Field Performance of Experimental Full-Depth Repair Joint Load-Transfer Systems in Illinois

MARK B. SNYDER AND DAVID L. LIPPERT

The Illinois Department of Transportation (IDOT) constructed 28 full-depth repairs with various dowel load-transfer system designs on I-70 in 1984. Design variables included dowel diameter, number of dowels per wheelpath, dowel anchor material, and the use of tie bars in lieu of dowels. IDOT and the University of Illinois monitored the faulting performance and loss of load-transfer efficiency of these repairs through 1988, when the project was overlaid. In general, it appeared that greater quantities of larger-diameter dowels improved leave-joint load-transfer efficiency; faulting improvements were less noticeable. Tied approach joints improved the load-transfer efficiency of both the approach and leave joints, presumably because repair movement was inhibited. The performance of repairs constructed using epoxy mortars was mixed. Repair leave joints generally performed more poorly than approach joints and were determined to be critical for design purposes. Repair leave-joint faulting was modeled as a function of load-transfer efficiency. Traffic and other important variables could not be introduced because they were relatively constant over the data base. The model that was developed was shown to have applications in repair load-transfer system design.

The full-depth repair performance data that were collected by the Illinois Department of Transportation (IDOT) and analyzed by Lippert in 1987 (*1*) are reexamined. Additional, longer-term performance data have been collected since the original analysis was completed, allowing a more detailed analysis at this time. More complete documentation of this research project is presented in previous papers by Snyder (*2,3*).

PROJECT DESCRIPTION AND DATA COLLECTION

IDOT and University of Illinois at Urbana-Champaign (UI) have been monitoring several experimental installations of full-depth repairs and other rehabilitation techniques since the early 1980s (*1*). One particular project, constructed in 1984, is located on Interstate 70 near St. Elmo, Illinois, and consists of 28 full-depth repairs of varying load-transfer system designs. These repairs have been subjected to an average of about 1.0 million 18-kip equivalent single-axle loads (ESALs) per year since their construction.

M. B. Snyder, A349 Engineering Building, Michigan State University, East Lansing, Mich. 48824-1226. D. L. Lippert, Illinois Department of Transportation, 126 East Ash Street, Springfield, Ill. 62704-4766.

This project was constructed to determine the effects of various load-transfer design parameters on repair performance. Variable features included dowel bar diameter [1.25-in. (32-mm) versus 1.50 in. (38-mm)], number of dowels per wheelpath (three, four, or five), dowel bar anchor material (nonshrink cement grout versus epoxy mortar), and the use of tie bars rather than dowels in the repair approach joint. The repairs were all constructed in the outer lane of the highway, using stringent quality control and inspection procedures. The repair joints were sawed and sealed after construction. A summary of the individual repair design features and locations is presented in Table 1. It can be seen that each design-material combination is replicated in at least two locations and that the experiment is designed for a comparison analysis.

IDOT has monitored the performance of these repairs since construction by periodically measuring deflection load transfer using a Dynatest Model 8000 falling-weight deflectometer. Measurements have been taken in the outer wheelpath at both the approach and leave repair joints with the load placed on both the original slab and the repair itself for a total of four measurements per repair. These measurements were taken six times during the first year of repair service and twice annually thereafter. Table 2 presents the deflection load-transfer data obtained from the repair approach joint when the load is placed on the approach side of the joint. Table 3 presents similar data for the repair leave joint when the load is placed on the approach side of the joint.

Repair joint faulting has also been measured annually by IDOT personnel (beginning in December 1984) and additional faulting measurements were obtained by the UI project team in July 1985, June 1987, and July 1988. Unfortunately, the IDOT and UI teams used different fault-measurement devices and performed measurements at slightly different locations on the repair joints (IDOT measures faulting in the outer wheelpath; UI measures faulting 1 ft from the lane-shoulder joint). A regression equation was developed using faulting measurements obtained concurrently by both teams during a single visit in July 1988. This equation provides a means of "converting" UI faulting measurements to IDOT measurements:

$$IDOT = (UI + 0.03514)/1.252 \quad (1)$$

where

IDOT = faulting using IDOT equipment and procedures (in.),

UI = faulting using UI equipment and procedures (in.),
R^2 = 0.81,
n = 56,
SEE = 0.081 in. (2.05 mm).

In addition to the good statistical fit of this model, the data were observed to fit the model well, particularly for faults exceeding 0.10 in. (2.5 mm).

Tables 4 and 5 present the changes in transverse-joint faulting since the first measurements for repair approach and leave joints (respectively). The UI measurements in these tables have been adjusted using Equation 1.

The data presented in Tables 2 through 5 represent relatively short-term performance, but they come from one of the few reasonably well-designed experimental repair projects that have been constructed and subjected to heavy traffic. They provide a good indication of general performance trends as well as an excellent basis for determining the field performance of various repair joint designs. They are also useful for identifying relationships between joint load transfer and repair faulting.

This experimental repair project was overlaid with bituminous concrete in late 1988 as part of IDOT efforts to raise overall network serviceability levels. Although additional deflection testing has been accomplished since the overlay was placed, the data are not appropriate for inclusion in the analyses described herein.

ANALYSIS OF PROJECT DATA

The following preliminary conclusions and recommendations were developed by Lippert in early 1987 (*1*) on the basis of a study of the data available at that time:

1. Full-depth repairs should be constructed using ten 1.5-in. (38-mm) diameter dowels per repair joint.
2. Dowel anchor material type seemed to have no influence on repair deflection or performance.
3. Minimum repair length should be 6 ft (2 m) to promote repair stability under heavy traffic.
4. Sawed or formed and sealed transverse-joint sealant reservoirs are very import for the prevention of joint spalling, which was often found along tight, unsawed approach joints.

A more detailed analysis was accomplished in late 1988 using the updated data set described previously (*2,3*). This most recent study included separate analyses of the faulting and load-transfer measurements for the repair approach and leave joints. Load-transfer measurements were also analyzed with consideration of load location. The details of these analyses have been presented previously (*2,3*).

The data presented in Tables 2 and 3 suggest that the deflection load-transfer efficiency of the repair approach joints was typically 10 to 25 percent higher than that of the leave joints, presumably because of the tendency of the repairs to move opposite to the direction of traffic flow, possibly through the mechanism shown in Figure 1, which produces approach-joint closure and increased deflection load-transfer capacity. The use of more or larger dowels, or both, further improved the approach-joint deflection load-transfer efficiency. It should also be noted that the use of deformed tie bars in repair

TABLE 1 INDIVIDUAL REPAIR DESIGN FEATURES AND LOCATIONS FOR THE I-70 EXPERIMENTAL REPAIR INSTALLATIONS

REPAIR ID	STATION	MILEPOST	DIR'N TRAVEL	DOWELS PER WHEEL PATH	DOWEL DIAM. (IN.)	ANCHOR MAT'L
1	1438	81.40	WB	3	1.25	CEMENT GROUT
2	1421	81.23	WB	4	1.25	CEMENT GROUT
3	1309	79.15	WB	5	1.25	CEMENT GROUT
4	1265	78.24	WB	3	1.50	CEMENT GROUT
5	1246	78.05	WB	4	1.50	CEMENT GROUT
6A	1205		WB	5 (Tied)	1.25	CEMENT GROUT
6B	1204		WB	5 (Tied)	1.25	CEMENT GROUT
6C	1203		WB	5 (Tied)	1.25	CEMENT GROUT
6	1162	76.01	WB	5	1.50	CEMENT GROUT
7	1209	77.22	EB	3	1.25	CEMENT GROUT
8	1210		EB	3	1.25	CEMENT GROUT
9	1211		EB	3	1.25	CEMENT GROUT
10	1212		EB	4	1.25	CEMENT GROUT
11	1214	77.27	EB	4	1.25	EPOXY MORTAR
12	1264	78.25	EB	4	1.25	CEMENT GROUT
12A	1271		EB	5	1.25	CEMENT GROUT
12B	1275		EB	5	1.25	CEMENT GROUT
13	1276		EB	5	1.25	CEMENT GROUT
13A	1277		EB	5	1.25	EPOXY MORTAR
14	1278+60	78.40	EB	3	1.50	CEMENT GROUT
15	1279		EB	3	1.50	CEMENT GROUT
16	1315+10	79.24	EB	3	1.50	CEMENT GROUT
17	1318		EB	4	1.50	CEMENT GROUT
18	1319	79.26	EB	4	1.50	CEMENT GROUT
19	1320		EB	4	1.50	CEMENT GROUT
20	1322	79.29	EB	5	1.50	CEMENT GROUT
21	1329	79.36	EB	5	1.50	CEMENT GROUT
22	1368	80.22	EB	5	1.50	CEMENT GROUT

approach joints produced excellent load transfer across those joints, with averages near 95 percent over the entire 41-month performance period (which compares with 55 to 85 percent for doweled approach joints after 41 months).

Table 4 shows that repair approach-joint faulting was generally not a problem on this project. Faults of 0.1 in. (2.54 mm) or less were typical, even when leave-joint faults of 0.25 in. (6.4 mm) or more were observed. The minor development of faulting at the repair approach joints can be attributed (at least in part) to the high deflection load-transfer capacity that was observed at these joints (see Table 2). A portion of this high deflection load-transfer capacity is presumed to be due to the previously described mechanism of repair movement.

Thus, the repair leave joint can be considered the critical joint for repair design. The remainder of this paper will focus primarily on the analysis of the repair leave-joint data.

Leave-Joint Faulting

Table 5 shows that although leave-joint faulting was generally small, it was occasionally quite large. Faults of 0.1 in. or less were typical for most repairs, but faults of 0.5 in. (13 mm) and more were also observed.

The influence of the number of dowels per wheelpath on leave-joint faulting is shown in Figures 2 and 3 for 1.25-in. (32-mm) and 1.50-in. (38-mm) dowels. Unfortunately, these figures suggest contradictory conclusions. Figure 2 indicates that increasing the number of dowels used has little effect (or may even increase) leave-joint faulting, whereas Figure 3 suggests that substantial reductions in faulting accompany increases in the number of dowels used. Further examination of these figures reveals that the repairs constructed using the three of the larger dowels in each wheelpath faulted much more than

TABLE 2 DEFLECTION LOAD TRANSFER DATA FOR THE I-70 EXPERIMENTAL REPAIR APPROACH JOINTS (LOAD ON APPROACH SIDE OF JOINT)

REPAIR ID	DESCRIPTION (DOWELS/DIAM/MAT'L)	Month 1 (NOV 84)	Month 2 (DEC 84)	Month 4 (FEB 85)	Month 5 (MAR 85)	Month 8 (JUN 85)	Month 11 (SEP 85)	Month 13 (NOV 85)	Month 17 (MAR 86)	Month 25 (NOV 86)	Month 29 (MAR 87)	Month 37 (NOV 87)	Month 41 (MAR 88)
7	3/1.25/GROUT	100	98	100	86	92	100	71	62	56	46	37	40
8	3/1.25/GROUT	95	78	93	78	95	100	61	52	47	61	51	63
9	3/1.25/GROUT	92	84	91	81	95	98	74	56	55	42	44	44
Average		96	87	95	82	94	99	69	57	53	50	44	49
10	4/1.25/GROUT	87	67	81	59	96	100	56	55	48	51	50	56
12	4/1.25/GROUT	86	100	87	82	93	100	68	94	68	71	63	72
Average		87	84	84	71	95	100	62	75	58	61	57	64
12A	5/1.25/GROUT	100	87	82	84	93	85	70	98	67	56	56	65
12B	5/1.25/GROUT	95	76	88	89	92	86	79	81	82	68	69	79
13	5/1.25/GROUT	93	89	87	79	95	98	67	69	54	56	63	61
Average		96	84	86	84	93	90	72	83	68	60	63	68
14	3/1.50/GROUT	96	96	89	76	92	76	73	71	67	62	52	65
15	3/1.50/GROUT	98	100	100	93	98	88	86	88	94	86	89	99
16	3/1.50/GROUT	100	95	100	100	96	99	94	94	29	15	27	11
Average		98	97	96	90	95	88	84	84	63	54	56	58
17	4/1.50/GROUT	97	100	100	100	97	94	92	72	78	62	74	81
18	4/1.50/GROUT	98	98	100	94	88	82	75	74	53	76	34	30
19	4/1.50/GROUT	95	100	100	95	99	95	89	75	66	63	68	80
Average		97	99	100	96	95	90	85	74	66	67	59	64
6A	5/1.25(T)/GROUT	100	100	100	100	96	96	92	98	100	89	95	90
6B	5/1.25(T)/GROUT	100	100	100	99	98	95	94	99	100	93	97	92
6C	5/1.25(T)/GROUT	100	100	100	100	100	96	100	96	100	93	98	97
Average		100	100	100	100	98	96	95	98	100	92	97	93
20	5/1.50/GROUT	93	100	100	88	91	97	77	74	70	57	66	73
21	5/1.50/GROUT	100	93	81	86	82	93	71	70	63	67	81	86
22	5/1.50/GROUT	96	94	98	96	84	83	75	74	65	59	68	68
Average		96	96	93	90	86	91	74	73	66	61	72	76
11	4/1.25/EPOXY	91	89	72	76	100	66	66	66	51	55	40	49
13A	5/1.25/EPOXY	93	100	100	93	94	94	83	81	81	83	75	75
1	3/1.25/GROUT	94	100	100	97	98	98	93	98	83	92	87	81
2	4/1.25/GROUT	97	100	88	97	95	96	86	98	84	81	80	80
3	5/1.25/GROUT	96	82	98	83	85	82	81	76	76	76	82	76
4	3/1.50/GROUT	84	77	75	97	100	93	65	74	57	52	60	60
5	4/1.50/GROUT	85	77	84	98	98	97	81	89	79	83	85	86
6	5/1.50/GROUT	90	78	80	94	92	92	70	96	71	67	69	58

TABLE 3 DEFLECTION LOAD TRANSFER DATA FOR THE I-70 EXPERIMENTAL REPAIR LEAVE JOINTS (LOAD ON APPROACH SIDE OF JOINT)

REPAIR ID	DESCRIPTION (DOWELS/DIAM/MAT'L)	Month 1 (NOV 84)	Month 2 (DEC 84)	Month 4 (FEB 85)	Month 5 (MAR 85)	Month 8 (JUN 85)	Month 11 (SEP 85)	Month 13 (NOV 85)	Month 17 (MAR 86)	Month 25 (NOV 86)	Month 29 (MAR 87)	Month 37 (NOV 87)	Month 41 (MAR 88)
7	3/1.25/GROUT	98	100	83	87	95	100	78	77	58	56	38	23
8	3/1.25/GROUT	93	95	76	96	86	100	72	59	57	52	52	32
9	3/1.25/GROUT	87	92	100	91	97	100	93	87	88	82	74	49
Average		93	96	86	91	93	100	81	74	68	63	55	35
10	4/1.25/GROUT	88	88	90	97	98	100	88	86	78	67	63	53
12	4/1.25/GROUT	95	100	92	84	97	100	79	94	40	42	25	26
Average		92	94	91	91	98	100	84	90	59	55	44	40
12A	5/1.25/GROUT	94	99	100	99	98	94	88	97	85	80	77	67
12B	5/1.25/GROUT	92	88	89	99	96	99	91	92	92	92	92	96
13	5/1.25/GROUT	94	87	100	88	100	93	76	89	72	65	63	78
Average		93	91	96	95	98	95	85	93	83	79	77	80
14	3/1.50/GROUT	96	100	100	92	97	95	86	82	83	76	85	87
15	3/1.50/GROUT	100	100	100	96	95	94	85	74	63	41	24	32
16	3/1.50/GROUT	96	90	100	92	98	94	82	94	40	18	7	13
Average		97	97	100	93	97	94	84	83	62	45	39	44
17	4/1.50/GROUT	91	79	70	96	92	64	52	81	41	53	23	51
18	4/1.50/GROUT	90	100	100	96	85	94	89	76	73	49	28	25
19	4/1.50/GROUT	87	100	92	90	100	81	79	88	76	70	45	54
Average		89	93	87	94	92	80	73	82	63	57	32	43
6A	5/1.25(T)/GROUT	92	100	100	100	100	100	81	88	76	71	74	76
6B	5/1.25(T)/GROUT	94	94	91	100	100	97	96	98	95	86	84	80
6C	5/1.25(T)/GROUT	100	100	85	93	100	100	85	86	93	86	93	83
Average		95	98	92	98	100	99	87	91	88	81	84	80
20	5/1.50/GROUT	96	88	93	94	82	98	93	96	73	69	41	31
21	5/1.50/GROUT	100	100	93	99	92	99	87	90	82	79	79	83
22	5/1.50/GROUT	96	100	100	95	80	93	90	85	88	82	82	84
Average		97	96	95	96	85	97	90	90	81	77	67	66
11	4/1.25/EPOXY	90	89	100	61	87	34	27	25	22	15	15	17
13A	5/1.25/EPOXY	99	100	100	99	98	93	94	97	95	91	95	92
1	3/1.25/GROUT	95	94	97	100	100	100	94	100	89	100	92	86
2	4/1.25/GROUT	93	83	100	99	100	98	100	99	98	98	99	95
3	5/1.25/GROUT	86	100	100	88	90	88	82	88	78	75	74	71
4	3/1.50/GROUT	95	88	100	85	100	99	75	96	74	73	76	79
5	4/1.50/GROUT	85	94	89	96	97	100	87	99	79	82	74	73
6	5/1.50/GROUT	91	85	80	88	98	95	86	100	91	83	68	56

those constructed using three of the smaller dowels. One would expect increases in the number or size of dowels used in order to reduce faulting. One possible explanation for these anomalies is given below.

The repairs in question are located sequentially in the eastbound lanes of the project, as shown in Table 1. Because their locations are not randomized along the length of the project, it is possible that some systematic error or bias has been introduced and is producing the unexpected faulting relationships that were observed in these areas. The faults generally increase from west to east until near Station 1318; it thus seems likely that drainage or support conditions may also deteriorate along that section. Construction-related defects may also be a factor. These effects (or whatever constitutes the source of bias) may be overshadowing the true effects of increasing the number and diameter of dowels. A better experimental design (featuring randomized location of each joint design, rather than clusters) might have reduced or eliminated this apparent bias and allowed a more conclusive analysis.

The effects of using epoxy mortar (rather than cement grout) anchor materials are also unclear. Repair 13A was constructed using epoxy mortar anchor materials and performed slightly better (leave-joint faulting of less than 0.1 in.) than corresponding repairs that used cement grout (see Figure 4). Repair 11 was also constructed using epoxy mortar anchor materials and performed quite poorly (leave-joint faulting exceeding 0.25 in.) (see Figure 5).

Both repairs are located in the same area as the repairs described above. Thus, their performance may have been

TABLE 4 FAULTING DATA FOR THE I-70 EXPERIMENTAL REPAIR APPROACH JOINTS (PRESENTED AS CHANGE IN FAULTING SINCE FIRST FAULTING MEASUREMENT)

REPAIR ID	DESCRIPTION (DOWELS/DIAM/MAT'L)	Month 2 (DEC 84) IDOT	Month 9 (JUL 85) UI	Month 13 (NOV 85) IDOT	Month 24 (OCT 86) IDOT	Month 32 (JUN 87) UI	Month 45 (JUL 88) IDOT	Month 45 (JUL 88) UI
7	3/1.25/GROUT	0.00	0.27	0.19	0.19	0.19	0.32	0.27
8	3/1.25/GROUT	0.00	0.02	-0.03	0.07	0.03	0.15	0.07
9	3/1.25/GROUT	0.00	0.01	0.01	0.05	-0.01	0.08	0.06
Average		0.00	0.10	0.06	0.10	0.07	0.18	0.13
10	4/1.25/GROUT	0.00	0.04	0.02	0.04	-0.11	0.04	-0.06
12	4/1.25/GROUT	0.00	0.12	0.00	0.02	0.04	0.03	0.11
Average		0.00	0.08	0.01	0.03	-0.03	0.03	0.02
12A	5/1.25/GROUT	0.00	-0.09	0.01	0.02	-0.05	-0.01	-0.10
12B	5/1.25/GROUT	0.00	-0.02	-0.09	-0.04	-0.04	-0.08	0.03
13	5/1.25/GROUT	0.00	0.00	-0.06	-0.02	-0.12	-0.03	-0.02
Average		0.00	-0.04	-0.05	-0.01	-0.07	-0.04	-0.03
14	3/1.50/GROUT	0.00	-0.06	-0.05	-0.01	-0.07	-0.00	-0.04
15	3/1.50/GROUT	0.00	-0.03	-0.02	-0.03	-0.07	-0.03	-0.03
16	3/1.50/GROUT	0.00	-0.09	-0.09	-0.06	-0.03	0.08	0.01
Average		0.00	-0.06	-0.05	-0.03	-0.06	0.02	-0.02
17	4/1.50/GROUT	0.00	-0.05	-0.01	0.02	-0.04	0.00	0.03
18	4/1.50/GROUT	0.00	0.01	-0.03	0.01	0.02	0.03	0.03
19	4/1.50/GROUT	0.00	0.03	-0.04	0.00	-0.00	0.02	-0.08
Average		0.00	-0.01	-0.03	0.01	-0.01	0.02	-0.01
6A	5/1.25(T)/GROUT	0.00	0.10	0.12	0.04	0.06	0.12	0.08
6B	5/1.25(T)/GROUT	0.00	-0.01	-0.02	0.04	-0.05	0.04	0.02
6C	5/1.25(T)/GROUT	0.00	0.07	-0.02	0.07	0.02	0.07	0.05
Average		0.00	0.05	0.03	0.05	0.01	0.08	0.05
20	5/1.50/GROUT	0.00	0.05	-0.04	-0.02	-0.08	-0.02	-0.14
21	5/1.50/GROUT	0.00	-0.04	-0.06	-0.04	-0.04	0.03	-0.11
22	5/1.50/GROUT	0.00	0.04	-0.03	0.00	-0.02	0.03	0.03
Average		0.00	0.02	-0.04	-0.02	-0.05	0.01	-0.07
11	4/1.25/EPOXY	0.00	-0.01	0.00	0.03	-0.02	0.05	0.05
13A	5/1.25/EPOXY	0.00	0.00	-0.03	-0.04	-0.08	-0.03	-0.03
1	3/1.25/GROUT	0.00	0.06	0.00	0.05	0.01	0.06	0.07
2	4/1.25/GROUT	0.00	0.01	0.00	0.02	-0.05	0.02	0.01
3	5/1.25/GROUT	0.00	0.03	0.02	-0.01	-0.00	0.02	-0.01
4	3/1.50/GROUT	0.00	0.05	0.02	0.02	0.03	0.06	-0.01
5	4/1.50/GROUT	0.00	0.02	-0.01	0.00	-0.02	0.02	-0.02
6	5/1.50/GROUT	0.00	-0.03	-0.08	0.00	-0.08	-0.02	-0.03

affected by the same source of bias or error. Contractor unfamiliarity with the epoxy material may have also produced the highly variable results that were observed; the location of the highly faulted repair suggests that it may have been constructed first. Thus, it cannot be determined whether the poor performance of the 4-4/epoxy repair is typical. Again, a better experimental design (featuring randomly located replicates of the epoxied repairs) might have allowed a more conclusive analysis concerning the effects of anchor material on faulting performance.

If the good performance of the 5-5/epoxy repair is typical, it would bear out the theory (presented in reference 3) that it is easier to achieve uniform dowel support in full-depth repairs using epoxy mortars than cement grouts. The consistency of cement grouts can vary widely over short periods of time, from very fluid grouts that run out of the drilled holes to very stiff grouts that make dowel installation very difficult. Many epoxy mortars are pre-proportioned for uniformity and are mixed and delivered "on demand" using caulking gun–style systems. This uniform consistency is crucial to achieving good dowel installations.

The use of deformed bars in the repair approach joint appears to have little influence on the development of repair leave-joint faulting (see Figure 6).

Leave-Joint Load Transfer

Examination of Figures 7 through 15 shows that load-transfer measurements are often somewhat variable immediately after repair construction. A definite performance trend is sometimes not apparent for 1 or 2 years (although some repairs

TABLE 5 FAULTING DATA FOR THE I-70 EXPERIMENTAL REPAIR LEAVE JOINTS (PRESENTED AS CHANGE IN FAULTING SINCE FIRST FAULTING MEASUREMENT)

REPAIR ID	DESCRIPTION (DOWELS/DIAM/MAT'L)	Month 2 (DEC 84) IDOT	Month 9 (JUL 85) UI	Month 13 (NOV 85) IDOT	Month 24 (OCT 86) IDOT	Month 32 (JUN 87) UI	Month 45 (JUL 88) IDOT	Month 45 (JUL 88) UI
7	3/1.25/GROUT	0.00	0.01	0.01	0.09	-0.00	0.14	0.09
8	3/1.25/GROUT	0.00	0.04	-0.04	-0.01	-0.02	0.00	0.04
9	3/1.25/GROUT	0.00	-0.06	0.00	-0.02	-0.07	-0.01	0.02
Average		0.00	-0.00	-0.01	0.02	-0.03	0.04	0.05
10	4/1.25/GROUT	0.00	0.08	0.01	0.08	0.02	0.09	0.09
12	4/1.25/GROUT	0.00	-0.00	-0.04	0.03	0.04	0.06	0.14
Average		0.00	0.04	-0.02	0.05	0.03	0.08	0.12
12A	5/1.25/GROUT	0.00	0.04	0.00	0.07	-0.02	0.07	0.01
12B	5/1.25/GROUT	0.00	0.10	0.10	0.13	0.12	0.15	0.14
13	5/1.25/GROUT	0.00	-0.02	0.01	-0.01	-0.04	-0.02	0.03
Average		0.00	0.04	0.04	0.06	0.02	0.07	0.06
14	3/1.50/GROUT	0.00	0.08	-0.10	0.01	-0.02	0.01	0.02
15	3/1.50/GROUT	0.00	-0.09	-0.02	0.06	-0.00	0.32	0.46
16	3/1.50/GROUT	0.00	0.03	-0.02	0.07	0.24	0.72	0.65
Average		0.00	0.01	-0.05	0.05	0.07	0.35	0.38
17	4/1.50/GROUT	0.00	-0.03	-0.13	-0.10	-0.09	-0.04	0.03
18	4/1.50/GROUT	0.00	-0.24	-0.09	-0.07	0.01	0.05	0.05
19	4/1.50/GROUT	0.00	-0.07	-0.08	-0.04	-0.06	0.04	0.05
Average		0.00	-0.11	-0.10	-0.07	-0.05	0.02	0.04
6A	5/1.25(T)/GROUT	0.00	-0.07	-0.02	0.03	-0.04	0.00	-0.06
6B	5/1.25(T)/GROUT	0.00	-0.05	-0.07	0.06	-0.07	-0.01	-0.06
6C	5/1.25(T)/GROUT	0.00	-0.12	-0.14	-0.07	-0.12	-0.07	-0.08
Average		0.00	-0.08	-0.08	0.01	-0.08	-0.03	-0.07
20	5/1.50/GROUT	0.00	0.08	-0.10	-0.04	-0.09	0.01	0.02
21	5/1.50/GROUT	0.00	-0.07	0.03	-0.01	-0.03	0.05	0.01
22	5/1.50/GROUT	0.00	-0.03	-0.04	-0.01	0.08	0.08	0.17
Average		0.00	-0.01	-0.04	-0.02	-0.01	0.05	0.07
11	4/1.25/EPOXY	0.00	0.12	0.08	0.16	0.16	0.23	0.31
13A	5/1.25/EPOXY	0.00	-0.02	-0.03	0.04	0.05	0.02	0.11
1	3/1.25/GROUT	0.00	0.03	-0.04	0.05	-0.05	0.03	0.08
2	4/1.25/GROUT	0.00	0.00	-0.04	-0.02	0.09	-0.05	0.11
3	5/1.25/GROUT	0.00	0.05	-0.04	0.02	0.05	0.01	0.07
4	3/1.50/GROUT	0.00	0.04	-0.05	0.04	0.07	-0.01	0.10
5	4/1.50/GROUT	0.00	-0.08	-0.07	-0.01	-0.02	0.01	0.08
6	5/1.50/GROUT	0.00	0.10	0.04	0.00	-0.00	0.11	0.09

obviously deteriorate rapidly and such trends are easily identified from the start). For this reason, the discussions and analyses in this section are derived mainly from the data collected after the first year of service.

Figures 7 and 8 show that repairs constructed using five dowels per wheelpath exhibited much better load-transfer histories than those constructed using either three or four dowels (65 to 80 percent versus 35 to 45 percent after 41 months). The effect of dowel diameter appeared small (see Figures 9 through 11), although the sources of bias and error described previously may be overshadowing this effect.

Figures 12 through 14 compare the leave-joint load-transfer measurements for the repairs using epoxy mortar to those of repairs using conventional cement grout anchor materials. As with the approach-joint load-transfer and faulting observations, the effect is unclear because only two repairs were constructed using the epoxy mortar, and they performed very differently.

The effect of the tied approach joint on leave-joint load transfer is presented in Figure 15, which suggests a modest improvement in long-term load-transfer performance (10 to 25 percent after 41 months) over repairs with dowels across both joints. The use of deformed bars in the approach joint should restrict the tendency of the repair to move against the flow of traffic, thus preventing the approach joint from closing and the leave joint from opening. This, in turn, reduces the bearing stresses under the leave-joint dowels and thus may reduce the faulting. The restricted repair movement may also improve the performance of the repair joint seals, reducing the entry of surface water to the pavement structure, and resulting in smaller pavement deflections and better load transfer.

Relationships Between Joint Design, Load Transfer, and Faulting

The IDOT experimental repair project data present an opportunity to quantify relationships between repair joint design, load transfer, and faulting. However, the use of these rela-

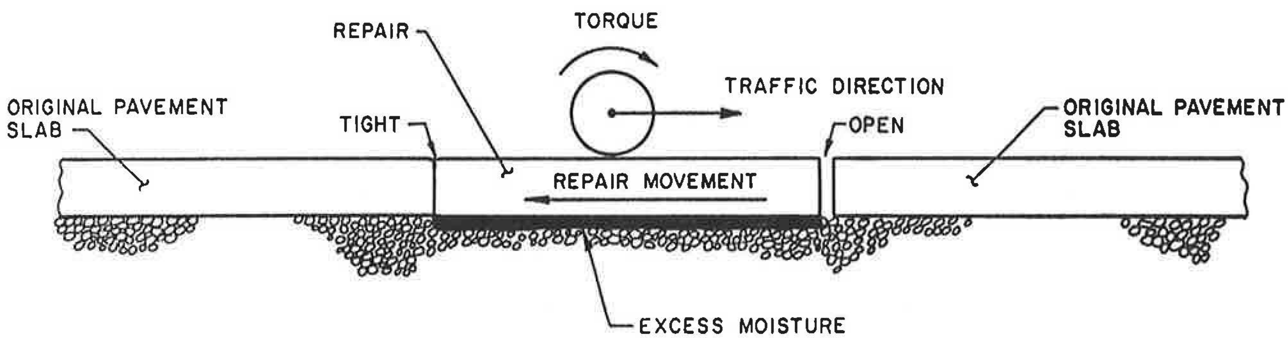

FIGURE 1 Movement of full-depth repairs under traffic loads.

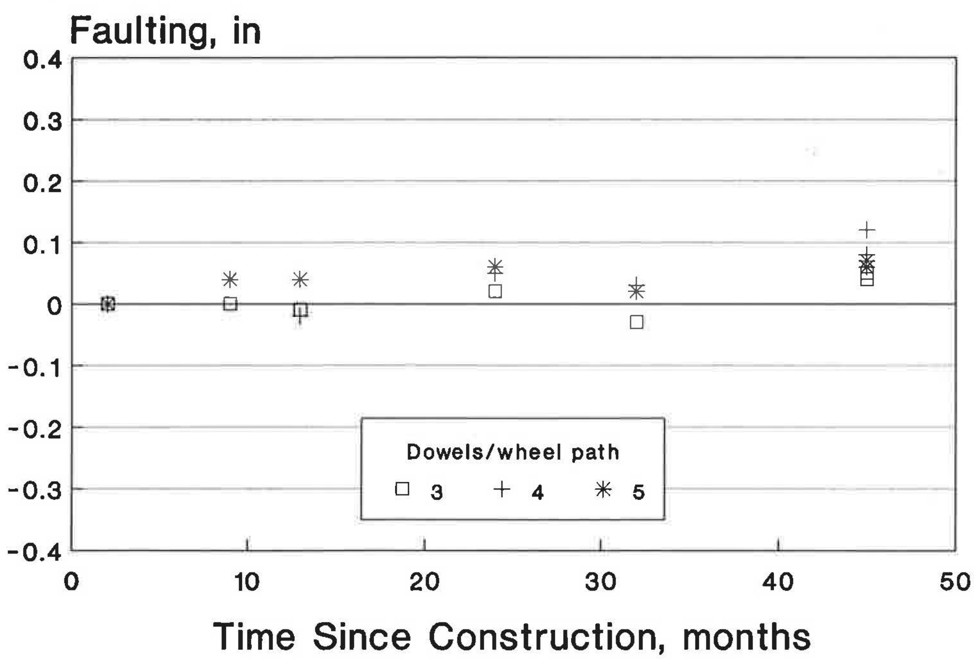

FIGURE 2 I-70 leave-joint faulting performance data (EB) [1.25-in. (32-mm) diameter dowels: three, four, or five dowels per wheelpath, cement grout].

tionships and models must be tempered with the knowledge that they are developed for a very limited range of repair designs that have been in service for a relatively short period of time (less than 4 years). Further, the effects of varying traffic, climate, and/or materials are not adequately considered. Nevertheless, these relationships and models are still of interest because they provide some insight which is useful in improving the design and performance of full-depth repairs [as demonstrated in a previous paper by Snyder (*3*)].

One goal of the reexamination of the I-70 performance data was to develop a model for the development of transverse-joint faulting. Because leave-joint faulting was generally more critical than approach-joint faulting, it was selected as the dependent variable. Several possible independent variables

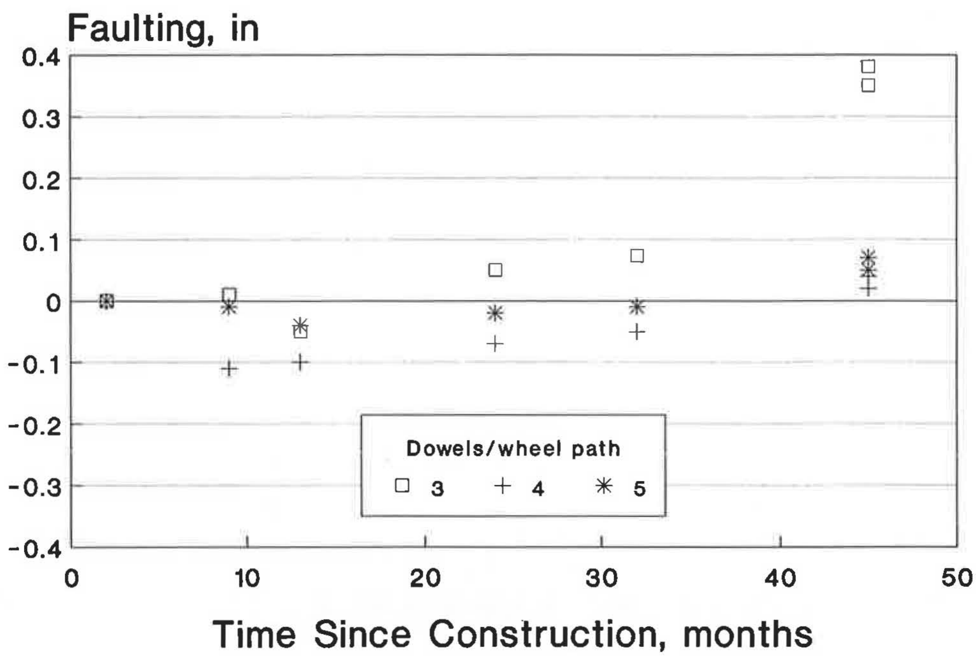

FIGURE 3 I-70 leave-joint faulting performance data (EB) [1.50-in. (38-mm) diameter dowels: three, four, or five dowels per wheelpath, cement grout].

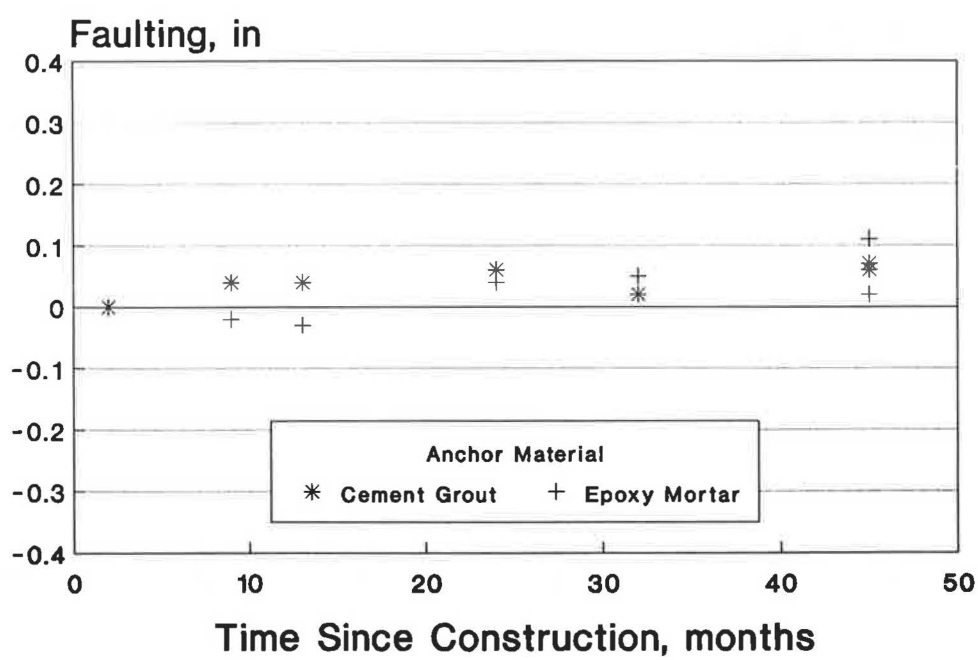

FIGURE 4 I-70 leave-joint faulting performance data (EB) [five 1.25-in. (32-mm) diameter dowels per wheelpath, varying anchor materials].

were also identified for study, including leave-joint bearing stress (BSTRESS), time since repair placement (MONTHS), cumulative 18-kip ESALs since placement (ESAL), leave-joint deflection-based load transfer (LT), the cumulative area under the load transfer versus ESAL curve (LT*ESAL), and the product of dowel bearing stress versus cumulative 18-kip ESALs since repair replacement (BS*ESAL). Table 6 presents the matrix of correlation coefficients for these variables with repair leave-joint faulting (FAULT). Dowel bar anchor material (cement grout versus epoxy mortar) was not included because the only two repairs that included epoxy mortar exhibited very different performances, as described previously.

Table 6 shows that repair leave-joint faulting exhibits a strong inverse correlation with leave-joint load transfer. Because traffic was relatively constant over time for all of the repairs, the effects of time and traffic are indistinguishable. Thus, the strong direct correlation of faulting with time represents the effects of both time and traffic.

A very weak (and probably insignificant) correlation was observed between faulting and bearing stress. This probably results from the fact that the range of bearing stresses was

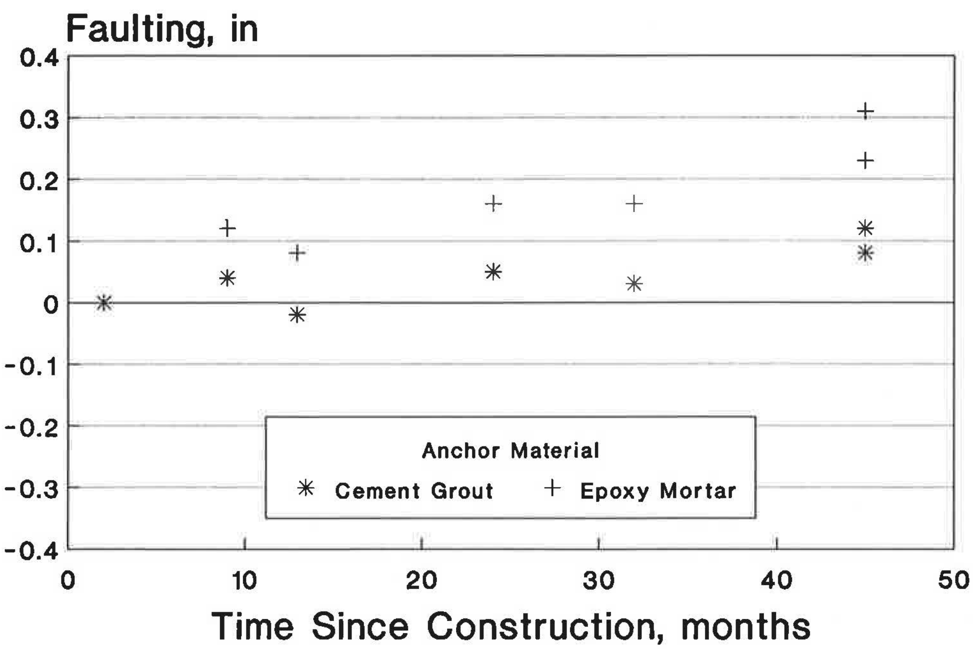

FIGURE 5 I-70 leave-joint faulting performance data (EB) [four 1.25-in. (32-mm) diameter dowels per wheelpath, varying anchor materials].

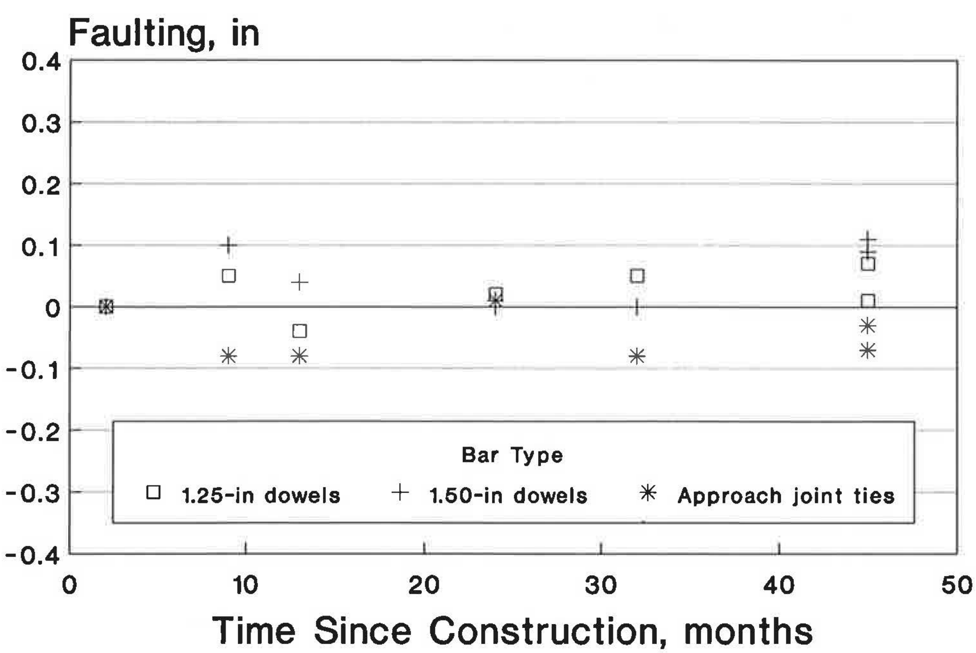

FIGURE 6 I-70 leave-joint faulting performance data (WB) (five dowels per wheelpath, varying dowel diameters, and use of approach-joint tie bars; cement grout).

very small (only two different dowel diameters were used and the computed bearing stress was constant for four- and five-dowel installations because of the stiffness of the slab). The product of bearing stress and ESAL did not correlate any better than ESAL or time alone.

This information was used with data plots to attempt to define functional forms for a repair leave-joint faulting model. Preliminary modeling attempts using multiple linear regression techniques produced models that were primarily a function of load transfer with insignificant terms for time/traffic factors. Many attempts to include significant time/traffic factors were made using both linear and nonlinear analyses, but all were unsuccessful. The repair leave-joint faulting model finally selected is purely a function of repair leave-joint load transfer.

$$\text{FAULT} = 141900 * \text{LT}^{-3.807} - 0.1288 * \text{LT} + 23.37 \quad (2)$$

where

FAULT = repair leave-joint faulting (in. × 100),
LT = repair leave-joint deflection load transfer [defined as DEFLECTION (unloaded side of joint)/DEFLECTION (loaded side)],
R^2 = 0.691,
n = 140 faulting measurements,
SEE = 0.057 in. (1.5 mm).

Figure 16 presents a plot of the I-70 repair leave-joint faulting versus deflection load-transfer data with the model superimposed. Although the model clearly fits the test data very well, it is not intended to suggest that faulting is purely a function of load-transfer capacity; a repair that has poor load-transfer characteristics will not fault until heavy traffic and moisture conditions activate the pumping-faulting mechanism. Because the model relates field measurements of faulting and load transfer without direct consideration of the effects of time and traffic, a more correct interpretation of the model may be to consider it as a relationship between faulting and loss of load-transfer capacity because of the effects of traffic,

TABLE 6 CORRELATION COEFFICIENTS FOR I-70 REPAIR FAULTING, LOAD TRANSFER, AND OTHER VARIABLES

	FAULT	LT	MONTHS	BSTRESS	LT*ESAL	BS*ESAL
FAULT	1.0000 (0) P=******	.6223 (140) P= .001	0.4086 (140) P= .001	-.0777 (140) P= .181	0.4098 (140) P= .001	0.3171 (140) P= .001
LT		1.0000 (0) P=******	-.4815 (308) P= .001	0.1341 (308) P= .009	-.4806 (308) P= .001	-.3813 (308) P= .001
MONTHS			1.0000 (0) P=******	0.0000 (308) P= .500	0.9996 (308) P= .001	0.9213 (308) P= .001
BSTRESS				1.0000 (0) P=******	0.0000 (308) P= .500	0.3562 (308) P= .001
LT*ESAL					1.0000 (0) P=******	0.9217 (308) P= .001
BS*ESAL						1.0000 (0) P=******

Note: Each block of data uses the following form:

CORRELATION COEFFICIENT
NO. OF VALID CASES
SIGNIFICANCE

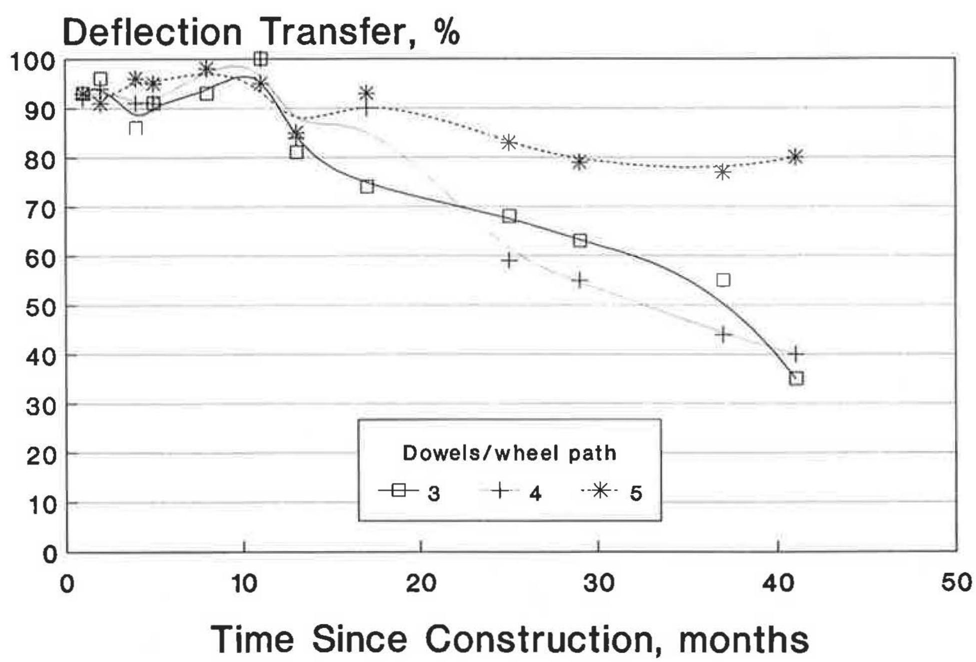

FIGURE 7 I-70 leave-joint load transfer performance data (EB) [1.25-in. (32-mm) diameter dowels: three, four, or five dowels per wheelpath].

environment, and other factors. In this manner, traffic and other important effects can be considered directly through the development of models for load-transfer capacity based on repair joint design parameters. Such models have been developed by Snyder (*3*).

CONCLUSIONS AND RECOMMENDATIONS

There is little doubt that the experiment could have been designed differently to reduce or eliminate the possible effects of bias from the analyses (the authors were not involved in the experimental design). However, this study produced much good, conclusive information, which is summarized below:

1. The recommendations and findings presented by Lippert (*1*) were valid and should produce repairs that perform well, particularly if high-quality construction practices can be adopted and enforced.
2. A comparison of the load-transfer and faulting performances of full-depth repair approach and leave joints suggest that the leave joint is the more critical of the two. Thus, load-

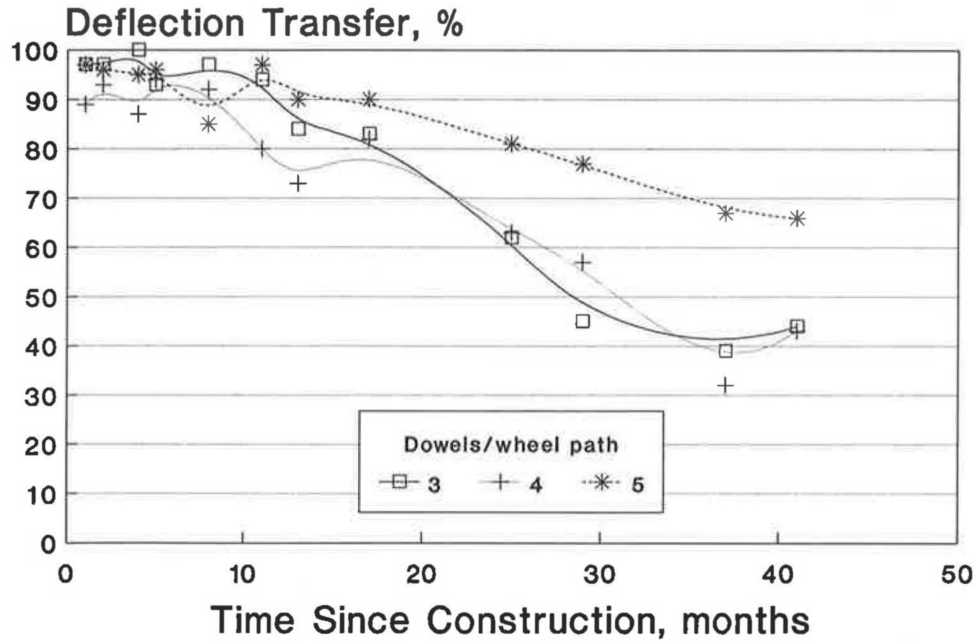

FIGURE 8 I-70 leave-joint load-transfer performance data (EB) [1.50-in. (38-mm) diameter dowels: three, four, or five dowels per wheelpath].

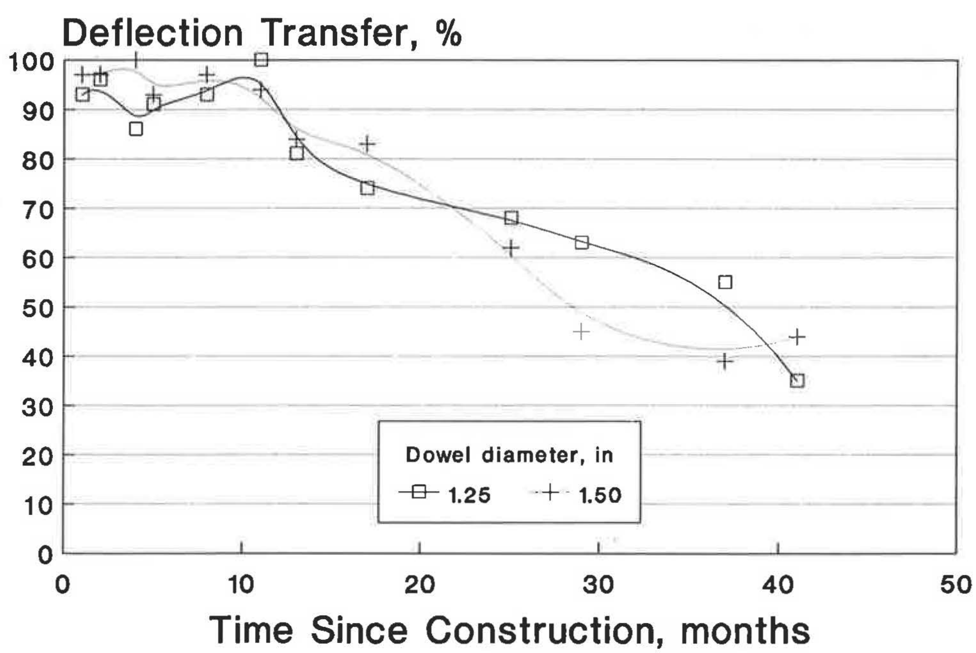

FIGURE 9 I-70 leave-joint load-transfer performance data (EB) (three dowels per wheelpath, varying dowel diameters).

transfer system designs that are suitable for this joint should also produce acceptable results in the repair approach joint as well.

3. Repair leave-joint faulting trends did not clearly indicate the impact of varying dowel diameters and quantities, but the measured faults were relatively small in most instances. These effects may become more pronounced over time. Load-transfer trends were much more clear, however, and verified that improved performance should accompany increased quantities and sizes of dowels.

4. The effect of varying dowel anchor material (from cement grout to epoxy mortar) was not determined in this study because the performance of the few repairs constructed using the latter material varied widely.

5. The use of deformed bars in the repair approach joint produced excellent long-term approach joint load-transfer characteristics, and produced modest improvements in leave-joint load-transfer characteristics. This type of design may improve repair performance by limiting repair movement, thereby preventing repair leave joints from opening, which

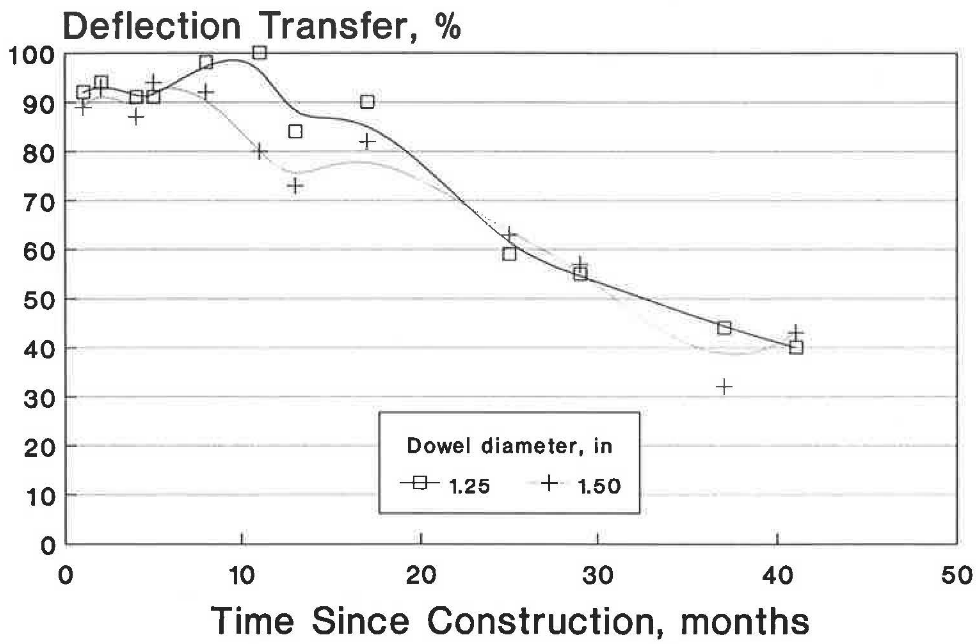

FIGURE 10 I-70 leave-joint load-transfer performance data (EB) (four dowels per wheelpath, varying dowel diameters).

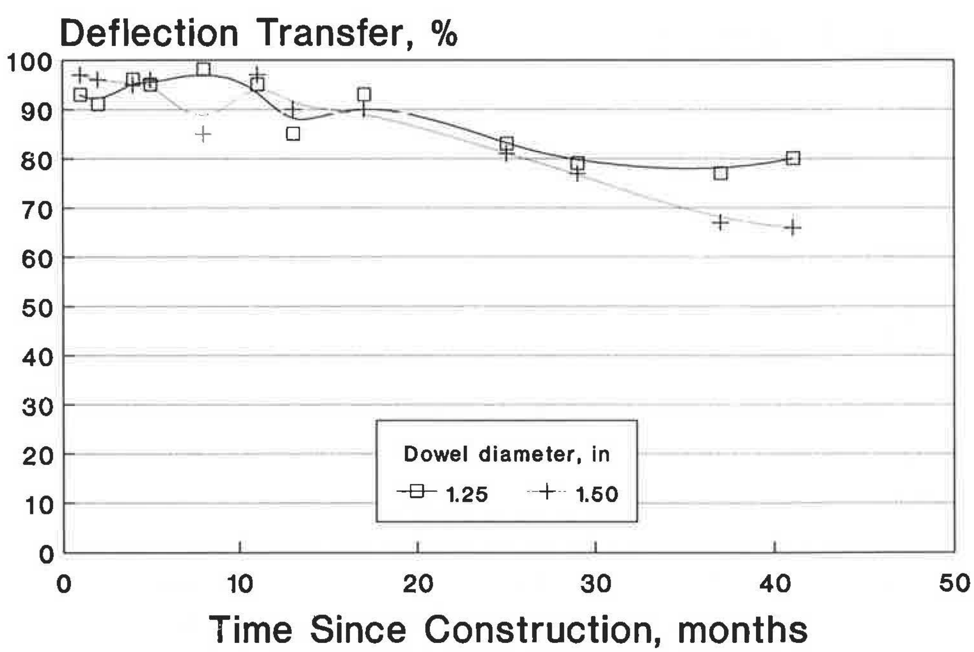

FIGURE 11 I-70 leave-joint load-transfer performance data (EB) (five dowels per wheelpath, varying dowel diameters).

can increase leave-joint dowel bearing stresses and sealant damage. Joint-faulting improvements due to the use of tie bars were negligible over the duration of the study.

6. A model was developed from the field performance data to relate repair leave-joint faulting with load-transfer measurements. Other important variables (such as dowel bearing stress and traffic factors) could not be introduced to the model because they were relatively constant for the entire data base. However, the model can be considered to represent the effects of traffic, environment, and other factors on joint faulting, since these factors combine to cause losses of load-transfer efficiency over time. This model has been used as a part of a demonstration design procedure for full-depth repair dowel load-transfer systems.

ACKNOWLEDGMENTS

The research study described herein was conducted by the University of Illinois Department of Civil Engineering at

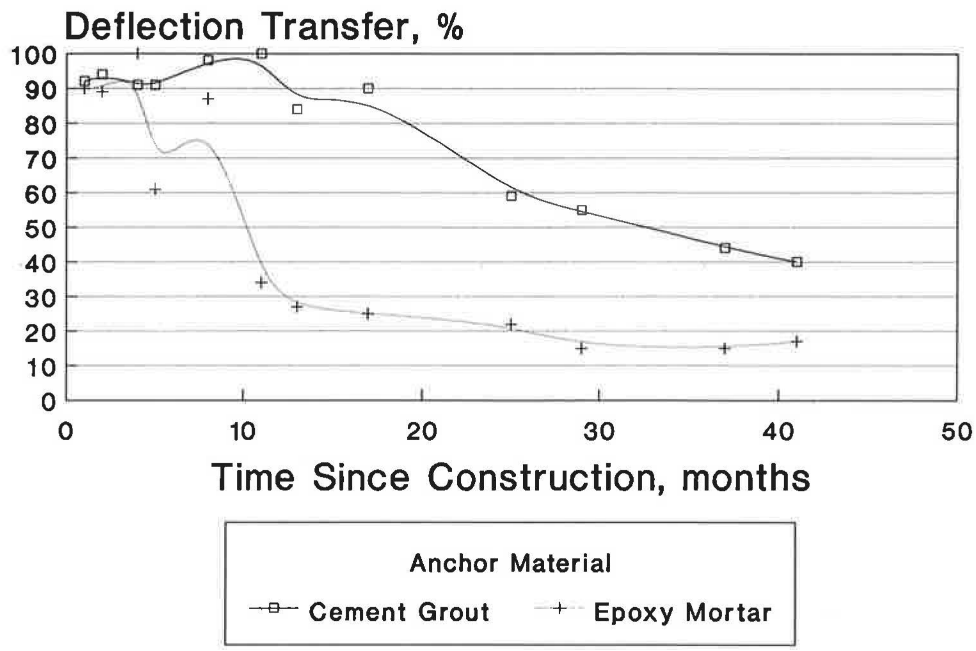

FIGURE 12 I-70 leave-joint load-transfer performance data (EB) [four 1.25-in. (32-mm) diameter dowels per wheelpath, varying anchor materials].

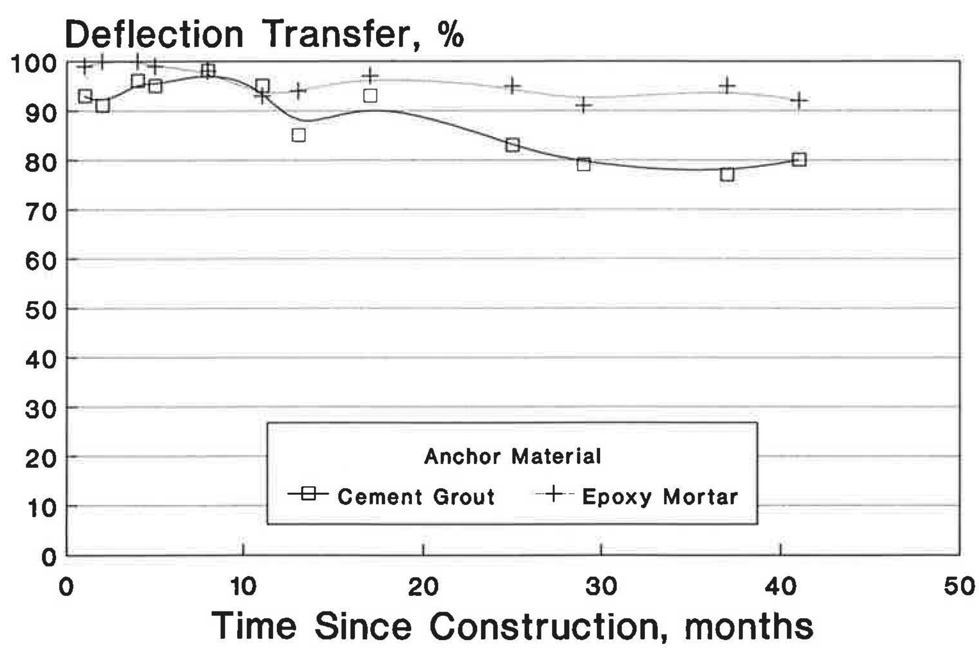

FIGURE 13 I-70 leave-joint load-transfer performance data (EB) [five 1.25-in. (32-mm) diameter dowels per wheelpath, varying anchor materials].

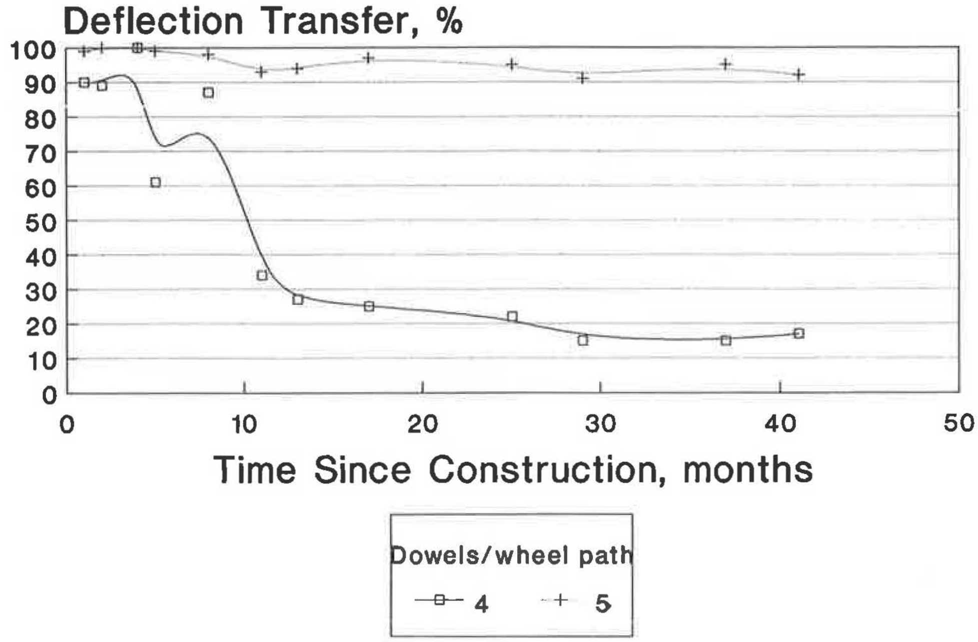

FIGURE 14 I-70 leave-joint load-transfer performance data (EB) [1.25-in. (32-mm) dowels, epoxy mortar anchor material, varying numbers of dowels per wheelpath].

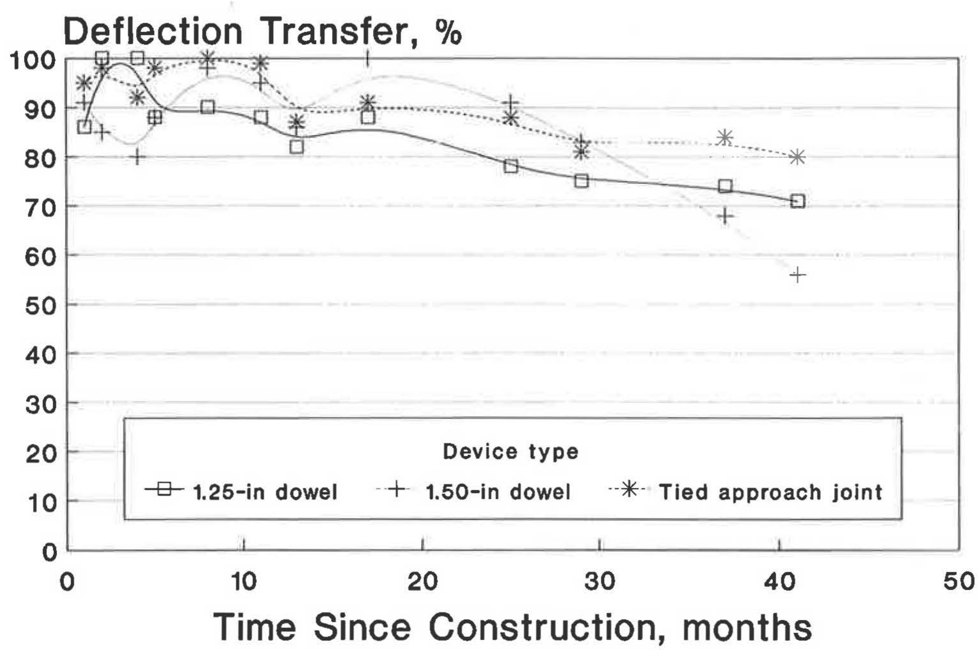

FIGURE 15 I-70 leave-joint load-transfer performance data (WB) (five dowels per wheelpath, varying dowel diameters and use of approach-joint tie bars).

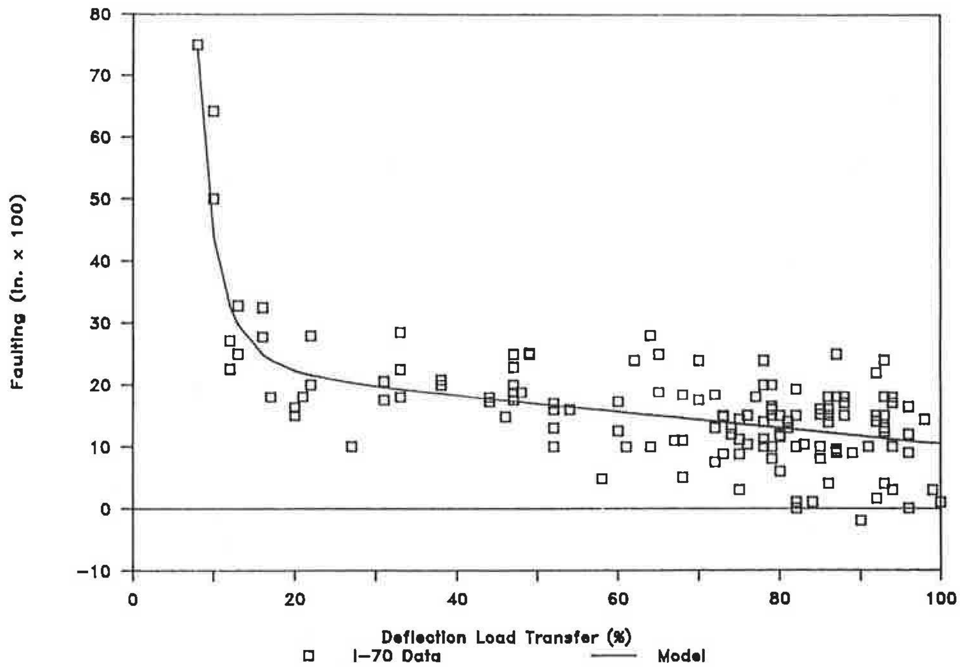

FIGURE 16 Joint faulting versus load-transfer data obtained from I-70 experimental repair project.

Urbana-Champaign with the cooperation of the Illinois Department of Transportation and funded by FHA. The authors gratefully acknowledge the efforts of all project team members and cooperating state highway agencies that made possible the successful completion of this research project. Special thanks are given to M. I. Darter and Kathleen Hall of the University of Illinois Department of Civil Engineering, who assisted in the collection and transfer of the field data described in this paper.

REFERENCES

1. D. L. Lippert. Performance Evaluation of Jointed Concrete Pavement Rehabilitation Without Resurfacing. In *Transportation Research Record 1109*, TRB, National Research Council, Washington, D.C., 1987.
2. M. B. Snyder, M. J. Reiter, K. T. Hall, and M. I. Darter. *Rehabilitation of Concrete Pavements*, Volume I: *Repair Rehabilitation Techniques*. Report FHWA-RD-88-071. FHWA, U.S. Department of Transportation, July 1989.
3. M. B. Snyder. Dowel Load Transfer Systems for Full-Depth Repairs of Jointed Portland Cement Concrete Pavements. Ph.D. thesis. University of Illinois Department of Civil Engineering, Urbana, Ill., 1988.

This paper is based on research performed under an FHWA contract. The contents of this paper reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policy of the U.S. Department of Transportation or the Federal Highway Administration. This paper does not constitute a standard, specification, or regulation.

Publication of this paper sponsored by Committee on Pavement Rehabilitation.