FIELD VERIFICATION OF ASPHALT AGING IN HOT MIX PLANTS

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ABSTRACT

As a measure of the aging of asphalt concrete mixes in the mixing and placement process, a formula was developed to determine the percentage of expected change in asphalt viscosity at the time of paving (Lund and Wilson, 1984). A value of 30 or higher was used in 1983-84 for acceptance on paving projects. At the conclusion of the 1981-83 study, a follow-up survey was made of all projects. Two major areas of interest were covered in the follow-up questionnaire: 1) the characteristics of the asphalt mix and pavement at the time of placement, and 2) the characteristics of the pavement at the time of receiving the questionnaire (March, 1984).

The responses to the questionnaire, even though they are subjective, appear to identify and confirm relationships between the "C" value and asphalt mix problems. The strongest correlation appears to be more with problems at the time of construction than with long term pavement performance problems. Using statistical tests, the significant problems that were identified during construction were tenderness, shoving and rutting, segregation and mix being too cold. The long term significant problems developing after construction were stripping and cracking.

When the individual characteristics were evaluated, the great majority had the significance level peak at the less than 40 "C" value. That is, a greater percentage of the samples that were below 40 had some problems in the field.

In early 1985, the Oregon Highway Department raised the minimum acceptable "C" value to 40. Mix with a value less than 40 is to be removed, or at the discretion of the Engineer, it may be left in place and a reduction in a Composite Pay Factor calculated (OSHD Spec. 403.39).

In 1985, "C" values were again analyzed to see if any changes had occurred since the 1981-1983 study. Forty-nine projects constructed or under construction from August 1983 to July 1985 were reviewed, from which 193 individual "C" values were obtained. Comparing the results with the 1981-83 data, indicated that individual variables such as burner fuel type, dust collection system, and plant type no longer are associated with changes in "C" values. Instead, the entire operation (adjustment) of the asphalt plant is the major influence on the "C" value. Due to plant adjustments, several contractors, having poor results in the past, have been able to raise their average "C" value.

TABLE OF CONTNENTS

INTRODUCTION

Background

Asphalt concrete pavement tenderness, due to inadequate aging or unexpected soft consistency of the asphalt, has caused problems such as rutting, surface flushing, stripping, ravelling and segregation in Oregon highways over the past ten years. In order to identify the causes of the pavement tenderness, data were gathered from various construction projects throughout the state. As a measure of the aging in the mixing and placement process the following formula was developed to determine the percentage of the expected change in asphalt viscosity at the time of paving (Lund and Wilson, 1984):

$$C = \frac{R - A}{B - A} \times 100\ \%$$

where, A = absolute viscosity of the original asphalt, B = absolute viscosity of the asphalt residue after rolling thin film oven aging, and R = absolute viscosity of the asphalt recovered from the mixture. Based on field observations of paving projects prior to the 1984 report, no paving problems (tenderness) were experienced when "C" values were above 50 percent, some problems were experienced when "C" values were from 30 to 50 percent, and pavement problems were always experienced when "C" values were less than 30 percent. A value of 30 or higher was then used in 1983-84 for acceptance on paving projects (OSHD Specification (403.39).

Starting in 1981 and continuing through July of 1983, data were collected from 29 different projects in Oregon. A total of 111 samples were collected for determining "C" values from these projects. For each project, the contractor, mixing plant type, dust collection system, asphalt concrete mix class, asphalt cement supplier and grade, and burner fuel type were recorded. These variables were correlated against the "C" value of the various paving mix samples.

Results from the study indicated that the selection of burner fuel type is critical in producing a satisfactory mix. Some lower grade fuels (reclaimed oils), due to poor combustion, cause contamination of the mix by softening the asphalt. Low temperature in the mixing or aggregate drying process, especially in drum mixer plant burners, is detrimental to the mix. This produces poor combustion of burner fuel and less aging. The overall operation and construction of asphalt plants, burner fuel type, mixing temperature and the use of bag house dust collectors, has a significant influence on the tenderness of the produced mix (Lund and Wilson, 1984).

In 1985, "C" values were again analyzed to see if any changes had occurred since the 1983 study. Forty-nine projects constructed or under construction from August 1983 to July of 1985 were reviewed, from which 193 individual "C" values were obtained. Data on contractor operation, asphalt plant type, dust collection system, asphalt grade and brand, and burner fuel were collected for each project. These data were then compared against the "C" values from the project.

The results of this study are presented in a series of figures which will be discussed in detail in subsequent sections. In summary, figures one, three and five relate average "C" values to asphalt concrete problems experienced during and after construction. Individual average "C" values for all projects with yes and with no responses or good and fair + poor indications of problems are shown on bar graphs. Figures two, four and six through fourteen show the percentage of "C" values that are less than the indicated limiting value for projects with problems and without problems. The bar graphs illustrate the yes and no responses or good and fair + poor ratings of pavements when "C" values are limited to less than 30, 40 and 50. Values for significance levels are included for each figure. These indicate the importance of the difference in average "C" values between the yes and no responses.

Purpose of The 1984 Study

At the conclusion of the 1981-83 study and the 1984 report, a follow-up survey was made on all of the projects covered in that study. A questionnaire was developed for this purpose, a copy of which is included in the Appendix. This questionnaire was sent to Highway Division project managers for completion. The information requested covered two major areas of interest: 1) the characteristics of the asphalt mix and pavement at the time of placement, and 2) the characteristics of the pavement at the time of receiving the questionnaire (March 1984).

A total of 80 questionnaires were mailed out and 73 were returned. The completed questionnaires covered 133 individual samples for which "C" values had been calculated, and were from 34 different projects. The number of samples per project varied from one to eleven, with the majority of projects having only one or two samples. For projects with multiple samples, the "C" values were averaged for use in the analysis. Some of the questionnaires were only partially complete due to lack of information; thus in subsequent calculations for this report less than 73 questionnaires are used

DATA ANALYSIS OF THE 1984 QUESTIONNAIRE

(1981-1983 PROJECTS)

Referring to the sample questionnaire in the Appendix, the data were analyzed in four different catagories as follows: 1) whether or not there were problems during construction (item I), 2) whether there were problems after construction (item II), 3) an overall rating (good, fair or poor), and 4) a detailed analysis of individual items under the first two categories (I and II). These responses were subjective, since no specific guidelines were given for completion of the questionnaire.

Problems During Construction

The average "C" value and standard deviation for each of the responses under item I were determined The "yes" and "no" value results were then compared for significance using the Student-t test. The results of these analyses are shown in Figure 1 with the data tabulated in the Appendix. The significance level is shown opposite each bar graph, indicating the level at which the "yes" and "no" data differ The higher the percentage of the significance level, the greater the difference. Thus, pavements with tenderness, shoving and rutting, and segregation appear to be strongly influenced by the "C" value of the mix. Note that the pavements exhibiting tenderness, shoving and rutting have lower average "C" values, whereas pavements exhibiting segregation have higher average "C" values.

Stripping (item E), ravelling (item F) and mix too hot (item H) are not shown due to lack of a significant number of "yes" responses. The average "C" value for all of the responses under item I is shown at the top of Figure 1.

The data from item I was also grouped according to the range of the "C" values. Based on the initial work, "C" values between 30 and 50 appeared to be in a critical transition range. For this reason, the percentage of "C" values <30, <40 and <50 were investigated. These grouping are shown graphically in Figure 2 and the detailed data listed in the Appendix. As can be seen the differences between the "yes" and "no" responses are somewhat significant for values less than 30 and 40. As was expected, those projects that had a problem during construction (Questionnaire items A through H) also had the higher percentage of "C" values below the indicated limits of 30, 40 or 50. The Chi-squared test was used for this analysis.

Problems After Construction

The average "C" value and standard deviation for each of the responses under item II were also determined. The "yes" and "no" value results were then compared for

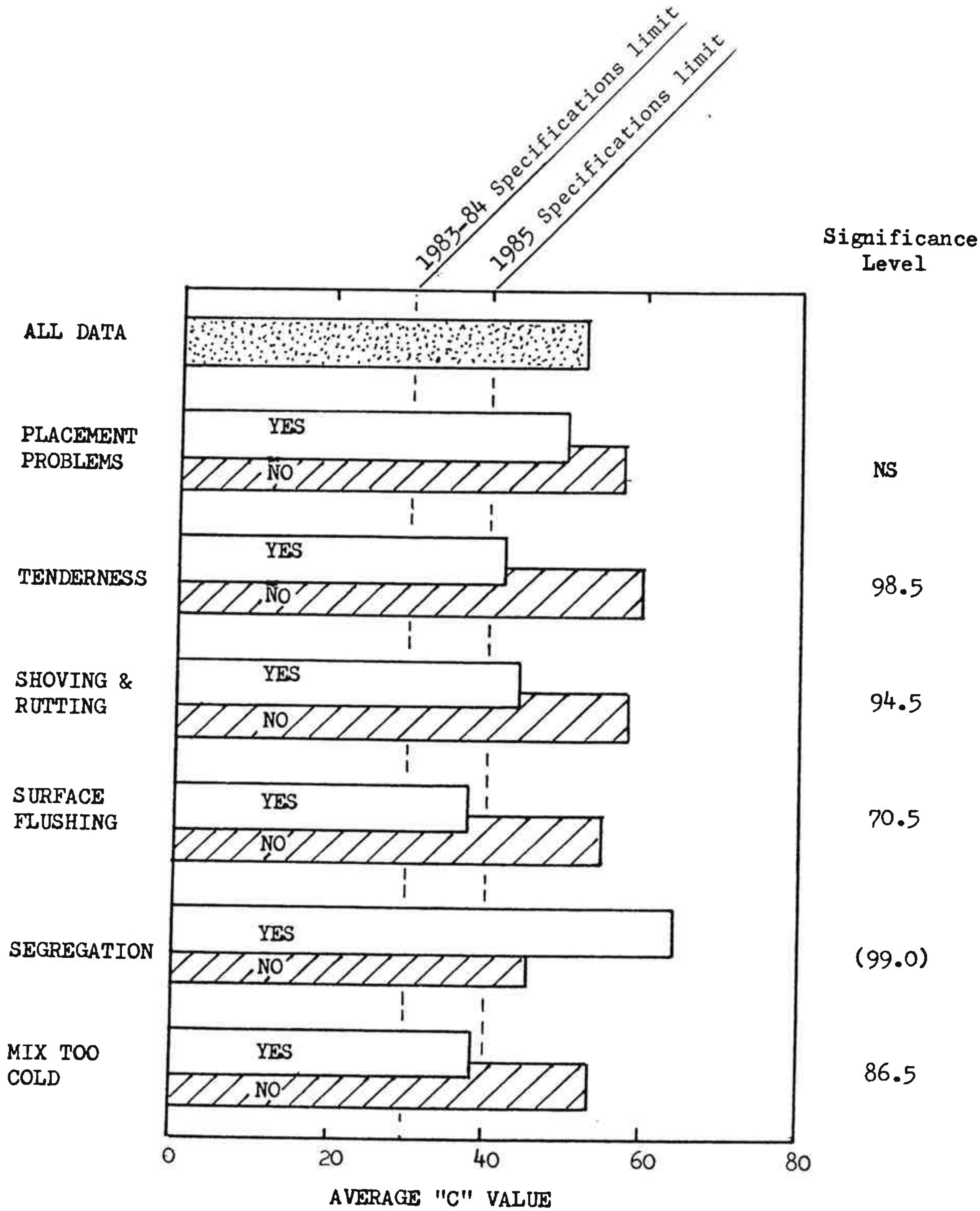

FIGURE 1. Problems during construction.

NS = not significant

Significance Level

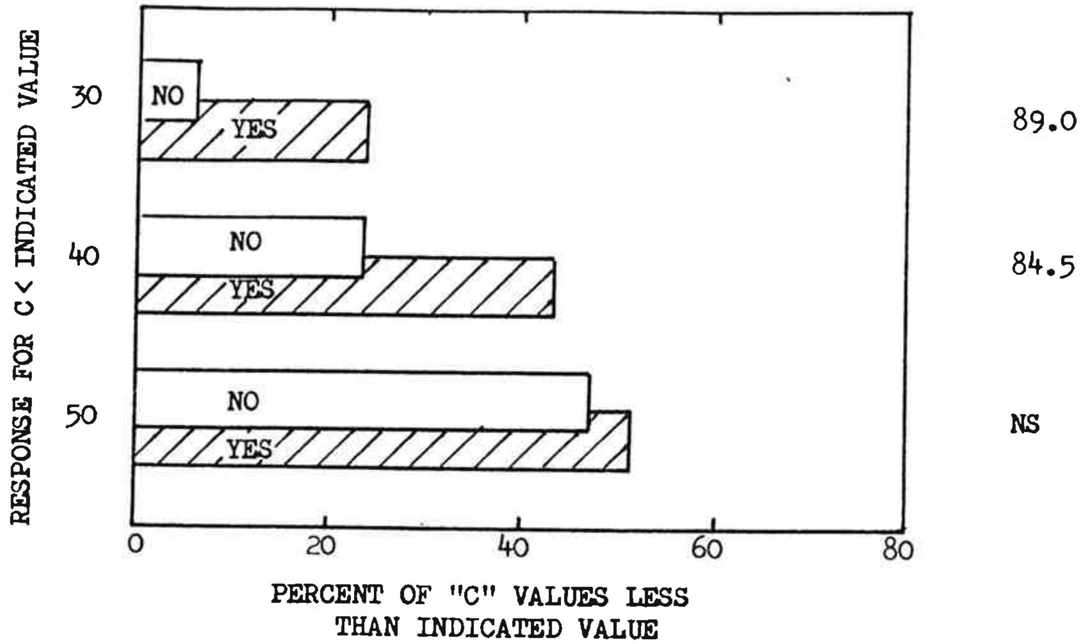

FIGURE 2. Any problems during construction.

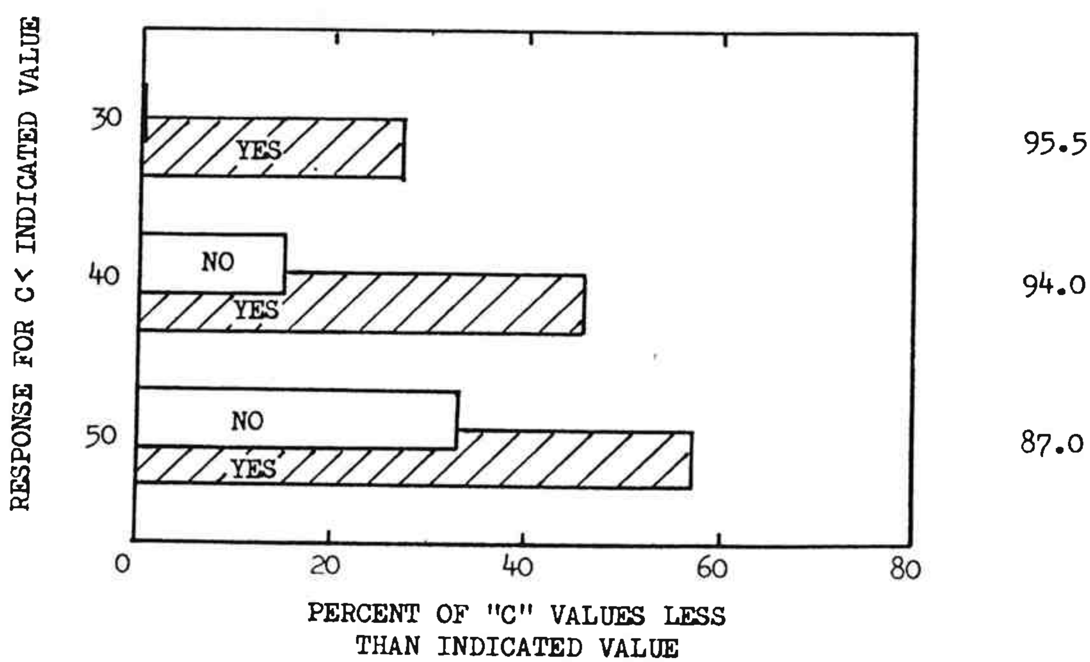

FIGURE 4. Any problems after construction.

NS = not significant

significance using the Student-t test. The results of these analyses are shown in Figure 3 with the data tabulated in the Appendix. As can be seen from the figure, the only statistically important items are stripping and cracking, both being highly significant.

The data were also grouped according to "C" value ranges of 30, 40 and 50. These results are shown in Figure 4. The differences at the <30 and <40 levels are highly significant, whereas the difference at the <50 level is only slightly significant. This follows the same general trend as the results shown in Figure 2 for problems during construction.

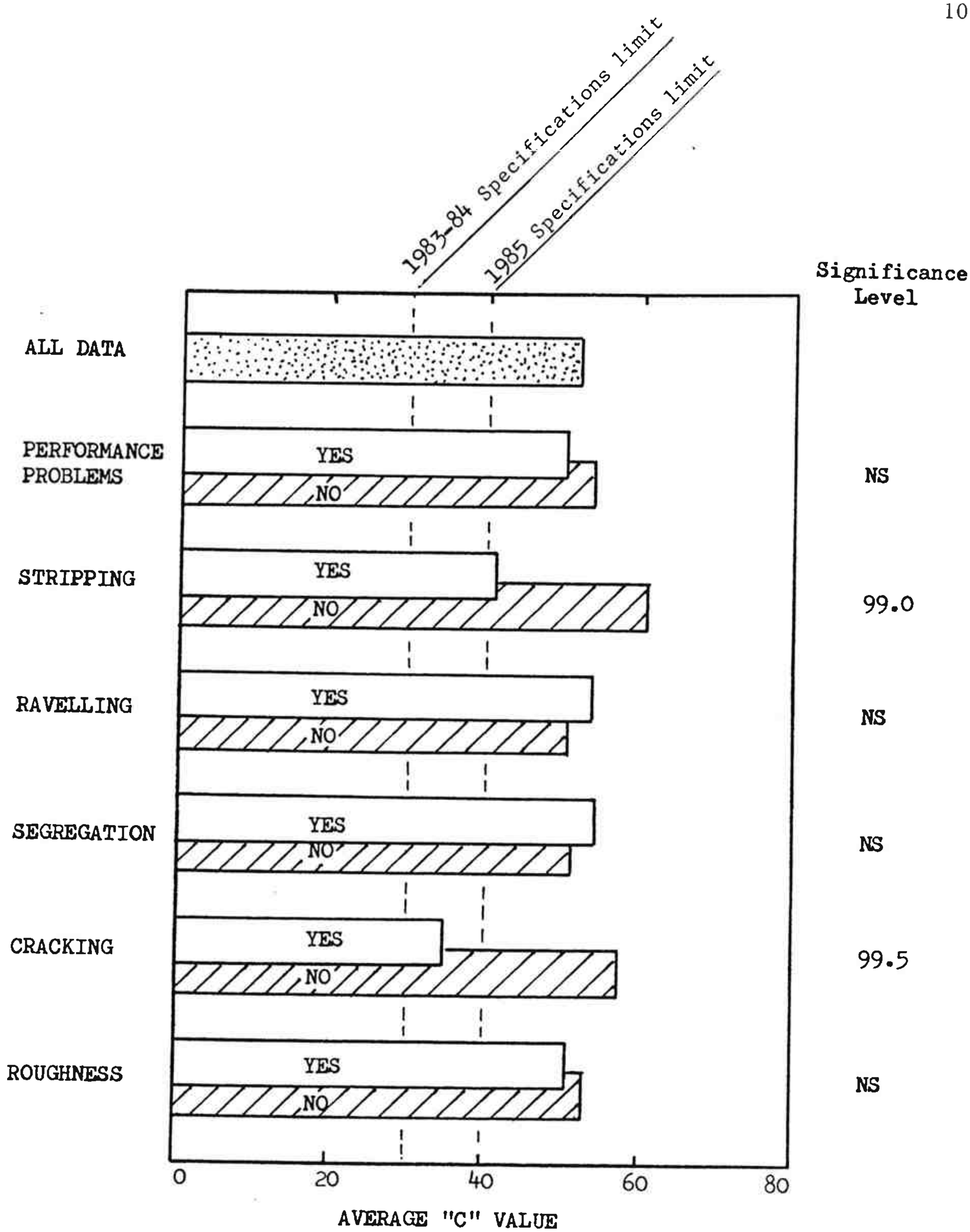

FIGURE 3. Problems after construction.

NS = not significant

Overall Rating

The questionnaire had three items where the project manager could rate the overall project performance as to the paving operation, mixing operation and the pavement performance with time. Categories of "good", "fair" and "poor" could be checked. Since very few of the "poor" category were checked, they were grouped with the "fair" values in the analysis. The three performance items were then compared for average "C" value, which is shown graphically in Figure 5. Only the paving operation appear to show a significant difference between the "good" and "fair + poor" groupings, and only weakly significant at that.

The paving operation results were then looked at in more detail. The data were grouped in the <30, <40 and <50 categories. As can be seen in Figure 6, the difference between the two groupings is highly significant for the <30 and <40 categories. The significance peaks at the <40 level.

Individual Characteristics

Individual characteristics under items I and II were then analyzed using the <30, <40 and <50 groupings and tested for significance with the Chi-squared distribution

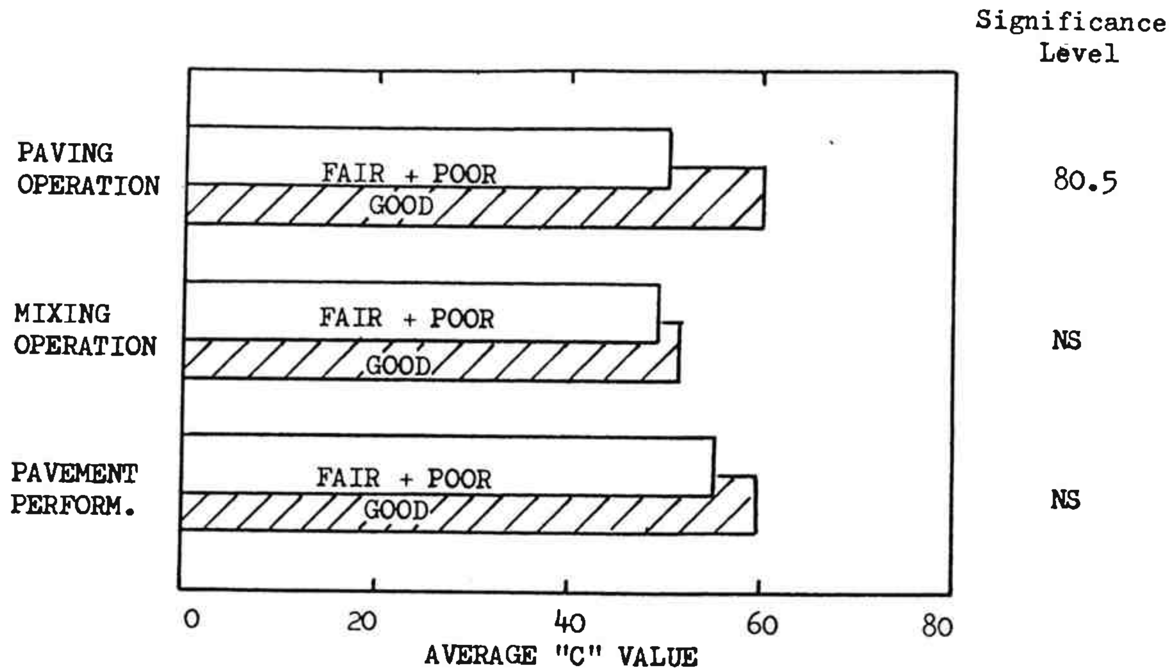

FIGURE 5. Overall rating.

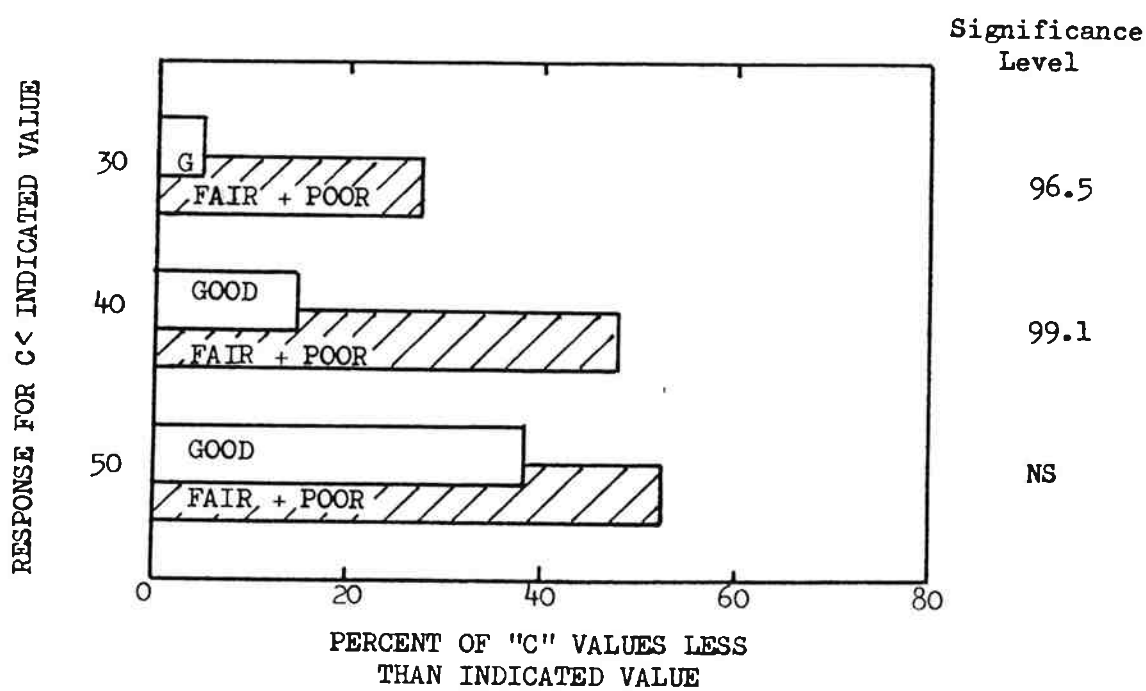

FIGURE 6. Paving operation.

NS = not significant

Figures 7 through 11 illustrate the results for characteristics during construction. All of these items have a large difference between the "yes" and "no" responses, peaking in significance in all but one case at the <40 value. Again, it should be noted that the segregation problem has results opposite of the others.

Figures 12 through 14 illustrate characteristics after construction. Again almost all of the comparisons are highly signficant, peaking at the <40 level. Note that the ravelling problem has results opposite of the others, that is, the "no" responses have a higher percentage of "C" values less than the indicated level.

DATA ANALYSIS OF THE 1983-1985 PROJECTS

The data were analyzed in a manner similar to the 1981-1983 study and report (Lund and Wilson, 1984). This was done so a comparison could be made between the two studies. The average "C" value for the 49 projects was 50.3, with a standard deviation of 28.4 and a range from -19.0 (very soft asphalt - tender mix) to 159.6 (very hard asphalt - stiff mix). A total of 14 percent had a value below 30 (1983-84 failure limit) and 41.5 percent had a value below 40 (1985 failure limit). The 1981-83 data had a mean of 53.6, 31 percent had a value below 30 and 42 percent had a value below 40.

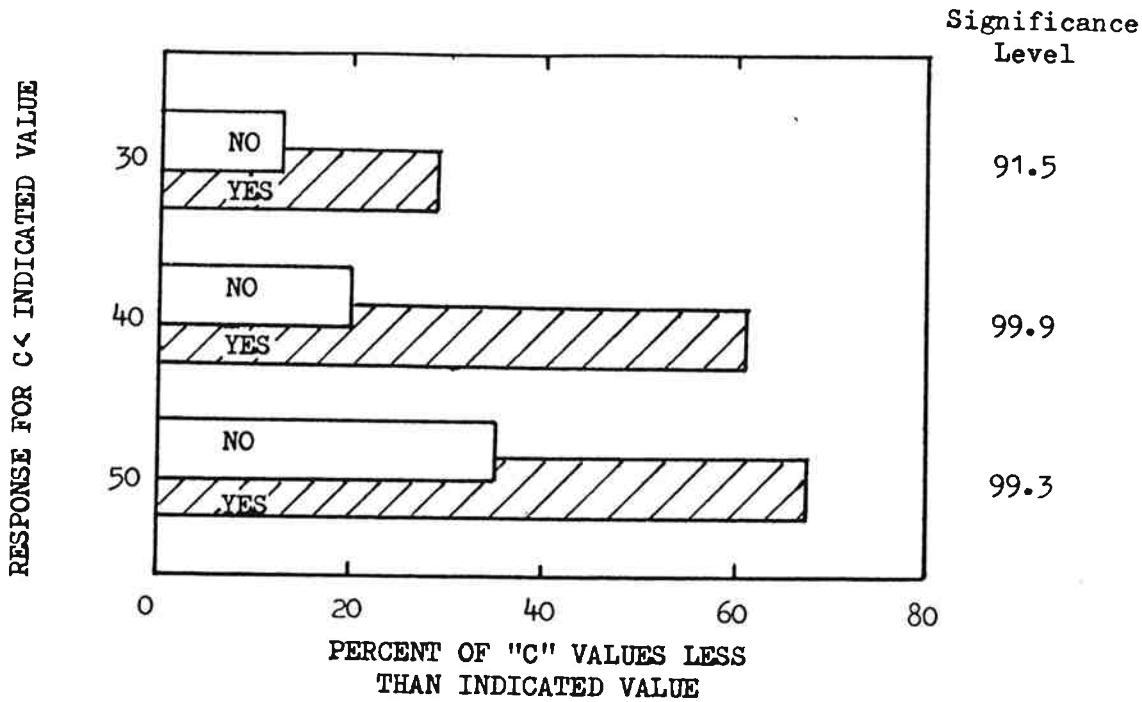

FIGURE 7. Tenderness at time of paving.

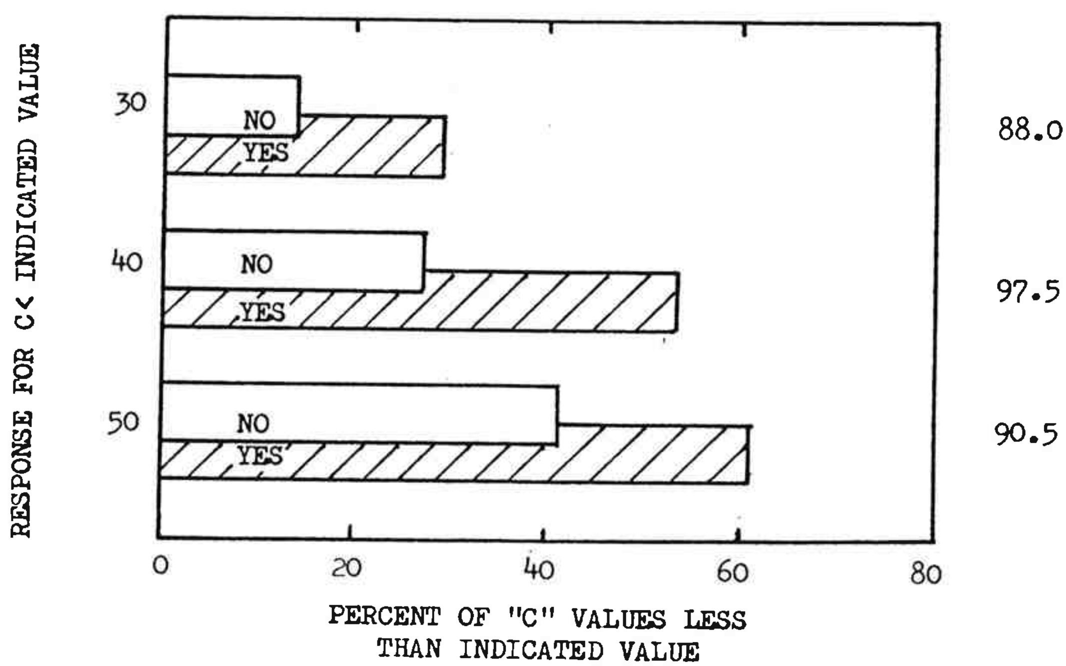

FIGURE 8. Shoving and rutting at time of paving.

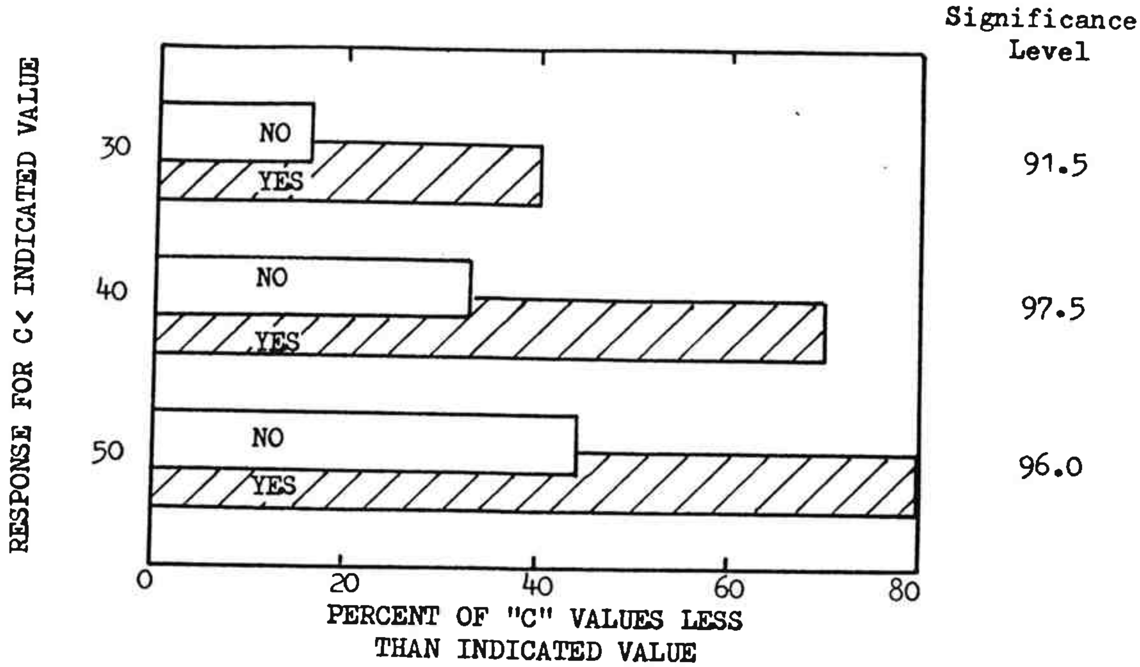

FIGURE 9. Surface flushing at time of paving.

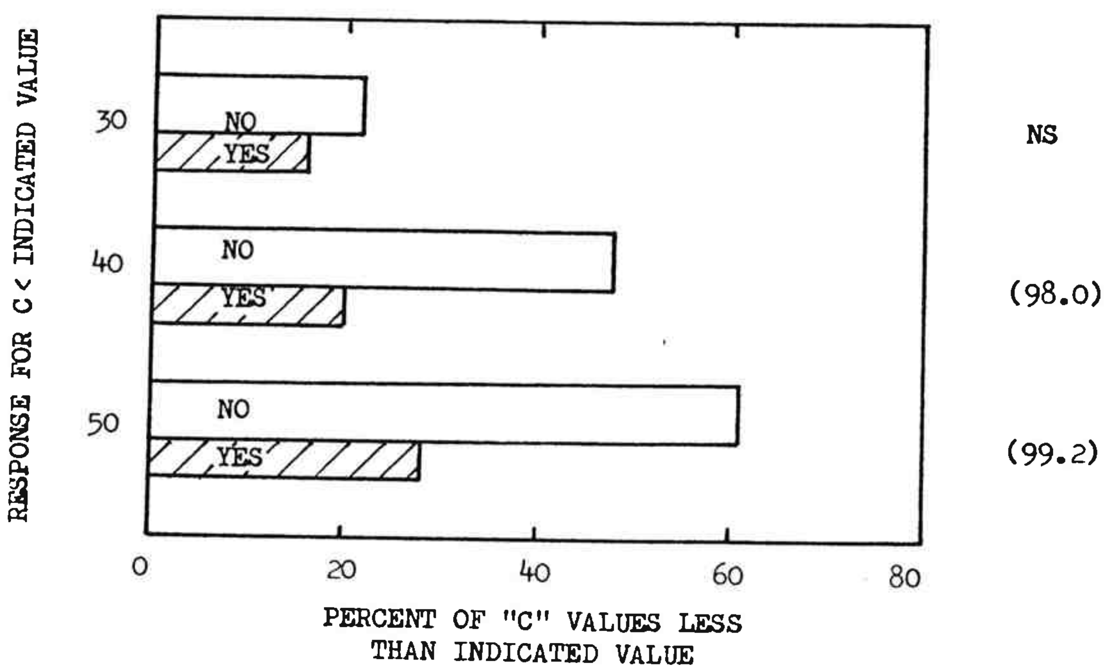

FIGURE 10. Segregation at time of paving.

NS = not significant

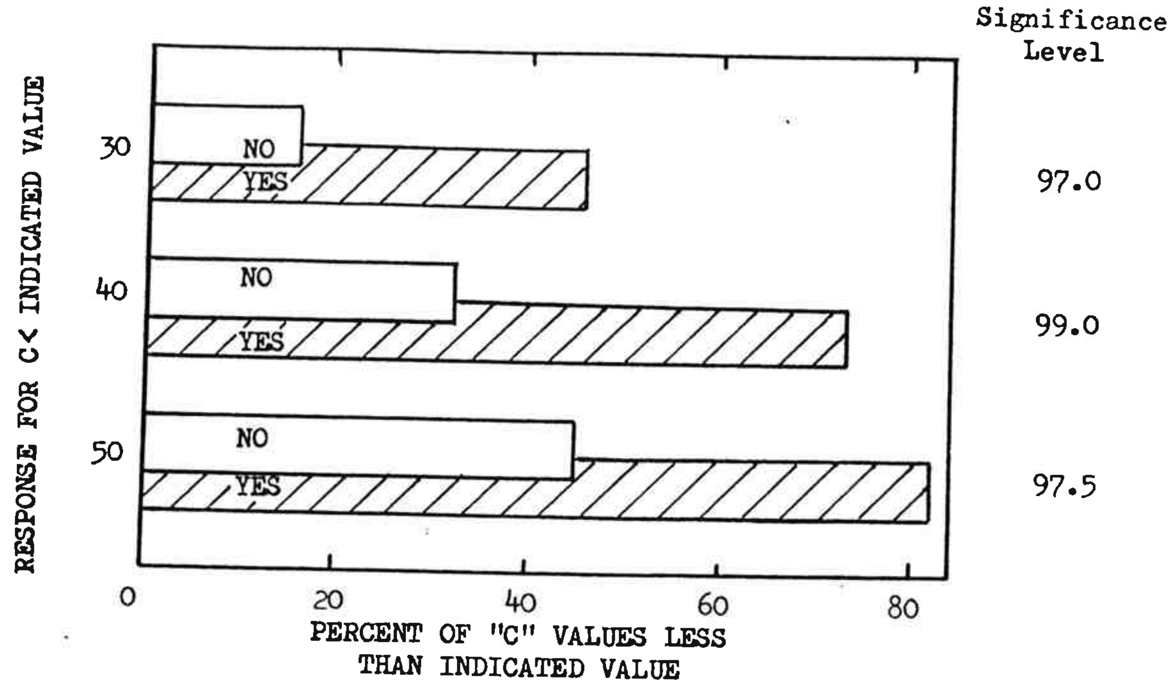

FIGURE 11. Mix too cold at time of paving.

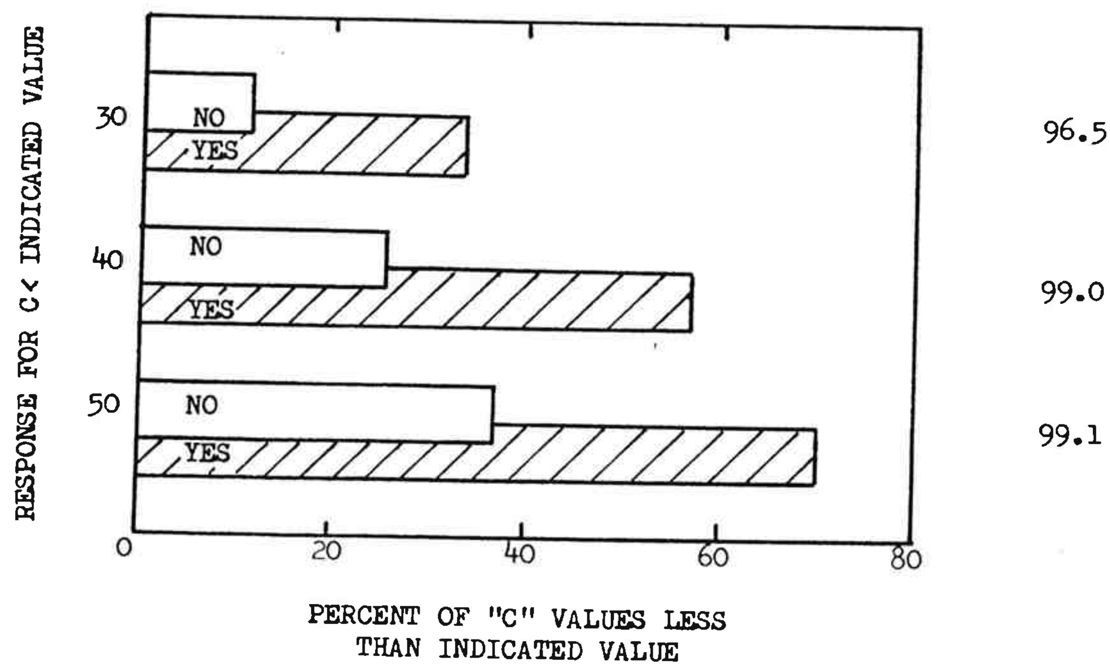

FIGURE 12. Stripping after construction.

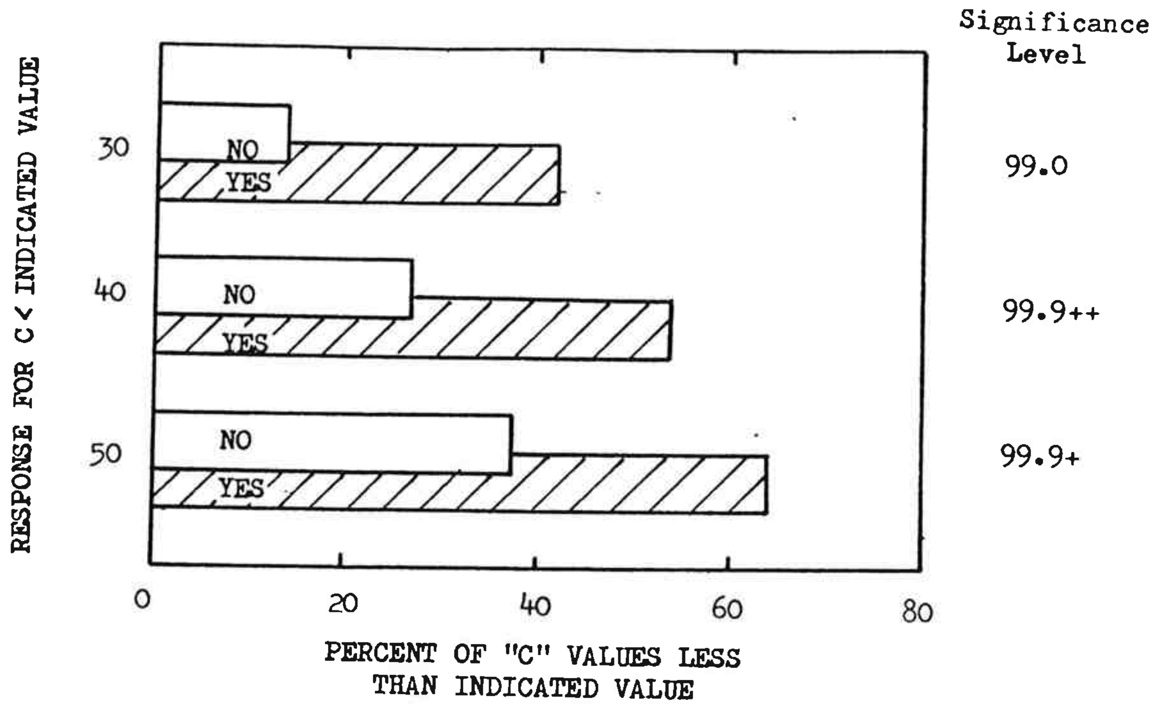

FIGURE 13. Cracking after construction.

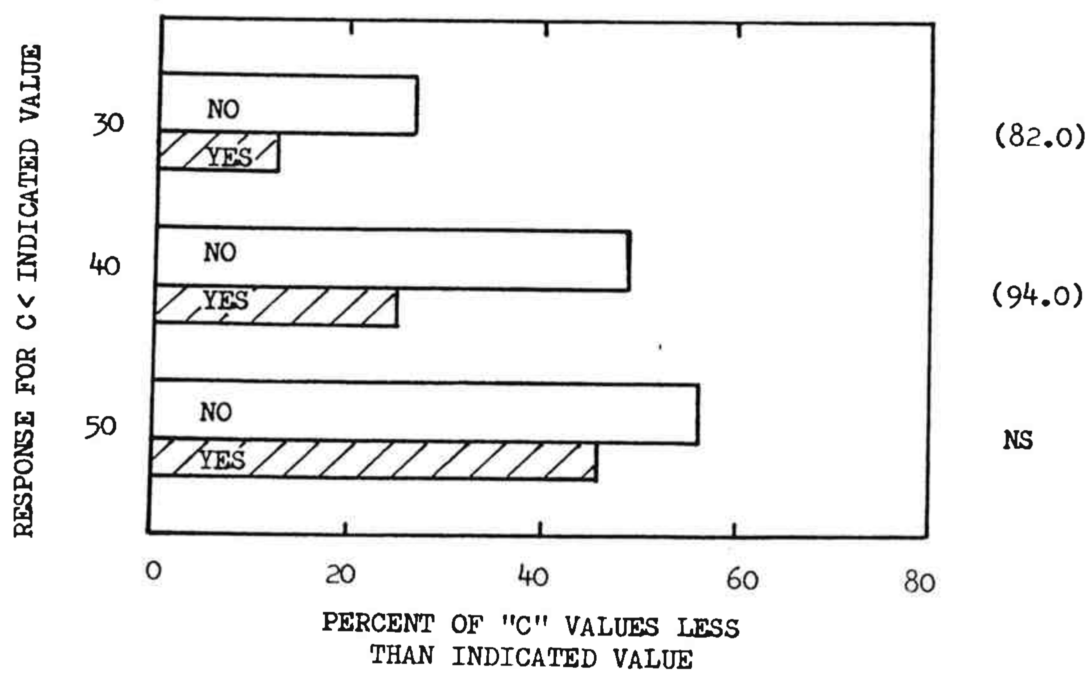

FIGURE 14. Ravelling after construction.

NS = not significant

Variables Analyzed

The following variables, analyzed in the 1981-83 study and 1984 report, were again analyzed for comparison.

1. Contractor Operation

New data were available on ten of the original 13 contractor operations. The results indicated that the average "C" value for each contractor remained essentially the same, with the three operations with the lowest average "C" value improving slightly. The overall change was statistically not significant. The 1981-83 data is shown below with the 1983-85 data shown in parenthesis. Two operations still have extremely low average "C" values and both would have 54 percent failing the 1985 specification of 40.

TABLE 1. CONTRACTOR OPERATION VS. AVERAGE "C" VALUE

Ops Number	Number of Tests	Mean "C" Value	Sta Dev.	Percent Failures <30	<40
1	9 (4)	115 (88)	65 (15)	11 (0)	(0)
2	6 (16)	79 (71)	16 (32)	0 (6)	(6)
3	4 (5)	71 (74)	39 (71)	0 (20)	(40)
4	11 (3)	69 (52)	16 (7)	0 (0)	(0)
5	6 (3)	43 (62)	19 (19)	33 (0)	(0)
6	5 (59)	36 (41)	8 (21)	40 (19)	(54)
7	49 (39)	36 (39)	47 (14)	49 (28)	(54)
8	2 (1)	107 (154)	8 –	0 (0)	(0)
9	2 (1)	93 (148)	61 –	0 (0)	(0)
10	2 (1)	72 (35)	4 –	0 (0)	(100)

2. Plant Type

Seven of the original 16 plants studied in 1983 had enough new information for comparison. Five were drum mix plants and two were batch plants. The two plants with the lowest average "C" values did improve their average, however all of the other plants dropped in average "C" value. The two plants having the lowest average "C" values also would have approximately 50 percent of their tests failing the 1985 specification limit of 40. The average value for all drum mixer plants and batch plants are essentially the same, differing from the 1981-1983 study where drum mixer plants had the lowest average "C" value. The following table shows the 1981-83 data with the 1983-85 data shown in parenthesis.

TABLE 2 ASPHALT PLANT TYPE VS. AVERAGE "C" VALUE

Plant Type	Number of Tests	Mean "C" Value	Sta. Dev.	Percent Failures <30	<40
Drum	82 (106)	54 (50)	52 (22)	35 (10)	(35)
Batch	16 (87)	74 (50)	51 (35)	19 (18)	(49)
		DRUM MIX PLANTS			
1	19 (31)	61 (39)	46 (16)	26 (26)	(48)
2	2 (2)	72 (45)	4 (14)	0 (0)	(50)
3	28 (2)	14 (55)	30 (10)	75 (0)	(0)
4	7 (4)	103 (88)	70 (15)	14 (0)	(0)
5	16 (3)	70 (52)	14 (7)	0 (0)	(0)
		BATCH PLANTS			
1	4 (3)	71 (51)	39 (12)	0 (0)	(33)
2	3 (60)	31 (41)	6 (21)	67 (18)	(53)

3. Dust Collection System

In the 1981-1983 study, bag house dust collection systems had a significantly lower average "C" value and higher failure rate when compared with wet scrubbers. In the 1983-1985 study, the two systems had essentially identical results as shown in the table below. The 1983-85 data is shown in parenthesis.

TABLE 3. DUST COLLECTION SYSTEM VS. AVERAGE "C" VALUE

Dust System	Number of Tests	Mean "C" Value	Sta. Dev.	Percent Failures <30	<40
Wet S.	54 (110)	72 (51)	44 (26)	9 (13)	(39)
Bag H.	42 (83)	30 (50)	40 (31)	62 (16)	(45)

4. Asphalt Cement Grade and Supplier

Of the two most used asphalt cements, the AC20 grade dropped significantly in average "C" value and increased in the percentage of failures, whereas the AR4000W did not change. The remaining grades and suppliers did change, but due to the low numbers of data, the results are probably inconclusive. The data from the two most used grades are shown below.

TABLE 4. ASPHALT CEMENT GRADE VS. AVERAGE "C" VALUE

Asphalt Cement	Number of Tests	Mean "C" Value	Std. Dev.	Percent Failures <30	<40
AC20	4 (54)	62 (41)	15 (14)	0 (13)	(52)
AR4000W	66 (61)	62 (61)	42 (33)	30 (10)	(31)

5. Burner Fuel Type

Three burner fuels were common between the two studies; No. 2 fuel oil, a commercial brand reclaimed fuel oil (referred to as brand A in the 1984 report), and natural gas and propane. As shown in the table below the results for the No. 2 fuel oil remained essentially unchanged, whereas the other two are associated with poorer results. The difference between the three fuels from the 1983-85 data is not statistically significant. The data are summarized below with the most recent information shown in parenthesis.

TABLE 5. BURNER FUEL TYPE VS. AVERAGE "C" VALUE

Fuel Type	Number of Tests	Mean "C" Value	Std. Dev.	Percent Failures <30	<40
No. 2	45 (124)	48 (48)	27 (25)	33 (15)	(53)
Reclaim.	11 (19)	82 (43)	44 (31)	9 (26)	(53)
NG/P	16 (44)	97 (56)	58 (35)	12 (16)	(39)

G Lime Additives

In the past two seasons, dry lime has been added as a filler to open graded mix or the aggregate has been treated with a lime slurry for all mixes on some projects. Lime is used as a means to improve asphalt-aggregate adhesion, especially where freeze-thaw is a problem, or in open graded mixes to increase the effective viscosity of the asphalt cement. No data on lime additives were available from the 1981-1983 study. Even though there were differences between treated mixes and untreated mixes, as shown in the following table, these difference were not statistically significant. Additional study will be performed in the future on the effects of various additives on the "C" value.

TABLE 6. LIME TREATMENT VS. AVERAGE "C" VALUE

Treatment	Number of Tests	Mean "C" Value	Sta. Dev.	Percent Failures <30	<40
w/ lime	52	45	15	6	46
w/o lime	141	52	32	17	40

DISCUSSION AND CONCLUSIONS OF 1984 QUESTIONNAIRE (1981-1983 PROJECTS)

Discussion

The responses to the questionnaire, even though they are subjective, appear to identify and confirm relationships between the "C" value and asphalt mix problems. The strongest correlation appears to be more with problems at the time of construction than with long term pavement performance problems. However, there are significant long term problems that were identified.

In the analysis of the data, the Student-t test was used to compare data where mean and standard deviation of "C" values were available. When comparing the number of items that either do or do not fall into a certain category, as in the case of the <30, <40 or <50 "C" values, a 2 x 2 contingency table tested against the Chi-squared distribution was used. It is important to note that the statistical tests do not indicate why there is a difference between two comparisons, only that there is a difference and the significance level. Generally a significance level above 90 or 95 percent is considered adequate for most engineering comparisons.

The significant problems of tenderness, shoving and rutting and mix too cold (see Figure 1) support the conclusions of the previous study (Lund and Wilson, 1984). The results of the segregation problem are more difficult to understand. This can best be explained in that the stiffer (less tender) and viscous mixes are more difficult to blend. The stripping and cracking problems identified by the after construction data (see Figure 3) are related to the tenderness problem. Tenderness tends to prevent adequate compaction, thus producing less dense pavements. Less dense pavements have a greater tendency to strip and crack.

When evaluating the individual characteristics at the <30, <40 and <50 "C" value level, the great majority have the significant level peak at the <40 value. That is, a greater percentage of the samples that are below 40 have some problem in the field as compared to those samples which have "C" values above 40.

Conclusions

The use of the "C" value to predict tenderness and related problems in asphaltic mixes and pavements appears to be reasonable. This field study as a follow-up to the original 1981-83 evaluation does verify the conclusions of that report. The 30 to 50 "C" value range still appears to be a critical area The value of 30 was originally established as the minimum acceptable, however it appears from this study that the value should be raised to 40, as this level has a higher significance with pavement problems.

Since 1983, at least two state highway departments, Nevada and Montana, have adopted the use of the "C" value. Both use the minimum acceptable value of 30. In discussion with materials personnel at these two highway departments, Nevada felt that the 30 value was too lenient and should be raised (Pradere, 1985) The Montana Highway Department has since dropped the use of the "C" value specification due to a problem with one contractor. They now specify the type of burner fuel that can be used instead (Wagner, 1985).

In early 1985, the Oregon Highway Department raised the minimum acceptable "C" value to 40. Mix with a value less than 40 is to be removed, or at the discretion of the Engineer it may be left in place and a reduction in a Composite Pay Factor calculated (OSHD Specification 403.39). This specification is reproduced in the Appendix.

DISCUSSION AND CONCLUSIONS OF 1983-85 PROJECTS

Discussion

The comparison of results betwen the 1981-83 data and the 1983-85 data indicate some significant changes. No longer do plant type, dust collection system and burner fuel type appear to significantly affect the "C" value. Evidently, operators have been able to adjust for these individual variables and produce mix with adequate "C" values. The item that still appears to influence the "C" value is the overall operation of the asphalt mixing plant. Rather than one individual item influencing the results, a combination of factors such as burner adjustment, where the asphalt cement is introduced in drum mixers, the amount of air pushed through the mixer or drier, etc., are the controlling items.

In addition to the plant operation, AC20 asphalt cement appears to produce low "C" values. Even though this grade was used on nine different projects, the majority of samples (89%) were associated with one contractor. Since this contractors operation has the lowest average "C" value of those studied, the low values for this asphalt cement is most likely due to the plant operation rather than the properties of the asphalt cement.

Conclusions

The "C" value still appears to be a good measure of asphalt properties relating to tenderness of asphalt paving mixes, especially during the initial placement time. The critical and most influential variable affecting this value is the operation (adjustment) of the asphalt plant. Once the plant is in balance, the tenderness of the mix will be reduced. Several contractors with low average "C" values and a high failure rate were able to improve their performance over the past two years since the original study.

The "C" value test provides a fairly reliable and rapid means of measuring asphalt properties relating to tenderness and can be used as feed-back to the contractor.

ACKNOWLEDGMENTS

The data were provided by the Oregon State Highway Division. In particular, the assistance of the project managers is greatly appreciated.

DISCLAIMER

The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those held by Oregon Department of Transportation or Oregon Institute of Technology.

REFERENCES

1. Lund, John W. and James E. Wilson, 1984. Evaluation of Asphalt Aging in Hot Mix Plants, Proceeding of the Association of Asphalt Paving Technologists, Vol. 53, pp. 1-18, Scottsdale, AZ.

2. Pradere, Peter, Materials Engineer, Nevada Department of Highways, Carson City, June, 1985 (personal conversation).

3. Wagner, Richard, Materials Engineer, Montana Department of Highways, Helena, June, 1985 (personal conversation)

ASPHALT AGING PROJECT ("C" VALUE - BURNER FUEL STUDY)

Project # ____________ Project name ____________________

Project manager ______________ Paving Contractor ______________

Sample # ____________ Date taken ______________

I. Characteristics of asphalt mix and pavment at time of placement (approximately where sample was taken):

	yes	no	unknown
A. tenderness (soft consistency)	☐	☐	☐
B. shoving and rutting during rolling	☐	☐	☐
C. Surface flushing	☐	☐	☐
D. segregation	☐	☐	☐
E. stripping	☐	☐	☐
F. ravelling	☐	☐	☐
G. mix too cold	☐	☐	☐
H. mix too hot	☐	☐	☐

Any other mixing or placement difficulties: ______________________

____

____

	good	fair	poor
How would you rate the overall paving operation:	☐	☐	☐
How would you rate the overall mixing operation:	☐	☐	☐

II. Characteristics of the pavement today (enter date: ____________) (approximately where sample was taken):

	yes	no	unknown
A. rutting and shoving	☐	☐	☐
B. surface flushing	☐	☐	☐
C. stripping	☐	☐	☐
D. ravelling	☐	☐	☐
E. segregation	☐	☐	☐
F. cracking	☐	☐	☐
G. roughness	☐	☐	☐

Any other pavement problems: ______________________________

____

____

How would you rate the overall pavment performance to date: good ☐ fair ☐ poor ☐

Please write any other comments below:

Please return this form to: James Wilson, Materials Section, Salem.

APPENDIX B

STATISTICAL DATA

Item	N	Ave.	S.D.	%<30	%<40	%<50
All Data I	71	52.5	30.4	19.7	38.0	49.3
All Data II	65	52.0	31.6	20.0	38.5	50.8
Placement Prob.						
Yes	51	50.3	32.5	23.5	43.1	51.0
No	17	57.4	22.4	5.9	23.5	47.1
Perform. Prob.						
Yes	52	50.6	33.2	26.9	40.2	57.7
No	12	53.6	19.8	0.0	16.7	33.3
Paving Ops.						
Good	21	60.1	23.1	4.8	14.3	38.1
Fair + Poor	44	50.2	30.9	27.3	47.7	52.3
Mixing Ops.						
Good	52	51.1	27.8	17.3	40.4	51.9
Fair + Poor	10	49.5	30.4	31.2	37.5	50.0
Pavement Perform.						
Good	17	59.0	26.6	11.8	23.5	35.3
Fair + Poor	40	55.0	33.2	15.0	30.0	42.5
Tenderness (IA)						
Yes	31	42.6	34.0	29.0	61.3	67.7
No	40	60.1	25.2	12.5	20.0	35.0
Shoving & Rutting (IB)						
Yes	28	44.2	35.9	28.6	53.6	60.7
No	44	58.1	25.1	13.6	27.3	40.9
Surface Flushing (IC)						
Yes	10	38.1	49.4	40.0	70.0	80.0
No	61	54.8	26.0	16.4	32.8	44.3
Segregation (ID)						
Yes	25	64.5	34.1	16.0	20.0	28.0
No	46	45.9	20.4	21.7	47.8	60.9
Mix Too Cold (IG)						
Yes	11	[illegible]	27.5	45.4	72.7	81.8
No	56	54.1	[illegible]	16.1	32.1	44.6
Stripping (IIC)						
Yes	30	41.6	[illegible]	33.3	56.7	70.0
No	35	60.9	[illegible]	11.4	25.7	37.1

Item	N	Ave.	S.D.	%<30	%<40	%<50
Ravelling (IID)						
Yes	24	54.0	34.1	12.5	25.0	45.8
No	41	50.9	30.5	26.8	48.8	56.1
Segregation (IIE)						
Yes	16	54.6	39.9	25.0	43.8	50.0
No	49	51.1	28.9	20.4	38.8	51.0
Cracking (IIF)						
Yes	19	35.6	29.4	42.1	73.7	84.2
No	45	57.7	29.7	13.3	26.7	37.8
Roughness (IIG)						
Yes	17	50.8	30.3	17.6	35.3	58.8
No	48	52.5	32.4	22.9	41.7	50.0

NOTE: Stripping (IE), Ravelling (IF), Mix Too Hot (IH), Rutting and Shoving (IIA), and Surface Flushing (IIB) did not have sufficient "yes" responses to be significant.

APPENDIX C

STATISTICAL CALCULATIONS

Item	Student-t Value "C" Value	Chi-squared Value C<30	C<40	C<50
During Construction (I)				
Any Problem	0.84	2.57	2.08	0.08
Tenderness	2.49	3.02	12.63	7.49
Shoving & Rutting	1.93	2.44	5.05	2.79
Surface Flushing	1.04	3.02	5.05	4.39
Segregation	(2.55)	(0.34)	(5.32)	(7.00)
Stripping	-	-	-	-
Ravelling	-	-	-	-
Mix Too Cold	1.49	4.80	6.38	5.08
Mix Too Hot			-	-
After Construction (II)				
Any Problem	0.30	4.14	3.51	2.32
Rutting & Shoving	-	-	-	-
Surface Flushing	-	-	-	-
Stripping	2.55	4.58	6.45	6.99
Ravelling	(0.37)	(1.84)	(3.57)	(0.64)
Segregation	(0.38)	0.15	0.12	0.00
Cracking	2.73	6.47	12.24	11.53
Roughness	0.19	0.21	0.21	0.39
Overall Ratings				
Paving Operation	1.30	4.50	6.83	1.14
Mixing Operation	0.19	1.45	0.04	0.02
Pavement Perform.	0.44	0.01	0.10	0.26

NOTE: the following symbols have been used:
- indicates insufficient data
a number in parenteses indicates a reverse relation

APPENDIX D

STATISTICAL SIGNIFICANCE

Item	Percent Significance "C" value	C<30	C<40	C<50
During Construction (I)				
Any Problem	NS	89.0	84.5	NS
Tenderness	98.5	91.5	99.9+	99.3
Shoving & Rutting	94.5	88.0	97.5	90.5
Surface Flushing	70.5	91.5	97.5	96.0
Segregation	(99.0)	NS	(98.0)	(99.2)
Stripping	-	-	-	-
Ravelling	-	-	-	-
Mix Too Cold	86.5	97.0	99.0	97.5
Mix Too Hot	-	-	-	-
After Construction (II)				
Any Problem	NS	95.5	94.0	87.0
Rutting & Shoving	-	-	-	-
Surface Flushing	-	-	-	-
Stripping	99.0	96.5	99.0	99.1
Ravelling	NS	(82.0)	(94.0)	NS
Segregation	NS	NS	NS	NS
Cracking	99.5	99.0	99.9++	99.9+
Roughness	NS	NS	NS	NS
Overall Rating				
Paving Operation	80.5	96.5	99.1	71.0
Mixing Operation	NS	77.0	NS	NS
Pavement Perform.	NS	NS	NS	NS

NOTE: the following symbols have been used:
- \- indicates insufficient data
- a number in parenteses indicates a reverse relation
- NS indicates the difference is not significant

Student-t Distribution Values

1-alpha:	99.9	99.0	98.0	95.0	90.0	80.0	70.0
t @ >30 df:	3.291	2.575	2.327	1.960	1.645	1.282	1.036

Chi-squared Distribution Values

1-alpha:	99.9	99.5	99.0	98.0	97.5	95.0	90.0
Chi @ 1 df:	10.827	7.879	6.635	5.412	5.024	3.841	2.706
	80.0	70.0					
	1.642	1.074					

APPENDIX E

403.39 Drying, Heating and Separating Aggregates into Designated Sizes:

(a) Drying - Aggregates shall be dried to the extent that any remaining contained moisture does not result in visible defects in the mixture such as slumping loads, boils or slicks.

Slumping loads shall not be incorporated into the pavement, but shall be disposed of by the Contractor at his expense and in a manner satisfactory to the Engineer.

Boils and slicks occurring in the pavement shall be immediately removed and replaced with suitable materials, all at the Contractor's expense.

The moisture content of the mix shall not exceed 0.7% at time of discharge from the mixing plant.

(b) Burner fuel - The Contractor shall use the same burner fuel for heating the aggregates throughout production of the asphalt mixture unless otherwise approved by the Engineer. To document the burner fuel actually utilized for heating the aggregates, the Contractor shall furnish the Engineer daily copies of invoices describing the burner fuel received for heating purposes.

(c) Aging asphalt - The burner used for heating the aggregates shall achieve complete combustion of the fuel and shall heat the aggregate sufficiently to achieve acceptable aging of the asphalt. Burner fuel combustion will be considered complete and acceptable aging of the asphalt attained, when "C" (percent of change in asphalt viscosity) in the following formula is equal to or greater than 40.0.

$$C = \frac{R-A}{B-A} \times 100 \text{ where;}$$

A = Absolute viscosity (OSHD TM 417) of original asphalt used in production of the mixture.
B = Absolute viscosity (OSHD TM 417) of rolling thin film oven residue (AASHTO T 240) for asphalt used in production of the mixture.
R = Absolute viscosity (OSHD TM 417) of asphalt removed from the mixture (OSHD Modified AASHTO T 170).

(d) Testing for asphalt aging - Testing to determine "C" will be made on a randomly selected sublot sample (subsection 403.16(b-2)) obtained from the first 500 tons of asphalt concrete production, from the next 2,000 tons of production, and from each 7,500 tons of production, thereafter.

Whenever "C" is less than 45 and represents 7,500 tons of production, two additional random sublot samples will be obtained and tested. Each of the three random samples will represent 2,500 tons of production.

For each failing "C" value (less than 40.0) representing 2,000 or 2,500 tons of production, a sample from each sublot (subsection 403.16(b-2)) of that 2,000 or 2,500 tons will be tested. Each of the random samples (failing and 3 or 4 additional) will represent 500 tons of production or portion thereof.

(e) Nonacceptable asphalt aging - Whenever "C" is less than 40.0, the Contractor shall make appropriate plant adjustments to comply with this requirement. Any mixture represented by such tests which has been placed will be rejected and shall be removed and disposed of by the Contractor at his expense and in a manner acceptable to the Engineer. However, if acceptable to the Engineer, the material may be left in place at the following reduction, in the COMPOSITE PAY FACTOR (CPF) calculated in accordance with subsections 403.16 and 106.19.

"C" Value		
Below	At or Above	Price Reduction
40.0	35.0	1%
35.0	30.0	3%
30.0	25.0	7%
25.0	20.0	14%
20.0	15.0	25%

For the first 2,500 tons of production, if the "C" value is less than 40.0 but greater than or equal to 25.0, removal of the pavement will not be required per this subsection nor will there be a reduction made in the CPF.

(f) Heating temperatures - For screen-type plants the temperature of the aggregates at discharge from the drier shall not exceed 325°F except when used for heat transfer in recycled mixtures. For drum mix plants the temperature of the mix at discharge from the mixer shall not exceed 325°F.

(g) Screening - Immediately after drying and heating, in plants which have plant screens, the aggregates shall be separated by screening into the designated sizes required for separate handling and proportioning at the mixing plant and each designated size of aggregate shall be separately handled or stored thereat for proper proportioning in the mix. The designated sizes of aggregates required for the mix shall be those specifically set forth for the kind of pavement and class of mix involved as set forth in the special provisions or called for by the plans and pertinent requirements given in subsection 403.17. The grading of each separated designated size of aggregate in the bins at the mixing plant shall be maintained uniform and within a tolerance of 20% oversize and 20% undersize.