Fibrous Portland Cement Concrete Overlay Research in Greene County, Iowa

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ABSTRACT

The project was constructed in October 1973 to evaluate the performance of steel fiber-reinforced concrete (fibrous concrete). The 33 fibrous concrete sections, four continuous reinforced concrete sections, two mesh-reinforced sections, and two sections with transverse reinforcing were rated relative to each other on a scale of 0 to 100 at ages of 5 and 10 years. All sections are essentially unbonded to or debonded from the underlying slab. All experimental overlay sections experienced only limited additional deterioration in the 5-10 year period. The 4-in. thick, nonfibrous, mesh, continuously reinforced concrete pavement overlay sections provided the best performance in this research project. A nonfibrous, 5-in. thick, transverse bar-reinforced overlay section with no longitudinal steel performed almost as well. The best performance of a fiber-reinforced concrete section was obtained with 160 lb of fiber per yd^3 of concrete. In the fibrous concrete overlays, 750 lb of cement per yd^3 provided no benefit over the use of 600 lb of cement per yd^3. The performance of the fibrous overlays was directly related to the fiber content of the concrete mix. The 2.5-in.-long higher aspect ratio fibers produced a higher performance rating than the 1-in.-long lower aspect ratio fibers. The 3-in. thick fibrous concrete overlays performed substantially better than the 2-in. thick fibrous overlays. In general, the thicker, nonfibrous pavement overlay sections constructed at a lower unit cost than the fibrous sections performed better than the fiber-reinforced concrete overlays.

The overlay project in Greene County, Iowa, which was completed in October 1973, is the most comprehensive study undertaken of fibrous concrete as an overlay for deteriorated highway pavement. The 3-mi overlay project, constructed by Hallett Construction Company, included 33 test sections of fibrous concrete, four test sections of continuously reinforced concrete pavement (CRCP), two test sections of mesh-reinforced concrete, and two sections with transverse reinforcing. The mix and design variables (in parentheses) for the fibrous concrete overlays include:

- Concrete mix design (3)
- Fiber type (2)
- Fiber content (3)
- Special cement (Chem Comp)
- Overlay thickness (2)
- Joint spacing
- Type of bonding (3)

Replicate sections of several of the test sections were constructed. Table 1 gives a summary of the project. The 3-mi project site is located on Road E-53 east of Jefferson, Iowa. The traffic count on the pavement is approximately 1,100 vehicles per day with 4 percent trucks. This partially reinforced concrete pavement, which originally was Lincoln Highway/U.S. 30, was constructed of 7- to 8-in. thick and 18-ft wide pavement without joints between 1921 and 1922. At the time of the overlay (1973), the old pavement was severely cracked and spalled. Prior to the overlay, nonreinforced lean concrete widening 4-in. thick and 2-ft wide was constructed on each side of the old pavement to increase the width from 18 ft to 22 ft.

Two basic concrete mixes were used in the majority of the fibrous concrete sections. The mixes were chosen to represent extremes in cement content, namely, 600 and 750 lb of cement per yd^3. Some fibrous concrete research had indicated that a greater cement content (750 lb) was needed to obtain the total benefit of the steel fiber reinforcement. Other fibrous concretes used in the project contained a cement/fly ash mixture (five sections) or a shrinkage-compensating cement (one section).

The steel fibers used were 0.010-in. x 0.022-in. x 1-in.-long rectangular slit sheet supplied by the U.S. Steel Corporation and 0.025-in. diameter x 2.5-in.-long drawn fiber supplied by the Atlantic Wire Company in Branford, Connecticut. Fiber addition rates were 60, 100, and 160 lb per yd^3. Twenty-three of the fibrous concrete sections contained the 0.010-in. x 0.022-in. x 1.0-in. fiber while 10 sections contained the 0.025-in. x 2.5-in. fibers.

All of the conventional portland cement concrete (PCC) and CRCP sections were constructed using the Iowa DOT Class A concrete mix proportion containing 569 lb of Type I cement, 1,499 lb of fine aggregate, 1,522 lb of coarse aggregate (1.5-in. maximum size), and approximately 270 lb of water per yd^3 of concrete. Two test sections were constructed with No. 4 bars 12-ft long placed transversely on 3-ft centers at a depth of 2.5-in. with no longitudinal steel. Two test sections were constructed with PCC-reinforced concrete with 6-in. x 6-in. steel mesh (wire diameter = 0.125-in.) placed at one-half the overlay depth. Twenty-two of the fibrous concrete test sections were 3-in. thick and 11 were 2-in. thick. The conventional PCC test sections were 4-in. and 5-in. thick and the CRCP sections were 3-in. and 4-in. thick.

Most of the fibrous concrete sections had transverse joints sawed .250-in. wide to one-third of the overlay depth at 40-ft spacings. The centerline joint (.250-in. wide) was cut to one-third the thickness of the overlay in most of the test sections.

Transverse joints for the rebar and mesh-reinforced concrete sections were sawed .250-in. wide and one-third of the overlay depth on 20- or 30-ft spacings. The centerline joint was cut (.250-in. wide and one-third of the overlay depth) in all of these sections. The bonding conditions for the fibrous concrete test sections were as follows:

1. Five sections intended to be fully bonded (cement spread on wet surface).
2. Twenty-five sections partially bonded (old pavement swept and cracks cleaned before overlay).
3. Three sections unbonded (double thickness of polyethylene sheet between overlay and old pavement).

Two fibrous concrete sections (3-in. design thickness) were placed on grade. The rebar and mesh-reinforced concrete sections were all partially bonded. The CRCP sections were both bonded and unbonded (paraffin base cure). A detailed report on the subject, which was prepared by the Iowa Concrete Paving Association, gives job data on concrete mixture proportioning, concrete properties, test results, section locations, core locations, and costs (1). A report on the subject was also written by Lankard and Henager (2).

PERFORMANCE EVALUATIONS

The performance of the various overlay sections was documented by crack surveys during the first 5 years. These surveys, which detail the location, type (transverse and longitudinal), and length of the cracks were made six times in the first 5 years. The first crack survey was conducted in April 1974, followed by crack surveys in October of the years 1974 through 1978. A report documenting these crack surveys is available from the Iowa Department of Transportation (3). Much of the cracking and deterioration is above the longitudinal joints between the original slab and the 2 ft of widening on each side. In retrospect, an evaluation of fibrous concrete overlay variables would have been better on a pavement without widening.

A 23-member rating panel evaluated all research sections in October 1978 at an age of 5 years. The 5-year evaluation was an effort to rate the performance of the overlay sections on the basis of more comprehensive performance criteria. There were 13 members on the original planning committee, twenty-three participants in the 5-year evaluation rating panel and 25 participants in the 10-year evaluation rating panel. The current assessment of the condition of the Greene County overlay project at 10 years was made on October 12, 1983, by members of the original planning committee and representatives from the Iowa Department of Transportation, Iowa County Government, FHWA, University of Illinois, and industry. Each of the 41 sections in the project was examined with particular attention given to

1. The type and amount of cracking;
2. The type and amount of other forms of pavement distress (spalling);
3. The presence of repaired areas and the prognosis for needed repairs or removal of the entire test section; and
4. Overall condition relative to the other sections on the project.

For the evaluation, each participant was requested to use the Greene County Evaluation Form that had been provided to them. Each evaluator was to assign a rating to each section with a maximum value of 100 assigned to a section showing zero distress and wear. The rating number was based on criteria previously noted with four general categories:

1. 75-100 (good with minor maintenance);
2. 50-75 (above average--average maintenance);
3. 25-50 (below average--repairs are needed); and
4. 0-25 (poor condition--major repairs needed).

The 23 values for 1978 and the 25 values for 1983 were averaged to provide a final rating number of each section. The ratings are given in Tables 1 and 2 where the sections have been listed in the order corresponding to the panel rating. The highest rating is listed first, descending to the lowest rating. It is believed that the rating systems used in the 5- and 10-year evaluation give a meaningful ranking of the experimental sections based on their current condition and on speculation concerning their short-term future performance.

A careful analysis of project records indicates that construction problems or the absence thereof had a definite effect on performance ratings. When few or no problems were noted in the project log and paving progressed rapidly, the ratings were higher than for sections where problems resulted in delays. A correlation of this factor is not realistic, however, as numeric values were not assigned to the problems.

DISCUSSION

The data given in Table 1 were analyzed with a view to identify the effect of a number of variables on the performance of the overlays through 10 years. Using the rating number as an index of relative performance, the effect of major material and design parameters on the performance of the overlay sections can be assessed.

General Comparison

A schematic display of the variables of each section is given in Figure 1. The bonding condition and the admixture type were not considered major variables and are disregarded for some evaluations within the report. The section identification numbers are contained in the individual spaces in the schematic display. A schematic display of the 10-year rating numbers is provided in Figure 2. The bonding condition and admixture type were disregarded in this schematic summary. Sections 23 (a bridge), 22 and 40A (on grade), and 25 (Chem Comp cement) were excluded from the rating summary.

By using this summary rating chart, the variables of the fibrous concrete overlay can be compared. These can also be compared with the nonfibrous sections listed beneath the schematic display with the panel rating listed at the bottom of each block. From this schematic summary, it can be noted that the section receiving the highest 10-year rating was section 3, which was a 4-in.-thick mesh, CRCD. The second highest average rating was achieved by the 5-in.-thick section with transverse steel (no longitudinal steel) and Type A concrete. The third highest rating (79) was given to a fiber-reinforced concrete section with 600 lb of cement and 160 lb of 1-in.-long fiber. The fourth highest rating was obtained by a 4-in. mesh-reinforced jointed section.

TABLE 1 Fibrous Concrete Overlay Summary

Section No.	Cement (lb)	Fiber Content (lb)		14-Day Flexural Strength (psi)	Overlay Thickness (in.)	Intended Bond	Joint Spacing (ft)	Center Line Joint	Panel Rating	
		1-in.	2.5-in.						Oct. 1978	Oct. 1983
1	569	–[a]	–[a]	563	5	Partial	20	Yes	90	86
2	569	–[b]	–[b]	559	4	Partial	30	Yes	81	80
3	569	–[c]	–[c]	575	4	Bonded		Yes	84	82
4	569	–[d]	–[d]	565	4	Unbonded	8	Yes	78	72
4A	569	–[d]	–[d]		Various	Unbonded	8	Yes		
5	569	–[d]	–[d]	671	3	Unbonded	8	Yes	52	46
6	569	–[c]	–[c]	614	3	Bonded		Yes	54	53
7	600	60		575	3	Partial	40[e]	Yes	64	56
8	750		60	730	3	Partial	40	Yes	69	60
9	600	100		603	3	Partial	40	Yes	69	65
10	750	100		680	3	Partial	40	Yes	59	55
11	750		100	739	3	Unbonded	40	Yes	68	66
12	750	100		811	3	Bonded	40	Yes	64	62
13	600	60		718	3	Partial	40	No	56	50
14	500	100		664	3	Partial	40	Yes	40	40
15	500		100	615	3	Partial	40	Yes	42	43
16	600		60	662	3	Partial	40	Yes	60	60
17	750	60		769	3	Partial	40	Yes	55	50
18	600	160		705	3	Partial	40	Yes	86	80
19	600	160		811	3	Partial	40	Yes	82	77
20	750	160		809	3	Partial	40	Yes	83	73
21	750		100	775	3	Bonded	40	Yes	68	59
22	500	160		677	3	On grade	40	Yes	69	55
23	750	160		775	2.250	Bonded		No	83	86
24	600	100		644	3	Partial	40	Yes	79	76
25	750		100	719	3	Unbonded		No	69	60
26	750		160	674	2	Partial	40	Yes	79	64
27	600	100		680	2	Partial	40	Yes	65	58
28	750	100		755	2	Partial	40[e]	Yes	55	45
29	750	100		741	2	Bonded	40[e]	Yes	56	50
30	750	160		834	2	Partial	40	Yes	70	60
31	600	100		612	2	Partial	40	No	56	52
32	750	100		726	2	Partial	40	No	50	48
33	600	160		664	2	Partial	40	Yes	72	62
34	750	160		808	2	Partial	40	Yes	69	56
35	750		100	731	2	Unbonded	40	Yes	44	37
36	750		100	791	2	Bonded	40	Yes	63	52
37	600		60	668	3	Partial	40	No	71	52
38	569	–[b]	–[b]	605	4	Partial	30	Yes	84	70
39	569	–[a]	–[a]	602	5	Partial	20	Yes	82	76
40	500	100		621	3	Partial	Various	No	59	45
40A	500	160		865	3	On grade	40	Yes	76	51
Grand average									67	60

[a]Transverse steel-reinforced section.
[b]Mesh-reinforced section.
[c]CRCP-anchored section.
[d]CRCP-section.
[e]Full depth.

The average cost of the various overlay sections (see Table 3) was determined by using 1973 prices. The cost for the special sections is as follows:

Special Section Description	Cost per Yd² ($)
5-in. Plain concrete	3.57
4-in. Type A concrete with mesh	3.58
4-in. CRCP with elastic joints	4.41
3-in. CRCP with elastic joints	3.48

In general, the use of fibrous reinforcement results in a unit price greater than that of thicker conventionally reinforced overlays.

Personnel who had been on the evaluation panel for the 5-year evaluation were pleasantly surprised with the condition of all overlay sections at the 10-year performance evaluation. It was the general consensus that based on the 5-year performance evaluation, substantially greater deterioration between 5 and 10 years had been expected. The grand average of the rating numbers of October 1978 (see Table 1) was 67 and the grand average of all ratings of October 1983 had decreased to 60. During the 5-year evaluation, many of the evaluators expressed the opinion that substantial rehabilitation would probably be needed at 10 years. The consensus of the 10-year evaluation panel was that the pavement had performed quite well and a substantial effort should be aimed at maintaining the research sections with further evaluation. A substantial patching project was completed in June 1984 to repair the badly deteriorated areas and allow evaluation of the overlay project through 15 years.

Cement Content

Most of the fibrous concrete overlays were placed with concrete made with either 600 or 750 lb of cement per cubic yard. There were, however, five overlay sections placed with 500 lb of cement and 234 lb of fly ash as the binder material. One section was placed using 750 lb of Chem Comp cement per cubic yard. Comparisons of sections in which the cement content is the only intended variable are given in Table 4. In five of six comparative sections where the only major variable is the cement content, the 600 lb of cement per yd³ mix performed better than that containing the 750 lb of cement per yd³. The grand average also favored the 600 lb of cement per yd³. This is a relatively small difference and may

TABLE 2 Overlay Sections Arranged in Order of the 10-Yr Performance Rating

Section No.	Panel Rating	Cement Content (lb/yd^3)	Reinforcement or Fiber Type	Amount of Fiber (lb/yd^3)	Overlay Thickness (in.)	Type of Bond
23	86	750	1 in.	160	2-1/4	Bridge
1	86	569	Transverse		5	Partial
3	82	569	CRCP		4	Bonded
2	80	569	Mesh		4	Partial
18	80	600	1 in.	160	3	Partial
19	77	600	1 in.	160	3	Partial
24	76	600	1 in.	100	3	Partial
39	76	569	Transverse		5	Partial
20	73	750	1 in.	160	3	Partial
4	72	569	CRCP		4	Unbonded
38	70	569	Mesh		4	Partial
11	66	750	2.5 in.	100	3	Unbonded
9	65	600	1 in.	100	3	Partial
26	64	750	2.5 in.	160	2	Partial
12	62	750	1 in.	100	3	Bonded
33	62	600	1 in.	160	2	Partial
8	60	750	2.5 in.	60	3	Partial
25	60	750	2.5 in.	100	3	Unbonded
30	60	750	1 in.	160	2	Partial
16	60	600	2.5 in.	60	3	Partial
21	59	750	2.5 in.	100	3	Bonded
27	58	600	1 in.	100	2	Partial
34	56	750	1 in.	160	2	Partial
7	56	600	1 in.	60	3	Partial
10	55	750	1 in.	100	3	Partial
22	55	500[a]	1 in.	160	3	On grade
6	53	569	CRCP		3	Bonded
36	52	750	2.5 in.	100	2	Bonded
37	52	600	2.5 in.	60	3	Partial
31	52	600	1 in.	100	2	Partial
40A	51	500[a]	1 in.	160	3	On grade
17	50	750	1 in.	60	3	Partial
13	50	600	1 in.	60	3	Partial
29	50	750	1 in.	100	2	Bonded
32	48	750	1 in.	100	2	Partial
5	46	569	CRCP		3	Unbonded
40	45	500[a]	1 in.	100	3	Partial
28	45	750	1 in.	100	2	Partial
15	43	500[a]	2.5 in.	100	3	Partial
14	40	500[a]	1 in.	100	3	Partial
35	37	750	2.5 in.	100	2	Unbonded

[a]500 lb of cement + 234 lb of fly ash.

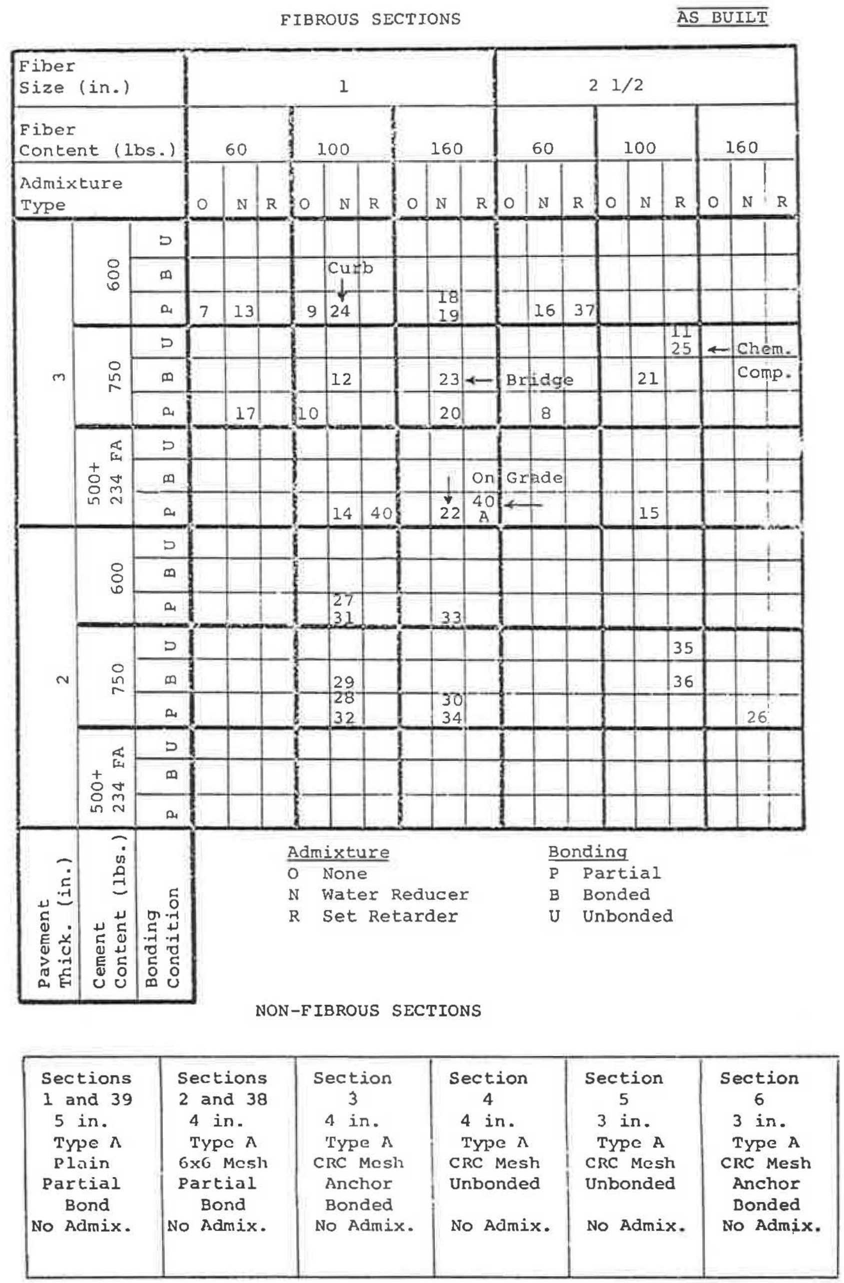

FIGURE 1 Schematic summary of the variables of each overlay section.

FIBROUS SECTIONS — AS BUILT

Pavement Thick. (in.)	Cement Content (lbs.)	Fiber Size (in.) 1			2 1/2		
	Fiber Content (lbs.)	60	100	160	60	100	160
3	600	*53	*70	*79	*56		
3	750	*50	*59	*73	*60	*63	
3	500+ 234 FA		*42			*43	
2	600		*55	*62			
2	750		*48	*58		*45	*64
2	500+ 234 FA						

*Average Performance Rating at 10 Years

Note: Sections 22, 23, 25 & 40A were not included in the average performance ratings.

NON-FIBROUS SECTIONS

Sections 1 and 39	Sections 2 and 38	Section 3	Section 4	Section 5	Section 6
5 in.	4 in.	4 in.	4 in.	3 in.	3 in.
Type A	Type A	Type A	Type A	Type A	Type A
Plain	6x6 Mesh	CRC Mesh	CRC Mesh	CRC Mesh	CRC Mesh
Partial Bond	Partial Bond	Anchor Bonded	Unbonded	Unbonded	Anchor Bonded
No Admix.	No Admix.	No Admix.	No Admix.	No Admix.	No Admix.
*81	*75	*82	*72	*46	*53

FIGURE 2 Schematic summary of overlay variables and performance ratings at 10 years.

TABLE 3 Average Cost of Overlays

Thickness (in.)	Cement (lb/yd^3)	Fiber (lb/yd^3)	Cost Per Yd^2 ($)
2	600	100	3.40
2	600	160	4.10
2	750	100	3.52
2	750	160	4.22
3	500 + 234 fly ash	100	4.94
3	500 + 234 fly ash	160	5.61
3	750	160	6.64
3	750	100	4.56
3	750	60	3.86
3	600	160	5.42
3	600	100	4.30
3	600	60	3.61

not be significant when considering other variables. The only explanation for this result would be the drying shrinkage caused by the additional cement with the relatively thin overlay sections that are 2 or 3 in.

The performance ratings of the sections with 500 lb of cement plus 234 lb of fly ash were somewhat less than the sections with 600 or 750 lb of cement per yd^3. Direct comparisons of panel ratings can be made between sections containing 500 lb of cement plus fly ash (Sections 14 and 40), 750 lb of cement (Sections 10 and 12), or 600 lb of cement (Sections 9 and 24), with ratings of 42, 59, and 70, respectively. The 500 lb of cement plus fly ash mix can also be compared with the 750 lb per yd^3 mix with

TABLE 4 Performance Ratings and Flexural Strengths of Overlay Sections Where Cement Content Was the Only Major Variable

Comparative Overlay Section Nos. by Cement Content (lb/yd^3)			Flexural Strength (psi) By Cement Content (lb/yd^3)			Avg 10-Yr Performance Rating by Cement Content (lb/yd^3)		
500(+ 234 lb F.A.)	750	600	500(+ 234 lb F.A.)	750	600	500(+ 234 lb F.A.)	750	600
14,40	10,12	9,24	643	745	624	42	59	70
	30,34	33		821	664		58	62
	8	37,16		730	665		60	56
	17	7,13		769	647		50	53
	28,29,32	27,31		741	646		48	55
	20	18,19		809	758		73	79
Grand Average				753	667		58	62
15	11,21		615	757		43	63	
Grand Average			629	751		42	61	

Note: F.A. = fly ash.

Section 15 versus Sections 11 and 21. Section 15 was rated at 43 and Sections 11 and 21 averaged 63. Sections 11 and 25 provided a comparison of Chem Comp expansive cement and a standard 750-lb cement concrete mix. There was no significant benefit derived from the use of the Chem Comp expansive cement.

Fiber Content

Fiber contents of 60, 100, or 160 lb per yd^3 were studied under this research. These fiber contents were used with both the 1-in. and the 2.5-in. fibers. A comparison of the overlay sections where the only intended major variable was the fiber content is given in Table 5. There are two sets of sections in which all three fiber contents were used. When averaging these two, the grand average shows that the 160 lb per yd is superior to both the 100- and 60-lb fiber contents with ratings of 76, 65, and 52 for the 160-, 100-, and 60-lb contents, respectively. The comparative sections would show that the 100-lb fiber content yields a rating number approximately 10 points higher than that of the 60-lb fiber content and the 160-lb fiber content yields a rating number approximately 10 points better than the 100-lb fiber content. It would appear that the fiber content is one of the more important major variables as two of the 160-lb-per-yd^3 fibrous sections compared favorably with the 4- and 5-in. nonfibrous sections. Unfortunately, however, the 160-lb-per-yd^3 substantially increases the cost of the overlay sections.

TABLE 5 Performance Ratings of Fibrous Concrete Overlay Sections Where Fiber Content Was the Only Major Variable

Comparative Overlay Section Nos. by Cement Content (lb/yd^3)			Avg 10-Yr Performance Rating by Cement Content (lb/yd^3)		
60	100	160	60	100	160
7,13	9,24	18,19	53	70	79
17	10,12	20	50	59	73
Grand average			52	65	76
	27,31	33		55	62
	28,29,32	30,34		48	58
	35,36	26		45	64
Grand average				55	67
8	11,21		60	63	
Grand average			54	64	

Fiber Type

Two different fiber types were used in this research. There are six sets of comparative sections (see Table 6) where fiber type is the only major variable. In all six cases, the 2.5-in.-long fibers exhibited a performance superior to that of the 1-in. fiber in the comparative sections. The grand average yields a rating six units higher for the 2.5-in. fibers than for the 1-in. fiber.

TABLE 6 Performance Ratings of Fibrous Concrete Overlay Sections Where Fiber Type Was the Only Major Variable

Comparative Overlay Section Nos. by Fiber Length (in.)		Avg 10-Yr Performance Rating by Fiber Length (in.)	
1-in.	2.5-in.	1-in.	2.5-in.
7,13	16,37	53	56
17	8	50	60
10,12	11,21	59	63
14,40	15	42	43
30,34	26	58	64
28,29,32	35,36	48	64
Grand average		52	58

Overlay Thickness

The thickness of the overlay was intended to be either 2 or 3 in. except for transition sections. This 2- or 3-in. thickness was to be a nominal thickness and because of the irregular surface of the underlying original concrete, there was substantial variation in the thickness. Some thicknesses of only 1 in. were cited. There were five sets of sections in which the only intended major variable was overlay thickness (see Table 7). In all five comparative sets, the 3-in. overlays provided substantially better performance ratings than did those of their comparative 2-in. sections. The grand average is 69 for the 3-in. sections versus 54 for the 2-in. sections or a 15-point superiority for the 3-in. overlays.

Type of Bonding

There are a few sections in which the type of intended bonding is the only variable (see Table 8).

TABLE 7 Performance Rating of Overlay Sections Where Overlay Thickness Was the Only Major Variable

Comparative Overlay Section Nos. by Thickness (in.)		Avg 10-Yr Performance Rating by Thickness (in.)	
3-in.	2-in.	3-in.	2-in.
18,19	33	78	62
11,21	35,36	63	45
9,24	27,31	70	55
10,12	28,29,32	59	48
20	30,34	73	58
Grand average		69	54

TABLE 8 Performance Ratings of Fibrous Concrete Overlay Sections Where the Only Intended Variable Was the Type of Bonding

Comparative Overlay Section Nos.			Avg 10-Yr Performance Rating		
Bonded	Unbonded	Partially Bonded	Bonded	Unbonded	Partially Bonded
12		10	62		55
21	11		59	66	
36	35		52	37	
29		28,32	50		47

At the time of construction, no equipment for determining the degree of bond was readily available and no testing of this aspect was conducted. During the 5 years following construction, a Delamtect testing device was developed to identify delaminations in bridge decks. This device was capable of indicating relatively thin delaminated layers. In October 1978, the entire length of the project was tested in the outside wheel track of both lanes. The project was almost completely delaminated except for the 4- and 5-in. sections. The bonded sections exhibited no greater degree of bonding than the partial or unbonded sections. Experience has shown that overlays are either bonded or unbonded as a partial bond yields an unbonded overlay. Research has shown that a cement grout "squeegeed" onto a properly prepared dry concrete surface before placing the new concrete results in a well-bonded overlay. For this reason, the type of bonding was not considered as a major variable in this evaluation. There are, however, four sets of comparative sections where the type of bonding is the only intended variable. Because of the limited number and the variation among the rating numbers on those comparative sections, no conclusions can be reached.

Pavement on Grade

The two sections that were placed on grade contained 160 lb of fiber per yd^3 and were 3-in. thick. These two sections had performed quite well through 5 years (ratings of 69 and 76) but have shown substantial deterioration in the period from 5 through 10 years and now exhibit ratings of 55 and 51.

CONCLUSIONS

Based on the results of the current survey using the rating numbers of the panel as the relative performance of the experimental overlay sections after 10 years of service, the following can be concluded:

1. The 4-in.-thick nonfibrous mesh CRCP provided the best performance in this research project. A nonfibrous 5-in.-thick concrete section with transverse steel only performed almost as well.
2. The best performance of fiber-reinforced concrete was by those sections containing 160 lb of fiber per yd^3.
3. In general, the fibrous concrete overlays have provided relatively good performance through 10 years.
4. The performance ratings of the fibrous concrete overlays containing 600 lb of cement per yd^3 were somewhat better than those of the overlays with 750 lb of cement per yd^3. In this project, increasing the cement content from 600 to 750 lb per yd^3 did not significantly improve overlay performance.
5. The performance of the overlays was directly related to the fiber content of the concrete mix with the mixes containing 160 lb of fibers per yd^3 providing the best performance followed by those mixes containing 100 lb of fiber per yd^3, and the poorest performance being exhibited by the mixes containing only 60 lb of fiber per yd^3.
6. The 0.025-in. x 2.5-in. higher aspect ratio fiber (aspect ratio of 100) produced a higher performance rating than the 0.010-in. x 0.022-in. x 1.0-in. fiber (aspect ratio of about 63).
7. The 3-in.-thick fibrous concrete overlays yielded substantially better performance than the 2-in.-thick fibrous overlays.
8. Satisfactory bonding was not achieved on any of the fibrous concrete overlay sections and, therefore, no conclusions can be reached with regard to type of bonding.
9. The additional cost of the fibrous reinforcement cannot be justified based on the 10-year comparative performance of the fibrous and 4- and 5-in.-thick nonfibrous sections.

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