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One hundred seventy-five Cement Treated Base (CTB) composite pavements, with varying cement contents, 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 of deficiencies in the AC surfacing thickness or quality.

A significant improvement in the performance of CTB composite pavements was attributed to: (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 rather than type I cement. (7) Using a minimum CTB thickness of 0.50 foot. (8) Providing a minimum in place CTB compressive strength of 500 psi.

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# HIGHWAY RESEARCH REPORT

# SERVICE PERFORMANCE OF CEMENT TREATED BASES AS USED IN COMPOSITE PAVEMENTS

By

Ernest Zube, Clyde G. Gates,
Earl C. Shirley and Harold A. Munday Jr.

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Presented at the 48th Annual Meeting
of the Highway Research Board
January, 1969

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STATE OF CALIFORNIA
TRANSPORTATION AGENCY
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT

# SERVICE PERFORMANCE OF CEMENT TREATED BASES AS USED IN COMPOSITE PAVEMENTS

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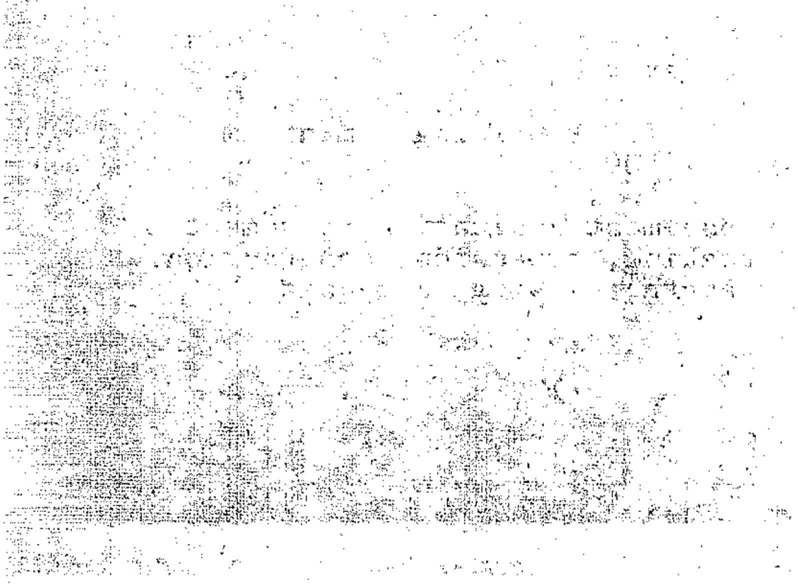

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# TABLE OF CONTENTS

## INTRODUCTION

Several hundred miles of roads using cement treated base (CTB) were built in California prior to 1950. 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. Table 1 shows the various quality requirements which were specified for these cement treated bases.

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 |

With this substantial amount of CTB composite pavement 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 considered too new to determine a valid performance rating.

## PROJECT EVALUATION

In order to evaluate the performance of the 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 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 thermal shrinkage of the CTB) was classified as normal, greater than normal or less than normal. An average CTB roadway was considered to have narrow transverse cracks at a spacing of about 20 feet and to have a small amount of intermittent longitudinal cracking throughout the length of the project. These ratings are strongly affected by the raters judgment but since the same rater reviewed all the projects they provide 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. 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.

## PROJECT MAINTENANCE INFORMATION

Questionnaires were sent to the 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.

## FIELD SAMPLING

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

Dynaflect (1) deflection measurements were made in February, 1966, on each of the thirty-five projects. The data was obtained at 25 foot intervals for a distance of 200 feet for two locations on each project.

The Dynaflect deflection data was used as an aid in locating the specific areas for coring. One sampling location on each project was selected to be representative of the better portions and the other was chosen to be representative of the poorer portions of the project. 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.

## 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, as illustrated in Figure 9, 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 representing the variables 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).

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.

## 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 the independent variable classed in the left column. Three vertical columns are used to show the percentage of projects falling within the selected ranges of the dependent variables. The right hand column lists the total number of projects or sample locations which were within each class 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.

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 3 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. Projects experiencing less than five million equivalent 5000 pound wheel loads (EWL) were excluded from this comparison to eliminate projects which had obviously failed prematurely (3).

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 |
| 1.0 or more | 70% | 28% | 2% | 43 |

Dependent at 98% Confidence.

Tables 3 and 4 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 contents and more thorough mixing is possible in a plant mixed operation.

TABLE 3

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 4

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.

Table 5 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. The higher humidity could also be a factor.

Block cracking was not significantly affected by the geographical location of the project.

TABLE 5

GEOGRAPHIC LOCATION VERSUS LONGITUDINAL AND TRANSVERSE CRACKING

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

Dependent at 99.5% Confidence.

Drainage had no statistically significant effect on either pumping or block cracking but there was a tendency for both to be greater when the drainage was rated poor. A significant relationship would probably have developed if these projects had been inspected in the wet season of the year when the drainage characteristics would have been more obvious.

Comparisons of the cement content used on the various projects with the amount of both longitudinal and transverse cracking and block cracking produced statistically independent relationships. This implies that our CTB design method has been producing structural sections of comparable strength throughout the full range of cement content which had been used on these projects (2.2 through 7.0 percent).

Longitudinal and transverse cracking was not significantly affected by increasing the compressive strength of the CTB. Table 6 shows block cracking was significantly reduced by increasing the compressive strength of the CTB.

TABLE 6

CTB CORE COMPRESSIVE STRENGTH VERSUS BLOCK CRACKING

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

Dependent at 99.5% Confidence.

The data in Table 6 is 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 7 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 7

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'.

A comparison of AC thickness and block cracking was found to be statistically independent but there appeared to be a trend for the amount of block cracking to be reduced as the AC surfacing thickness was increased.

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.

The amount of commercial traffic and 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 (3) has been successful in overcoming the effects of variations in heavy truck traffic and in basement soil quality.

Within a 20 to 80 range of sand equivalent, the sand equivalent of the CTB aggregate had no significant effect on the amount of cracking, pumping or the compressive strength of the CTB construction control samples. The sand equivalent is a relative measure of the amount of clay-like material in an aggregate mixture.

Tables 8 and 9 show both block cracking and longitudinal and transverse cracking are 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 thicker 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.

TABLE 8

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 9

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.

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

Table 10 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 (4). As is often the case, however, 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. Due to the difficulty in achieving adequate compaction, grading variations had no significant effect on the amount of either longitudinal and transverse cracking or block cracking.

TABLE 10

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.

The season of the year in which the CTB was placed had no significant effect on cracking.

Table 11 shows that sections with the highest CTB compressive strength had the longest maintenance-free service life.

TABLE 11

CTB CORE COMPRESSIVE STRENGTH
VERSUS MAINTENANCE-FREE SERVICE LIFE

| CTB Core Compressive Strength (PSI) | Maintenance-Free Life: Less than 10 years | Maintenance-Free Life: More than 10 years | Number of Sample Locations |
|---|---|---|---|
| 200 to 500 | 50% | 50% | 20 |
| 500 to 750 | 40% | 60% | 20 |
| >750 | 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.

For 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 projects 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 12 shows type II cement to be better than type I cement in preventing block cracking. Longitudinal and transverse cracking was unaffected by the type of cement that was used. California's present specifications require the use of type II cement for all CTB construction.

TABLE 12

TYPE OF CEMENT VERSUS BLOCK CRACKING

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

Dependent at 95% Confidence.

When a minimum of 92 percent relative compaction was maintained, cracking was unaffected by variations in relative compaction. Only three out of the 32 projects which were available for this comparison had relative compactions of less than 95 percent.

Eleven percent of the 175 projects evaluated required extensive maintenance within three years after they were built. Over half of these projects were in Shasta and Siskiyou Counties and were built with a maximum cement content of three percent and one used as little as 2.2 percent. When such low cement contents are used, small variations in cement distribution and mixing can 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 (5), 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 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 and 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 (6) found that a minimum of three percent 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 possibility that some of the distress that developed on these projects was caused by a freezing and thawing action.

TABLE 13

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

| CTB Condition in Vicinity of Sample Location | CTB Thickness Deviations: Thinner | CTB Thickness Deviations: Design Thickness ± 0.04 Ft. | CTB Thickness Deviations: Thicker | Number of Sample Locations |
|---|---|---|---|---|
| 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.

Table 13 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 were shy of their design thicknesses by more than 0.04 feet. The majority of the locations which were deficient in CTB thickness were badly cracked.

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 increased thickness of CTB, which is presently added to our structural section designs as a safety factor, 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 tolerences specified for the project.

Only four 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 5 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 1 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 (7) 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 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.

Figure 2 shows a comparison 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 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 advisable, therefore, to design new cement treated bases for a strength 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 (8). 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 compensate for the lesser field densities.

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 these 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 3 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 4 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 pavement. Figure 5 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.

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 extensive cracking and pumping in the AC surfacing developed.

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.

Figure 6 shows a plot of the maximum Dynaflect deflection versus the maximum slope of the deflected pavement 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 will probably do so before their design lives are exceeded.

Figure 7 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 that 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 that range of compressive strength. This data clearly demonstrates the superiority of plant mixing over road mixing and the disadvantage of specifying a cement content which is too low.

Figure 8 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 5 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 seven projects were built by the road mixed method of construction and, as previously shown by Figure 7, road mixing is much more likely to produce an inferior CTB.

A straight line would appear to best fit the data in Figure 8 but this line would pass a year or two to the left to the point representing the end of a ten year design life. This indicates we have been slightly underestimating the design wheel loads on most of our projects.

This report is a condensation of the final report for this research project. Anyone interested in more of the details of the study should refer to reference number (9).

## SUMMARY AND CONCLUSIONS

### Major

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

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

3. 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.

4. Block cracking was significantly less 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.

5. 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.

6. The number of heavy wheel loads and the stability of the basement soil, as measured by the R-value test, 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.

7. CTB compacted in one 0.67 foot thickness did not perform as well as CTB compacted in two 0.33 foot thicknesses.

8. When the CTB was placed in two compacted layers, there was generally very little bond between these layers. The asphalt concrete surfacing was well bonded to the CTB at most sampling locations, however. This bond was undoubtedly produced by the asphaltic curing seal used on the CTB.

9. The season of the year in which the CTB was placed had no significant effect on the amount of either block cracking or longitudinal and transverse cracking.

10. 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.

11. The average CTB compressive strength of cores from about half of the projects sampled during this investigation did not exceed that of their respective construction control 7 day compressive strengths and the average 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 lower strengths are undoubtedly due to the fact that only 95% relative compaction is required during construction.

12. The structural sections with the greatest CTB compressive strength had the longest maintenance-free service life.

13. The majority of the locations in which the CTB thickness was deficient were badly cracked and the CTB was badly cracked at every location in which it was less than 0.46 foot thick.

14. 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.

<u>Minor</u>

1. Although the comparisons were statistically independent, projects with poor drainage tended to have more block cracking and more pumping of mud fines.

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

3. 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.

4. 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 cores from the roadway. Therefore, grading had no significant effect on the amount of cracking.

5. 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.

6. Relative compaction had no effect on the amount of cracking when a minimum of 92 percent relative compaction was achieved. Only three of the 31 projects from which relative compaction data was available had any cores that were below 95 percent relative compaction.

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

8. 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 percent.

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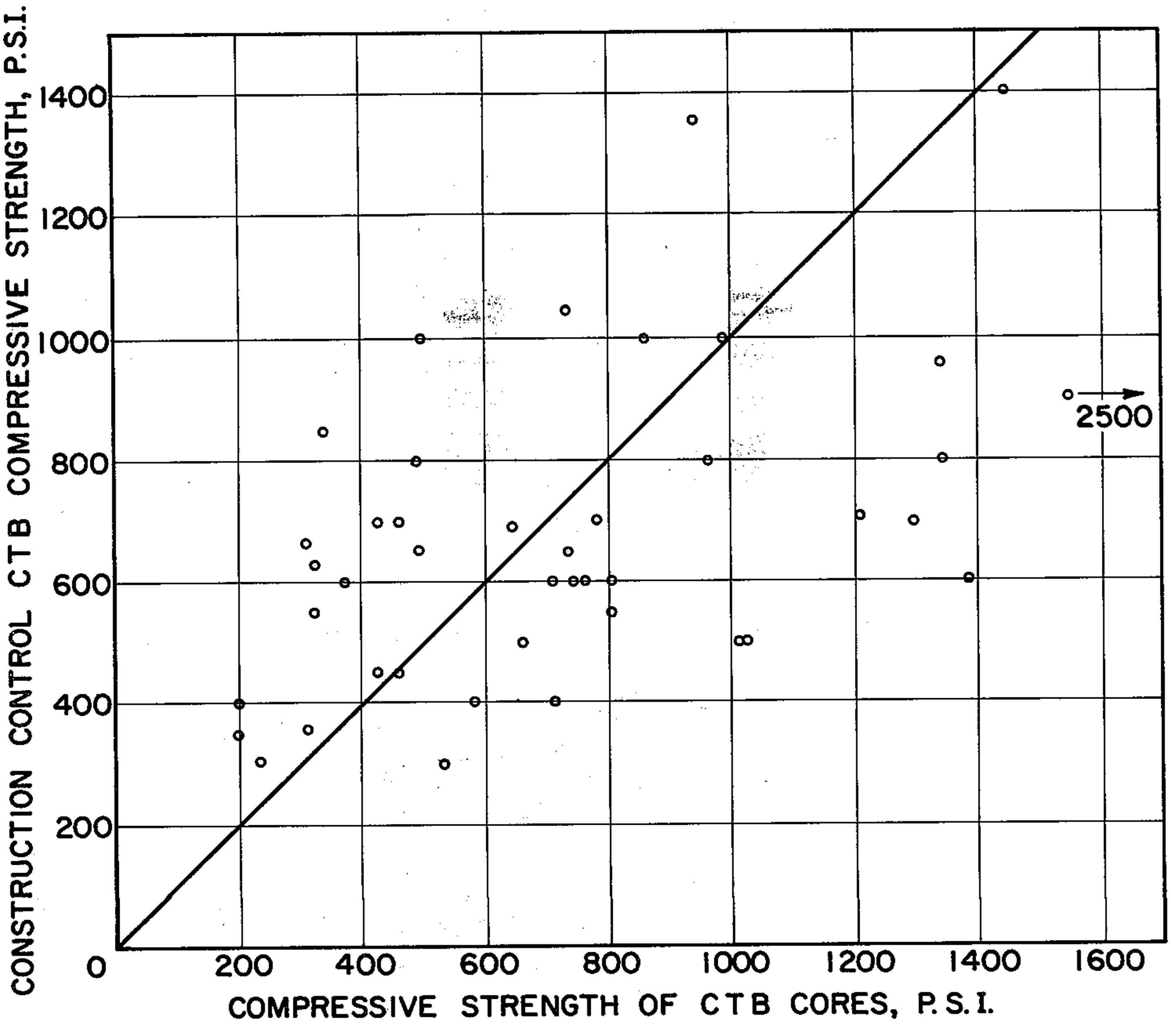
Figure 1

CLASS "A" & CLASS "B" CTB CORES
Project 04-Mrn-17 - 0.3/2.3

Figure 2

# 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.

Figure 3

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

Figure 4

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

Project 05 - Mon - 101 - 43.9/51.7

Figure 5

"12" CORE HOLE

Project 05-Mon-101-43.9/51.7

NOTE: VOID UNDER AC SURFACING

Figure 6

MAXIMUM DEFLECTION VERSUS MAXIMUM SLOPE OF DEFLECTED PAVEMENT FROM DYNAFLECT READINGS

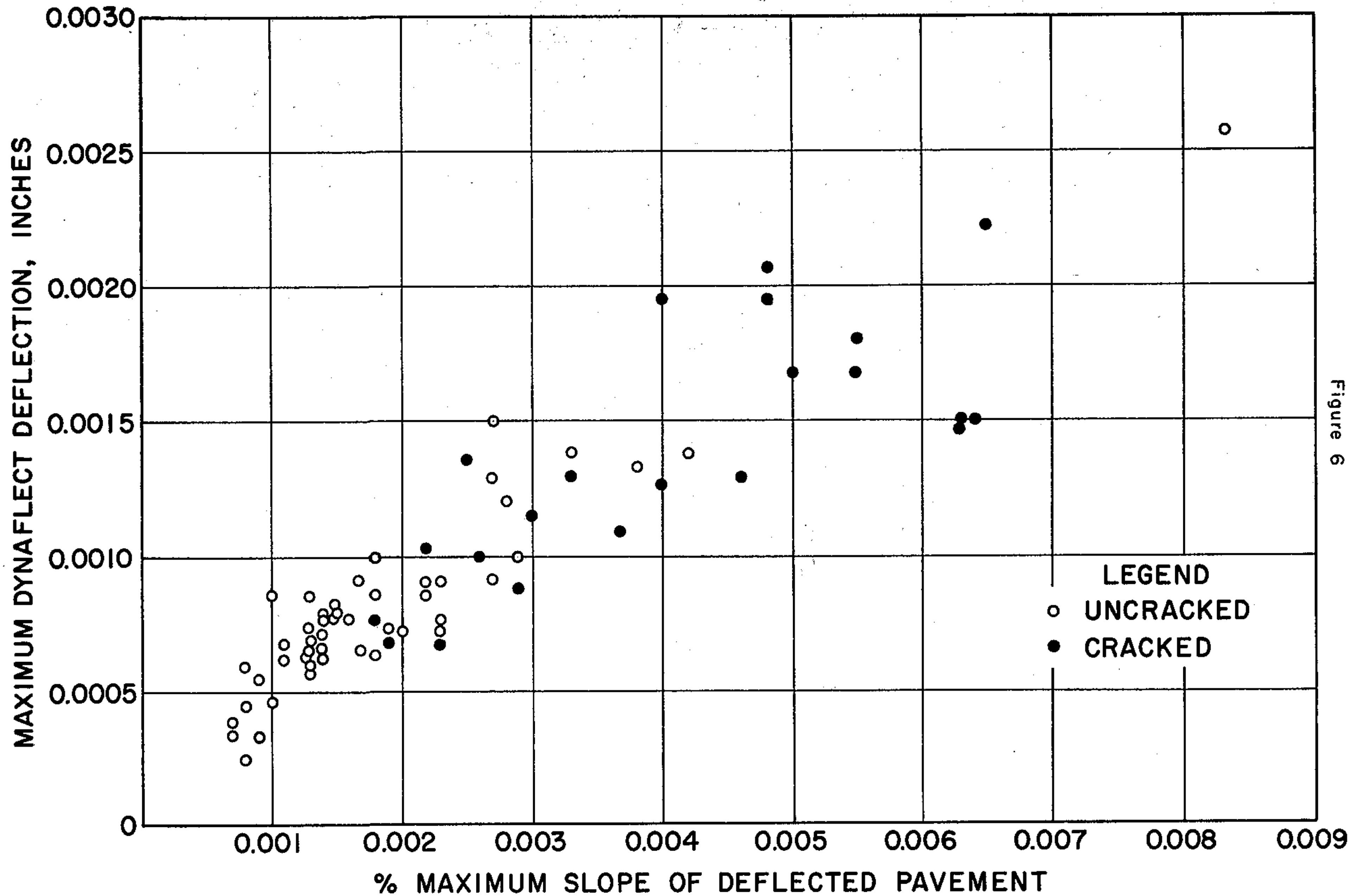


Figure 7

# 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

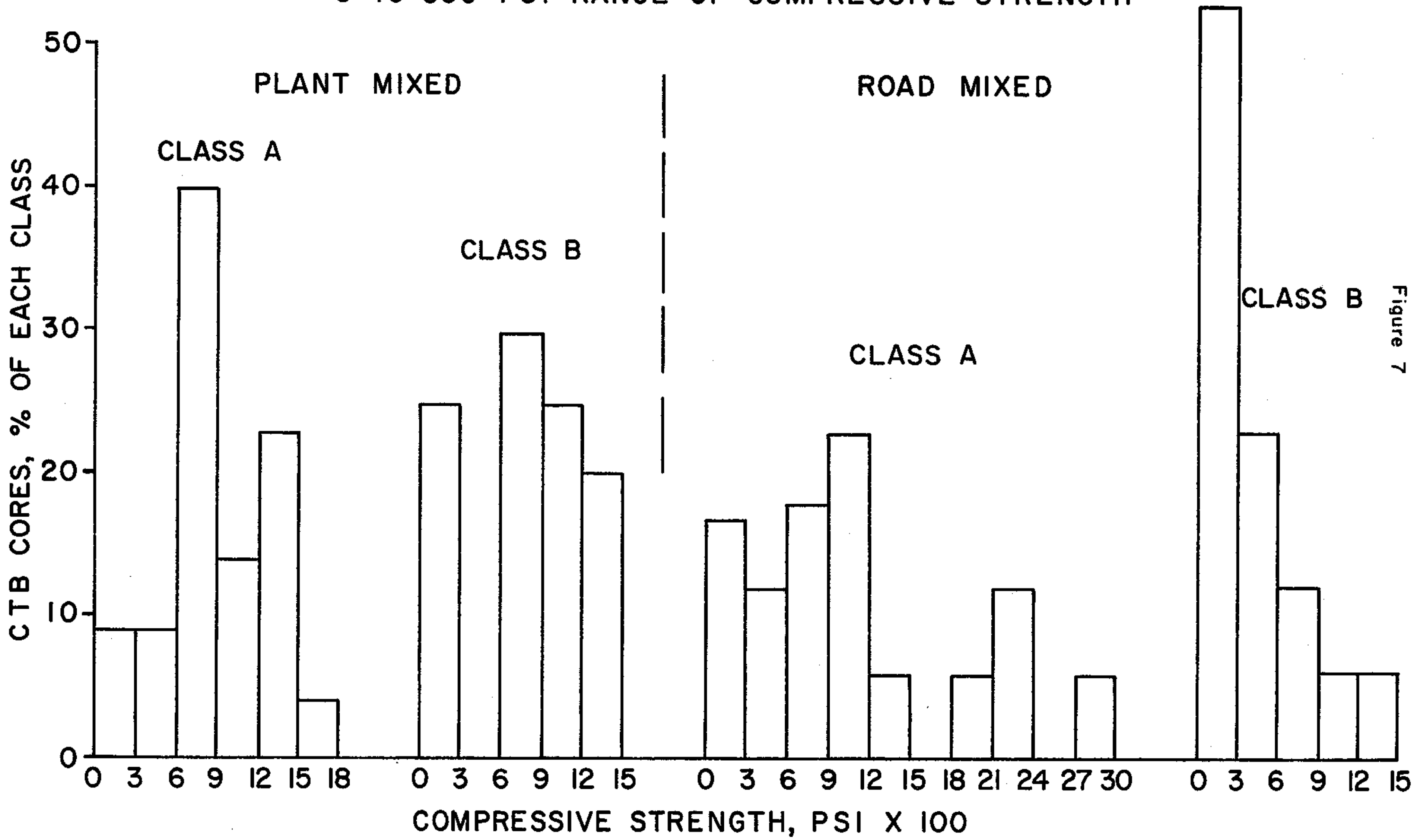
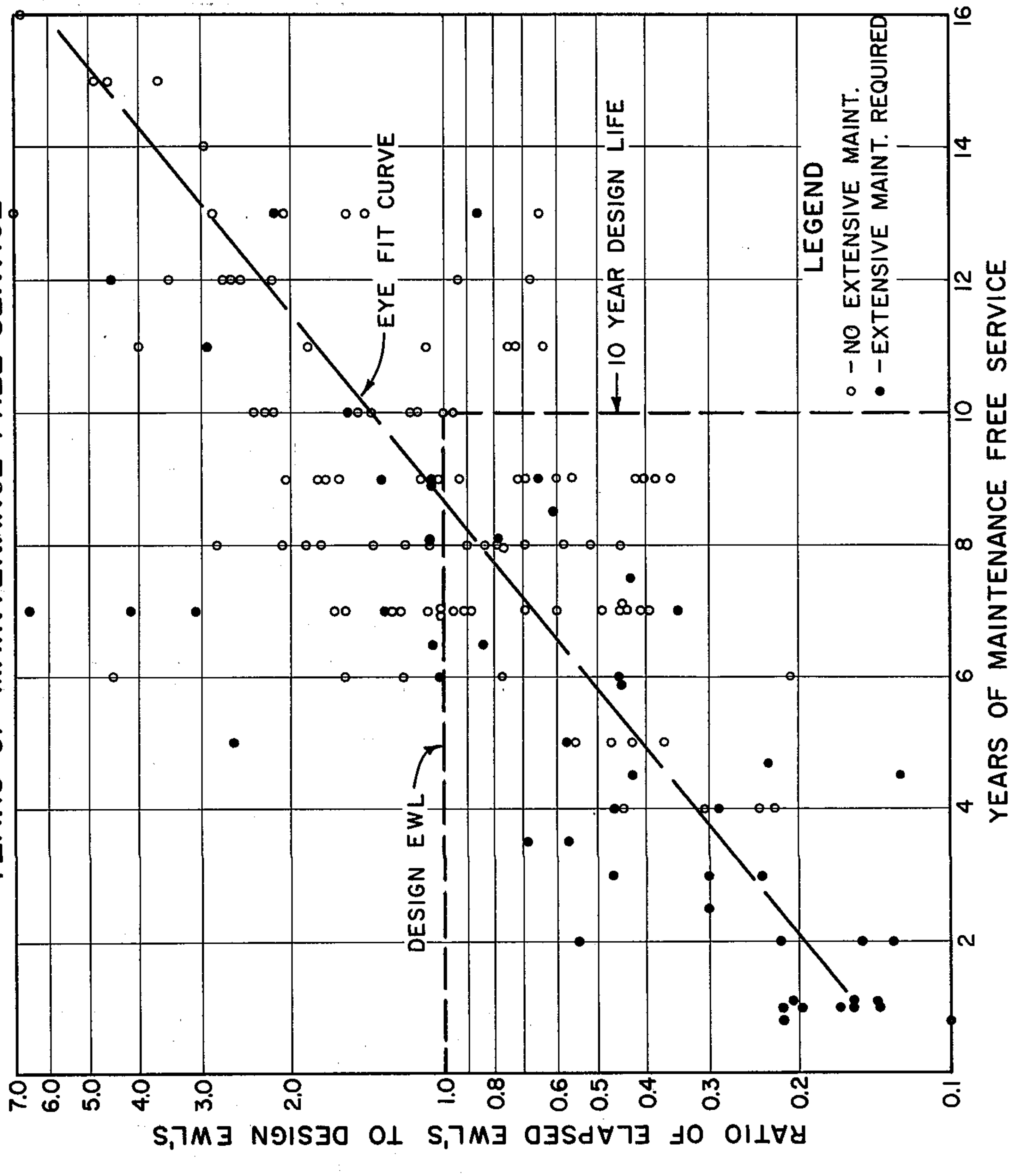


Figure 8




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

Figure 9

# OPTICAL COINCIDENCE SYSTEM

| PROJECT | | | | |
|---|---|---|---|---|
| ● | ● | ● | ● | ● |
| 6 | ● | 8 | ● | 10 |
| ● | ● | ● | 14 | 15 |
| ● | 17 | ● | 19 | 20 |
| 21 | 22 | 23 | 24 | 25 |
| ● | ● | 28 | ● | ● |

| PLANT MIX | | | | |
|---|---|---|---|---|
| 1 | ● | 3 | 4 | ● |
| 6 | 7 | 8 | ● | 10 |
| ● | 12 | ● | 14 | 15 |
| ● | 17 | 18 | 19 | 20 |
| 21 | 22 | 23 | 24 | 25 |
| 26 | ● | 28 | 29 | ● |

| CORES 750+ PSI | | | | |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |
| 6 | ● | 8 | 9 | 10 |
| ● | 12 | ● | 14 | 15 |
| 16 | 17 | 18 | 19 | 20 |
| 21 | 22 | 23 | 24 | 25 |
| 26 | ● | 28 | ● | 30 |

| 0-3% BLOCK CRACKING | | | | |
|---|---|---|---|---|
| 1 | ● | 3 | 4 | 5 |
| 6 | ● | 8 | ● | 10 |
| 11 | 12 | ● | 14 | 15 |
| ● | 17 | 18 | 19 | 20 |
| 21 | 22 | 23 | 24 | 25 |
| 26 | ● | 28 | 29 | 30 |