Subsealing and Load Transfer Restoration

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Presented are the evaluation results of slab subsealing and load transfer restoration using dowel bars and double vee shear devices of a jointed concrete pavement at a large truck terminal facility. Nondestructive deflection testing (NDT) procedures using the falling-weight deflectometer (FWD) were used before and after slab subsealing and installation of the load transfer devices to evaluate the efficiency of the slab subsealing and load transfer devices.

The results of cement grout slab subsealing and load transfer restoration at a large truck terminal facility are presented in this paper. Cement grout subsealing was performed to restore support to slabs exhibiting loss of support due to the presence of voids. Retrofit dowel bars and double vee shear devices were installed on an experimental basis in a small test section of the truck terminal to evaluate the effectiveness of the devices and to answer the following questions:

1. What type of device (e.g., dowel bars or double vee shear devices) is best suited for this facility?
2. What is the relative effectiveness of each device as installed in this facility?
3. Is the slab thickness sufficient to support retrofit load transfer devices?

Based on the performance of the load transfer test section and other areas of the terminal, a decision could be made to expand the load transfer program to other areas of the terminal.

SLAB SUBSEALING

Void Detection

Pumping of base material was observed over much of the terminal. This visual indication of voids was confirmed through nondestructive deflection testing (NDT) procedures using the falling-weight deflectometer (FWD). Void detection procedures developed under NCHRP Project 1-21 *(1)* were used to define the areas for cement grout subsealing and to evaluate the effectiveness of the subsealing operation.

The void detection method used corner deflections measured at three load levels to establish a load versus deflection response for the test location. Corners with no voids cross the deflection axis near the origin, usually at ≤0.002 in. The load versus deflection response line for corners with voids intersects the deflection axis at a point >0.002 in. from the origin.

After a corner that had a void had been subsealed, the load-versus-deflection response line moves back towards the origin. This void detection concept is shown in Figure 1. The areas selected for subsealing based on this void detection procedure are shown in Figure 2.

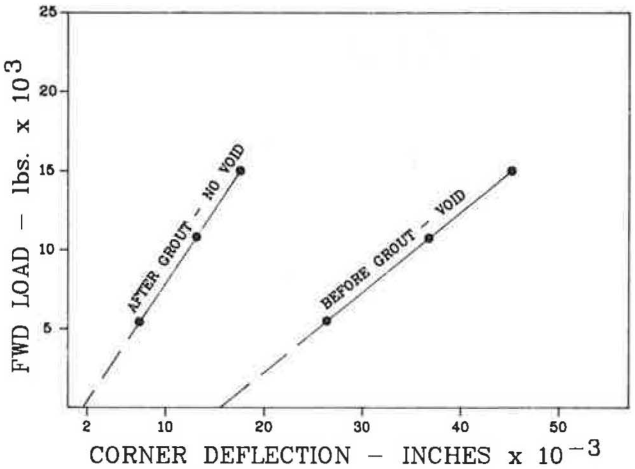

FIGURE 1 Void detection concept.

Construction Procedures

Several test areas were used to determine a grout injection hole pattern that would provide adequate flow of the cement grout and restoration of support to areas exhibiting voids. Results of the test areas and NDT testing indicated that two grout injection holes per slab would be adequate to restore support to the corner. These holes were located 2 ft off the slab edges as shown in Figure 3.

A cement grout mixture of one part portland cement and three parts pozzolan with a flow within 10 to 16 sec was used. The 7-day strength of the grout mixture was ≥600 psi.

The grout plant consisted of a colloidal mixing machine; maximum pumping pressure was 50 psi. Vertical slab movement detection equipment was used to monitor slab deflection during pumping.

Efficiency of Slab Subsealing

The void detection procedures discussed earlier were used after subsealing to evaluate the effectiveness of the grout in restoring slab support. If a void was present after subsealing, the corner was regrouted. Results of the NDT testing indicated that the subsealing operation was successful in restoring slab support.

In addition to the subsealing operations, a limited test area of load transfer restoration devices was installed to evaluate the effectiveness of the devices in restoring load transfer and retarding further slab deterioration.

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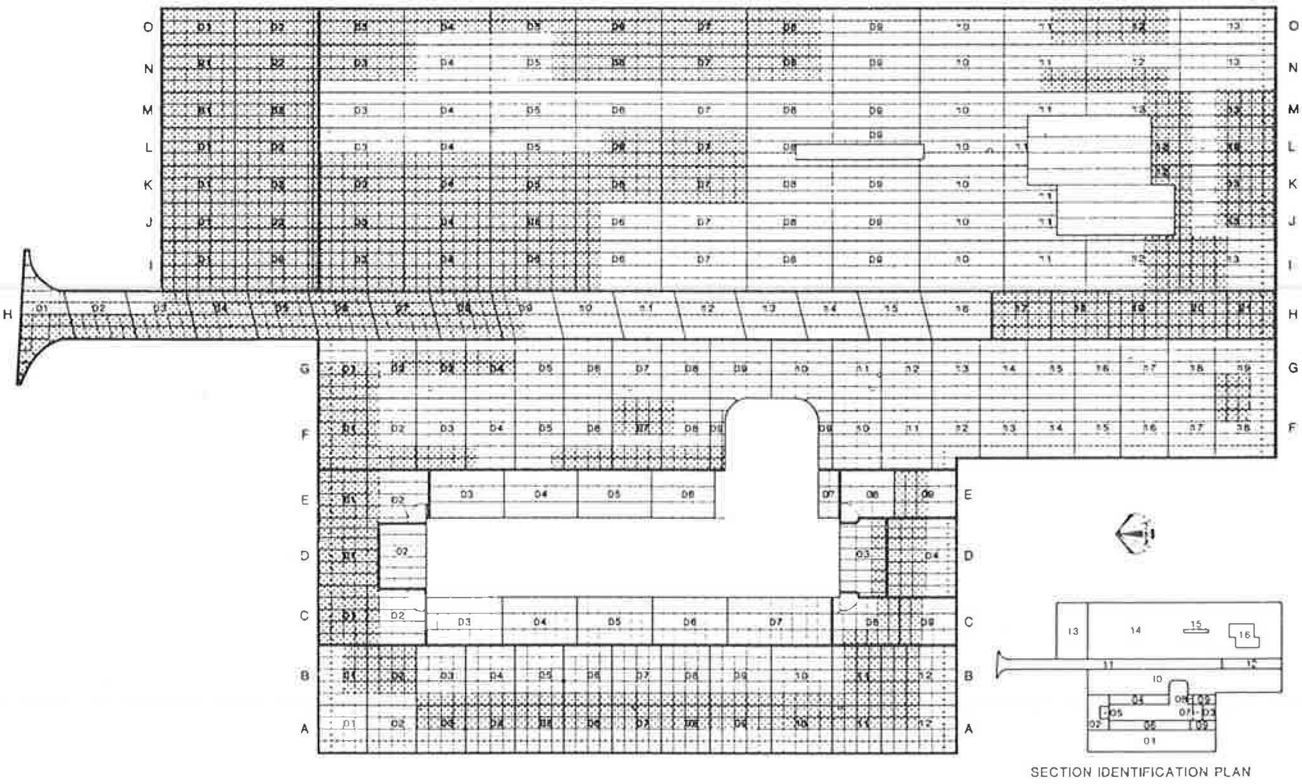

FIGURE 2 Cement grout subseal locations.

LOAD TRANSFER RESTORATION

Load Transfer Efficiency

The ability of a joint or crack to transfer load is a major factor in its structural performance. Load transfer efficiency across a joint or crack may be defined as the ratio of deflection of the unloaded side to the deflection of the loaded side. If perfect load transfer exists, the ratio is 1.00 (100 percent); if no load transfer exists, the ratio is 0.00 (0 percent). Good deflection load transfer efficiencies are in the range 70 to 100 percent. Poor deflection load transfer efficiencies are in the range 0 to 60 percent.

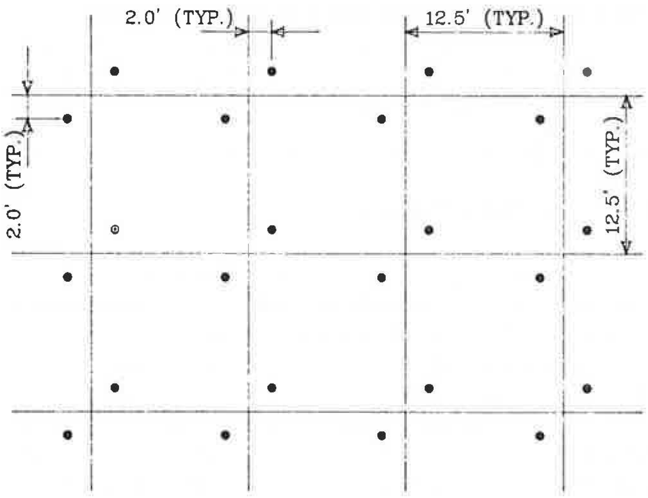

FIGURE 3 Grout injection hole pattern.

Load Transfer Efficiencies at the Terminal

The terminal pavement consists of a 7.7-in. undoweled plain-jointed portland cement concrete (PCC) parking area constructed in early 1982. East-west joints were formed by placing a 2-in.-deep masonite strip into the plastic concrete. North-south joints served as construction joints, and they are keyed with a rounded half-moon keyway. The exception to this is the part of the access drive identified as Sample Units H01–H16 in Figure 2. The east-west joints were also formed with masonite; however, the north-south joints in Section 11 are keyed and tied together with No. 4 deformed tie bars spaced approximately every 2 to 3 ft on center. A summary of the average load transfer efficiency for the pavement sections is presented in Table 1. The values in Table 1 and all load transfer efficiencies in this paper have been corrected for slab bending. The section descriptions refer to Figure 4.

Need For Load Transfer

Restoration of load transfer across a joint is used to retard further deterioration of the concrete slabs. Poor load transfer leads to joint deterioration, including corner breaks, faulting, pumping, and spalling. Load transfer restoration reduces deflections, stresses, and further slab deterioration.

TABLE 1 AVERAGE LOAD TRANSFER EFFICIENCY FOR PAVEMENT SECTIONS

Section	Average Load Transfer Efficiency % N-S Joints	E-W Joints
East of Access	66	45
West of Access 1	63	68
West of Access 2	--	21
West of Access 3	--	37
West of Access 4	--	24
Cargo	--	36
Tied Access	96	43
United Access	--	27

-- Not Tested

Several types of retrofit load transfer devices have been used in the past. However, the procedures to successfully install these devices are still in the experimental stage and cannot be proven effective because of lack of sufficient data on long-term performance. Therefore, although several sections of the terminal were exhibiting poor load transfer, only one test section was selected for retrofit load transfer devices. The test section chosen is part of the untied access as shown in Figure 5. The objectives of limiting installation of load transfer devices to this area were to determine (a) the type of device that will perform adequately, (b) the relative effectiveness of each device as installed at this facility, (c) the slab thickness sufficient to support retrofit load transfer devices, and (d) an adequate repair material.

LOAD TRANSFER RESTORATION TEST AREA

Location of Test Area

The load transfer test area is located in the untied section of the access road as shown in Figure 5. This section had one of the poorest load transfer efficiencies and was also exhibiting pumping.

Layout of Load Transfer Devices

The test area consisted of an area approximately 62 × 48 ft and contained 20 concrete slabs. The locations of the retrofit load

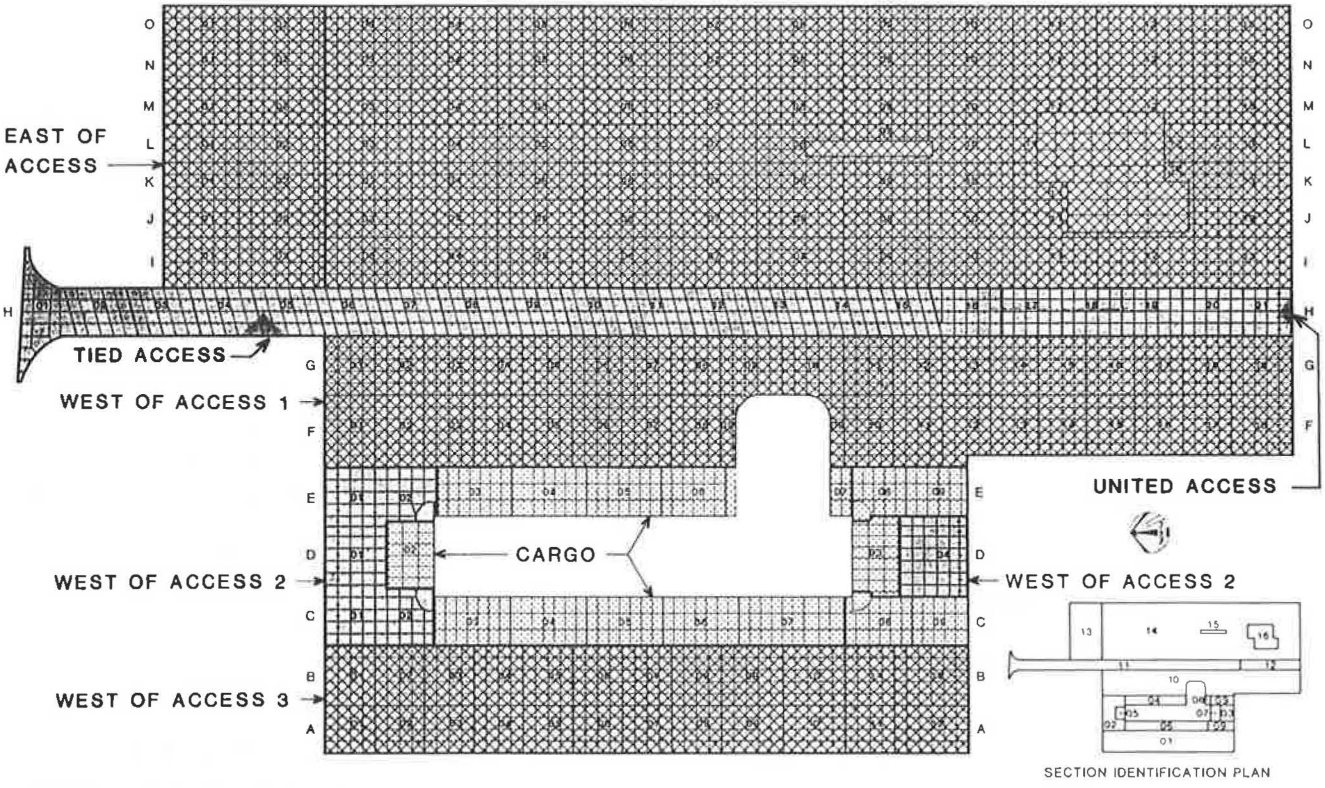

FIGURE 4 Deflection file location plan.

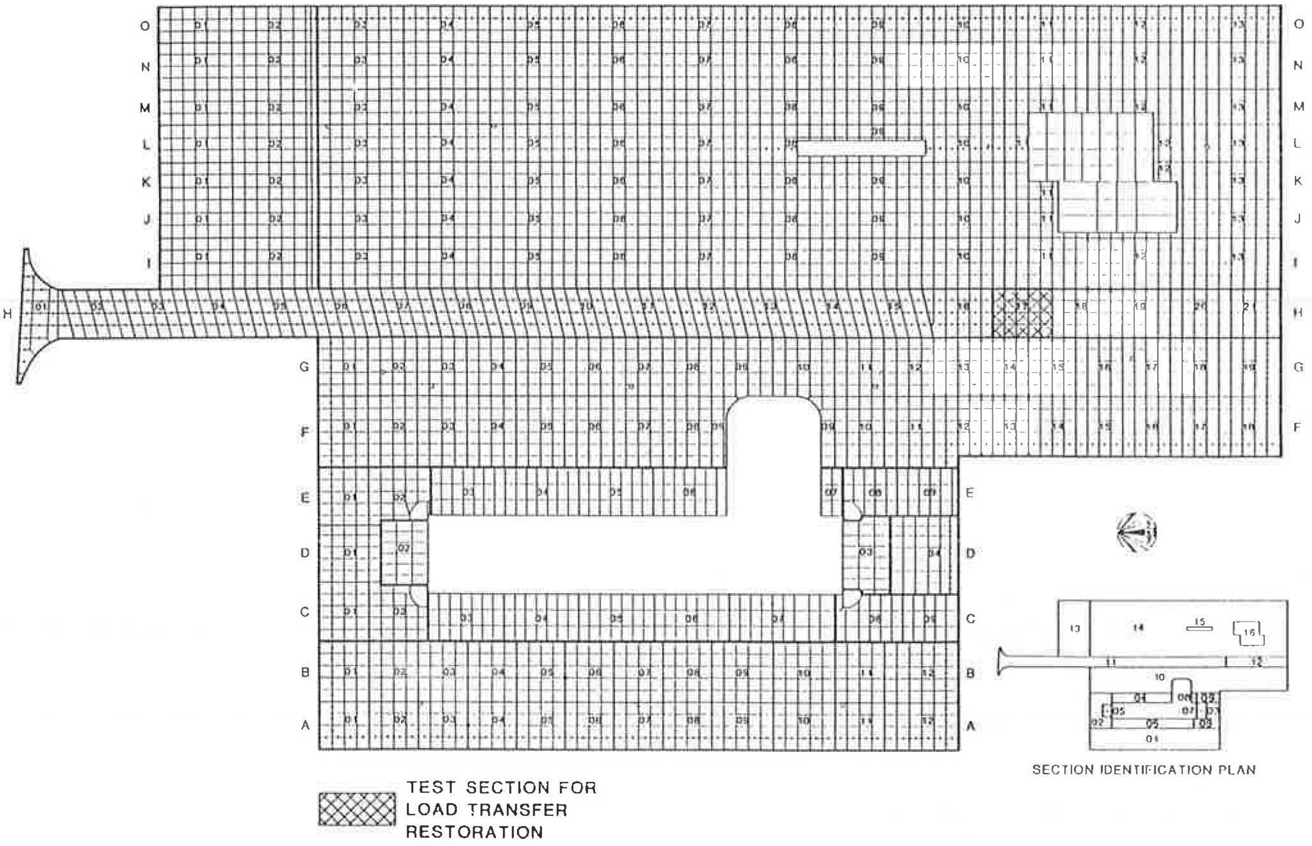

FIGURE 5 Test section for load transfer.

transfer devices as installed in the field are shown in Figure 6. Double vee shear devices were used on two joints. No devices were installed in one joint. This joint served as a control joint. Dowel bars were installed in the last joint in the test section.

LOAD TRANSFER DEVICES

Double Vee Device

The double vee device is a shear device for transferring load across joints. This device is illustrated in Figure 7. Load transfer restoration across joints is accomplished through a bond between the device, the concrete slab, and the repair material. This device is installed in a core hole of 6-in. diameter and is designed to allow for joint movements due to expansion and contraction. The center section of the device is filled with foam to prevent debris and incompressibles from entering the device. The devices used on this project were 6$^3/_4$ in. in length and 6$^1/_4$ in. in diameter. The device was precompressed and dropped into the core hole of 6-in. diameter. Maintaining a thoroughly dry core hole during installation was difficult because of a high water table at the site. A particle board was inserted on top of the double vee device to maintain the joint and prevent the repair material from being continuous across the joint. The double vee devices were installed at a cost of $52.00 each.

Dowel Bars

Dowel bars are an effective alternative to using shear devices to restore load transfer across joints. The dowel bars used in the test section were 1 in. in diameter, 18 in. in length, and epoxy coated to protect the dowel bar against corrosion. The dowel bar is installed in a kerf that is saw cut, and the joint is maintained with a fiberboard material as shown in Figure 8. The dowel bars were installed at a cost of $79.00 each.

REPAIR MATERIALS

Several repair materials have been used on past load transfer projects including polymer concretes and high early-strength concrete. Repair materials must be able to develop sufficient bond between the load transfer device and repair material as well as between the existing concrete and the repair material to carry the traffic loads and movement from thermal changes. A high early-strength concrete and a polymer concrete were chosen for this project.

High Early-Strength Concrete

Dayton Superior HD-50 concrete patch is a prepackaged cement-based repair material and was used as the repair material

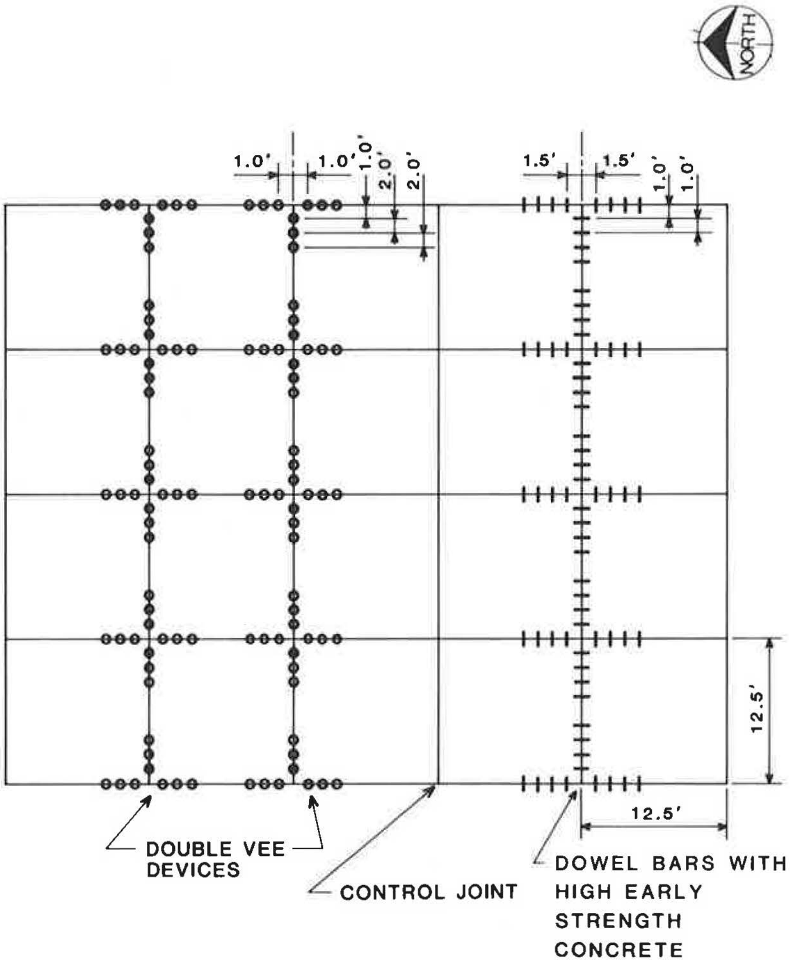

FIGURE 6 Layout of load transfer device test area.

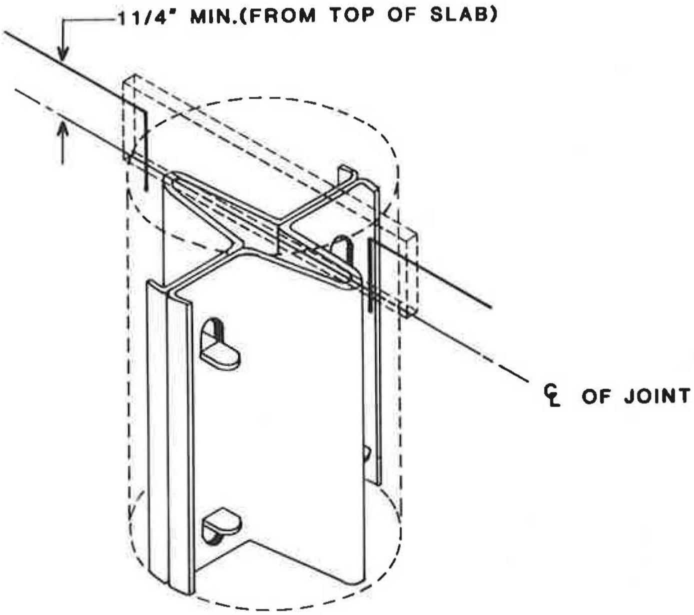

FIGURE 7 Double vee load transfer device.

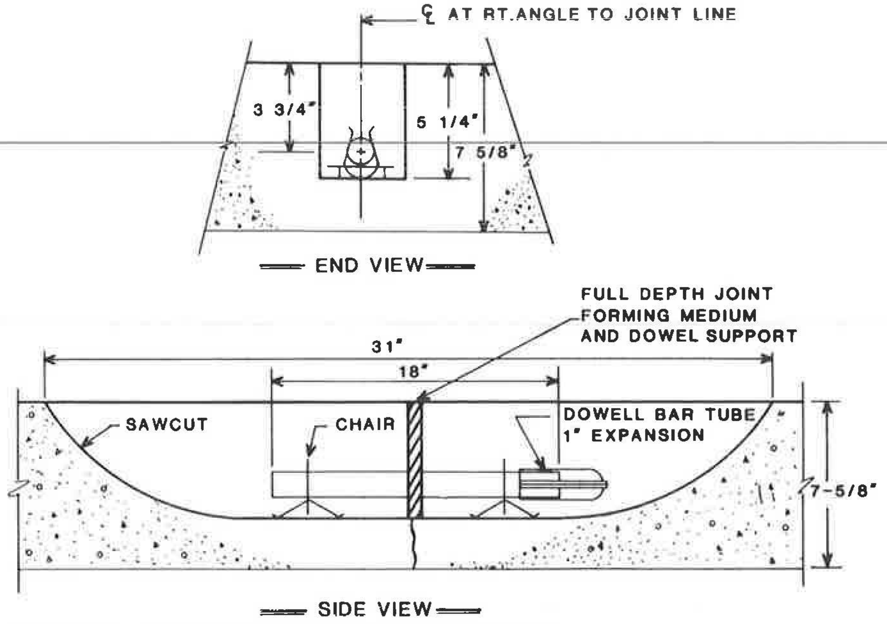

FIGURE 8 Retrofit dowel bar load transfer device.

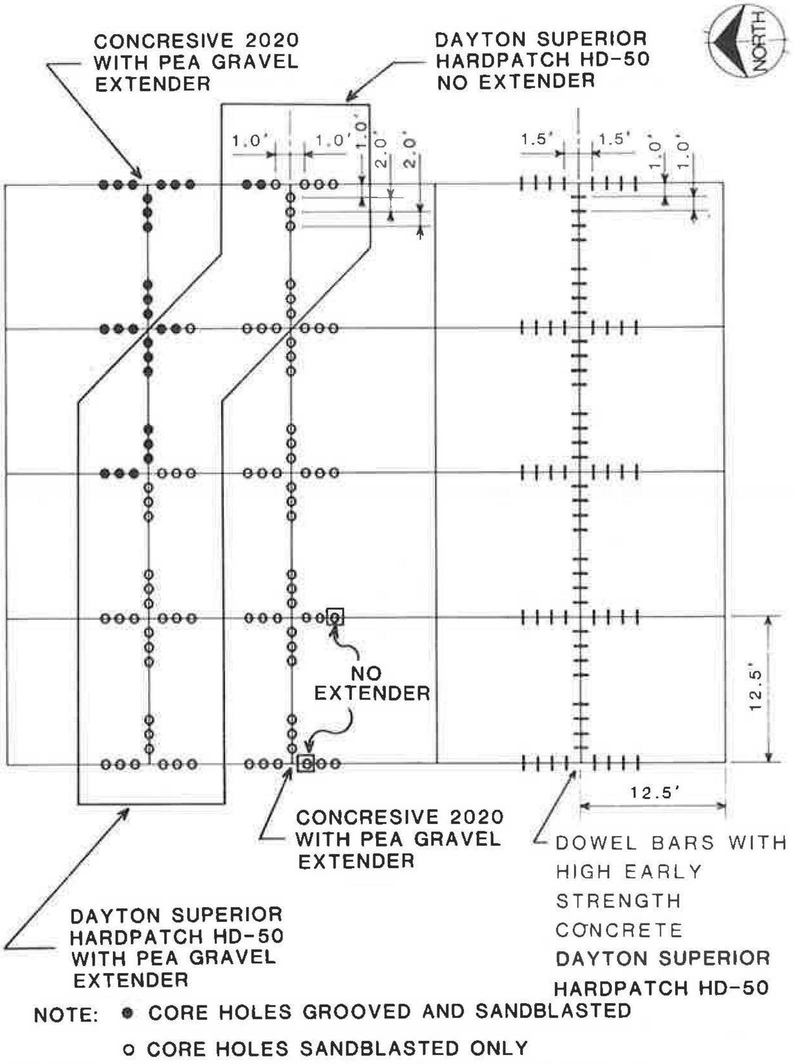

FIGURE 9 Combinations of device type and repair material type.

for the dowel bars and one-half of the double vee devices. Dayton Superior HD-50 is a one-component material that requires only the addition of water. Typical compressive strengths for this material are 2,000 psi within 45 min, 4,000 psi after 3 hr, and 7,000 psi after 7 days.

Polymer Concrete

A polymer concrete called Concresive 2020 was used with one-half of the double vee devices. This material consists of a liquid component and powder component mixed together. After 3 days, the compressive strength of this material is approximately 8,000 psi. This material can be used as is or can be extended with a clean kiln-dried aggregate.

Location of Repair Materials

The combinations of device type and repair material type are shown in Figure 9. The Dayton Superior HD-50 concrete patch used with the dowel bars was extended using 1 quart of sand-blasting sand with each two-bag (100-lb) batch of HD-50.

Twenty-one double vee devices were placed with Dayton Superior HD-50 and no extender. Thirty-three double vee devices were placed with Dayton Superior HD-50 extended with a washed, air-dried $^3/_8$-in. pea gravel.

The polymer concrete used to place the double vee devices was extended with the same $^3/_8$-in. washed and air-dried aggregate for all but two double vee devices that were placed with no aggregate extender.

Carter Waters concrete bonding agent compound No. 202 Type I was applied to all core walls and bottoms and sides of kerfs before the repair materials were placed to facilitate bond between the concrete and repair material.

EVALUATION OF PERFORMANCE

Nondestructive Deflection Testing Program

An NDT program was conducted using an FWD to evaluate the effectiveness of the load transfer devices in restoring load transfer across the joints. Test points were established along each of the four joints in the test area. The test points were assigned station numbers as shown in Figure 10. Each test

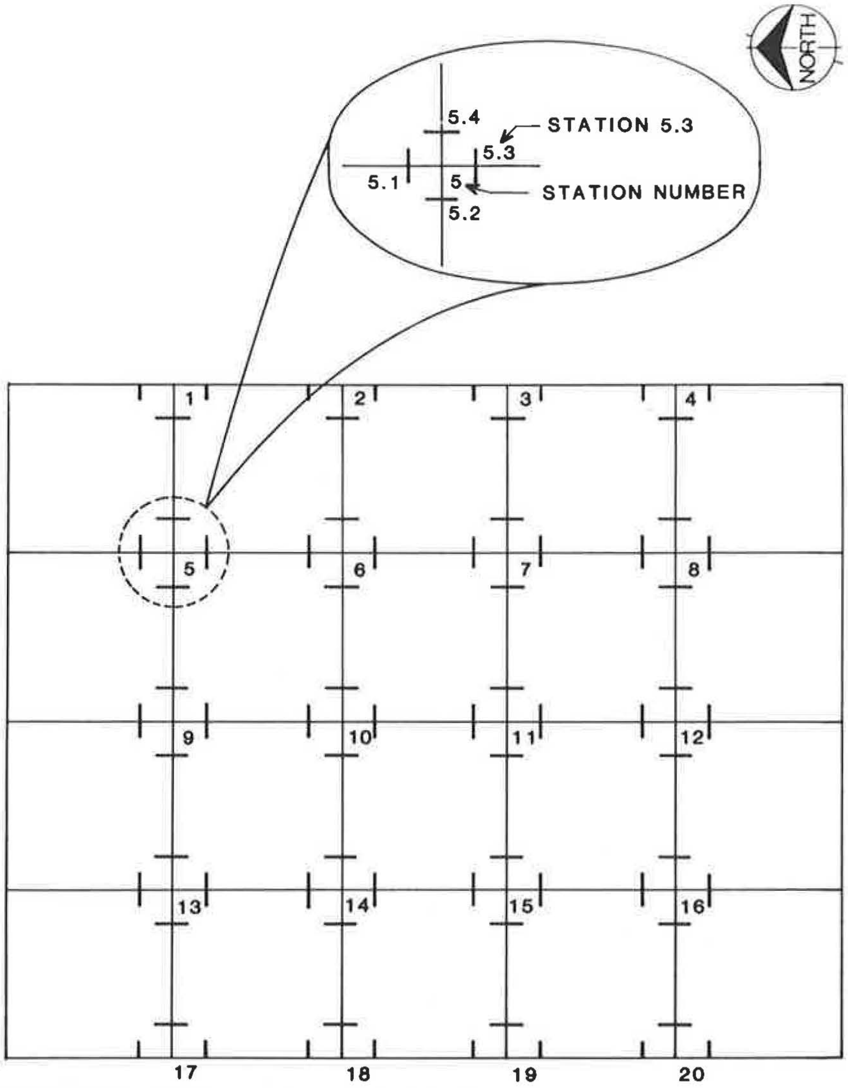

FIGURE 10 Station numbers for load transfer test area.

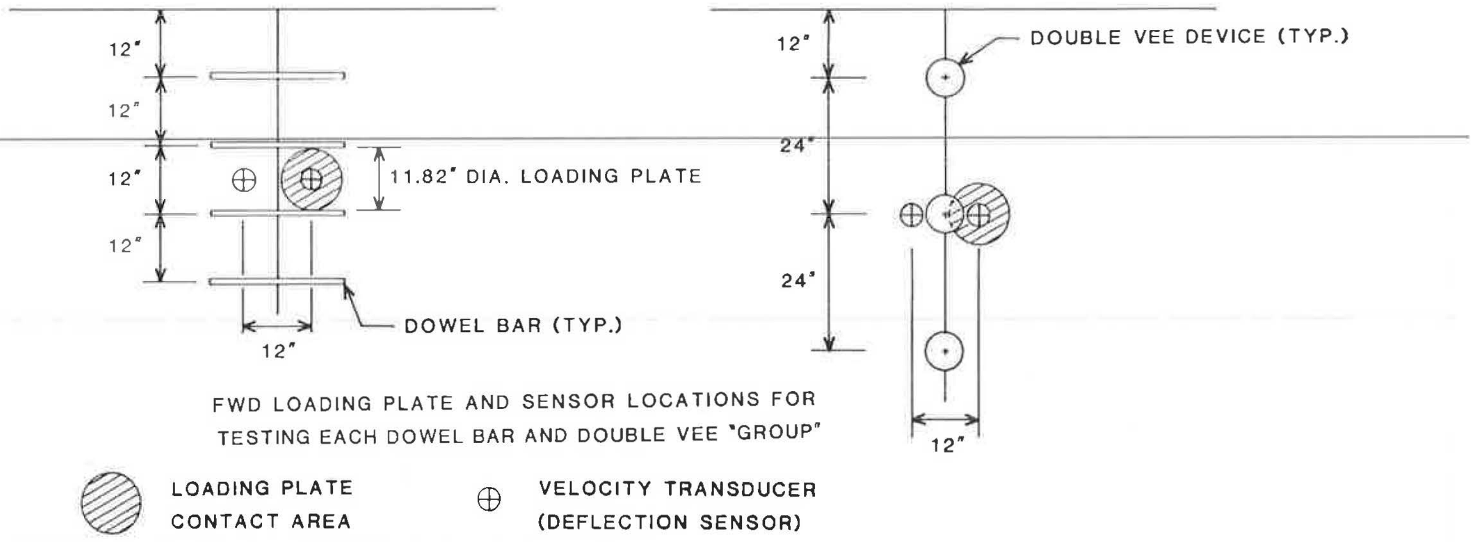

FIGURE 11 Positioning of FWD load plate during testing.

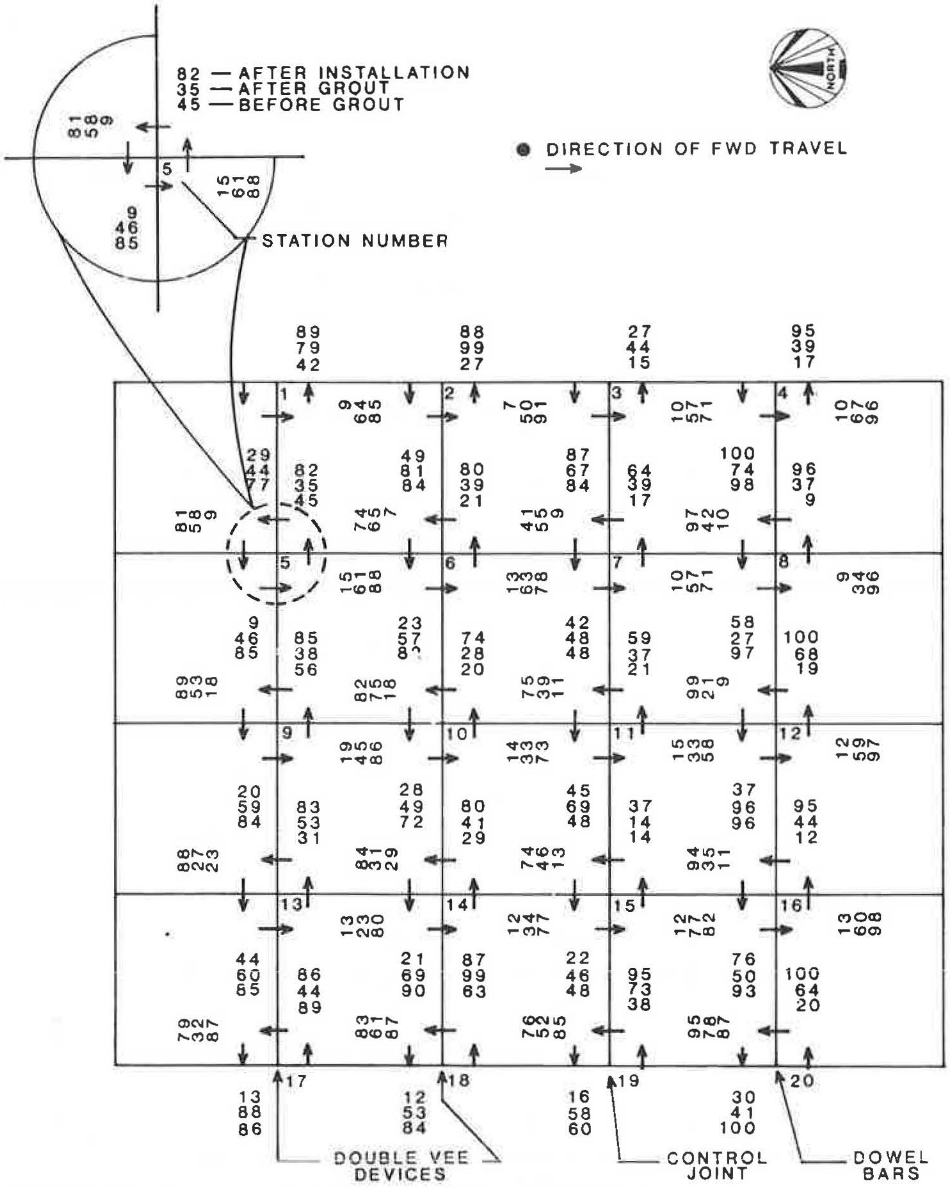

FIGURE 12 Summary of load transfer efficiencies.

point was tested with the FWD before subsealing, after subsealing, and after installation of the load transfer devices. The typical location of the FWD load plate in relation to the installed load transfer devices is shown in Figure 11. A summary of load transfer efficiencies as measured before subsealing, after subsealing, and after installation of the load transfer devices is shown in Figure 12. Additional NDT data are being collected on the test section so that the performance of the devices after 1 year of service can be evaluated.

Effectiveness of Double Vee Devices

The double vee devices were effective in restoring load transfer efficiency across the joint. The two joints where double vee devices were installed had an average load transfer efficiency of 29 percent before subsealing, 54 percent after subsealing, and 83 percent after installation of the load transfer devices. The increase in load transfer efficiencies after subsealing can be attributed to the filling of voids and restoration of slab support and an increased amount of mechanical interlock at the joints from grout's being forced out of the joints during the subsealing operation. A summary of load transfer efficiencies for each station is presented in Table 2.

Effectiveness of Dowel Bars

The dowel bars were also effective in restoring load transfer across the joints and appear to be more effective than the double vee device. The joint where dowel bars were installed had a load transfer efficiency of 29 percent before subsealing, 52 percent after subsealing, and 97 percent after installation of the dowel bars. The increase in load transfer efficiencies after subsealing can be attributed to the filling of voids and restoration of slab support and an increased amount of mechanical

TABLE 2 LOAD TRANSFER EFFICIENCIES FOR STATIONS WITH DOUBLE VEE DEVICES

Station	Grooved	Repair Material Type	Load Transfer Efficiency Before Subsealing	After Subsealing	After LTD Installation
1.1	+	2020	29	44	77
1.2	+	2020	9	64	85
1.3	+	2020	42	79	89
2.1	+	HD-50	49	81	84
2.2		HD-50	7	50	91
2.3		HD-50	27	99	88
5.1	+	2020	9	46	85
5.2	+	HD-50	15	61	88
5.3	+	HD-50	45	35	82
5.4	+	2020	9	58	81
6.1		HD-50	23	57	82
6.2		2020	13	63	78
6.3		2020	21	39	80
6.4		HD-50	7	65	74
9.1	+	HD-50*	20	59	84
9.2		HD-50*	19	45	86
9.3		HD-50*	56	38	85
9.4	+	HD-50*	18	53	89
10.1		2020	28	49	72
10.2		2020	14	33	73
10.3		2020	20	28	74
10.4		2020	18	75	82
13.1		HD-50*	44	60	85
13.2		HD-50*	13	23	80
13.3		HD-50*	31	53	83
13.4		HD-50*	23	27	88
14.1		2020	21	69	90
14.2		2020	12	34	77
14.3		2020	29	41	80
14.4		2020	29	31	84
17.1		HD-50*	13	88	86
17.3		HD-50*	89	44	86
17.4		HD-50*	87	32	79
18.1		2020	12	53	84
18.3		2020	63	99	87
18.4		2020	87	61	83
Average Load Transfer Efficiency			29.2	53.8	82.8

* Hardpatch HD-50 Extended With Pea Gravel

TABLE 3 LOAD TRANSFER EFFICIENCIES FOR STATIONS WITH DOWEL BARS

Station	Load Transfer Efficiency Before Subsealing	 After Subsealing	 After Dowel Installation
4.1	100	74	98
4.2	10	67	96
4.3	17	39	95
8.1	58	27	97
8.2	9	34	96
8.3	9	37	96
8.4	10	42	97
12.1	37	96	96
12.2	12	59	97
12.3	19	68	100
12.4	9	21	99
16.1	76	50	93
16.2	13	60	98
16.3	12	44	95
16.4	11	35	94
20.1	30	41	100
20.3	20	64	100
20.4	87	78	95
Average Load Transfer Efficiency	29.2	52.0	96.8

Note: Patch Material, Dayton Superior Hardpatch HD–50; Bonding Agent, Carter Waters concrete bonding agent compound No. 202 Type I; Extender, Sandblasting sand (one pint per 2 bags HD–50).

interlock at the joints from grout's being forced out of the joints during the subsealing operation. Table 3 presents a summary of the load transfer efficiencies for stations where dowel bars were installed.

Control Joint

A control joint was maintained in the load transfer test area as shown in Figure 4. The control section was maintained to compare a joint with no load transfer device to those with the retrofit load transfer devices. The measured load transfer efficiencies before subsealing, after subsealing, and at the time load transfer devices were installed in the other joints are presented in Table 4. The average load transfer efficiency increased from 25 percent before subsealing to 47 percent after subsealing. The increase in load transfer efficiencies after subsealing can be attributed to the filling of voids and restoration of slab support and an increased amount of mechanical inter-

TABLE 4 LOAD TRANSFER EFFICIENCIES FOR CONTROL JOINT

Station	Load Transfer Efficiency Before Slab Subsealing 9-16-85	 After Slab Subsealing 9-25-85	 10-07-85
3.1	87	67	84
3.2	10	57	71
3.3	15	44	27
7.1	42	48	48
7.2	10	57	71
7.3	17	39	64
7.4	9	55	41
11.1	45	69	48
11.2	15	33	58
11.3	21	37	59
11.4	11	39	75
15.1	22	46	48
15.2	12	77	82
15.3	14	14	37
15.4	13	46	74
19.1	16	58	60
19.3	38	73	95
19.4	85	52	76
Average	26.8	50.6	62.1

lock at the joints from grout's being forced out of the joints during the subsealing operation. The amount of mechanical interlock will decrease with time and traffic, resulting in a loss of load transfer efficiency due to mechanical interlock.

Evaluation of Repair Materials for Double Vee Devices

Two repair materials were used with the double vee devices, Dayton Superior HD-50 concrete patch and Concresive 2020 polymer concrete. In addition to the two repair materials, two techniques were used to prepare the core wall, grooving and sandblasting and sandblasting only. Results of deflection testing after installation of the double vee devices indicate that at this early date there is no significant difference in load transfer efficiencies between repair materials or between those core walls that were grooved and sandblasted and those that were sandblasted only. The use of an aggregate extender also appears to have no effect on the performance of the double vee device.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are presented as a summary of the load transfer restoration effort:

1. Both the double vee devices and dowel bars are capable of restoring load transfer across a joint.
2. Dowel bars are a more appropriate device to restore load transfer at this particular site because of the high water table and moisture problems encountered when installing the double vee devices.
3. A visual and nondestructive deflection survey should be conducted approximately every 2 years to evaluate long-term performance of the load transfer devices and patching materials.
4. A pavement condition index *(2)* of the load transfer test area and the remainder of Section 12 as shown in Figure 4 should be conducted every 2 years after installation of the load transfer devices to evaluate any differences in pavement condition between the load transfer test area and remaining pavement section.

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