	8	14	17	26	13
No. 100	6	6	11	2	8	4	16	8
No. 200	4	4	9	0	5	0	11	6
Surface Area	23.05	22.30	35.78	12.26	26.50			27.85
F.M.	4.55	4.64	4.39	4.77	4.51			4.52
S. E.	33	33	28		58			
D_c							82	
D_f							54	

~~Fr-33 s~~

Fr-33 s

~~APPENDIX B~~

Sieve Size	Orig. Grad.	Unwashed Idaho Deg. Orig. Grad.	Unwashed Idaho Deg. After Test	Washed Idaho Deg. Orig. Grad.	Washed Idaho Deg. After Test	Calif. Deg. Before Test Grad. Coarse	Calif. Deg. After Test Grad. Coarse	Calif. Deg. After Test Grad. for Surface Area (Based upon 50% Passing - No. 4)
3/4"	100	100	100	100	100	100	100	
1/2"	89	83	83	83	84	58	58	
3/8"	75	67	67	67	67	36	37	
No. 4	56	50	50	50	51	0	2	50
						Fine	Fine	
No. 6	48	43	44	43	44	87	90	45
No. 8	41	37	39	36	38	74	78	39
No. 16	25	22	26	21	24	44	50	25
No. 20	19	17	21	15	19	32	39	20
No. 30	13	12	16	10	14	21	28	14
No. 40	9	8	13	6	11	13	21	11
No. 50	7	6	11	4	8	8	17	9
No. 100	4	4	8	1	6	3	13	7
No. 200	3	3	7 ✓	0	5 ✓	0	11	6
Surface Area	22.22	17.70	29.31	10.21	23.15			25.65
F.M.	4.54	4.69	4.50	4.78	4.59			4.56
S.E.	80 ✓	80 ✓	67 ✓		76 ✓			
D_c							82 ✓	
D_f							69 ✓	

APPENDIX D

Test Results & Averages

Source	California Degradation Test Ave. D_c	California Degradation Test Ave. D_f	Average Original S. E.	Unwashed Idaho Degradation Test Average Final S. E.	Unwashed Idaho Degradation Test Average Final -#200	Washed Idaho Degradation Test Average Final S. E.	Washed Idaho Degradation Test Average Final -#200
Bl-94 & 94 A	80, 80, 82 → 80	47, 46, 49 → 47	70, 72 → 71	51, 52, 54 → 53	7, 7, 7 → 7	63, 65, 62 → 64	4, 4, 4 → 4
Bu-58	78, 78 → 78	36, 31, 33 → 33	66, 63 → 65	39, 39, 40 → 40	8, 8, 8 → 8	57, 57, 58 → 58	5, 5, 5 → 5
Cs-57	78, -, - → 78	55, 54, 49 → 53	67, 67 → 67	50, 47, 51 → 50	7, 8, 7 → 7	66, 67, 67 → 67	-, -, 4 → 4
Cs-84 A	67, 67 → 67	46, 40, 40 → 42	54, 56 → 55	28, 30 → 29	16, -, 11 → 14	51, 47 → 49	6, 6 → 6
Cu-39	73, 73, 72 → 73	42, 40, 35 → 39	63, 63 → 63	38, 40, 38 → 39	8, 7, 8 → 8	54, 52, 51 → 53	6, -, - → 6
Jr-2	72, 73, 74 → 73	27, 27, 27 → 27	62, 61 → 62	35, 34, 34 → 35	13, 13, 13 → 13	44, 45, 46 → 45	9, 9, 9 → 9
Jr-38	74, 71, 70 → 72	51, 53, 54 → 53	42, 42 → 42	27, 24, 24 → 25	18, 17, 18 → 18	64, 59, 62 → 62	10, 10, 18 → 10
TF-63	67, 68, 67 → 67	41, 41, 40 → 41	61, 63 → 62	42, 44, 44 → 44	10, 9, 9 → 9	58, 58, 59 → 59	7, 6, 6 → 6
TF-66	80, 80-, 80 → 80	67, 64, 64 → 65	70, 69 → 70	49, 50, 51 → 50	5, 6, 6 → 6	62, 66, 66 → 65	4, 4, 4 → 4
TF-67	55, 54, 55 → 55	25, 24, 25 → 25	43, 43 → 43	26, 26, 25 → 26	18, 18, 18 → 18	40, 43, 42 → 42	11, 11, 11 → 11
Id-93	58, 59, 60 → 59	32, 32, 30 → 32	58, 58 → 58	32, 32, 35 → 33	14, 14, 14 → 14	51, 54, 52 → 53	9, 9, 9 → 9

Lt-102	62 62 62	62	37 39 37	38	72 71	72	46 43 44	45	12 12 11	12	59 59 57	59	7 7 8	7
Lt-126	78 78 79	78	57 58 58	58	70 69	70	57 51 51	53	12 12 12	12	68 67 66	67	7 7 7	7
NP-11	80 80 80	80	61 59 59	59	85 85	85	70 66 63	67	7 7 6	7	78 79 74	77	4 4 4	4
NP-32	85 85 85	85	76 75 79	77	88 88 88	88	78 80 80	80	5 6 5	5	88 88 88	88	3 3 3	3
NP-96	74 74 74	74	56 54 59	57	73 75	74	52 54 52	53	12 11 12	12	73 69 67	70	7 7 7	7
Kt-1	85 85 85	85	70 70 68	70	81 82	82	68 66 66	67	9 9 9	9	75 77 75	76	6 6 7	6
Bn-33 s	87 87 -	87	38 41 39	39	54 53	54	33 34 38	35	11 11 11	11	54 56 57	56	6 6 6	6
Cl-56 s	82 82 82	82	57 52 54	54	32 34	33	28 29 26	28	9 9 9	9	58 58 57	58	5 5 5	5
Fr-33 s	82 82 -	82	69 69 -	69	79 80	80	66 67 67	67	7 7 7	7	76 75 75	76	5 4 5	5

APPENDIX E

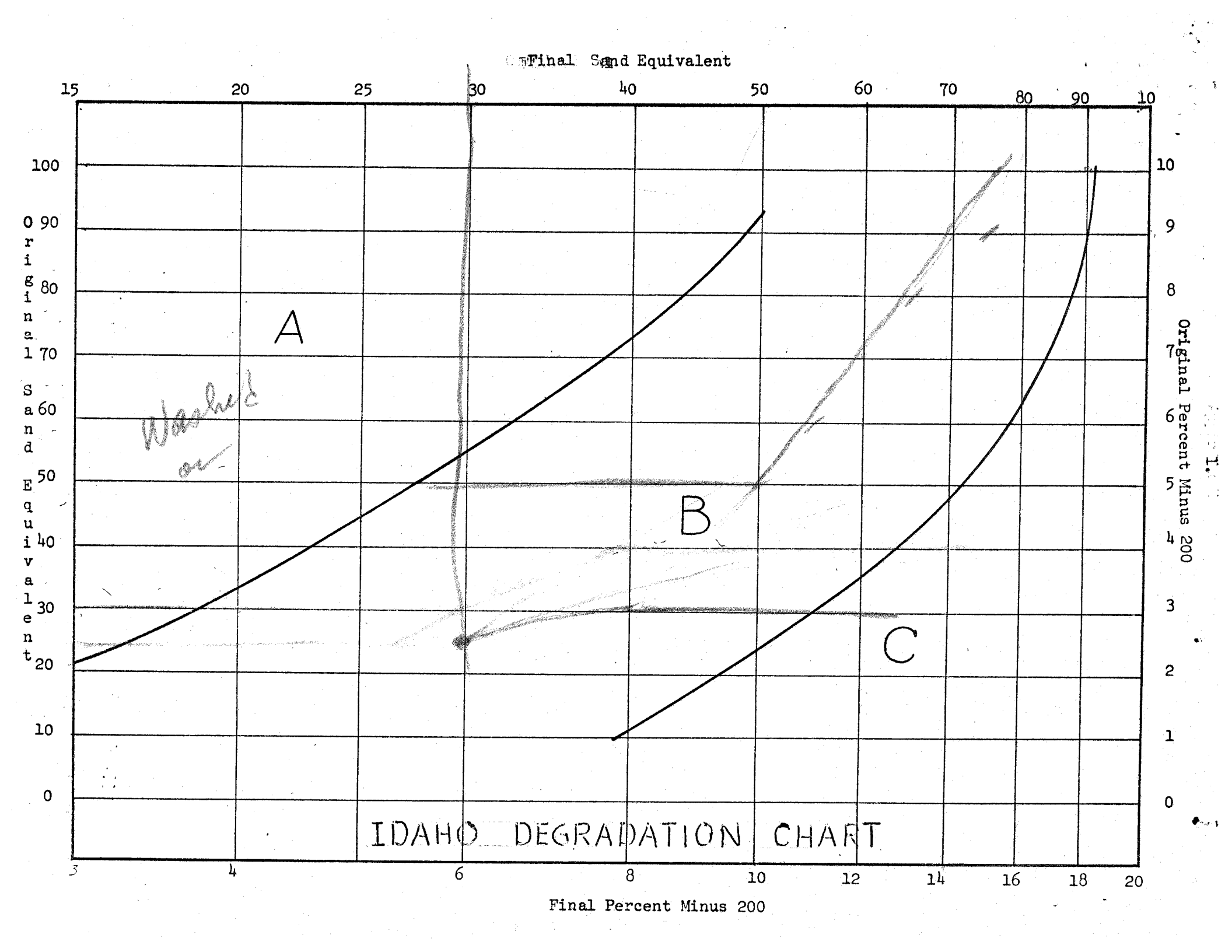
The test results from the individual tests are listed opposite the sources. A rating of good or poor was assigned to each source based upon the respective California degradation test and Idaho degradation test results. A rating of good was assigned to those sources having California degradation test values of 40 or more for D_c or D_f. (California standard specifications specify a minimum value of 40 for Class I bases and permeable materials.) The Idaho degradation test results were plotted on the degradation chart shown in Appendix "F" to obtain a rating. Zones "A" and "C" indicate poor or undesirable material while Zone "B" indicates good or acceptable material.

The washed Idaho degradation test could not be assigned a good or a poor rating because there is no criteria for evaluation.

Comparison of Basic Data

Source	California Degradation Test				Unwashed Idaho Degradation Test						Washed Idaho Degradation Test			
	D_c	D_f	Rating Good	Rating Poor	Orig. S.E.	Final S.E.	Orig. #200	Final 200	Rating Good	Rating Poor	Orig. S.E.	Final S.E.	Orig. 200	Final 200
Bl-94 & 94-A	80	47	X		71	53	4	7	X		71	64	0	4
Bu-58	78	33		X	65	40	4	8	X		65	58	0	5
Cs-57	78	53	X		67	50	3	7	X		67	67	0	4
Cs-84-A	67	42	X		55	29	4	14		X	55	49	0	6
Cu-39	73	39		X	63	39	3	8	X		63	53	0	6
Jr-2	73	27		X	62	35	5	13	X		62	45	0	9
Jr-38	72	53	X		42	25	10	18	X		42	62	0	10
TF-63	67	41	X		62	44	4	9	X		62	59	0	6
TF-66	80	65	X		70	50	3	6	X		70	65	0	4
TF-67	55	25		X	43	26	9	18		X	43	42	0	11
Id-93	59	32		X	58	33	7	14	X		58	53	0	9
Lt-102	62	38		X	72	45	4	12	X		72	59	0	7
Lt-126	78	58	X		70	53	7	12	X		70	67	0	7
NP-11	80	59	X		85	67	3	7	X		85	77	0	4
NP-32	85	77	X		88	80	3	5	X		88	88	0	3
NP-96	74	57	X		74	53	5	12	X		74	70	0	7
Kt-1	85	70	X		82	67	4	9	X		82	76	0	6
Bn-33 s	87	39		X	54	35	6	11	X		54	56	0	6
Cl-56 s	82	54	X		33	28	4	9	X		33	58	0	5
Fr-33 s	82	69	X		80	67	3	7	X		80	76	0	5

APPENDIX F


Final Sand Equivalent
15
20
25
30
40
50
60
70
80
90
10
100
90
80
70
60
50
40
30
20
10
0
Original Sand Equivalent
A
B
C
Washed on
10
9
8
7
6
5
4
3
2
1
0
Original Percent Minus 200
IDAHO DEGRADATION CHART
3
4
6
8
10
12
14
16
18
20
Final Percent Minus 200

APPENDIX G

Comparison of Finenesss Modulus (F.M.) and Surface Area (S.A.)

Service Record	Original Sample Surface Area	Original Sample F.M.	Unwashed Idaho Degradation Test Original Gradation S.A.	Unwashed Idaho Degradation Test Original Gradation F.M.	Unwashed Idaho Degradation Test After Test S.A.	Unwashed Idaho Degradation Test After Test F.M.	Washed Idaho Degradation Test Original Gradation S.A.	Washed Idaho Degradation Test Original Gradation F.M.	Washed Idaho Degradation Test After Test S.A.	Washed Idaho Degradation Test After Test F.M.	California Degradation After Test S.A.	California Degradation After Test F.M.
Good												
NP-32	17.21	4.73	16.79	4.82	22.24	4.73	9.11	4.95	16.59	4.84	19.27	4.80
Bl-94	24.81	4.23	23.15	4.39	32.25	4.24	13.84	4.49	24.62	4.34	26.56	4.34
Kt-1	22.69	4.56	21.25	4.69	35.71	4.42	10.97	4.85	29.59	4.60	29.11	4.57
NP-96	26.22	4.55	23.15	4.70	39.97	4.50	9.99	4.91	27.03	4.68	32.47	4.57
NP-11	17.77	4.73	17.27	4.85	27.45	4.65	9.62	4.95	19.70	4.79	24.92	4.69
Acceptable												
Bu-58	25.20	4.34	23.52	4.50	35.62	4.29	14.24	4.60	27.34	4.42	29.27	4.41
Cu-39	21.41	4.38	20.42	4.53	31.21	4.32	12.99	4.70	27.72	4.42	27.48	4.43
Bn-33 s	36.45	4.16	33.06	4.30	46.20	4.14	18.86	4.47	34.28	4.29	38.89	4.25
Cs-84 A	21.23	4.72	20.01	4.84	46.29	4.42	10.26	4.99	25.57	4.77	30.42	4.71
Cs-57	22.71	4.30	18.22	4.67	29.69	4.47	11.24	4.76	28.81	4.60	23.71	4.56
TF-66	19.63	4.39	19.00	4.54	27.50	4.39	12.41	4.59	22.03	4.48	21.34	4.49
Cl-56 s	23.05	4.55	22.30	4.64	35.78	4.39	12.26	4.77	26.50	4.51	27.85	4.52
Fr-33 s	22.22	4.54	17.70	4.69	29.31	4.50	10.21	4.78	23.15	4.59	25.65	4.56
Poor												
Jr-38	36.39	4.50	41.12	4.26	61.12	3.98	15.55	4.62	42.00	4.24	42.73	4.26
TF-67	35.50	4.46	35.50	4.46	59.27	4.05	12.45	4.77	40.82	4.34	45.41	4.33
Lt-126	35.07	4.23	31.84	4.39	44.41	4.22	14.83	4.60	31.30	4.43	33.73	4.39
TF-63	20.95	4.58	20.11	4.70	34.23	4.42	10.74	4.82	26.86	4.55	30.67	4.52
Jr-2	24.80	4.45	23.30	4.59	46.39	4.21	11.40	4.75	36.17	4.33	37.70	4.34
Id-93	28.95	4.57	27.68	4.66	46.89	4.32	10.20	4.91	33.41	4.58	40.14	4.48
Lt-102	23.24	4.64	20.23	4.78	40.18	4.48	8.80	4.99	27.16	4.68	34.80	4.57

APPENDIX H

The service record column is a compilation of the opinions of the District Materials Engineers together with the Materials and Research Engineer concerning the service histories of the named sources. The other twenty-one columns have been compared to the service record column after the mathematical manipulation indicated at the top of each column was performed.

Figure 1 is a plot of the final minus #200 of the California degradation test against the final minus #200 of the washed Idaho degradation test. Figure 2 is a comparison between D_f of the California degradation test and the final sand equivalent of both the washed and unwashed Idaho degradation tests. The coefficient of correlation, r, has been computed for both comparisons. Figures 3 and 4 are plots of D_f from the California test against the final sand equivalent from the washed and unwashed Idaho tests, respectively. The final minus #200 of the California test has been plotted against the final sand equivalent from the washed and unwashed Idaho tests in Figures 5 and 6 respectively.

Figure 7 is a relative comparison between sources of the surface area divided by the fineness modulus for the original sample and for the unwashed Idaho test. This provides a graphic picture of Columns 2 and 5, respectively. Figure 8 is a relative comparison between sources of the original sand equivalent divided by the final sand equivalent for both the unwashed and washed Idaho tests. This is a pictorial representation of Columns 4 and 8, respectively.

Test Result Comparison of Sources
(Arranged in order according to results of mathematical manipulation indicated)

	Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9
			Unwashed Idaho Degradation					Washed Idaho Degradation	
	rvice cord ood	Calif. Deg. D_f	Orig. Sample S.A. / F.M.	Orig. S.E.	Orig. S.E. / Fin. S.E.	S.A. / F.M.	Fin. 200 / Orig. 200	Orig. S.E. / Fin. S.E.	S.A. / F.M.
	P-32	NP-32	NP-32	NP-32	NP-32	NP-32	NP-32	Cl-56 s	NP-32
	l-94	Kt-1	NP-11	NP-11	Cl-56 s	NP-11	Lt-126	Jr-38	NP-11
	t-1	Fr-33 s	TF-66	Kt-1	Fr-33 s	TF-66	Bl-94	Bn-33 s	Cs-57
	P-96	TF-66	Cs-84 A	Fr-33 s	Kt-1	Fr-33 s	Jr-38	NP-32	TF-66
	P-11	NP-11	TF-63	NP-96	NP-11	Cs-57	Bn-33 s	Cs-57	Fr-33 s
	ceptable								
	u-58	Lt-126	Fr-33 s	Lt-102	Lt-126	Cu-39	TF-66	TF-67	Cs-84 A
	u-39	NP-96	Cu-39*	Bl-94	Cs-57	Bl-94	Bu-58*	Lt-126	Bl-94
	n-33 s	Cl-56 s	Kt-1	TF-66	Bl-94*	TF-63	TF-67*	Fr-33 s	NP-96
	s-84 A	Cs-57	Lt-102	Lt-126	TF-66	Kt-1	Id-93*	TF-63*	Lt-102
	s-57	Jr-38	Cl-56 s	Cs-57	NP-96	Cl-56 s	TF-63	NP-96	Cl-56 s
	F-66	Bl-94	Cs-57	Bu-58	TF-63	Bu-58	Cl-56 s*	TF-66	TF-63
	l-56 s	Cs-84 A	Jr-2	Cu-39	Bn-33 s	NP-96	Kt-1*	Kt-1	Bu-58
	Fr-33 s	TF-63	NP-96	Jr-2	Lt-102	Lt-102	Fr-33 s	Id-93*	Cu-39
	Poor								
	Jr-38	Bn-33 s	Bu-58	TF-63	Cu-39	Cs-84 A	NP-11*	NP-11	Kt-1
	TF-67	Cu-39	Bl-94	Id-93	Bu-58	Lt-126	Cs-57*	Bl-94	Lt-126
	Lt-126	Lt-102	Id-93	Cs-84 A	TF-67	Id-93	NP-96	Cs-84 A	Id-93
	TF-63	Bu-58	TF-67	Bn-33 s	Jr-38	Jr-2	Jr-2	Cu-39	Bn-33 s
	Jr-2	Id-93	Jr-38	TF-67	Id-93	Bn-33 s	Cu-39	Cl-56 s	Bn-58
	Id-93	Jr-2	Lt-126	Jr-38	Jr-2	TF-67	Lt-102	TF-67	Lt-102
	Lt-102	TF-67	Bn-33 s	Cl-56 s	Cs-84 A	Jr-38	Cs-84 A	Jr-38	Jr-2

* Indicates same value as source above

0	1	0	0	0	2	0	2	1
3	2	3	3	2	3	2	3	1
3	3	3	3	2	5	2	5	2
6	6	6	6	4	10	4	10	4

Test Result Comparison of Sources

(Arranged in order according to results of mathematical manipulation indicated)

Col. 10		Col. 11	Col. 12	Col. 13	Col. 14	Col. 15	Col. 16
		Washed Idaho Degradation Test					
Service Record	Calif. Deg. Test Final	Final % -#200	Final S.E.	Final S.E. Final.% -#200	Increase in Surface Area	Decrease in F.M.	Col. 11 x Col. 15 x 100
Good							
NP-32	TF-66	NP-32	NP-32	NP-32	NP-32	NP-32	NP-32
Bl-94	NP-32	TF-66	NP-11	NP-11	TF-66	TF-66	TF-66
Kt-1	Bl-94	NP-11	Fr-33 s	Fr-33 s	NP-11	Bl-94	Bl-94
NP-96	Cs-57	Cs-57	Kt-1	TF-66	Cs-57	NP-11	NP-11
NP-11	NP-11	Bl-94	NP-96	Cs-57	Bl-94	Cs-57	Cs-57
Acceptable							
Bu-58	Bu-58 *	Fr-33 s	Cs-57	Bl-94	Fr-33 s	Lt-126	Bu-58
Cu-39	Fr-33 s *	Bu-58	Lt-126	Kt-1	Bu-58	Bn-33 s	Fr-33 s
Bn-33 s	Cu-39 *	Cu-39	TF-66	Bu-58	Cl-56 s	Bu-58	Bn-33 s
Cs-84 A	Cl-56 s *	Cl-56 s	Bl-94	Cu-39	Cu-39	Fr-33 s	Lt-126
Cs-57	Kt-1	Kt-1	Jr-38	TF-63	Cs-84 A	Cs-84 A	Cl-56 s
TF-66	TF-63	TF-63	TF-63	Cl-56 s	Bn-33	NP-96	Cs-84 A
Cl-56 s	Cs-84 A	Bn-33 s	Lt-102	NP-96	TF-63	Kt-1	TF-63
Fr-33 s	Bn-33 s *	Lt-126	Bu-58	Lt-126	Lt-126	Cl-56 s	Kt-1
Poor							
Jr-38	Lt-126 *	NP-96	Cl-56 s	Bn-33 s	NP-96	TF-63	NP-96
TF-67	NP-96	Lt-102	Bn-33 s	Lt-102	Lt-102	Cu-39	Cu-39
Lt-126	Jr-2	Jr-2	Cu-39	Id-93	Kt-1	Lt-102	Lt-102
TF-63	Lt-102	Cs-84 A	Id-93	Cs-84 A	Id-93	Id-93	Id-93
Jr-2	Jr-38	Id-93	Cs-84 A	Jr-2	Jr-2	Jr-38	Jr-2
Id-93	Id-93	Jr-38	Jr-2 A	Jr-38	Jr-38	Jr-2	Jr-38
Lt-102	TF-67	TF-67	TF-67	TF-67	TF-67	TF-67	TF-67

* Indicates same value as source above

1 0 2/3

1 1 2/4

0 4 4/4

0 2 2/4

2 0 2/4

0 1 1/2

1 1 2/4

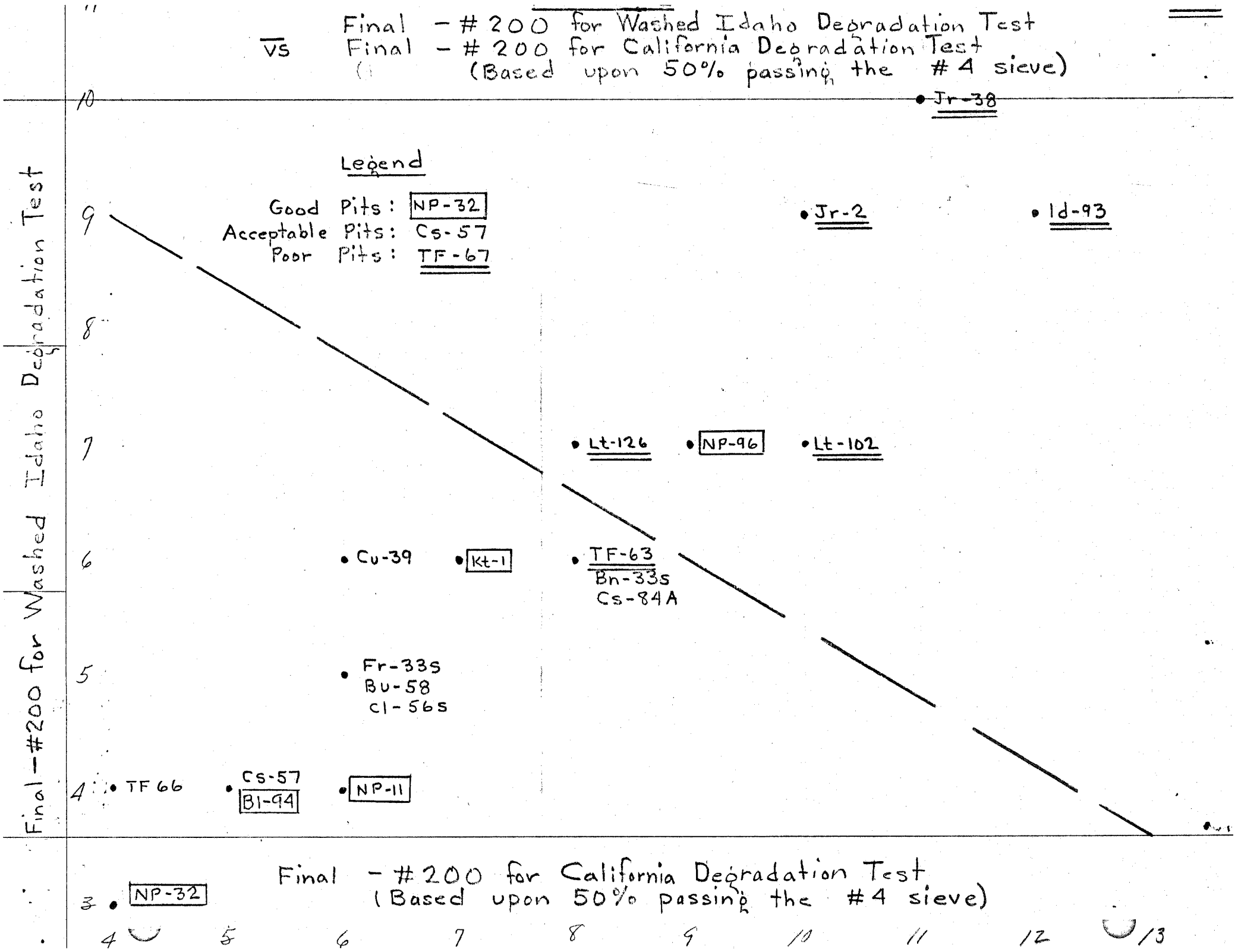
Test Result Comparison of Sources

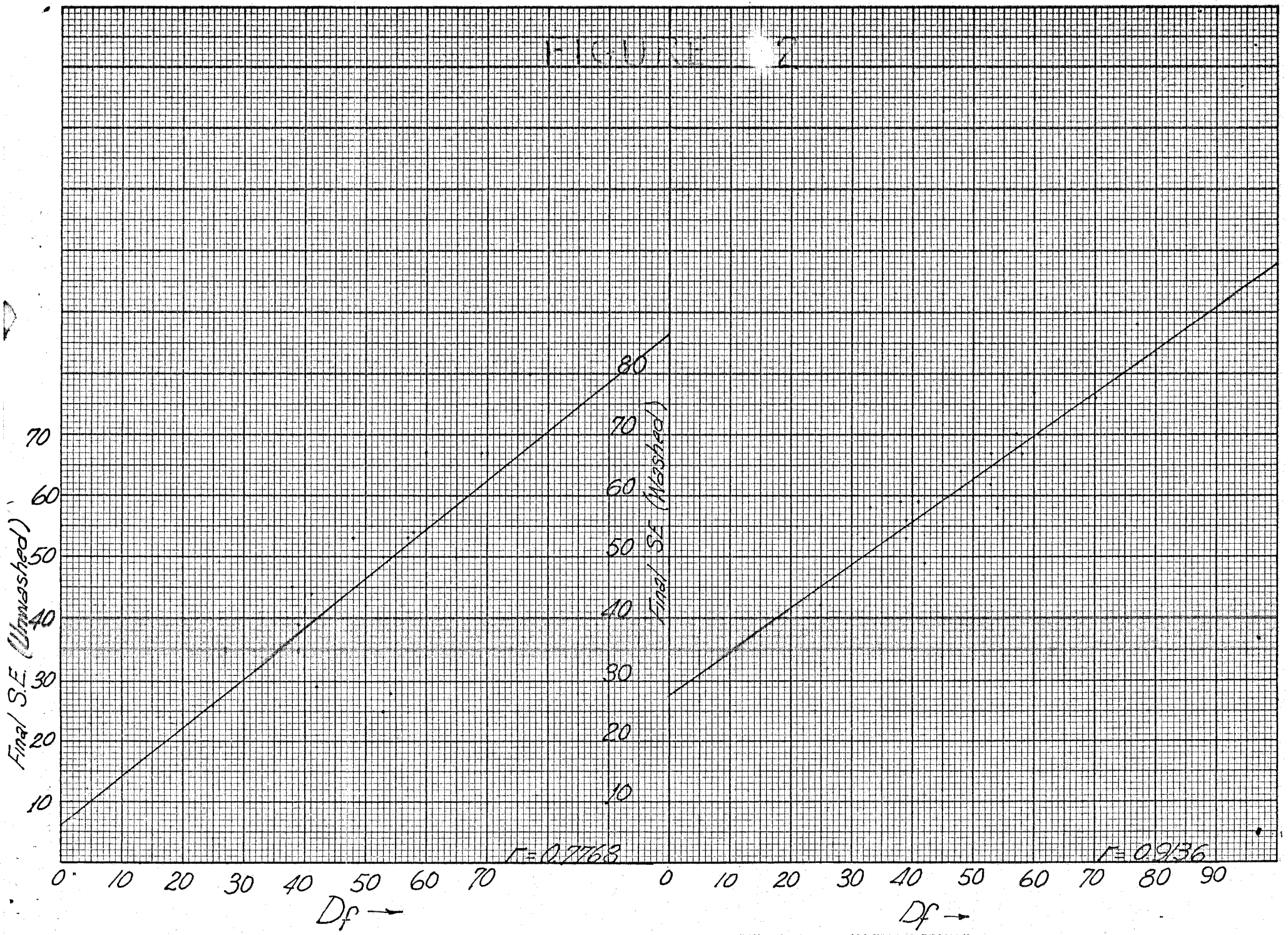
(Arranged in order according to results of mathematical manipulation indicated)

5

Service Record	Col. 17	Col. 18	Col. 19	Col. 20	Col. 21
	Unwashed Idaho Degradation Test				
	Increase in %--#200	Numerical Decrease in S.E.	Increase in Surface Area	Decrease in F.M.	Col. 17 x Col. 20 x 100
Good					
NP-32	NP-32	NP-32	NP-32	NP-32	NP-32
Bl-94	Lt-126	Cl-56 s	TF-66	TF-66	Bl-94
Kt-1	Jr-38	Fr-33 s	Bl-94	Bl-94	Bn-33 s
Np-96	Bl-94	Kt-1	NP-11	Bn-33 s	Lt-126
NP-11	Bn-33 s	NP-11	Cu-39	Lt-126	TF-66
Acceptable					
Bu-58	TF-66	Lt-126	Cs-57	Fr-33 s	Bu-58
Cu-39	Bu-58	Cs-57	Fr-33 s	Np-11	Fr-33 s
Bn-33 s	Id-93	Bl-94	Bu-58	Cs-57	Cs-57
Cs-84 A	TF-67	NP-96	Lt-126	NP-96	NP-11
Cs-57	Cl-56 s	TF-66	Bn-33 s	Cu-39	NP-96
TF-66	Kt-1	TF-63	Cl-56 s	Bu-58	Jr-38
Cl-56 s	TF-63	Bn-33 s	TF-63	Cl-56 s	Cu-39
Fr-33 s	Fr-33 s	Lt-102	Kt-1	Kt-1	Cl-56 s
Poor					
Jr-38	Cs-57	Cu-39	NP-96	TF-63	Kt-1
TF-67	NP-11	Bu-58	Id-93	Jr-38	TF-63
Lt-126	NP-96	TF-67	Lt-102	Lt-102	Id-93
TF-63	Lt-102	Jr-38	Jr-38	Id-93	Lt-102
Jr-2	Jr-2	Id-93	Jr-2	Jr-2	TF-67
Id-93	Cu-39	Jr-2	TF-67	TF-67	Jr-2
Lt-102	Cs-84 A	Cs-84 A	Cs-84 A	Cs-84 A	Cs-84 A
	2	0	1	0	1
	3	3	1	1	1
	5	3	2	1	2
	10	6	4	2	4

Final - #200 for Washed Idaho Degradation Test
vs
Final - #200 for California Degradation Test
(Based upon 50% passing the #4 sieve)





K+E 10 X 10 TO THE ½ INCH 359-11
KEUFFEL & ESSER CO. MADE IN U.S.A.

Figure 2

Final S.E. for Washed Idaho Degradation Test vs Df for California Degradation Test

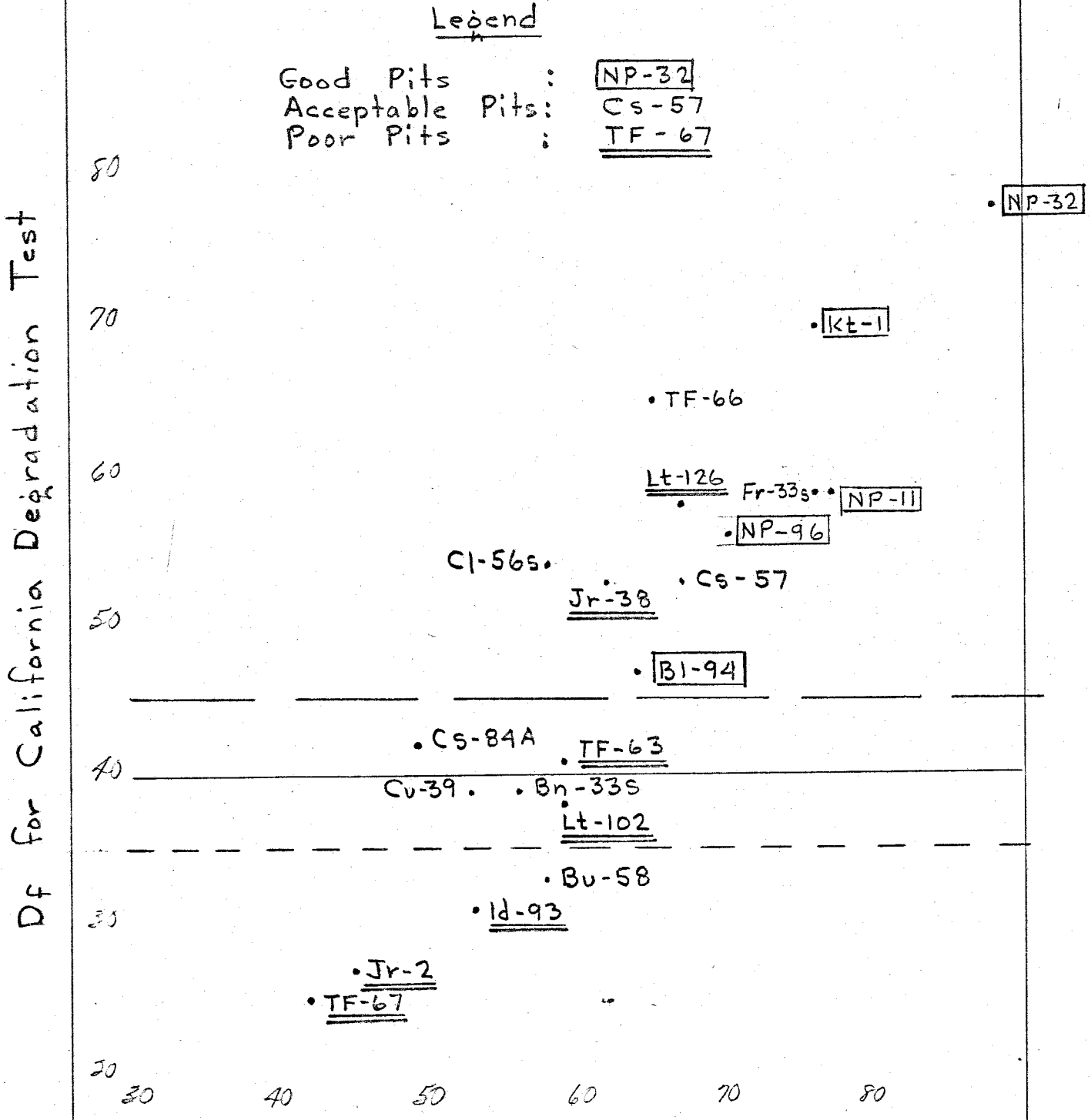
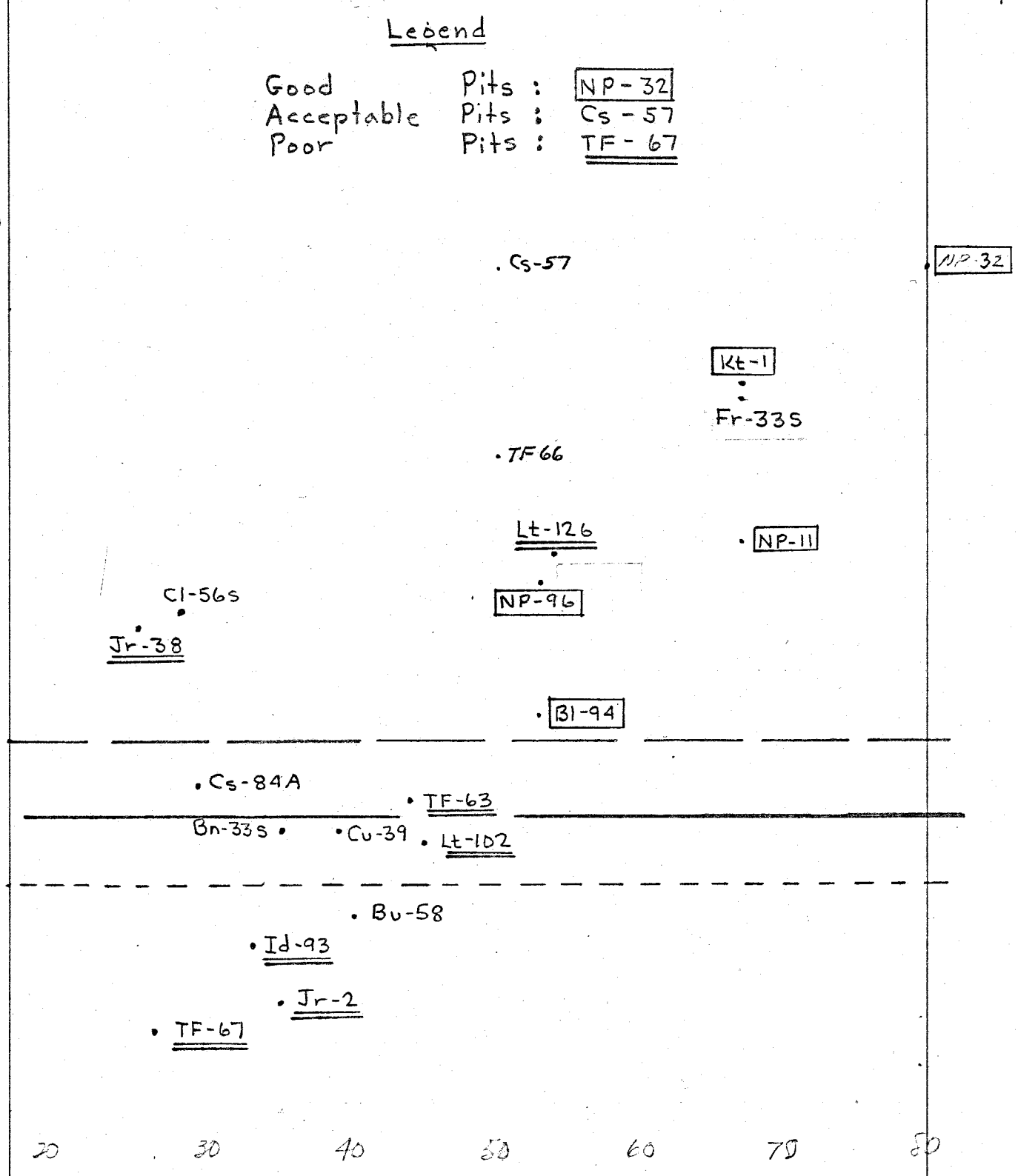


FIGURE 1

Final S.E. for Unwashed Idaho Degradation Test vs Df for California Degradation Test

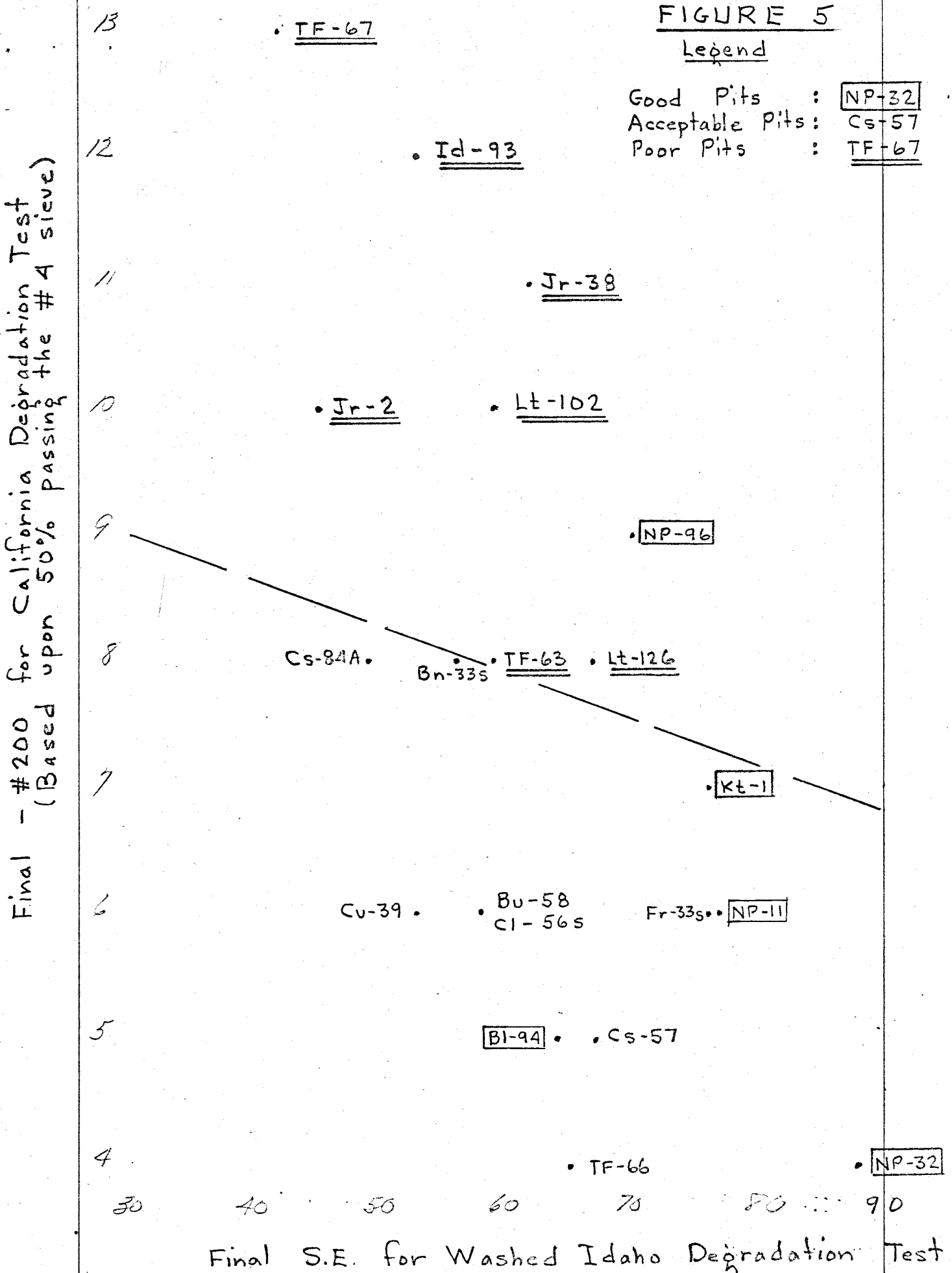


(Based upon 50% passing the #4 sieve)

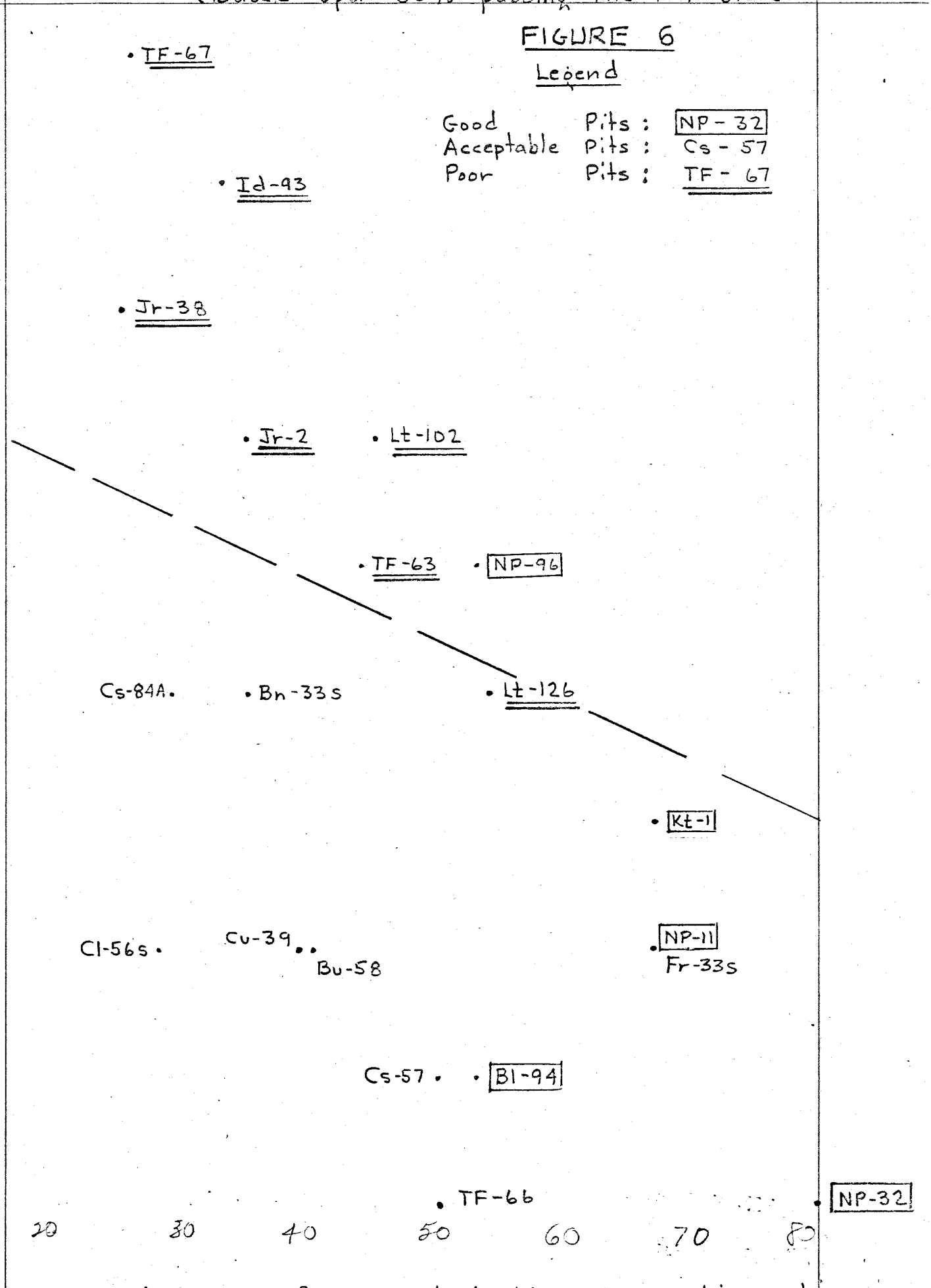
FIGURE 5

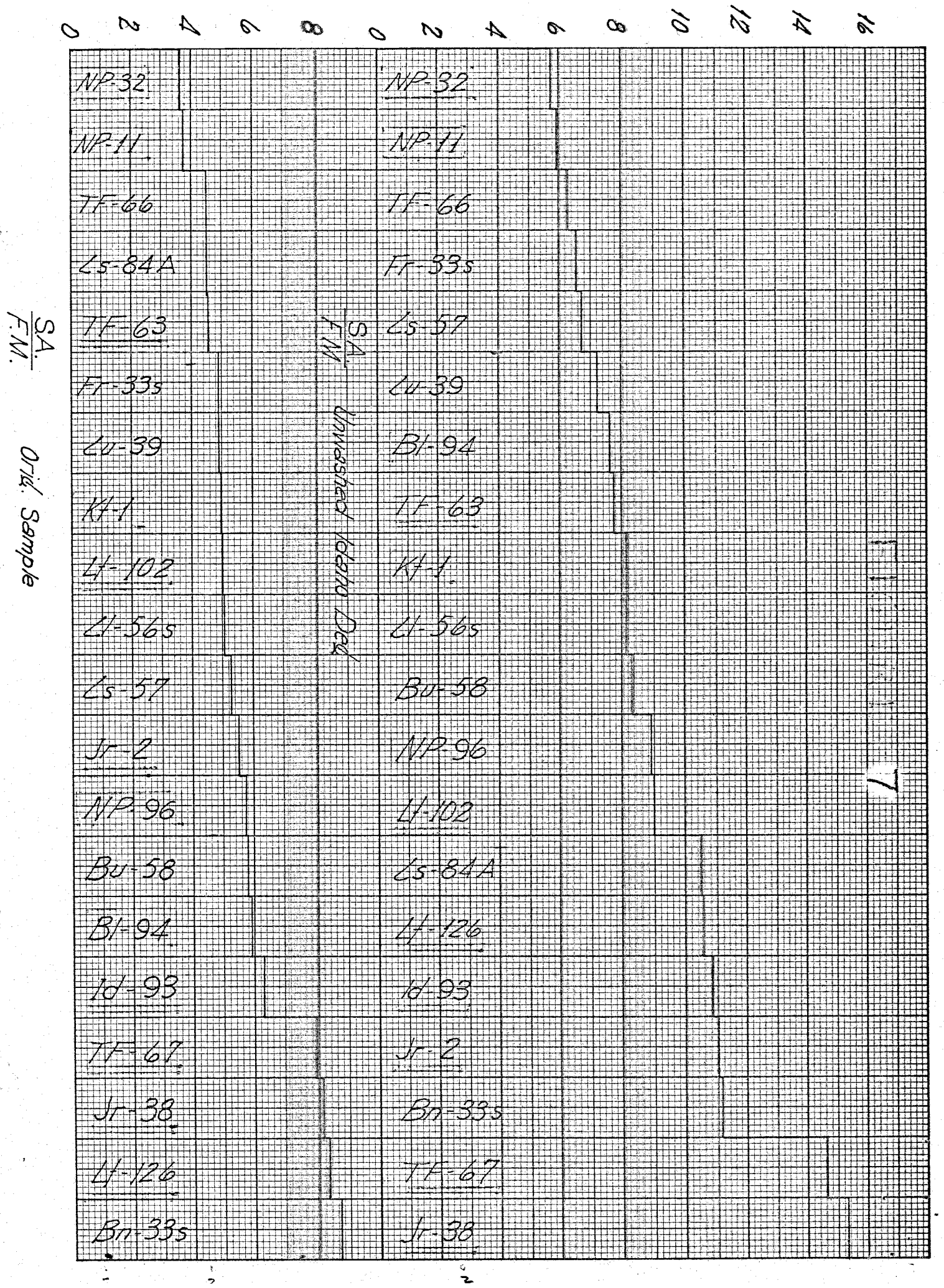
Legend

Good Pits : NP-32
Acceptable Pits : Cs-57
Poor Pits : TF-67



Final S.E. for Unwashed Idaho Degradation Test vs Final -#200 for California Degradation Test (Based upon 50% passing the #4 sieve)





0 2 4 6 8 0 2 4 6 8 10 12 14 16
NP-32
NP-11
TF-66
Ls-84A
TF-63
Fr-33s
Lu-39
Kt-1
Lt-102
Ll-56s
Ls-57
Jr-2
NP-96
Bu-58
Bl-94
Id-93
TF-67
Jr-38
Lt-126
Bn-33s
S.A./F.M.
Unwashed Idaho Ded
NP-32
NP-11
TF-66
Fr-33s
Ls-57
Lu-39
Bl-94
TF-63
Kt-1
Ll-56s
Bu-58
NP-96
Lt-102
Ls-84A
Lt-126
Id-93
Jr-2
Bn-33s
TF-67
Jr-38
S.A./F.M.
Orid. Sample
7
10 X 10 TO THE ½ INCH 359-11
KEUFFEL & ESSER CO. MADE IN U.S.A.

Orig. S.E.
Fin. S.E.

Unwashed

NP-32
Lt-56s
Fr-33s
Kf-1
NP-11
Lt-126
Ls-57
Bl-94
TF-66
NP-96
TF-63
Bn-33s
Lt-102
Lu-39
Bu-58
TF-67
Jr-38
Id-93
Jr-2
Ls-84A

Orig. S.E.
Fin. S.E.

Washed

Lt-56s
Jr-38
Bn-33s
NP-32
Ls-57
TF-67
Lt-126
Fr-33s
TF-63
NP-96
TF-66
Kf-1
Id-93
NP-11
Bl-94
Ls-84A
Lu-39
Bn-58
Lt-102
Jr-2

10 X 10 TO THE ½ INCH
KEUFFEL & ESSER CO.
339-11
MADE IN U.S.A.

APPENDIX J

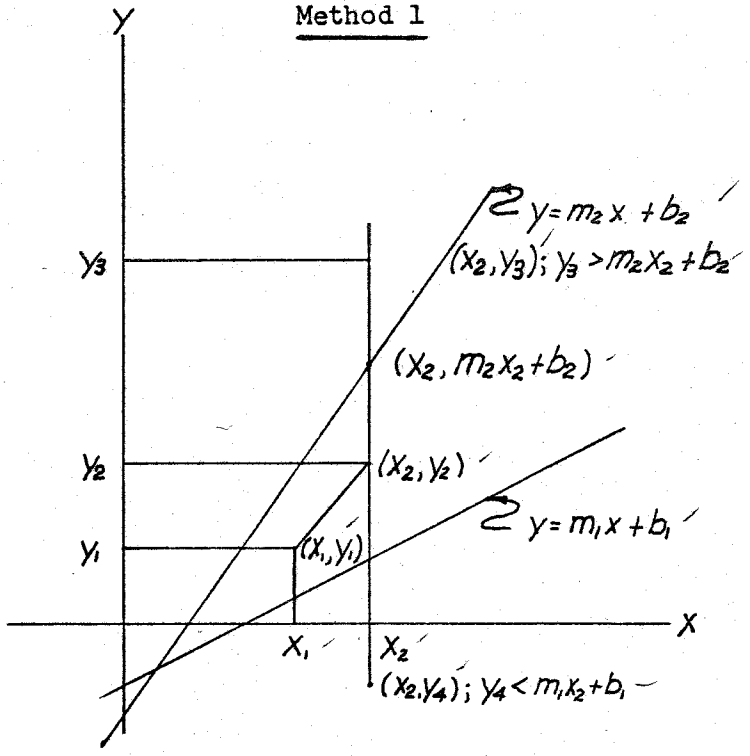
Mathematical Derivation of Formulas

This appendix contains three methods (along with an explanation for each method) by which a numerical value can be assigned to the degradation potential of an aggregate. Each of the three methods gives identical results and each is based upon the curves shown on the Idaho Degradation Chart in Appendix "F".

Figure 9 is a comparison between the original sand equivalent and the final sand equivalent and between the original minus #200 and the final minus #200 for the unwashed Idaho degradation test. The coefficient of correlation, r, has been computed for both comparisons.

Mathmatical Derivation Formulas

Method 1



e.g. $m_1 x_1 + b_1 \leq y_1 \leq m_2 x_1 + b_2$

$m_1 x_2 + b_1 \leq y_2 \leq m_2 x_2 + b_2$

Where $m_1 = 0.657$ $m_2 = 1.96$

$b_1 = -4.14$ $b_2 = -5.88$

x_1 = Final -#200 x_2 = Final S. E.

y_1 = Original -#200 y_2 = Original S. E.

Method 1 was derived by plotting the lines given on the present Idaho degradation evaluation chart, as shown in Appendix E, on arithmetic graph paper and computing the slopes, m_1 and m_2, of the lines. From that analysis the equation for both lines was derived as:

$y = m_1 x + b_1$ and $y = m_2 x + b_2$.

The area between the lines is the "B" or good area that can be defined for any x value in terms of y. That is, for any x value such as x_2, the upper limit is given by $m_2x_2 + b_2$ and the lower limit is given by $m_1x_2 + b_1$. This defines a set of limits for the y_2 value. If the y_2 value is within the specified limits, the value is acceptable.

Example:

Let: Final -#200 = 15 Final S E = 24

Original -#200 = 10 Original S E = 40

Then: $x_1 = 15$ $x_2 = 24$

$y_1 = 10$ $y_2 = 40$

$m_1x_1 + b_1 \leq y_1 \leq m_2x_1 + b_2$ $m_1x_2 + b_1 \leq y_2 \leq m_2x_2 + b_2$

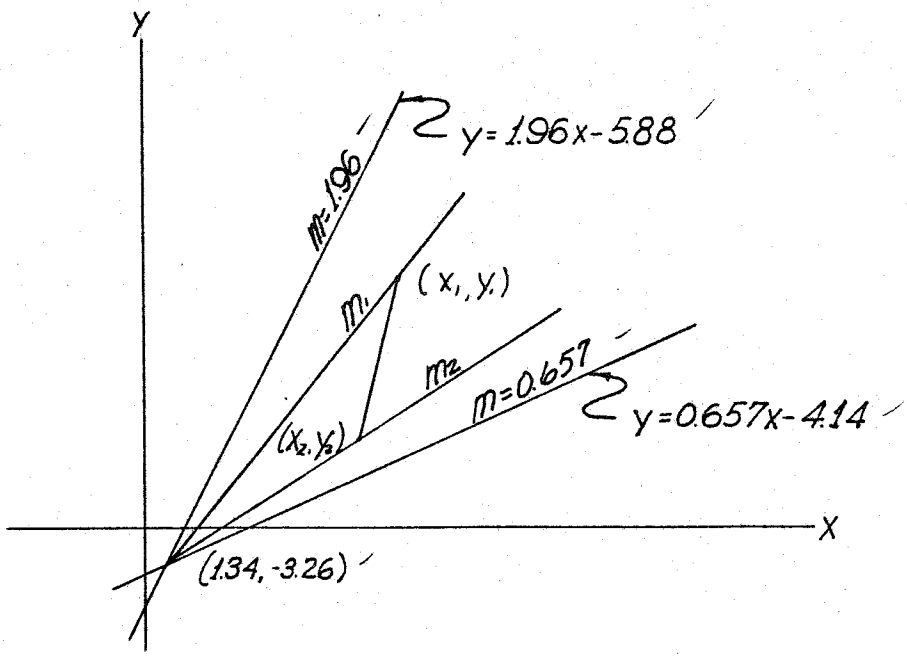
$0.657\ (15) + (-4.14) \leq 10 \leq 1.96\ (15) + (-5.88)$

$0.657\ (24) + (-4.14) \leq 40 \leq (1.96)\ (24) + (-5.88)$

$5.72 < 10 < 23.52$ $11.63 < 40 < 41.16$

Both values of y are within the calculated limits indicating that the material is acceptable. Note, however, that the sand equivalent values for the material are borderline since the value of y_2=40 is very close to the calculated upper limit of 41.16 in the second equation.

Method 2



$y = 1.96\,x - 5.88$

$(-)y = -0.66\,x + 4.14$

$0 = 1.30\,x - 1.74$

$x = 1.34$

$y = 1.96\,(1.34) - 5.88$

$y = -3.26$

$$m_1 = \frac{y_1 - (-3.26)}{x_1 - 1.34} \quad ; \quad m_2 = \frac{y_2 - (-3.26)}{x_2 - 1.34}$$

i.e. $0.657 \leq m_1 \leq 1.96$

$0.657 \leq m_2 \leq 1.96$

Where: x_1 = Final -#200 x_2 = Final S.E.

y_2 = Original -#200 y_2 = Original S.E.

Method 2 was derived in the same manner as Method 1. Again, as in Method 1, the area enclosed by the two defined lines is the "B" or good area.

As shown in the diagram both lines are defined by slope and an equation. The equations were solved simualtaneously to locate the point of intersection of the lines at (1.34, -3.26). Then, for any point, such as (x_1, y_1) denoting final and original -#200, or (x_2, y_2) denoting final and original sand equivalent, a line can be drawn through the point and through (1.34, -3.26). This line is then defined by slope, m, via the equation

$$m = \frac{y_1 - y_2}{x_1 - x_2}$$

If the computed slope, m, falls between m = 1.96 and m = 0.657, the point (x_1, y_1) or (x_2, y_2) must necessarily be within the previously defined area. Further, if the computed slope, m, approaches either of the set limits, (m = 1.96 or m = 0.657), the point (x_1, y_1) or (x_2, y_2) can be denoted as "borderline".

Example:

Let: Final -#200 = 15 Final S E = 24

Original -#200 = 10 Original S E = 40

Then $x_1 = 15$ $x_2 = 24$

$y_1 = 10$ $y_2 = 40$

$$m_1 = \frac{y_1 - (-3.26)}{x_1 - 1.34} \qquad m_2 = \frac{y_2 - (-3.26)}{x_2 - 1.34}$$

$$m_1 = \frac{10 + 3.26}{15 - 1.34} \checkmark \qquad m_2 = \frac{40 + 3.26}{24 - 1.34} \checkmark$$

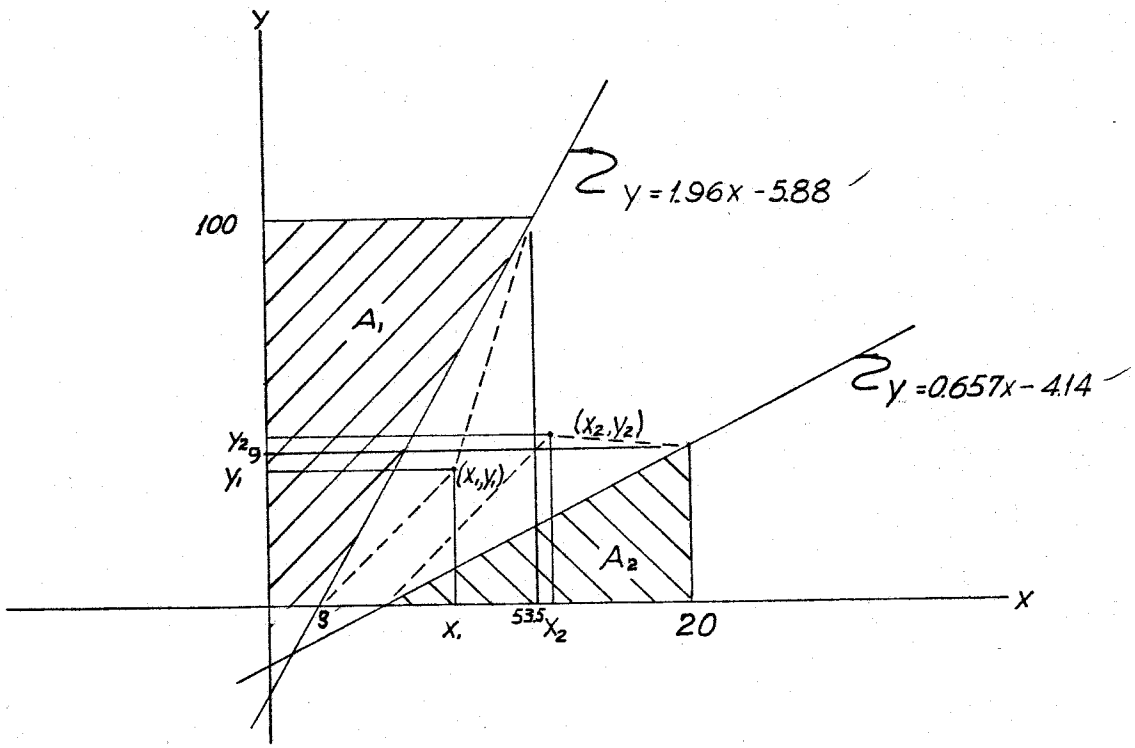
$$= 0.971 \checkmark \qquad = 1.909 \checkmark$$

$$0.657 < 0.971 < 1.96 \checkmark$$

$$0.657 < 1.909 < 1.96 \checkmark$$

Note: That for this example the value of $m_2 = 1.909$ is very close to the upper limit of 1.96 indicating that the values for the sand equivalent denote a borderline condition.

Method 3



$$y = 1.96x - 5.88$$

$$x = \frac{y + 5.88}{1.96}$$

$$A_1 = \int_0^{y^2} \left(\frac{y}{1.96} + 3 \right) dy$$

$$A_1 = \frac{y^2}{3.92} + 3y \Big|_0^{100}$$

$$A_1 = 2851.2$$

$$A_1' = 1/2\,(3 + x_1)\,y_1 + 1/2\,(x_1 + 54)\,(100 - y_1)$$

$$A_1' = 1.5\,y_1 + 0.5\,x_1\,y_1 + 50\,x_1 + 2700 - 0.5\,y_1\,x_1 - 27\,y_1$$

$$A_1' = 50\,x_1 - 25.5\,y_1 + 2700$$

For the source to be considered as acceptable:

$$50\,x_1 - 25.5\,y_1 + 2700 \geq 2851.2$$

Where x_1 = Final S.E.

y_1 = Original S.E.

$$y = 0.657\,x - 4.14$$

$$A_2 = \int_{6.3}^{20} (0.657\,x - 4.14)\,dx$$

$$A_2 = \frac{0.657\,x^2}{2} - 4.14\,x \Big|_{6.3}^{20}$$

$$A_2 = 61.64$$

$$A_2' = 1/2\,(x_2 - 6.3)\,y_2 + 1/2\,(y_2 + 9)\,(20 - x_2)$$

$$A_2' = 1/2\,x_2\,y_2 - 3.15\,y_2 + 10\,y_2 + 90 - 1/2\,x_2\,y_2 - 4.5\,x_2$$

$$A_2' = 6.85\,y_2 - 4.5\,x_2 + 90$$

For the source to be considered as acceptable:

$$6.85\,y_2 - 4.5\,x_2 + 90 \geq 61.64$$

Where x_2 = Final -#200

y_2 = Original -#200

This particular method uses areas to define limits. Using the same basic data as shown in Methods 1 and 2, areas A_1 and A_2 were computed using integration. It can readily be seen from the diagram that area A_1 would be less than an area, A_1', which includes the point (x_1, y_1), and that area A_2 would be less than an area, A_2', which includes the point (x_2, y_2).

If the areas A_1 and A_2 are computed and compared to areas A_1' and A_2', the potential degradation of the material can be determined.

Example:

Let Final S.E. = 24 Final -#200 = 15

Original S.E. = 40 Original -#200 = 10

Then $x_1 = 24$ $x_2 = 15$

$y_1 = 40$ $y_2 = 10$

$$A_1' = 1/2\ (3 + x_1)\ y_1 + 1/2\ (x_1 + 54)\ (100 - y_1)$$

$$= 1/2\ (3 + 24)\ 40 + 1/2\ (24 + 54)\ (100 - 40)$$

$$= 540 + 2340$$

$$A_1' = 2880$$

$$A_1' = 2880 \geq 2851.2$$

$$A_2' = 1/2\ (x_2 - 6.3)\ y_2 + 1/2\ (y_2 + 9)\ (20 - x_2)$$

$$= 1/2\ (15 - 6.3)\ 10 + 1/2\ (10 + 9)\ (20 - 15)$$

$$= 43.5 + 47.5$$

$$= 91.0$$

$$A_2' = 91.0 \geq 61.64$$

Note that for this example the value of $A_1 = 2880$ is very close to the limit of $A_1 = 2851.2$ indicating that the values for the sand equivalent denote a borderline degradation potential.