

Field Performance Evaluation of Cement-Treated Bases With and Without Fly Ash

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A field evaluation of pavement sections containing cement-treated bases with and without fly ash was undertaken at the University of Wyoming. The study was conducted using historical data from Wyoming Transportation Department (WTD) construction documents and field performance data collected with the WTD road profiler. Pavement performance models were first developed on the basis of the physical attributes of the sections. Another analysis was also conducted to determine if the performance of sections with fly ash in the base was statistically different from the performance of sections without fly ash.

Traffic volumes and the loads associated with them keep increasing on roads and highways throughout the United States. This increase has created a need for stronger pavement structures. Because of these circumstances, the use of cement-treated bases (CTBs) was implemented to increase the strength of roadway sections subjected to heavy loads or where aggregate sources for base materials demonstrated less than optimal characteristics. CTB can be defined as a compacted mixture of fine and coarse aggregate, cement, and water (1). CTB is mixed in a batch plant or in situ depending on the strength, durability, and uniformity requirements of the layer being constructed. Although cement, aggregate, and water are the primary materials used in CTB, there are other materials that can be added to CTB to reduce the quantity of cement required. Fly ash has been shown to accomplish this goal (2).

There are many factors that make the use of fly ash in cement-treated bases attractive. The most important of these considerations is economic. Fly ash is much less expensive than the alternate base materials it replaces. In fact, transportation agencies began using fly ash as a partial replacement for cement in the 1970s because of the dramatic increases in cement prices. Currently, 86 percent of the fly ash produced each year is wasted, and therefore most of the cost associated with fly ash use is the cost of transportation (3). Another positive aspect of using fly ash as a partial replacement for portland cement is that fly ash in cement-treated bases may continue to gain strength for years after placement, thus resulting in higher ultimate strengths (4). Although cement- and fly ash-treated bases have been successfully used in roadway construction for several years, little work has been done to evaluate their field performance. The main objective of this research was to evaluate the field performance of pavement sections containing CTB with and without fly ash.

DESIGN OF EXPERIMENT

In this experiment, a large number of test sections were first selected in Wyoming. Physical and performance data were then col-

lected on the selected sections. All data were later compiled in a computerized data base and a statistical analysis was conducted. The overall field performance evaluation strategies are shown in Figure 1.

CTB Construction Requirements in Wyoming

The Wyoming Department of Transportation has extensive experience in the construction of cement-treated bases. All CTBs are mixed in a center mixing plant by either batch or continuous mixing. Mixed materials are then transported to the roadway and spread on a moistened subgrade or base in a uniform layer. Spreading and compacting the CTB is accomplished by using a Jersey spreader in combination with a motor grader followed by rolling. CTB mixtures are normally compacted to at least 100 percent of maximum density determined in accordance with AASHTO (American Association of Highway and Transportation Officials) T-99. After the mixture has been compacted, the surface is reshaped to the required lines, grades, and cross sections. No more than 60 min is allowed between the start of mixing to the time of starting compaction. Finally, in order to ensure proper curing, the air temperature should be 4°C (40°F) in the shade and rising.

Strength of CTB in Wyoming

In a recent laboratory study performed at the University of Wyoming (2), the most commonly used CTB materials in Wyoming were tested for strength and durability. The aggregate used in this testing was scoria, volcanic ash or cinders composed of basalt. This type of aggregate is incorporated in approximately 50 percent of the CTB projects in the state of Wyoming. Three fly ash sources and Type II cement (moderate sulfate resistance) manufactured by Mountain Cement in Laramie were used in the testing.

The strength of samples were determined by conducting the unconfined compressive test. Samples were prepared with 8 percent cement by weight, 16.5 percent moisture content, and 1.3:1 fly ash to cement replacement ratio. The samples were cured for 7 and 28 days and then loaded to failure. The results from the 7- and 28-day compressive strength tests are shown graphically in Figures 2 and 3, respectively. These figures show that up to 55 percent of the cement can be replaced with fly ash without causing any reduction in the unconfined compressive strength of the samples.

Selection of Test Sections

The test sections were selected based on data obtained from WTD data files. These files contained important information on a variety

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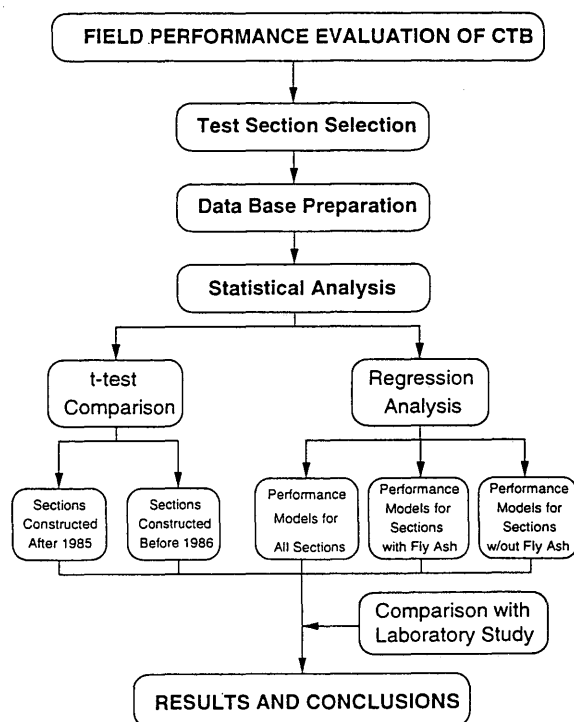


FIGURE 1 Field performance testing strategy.

of parameters that affect pavement performance. The files were reviewed extensively to identify appropriate sections with CTB. Each section was 0.322 km (0.2 mi) long. In total, 29 sections were selected, of which 18 sections contained CTB with fly ash and the other 11 sections contained CTB with no fly ash. The sections without fly ash were included in the experiment to act as control sections. The geographical locations of the sections are shown in Figure 4.

Data Collection and Data-Base Preparation

After the test section selection process was completed, detailed information was gathered on each site. The physical characteristics and current condition of all sections are summarized in Tables 1 and 2. The thickness of the asphaltic surface of test sections ranged between 5.0 and 10.2 cm (2 to 4 in.). On the other hand, the base thickness varied from 12.7 to 33 cm (5 to 13 in.). The sections were selected with variable thicknesses to determine the effect of base thickness on the long-term performance of pavement. The soil classifications and R (resistance) Values were also obtained to account for the effect of subgrade strength on pavement performance. The cement content in the base was about 7 percent in all test sections. In addition, fly ash percentages and types (C or F) were obtained for all sections containing fly ash in the base. It was found that all sections except one contained type C fly ash. Therefore, fly ash type and source were eliminated as a factor in the analysis. It should be mentioned that fly ash percentages ranged from 18.6 to 40 percent. These percentages reflect the amount of cement replaced with fly ash.

Two factors related to age were also considered in this study. First, the number of years in service, which ranged from 1 to 10

years, were obtained for every section. Second, the accumulated equivalent single axle loads (ESAL) applied since construction were estimated from the WTD data files. The ESALs ranged between 16,000 and 1,012,000. Current field conditions of test sections were determined with two indices: Present Serviceability Index (PSI) and rut depth. The PSI was determined with the WTD road profiler, which is a duplicate of the South Dakota road profiler. The PSI is rated on a 5-point scale on which a rating of 5 indicates a perfect pavement (one that conceivably does not exist) and a rating of 0 means very poor condition. The PSI of the test sections ranged between 2.7 and 4.4. Rut depth measurements were also obtained with the Wyoming road profiler. These measurements ranged between 0.025 and 0.51 cm (0.01 and 0.20 in.). After all the data were obtained, a comprehensive computerized data base was compiled and prepared for data analysis.

DATA ANALYSIS

The field performance of pavement sections included in the study was evaluated using two techniques. First, a regression analysis was used in developing performance models to predict the PSI and rut depth based on the physical attributes of test sections (base thickness, fly ash percentage, etc.). The second technique compared the performance of sections containing fly ash with the sections without fly ash. This was accomplished by using the standard t -test. The sections were first broken down into two age groups and then the t -test was performed to determine if there was a significant difference in performance between sections with and without fly ash.

Regression Analysis

In this analysis, the dependent variables were PSI or rut depth and the independent variables were age, base thickness, asphalt layer thickness, fly ash percentage, and R -value of the subgrade. The following general regression model was considered in the

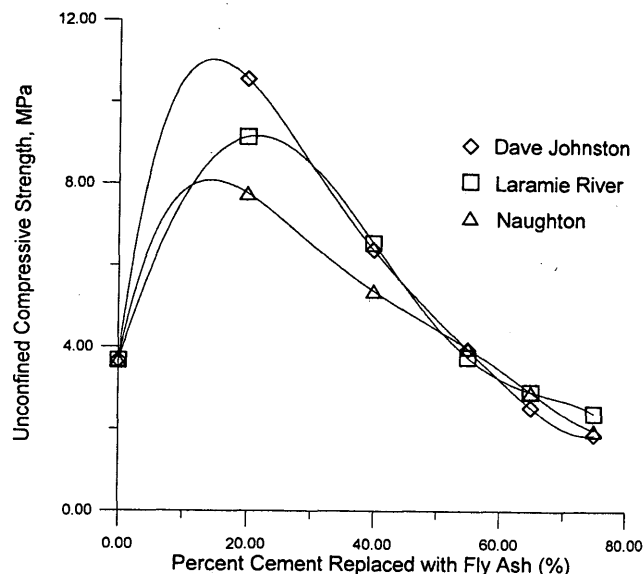


FIGURE 2 Seven-day unconfined compressive strengths.

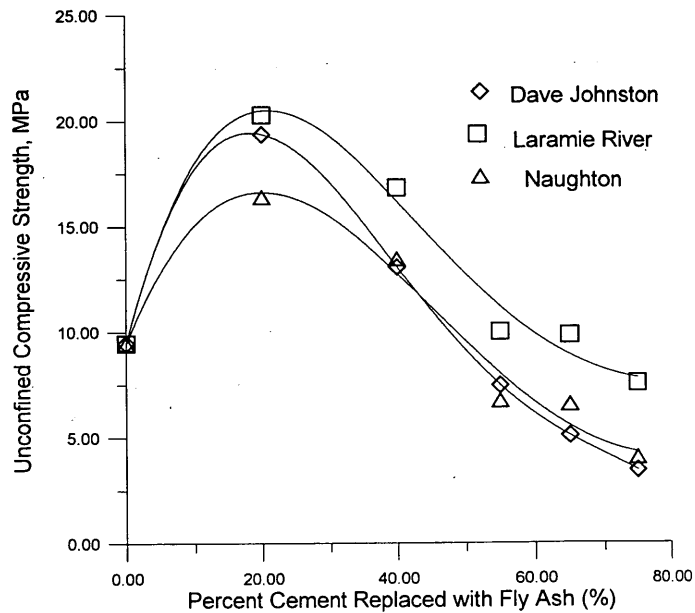
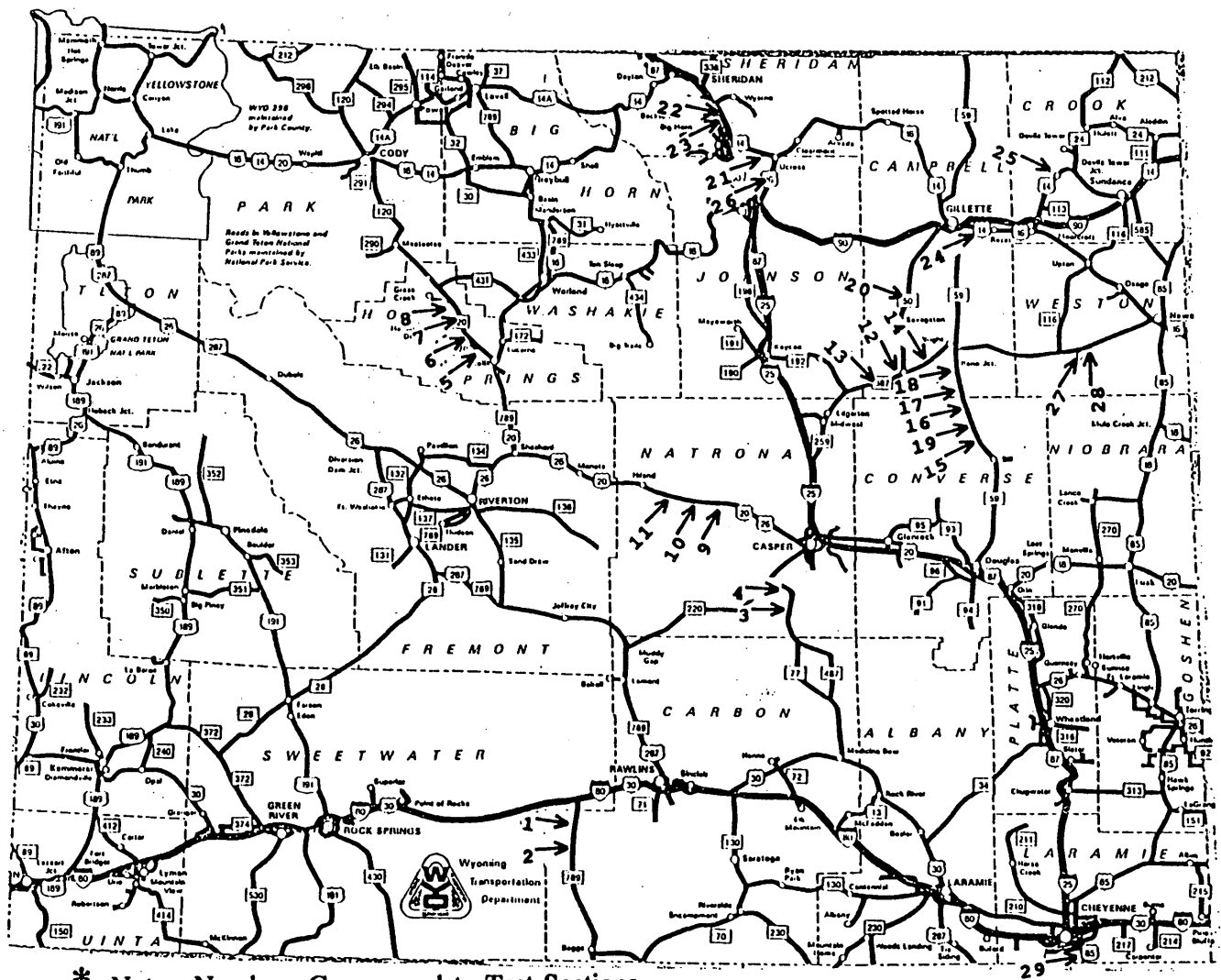


FIGURE 3 Twenty-eight-day unconfined compressive strengths.



* Note: Numbers Correspond to Test Sections

FIGURE 4 Location of roadway sections.

analysis:

$$y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \dots + \beta_j x_{ij} + \epsilon_i \quad (1)$$

where

- y_i = dependent variable (rut depth or PSI);
 x_{ij} = independent variable (base thickness, fly ash percent, etc.);
 β_j = regression coefficients ($j = 0$ to n); and
 ϵ_i = random error.

Initially, performance models were obtained for all test sections with and without fly ash in the base. These models are shown as follows:

Equations	R^2 (%)
PSI = 2.10 + 0.116 asphalt + 0.0469 base - 0.0677 age	18.3
Rut = 0.0820 + 0.0282 age	32.8

The coefficients of determination for these models indicate little correlation among the factors involved. The data were then divided into two major sets: one for the 10 sections with no fly ash in the base and another for the 19 sections with variable fly ash percentages. The models developed for the test sections that contained no fly ash are summarized as follows:

Equations	R^2 (%)
PSI = 2.16 + 0.0658 base - 0.0661 age	80.5
Rut = 0.033 - 0.00301 base + 0.0476 age	73.3

The coefficients of determination for the PSI and rut depth were 80.5 percent and 73.3, respectively. These models indicate that the thickness of the base layer and the age of the section do have an influence on the PSI and rut depth. PSI decreases with age and increases with increasing base thickness. On the other hand, rut depth increases with age and decreases as the thickness of the base increases. The relatively high R^2 values for these models indicate that pavement sections without fly ash have similar performance.

An analysis similar to the one already described was conducted on all test sections containing variable percentages of fly ash. As shown in the following table, the coefficients of determination for these models were low, indicating that adding fly ash to cement-treated bases will cause some variations in pavement performance.

Equations	R^2 (%)
PSI = 3.55 + 0.100 asphalt - 0.0255 base + 0.00685 R-value - 0.0655 age	32.4
Rut = - 0.071 + 0.00847 base + 0.0227 age	25.9

where

- Rut = rut depth (cm),
 PSI = Present Serviceability Index (0-5),
 Asphalt = thickness of the asphalt layer (cm),
 Base = thickness of the base layer (cm),
 R-value = the R-value of the subgrade material, and
 Age = the number of years since section was constructed.

TABLE 1 Physical Attributes of Test Sections

Section Number	Pavement Thickness (cm)	Base Thickness (cm)	Year Constructed	Soil Classification	Resistance Value (R-Value)	Percentage of Fly Ash Used
1	7.6	30.5	1987	A-4(2)-(5)	67	30.0
2	7.6	30.5	1988	A-4(1)	25	20.2
3	10.2	20.3	1988	A-7-6(12)	1	20.0
4	10.2	20.3	1987	A-4(3)	40	25.0
5	5.1	30.5	1986	A-1-a(0)	74	0.0
6	7.6	25.4	1987	A-4(0)-(8)	16	20.5
7	7.6	25.4	1988	A-6(11)	10	20.2
8	10.2	25.4	1989	A-2-4(0)	45	0.0
9	10.2	33.0	1985	A-6(12)	6	24.7
10	7.6	25.4	1984	A-4(2)-(6)	43	0.0
11	7.6	15.2	1985	A-2-4(0)	61	20.0
12	10.2	27.9	1984	A-4(3)-(6)	50	0.0
13	7.6	30.5	1983	A-4(5)-(7)	26	0.0
14	7.6	30.5	1982	A-4(1)-(6)	15	0.0
15	5.1	20.3	1989	A-2-4(0)	58	20.0
16	5.1	20.3	1989	A-2-4(0)	51	20.0
17	10.2	25.4	1984	A-2-4(0)	68	40.0
18	10.2	25.4	1985	A-2-4(10)	40	40.0
19	5.1	22.9	1988	A-2-4(0)	63	20.0
20	7.6	22.9	1986	A-4(1)-(4)	30	0.0
21	7.6	17.8	1987	A-2-4(0)	45	0.0
22	5.1	17.8	1987	A-4(2)-(3)	15	25.3
23	5.1	17.8	1987	A-6(1)-(10)	16	0.0
24	7.6	17.8	1987	A-2-4(0)	40	20.3
25	7.6	20.3	1988	A-2-4(0)	7	20.5
26	7.6	12.7	1986	A-2-4(0)	59	0.0
27	5.1	20.3	1982	A-4(8)	7	18.9
28	5.1	20.3	1980	A-4(3)-(6)	15	0.0
29	7.6	20.3	1988	A-6(5)-(6)	6	25.3

T-Test Comparison

The main objective of this statistical test was to determine whether the field performance of sections with fly ash was significantly different from that of sections without fly ash. A 95 percent confidence level was used in the whole analysis to be within practical limits, and assumptions were made that (a) the population samples are small and (b) both the populations are normal with $S_1 = S_2 = S$ and the design is completely randomized. The t_0 value was calculated with the following equation:

$$t_0 = \frac{(\bar{Y}_1 - \bar{Y}_2)}{S_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \quad (2)$$

where

\bar{Y}_1 and \bar{Y}_2 = sample means (PSI or rut depth),

n_1 and n_2 = sample sizes, and

S_p = estimate of the common variance $S_1^2 = S_2^2 = S^2$.

The common variance S_p was computed with the following equation:

$$S_p^2 = \frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2} \quad (3)$$

where S_1^2 and S_2^2 are the two individual sample variances.

The data were first broken down into two age groups to eliminate the effect of age factor from the analysis. One age group contained sections built before 1986 and the second group contained sections built in 1986 or later. Means of PSI and rut depths for both age groups were then calculated. PSI means for sections with fly ash were compared with PSI means for sections without fly ash for both age groups. A similar analysis was conducted on rut depth measurements. The test statistic t_0 was determined by using Equation 2, and finally its absolute value was compared with $t^* = t_{\alpha/2, n_1+n_2-2}$. If $ABS(t_0) > t^*$, it would be concluded that the two means are statistically different. Four paired comparisons were made on two age groups. The results from the comparisons are summarized in the following table for PSI:

Date Constructed	t^0	t^*	Statistical Difference
Before 1986	2.08	2.11	Not significant
1986 or later	0.892	2.36	Not significant

and for rut depth measurements:

Date Constructed	t^0	t^*	Statistical Difference
Before 1986	0.388	2.11	Not significant
1986 or later	0.912	2.31	Not significant

It is clear from examining these tables that there is no significant difference between the field performance of sections with fly ash and those without fly ash. This result indicates that using fly ash as a partial replacement for cement has no significant negative effect on field performance.

TABLE 2 Data Related to Field Performance of Test Sections

Section Number	ESAL's (thousands)	Rut Depth (cm)	Present Serviceability Index
1	299	.254	3.7
2	227	.330	3.3
3	68	.127	3.3
4	89	.178	4.0
5	176	.076	3.8
6	143	.051	4.0
7	112	.152	3.6
8	76	.025	3.9
9	881	.178	3.9
10	1012	.203	3.7
11	1012	.025	4.4
12	270	.203	3.3
13	303	.279	3.6
14	335	.356	3.8
15	99	.127	3.3
16	99	.203	4.3
17	954	.330	3.7
18	847	.254	4.0
19	143	.102	3.8
20	74	.330	3.5
21	36	.025	2.8
22	16	.025	3.5
23	16	.076	3.2
24	469	.203	4.3
25	37	.203	3.5
26	26	.229	2.8
27	81	.330	2.7
28	96	.432	2.8
29	54	.279	4.2

CONCLUSIONS AND RECOMMENDATIONS

In this research, a field evaluation was performed to examine the factors affecting the performance of pavement sections containing CTB with and without fly ash. The study consisted of selecting previously constructed sections, collecting data, preparing a computerized data base, and finally conducting statistical analysis. Based on the evaluation performed, the following conclusions can be drawn:

1. The field performance of the sections containing CTB without fly ash is affected by the thickness of the base. The thicker the base, the better the performance.
2. The R^2 of fly ash performance models are lower than the R^2 for CTB performance models. This is because fly ash characteristics vary from time to time within a plant, which causes more variations in field performance.
3. There is no significant statistical difference in performance of sections with and without fly ash.

There are several implications associated with these conclusions. First, CTB sections containing fly ash perform as well as sections without fly ash. Therefore, fly ash should be used more often in highway construction because it is an inexpensive waste material. Second, more extensive research needs to be conducted with better control over construction parameters. Specifically, it is recommended that test sections be constructed to provide varying levels of pavement layer thicknesses, base layer thicknesses, fly ash replace-

ment percentages, and cement content. This will ensure that all possible parameters are taken into account and will help improve the reliability of performance models developed in this research.

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