HIGHWAY RESEARCH REPORT

INVESTIGATION AND APPRAISAL OF THE PERFORMANCE OF CEMENT TREATED BASES AS USED IN COMPOSITE PAVEMENTS IN CALIFORNIA

FINAL REPORT

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STATE OF CALIFORNIA

TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMEN

RESEARCH REPORT

NO. M & R 633208

Prepared in Cooperation with the U.S. Department of Transportation, Bureau of Public Roads June, 1968

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RONALD REAGAN, Governor

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June 1968
Final Report
M&R No. 633208

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is a research report entitled:

INVESTIGATION AND APPRAISAL OF THE
PERFORMANCE OF CEMENT TREATED BASES AS USED
IN COMPOSITE PAVEMENTS IN CALIFORNIA

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REFERENCE: Zube, E., Gates, C. G., Shirley, E. C. and Munday, H. A. Jr., "Investigation and Appraisal of the Performance of Cement Treated Bases as Used in Composite Pavements in California", State of California, Department of Public Works, Division of Highways, Materials and Research Department, Research Report 633208, June 1968.

ABSTRACT: One hundred seventy-five Class "A" and Class "B" CTB projects built between 1950 and 1962 were evaluated. Sixty-four percent are giving excellent service, seventeen percent were rated good, eight percent fair and eleven percent required extensive maintenance early in their design lives. The main causes of failure appeared to be: insufficient cement content, poor mixing of cement, excessive trimming of the compacted CTB, insufficient CTB thickness, inadequate CTB compaction or deficiencies in the AC surfacing thickness or quality.

A significant improvement in the performance of CTB composite pavements was caused by (1) Extending the CTB at least one foot into the shoulder. (2) Plant mixing the CTB. (3) Building the project in a temperate climate. (4) Increasing the thickness of the AC surfacing. (5) Limiting the compacted thickness of any one layer of CTB to 0.50 foot. (6) Using type II cement rather than type I. (7) Using a minimum CTB thickness of 0.50 foot. (8) Providing a minimum in situ CTB compressive strength of 500 psi.

Field sampling observations showed there was generally very little bond between layers of CTB but the AC was nearly always well bonded to the top of the CTB. Excessive trimming of a compacted CTB was shown to cause disintegration of a thin layer at the top of the CTB which subsequently caused extensive pumping and cracking of the AC surfacing.

KEY WORDS: Cement treated base, pavement evaluation, composite pavement, pavement distress, pavement deflection, cracking, expansion contraction, laboratory tests.

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FOREWORD

Since California has constructed a substantial amount of cement treated bases (CTB) surfaced with asphalt concrete pavement, an evaluation of the effectiveness of this type of construction was considered to be timely.

An attempt was made to analyze all factors which might affect the performance of CTB projects.

This investigation was performed under expenditure authorization 633208 in cooperation with the U. S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads.

The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the Bureau of Public Roads.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to our 11 highway districts which furnished essential maintenance and construction information for these projects. We realize that considerable time and effort were necessary to accumulate this data.

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INTRODUCTION

Cement treated bases have been used in California for a great many years. In fact California experimented with mixing portland cement with heavy clay soils as far back as 1921. There was no immediate attempt, however, to develop the process further. Interest was revived in 1936 by reports from South Carolina praising the merits of cement treatment. Therefore, two projects approximately one mile long were constructed using state forces in 1937. Additional projects, each approximately three miles long, were constructed under contract in 1938 and 1939.[14]

All of these projects were constructed using the road mix method. It was often difficult, however, to secure uniform construction both in depth of material treated and in thorough distribution of the cement. Furthermore, road mixing with farm equipment, such as disc and harrow which was then generally used, required considerable time and it was common to have a delay of six or eight hours between the introduction of cement and water and final compaction. This, of course, caused a considerable reduction in the ultimate compressive strength of the cement treated material.

Due to the poor results obtained with road mixing, plant mixing was specified for most of the cement treated base projects built between 1940 and 1950. As better road mixing machines were developed more and more road mixed projects were built and between 1950 and 1962 about half the cement treated base projects utilizing asphalt concrete surfacing were built by the road mixed method.

Prior to 1949 all specifications for cement treatment were presented in the contract special provisions. The early specifications had a minimum compressive strength requirement of 850 lb. per sq. in. at 7 days and 1000 lb. per sq. in. at 28 days. In the 1949 edition of the California Standard Specifications, specifications for only one class of cement treated base (Class "A", CTB) were provided. In the 1954 edition, specifications for three classes of CTB (A, B and C) were provided and in the 1960 edition, specifications for four classes of CTB (A, B, C and D) were provided.

Table 1 shows the changes in Class "A" and Class "B" CTB brought about by these three editions of the California Standard Specifications.

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[14] Superscripts refer to references at the end of the report.

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TABLE 1

VARIATION OF CTB QUALITY REQUIREMENTS
DUE TO SPECIFICATION CHANGES

Standard Specs.	Class of CTB	Minimum Compressive Strength @ 7 Days Pounds/sq. inch	Cement Content % of Dry Wt. of Aggr.
1949	A	650	4 to 7
1954	A	650	3-1/2 to 6
	B	300	2-1/2 to 3-1/2
1960	A	750	3-1/2 to 6
	B	400	2-1/2 to 4-1/2

Our present specifications (1964 edition) use the same ranges of cement content as required by the 1960 specifications, but the compressive strength requirements have been dropped. Aggregate quality is now controlled by grading specifications and requiring that the aggregate for both classes of CTB be of such quality that when mixed with portland cement in an amount not to exceed 5 percent by weight of the dry aggregate, shall produce a compacted mixture having not less than 750 psi compressive strength after curing seven days. Although not specified, the same minimum compressive strengths are expected for the two types of CTB as were specified in the 1960 specifications.

Several hundred miles of cement treated base projects were built prior to 1950 and between 1950 and 1962 over 700 miles of California highways were built with either Class "A" or Class "B" cement treated base which was surfaced with asphalt concrete.

With this substantial amount of CTB construction completed we felt it was time to make a comprehensive evaluation of this type of construction.

Scope of Investigation

In order to limit the scope of the investigation, we decided to consider only Class "A" and "B" CTB's. Since the 1949, 1954 and 1960 Standard Specifications were not too radically different from one another, we further limited the investigation to include only those projects which were built between 1950 and 1962. Projects built more recently than 1962 were felt to be too new to determine a valid performance rating.

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Project Evaluation

In order to evaluate the performance of these CTB projects, a visual examination was made in which the amount and type of cracking and the amount and type of maintenance performed was noted. Also physical characteristics of the terrain were observed. On projects with four or more lanes, only the outside truck travel lane was evaluated. Visual observations were made by driving along the shoulder of the road at a slow speed (5 ± MPH) and using the odometer of the vehicle to measure the extent of distressed areas. A verbal description of the type of distress and photographs of typical cracking were made for each project. The total amount of block cracking, (normally caused by excessive deflection under traffic) and pumping for each project was established by totaling the length of each type of distress, dividing this value by the length of the travel lanes and then converting the resulting value to a percentage.

Longitudinal and transverse cracking (normally caused by CTB shrinkage and possibly construction joints) was classified as normal, greater than normal or less than normal. A CTB roadway was considered to have a normal amount of cracking when it had narrow transverse cracks at about 20 feet intervals and had a small amount of intermittent longitudinal cracking throughout the length of the project. This rating is strongly affected by the raters judgment but since the same rater reviewed all the projects, it provides fairly valid comparative values. There was such a small amount of alligator cracking observed on these CTB projects that it was combined with the block cracking and no separate evaluation was made. Localized patched areas were considered to have been block cracked and were included in that rating unless the patching was obviously necessitated by something other than a failure of the structural section, e.g., fill settlement. The field review of these projects was completed in the summer of 1966.

Contract Construction Data

Contract files for all the projects investigated were searched for all pertinent information on construction equipment, construction methods, control test values and structural section design criteria.

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Project Maintenance Information

Questionnaires were sent to District maintenance personnel requesting information concerning the amount of maintenance performed on each project and the time at which the first significant amount of maintenance was necessary.

Selection of Projects for Field Sampling

Upon completion of the visual survey of all the projects, thirty-five were chosen for field sampling. In most cases, two projects showing good performance and two that performed poorly, were chosen from each district. A few of our districts had used little or no CTB meeting the requirements established for this evaluation and could not provide four projects suitable for sampling. A completely random selection of projects was sacrified in order to insure that projects were evaluated from as many parts of the state as was possible.

Field Sampling Procedures

Dynaflect[1] deflection measurements were made at twenty-five foot intervals at two different locations, two hundred feet long, on each of the thirty-five projects. The Dynaflect deflection measuring device consists of a set of eccentrically attached weights which are rotated in opposite directions such that a purely vertical dynamic force is applied to the pavement. The peak to peak excursion of the dynamic force is 1,000 pounds. This force is applied to the pavement through a pair of rigid wheels. The vibrations induced into the pavement are then read from a series of five geophones at one foot intervals. This allows a measure of the overall deflection of the pavement and also the extent of the deflected basin. The Dynaflect was chosen over the Benkleman beam or Deflectometer to measure the deflections on these projects because we had hoped to be able to identify cracks in the CTB by noting a discontinuity in the curve of the deflected basin at the location of the cracks in the CTB that had not reflected through the surfacing. In many cases, however, there was evidently a great enough particle interlock of the crack interfaces to prevent a discontinuity of the deflection curve from developing.

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[1]Superscripts refer to references at the end of the report.

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The Dynaflect deflection data was used to help locate the specific areas for coring. One large core ranging from six to twelve inches in diameter and two, four inch diameter cores were cut at each sampling location. The larger cores were used to check the extent of cracking and the small CTB cores were used for compressive strength and density determinations. One sampling location on each project was selected to be representative of the better portions of the project and the other was chosen to be representative of the poorer portions of the project.

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Summary and Findings

1. Block cracking is reduced by extending the CTB at least one foot into the shoulder. Longitudinal and transverse cracking is not similarly affected, however.

2. Plant mixed CTB projects have less cracking of all types than do road mixed CTB projects.

3. Open graded AC surfacing does not reduce the amount of longitudinal and transverse cracking but it does camouflage it such that it becomes less noticeable.

4. CTB projects along the coast have much less longitudinal and transverse cracking than projects built inland. This is very likely due to the more uniform temperatures that are found along the coast. There was no significant effect on the amount of block cracking, however.

5. As would be expected projects with poor drainage tend to have more block cracking and more pumping of mud fines.

6. The compressive strength of contract control samples varied directly with cement content but cement content had no significant effect on the amount of either block cracking or longitudinal and transverse cracking.

7. Block cracking was significantly reduced when the in situ CTB compressive strength exceeded 500 psi. Longitudinal and transverse cracking was not significantly affected by the compressive strength of the CTB.

8. Increasing the AC surfacing thickness is very effective in reducing the amount of longitudinal and transverse cracking but has no statistically significant effect on block cracking. There is a trend toward a reduction in block cracking as the AC surfacing thickness is increased, however.

9. The number of equivalent 5000 pound wheel loads and the stability of the basement soil as measured by the R-value had no significant effect on the amount of either longitudinal and transverse cracking or block cracking. This implies that our design method is adequately accounting for these variables.

10. The type of terrain in which the CTB projects were built had no significant effect on either block cracking or longitudinal and transverse cracking.

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11. Within a range of 20 to 80, the sand equivalent of the CTB aggregate had no significant effect on block cracking, longitudinal and transverse cracking, pumping or the compressive strength of the construction control samples.

12. CTB thicknesses of 0.67 feet were no more effective in preventing block cracking than were 0.50 feet thicknesses. This attests to the adequacy of our design method, since designs using either thickness of CTB were equally successful.

13. Projects compacted in one 0.67 feet thickness of CTB did not perform as well as projects compacted in two 0.33 feet thicknesses.

14. When the CTB was placed in two compacted layers, there was generally very little bond between these layers.

15. The asphalt concrete surfacing was well bonded to the CTB at most sampling locations. This bond was undoubtedly produced by the asphaltic curing seal used on the CTB.

16. Contract control compressive strengths increased as the CTB aggregate gradings moved from the fine side to the coarse side of the grading specifications but the coarser gradings were more difficult to compact and this increase in strength was not realized in the roadway. Therefore, grading had no significant effect on the amount of cracking.

17. Neither the season of the year in which the CTB was placed nor the time interval between the construction of the CTB and the construction of the AC surfacing produced a statistically significant effect on cracking. These comparisons are subject to some doubt, however, due to the inaccuracies of this particular data.

18. The structural sections with the strongest CTB had the longest maintenance free service life. Cracking of the CTB was not harmful when the CTB was strong enough to carry the loads.

19. The compressive strength of field cored CTB samples was statistically independent of cement content. However, there was a definite trend of increased compressive strength with increases of cement content.

20. As would be expected, the compressive strength of contract control samples increased as the density of the samples increased.

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21. CTB projects built with type II cement had less block cracking than those built with type I cement. The type of cement had no significant effect on the amount of longitudinal and transverse cracking, however.

22. Neither block cracking nor longitudinal and transverse cracking were significantly affected by class A or B CTB.

23. Relative compaction had no effect on the amount of cracking when a minimum of 92 percent relative compaction was achieved. Only 3 of the 32 projects from which relative compaction data was available had any cores that were below 95 percent relative compaction, however.

24. The average CTB compressive strength of cores from about half of the projects cored during this investigation did not exceed that of their respective construction control 7 day compressive strengths and the average CTB compressive strength of about 1/3 of the CTB cores did not reach 75 percent of the strength indicated by the construction control samples. These low strengths are undoubtedly due to the fact that only 95% relative compaction is required during construction.

25. The surface of a CTB can be badly damaged by trimming it after it has been compacted.

26. All five of the plant mixed CTB projects which were spread with a paving machine have provided good maintenance free service for periods ranging from 5 to 9 years and they all appear to be able to continue this good performance throughout their expected design lives.

27. In order to preclude block cracking, the maximum tolerable slope of deflected California CTB structural sections between any two geophones of the Dynaflect was found to be approximately 0.002%.

28. Fifty-five percent of the locations in which the CTB thickness was deficient were badly block cracked and the CTB was badly cracked at every location in which it was less than 0.46 feet thick.

29. From a total of 175 CTB projects 64 percent performed excellently, 17 percent were rated good, 8 percent were fair and 11 percent performed poorly.

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11 Alternative to widening the thickness tolerance for CTB's in order to eliminate excessive trimming of the compacted CTB would be to require that plant mixed CTB be spread by a paving machine such as is used for AC paving.

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TABLE 2

CTB SHOULDER EXTENSION VERSUS BLOCK CRACKING (PROJECTS HAVING GREATER THAN 5 MILLION EQUIVALENT WHEEL LOADS (EWL))

Extension of CTB into Shoulder (Feet)	Percent of Length Affected by Block Cracking			Number of Projects
	0% to 3%	3% to 31%	31% to 100%	
0 through 0.5	53%	24%	23%	38
1 through 10	70%	28%	2%	43

Dependent at 98% Confidence.

As shown in Table 3, longitudinal and transverse cracking was unaffected by extending the CTB into the shoulder. A project having narrow transverse cracks at a spacing of about 20 feet and having a small amount of intermittent longitudinal cracking was considered to have a normal amount of cracking. Projects experiencing less than 5 million EWL were excluded from these first two comparisons to eliminate projects which had obviously failed prematurely.

TABLE 3

CTB SHOULDER EXTENSION VERSUS LONGITUDINAL AND TRANSVERSE CRACKING (PROJECTS HAVING GREATER THAN 5 MILLION EWL)

Extension of CTB into Shoulder (Feet)	Longitudinal and Transverse Cracking Rating			Number of Projects
	Less than Normal	Normal	More than Normal	
0 through 0.5	43%	27%	30%	33
1 through 10	45%	14%	41%	42

Independent

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Tables 4 and 5 show plant mixed CTB projects to be more effective in preventing both block cracking and longitudinal and transverse cracking than are the road mixed projects. This is probably due to the fact that better control of the cement and moisture content and more thorough mixing is possible in a plant mixed operation.

TABLE 4

TYPE OF CTB MIXING VERSUS BLOCK CRACKING

Type of CTB Mixing	Percent of Length Affected by Block Cracking			Number of Projects
	0% to 3%	3% to 31%	31% to 100%	
Plant	72%	16%	12%	67
Road	48%	30%	22%	83

Dependent at 98% Confidence.

TABLE 5

TYPE OF CTB MIXING VERSUS LONGITUDINAL AND TRANSVERSE CRACKING

Type of CTB Mixing	Longitudinal and Transverse Cracking Rating			Number of Projects
	Less than Normal	Normal	More than Normal	
Plant	60%	13%	27%	60
Road	40%	22%	38%	76

Dependent at 95% Confidence.

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Table 6 shows open graded AC surfacing to be no more effective than dense graded AC in preventing longitudinal and transverse cracking. The surface texture of the open graded AC did make this type of cracking much less noticeable. In many cases, longitudinal and transverse cracks could not be seen through the open graded AC unless you stood directly over the crack.

TABLE 6

AC SURFACING GRADING VERSUS LONGITUDINAL AND TRANSVERSE CRACKING

AC Surfacing Grading	Longitudinal and Transverse Cracking Rating			Number of Projects
	Less than Normal	Normal	More than Normal	
Open Graded	58%	23%	19%	43
Dense Graded	55%	19%	26%	77

Independent

Table 7 shows that CTB projects built along the coast had much less longitudinal and transverse cracking than did the projects which were built in our inland valleys. The temperature along the coast is not subject to nearly the degree of change as in the inland valleys. This is very likely the reason for CTB projects along the coast having substantially less longitudinal and transverse cracking. The higher humidity along the coast could also be a factor affecting this type of cracking.

TABLE 7

GEOGRAPHIC LOCATION VERSUS LONGITUDINAL AND TRANSVERSE CRACKING

Geographic Location	Longitudinal and Transverse Cracking Rating			Number of Projects
	Less than Normal	Normal	More than Normal	
Coastal	63%	21%	16%	81
Inland	29%	15%	56%	55

Dependent at 99.5% Confidence.

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Table 8 shows that the amount of block cracking was not significantly affected by the geographical location of the project.

TABLE 8

GEOGRAPHIC LOCATION VERSUS BLOCK CRACKING

Geographic Location	Percent of Length Affected by Block Cracking			Number of Projects
	0% to 3%	3% to 31%	31% to 100%	
Coastal	62%	27%	11%	88
Inland	55%	20%	25%	65

Independent

Table 9 shows longitudinal and transverse cracking to be unaffected by the drainage characteristics of the project. As would be expected, pumping tends to be more extensive on projects with poor drainage. Table 10 shows this relationship to be dependent at only 90 percent confidence, but considering that the drainage rating was established by a "one shot" inspection made in the dry season of the year, that is probably a sufficient level of confidence to establish the significance of this relationship.

TABLE 9

DRAINAGE VERSUS LONGITUDINAL AND TRANSVERSE CRACKING

Drainage Rating	Longitudinal and Transverse Cracking Rating			Number of Projects
	Less than Normal	Normal	More than Normal	
Poor	47%	20%	33%	61
Fair	52%	16%	32%	44
Good	49%	19%	32%	31

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TABLE 10

DRAINAGE VERSUS PUMPING

Drainage Rating	Percent of Length Affected by Pumping		Number of Projects
	0% to 3%	3% to 100%	
Poor	68%	32%	74
Fair	72%	28%	47
Good	88%	12%	32

Dependent at 90% Confidence.

Table 11 shows a trend toward more block cracking on projects with poor drainage. As explained in the previous paragraph, this is probably a significant relationship even though it is statistically dependent at only an 85 percent level of confidence.

TABLE 11

DRAINAGE VERSUS BLOCK CRACKING

Drainage Rating	Percent of Length Affected by Block Cracking			Number of Projects
	0% to 3%	3% to 31%	31% to 100%	
Poor	49%	27%	24%	74
Fair	64%	25%	11%	47
Good	75%	16%	9%	32

Dependent at 85% Confidence.

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The seven day compressive strength of contract control samples is shown by Table 12 to be dependent upon the cement content of the CTB. As would be expected, the majority of the CTB's with a low cement content were in the 500 to 750 psi compressive strength range. It might seem strange that this is also the case for the CTB's with a high cement content, but this is explained by the fact that the majority of the CTB's in the high cement range were made with poorer quality aggregate and more cement was needed just to reach the 500 to 750 compressive strength range. Also, the majority of the projects in the extreme ranges of cement content were designed as Class "B" CTB and the majority of the projects in the middle ranges of cement content were designed as Class "A" CTB. Tables 13 and 14 show no relationship between the cement content and either longitudinal and transverse cracking or block cracking, however.

TABLE 12

CEMENT CONTENT VERSUS CONTRACT CONTROL
CTB COMPRESSIVE STRENGTH

Cement Content (% of Dry Wt.)	Seven Day Compressive Strength, PSI			Number of Projects
	200 to 500	500 to 750	750 to 1450	
2 to 3	22%	52%	26%	50
3 to 4	13%	43%	44%	76
4 to 5	8%	35%	57%	66
5 through 7	11%	53%	36%	45

Dependent at 97.5% Confidence.

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TABLE 13

CEMENT CONTENT VERSUS LONGITUDINAL AND TRANSVERSE CRACKING

Cement Content (% of Dry Wt.)	Longitudinal and Transverse Cracking Rating			Number of Projects
	Less than Normal	Normal	More than Normal	
2 to 3	50%	20%	30%	30
3 to 4	55%	17%	28%	47
4 to 5	47%	19%	34%	47
5 through 7	54%	18%	28%	28

Independent

TABLE 14

CEMENT CONTENT VERSUS BLOCK CRACKING

Cement Content (% of Dry Wt.)	Percent of Length Affected by Block Cracking			Number of Projects
	0% to 3%	3% to 31%	31% to 100%	
2 to 3	60%	20%	20%	35
3 to 4	59%	26%	15%	53
4 to 5	64%	22%	14%	50
5 through 7	61%	23%	16%	31

Independent

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Table 15 shows longitudinal and transverse cracking was not significantly affected by increasing the compressive strength of the CTB.

TABLE 15

CTB CORE COMPRESSIVE STRENGTH VERSUS LONGITUDINAL AND TRANSVERSE CRACKING

CTB Core Compressive Strength (PSI)	Longitudinal and Transverse Cracking Rating			Number of Sample Locations
	Less than Normal	Normal	More than Normal	
200 to 500	68%	11%	21%	19
500 to 750	50%	14%	36%	14
>750	55%	13%	32%	31

Independent

Table 16 shows block cracking was significantly reduced by increasing the CTB compressive strength.

TABLE 16

CTB CORE COMPRESSIVE STRENGTH VERSUS BLOCK CRACKING

CTB Core Compressive Strength (PSI)	Percent of Length Affected by Block Cracking			Number of Sample Locations
	0% to 3%	3% to 31%	31% to 100%	
200 to 500	42%	11%	47%	19
500 to 750	87%	7%	6%	15
>750	91%	6%	3%	33

Dependent at 99.5% Confidence.

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The data in Tables 15 and 16 have been based on the 35 projects which were sampled during this study. The compressive strength values were based on four inch diameter specimens which were cut with a surface set diamond core barrel. The CTB in locations in which the core disintegrated during the coring process was given an arbitrary compressive strength of 200 psi. This value was chosen since we were able to retrieve a core from one location which had a compressive strength as low as 232 psi, and it is unlikely that the CTB at all of the uncoreable locations had absolutely no compressive strength.

Table 17 shows that longitudinal and transverse cracking was greatly reduced by using an AC thickness of 0.29 feet or greater. The projects which were less than 7 years old were eliminated from this comparison to reduce the effect of age on the longitudinal and transverse cracking rating.

TABLE 17

AC THICKNESS VERSUS LONGITUDINAL AND TRANSVERSE CRACKING (PROJECTS 7 TO 16 YEARS OLD)

AC Design Thickness (Feet)	Longitudinal and Transverse Cracking Rating			Number of Projects
	Less than Normal	Normal	More than Normal	
0.15 to 0.25	28%	20%	52%	25
0.25	28%	24%	48%	50
0.29*to 0.51	73%	11%	16%	19

Dependent at 98% Confidence.
*Only 2 of the 19 projects had AC thicknesses of less than 0.33'.

Tables 15 and 17 emphasize the fact that excessive longitudinal and transverse cracking is not caused by a CTB with high compressive strength but by using an insufficient thickness of AC surfacing over the CTB.

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Table 18 shows a comparison of AC thickness and the block cracking rating to be statistically independent but there is a trend for the amount of block cracking to be reduced as the AC surfacing thickness is increased.

In a Canadian study of the causes of AC shrinkage cracking on projects constructed of two inch AC over a six inch soil-stabilized crushed base, R. W. Culley found the source of the asphalt was a significant factor in the occurrence of transverse cracking in AC pavement.[5]

TABLE 18

AC THICKNESS VERSUS BLOCK CRACKING
(PROJECTS 7 TO 16 YEARS OLD)

AC Thickness (Feet)	Percent of Length Affected by Block Cracking			Number of Projects
	0% to 3%	3% to 31%	31% to 100%	
0.15 to 0.25	37%	41%	22%	27
0.25	48%	25%	27%	64
0.29*to 0.50	67%	24%	9%	21

Dependent at 85% confidence.
*Only 2 of the 21 projects had AC thicknesses of less than 0.33'.

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The comparison shown in Table 19 was made to see if California asphalt sources would similarly have an effect on the incidence of longitudinal and transverse cracking. It is readily apparent that such is not the case for the most commonly used California asphalt sources. In order to have enough projects to perform a statistical dependency test, the asphalts from the Santa Maria area and the asphalts from the Wilmington area were grouped together into their respective sources of crude oil. Apparently our asphalt specifications are causing California refineries to produce a more uniform product than is the case in Saskatchewan or possibly our winters are so much milder that shrinkage cracking of AC is not a problem here. Also, reflection cracking from the shrinkage cracks in the CTB would probably overshadow the shrinkage cracking that might occur solely in the AC pavement.

TABLE 19

ASPHALT SOURCE VERSUS LONGITUDINAL AND TRANSVERSE CRACKING

Asphalt Source	Longitudinal and Transverse Cracking Rating			Number of Projects
	Less than Normal	Normal	More than Normal	
Standard Richmond	44%	28%	28%	18
Shell Martinez	54%	18%	28%	39
Douglas & Union Santa Maria	43%	24%	33%	21
Richfield MacMillan Standard Union Wilmington	48%	8%	44%	25

Independent

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Tables 20 and 21 show that the amount of commercial traffic, represented by equivalent 5000 pound wheel loads[3] (EWL), had no significant effect on the amount of either block cracking or longitudinal and transverse cracking for projects 7 to 16 years old. This indicates our design method is adequately accounting for variations in heavy truck traffic. As might be expected, however, there was a tendency for both types of cracking to be less on projects with very little heavy truck traffic. The same trends developed for projects 7 to 10 years old but there were too few projects in the high EWL category to make a valid statistical analysis with such a restriction on the age of the projects being compared. These comparisons were made using projects of a limited age bracket in an attempt to eliminate the effect of age on the analysis.

TABLE 20

EWL VERSUS BLOCK CRACKING
(PROJECTS 7 TO 16 YEARS OLD)

EWL (Millions)	Percent of Length Affected by Block Cracking			Number of Projects
	0% to 3%	3% to 31%	31% to 100%	
0 to 5	85%	15%	0%	13
5 to 20	68%	27%	5%	37
20 to 120	54%	23%	23%	13

Independent

TABLE 21

EWL VERSUS LONGITUDINAL AND TRANSVERSE CRACKING (PROJECTS 7 TO 16 YEARS OLD)

EWL (Millions)	Longitudinal and Transverse Cracking Rating			Number of Projects
	Less than Normal	Normal	More than Normal	
0 to 5	54%	31%	15%	13
5 to 20	38%	19%	43%	37
20 to 120	33%	25%	42%	12

Independent

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Tables 22 and 23 show that the type of terrain in which the project was built had no significant effect on the amount of either longitudinal and transverse cracking or block cracking.

TABLE 22

TYPE OF TERRAIN VERSUS BLOCK CRACKING

Terrain Classification	Percent of Length Affected by Block Cracking			Number of Projects
	0% to 3%	3% to 31%	31% to 100%	
Flat	62%	22%	16%	90
Rolling	53%	29%	18%	34
Mountainous	54%	25%	21%	28

Independent

TABLE 23

TYPE OF TERRAIN VERSUS LONGITUDINAL AND TRANSVERSE CRACKING

Terrain Classification	Longitudinal and Transverse Cracking Rating			Number of Projects
	Less than Normal	Normal	More than Normal	
Flat	45%	19%	36%	80
Rolling	63%	13%	24%	30
Mountainous	44%	24%	32%	25

Independent

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Within a 20 to 80 range of sand equivalent, tables 26 through 29 show the sand equivalent[6] of the CTB aggregate had no significant effect on the amount of cracking, pumping or the compressive strength of the CTB construction control samples.

TABLE 26

SAND EQUIVALENT VERSUS LONGITUDINAL AND TRANSVERSE CRACKING

Sand Equivalent (%)	Longitudinal and Transverse Cracking Rating			Number of Projects
	Less than Normal	Normal	More than Normal	
20 to 30	80%	20%	0%	10
30 to 50	52%	15%	33%	33
50 to 80	49%	19%	32%	31

Independent

TABLE 27

SAND EQUIVALENT VERSUS CONTRACT CONTROL CTB COMPRESSIVE STRENGTH

Sand Equivalent (%)	Compressive Strength, PSI			Number of Projects
	300 to 500	500 to 750	750 to 1450	
20 to 30	13%	60%	27%	15
30 to 50	17%	38%	45%	47
50 to 80	10%	50%	40%	40

Independent

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TABLE 28

SAND EQUIVALENT VERSUS PUMPING

Sand Equivalent (%)	Percent of Length Affected by Pumping		Number of Projects
	0% to 3%	3% to 100%	
20 to 30	55%	45%	11
30 to 50	68%	32%	38
50 to 80	67%	33%	33

Independent

TABLE 29

SAND EQUIVALENT VERSUS BLOCK CRACKING

Sand Equivalent (%)	Percent of Length Affected by Block Cracking			Number of Projects
	0% to 3%	3% to 31%	31% to 100%	
20 to 30	46%	45%	9%	11
30 to 50	61%	18%	21%	38
50 to 80	55%	30%	15%	33

Independent

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Table 32 shows that a 0.67 feet thickness of CTB was no more effective than a 0.50 feet thickness in preventing block cracking. This also attests to the adequacy of our design formula since a sufficient over-all structural strength was apparently provided when either thickness of CTB was used.

TABLE 32

CTB THICKNESS VERSUS BLOCK CRACKING

CTB Thickness (Feet)	Percent of Length Affected by Block Cracking			Number of Projects
	0% to 3%	3% to 31%	31% to 100%	
0.50	59%	22%	19%	37
0.67	56%	25%	19%	108

Independent

Table 33 shows the compressive strength of contract control samples to be increased as the CTB aggregate grading moves from the fine to the coarse side of Talbots optimum density grading limits.[7] As is often the case, an adjustment which improves one characteristic adversely affects another. Using a coarse grading in order to improve the compressive strength makes the CTB more difficult to compact. Figure 1 shows the honeycomb appearance that is common for a CTB with an excessively coarse grading. This CTB consists of 1-1/2 inch maximum size aggregate and had broad grading control on only two other sieve sizes, the No. 4 and No. 200 sieves. It was easily possible, therefore, to be within the grading tolerences for this project and still have a grading which was much too coarse for adequate compaction.

TABLE 33

CTB AGGREGATE GRADATION VERSUS
CONTRACT CONTROL CTB COMPRESSIVE STRENGTH

Grading	Compressive Strength, PSI			Number of Projects
	200 to 500	500 to 750	750 to 1450	
Coarser	3%	36%	61%	33
Talbots Optimum Density	9%	37%	54%	78
Finer	21%	58%	21%	47

Dependent at 99% Confidence.

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Tables 36 and 37 show the time interval between the placement of the CTB and the placement of the surfacing had no significant effect on cracking. It was not possible to determine areas of each project that were subject to a given amount of time lag and projects were roughly placed into the range of time lag that best approximated each job. If more accurate data had been available, the comparison shown in table 36 might have shown longitudinal and transverse cracking to be significantly reduced by reducing the time interval between the time the CTB was compacted and the time the AC surfacing was placed.

TABLE 36

TIME LAG BETWEEN PLACEMENT OF CTB AND AC VERSUS LONGITUDINAL AND TRANSVERSE CRACKING

Time Lag (Days)	Longitudinal and Transverse Cracking Rating			Number of Projects
	Less than Normal	Normal	More than Normal	
0 to 10	60%	14%	26%	42
10 to 40	49%	14%	37%	76
40 to 180	34%	28%	38%	29

Independent

TABLE 37

TIME LAG BETWEEN PLACEMENT OF CTB AND AC VERSUS BLOCK CRACKING

Time Lag (Days)	Percent of Length Affected by Block Cracking			Number of Projects
	0% to 3%	3% to 31%	31% to 100%	
0 to 10	53%	27%	20%	49
10 to 40	59%	24%	17%	86
40 to 180	61%	20%	19%	31

Independent

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Table 40 shows that the sections with the highest CTB compressive strength had the longest maintenance free service life. In this report maintenance free service life is defined as the projects life to the point at which major repair of the roadway is necessary. Minor repairs such as crack sealing and patching of a limited amount of localized failures are disregarded. Also, the maintenance free service life of each project which had not reached the point of requiring extensive maintenance was estimated to be in one of the three tabulated ranges of service life based on their condition at the time of the field survey. In most cases this amounted to a projection of service life by no more than three years which is felt to be a realistic extrapolation of the data.

TABLE 40

CTB CORE COMPRESSIVE STRENGTH
VERSUS MAINTENANCE FREE SERVICE LIFE

CTB Core Compressive Strength (PSI)	Maintenance Free Life, Years			Number of Sample Locations
	0 to 5	5 to 10	>10	
200 to 500	25%	25%	50%	20
500 to 750	35%	5%	60%	20
>750	0%	10%	90%	30

Dependent at 99.5% Confidence.

Projects which were in very good condition but not 10+ years old were assumed to be 10+ years old.

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The compressive strength of field CTB core samples is shown by table 41 to be statistically independent of cement content. We feel, however, that it is significant that the low range of cement content shows such a high percentage of projects in the 200 to 500 psi compressive strength range. Since table 16 shows the performance of sections in this compressive strength category to be so poor, it seems logical to raise our minimum cement content for Class "B" cement treated bases from 2.5 to 3.5 percent. With a minimum value of 3.5 percent very few areas should be below three percent cement due to the normal deviations in cement content which occur during construction.

TABLE 41

CEMENT CONTENT VERSUS CTB CORE COMPRESSIVE STRENGTH (4" DIA. CORES)

Cement Content (% of Dry Wt.)	Compressive Strength of CTB Core Samples, PSI			Number of Projects
	200 to 500	500 to 750	>750	
2.5 to 3	60%	20%	20%	10
3 to 4	33%	34%	33%	12
4 to 7	29%	24%	47%	21
	Independent			

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Tables 4 and 5 show plant mixed CTB projects to be more effective in preventing both block cracking and longitudinal and transverse cracking than are the road mixed projects. This is probably due to the fact that better control of the cement and moisture content and more thorough mixing is possible in a plant mixed operation.

TABLE 4

TYPE OF CTB MIXING VERSUS BLOCK CRACKING

Type of CTB Mixing	Percent of Length Affected by Block Cracking			Number of Projects
	0% to 3%	3% to 31%	31% to 100%	
Plant	72%	16%	12%	67
Road	48%	30%	22%	83

Dependent at 98% Confidence.

TABLE 5

TYPE OF CTB MIXING VERSUS LONGITUDINAL AND TRANSVERSE CRACKING

Type of CTB Mixing	Longitudinal and Transverse Cracking Rating			Number of Projects
	Less than Normal	Normal	More than Normal	
Plant	60%	13%	27%	60
Road	40%	22%	38%	76

Dependent at 95% Confidence.

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11. An alternative to widening the thickness tolerance for CTB's in order to eliminate excessive trimming of the compacted CTB would be to require that plant mixed CTB be spread by a paving machine such as is used for AC paving.

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DISCUSSION

Method of Data Analysis

In order to simplify the data analysis for this project an optical coincidence method was used. Numbered cards with a printed coordinate system were used. Holes were punched in these cards at a specific set of coordinates for each project. By using a different card to represent a specified range of each variable, it was possible to compare a number of different variables by lining up the cards and counting the number of holes which coincided. This number could then be divided by the total number of holes in the independent variable card to determine the ratio of all the projects within the range of the independent variable which were also within the ranges of the other variables being considered. This procedure provided a fairly rapid means of comparing a large number of different variables.

Having established the various relationships by the optical coincidence method, each was then tested for statistical independence by comparing it to the chi square distribution.[2]

With the multitude of variables involved in an investigation of this type, it is impossible to hold all other variables constant while any two are compared. Any relationships established among a group of variables should be very pronounced before they can be considered significant. Therefore, a 95 percent level of confidence was chosen to establish significance. When the data indicated a definite trend toward dependency, and was above a confidence level of 85 percent, we indicated the data tended to be dependent. All data showing a statistical dependency at less than an 85 percent level of confidence was considered to be totally independent.

Traffic data for each project was obtained by inputing the data from all 10 truck counts which had been taken between 1950 and 1963 into a computer program which calculated the equivalent 5 thousand pound wheel loads[3] (EWL's) for each count year and then calculated the linear regression line of best fit through the ten EWL values. The area under this curve was integrated between the limits of the time the project was completed and the time its condition was evaluated to provide an estimate of the amount of truck traffic which had traveled over each roadway.

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Some of the samples were tested for surface abrasion loss, a tentative test method for measuring the ability of a cemented construction material to resist surface abrasion or raveling in the presence of water.[4] Briefly, the method for testing a 4 inch diameter CTB core consists of sealing it in a compaction mold and clamping it into an apparatus capable of providing a vertical oscillation of one inch at a speed of 1200 cycles per minute. Two-hundred-fifty ml. of distilled water and four 1-1/8 inch diameter hard rubber balls are added and the system is tested for a period of 10 minutes at room temperature. The abraded material is then washed from the surface, dried to constant weight and reported as grams of abrasion loss.

Analysis of Data

The following tables show comparisons of the many variables which were considered likely to affect the service life of CTB projects. All of these tables have ranges of the independent variable listed in the left column, and the percentage of projects which were in each range of the independent variable are shown in their respective rows under columns listing the ranges of the dependent variable within which the particular percentage of projects pertains. The right hand column lists the total number of projects or sample locations which were within each range of the independent variable. Below each table is a statement as to whether or not the variables considered in the table were statistically dependent and if so, at what degree of confidence they are dependent. Only variables which were dependent at 95 percent confidence or higher were considered significant.

Table 2 shows that block cracking is significantly reduced by extending the CTB one foot or more into the shoulder. The zero to three percent range of block cracking is representative of good to excellent performance, the three to 31 percent range is representative of fair to good performance and the 31 to 100 percent range is representative of poor performance. The reduction in block cracking is very likely caused by the additional lateral support which develops in the outer wheel path when the CTB is extended one foot or more into the shoulder. The majority of the projects in the one through ten foot width of CTB shoulder extension category had the CTB extending only one foot into the shoulder.

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Conclusions and Recommendations

1. When imported material is used as CTB aggregate, plant mixing should be specified since it insures better performance and normally should not be any more expensive than road mixing.

2. The absolute minimum thickness of a CTB, which is to be surfaced with asphalt concrete, should be 0.50 feet.

3. A minimum thickness of 0.35 feet of AC should be specified for cement treated base structural sections used on all main line highways in order to reduce longitudinal and transverse reflection cracking. In no case should less than 0.25 feet of AC be used over a cement treated base.

4. About half of the design safety factor should be applied to the AC surfacing since a greater thickness of AC would tend to reduce the incidence of longitudinal and transverse cracking and would produce a smoother riding surface.

5. The minimum cement content of Class "B" CTB should be raised from 2.5% to 3.5% cement to protect against the development of weak areas produced by normal variations in cement distribution and mixing.

6. Consideration should be given to raising the level of compressive strengths which Class "A" and Class "B" CTB's are expected to achieve, in order to insure the construction of a higher quality base. This should help reduce the number of poorly performing projects.

7. Open graded AC blankets should be used to prevent spalling of crack interfaces and to improve the appearance of CTB projects which have developed extensive longitudinal and transverse cracking.

8. Unless new equipment or methods of compaction are developed which can produce a more uniform density throughout a greater depth of material, the present standard specification limitation for the compacted thickness of any layer of CTB should remain at 0.50 feet.

9. Some method of achieving an effective bond between the layers of CTB should be developed.

10. If it is too difficult to meet the present CTB grade tolerance of $\pm$ 0.05' without excessive trimming of the compacted CTB, consideration should be given to increasing this tolerance.

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Tables 24 and 25 show the quality of the basement soil also had no significant effect on the amount of cracking. This is significant in that it implies that our design method has been successful in overcoming the effect of variations in basement soil quality.

TABLE 24

BASEMENT SOIL R-VALUE
VERSUS BLOCK CRACKING

Basement Soil R-value	Percent of Length Affected by Block Cracking			Number of Projects
	0% to 3%	3% to 31%	31% to 100%	
0 to 25	61%	23%	16%	79
25 to 65	54%	23%	23%	39

Independent

TABLE 25

BASEMENT SOIL R-VALUE VERSUS
LONGITUDINAL AND TRANSVERSE CRACKING

Basement Soil R-value	Longitudinal and Transverse Cracking Rating			Number of Projects
	Less than Normal	Normal	More than Normal	
0 to 25	53%	18%	29%	72
25 to 65	47%	28%	25%	32

Independent

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Tables 30 and 31 show both block cracking and longitudinal and transverse cracking is significantly reduced by compacting the CTB in two 0.33 feet thicknesses rather than one 0.67 feet thickness. This is undoubtedly due to the fact that it is more difficult to achieve adequate compaction in the lower portion of a single 0.67 feet thick lift of CTB. Also, it is more difficult to achieve adequate cement distribution in heavier road mixed lifts. A number of the CTB core samples were cut in half and the top and bottom portions were tested separately. Some of these samples showed a significantly lower density for the bottom half of the core and the majority of the cores had a lesser compressive strength in the bottom half than in the top half (See Table 1-A in the Appendix.)

TABLE 30

NUMBER AND THICKNESS OF CTB LIFTS VERSUS BLOCK CRACKING

Number of Lifts	Thickness of Lifts (Feet)	Percent of Length Affected by Block Cracking			Number of Projects
		0% to 3%	3% to 31%	31% to 100%	
1	0.67	35%	38%	27%	29
2	0.33	62%	23%	15%	66

Dependent at 95% Confidence.

TABLE 31

NUMBER AND THICKNESS OF CTB LIFTS VERSUS LONGITUDINAL AND TRANSVERSE CRACKING

Number of Lifts	Thickness of Lifts (Feet)	Longitudinal and Transverse Cracking Rating			Number of Projects
		Less than Normal	Normal	More than Normal	
1	0.67	20%	24%	56%	25
2	0.33	59%	18%	23%	60

Dependent at 97.5% Confidence.

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Due to the compaction problems created by a coarse aggregate gradation, tables 34 and 35 show grading variations had no significant effect on the amount of either longitudinal and transverse cracking or block cracking.

TABLE 34

CTB AGGREGATE GRADATION VERSUS
LONGITUDINAL AND TRANSVERSE CRACKING

Grading	Longitudinal and Transverse Cracking Rating			Number of Projects
	Less than Normal	Normal	More than Normal	
Coarser	62%	17%	21%	24
Talbots Optimum Density	45%	17%	38%	53
Finer	36%	20%	44%	36

Independent

TABLE 35

CTB AGGREGATE GRADATION
VERSUS BLOCK CRACKING

Grading	Percent of Length Affected by Block Cracking			Number of Projects
	0% to 3%	3% to 31%	31% to 100%	
Coarser	58%	27%	15%	26
Talbots Optimum Density	56%	22%	22%	63
Finer	59%	23%	18%	39

Independent

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Tables 38 and 39 show the season of the year in which the CTB was placed had no effect on cracking.

TABLE 38

SEASON OF CTB PLACEMENT VERSUS
LONGITUDINAL AND TRANSVERSE CRACKING

Season of CTB Placement	Longitudinal and Transverse Cracking Rating			Number of Projects
	Less than Normal	Normal	More than Normal	
Winter	53%	19%	28%	32
Summer	45%	20%	35%	78
Spring	47%	18%	35%	34
Fall	52%	16%	32%	69

Independent

TABLE 39

SEASON OF CTB PLACEMENT
VERSUS BLOCK CRACKING

Season of CTB Placement	Percent of Length Affected by Block Cracking			Number of Projects
	0% to 3	3% to 31%	31% to 100%	
Winter	66%	23%	11%	35
Summer	55%	24%	21%	91
Spring	63%	21%	16%	38
Fall	57%	24%	19%	80

Independent

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As should be expected, table 42 shows the density of contract control samples strongly affects their compressive strengths. This table points out the power of the Chi square statistical comparison since it shows a 99.5 percent level of confidence for a comparison which is known to be a dependent relationship.

TABLE 42

DENSITY VERSUS CONSTRUCTION CONTROL CTB COMPRESSIVE STRENGTH

Density (PCF)	Compressive Strength, PSI 200 to 500	500 to 750	750 to 1450	Number of Projects
95 to 125	23%	53%	24%	17
125 to 135	20%	55%	25%	56
135 to 150	6%	40%	54%	103

Dependent at 99.5% Confidence.

Table 43 shows type II cement to be better than type I cement in preventing block cracking from developing. Table 44 shows longitudinal and transverse cracking to be unaffected by the type of cement that was used. California's present specifications require the use of type II cement for all CTB construction. An attempt was made to analyze the effect of construction moisture deviations on the density and compressive strength of the CTB but the available moisture data was insufficiently accurate for a valid analysis.

TABLE 43

TYPE OF CEMENT VERSUS BLOCK CRACKING

Type of Cement	Percent of Length Affected by Block Cracking 0% to 3%	3% to 31%	31% to 100%	Number of Projects
I	41%	26%	33%	27
II	66%	22%	12%	82

Dependent at 95% Confidence.

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TABLE 44

TYPE OF CEMENT VERSUS
LONGITUDINAL AND TRANSVERSE CRACKING

Type of Cement	Longitudinal and Transverse Cracking Rating			Number of Projects
	Less than Normal	Normal	More than Normal	
I	40%	20%	40%	20
II	52%	17%	31%	77

Independent

Table 45 shows that certain types of CTB construction were used more extensively during certain periods of time. Over half the projects built between 1950 and 1957 were built with Class "A" CTB. In more recent years Class "B" CTB had been used more extensively but the most recent trend especially during the period covered by this study, was for more of the 0.33 feet Class "A" over 0.33 feet Class "B" type of construction. As shown in Table 46, each of these types of construction have generally been used predominately with a specific thickness of AC surfacing. The Class "A" over Class "B" type of construction has been discontinued. It was found to be causing increased construction difficulties with no tangible improvement in the structural section design.

TABLE 45

CLASS OF CTB VERSUS PROJECT AGE
(AGE MEASURED FROM THE MIDDLE OF 1966)

Class of CTB	Age of Projects, Years			Number of Projects
	4 to 7	7 to 10	10 to 16	
A	13%	31%	56%	77
A over B	36%	41%	23%	39
B	28%	44%	28%	64

Dependent at 99.5% Confidence.

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TABLE 46

CLASS OF CTB VERSUS PLANNED THICKNESS OF AC

Class of CTB	Dense Graded AC Thickness, Feet 0.15 to 0.25	0.25	0.29 to 0.50	Number of Projects
A	30%	50%	20%	66
A over B	3%	33%	64%	30
B	15%	69%	16%	55

Dependent at 99.5% Confidence.

Tables 47 and 48 show the type of CTB construction has no significant effect on cracking. There appears to be a trend towards better performance for the Class "A" over Class "B" type of construction, but this is very likely due to the effect of the relationships mentioned in the previous paragraph, i.e. the Class "A" over Class "B" type of construction has been used more extensively on newer projects and has generally used thicker AC surfacing. As discussed earlier, the thickness of the AC surfacing was shown to have a strong effect on the amount of longitudinal and transverse cracking.

TABLE 47

CLASS OF CTB VERSUS LONGITUDINAL AND TRANSVERSE CRACKING

Class of CTB	Longitudinal and Transverse Cracking Rating Less than Normal	Normal	More than Normal	Number of Projects
A	42%	17%	41%	59
A over B	63%	17%	20%	30
B	49%	21%	30%	47

Independent

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TABLE 48

CLASS OF CTB VERSUS BLOCK CRACKING

Class of CTB	Percent of Length Affected by Block Cracking			Number of Projects
	0% to 3%	3% to 31%	31% to 100%	
A	55%	26%	19%	67
A over B	77%	20%	3%	30
B	54%	25%	21%	56

Independent

Tables 49 and 50 show cracking is unaffected by relative compaction when a minimum of 92 percent compaction is achieved. These two comparisons were based on the field cored projects from which we had construction control density data. Only three out of 32 of these projects had a relative compaction lower than 95 percent.

TABLE 49

CTB RELATIVE COMPACTION VERSUS BLOCK CRACKING (CORED PROJECTS)

Relative Compaction (%)	Percent of Length Affected by Block Cracking		Number of Projects
	0% to 3%	3% to 100%	
92 to 97	56%	44%	9
97 to 102	55%	45%	11
102 to 106	58%	42%	12

Independent

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TABLE 50

CTB RELATIVE COMPACTION VERSUS
LONGITUDINAL AND TRANSVERSE CRACKING
(CORED PROJECTS)

Relative Compaction (%)	Longitudinal and Transverse Cracking Rating		Number of Projects
	Less than Normal	More than Normal	
92 to 97	67%	33%	9
97 to 102	63%	37%	8
102 to 106	67%	33%	15

Independent

From a total of 175 CTB projects, 24 percent have equaled or exceeded their design life (10 years) with little or no necessary maintenance and it appears to be highly probable that another 40 percent of these projects will do the same. Eleven percent required extensive maintenance within three years after they were built. Eight percent required extensive maintenance within four to seven years after they were built and ten percent required extensive maintenance within seven to ten years after they were built. The remaining seven percent of the projects appear to be likely to need extensive maintenance within seven to ten years from the time they were built.

Over half of the projects which failed within three years after they were built were in Shasta and Siskiyou Counties. These projects were built with a maximum cement content of three percent and one used as little as 2.2 percent. When such a low cement content is used, very little variation in cement distribution and mixing is necessary to cause serious reductions in the compressive strength of the CTB.

Our present specifications allow a variation in cement content of ± 0.6 percent for road mixed CTB and ± 0.4 percent for plant mixed CTB. In a recently published investigation concerning the "Control of Cement in CTB" made by this department,[8] it was shown that for plant mixed operations using good to excellent equipment and operating procedures approximately three to eight percent of the CTB placed on each of three projects was shy of the planned cement content by more than the allowable

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deviation of -0.4 percent. These percentages were based on the calculated standard deviation and the assumption that the material was normally distributed. It is easy to see, therefore, how projects built under less than ideal conditions with a minimal cement content could develop many areas that require extensive maintenance. This would be particularly true for plant mixed projects in which the equipment was not in perfect operating condition or for most road mixed projects.

Shasta and Siskiyou Counties are in mountainous areas subject to freezing winter weather. In a laboratory and field test of the effect of cement content on the durability of CTB when subjected to freezing and thawing action, Abrams[9] found that a minimum of 3% cement was necessary to insure that the CTB would withstand freezing and thawing conditions. Admittedly his tests were on materials quite different from those found in the Shasta-Siskiyou area, but there is still a strong possiblity that some of the distress that developed on these projects was caused by a freezing and thawing action.

A number of these poorly performing projects were investigated shortly after they began to fail and these investigations [10,11] indicated that the AC pavement was not properly compacted and was therefore highly permeable, allowing water to penetrate to the surfacing-base interface. This free water, combined with the action of heavy wheel loads, allowed a pumping action to develop which erroded the base and leached the asphalt coating from the AC aggregate. The poor compaction was attributed to paving late in the year when the air and ground temperatures were too low.

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Table 51 shows that 55 percent of the twenty sample locations in which the CTB was block cracked were shy of their CTB design thickness by more than 0.04 feet and that none of the sample locations were block cracked when the CTB exceeded its design thickness by more than 0.04 feet. It is readily seen that shrinkage cracking is unaffected by CTB thickness variations. Only 21 percent of the locations with no block cracking had a thickness which was shy of the design thickness by more than 0.04 feet. The majority of the locations which were deficient in CTB thickness were badly cracked.

TABLE 51

CTB CONDITION VERSUS
DEVIATIONS FROM THE CTB DESIGN THICKNESS
(CORED PROJECTS)

CTB Condition in Vicinity of Sample Location	CTB Thickness Deviations			Number of Sample Locations
	Thinner	Design Thickness ± 0.04 Ft.	Thicker	
Block Cracked	55%	45%	0%	20
Extensive Shrinkage Cracking	20%	60%	20%	10
Uncracked or Slight to Moderate Shrinkage Cracking	21%	42%	37%	38

Dependent at 99% Confidence.

The CTB was badly cracked at every location in which it was less than 0.46 feet thick. This data indicates that many of our past CTB designs should have been increased in thickness in order to protect against thickness deficiencies due to normal construction operations and that in some cases closer control should have been maintained over the construction operations. The safety factors[3] which are presently added to our structural section designs should reduce the amount of future pavement failures caused by slight deviations from the design thickness. We can't emphasize too strongly, however, the importance of good inspection of the construction operations to insure that the structural section is built within the tolerances specified for the project.

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Only 4 of the 175 projects which were included in this study had a design CTB thickness which was less than 0.50 feet. Two were 0.42 feet thick and two were 0.33 feet thick. None of these projects were successful. All required major repairs before they were 7 years old and the 0.33 feet thick CTB projects required major repairs within five years after they were completed.

From a total of 32 coring locations in which the CTB had been placed in two compacted lifts, only two locations produced cores which were bonded together at the interface of the two lifts. Both of these coring locations were on the same project which had used a volcanic tuff material as the CTB aggregate.

Figure 2 shows an example of a situation which was observed on several of the sampled projects. The upper layer of Class "A" CTB had a transverse crack which did not extend through the lower layer of Class "B" CTB showing that the two layers were definitely acting independently.

Since the value of having the CTB layers well bonded together is self evident, it is imperative that some means of achieving this bond be developed. Arman and Dantin[12] found set retarding agents to be effective in producing bond between CTB lifts in laboratory tests with up to 7 hours time lag between placement of the two lifts. Set retarding agents could also be of value in achieving better compaction when the contractor is slow in achieving compaction. Use of an asphaltic bonding agent could also prove to be an effective solution to the CTB bonding problem.

The asphalt concrete surfacing was well bonded to the CTB at 57 out of 66 sample locations. This bond is undoubtedly caused by the asphalt curing seal which is used on the CTB. Information as to the type of CTB curing seal used was available for only three of the nine locations which had poor bond. The curing seal used at all three of these locations consisted of an asphaltic emulsion. This is probably not significant, however, since 86 percent of the 142 projects from which this information was available had used an asphaltic emulsion curing seal.

Figure 3 shows a comparision of the average construction control compressive strength for each sampled project versus the average compressive strength of the field cores from each of these projects. These points appear to be randomly distributed about the line of perfect correlation with about 50 percent having a lesser strength than that obtained from the construction control samples. This implies that there has been about an even

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chance that the strength indicated by the CTB construction control samples would never be reached by the CTB in the structural section. About one-third of the CTB cores didn't even reach 75 percent of the strength indicated by the construction control samples. It would appear to be worthwhile, therefore, to design new cement treated bases for a strength of about 25 to 30 percent higher than that which is considered to be necessary in the completed CTB. The State of Washington, Department of Highways is presently doing just that.[13] Their experience indicates an in situ minimum 7-day compressive strength of 650 psi is necessary for a CTB to be successful on their highways. Since their compaction specifications allow acceptance with only 95 percent of the density upon which the design cement content is based, they have increased the minimum design compressive strength to 850 psi at seven days to allow for the lesser field densities. Since we also allow CTB to be compacted to 95 percent relative compaction, our design compressive strengths should be adjusted accordingly.

Four of the 35 projects which were sampled had thin layers of disintegrated CTB about 0.04 to 0.08 feet thick at the top surface of the CTB while the lower portions remained sound. This is a situation which has been noted on projects other than those investigated during this study. In nearly every case, this condition has led to block cracking and pumping early in the design life of the project even though the underlying CTB remained sound.

One of the four projects appeared to have been trimmed excessively to reduce the thickness of the partially cured CTB. This process undoubtedly weakens the upper surface of the CTB. Figure 4 shows how the CTB sheared off just below the surfacing in this weakened portion of the CTB while being cored.

A thin layer of CTB was known to have been placed on another of these projects in order to bring it to design grade. Figure 5 shows the smooth separation of these two layers of CTB and that the thin layer remained bonded to the AC surfacing. This core was cut from the center of the lane. The thin layer of CTB was pulverized in the wheel tracks at this location and had caused extensive cracking and pumping of the travel lane wheel tracks.

Figure 6 shows how the thin layer of disintegrated CTB in the outer wheel track at this location was washed out from beneath the AC by the drill water. Since it is difficult to spread and compact a thin layer of CTB and it is unlikely that this layer would bond to the underlying CTB, it is easy to see how it could be pulverized between the underlying CTB and the AC surfacing by the action of heavy wheel loads.

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Another of these projects had been an experimental project in which an attempt had been made to pave a CTB with an armor coat. The first course of the armor coat was to have been spread and compacted into the CTB before the CTB's initial set. When this was attempted the weather was too cold and the paving asphalt chilled before the rock could be rolled in. Therefore, a two inch AC surfacing was used instead of the armor coat. The surface of the CTB was damaged in the portion of the project in which the attempt at placing the armor coat was made. This caused it to disintegrate under the action of heavy truck traffic and caused extensive cracking and pumping in the AC surfacing.

These projects point out the disadvantages of placing extremely thin CTB layers or trying to manipulate the surface of the CTB after it has been compacted and partially cured.

Information as to the type of mixing and spreading equipment was available for only about half of the projects which were evaluated in this study and only five out of 37 of the plant mixed projects from which this information was available were spread with a paving machine. All five of these projects had good quality CTB at the time of the field review and had not received any extensive maintenance throughout 5 to 9 years of service life.

Figure 7 shows a plot of the maximum Dynaflect deflection versus the maximum slope of the Dynaflect curve between any two of the five geophones for both cracked and uncracked locations. Although both deflection and slope seem to indicate a maximum tolerable value, it is apparent from this plot that the maximum slope of the deflected pavement provides a more sensitive break between cracked and uncracked locations than does the maximum deflection. This data indicates the maximum tolerable slope to be about 0.002 percent. Fifty-nine percent of the locations with a greater slope were block cracked and many of those that have not cracked yet will probably do so before their design lives are exceeded.

Figure 8 shows that the abrasion loss[4] does not correlate very well with the compressive strength of the CTB cores. Abrasion loss did not appear to be a good indicator of cracking and only a limited amount of the CTB cores were tested for abrasion loss.

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Figure 9 shows the compressive strength frequency distribution of the CTB cores for each type of mixing and class of CTB. The plant mixing produces more of a normal frequency distribution whereas road mixing produces a distribution which is skewed toward the low compressive strength range. Also, the Class "A" road mixed CTB cores produced a broad range of compressive strengths indicating poor uniformity very likely caused by a poor distribution of cement. Twenty-five percent of the Class "B" plant mixed projects had CTB compressive strengths of less than 300 psi whereas 53 percent of the Class "B" road mixed projects were in the low range of compressive strength. Eighteen percent of the Class "A" plant mixed projects had CTB compressive strengths of less than 600 psi whereas 29 percent of the Class "A" road mixed projects were in the low range of compressive strength. This data clearly demonstrates the superiority of plant mixing over road mixing and the superiority of Class "A" CTB over Class "B" CTB.

Figure 10 presents a plot of the ratio of the elapsed number of equivalent 5,000 pound wheel loads to that for which the structural section was designed versus the number of years of relatively maintenance free service life. This figure shows that the majority of the projects requiring extensive maintenance were less than five years old and that over half of these projects had experienced less than 25 percent of their design traffic loading. Eighteen of the 25 projects requiring extensive maintenance before they were five years old were built with Class "B" CTB and had low cement contents. Five of the remaining 7 projects were built by the road mixed method of construction and as previously shown by figure 9, road mixing is much more likely to produce an inferior CTB.

A straight line would appear to best fit the data in figure 10 but this line would pass a year or two to the left of the point representing the end of the ten year design life. This indicates we have been slightly underestimating the design wheel loads on most of our projects.

One of the field sampled projects produced an interesting bit of supplemental information. This project had been built using cement stack dust as a filler material in the aggregate subbase. The cement stack dust cemented the aggregate subbase together so strongly in one portion of the project that we were able to core it and test its compressive strength. It produced a compressive strength of 760 psi which was very nearly as much strength as the Class "B" CTB for this project developed. The deflections measured in the areas in which the subbase had developed slab strength were quite low and the performance of

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this project has been excellent. This appears to be a very worthwhile practice if the cement stack dust is readily available at an economical price and the aggregate subbase is lacking in fines. You stand to gain a bonus of any slab strength which may develop while improving the materials compactability.

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Figure 1

CLASS "A" CTB CORES

Project 04-Mrn-17 — 0.3 /2.3

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Figure 2

CLASS "A" & CLASS "B" CTB CORES

Project 04-Mrn-17 - 0.3/2.3

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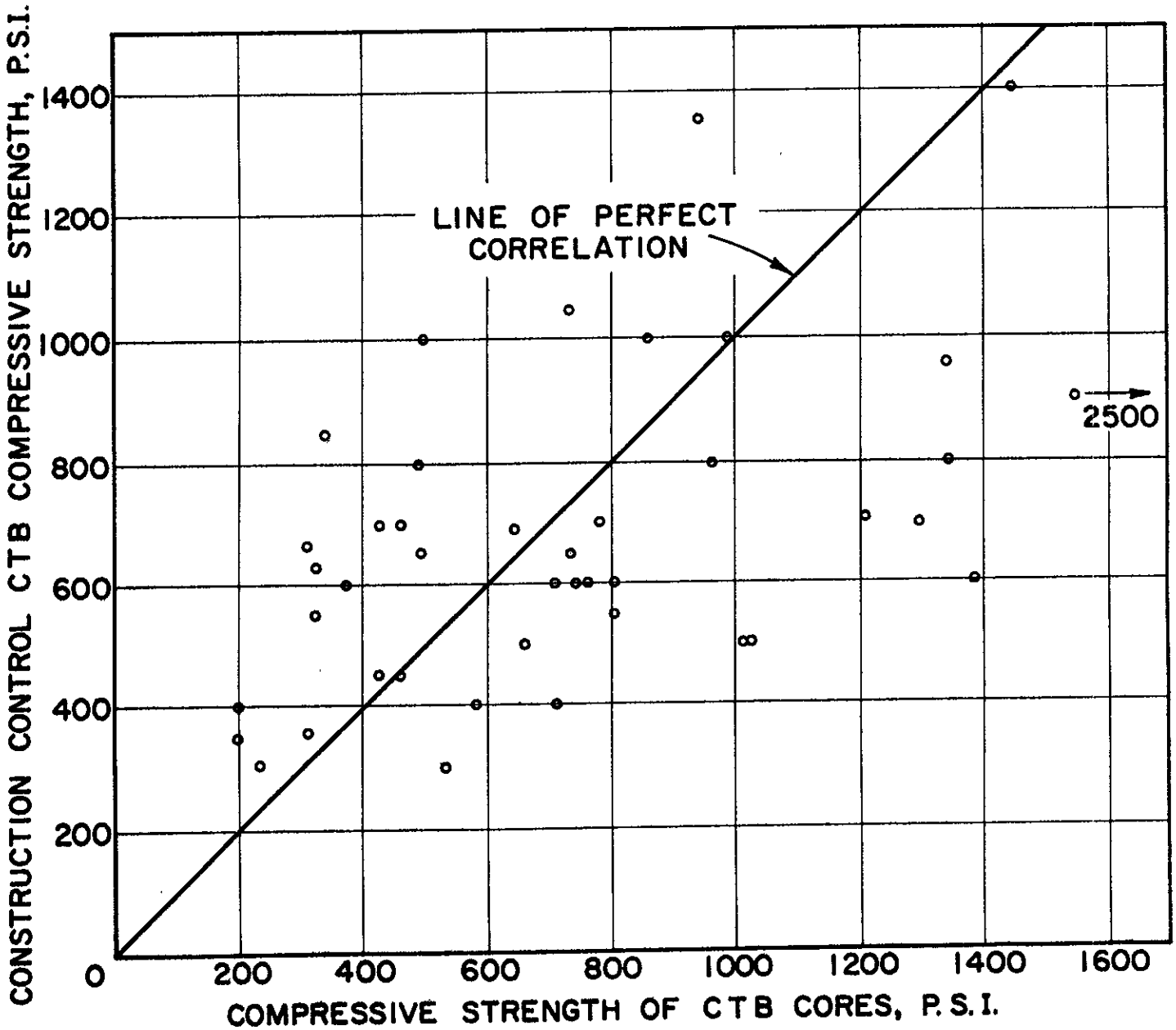
Figure 3

COMPARISON OF COMPRESSIVE STRENGTH OF CONSTRUCTION CONTROL SAMPLES WITH THAT OF THE FIELD CORES



NOTES:

1. CTB CORES WHICH DISINTEGRATED DURING CORING WERE GIVEN AN ARBITRARY COMPRESSIVE STRENGTH OF 200 P.S.I.
2. EACH POINT REPRESENTS THE AVERAGE COMPRESSIVE STRENGTH OF FOUR 4 INCH DIAMETER CORES.

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SHEAR PLANE IN CLASS "A" CTB
Project 08-Riv-10-30.1/44.5

Figure 4

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Figure 5

COMPACTION PLANE BETWEEN TWO LIFTS OF CLASS "B" CTB.

Project 05 - Mon - 101 - 43.9/51.7

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Figure 6

"12" CORE HOLE

Project 05-Mon-101-43.9/51.7

NOTE: VOID UNDER AC SURFACING

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MAXIMUM DEFLECTION VERSUS MAXIMUM SLOPE OF DEFLECTED PAVEMENT FROM DYNAFLECT READINGS

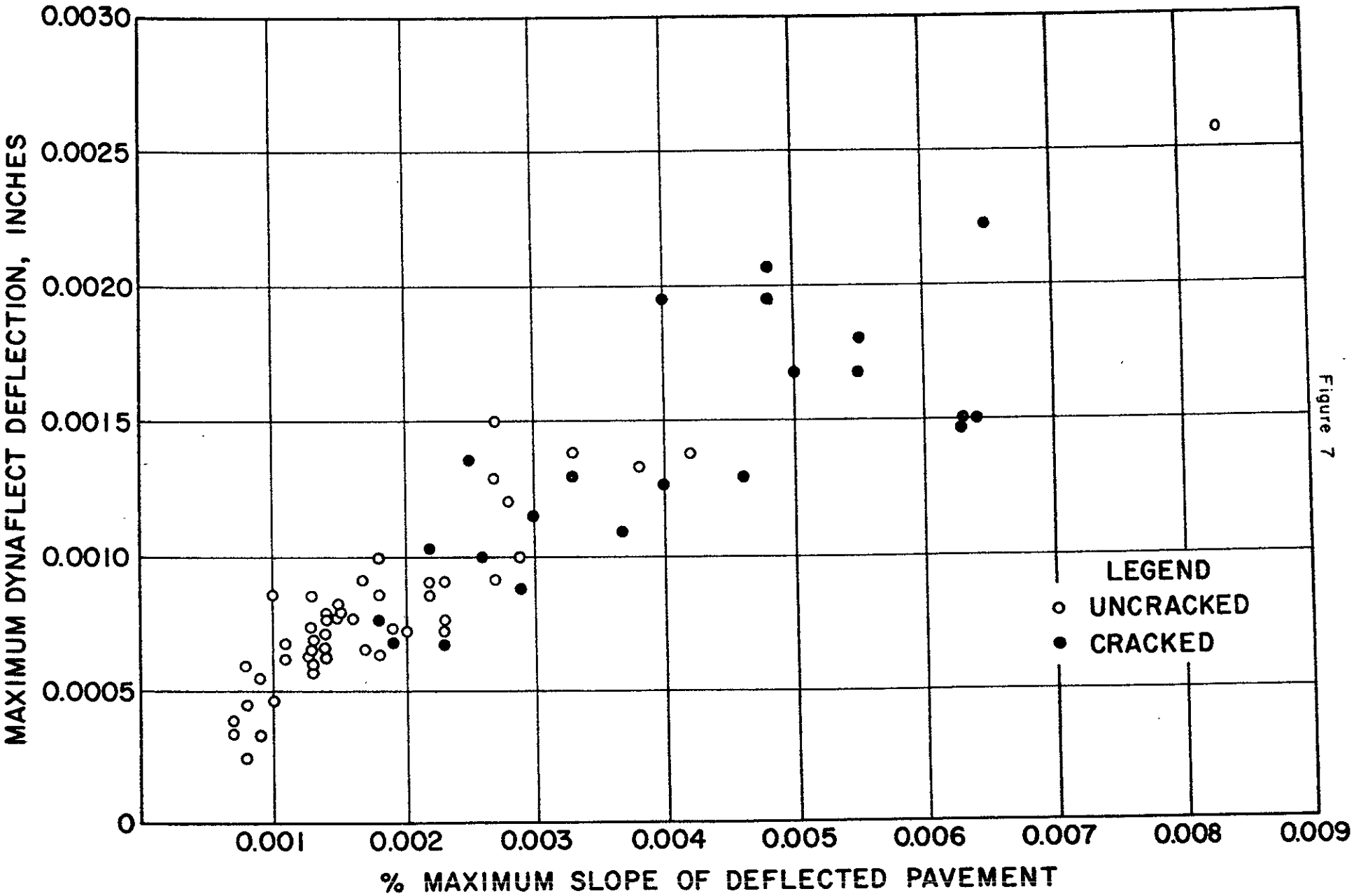
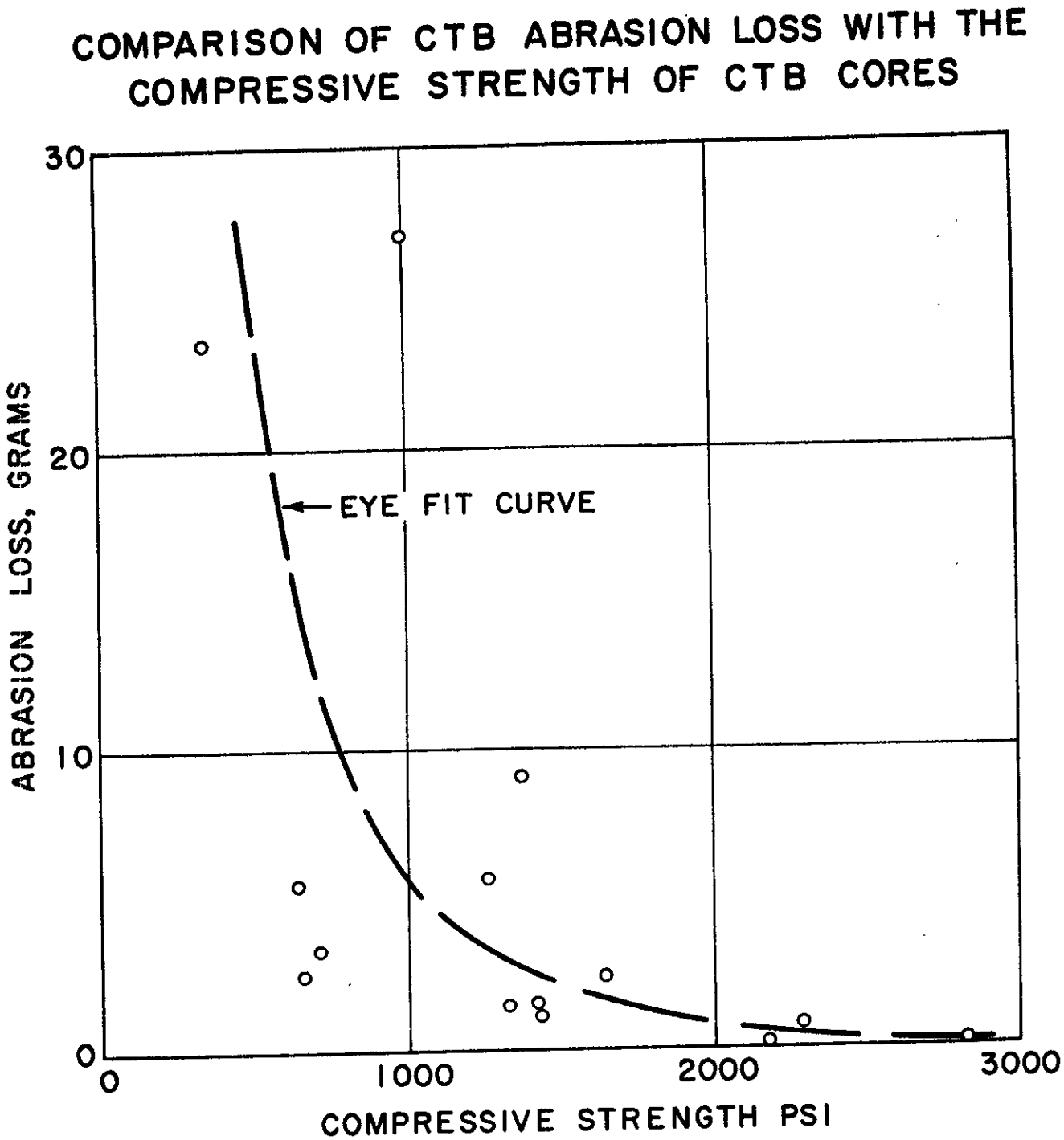


Figure 7

Figure 8



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COMPRESSIVE STRENGTH FREQUENCY DISTRIBUTION OF CTB CORES BY CLASS OF CTB AND TYPE OF MIXING

NOTE: UNCOREABLE LOCATIONS WERE GROUPED IN THE 0 TO 300 PSI RANGE OF COMPRESSIVE STRENGTH

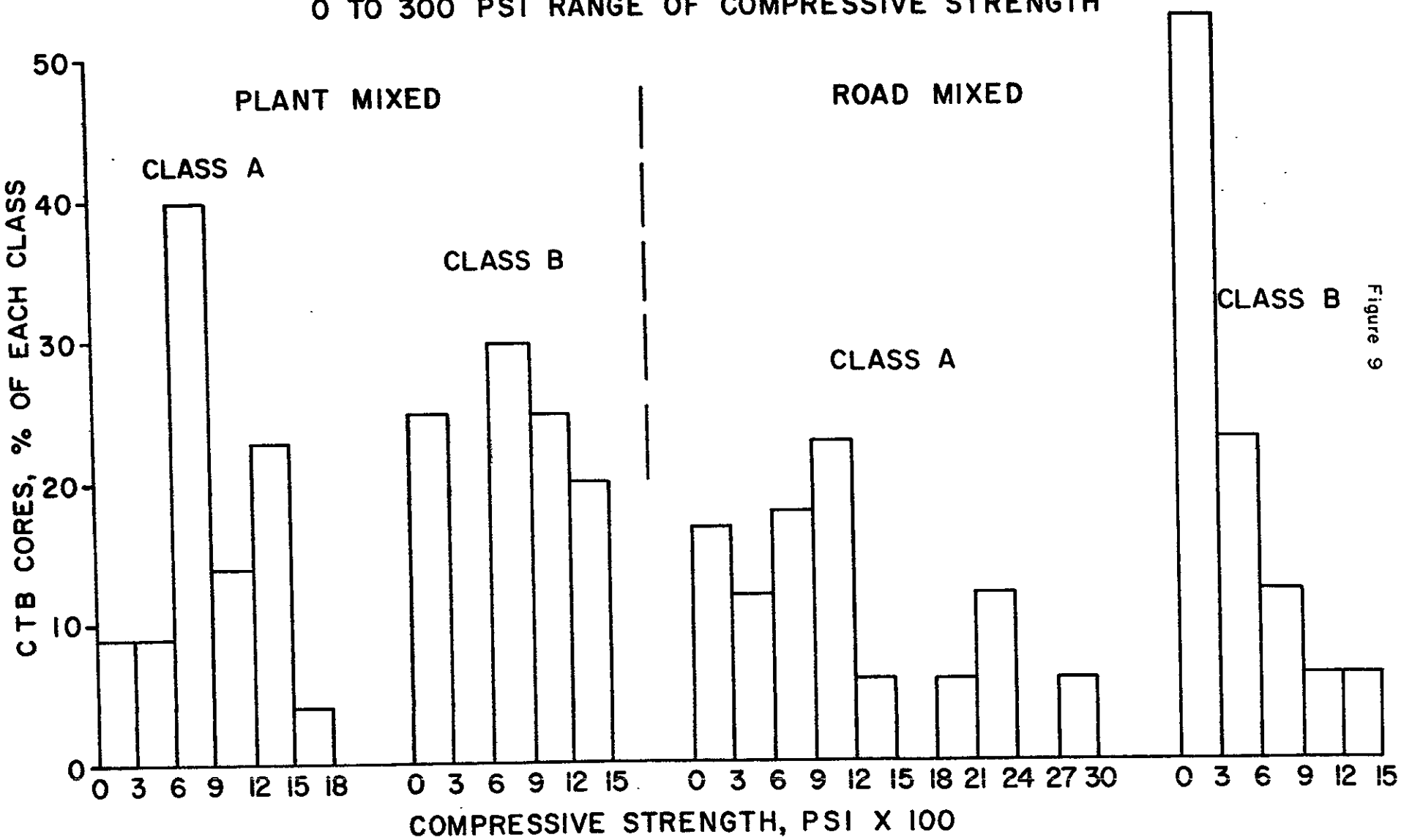

Figure 9

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RATIO OF DESIGN WHEEL LOADS ELAPSED VERSUS YEARS OF MAINTENANCE FREE SERVICE

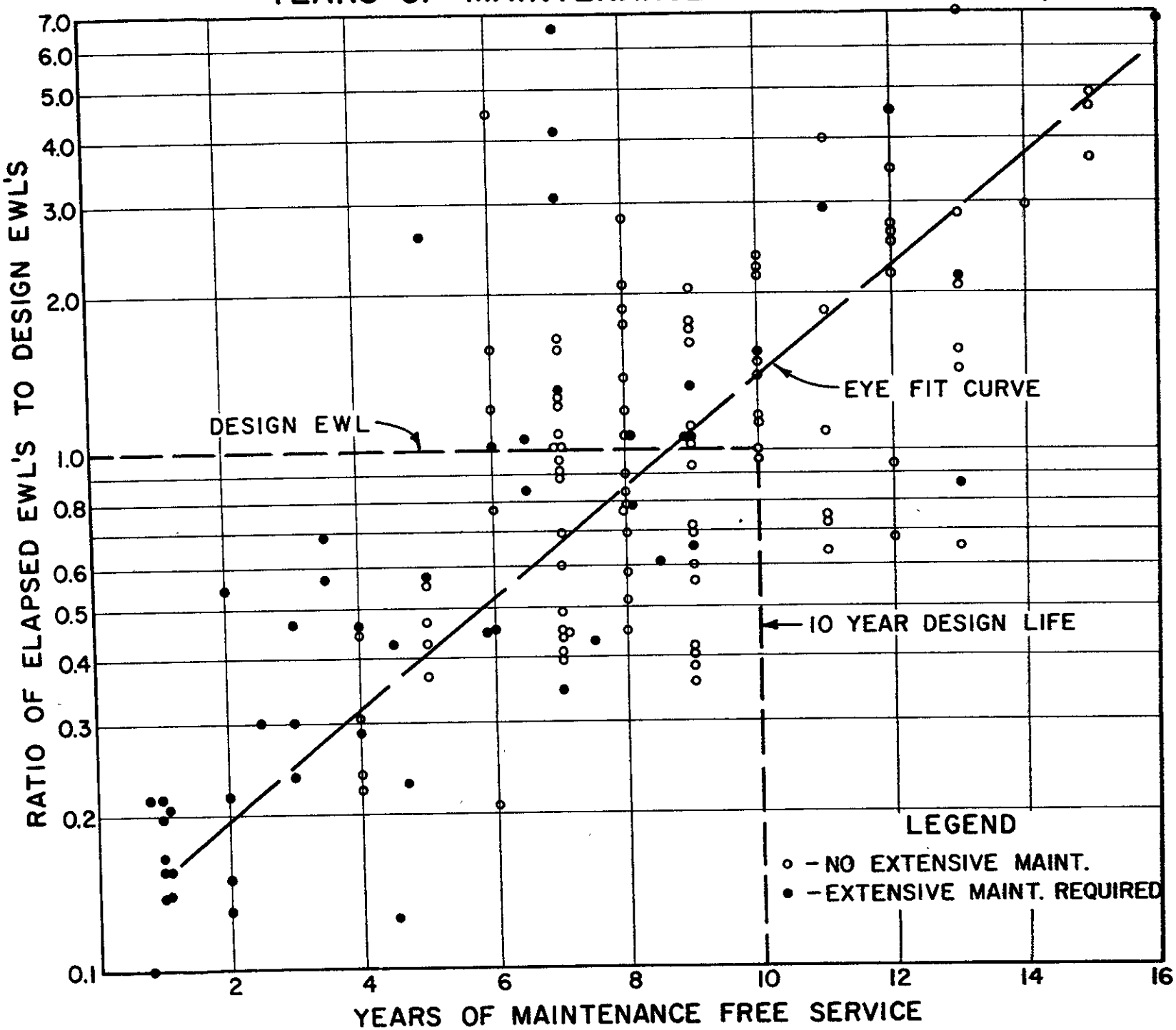

Figure 10

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APPENDIX

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TABLE 1-A

C.T.B. CORE TEST RESULTS

Sample Location Number	Project Location Dist.-Co.-Rte.P.M.	Outer Lane Sample Location	Abrasion Loss Gms		Density, PCF		Compressive Strength, PSI	
			Class B	Class A	Class B	Class A	Class B	Class A
1	01-Hum-101-104.2/ 107.8	P.M.109.03 3'Rt.℄NBTL	0	0	145*	145	902*	802
2		PM 107.23 3'Lt.℄ SBTL	3.6*	0.6*	-	142*	-	-
3	01-Hum-101-61.7/ 65.0	PM 63.68 3'Lt.℄ SBTL	-	0*	-	146	-	1246
4		PM 62.95 3'Rt.℄ NBTL	0*	0*	148*	149	1260*	1419
5	01-Hum-101-28.1/ 35.7	PM 34.31 3'Lt.℄ SBTL	1.3*	8.2	142*	141	690*	552
6		PM 31.51 3'Rt.℄ NBTL	1.5*	0.8*	142*	141	633*	1173
7	01-Men-101-54.8/ 56.9	PM 55.59 3'Rt.℄ NBTL		0.1		135		800
8		PM 56.30 3'Lt.℄ SBTL		0		137		1880
9	01-Men-101-36.0/ 40.9	PM 39.43 2'Rt.℄ NBTL		0.6		143		1342
10		PM 38.22 3'Lt.℄ SBTL		1.9		139		622

Note: NBTL = Northbound travel lane. PM = Post mile.
Unless otherwise noted, all values are the average of the results from two CTB cores.

* Results from only one core.

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TABLE 1-A

C.T.B. CORE TEST RESULTS (CONT.)

Sample Location Number	Project Location Dist.-Co.-Rte. P.M.	Outer Lane Sample Location	Abrasion Loss Gms		Density, PCF		Compressive Strength, PSI	
			Class B	Class A	Class B	Class A	Class B	Class A
11	02-Sha-5-22.8/26.5	PM 25.12 3'Rt.℄ NBTL	3.2*		141*		707*	
12		PM 24.68 ℄ SBTL		Not Coreable				
13	02-Sha-5-1.1/5.0	PM 5.0 3'Lt.℄ SBTL		Not Coreable				
14		PM 4.4 3'Lt.℄ SBTL	1.4		143		1417	
15	02-Sha-5-49.5/56.2	PM 54.09 3'Rt.℄ NBTL	27.0*		140*		1102*	
16		PM 52.00 1.5'Lt.℄ SBTL		Not Coreable				
17	02-Teh-99-12.0/ 24.2	PM 13.00 3'Rt.℄ NBL		Not Coreable				
18		PM 16.60 3'Rt.℄ NBL			136		651	

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TABLE 1-A

C.T.B. CORE TEST RESULTS (CONT.)

Sample Location Number	Project Location Dist.-Co.-Rte.P.M.	Outer Lane Sample Location	Abrasion Loss Gms		Density, PCF		Compressive Strength, PSI	
			Class B	Class A	Class B	Class A	Class B	Class A
19	03-But-70-21.0/34.7	PM 29.55 3'Rt.℄ NBL	1.0		129		1428	
20		PM 32.63 3'Lt.℄ SBL	1.3		137		1318	
21	03-Sac-50-3.5/17.4	PM 8.89 3'Lt.℄ WBTL	5.7*		141		1258	
22		PM 6.82 3'Lt.℄ WBTL	9.0*		145*		1380*	
23	03-Pla-80-13.3/16.9	PM 14.2 3'Lt.℄ WBTL		0		147		2170
24		PM 14.95 3'Lt.℄ WBTL		2.3		149		1640*
25	03-Sac-99-28.1/ 33.6	PM 29.68 ℄ NBL		0.8		146*		2288
26		PM 33.12 1.5'Lt.℄ SBL		0.1*		151*		2820

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TABLE 1-A

C.T.B. CORE TEST RESULTS (CONT.)

Sample Location Number	Project Location Dist.-Co.-Rte.P.M.	Outer Lane Sample Location	Abrasion Loss Gms		Density, PCF		Compressive Strength, PSI	
			Class B	Class A	Class B	Class A	Class B	Class A
27	04-SM-1-3.9/7.0	PM 5.91 4'Rt.℄ NBTL			124		625	
28		PM 4.98 3'Lt.℄ SBTL			132		800	
29	04-Mrn-101-9.2/ 10.6	PM 9.52 ℄ SBTL		Top half+ Bottom half	120 121	133 130	1111 781	819 709
30	04-Mrn-17-0.3/2.3	PM 1.00 ℄ SBTL			137	137	949	727
31		PM 1.69 ℄ SBTL			144	137	946	733

\+ Top half and bottom half refer to the respective portions of cores which were sawed in half and tested separately.

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TABLE 1-A

C.T.B. CORE TEST RESULTS (CONT.)

Sample Location Number	Project Location Dist.-Co.-Rte.P.M.	Outer Lane Sample Location	Abrasion Loss Gms		Density, PCF		Compressive Strength, PSI	
			Class B	Class A	Class B	Class A	Class B	Class A
32	05-Mon-101-43.9 51.7	PM 48.21 3'Rt.℄ NBTL	Top half Bottom half		124 125		628 610	
33		PM 46.00 2'Rt.℄ NBTL			118 123		543 532	
34	05-SBt-156-2.0/4.0	PM 3.49 5'Lt.℄ WBL			139		979	
35		PM 2.93 3.5'Lt.℄ WBL	Top half Bottom half AS+Ideal Cement stack dust		138 138	126*	747 811	763*
36	05-Slo-46-41.6/ 50.3	PM 43.02 1'Rt.℄ EBL	2.4		126*		660*	
37		PM 45.98 3'Lt.℄ WBL			118*		-	
38	06-Tul-43-7.8/10.5	PM 8.02 ℄ NBL			125		670	
39		PM 9.84 3'Lt.℄ SBL	Top half Bottom half		120 116		976 542	

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TABLE 1-A

C.T.B. CORE TEST RESULTS (CONT.)

Sample Location Number	Project Location Dist.-Co.-Rte.P.M.	Outer Lane Sample Location	Abrasion Loss Gms		Density, PCF		Compressive Strength, PSI	
			Class B	Class A	Class B	Class A	Class B	Class A
40	07-LA-138-44.8/ 46.1	PM 45.20 4'Rt.℄ EBTL	Top half Bottom half			145 142		1004 882
41		PM 45.34 1'Lt.℄ WBTL	Top half Bottom half			140 140		1015 861
42	07-LA,Ven-1-51.8/ 62.9	PM 61.50 3'Lt.℄ SBTL	Top half Bottom half		136 -		- -	
43		PM 60.02 2'Rt.℄ NBTL	Top half Bottom half		133 127		545 763	
44	07-Ven-1-9.7/16.9	PM 13.30 2'Rt.℄ NBTL	10.4'		-	121	-	-
45		PM 16.50 3'Rt.℄ NBTL			-	119	-	487
46	07-Ven,SB-101-40.6/ 43.5	PM 42.90 ℄ SBTL			127 -		649* -	
47		PM 42.33 1'Rt.℄ NBTL			122 135		640* 1180*	

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TABLE 1-A

C.T.B. CORE TEST RESULTS (CONT.)

Sample Location Number	Project Location Dist.-Co.-Rte.P.M.	Outer Lane Sample Location	Abrasion Loss Gms		Density, PCF		Compressive Strength, PSI	
			Class B	Class A	Class B	Class A	Class B	Class A
48	08-Riv-10-30.1/ 44.5	PM 39.94 2'Rt.℄ EBTL			128	129	281	812
49		PM 41.42 2'Lt.℄ WBTL			131*	128*	792	669
50	08-Riv-395-23.5/ 28.2	PM 26.95 3'Lt.℄ SBTL				121		545*
51		PM 27.47 3'Lt.℄ SBTL				123		263
52	08-SBd-71-3.1/8.4	PM 4.60 4'Rt.℄ EBL			114		264	
53		PM 5.65 3'Rt.℄ EBL	Not Coreable					

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TABLE 1-A

C.T.B. CORE TEST RESULTS (CONT.)

Sample Location Number	Project Location Dist.-Co.-Rte.P.M.	Outer Lane Sample Location	Abrasion Loss Gms		Density, PCF		Compressive Strength, PSI	
			Class B	Class A	Class B	Class A	Class B	Class A
54	10-Cal-4-21.4/ 30.1	PM 23.99 ℄ EBL	5.5		86		635	
55		PM 28.17 ℄ WBL	23.6*		87		351	
56	10-Sol-80-0.32/ 1.57	PM 0.81 3'Lt.℄ WBTL		Top half Bottom half	124 123		728 661	
57		PM 1.00 3'Rt. ℄ EBTL			120		603	
58	10-Sol-680-3.98/ 7.21	PM 4.93 ℄ NBTL			127 123		872 544*	
59		PM 6.71 3'Lt.℄ SBTL			121 120		652 864	

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TABLE 1-A

C.T.B. CORE TEST RESULTS (CONT.)

Sample Location Number	Project Location Dist.-Co.-Rte.P.M.	Outer Lane Sample Location	Abrasion Loss Gms		Density, PCF		Compressive Strength, PSI	
			Class B	Class A	Class B	Class A	Class B	Class A
60	11-Imp-86-20.61/ 22.33	PM 21.38 3'Rt.℄ NBTL				136 136		836 620*
61		PM 21.35 3'Lt.℄ SBTL				142 133		1684 -
62	11-Riv-10-54.0/ 56.1	PM 55.59 3'Lt.℄ WBTL	Not Coreable			-		-
63		PM 55.34 3'Lt.℄ WBTL			Top half Bottom half	125 126		795 660
64	11-Riv-10-44.5/ 54.0	PM 49.83 3'Lt.℄ WBTL				135		
65		PM 49.51 3'Lt.℄ WBTL				133		705
66	11-SD-5-0.0/3.9	PM 3.62 3'Lt.℄ SBTL				124 125*		756 1278*
67	11-SD-75-11.0/ 18.9	PM 16.48 1.5'Lt.℄ SBTL			Top half Bottom half	130 129		1389 842
68		PM 11.98 1.5'Lt.℄ SBTL			Top half Bottom half	134 132		1789 1173

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TABLE 2-A

DYNAFLECT DATA

Sample Location Number	Dynaflect Deflections, 0.001 Inches			Maximum Slope of Deflection Curve	Road Condition at Sample Location
	Minimum	Maximum	Median		
1	0.44	0.62	0.51	0.0007 to 0.0011	Uncracked
2	0.32	0.96	0.45	0.0005 to 0.0017	Moderately Alligator cracked
3	0.50	0.77	0.54	0.0008 to 0.0015	Uncracked
4	0.42	0.66	0.55	0.0007 to 0.0011	"
5	0.34	0.99	0.54	0.0010 to 0.0013	Extensive Shrinkage cracking
6	0.30	0.45	0.38	0.0005 to 0.0007	Slight Shrinkage cracking
7	0.27	0.59	0.30	0.0007 to 0.0013	Extensive Shrinkage cracking
8	0.51	0.96	0.75	0.0011 to 0.0022	"
9	0.28	0.99	0.45	0.0006 to 0.0008	Moderate Shrinkage cracking
10	0.55	1.29	0.99	0.0014 to 0.0026	Extensive Block cracking
11	0.75	1.35	1.08	0.0018 to 0.0040	Extensive Block cracking

Note: Sample location number refers to sample location shown on Table 1-A.

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TABLE 2-A

DYNAFLECT DATA

Sample Location Number	Dynaflect Deflections, 0.001 Inches			Maximum Slope of Deflection Curve	Road Condition at Sample Location
	Minimum	Maximum	Median		
12	0.58	0.87	0.78	0.0018 to 0.0029	Extensive Block cracking
13	0.81	1.50	1.32	0.0040 to 0.0063	Extensive Alligator cracking
14	0.19	0.38	0.33	0.0004 to 0.0007	Slight shrinkage cracking
15	1.05	1.65	1.23	0.0048 to 0.0063	Extensive Alligator cracking
16	0.37	0.75	0.64	0.0013 to 0.0023	Uncracked AC blanket
17	0.22	0.75	0.52	0.0006 to 0.0023	Moderate Shrinkage cracking
18	0.45	0.72	0.57	0.0008 to 0.0013	Uncracked
19	0.18	0.90	0.54	0.0020	Extensive shrinkage cracking
20	0.27	0.66	0.35	0.0006 to 0.0010	"
21	0.36	0.72	0.48	0.0006 to 0.0014	"
22	0.48	0.66	0.56	0.0011 to 0.0014	"
23	0.59	1.02	0.67	0.0014 to 0.0022	Slight Block cracking, Extensive shrinkage cracking
24	0.30	1.50	0.76	0.0008 to 0.0046	Moderate Block cracking, Extensive shrinkage cracking

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TABLE 2-A

DYNAFLECT DATA

Sample Location Number	Dynaflect Deflections, 0.001 Inches			Maximum Slope of Deflection Curve	Road Condition at Sample Location
	Minimum	Maximum	Median		
25	0.72	0.93	0.81	0.0009 to 0.0010	Slight shrinkage cracking
26	0.55	0.84	0.59	0.0008 to 0.0013	"
27	0.75	0.99	0.90	0.0020 to 0.0029	Slight shrinkage cracking
28	0.44	0.65	0.56	0.0008 to 0.0013	"
29	0.10	0.28	0.19	0.0002 to 0.0008	"
30	0.54	0.84	0.72	0.0013 to 0.0014	Moderate shrinkage cracking
31	0.49	1.11	0.76	0.0015 to 0.0016	"
32	0.87	2.22	0.99	0.0018	Uncracked
33	0.87	1.98	1.11	0.0024 to 0.0055	Extensive Alligator cracking
34	0.84	1.23	0.90	0.0008 to 0.0017	Moderate shrinkage cracking
35	0.37	0.53	0.50	0.0007 to 0.0009	Slight shrinkage cracking
36	1.20	1.68	1.50	0.0040 to 0.0055	Moderate Block and Shrinkage cracking
37	1.44	2.19	1.65	0.0036 to 0.0048	Extensive Block and Moderate shrinkage cracking

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TABLE 2-A

DYNAFLECT DATA

Sample Location Number	Dynaflect Deflections, 0.001 Inches			Maximum Slope of Deflection Curve	Road Condition at Sample Location
	Minimum	Maximum	Median		
38	1.77	2.90	2.04	0.0048	Slight Block and Extensive shrinkage cracking
39	1.59	2.37	1.95	0.0040 to 0.0050	"
40	0.40	1.02	0.60	0.0011 to 0.0014	Moderate shrinkage cracking
41	0.47	0.71	0.56	0.0007 to 0.0013	"
42	0.90	1.65	1.08	0.0019 to 0.0033	Extensive Block cracking
43	0.30	0.58	0.48	0.0006 to 0.0011	Uncracked
44	1.14	1.98	1.50	0.0022 to 0.0027	Moderate shrinkage cracking
45	0.72	1.29	0.99	0.0010 to 0.0027	Slight shrinkage cracking
46	0.68	1.56	0.96	0.0023 to 0.0037	Extensive shrinkage cracking, AC Patch
47	0.48	0.75	0.65	0.0012 to 0.0018	Moderate shrinkage cracking, AC Patch
48	0.64	1.35	0.81	0.0009 to 0.0022	Extensive shrinkage cracking
49	0.67	0.81	0.73	0.0012 to 0.0015	Moderate shrinkage cracking

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TABLE 2-A

DYNAFLECT DATA

Sample Location Number	Dynaflect Deflections, 0.001 Inches			Maximum Slope of Deflection Curve	Road Condition at Sample Location
	Minimum	Maximum	Median		
50	0.81	1.50	1.26	0.0026 to 0.0063	Extensive Block cracking
51	0.40	1.08	0.74	0.0013 to 0.0027	Slight Block cracking
52	0.68	0.81	0.71	0.0012 to 0.0015	Uncracked
53	1.05	1.74	1.29	0.0023 to 0.0033	Moderate shrinkage cracking
54	0.63	1.44	0.99	0.0023 to 0.0042	Uncracked
55	1.05	2.58	1.89	0.0033 to 0.0083	Slight shrinkage cracking
56	0.87	1.68	1.38	0.0029 to 0.0050	Extensive Block cracking
57	0.52	1.41	1.05	0.0008 to 0.0030	AC Blanket uncracked
58	0.77	1.38	1.05	0.0017 to 0.0038	Slight shrinkage cracking
59	0.52	0.84	0.66	0.0011 to 0.0018	"
60	0.84	1.56	1.29	0.0018 to 0.0025	Slight Block and Extensive shrinkage cracking
61	0.81	1.35	0.96	0.0018 to 0.0028	Moderate shrinkage cracking

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TABLE 2-A

DYNAFLECT DATA

Sample Location Number	Dynaflect Deflections, 0.001 Inches			Maximum Slope of Deflection Curve	Road Condition at Sample Location
	Minimum	Maximum	Median		
62	0.65	1.20	0.87	0.0015 to 0.0048	Moderate Alligator cracking
63	0.51	0.84	0.64	0.0007 to 0.0019	Extensive shrinkage cracking
64	0.68	0.90	0.81	0.0018 to 0.0023	"
65	0.57	0.81	0.62	0.0011 to 0.0018	Moderate shrinkage cracking
66	0.60	0.82	0.69	0.0013 to 0.0023	"
67	0.55	0.84	0.63	0.0011 to 0.0013	Uncracked
68	0.64	0.90	0.74	0.0014	Slight shrinkage cracking

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