Service Performance of Cement-Treated Bases as Used in Composite Pavements

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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; 64 percent are giving excellent service, 17 percent were rated good, 8 percent were rated fair, and 11 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 asphalt concrete surfacing thickness or quality.

A significant improvement in the performance of CTB composite pavements was attributed to extending the CTB at least 1 ft into the shoulder; plant-mixing the CTB; building the project in a temperate climate; increasing the thickness of the asphalt concrete surfacing; limiting the compacted thickness of any one layer of CTB to 0.50 ft; using type II rather than type I cement, using a minimum CTB thickness of 0.50 ft; and providing a minimum in-place CTB compressive strength of 500 psi.

•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 (AC). Table 1 gives the various quality requirements specified for these cement-treated bases.

With this substantial amount of CTB composite pavement construction completed, we felt that a comprehensive evaluation should be made of this type of construction. The scope of the investigation was limited to include only classes A and B CTB. Because 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 built between 1950 and 1962. Projects built after 1962 were considered too new for a valid performance rating.

PROJECT EXAMINATION AND SELECTION

The performance of the projects was evaluated by a visual examination in which the amount and type of cracking and the amount and type of maintenance performed were noted. Physical characteristics of the terrain were also 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 (approximately 5 mph), 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

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TABLE 1

VARIATION OF CTB QUALITY REQUIREMENTS DUE TO SPECIFICATION CHANGES

Standard Specs.	Class of CTB	Minimum Compressive Strength at 7 Days (psi)	Cement Content (percent of dry wt. of aggr.)
1949	A	650	4 to 7
1954	A	650	3½ to 6
	B	300	2½ to 3½
1960	A	750	3½ to 6
	B	400	2½ to 4½

each project. The 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 ft and to have a small amount of intermittent longitudinal cracking throughout the length of the project. These ratings are strongly influenced by the rater's judgment but, because 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, such as fill settlement. The field review of these projects was completed in the summer of 1966.

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. 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.

Upon completion of the visual survey, 35 projects were selected for field sampling. In most cases, 2 projects that performed well and 2 projects that performed poorly were chosen from each district. A few districts had used little or no CTB that met the conditions established for this evaluation and could not provide 4 projects for sampling. A completely random selection of projects was sacrificed to ensure that projects were evaluated from as many parts of the state as possible.

Dynaflect deflection measurements (1) were made in February 1966, on each of the 35 projects. The data were obtained at 25-ft intervals for a distance of 200 ft for 2 locations on each project.

The Dynaflect deflection data were used as an aid in locating the specific areas for coring. One sampling location was selected to be representative of the better portions of the project and the other was chosen to be representative of the poorer portions. One large core, ranging from 6 to 12 in. in diameter, and two 4-in. diameter cores were cut at each sampling location. The larger cores were used to check the extent of cracking, and the small cores were used for compressive strength and density determinations.

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, shown in Figure 1, were used. Holes were punched in these cards at a specific set of coordinates for each project. The use of a different card to represent a specified range of each variable made it possible to compare a number of different variables by lining up the cards representing the variables and counting the number of holes that 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 that 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.

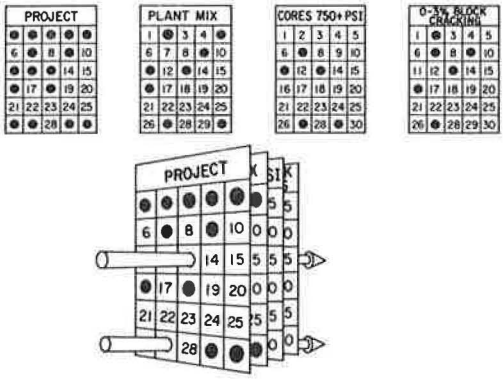

Figure 1. Optical coincidence system.

TABLE 2

CTB SHOULDER EXTENSION VS BLOCK CRACKING ON PROJECTS HAVING GREATER THAN 5 MILLION EWL

Extension of CTB into Shoulder (ft)	Percent of Length Affected by Block Cracking			Number of Projects
	0-3	3-31	31-100	
0 through 0.5	53	24	23	38
1.0 or more	70	28	2	38

Dependent at 98 percent confidence.

After the various relationships were established 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 were above a confidence level of 85 percent, we indicated the data tended to be dependent. All data showing a statistical dependency at less than a confidence level of 85 percent were considered to be totally independent.

Tables 2 through 13 give comparisons of the many variables that were considered likely to affect the service life of CTB projects. All of these tables have the independent variable in the left column. Three columns are used to show the percentage of projects falling within the selected ranges of the dependent variables. The right column lists the total number of projects or sample locations that 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 are statistically dependent and, if so, at what degree of confidence they are dependent.

Data in Table 2 indicate that block cracking is significantly reduced by extending the CTB 1 ft or more into the shoulder. The 0 to 3 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 that develops in the outer wheelpath when the CTB is extended 1 ft or more into the shoulder. Projects experiencing less than 5 million equivalent 5,000-lb wheel loads (EWL) were excluded from this comparison to eliminate projects that had obviously failed prematurely (3).

Data in Tables 3 and 4 show that plant-mixed CTB material is more effective in preventing both block cracking and longitudinal and transverse cracking than is road-mixed material. This is probably because better control of the cement and moisture content and more thorough mixing are possible in a plant-mixed operation.

CTB projects that were built along the coast had much less longitudinal and transverse cracking than did projects built in inland valleys (Table 5). The temperature

TABLE 3

TYPE OF MIXING OF CTB MATERIAL VS BLOCK CRACKING

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

Dependent at 98 percent confidence.

TABLE 4

TYPE OF MIXING OF CTB MATERIAL VS LONGITUDINAL AND TRANSVERSE CRACKING

Type of Mixing	Longitudinal and Transverse Cracking (percent)			Number of Projects
	Less Than Normal	Normal	More Than Normal	
Plant	60	13	27	60
Road	40	22	38	76

Dependent at 95 percent confidence.

TABLE 5

GEOGRAPHIC LOCATION VS LONGITUDINAL AND TRANSVERSE CRACKING

Geographic Location	Longitudinal and Transverse Cracking (percent)			Number of Projects
	Less Than Normal	Normal	More Than Normal	
Coastal	63	21	16	81
Inland	29	15	56	55

Dependent at 99.5 percent confidence.

TABLE 6

CTB CORE COMPRESSIVE STRENGTH VS BLOCK CRACKING

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

Dependent at 99.5 percent confidence.

along the coast is not subject to nearly the degree of change as that 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.

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 during the wet season 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 used on these projects (2.2 through 7.0 percent).

Longitudinal and transverse cracking was not significantly affected by an increase in the compressive strength of the CTB. Block cracking was significantly reduced by increasing the compressive strength of the CTB (Table 6).

The data in Table 6 are based on the 35 projects that were sampled during this study. The compressive strength values were based on 4-in. diameter specimens that 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 because at one location we were able to retrieve a core that 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.

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

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 implies that our design method (3) has been successful in overcoming the effects of variations in heavy truck traffic and in basement-soil quality.

TABLE 7

AC THICKNESS VS LONGITUDINAL AND TRANSVERSE CRACKING ON PROJECTS 7 TO 16 YEARS OLD

AC Design Thickness (ft)	Longitudinal and Transverse Cracking (percent)			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[a] to 0.51	73	11	16	19

Dependent at 98 percent confidence.

[a]Only 2 of the 19 projects had AC thicknesses of less than 0.33 feet.

TABLE 8

NUMBER AND THICKNESS OF CTB LIFTS VS BLOCK CRACKING

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

Dependent at 95 percent confidence.

Within a 20 to 80 range, the sand equivalent of the CTB aggregate had no significant effect on the amount of cracking and pumping or on 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.

Data in Tables 8 and 9 show that both block cracking and longitudinal and transverse cracking are significantly reduced by compacting the CTB in two 0.33-ft thicknesses rather than one 0.67-ft thickness. The reason for this, undoubtedly, is that it is more difficult to achieve adequate compaction in the lower portion of a single lift of CTB 0.67 ft thick. 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.

A CTB 0.67 ft thick was no more effective than a CTB 0.50 ft thick in preventing block cracking. This also attests to the adequacy of our design formula, in that a comparable overall structural strength was provided when either thickness of CTB was used.

Table 10 data show that the compressive strength of contract control samples increased as the CTB aggregate grading moved from the fine to the coarse side of Talbot's optimum density grading limits (4). As is often the case, however, an adjustment that improves one characteristic adversely affects another. Using a coarse grading in order to improve the compressive strength makes the CTB more difficult to compact. The difficulty in achieving adequate compaction caused the grading variations to have no significant effect on the amount of either longitudinal and transverse cracking or block cracking. The season of the year in which the CTB was placed had no significant effect on cracking.

Sections with the highest CTB compressive strength had the longest maintenance-free service life (Table 11). In this report, maintenance-free service life is defined as the project's 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 that 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 reasonable extrapolation of the data.

According to Table 12, type II cement is 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.

When a minimum of 92 percent relative compaction was maintained, cracking was unaffected by variations in relative compaction. Only 3 of the 32 projects that were available for this comparison had relative compactions of less than 95 percent.

TABLE 9

NUMBER AND THICKNESS OF CTB LIFTS VS LONGITUDINAL AND TRANSVERSE CRACKING

Number of Lifts	Thickness of Lifts (ft)	Longitudinal and Transverse Cracking (percent)			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 percent confidence.

TABLE 10

CTB AGGREGATE GRADATION VS CTB COMPRESSIVE STRENGTH OF CONTRACT CONTROL SAMPLES

Grading	Compressive Strength (psi) Percentage			Number of Projects
	200-500	500-750	750-1450	
Coarser	3	36	61	33
Talbot's optimum density	9	37	54	78
Finer	21	58	21	47

Dependent at 99 percent confidence.

TABLE 11

CTB CORE COMPRESSIVE STRENGTH VS MAINTENANCE-FREE SERVICE LIFE

CTB Core Compressive Strength (psi)	Percent Maintenance-Free Life		Number of Sample Locations
	Less Than 10 Years	More Than 10 Years	
200 to 500	50	50	20
500 to 750	40	60	20
Over 750	10	90	30

Dependent at 99.5 percent confidence.

Projects that were in very good condition but not 10 or more years old were assumed to be 10 or more years old.

TABLE 12

TYPE OF CEMENT VS BLOCK CRACKING

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

Dependent at 95 percent confidence.

Eleven percent of the 175 projects evaluated required extensive maintenance within 3 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 3 percent; 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 material and ±0.4 percent for plant-mixed. One of our recent investigations showed that, for plant-mixed operations using good to excellent equipment and operating procedures, approximately 3 to 8 percent of the CTB material placed on each of three projects was shy of the planned cement content by more than the allowable deviation of -0.4 percent (5). 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 is particularly true for plant-mixed material in which the equipment was not in perfect operating condition and for most road-mixed projects.

Shasta and Siskiyou Counties are in mountainous areas that are 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 found that a minimum of 3 percent cement was necessary to insure that the CTB would withstand freezing and thawing conditions (6). Admittedly his tests were on materials quite

TABLE 13

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

CTB Condition in Vicinity of Sample Location	Percent CTB Design Thickness Deviations			Number of Sample Locations
	Thinner	± 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 percent confidence.

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.

According to Table 13, 55 percent of the 20 sample locations where the CTB was block-cracked were shy of their CTB design thickness by more than 0.04 ft, and none of the sample locations was block-cracked when the CTB exceeded its design thickness by more than 0.04 ft. 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 ft. The majority of the locations that were deficient in CTB thickness were badly cracked.

The CTB was badly cracked at every location where it was less than 0.46 ft thick. These data indicate that many of our past CTB designs should have required increased thickness in order to protect against thickness deficiencies resulting from normal construction 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 emphasize strongly, however, that it is important to inspect the construction operations to insure that the structural section is built within the tolerences specified for the project.

Only 4 of the 175 projects that were included in this study had a design CTB thickness that was less than 0.50 ft: 2 were 0.42 ft thick and 2 were 0.33 ft thick. None of these projects was successful. All required major repairs before they were 7 years old, and the 0.33-ft 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 2 locations produced cores that 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 that was observed on several of the sampled projects. The upper layer of class A CTB had a transverse crack that did not extend through the lower layer of class B CTB, indicating that the two layers were definitely acting independently.

The value of having the CTB layers well bonded together is self evident, and it is imperative that some means of achieving this bond be developed. Arman and Dantin

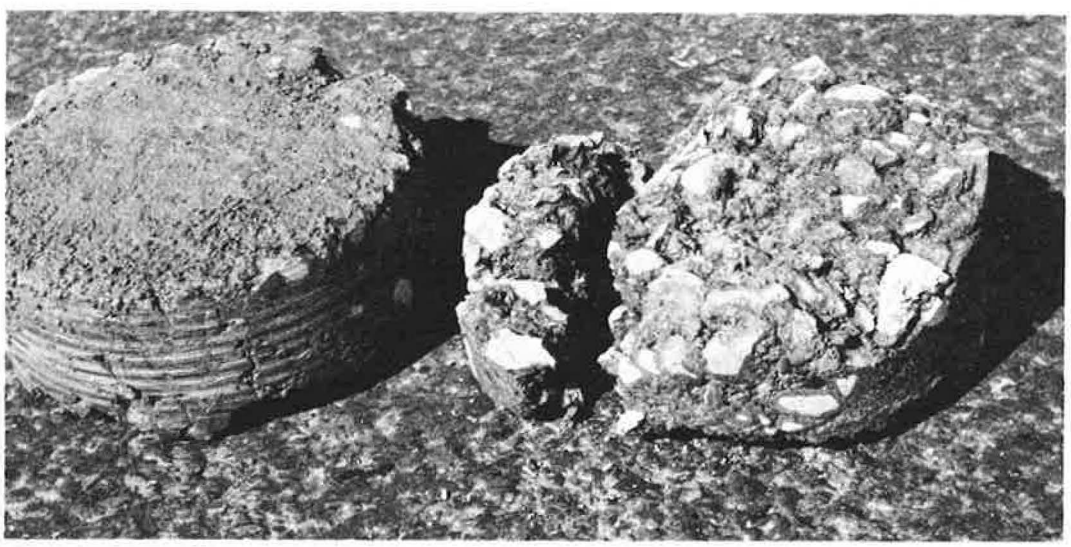

Figure 2. Class A and class B CTB cores.

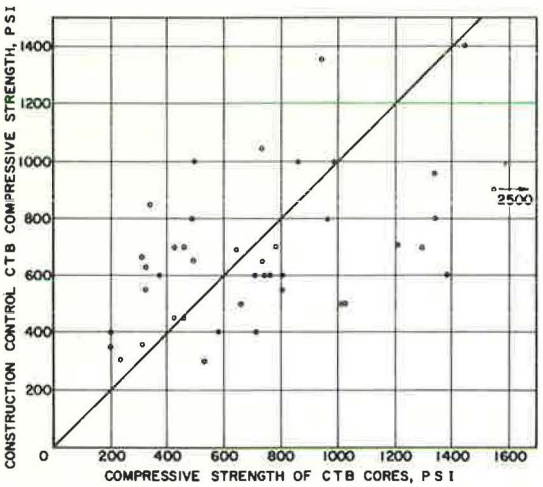

Figure 3. Compaction of compressive strength of construction control samples with that of the field cores: Each point represents the average compressive strength of four 4-in. diameter cores.

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 (7). 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 used on the CTB.

Figure 3 shows a comparison of the average construction control compressive strength for each sampled project vs the average compressive strength of the field cores from each of these projects. The points appear to be randomly distributed about the line of perfect correlation with about 50 percent having a strength less 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 never even reached 75 percent of the strength indicated by the construction control samples. It would appear to be advisable, therefore, to design new cement-treated

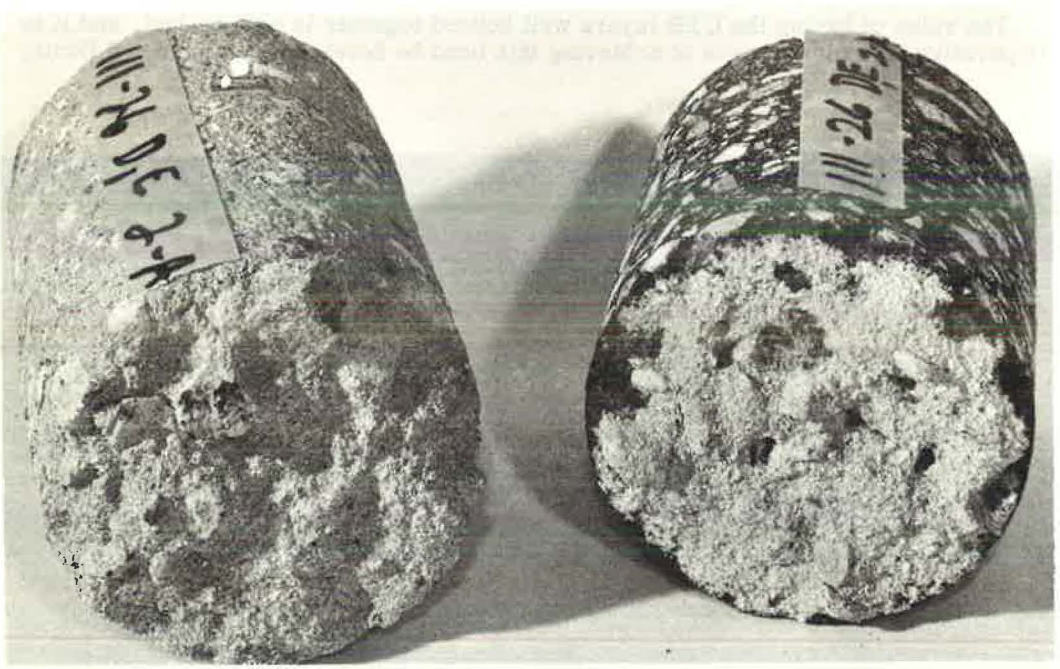

Figure 4. Shear plane in class A CTB.

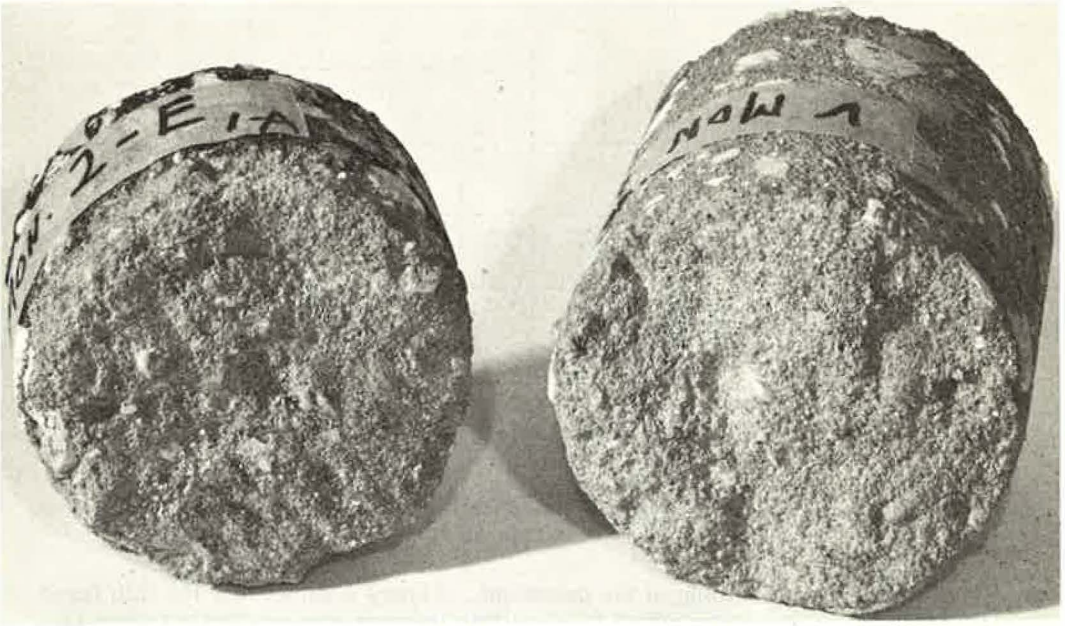

Figure 5. Compaction plane between two lifts of class B CTB.

bases for a strength about 25 to 30 percent higher than that considered necessary in the completed CTB. The Washington State Department of Highways is presently doing just that (8). Experience there indicates that an in situ minimum 7-day compressive strength of 650 psi is necessary for a CTB to be successful on Washington highways. Because the compaction specifications allow acceptance with only 95 percent of the density upon which the design cement content is based, Washington's highway department has increased the minimum design compressive strength to 850 psi at 7 days to compensate for the lesser field densities.

Four of the 35 projects that were sampled had thin layers of disintegrated CTB about 0.04 to 0.08 ft thick at the top surface of the CTB while the lower portions remained sound. This situation has also 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 4 shows how the CTB sheared off in this weakened portion just below the surfacing while being cored.

Figure 6. Core hole with void under AC surfacing.

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 the thin layer that 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

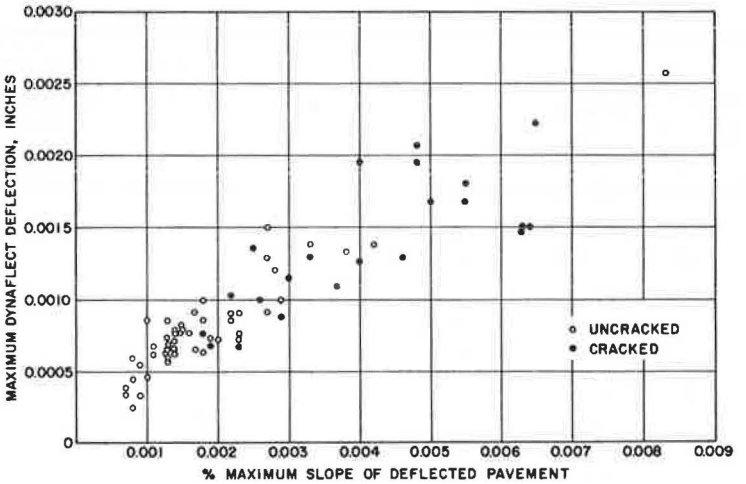

Figure 7. Maximum deflection vs maximum slope of deflected pavement from Dynaflect readings.

extensive cracking and pumping of the pavement. 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. 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, therefore, how the thin layer between the underlying CTB and the AC surfacing could be pulverized by the action of heavy wheel loads.

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 7 shows the maximum deflection vs the maximum slope of the deflected pavement between any 2 of the 5 geophones of the Dynaflect for both cracked and uncracked locations. Both deflection and slope seem to indicate a maximum tolerable value. However, it is apparent that the maximum slope of the deflected pavement provides a more sensitive break between cracked and uncracked locations than does the maximum deflection. These data indicate the maximum tolerable slope to be about 0.002 percent; 59 percent of the locations with a greater slope had already block-cracked, and many

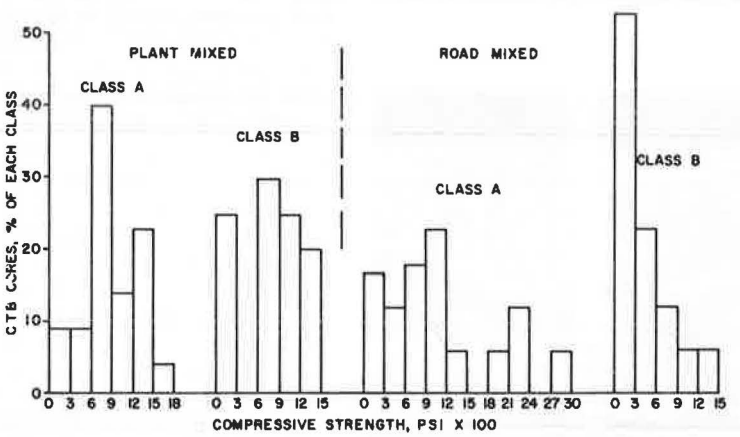

Figure 8. Compressive strength frequency distribution of CTB cores by class of CTB and type of mixing (uncoreable locations were grouped in the 0- to 300-psi range of compressive strength).

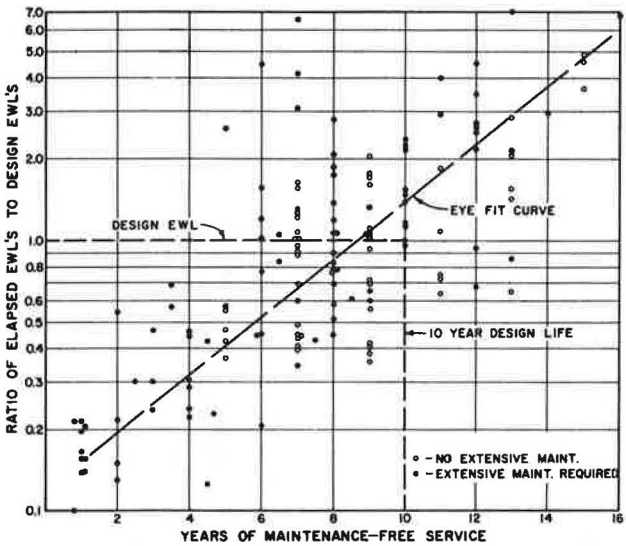

Figure 9. Ratio of design wheel loads elapsed vs years of maintenance-free service.

that had not will probably do so before their design lives are exceeded.

Figure 8 shows the compressive strength frequency distribution of the CTB cores for each type of mixing and class of CTB. Plant-mixing produces more of a normal frequency distribution, whereas road-mixing produces a distribution that is skewed toward the low range. Also, the broad range of compressive strengths produced by class A road-mixed CTB cores indicates poor uniformity that was very likely caused by a poor distribution of cement; 25 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, and 18 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. These data clearly demonstrate the superiority of plant-mixing over road-mixing and the disadvantage of specifying a cement content that is too low.

Figure 9 shows the ratio of the number of elapsed equivalent 5,000-lb wheel loads to the number for which the structural section was designed vs the number of years of relatively maintenance-free service life. The majority of the projects requiring extensive maintenance were less than 5 years old, and over half of these projects had experienced less than 25 percent of their design traffic loading. Of the 25 projects requiring extensive maintenance before they were 5 years old, 18 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, which is much more likely to produce an inferior CTB (Fig. 8).

A straight line would appear to best fit the data in Figure 9, but this line would pass a year or two to the left of a point that represents the end of a ten-year design life. This indicates that we have been slightly underestimating the design wheel loads on most of our projects.

SUMMARY AND CONCLUSIONS

1. Block cracking is reduced by extending the CTB at least 1 ft 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 likely due to the more uniform temperatures that are found along the coast. There is no significant effect on the amount of block cracking.

4. Block cracking is significantly less when the in situ CTB compressive strength exceeds 500 psi. Longitudinal and transverse cracking is 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, have no significant effect on the amount of either longitudinal and transverse cracking or block cracking. This implies that our design method adequately accounts for these variables.

7. CTB compacted in one 0.67-ft thickness does not perform as well as CTB compacted in two 0.33-ft thicknesses.

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

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

10. CTB projects built with type II cement have less block cracking than those built with type I cement. The type of cement has no significant effect on the amount of longitudinal and transverse cracking.

11. The average compressive strength of CTB cores from about half of the projects sampled during this investigation did not exceed that of their respective construction control samples, and the average compressive strength of about a third of the CTB cores did not reach 75 percent of the strength indicated by the construction control samples. These lower strengths undoubtedly occur because only 95 percent relative compaction is required during construction.

12. The structural sections with the greatest CTB compressive strength have 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 ft thick.

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

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

16. The type of terrain in which the CTB projects are built has no significant effect on either block cracking or longtiudinal and transverse cracking.

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

18. Compressive strengths of contract control samples 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 has no significant effect on the amount of cracking.

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

20. Relative compaction has no effect on the amount of cracking when a minimum of 92 percent relative compaction is achieved. Only 3 of the 31 projects from which relative compaction data were available had any cores that were below 95 percent relative compaction.

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

22. Block cracking did not occur where 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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