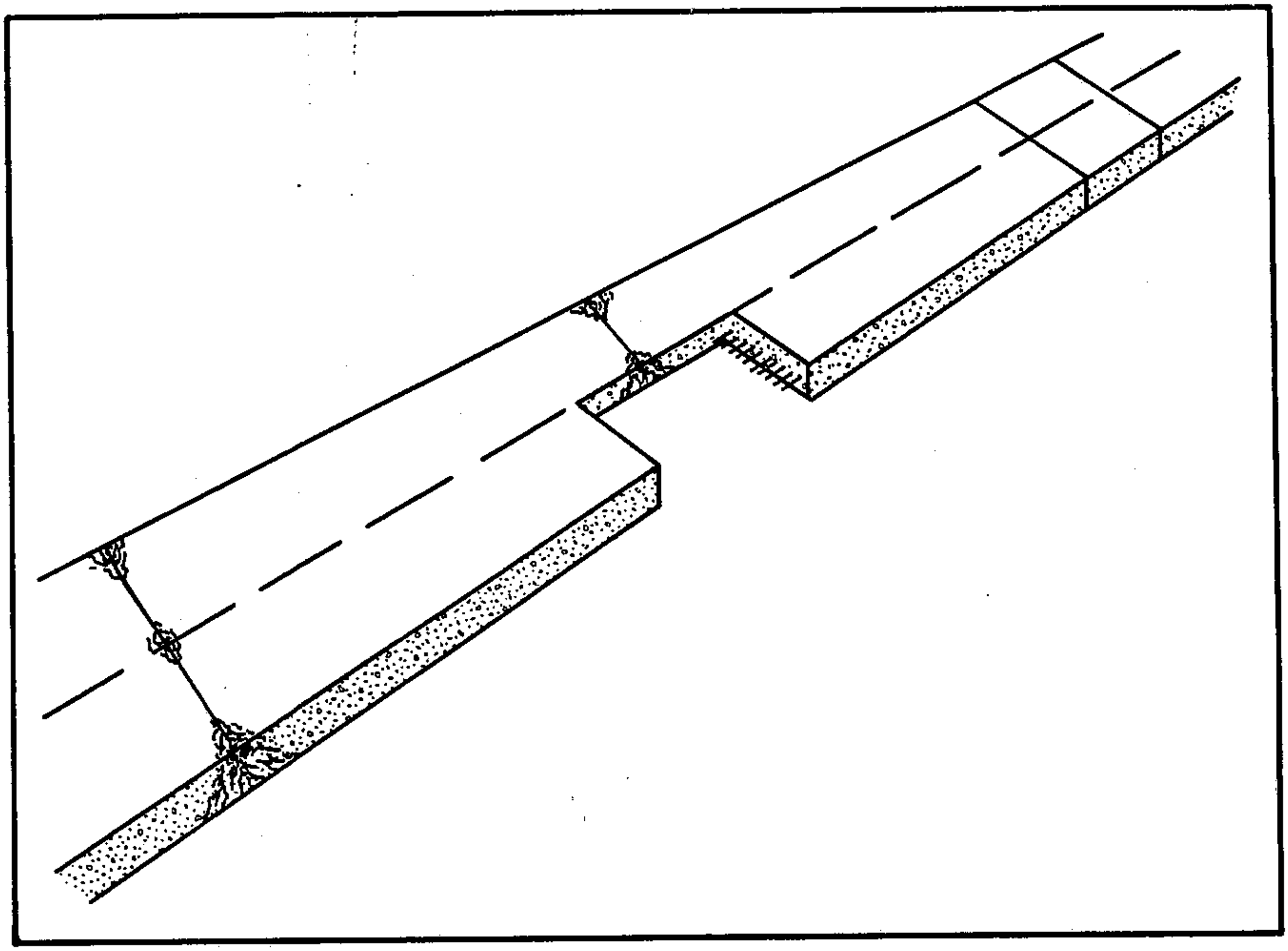

Performance Evaluation of Jointed Concrete Pavement Rehabilitation Without Resurfacing

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FINAL REPORT

IHR-514

PERFORMANCE EVALUATION OF JOINTED CONCRETE PAVEMENT REHABILITATION WITHOUT RESURFACING

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16. Abstract

This paper describes the results of a research project which evaluated the effectiveness of Concrete Pavement Restoration (CPR) on jointed Portland Cement Concrete Pavement. The CPR methods evaluated were: pavement grinding, grout undersealing, installing underdrains, retrofitting Double Vee load transfer devices, and pavement patching. Five construction sections, located throughout the State of Illinois, were selected for evaluation. All sections were located on four lane Interstate routes. The sections ranged in length from 3 to 8 miles for a total of approximately 30 miles. The original pavement sections were constructed between 1960 and 1963, then rehabilitated in 1983 and 1984. All pavements were the same design with a slab thickness of 10 inches over a 6 inch granular base and a joint spacing of 100 feet. The evaluation began just prior to rehabilitation of each section and continued until May of 1986. The means of evaluation were by use of crack surveys, destructive testing and non-destructive testing. Performance factors monitored were faulting, pavement cracking, pavement roughness, skid resistance, deflection, load transfer, void development and drainage. A great deal of emphasis was placed upon grout undersealing and doweled patching in lab and field experiments. Undersealing effectiveness was determined by deflection testing using a Dynatest 8002 Falling Weight Deflectometer (FWD) and Road Rater 2008. Another field experiment investigated the effects of dowel bar size and number of dowels in full-depth patch performance. Several different techniques for dowel bar grouting were tested in the laboratory to establish grouting procedures.

The findings of this research resulted in improvements in full-depth patch design, improved construction procedures and proper use of undersealing. The most important improvements in pavement patching were the use of sawed and sealed joints at the patch face to prevent spalling and the use of larger and more dowel bars. It was found that blanket undersealing is rarely needed. Undersealing of existing rocking and pumping patches will greatly reduce deflections, but will only be effective for about one year. The Falling Weight Deflectometer proved to be a powerful tool for locating voids using void detection procedures.

17. Key Words

Jointed Concrete, Concrete Pavement Restoration (CPR), patching, grinding, undersealing, joing sealing, performance, deflection

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I. INTRODUCTION

The State of Illinois has many miles of highways composed of with Jointed Portland Cement Concrete (JPCC). Many of these pavements have approached or are approaching the end of their design life and are in need of major rehabilitation.

Resurfacing with asphalt concrete (AC) is one of the primary methods of rehabilitation used in Illinois. However, asphalt concrete overlays may not be cost-effective for a JPCC pavement which has faulted joints, transverse cracks and possibly some spalling, but is otherwise sound. On this type of pavement, it is possible that rehabilitation without resurfacing can be much less expensive and more cost-effective.

The main objective of this study was to determine whether pavements with faulted joints and transverse cracks or general joint deterioration can be restored by grinding, pressure grouting, placement of underdrains, retrofitting with load-transfer devices, or replacement of the joints more economically over the long run than by resurfacing. Five rehabilitation projects were monitored for performance by studying such indicators as ride quality, faulting and pavement deflection.

Initial poor performance of dowelled patches resulted in a pavement patching experiment. The experiment investigated such variables as number of dowel bars, size of dowel bars and grout type. Also included in the experiment were sawed and sealed joints at the patch-pavement interface. Patching performance was monitored through measurements of pavement deflection, faulting and patch distress.

Also of interest was the effectiveness of grout undersealing. Two areas of undersealing were investigated. First, undersealing of joints and cracks to fill voids (1) and, second, the filling of voids to stabilize rocking and pumping patches. Undersealing was evaluated using Road Rater deflection testing and void detection procedures (2) using a Falling Weight Deflectometer (FWD).

In the laboratory, the problem of proper dowel bar grouting was investigated. This was done by using several methods of applying the grout at different consistencies. The methods were then rated subjectively with respect to grout coverage, ease of use and cost.

II. PAVEMENT EVALUATION SECTIONS

Five projects, which were located on Interstate Routes 55, 70, 80, and 280-74 were evaluated. All pavement sections consist of 10-inch thick jointed reinforced concrete pavement with a 6-inch granular subbase. Joints are spaced 100-feet apart and include 1-1/4 inch x 18 inch dowel bars spaced at 12 inches for load transfer. Figure 1 shows the general location of the projects.

Each rehabilitation project was designed to address such problems as ride quality, joint deterioration, filling of voids, and restoring load transfer. Ride quality was improved by diamond grinding of faults, partial depth pavement patching, and full-depth pavement patching of deteriorated joints. Voids were filled by grout undersealing and load transfer was restored by use of the Double Vee load transfer devices developed at the University of Illinois. The Double Vee device used is shown in Figure 2.

Rehabilitation features such as experimental undersealing, experimental patching, load transfer devices, and drainage mats are not included in the economic analysis due to the smaller quantities associated with these experiments. A summary of the original pavement designs and rehabilitation techniques used are shown in Table 1 and 2 respectfully.

Project Number 1

This project is located on Interstate 55 near Springfield, Illinois between milepost 98.00 and 102.36 and has two lanes in both directions. Traffic on this project averages 11,500 vehicles per day with 26 percent trucks. The pavement has a low to medium D-cracking aggregate which was evident at joints and cracks at the time of rehabilitation. The main distress types were: medium severity joint faulting, medium and high severity joint deterioration (due to D-cracking), and poor ride due to faulting and joint distress.

Rehabilitation first took place in 1983 and again in 1984. The 1983 rehabilitation was in the form of full-depth patching using a 3-2 patch design, as shown in Figure 3, to replace deteriorated joints. Pipe underdrains were installed to facilitate removal of water which may have been causing faulting. In 1984, a number of poorly performing patches needed to be replaced as well as a few joints which had further deteriorated since 1983. Pavement patching in 1984 used the 3-2 patch design in the northbound lanes and the 3-3 patch design in the southbound lanes, as detailed in Figure 3. Also part of the 1984 rehabilitation was blanket undersealing of existing patches.

Project Number 2

This project is also located on Interstate 55, near Springfield, Illinois and is immediately north of Project Number 1. This section is between milepost 102.36 and 105.52 and has two lanes in the northbound direction and three lanes in the southbound direction which taper into two lanes near the southern end of the project. The traffic is the same as in Project Number 1.

The pavement showed no signs of a D-cracking aggregate at the time of rehabilitation, only localized distress and spalling at a limited number of joints. The main distress types were: high severity joint faulting, limited medium severity joint spalling, limited low severity joint deterioration, medium severity spalling and scaling due to high reinforcing steel, and poor ride quality due to joint faulting.

The main feature of this rehabilitation project was removal of joint faulting by diamond grinding to improve the ride of the pavement. Other features were: full-depth patching using a 3-2 patch design, partial depth patching to remove areas of spalling and scaling due to high reinforcing steel, and installation of pipe underdrains. Included in the rehabilitation was a grout undersealing experiment (1). Due to the experimental nature of the undersealing, it was not included in the economic analysis. A more detailed account of the undersealing experiment is given in the section on Undersealing.

Project Number 3

This project is located on Interstate 70 near St. Elmo and Altamont, Illinois, from milepost 74.28 to 82.23. This section of highway consists of two lanes in each direction. Traffic on this project averages 10,500 vehicles per day, with 36 percent trucks. The aggregate in this pavement has low severity D-cracking which was evident at joints before rehabilitation. The main distresses in the pavement at the time of rehabilitation were: medium severity joint deterioration, medium severity joint faulting and poor ride.

In 1983, the pavement was first rehabilitated by full-depth patching of deteriorated joints and cracks using the 3-2 doweled patch design. The following spring a number of these patches began to experience deep spalling and pumping. In a few cases, the spalling was so deep that the dowel bars were exposed. As a result in blanket undersealing of existing patches was undertaken in 1984. Several poor, fair and excellent performing patches were removed to investigate the cause of the deep spalling and why it did not occur in all patches. It was found that the concrete was being over-stressed by evidence of large egg-shaped holes around the dowel bars. No evidence of the non-shrink grout used to install the dowel bars could be found in the dowel holes. As a result, a doweled patching experiment was conducted which investigated the impact of dowel bar size, bar arrangement, grout type and joint sealing upon patch performance. This study is detailed in the section on Full-Depth Patching.

Project Number 4

This project is located near Morris, Illinois on Interstate 80 between milepost 105.30 and 111.70. This section of highway has two lanes in each direction. Traffic on this project averages 13,300 vehicles per day with 32 percent trucks. At the time of rehabilitation, the pavement showed no signs of a D-cracking aggregate. The main distresses were medium severity joint spalling, medium severity localized distress, and high severity faulting. Due to the faulting, this section of pavement had a rough ride.

In 1983 this section underwent an ambitious rehabilitation which included: full-depth patching using a 3-2 patch design, blanket undersealing of cracks and joints, retro-fitted Double Vee load transfer devices, pavement grinding and installation of underdrains. Another experimental feature of this project, besides the load transfer devices, was the use of a drainage mat developed by Monsanto, in the place of standard pipe underdrains on a portion of the project.

As a result of poor patch performance, similar to that of Projects Number 1 and 3, several patches were replaced in 1985 using 10 dowel bars in each joint rather than the 5 or 6 used previously.

Project Number 5

This project is located on Interstate 280 and 74 near Rock Island, Illinois between milepost 14.70 and 18.00 on I-280 and milepost 5.00 to 9.64 on I-74. Traffic on the I-280 section averaged 16,400 vehicles per day and 19 percent trucks, while the I-74 section averaged 8,700 vehicles per day with 25 percent trucks. This section of highway has two lanes in each direction and showed no sign of a D-cracking aggregate. Distresses before rehabilitation consisted of medium severity joint spalling, medium severity localized distress and low severity faulting.

The rehabilitation of this section consisted of full-depth patching using a 3-3 patch design, partial depth patching, joint sealing, blanket undersealing, pavement grinding and installation of underdrains.

III. PERFORMANCE OF REHABILITATION TECHNIQUES

Pavement Grinding

Projects 2, 4, and 5 used pavement grinding to improve the riding qualities of the pavement. To remove the severe faulting in Projects 2 and 4, the pavement was ground in the opposite direction of traffic. This was done to better utilize the leveling properties of the grinding machine and resulted in a smoother profile. Project Number 5 was ground in the direction of traffic since faulting on this project was minor. A limited amount of friction and faulting data was collected before and after rehabilitation. The friction and faulting data are presented in Tables 3 and 4 respectively. Roadometer readings were taken before rehabilitation and annually thereafter. The roadometer data are given in Table 5. From the roadometer data, predictions of the Roughness Index were made by plotting the data on Log-Log paper and extending a best fit line through the points. The results are given in Figure 4. It is expected that diamond grinding will provide a smooth ride for about 5 years after construction and an acceptable ride for another 5 years.

In isolated areas of Project No. 2, high reinforcing steel caused spalling and scaling of the pavement surface. Known areas of high steel distress were partial-depth patched in an effort to eliminate the problem. The grinding process removed only a fraction of an inch from these areas, but may have caused the spalling to accelerate in areas not patched. While grinding a pavement with a few isolated areas of high steel should not present much of a problem, caution should be used in grinding a pavement with uniform high steel.

Pavements with D-cracking aggregate should not be ground since this opens the aggregate to water intrusion and can greatly accelerate the

D-cracking process. Unfortunately, in Illinois, many miles of pavement have low to moderate D-cracking aggregates and, therefore, care must be taken in selecting pavements to be diamond ground.

Retro-Fit Double Vee Load Transfer Devices

Project Number 4 was the only project to use retro-fit load transfer devices shown in Figure 2. Several problems were encountered in the installation of these devices. First, the contract did not call for grooving or roughing the inside of the core hole before installing the device. The manufacturer of the load transfer device provided a tool which applied several grooves to the inside of the core hole. Grooving of the holes provided more surface area for the polymer concrete to bond. Since the contract did not require the grooving, only a small number of the core holes were grooved. These locations were noted for comparison.

The second problem was the polymer concrete used. Improper mixing resulted in a mixture which did not take a final set for several days. When mixed properly, the polymer concrete was almost unworkable. Adjustments in the mixing procedures by pre-wetting the course aggregate resulted in an acceptable product.

Within a few months of installation, over 50% of the devices debonded at the pavement-polymer concrete interface. There seemed to be no pattern to the debonding in that it occurred on either or both sides of the joint or crack. The grooving of the core hole had no influence upon the debonding. By 1985, all 671 devices installed have failed by debonding.

Underdrains

Underdrains were installed upon all projects except Project Number 3, in which underdrains had been installed at the pavement edge in previous construction.

On Project Number 4, a new drainage product was included, the Monsanto Drainage Mat (MDM). Figure 5 compares the design of standard pipe underdrains and the MDM. Sections of the pipe underdrains and MDM were monitored by use of a tipping bucket device which measures outflow with time. Figure 6 shows the typical outflow characteristics of the two underdrains.

The outflow characteristics of the MDM drain showed a desirable improvement in two areas. First, the MDM removed 1.11 to 1.87 times the water of the standard pipe underdrain. Second, the MDM removed the water from the pavement faster, while the standard drain continued to flow for several days.

Since first installed on this project, it has been found that a 12-inch mat will perform as well as the standard pipe underdrains. The reduction in mat size, along with the elimination of the granular backfill, has made the MDM very competitive with pipe underdrains in cost. More long-term research is planned to determine the effectiveness of these and other types of underdrains.

Partial Depth Patching

Projects Number 2 and 5 used partial-depth patching to repair spalls at joints, and in Project Number 2, to repair areas of high steel which were exposed. Patches on both projects are performing exceptionally well and are expected to last the life of the pavement. The only problem found was that more areas should have been repaired using partial-depth patching on both projects. Since rehabilitation, several areas of spalls at joints on Project Number 5 and spalls due to high steel in Project Number 2 have shown up. Since these areas were outside of the condition surveys, it is not certain if any visual evidence of distress was present at the time of rehabilitation. If these areas showed no visual distress, perhaps delamination detection techniques such as those used on bridge decks could be utilized to detect delaminations at joints.

Full-Depth Patching

All projects included full-depth patching with the percentage of patching ranging from 0.2% to 4.5% of the total pavement area. Projects 1, 2, 3 and 4 were patched in 1983 using a 3-2 patch design as detailed in Figure 3. The following Spring (1984), Projects 1 and 3 experienced severe spalling of a number of patches. Along with the spalling, evidence of pumping could be seen. When heavy trucks passed over the patches, a rocking motion could be visually detected.

Detailed surveys of patch performance on Project Number 3 showed that about an equal number of patches were in good, fair and poor categories. There was no apparent correlation between cut, fill, well-drained or poorly drained areas and patch performance. The spalling was limited to the new patch and rarely occurred in the original pavement. Several concrete cores were taken in good, fair and poorly performing patches, but testing showed no significant strength differences in the samples.

The survey showed that the approach side of the patches had the greatest amount of spalling. Upon closer investigation, it was found that the approach joint of the patch (first joint to be crossed by traffic) was typically very tight and in spalled areas, the joints were closed. The opposite or leave joint would be 1/16 to 1/8 inch wide with little or no spalling.

As a result of problems with the 1983 3-2 patches, an extra dowel bar was placed in the inner wheelpath for 1984 construction as detailed by the 3-3 patch design in Figure 3. Project Number 5 used a 3-3 patch design and also included a joint seal at all joints. Also using the 3-3 patch design was Project 1 (southbound lanes only) in 1984 when a few badly distressed patches were replaced.

To better understand the effects of dowel bar arrangement, size and grout used in dowel bar holes, a patching experiment was incorporated in Project Number 3 in 1984. The experiment called for removing 28 patches which were from good, fair and poor performing groups. All patches were selected in the driving lanes of the roadway with 8 patches in the westbound driving lane and 20 patches in the eastbound driving lane.

Since the patches which were to be removed were 4 feet in length, sawing requirements were such that the new patch would have to be 6 feet in length. Patches were removed by using the lift-out method. As patches were removed, the dowel bars were found to be laying loose in an egg-shaped hole. The holes measured about 1-3/8 inches horizontally, as drilled, but would be larger in the vertical direction. The egg-shaped hole occurred in both the old pavement and the patch. No evidence of the non-shrink grout could be found in any of the patches. Also, the epoxy coating used on dowel bars to prevent corrosion was chipped off or debonded for several inches near the center of the dowel bars. All evidence indicates that the concrete was being over-stressed at the dowel bars in 3-2 patches using 1-1/4 inch dowel bars.

Variables in the experiment were selected such that some patch designs would be underdesigned while some were overdesigned. The patching experiment investigated two dowel bar sizes, three dowel bar arrangements, tied joints, non-shrink grout and an epoxy grout. The experimental features are detailed in Table 6 by number of patches constructed in each design variable. Another feature of the experiment was transverse joint seals which were included on all patches, as well as undersealing the old pavement near the patch joint. Design details of experimental patching are shown in Figure 7.

Evaluation of the patches was by visual inspection and deflection testing using an FWD. From the visual inspection, all of the experimental patches were in excellent condition with no indication of spalling or any other distresses. Deflection testing results are present in terms of a deflection due to a 9 kip load and load transfer across the patch joints in the outer wheel path. Load transfer is measured by dividing the deflection on the unloaded side of a joint by the deflection on the loaded side and is reported on a percentage basis. Testing was conducted before the experimental patches were undersealed then after undersealing before the roadway was opened to traffic. After the roadway was opened to traffic, the patches were tested periodically. Deflection and load transfer results for dowel bar size are presented in Figures 8 and 9, while results for dowel bar arrangement are presented in Figures 10 and 11. Also shown on the deflection plots are center of slab tests, which are taken at least 6 feet away from any joints or cracks and give an indication of subgrade support. At the end of the evaluation, all deflections and load transfers indicated that the patches were performing outstandingly.

The tied patches showed the best performance with respect to deflection and load transfer. Patches with 1.5 inch dowel bars and a 5-5 dowel bar arrangement performed second best. Although patches with 1.25 inch dowel bars and a 3-3 dowel bar arrangement performed the worst relative to the other designs, the deflection measurements and load transfer percentages were still good. Grout type seemed to have no influence on deflections or performance. It is felt that the sealed transverse joint is very important for a successful patch not to keep water out of the patch, but to prevent spalling. By using a 1.5 inch dowel bar, a 5-5 dowel bar arrangement, a sawed and sealed joint along with a 6-foot minimum patch a low maintenance life of 10 or more years can be expected compared to 1-3 years for the original 3-2 patch design.

Joint Sealing

Project Number 5 was the only project to incorporate the complete sealing of all joints and cracks. Projects 3 and 4 used joint sealing, but only at newly constructed patches, mainly for spall prevention. All joint sealing was done using a hot poured joint sealant in accordance with ASTM 3405.

In Project 5, existing cracks and joints were routed to a depth of 1 inch and a width of approximately 5/8-inch. The crack or joint was then sandblasted and blown clean of dust prior to sealing. No backer rod or tape was required by the contract.

After the first winter, it was noted that the sealant had failed by pulling away from one side of the concrete joint in full 100-foot panels. In areas where joints had been patched, the sealant was intact and performing well. This indicates that the joint reservoir did not have a properly designed shape factor for the amount of contraction in 100-foot panels.

Blanket Undersealing of Joints and Cracks

Blanket undersealing was part of the original rehabilitation on Projects 4 and 5. An undersealing experiment (1) in Project 2 compared grouts using fly ash and limestone as an aggregate as well as the effects of admixtures such as superplasticizers and water-reducers. Also investigated was the use of different pumping pressures, namely 10, 20 and 30 psi.

From the experiment, little difference was found between 20 and 30 psi pumping pressures, but the time required for injection at 10 psi was considerably longer. Fly ash grouts were found to be stronger and did a better job of reducing pavement deflections.

In several cases, undersealing with limestone grouts actually increased pavement deflection. When fly ash grouts were used in areas of initial low deflection, minimal improvement in deflection was noted. Removal of four slabs after undersealing verified the increased flowability of fly ash grouts. Fly ash grouts spread out and covered significantly more void space than the limestone grouts.

Blanket undersealing on Projects 4 and 5 were monitored by deflection testing before undersealing, after undersealing and then periodically. On Project 4, the Department's Road Rater 2008 was used to apply an oscillating 8 kip peak to peak load at a frequency of 15 Hertz to the pavement. The deflection histories of outer wheelpath deflection and center of slab deflection of Project 4 are given in Figure 12. The figure shows a reduction in deflection after undersealing, but the reduction is so small that it is doubtful whether the undersealing produced any benefits. The effects of subgrade support, which are reflected in the center deflection, seem to have more influence on deflections than undersealing in this case.

On Project Number 5, a Dynatest 8002 FWD was used, along with void detection procedures (2). In brief, the procedures for void detection are as follows:

1. Three load ranges are applied to the approach and leave sides of joints and cracks. (Typically, these loads are 4, 8 and 12 kips or 6, 9 and 12 kips.)
2. Plots of load versus deflection are made for each test site.
3. A best fit line is drawn through the points and extended to the axis.
4. If the line intersects the deflection axis at a number greater than 0-1 mils, then a void is present.

Also compared in the procedure are load transfer efficiency, 9 kip deflection and center of slab deflections. By using these procedures, only 2 voids were found in the 53 joints and cracks tested before undersealing. Tests after undersealing and the following year showed the voids were filled and remained stable. The deflection and load transfer histories are given in Figure 13.

From the deflection graphs for Projects 4 and 5, it can be seen that little benefit was gained from blanket undersealing. To be effective, undersealing must be done on a selective basis by only undersealing locations of known voids.

Blanket Undersealing of Pumping Patches

In Project 1, nine patches, which were pumping and rocking under traffic, were selected for undersealing in conjunction with rehabilitation on Project 2 in 1983. Deflection testing, using the Road Rater, was conducted before and after undersealing. Deflections were greatly reduced, but continued testing showed that within one year deflections had nearly reached pre-undersealing levels. These patches, along with all other patches in Project 1, were undersealed again in the Fall of 1984. The Road Rater deflection history is shown in Figure 14.

Project 3 was also undersealed in the Fall of 1984 at all patch locations to arrest pumping and spalling of the patches. Before undersealing, a group of 21 patches were selected for evaluation. Deflection testing results using the FWD are given in Figure 16, which again shows that patch undersealing was effective for about one year.

IV. DOWEL BAR GROUTING EXPERIMENT

A laboratory experiment was conducted to resolve problems encountered when grouting in dowel bars. In order to evaluate the different techniques, a number of "hole" specimens were made by casting a PVC pipe, with a 1-5/8 inch outside diameter, into a 6 inch diameter by a 12 inch high concrete cylinder. A bond breaker was also cast into each specimen in order that the cylinder may be split in half along the dowel bar after it had been grouted and cured. Cylinders were laid on their sides and different grouting techniques were used to grout in 1-1/2 inch dowel bars, along with different grout types and consistencies.

The different techniques and grouts were as follows:

PVC Pipe Sleeve:	Consists of a 9-inch section of 1-5/8 inch inside diameter PVC pipe. The dowel bar is inserted about 3 inches into the pipe, then the pipe is filled with grout. The sleeve is then held against the pavement over the hole and the dowel bar inserted through the sleeve into the hole, pushing the grout ahead of the bar. The sleeve is then pulled off the end of the dowel bar.
Grout Bag:	This consisted of a vinyl bag similar to a pastry bag except, in the bottom, a 3/4 inch diameter PVC pipe, 12 inches long with a reducer on the end was used to extrude the grout. The pipe was inserted and grout deposited at the rear of the hole. The dowel bar was then inserted.
Grout Gun:	This is a commercially available device and is similar to a caulking gun, except the nozzle was extended with a 9 inch length of tubing. The nozzle was inserted and grout deposited at the rear of the hole. The dowel bar was then inserted.

Push Rod and Half Sleeve:	The push rod was made from a thread rod on which a 1.5 inch rubber "washer" was secured by metal washers and nuts. The half sleeve was made from a piece of sheet metal fastened to fit into the 1-5/8 inch hole. The sleeve was filled with grout, inserted into the hole about an inch, then the rod was used to push the grout to the rear of the hole. Lastly , the dowel bar was inserted.
Grout Pump:	Commercially available grout pump. Grout is mechanically pumped through a hose into dowel bar hole. On/Off switch at end of applicator allows very high production. A mixer is also available which will mix grout and pour it into pump. After grout is applied, the dowel bar is inserted.
Hilti Hit C-10 Resin System	A two component polyester resin packaged in a caulking gun type applicator which mixes components while applying resin in rear of hole. after application, the dowel bar is inserted. Resin has rapid strength gain.

Sand and silica non-shrinking grouts were evaluated on their ability to remain in the hole without excessive run out. The sand grout used worked well over a wide range of water contents. The silica grout was very flowable, even at very low water contents and continually ran out of the hole. Because of the run out problem, only sand grouts are recommended for dowel bar grouting. The sand grout was then used to evaluate the various grouting techniques.

Once dowel bars were grouted in and allowed to cure overnight, the specimens were split in half, the dowel bar removed, and a visual inspection made of the coverage quality. Very good coverage of grout was achieved with techniques which deposited the grout at the rear of the hole before inserting the dowel bar. When using the PVC pipe sleeve, which uses the dowel bar to push the grout to the rear of the hole, small air voids would be trapped on top of the dowel bar. This resulted in a fair to poor quality of coverage. The results of the experiment are present in terms of coverage quality, production, workability, material and equipment cost in Table 7.

As a result of the lab experiment, it was found that grout should be deposited at the rear of the hole before dowel bar insertion. Dowel bars should not be oiled before inserting, by doing this the cement is displaced and/or retarded around the dowel bar. The thickness of the grout should be such that it does not run out of the hole. It is very important to use a back and forth twisting motion while inserting the dowel as this will eliminate any air voids. By using the back and forth twisting motion, dowels were inserted easily, even when using very dry grouts. There is no need to "drive" the dowel bar into the hole with a hammer unless the hole is out of alignment or very dirty. Non-shrink grout properties are such that initial set does not take place for 2 hours and final set for about 7 hours. For early open patches, those to be opened to traffic in less than 24 hours, a high early strength resin or epoxy should be used.

V. REHABILITATION COST EFFECTIVENESS

The actual bid prices for the five projects were converted to cost per two-lane mile and presented in Table 8. On patching, the percentage of pavement patched is also reported. Cost of experimental features were not included since these costs were not representative due to the small amount of work involved or due to work inexperience. The cost of the Double Vee load transfer devices was included only for informational purposes, and is not included in the project total.

A form of rehabilitation on Interstates in Illinois is to resurface with 3 inches of asphalt concrete. This consists of applying a prime or tack coat, prime coat aggregate, 1.5 inches of binder course, and 1.5 inches of surface course. The cost of one mile of resurfacing on 6 feet of inside shoulder, 24 feet of pavement, and 10 feet of outside shoulder averaged $124,500 in 1983, the year most of the projects were first rehabilitated. With traffic control and mobilization, the total cost for resurfacing one mile of Interstate was $137,000. Whether the pavement is resurfaced or not, full-depth patching and undersealing would be about the same in quality and cost, since the procedures for determining patching and undersealing needs are the same. Underdrains are installed on all Interstate projects which have not had underdrains installed previously, so this cost would also be the same.

Items which are unique to CPR are: partial depth patching, joint sealing and pavement grinding. When comparing the cost of these techniques to resurfacing, it is seen that CPR costs are about 50% that of resurfacing.

VI. CONCLUSIONS

Jointed concrete pavement can be rehabilitated cost effectively. Pavement grinding of the projects evaluated is expected to provide good ride quality for 10 or more years. Improved full depth patch design and procedures have resulted in greatly improved performance. Important features of the improved design are the use of 10 dowel bars per joint, which are 1.5 inches in diameter, the use of a sawed and sealed joint and a minimum patch length of 6 feet. The improved design is expected to give about 10 years of service. Another important requirement of full-depth patching is the close inspection of dowel bar grouting. Grouting techniques which deposit grout at the rear of the drilled hole are best. Partial depth patching has performed exceptionally well, but there is a need to locate and patch potential areas of spalling or delaminations to reduce pavement maintenance cost after rehabilitation. Underdrains will remove water from the pavement. More research is planned to determine if underdrains are cost-effective. In the future, undersealing should only be done on a selective basis where voids are known to exist at cracks and joints. Undersealing of distressed patches is not cost-effective. Debonding failures of load transfer devices in Illinois and other states (3) indicate the need for more laboratory research in this area. When resealing joints, the reservoir shape must be designed properly in order to prevent debonding of the sealant.

VII. RECOMMENDATIONS

- Only sound, non-D-cracking pavements should be rehabilitated using CPR methods.

- The cost-effectiveness of pavement grinding can be further increased by grinding only the driving lane on Interstate Routes.

- Delamination detection techniques should be used as an aid in locating areas in need of partial depth patching.

- Full depth patches should be constructed using 10 dowels in each joint with a diameter of 1.5 inches.

- When grouting in dowel bars, the grout should be deposited at the rear of the hole and the dowel bar inserted using a back and forth twisting motion. The grout should be thick enough so there is no appreciable run out.

- A sawed or formed and sealed joint should be used in full depth patching to prevent spalling.

- Void detection is necessary to determine the need and locations of undersealing. Blanket undersealing is rarely needed.

- Spalled, rocking and pumping patches should be replaced rather than undersealed.

- Future use of Double Vee or similar load transfer devices should be on a limited experimental basis to determine performance.

- More research is needed to determine the effectiveness of underdrains.

- Joint sealant reservoirs should be designed to provide the proper shape factors for the sealant and movement needs.

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2. Darter, M. I.; Barenberg, E. J.; and Yrjanson, W. A., "Joint Repair Methods for Portland Cement Concrete Pavements", Report No. 281, National Cooperative Highway Research Program, 1985.

3. Gulden, W., Brown, D., "Establishing Load Transfer in Existing Jointed Concrete Pavements", presented at the 64th Annual Meeting of the Transportation Research Board, Washington, D. C., January, 1985.

ACKNOWLEDGMENTS/DISCLAIMER

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The contents of this paper reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Illinois Department of Transportation or the Federal Highway Administration. This paper does not constitute a standard, specification or regulation.

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Table 1. Original Pavement Design

Project Number	Route and Milepost Location	Year Constructed	PCC Pavement Thickness (inches)	Joint Spacing (feet)	PCC Aggregate Quality	Subbase Thickness And Type	Shoulder Design	Pavement Distress At Time of Rehabilitation
1	I-55 98.00 - 102.36	1962	10.0	100	Fair (Moderate D-cracking)	6 in. - Granular	0.5 inch surface treatment on granular base[1]	Moderate joint faulting Joint deterioration Rough ride
2	I-55 102.36 - 105.52	1962	10.0	100	Very Good	6 in. - granular	0.5 inch surface treatment on granular base[1]	High severity joint faulting Rough ride High reinforcing steel spalling Limited joint deterioration
3	I-70 74.28 - 82.23	1960-1963	10.0	100	Good (Low D-Cracking)	6 in. - granular	3 inch bituminous concrete on granular base	Joint deterioration Moderate joint faulting Rough ride
4	I-80 105.30 - 111.70	1960	10.0	100	Very Good	6 in. - granular	3 inch bituminous concrete on granular base	Severe joint faulting Joint deterioration Rough ride
5	I-280 14.70 - 18.0 I-74 5.00 - 9.64	1962	10.0	100	Very Good	6 in. - granular	0.5 inch surface treatment on granular base	Low severity joint faulting Poor skid properties Joint spalling

1 - Surface treatment replaced with 3-inch bituminous concrete in early 1970's

Table 2. Rehabilitation Techniques Used on Projects

Project	Route	Year of Rehab	Full-Depth Patching	Partial-Depth Patching	Joint Sealing	Blanket Undersealing	Retro-fit Load Transfer Devices	Pavement Grinding	Underdrains
1	I-55	1983	X	--	--	--	--	--	X
		1984	X	--	--	X	--	--	--
2	I-55	1983	X	X	--	X^1	--	X	X
3	I-70	1983	X	--	--	--	--	--	--
		1984	X^1	--	X^1	X	--	--	--
4	I-80	1983	X	--	--	X	X^1	X	X
		1985	X	--	X^2	--	--	--	--
5	I-280 I-74	1984	X	X	X	X	--	X	X

-- Technique not used

1 - Experimental (not included in economic analysis)

2 - Patches only (not included in economic analysis)

Table 3. Friction Number History of Grinding Projects

		FRICTION NUMBER						
PROJECT	ROUTE	'80	'81	'82	'83	'84	'85	'86
2	55	--	44	--	--	46[1]	41	--
3	80	35	--	--	48[1]	40	--	40
4	280-74	--	--	--	--	--	42	--

-- Data not available

1 - After Grinding

Table 4. Average Joint Fault History of Grinding Projects
(Inches)

PROJECT	ROUTE	YEAR MEASURED			
		1983	1984	1985	1986
2	55	0.31	0.00[1]	0.03	0.06
4	80	0.18	0.00[1]	0.04	--
5	280-74	--	0.00[1]	0.01	--

-- Data not available

1 - After Grinding

Table 5. Roadometer History of Rehabilitation Projects (Inches/Mile)

				Year Tested		
Project	Route	1982	1983	1984	1985	1986
1	55	--	129	--	--	113
2	55	--	165	73	66	78
3	70	104	--	--	--	112
4	80	151	51	73	64	82
5	280-74	--	--	82	40	47

-- Not tested
1 Before rehabilitation

Note: The following ranges are used to route ride quality:

R.I. (Inches/Mile)	
Under 75	Very smooth
76-90	Smooth
91-125	Slightly rough
126-170	Rough
Over 171	Very rough

Table 6. Number of Patches Constructed by Variable in Patching Experiment

		DOWEL DESIGN					
		3-3	4-4		5-5		Tied[1]
GROUT TYPE		Non-Shrink	Non-Shrink	Epoxy	Non-Shrink	Epoxy	Non-Shrink
DOWEL SIZE	1.25 inch	4	3	1	4	1	3
	1.50 inch	4	4	-	4	-	-

[1] Tied patch design consists of #8 tie bar on approach joint and 1.25 inch dowel bar on leave side of patch.

-- Not constructed

NOTE: All patch lengths are 6 feet.

Table 7. Dowel Bar Brouting Technique Results

Method	Quality of Coverage	Production	Workability	Approximate Non-Shrink Grout Cost $/Hole	Approximate Equipment Cost $
PVC Pipe Sleeve	Fair	Good	Good	.10	.30
Grout Bag	Very Good	Good	Good	.10	5.00
Grout Gun	Very Good	Poor	Poor	.10	40.00
Push Rod and Half Round	Very Good	Good	Good	.10	5.00
Grout Pump With Mixer	Very Good	Excellent	Excellent	.10-.15	$1,500-$2,600
	Very Good	Excellent	Excellent	.10-.15	$5,000
Hilti Hit C-10 Resin	Very Good	Good	Good	4.00[1]	0.00

1 - Two component Polyester Resin

Table 8. Rehabilitation Technique Cost
(Dollars Per Lane-Mile)

Project Number	Route	Year of Rehab	Full-Depth Patching	Partial-Depth Patching	Joint Sealing	Blanket Under Sealing	Retro-fit Load Transfer Devices	Pavement Grinding	Pipe Under Drains	Traffic Control and Mobilization	Project Total
1	I-55	1983	42910/4.5[1]	--	--	--	--	--	12,700	9,750	65,360
		1984	3540/0.2	--	--	13,140	--	--	--	3,330	20,010
2	I-55	1983	4340/0.3	8740/0.4[1]	--	--	--	43,110	9,930	8,710	74,830
3	I-70	1983	38,300/3.9	--	--	--	--	--	--	6,600	44,900
		1984	--	--	--	7,210	--	--	--	1,820	9,030
4	I-80	1983	8,080/0.7	--	--	15,290	25,540[2]	36,700	20,220	6,690	86,980
		1985	10,260[3]/0.7	--	--	--	--	--	--	2,710	12,970
5	I-280	1984	26,070/2.4	2570/0.2	5,870	16,220	--	45,590	33,010	18,930	148,260

[1] Percent of pavement patched

[2] Based upon 2 devices per wheelpath and average spacing of 100'; presented for information only and not included in total

[3] 5-5 doweled patch design

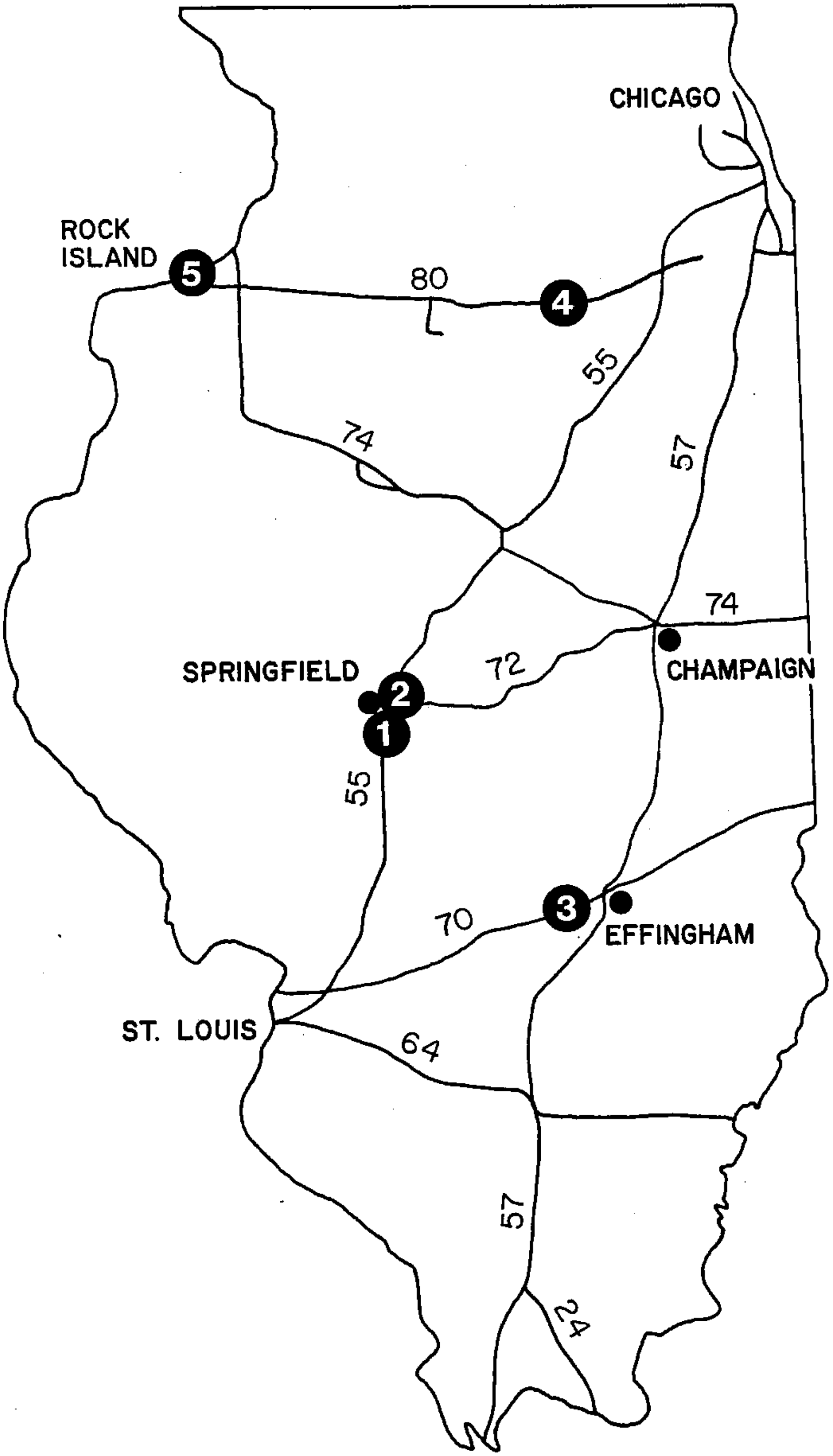

Figure 1. Project Location Map

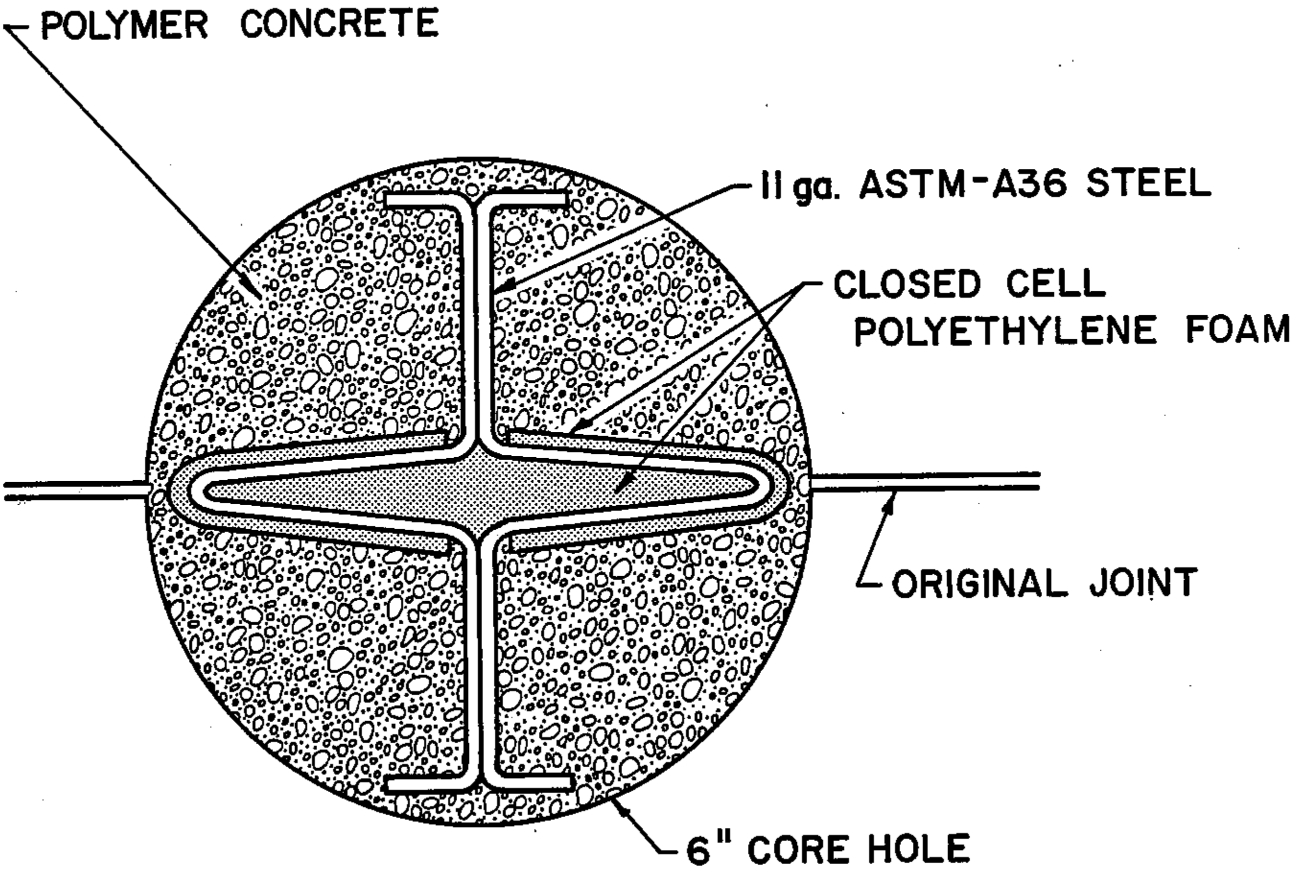

Figure 2. Double Vee Load Transfer Device

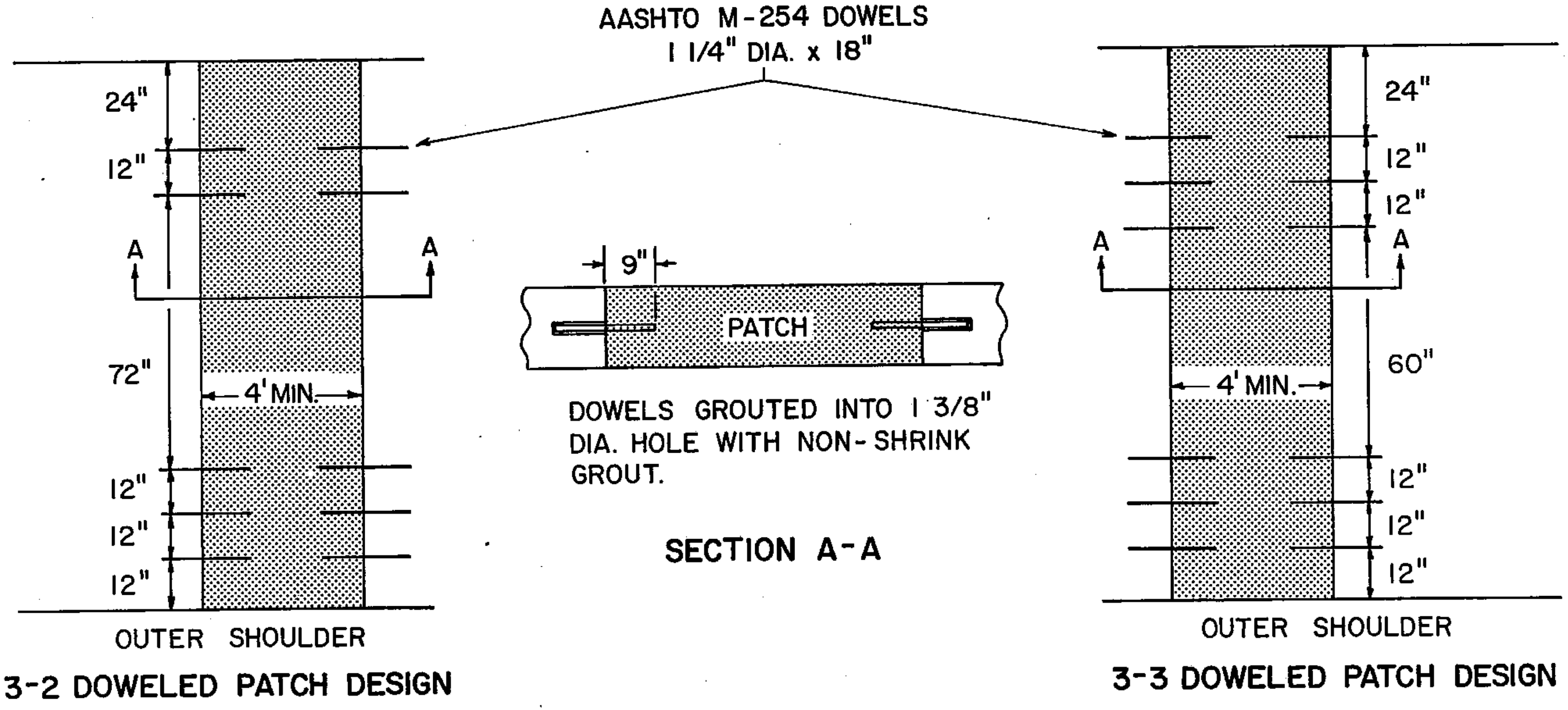

Figure 3. Patch Design Details of 3-2 and 3-3 Patches

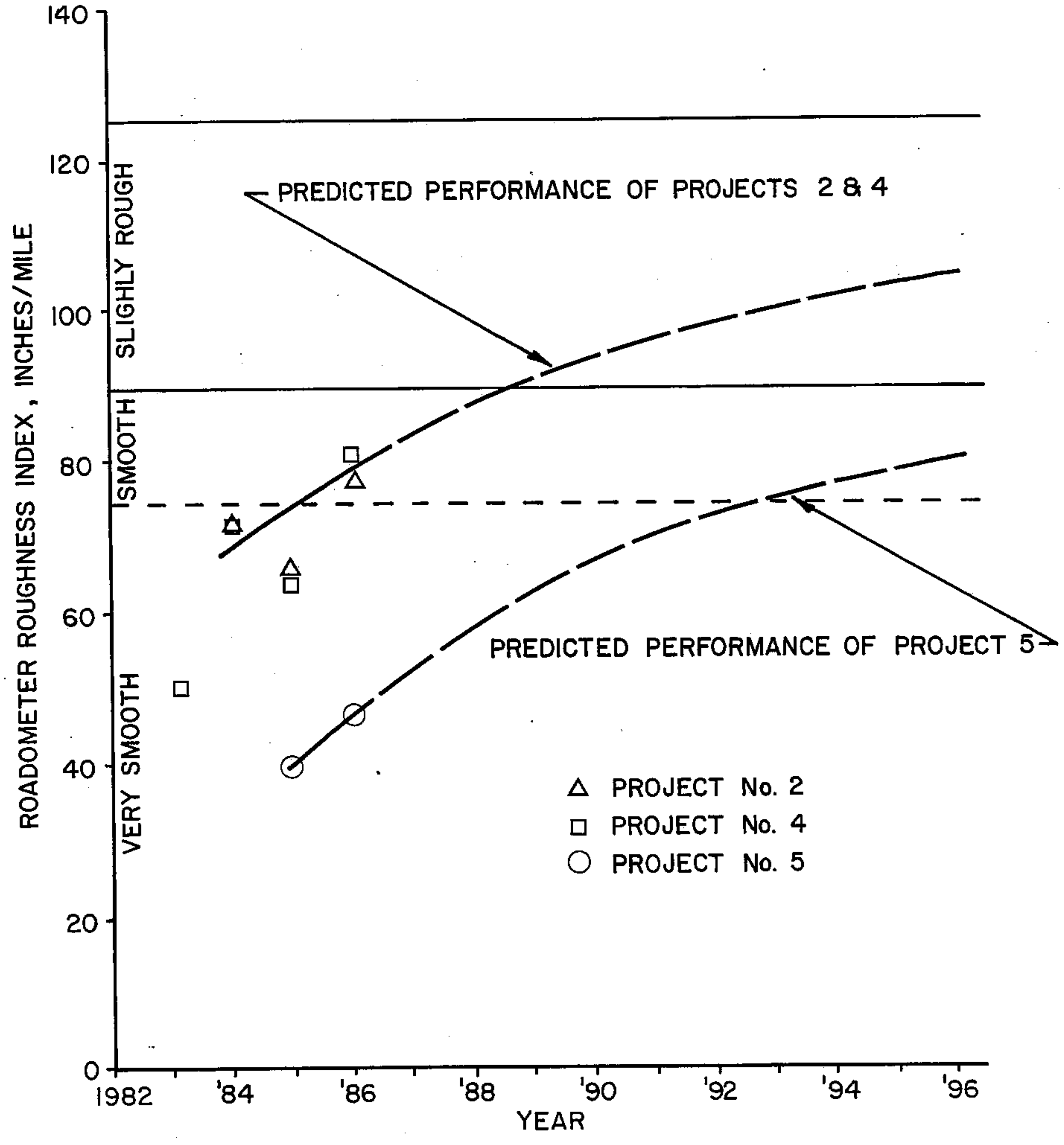

Figure 4. Predicted Roadometer Roughness Index

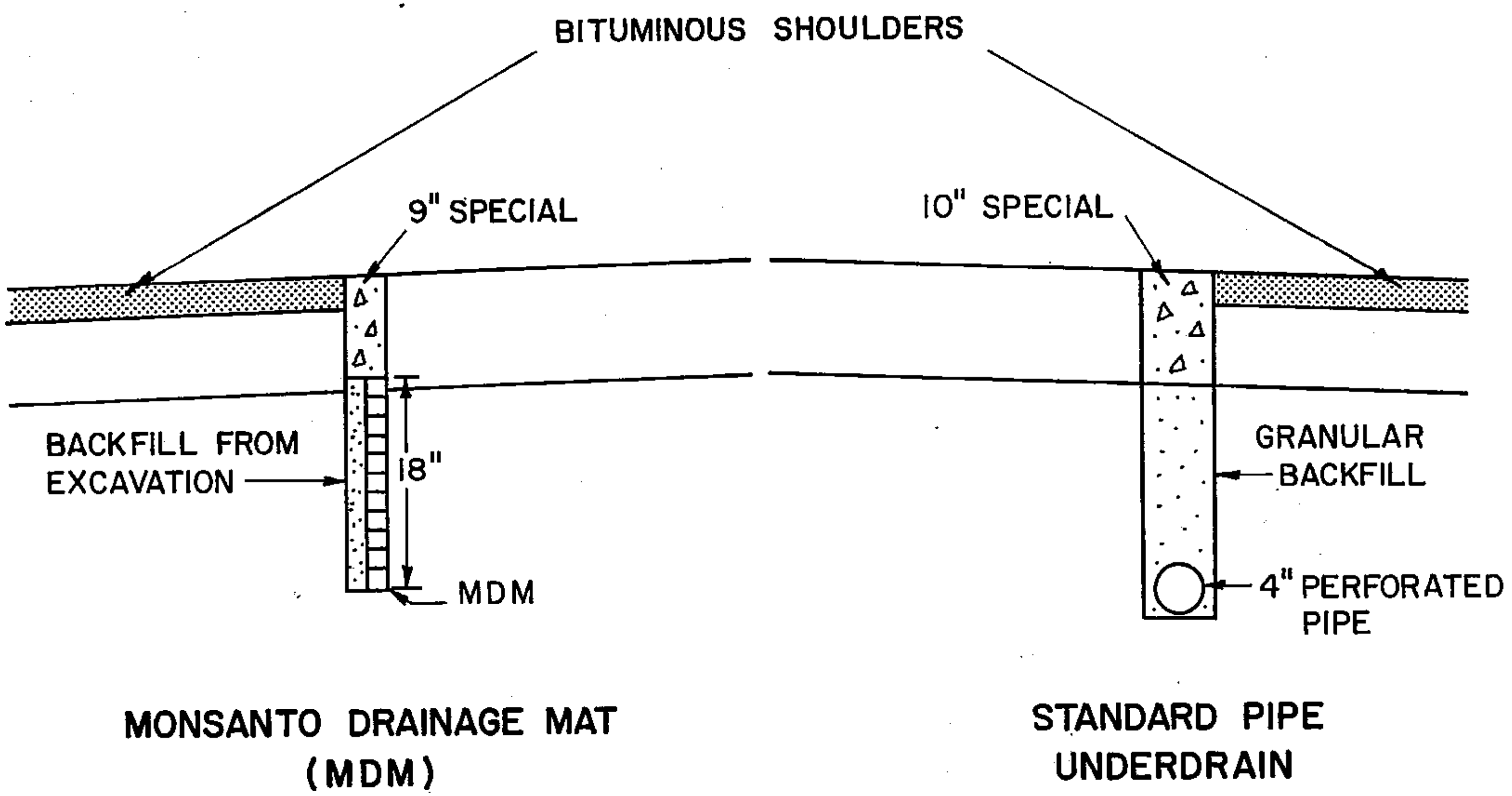

Figure 5. Details of Monsanto Drainage Mat and Standard Pipe Underdrains

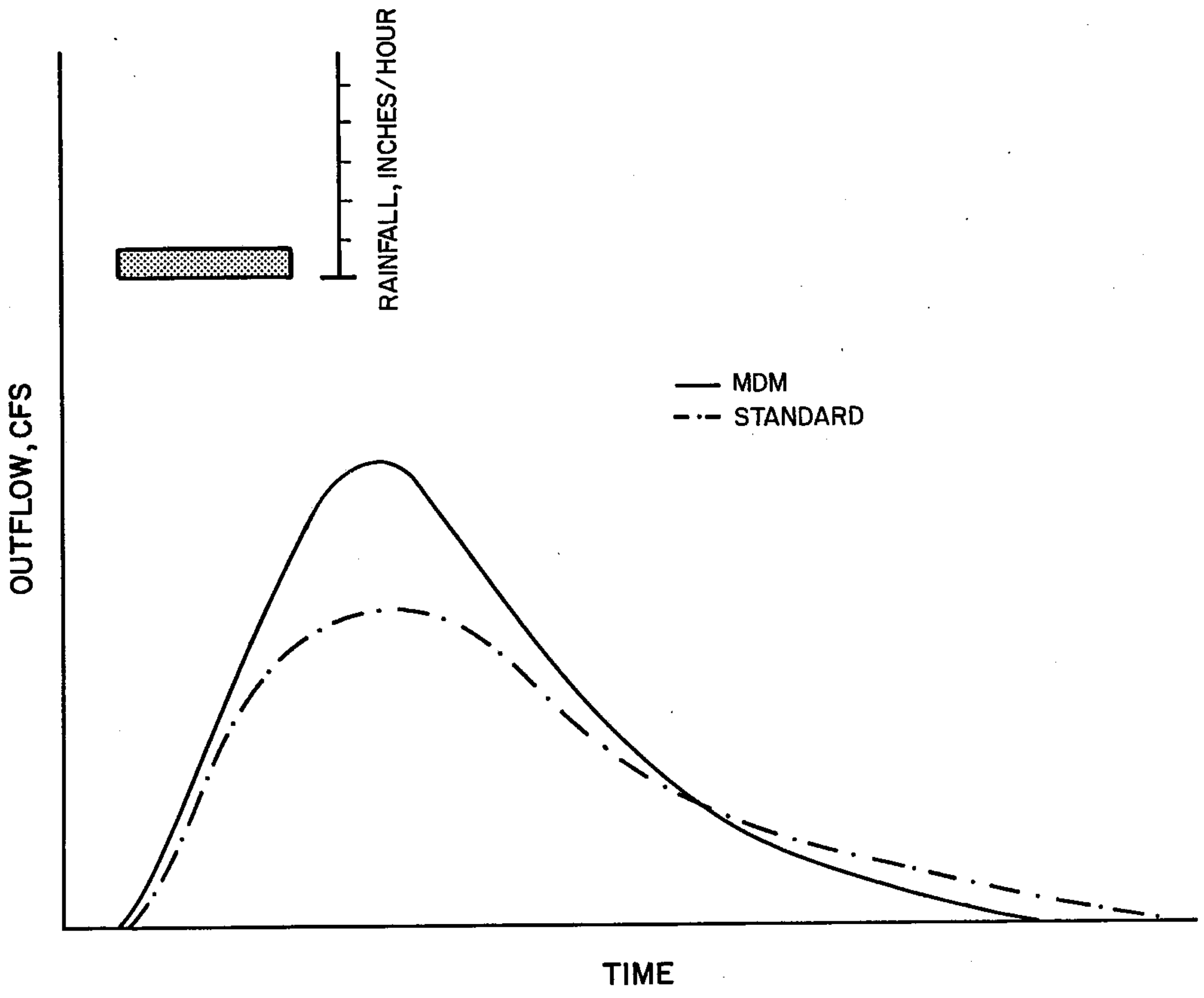

Figure 6. Typical Outflow Characteristics of Monsanto Drainage Mat and Standard Pipe Underdrains

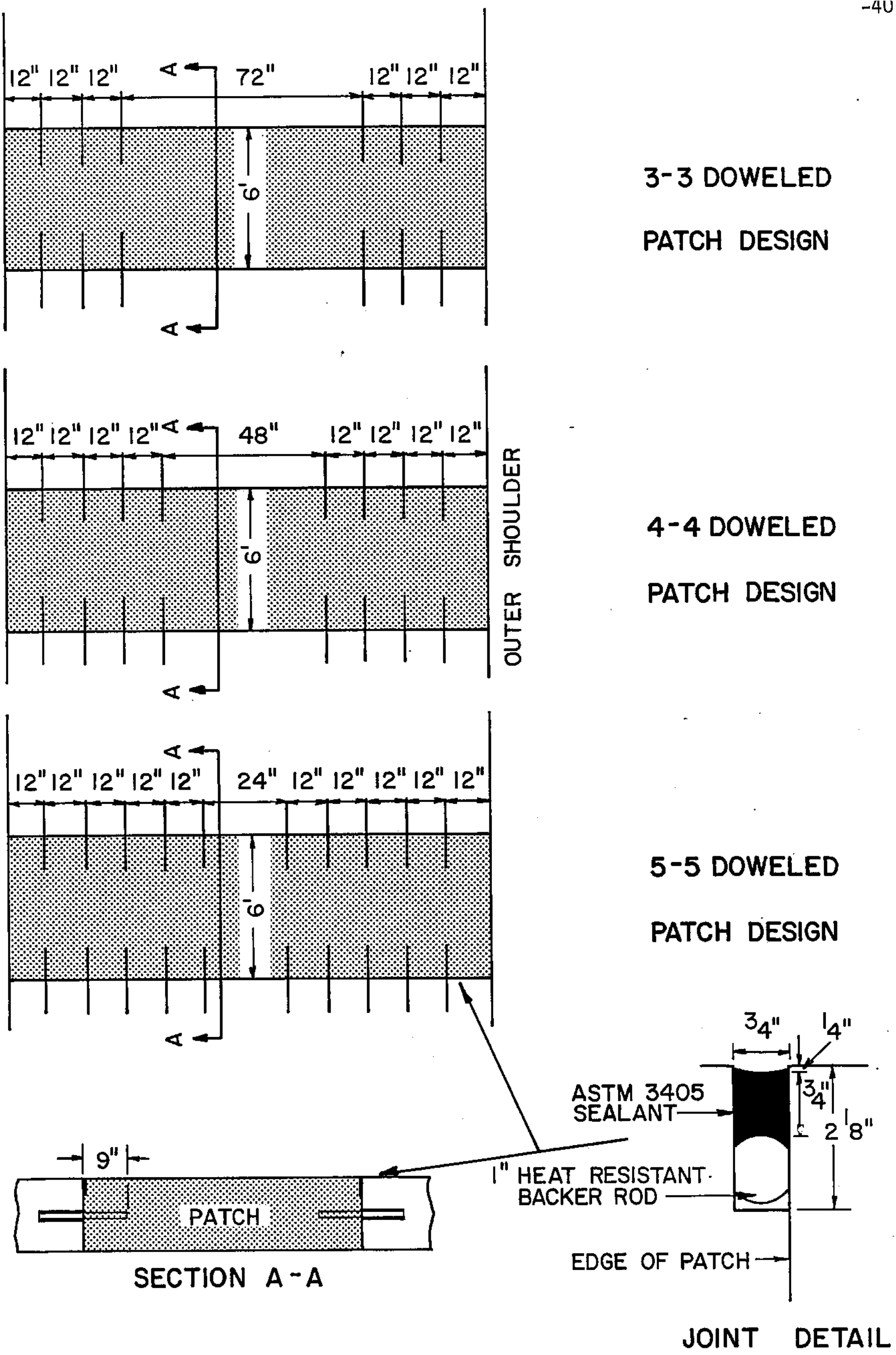

Figure 7. Experimental Patch Details

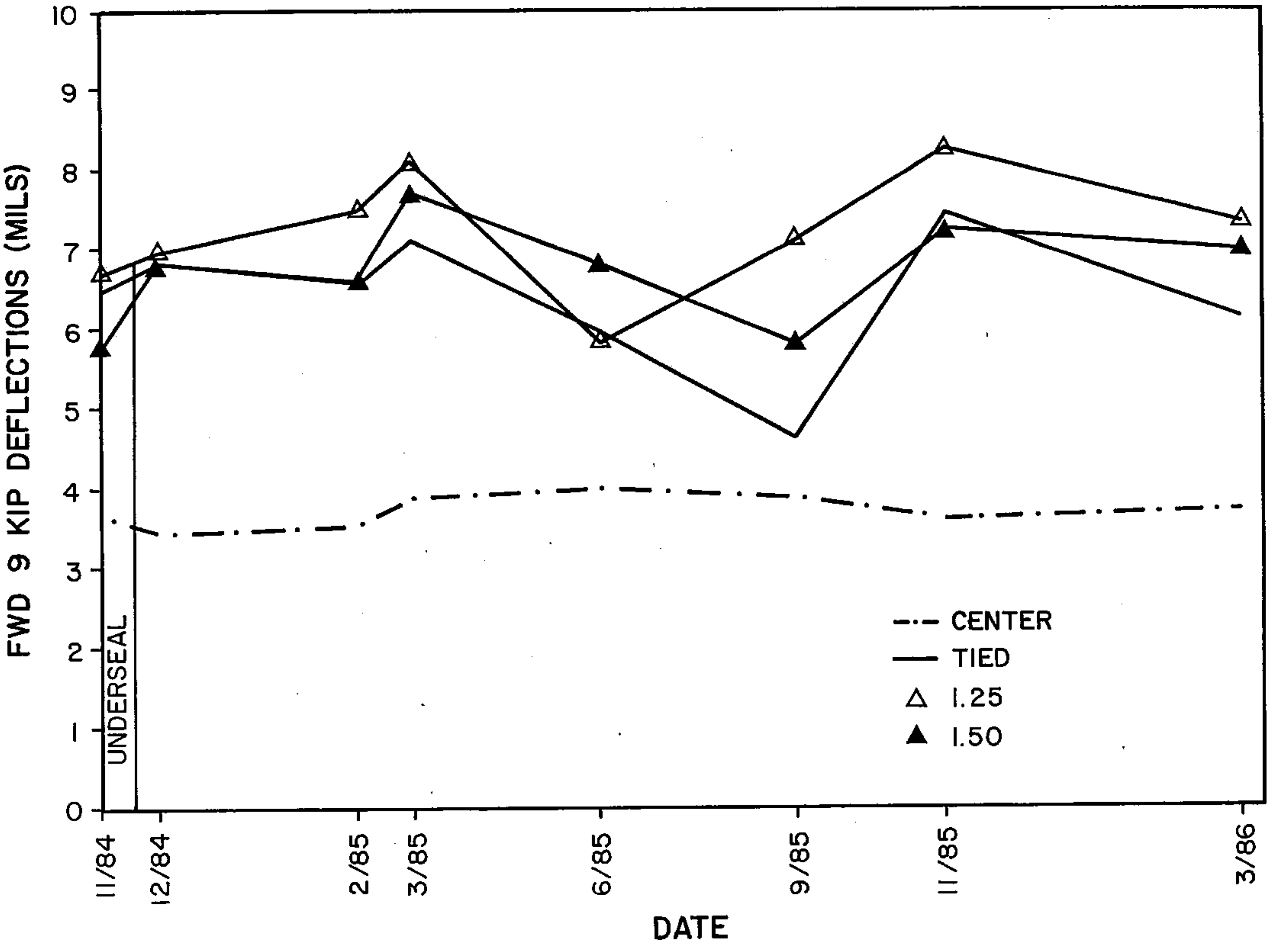

Figure 8. Deflection History of Dowel Bar Size

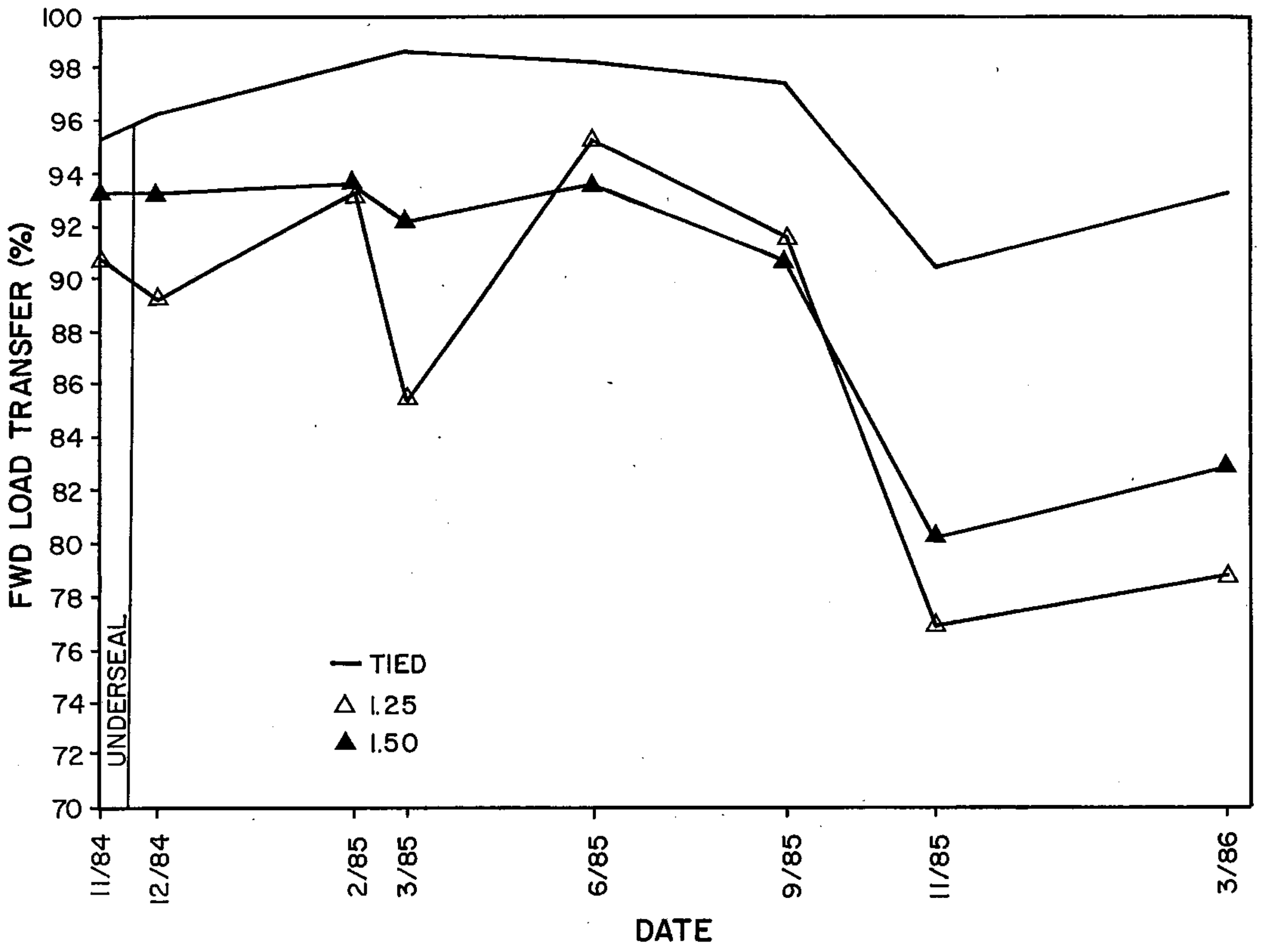

Figure 9. Load Transfer History of Dowel Bar Size

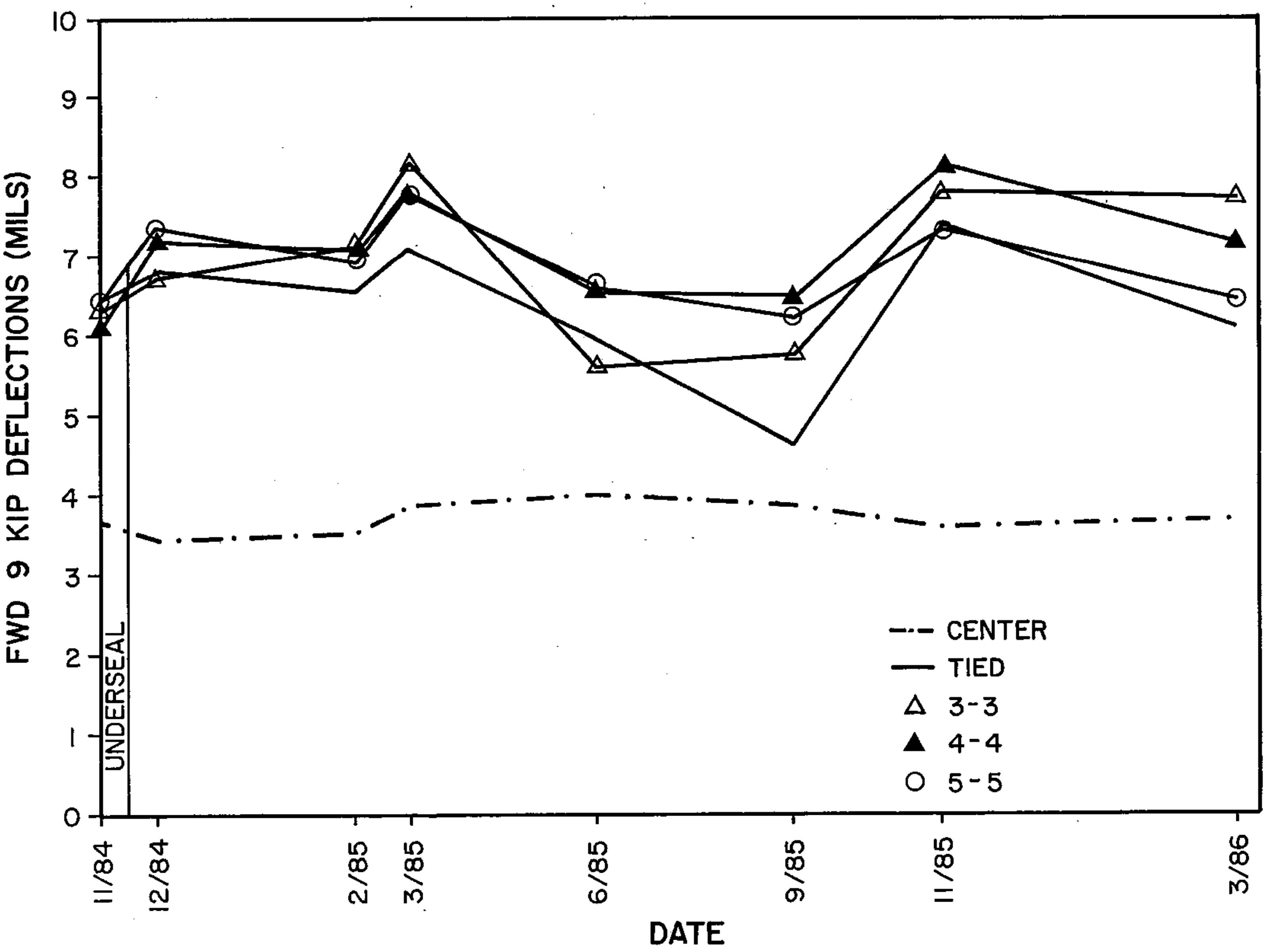

Figure 10. Deflection History of Dowel Bar Arrangement

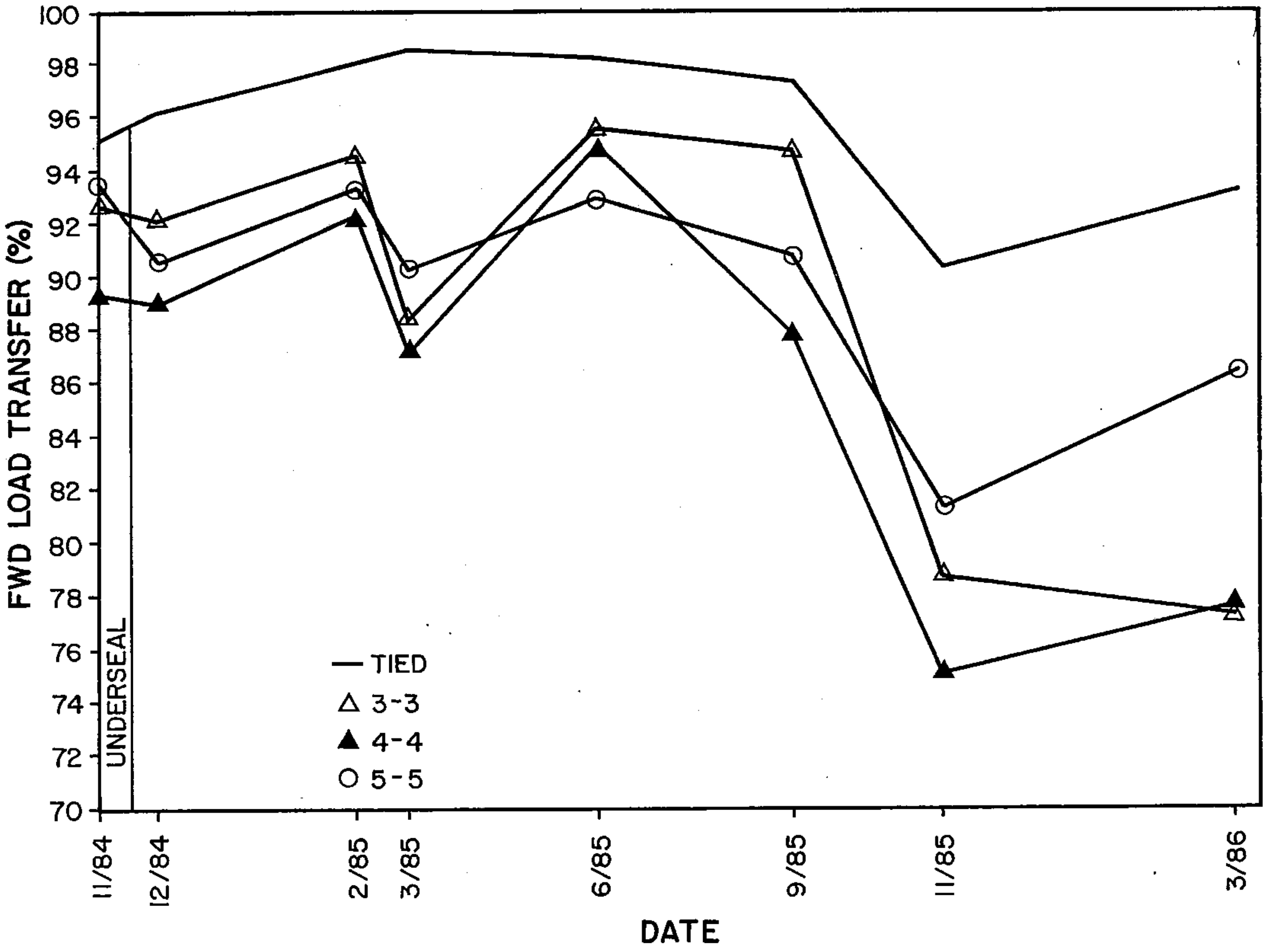

Figure 11. Load Transfer History of Dowel Bar Arrangement

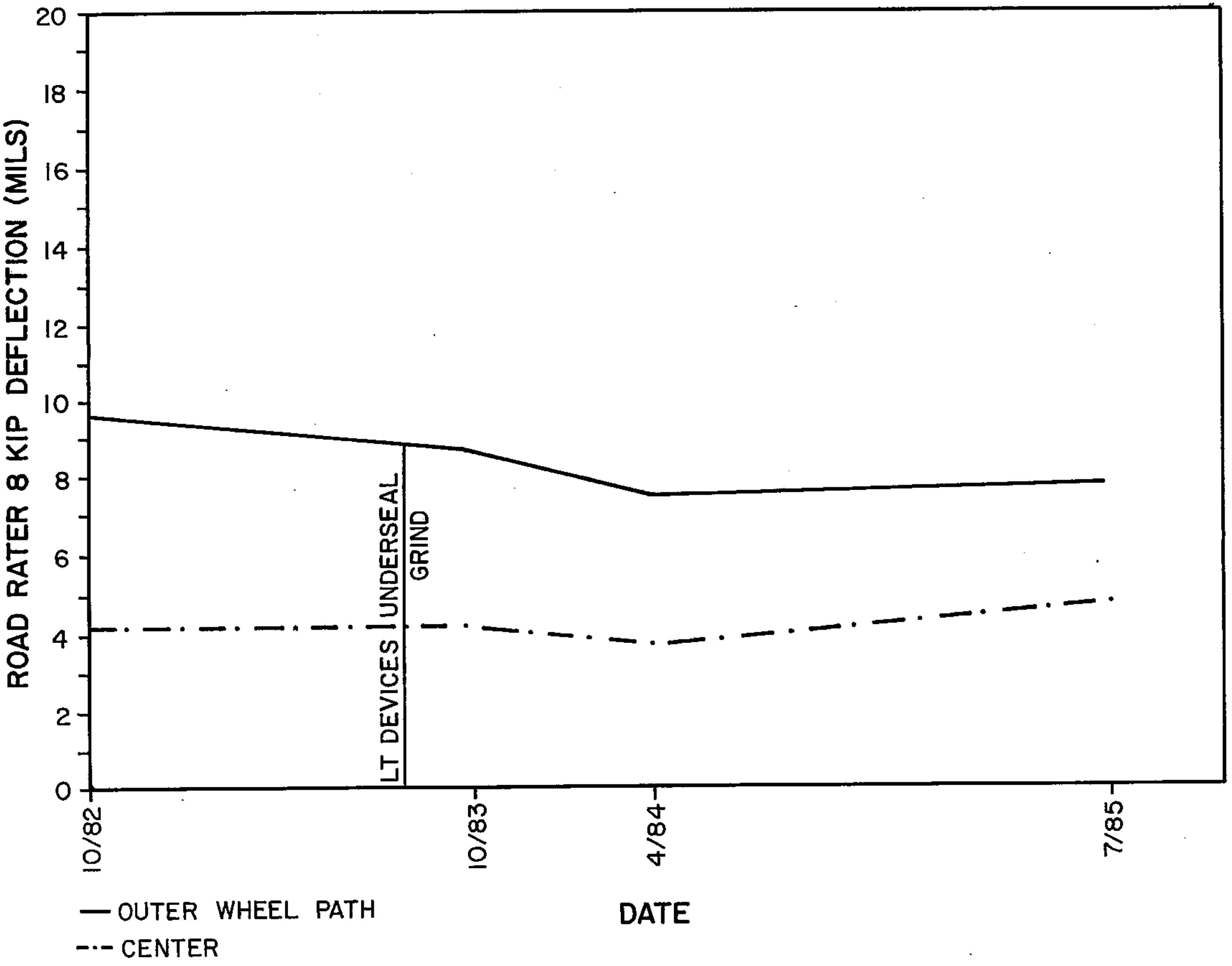

Figure 12. Deflection History of Undersealing on Project Number 4

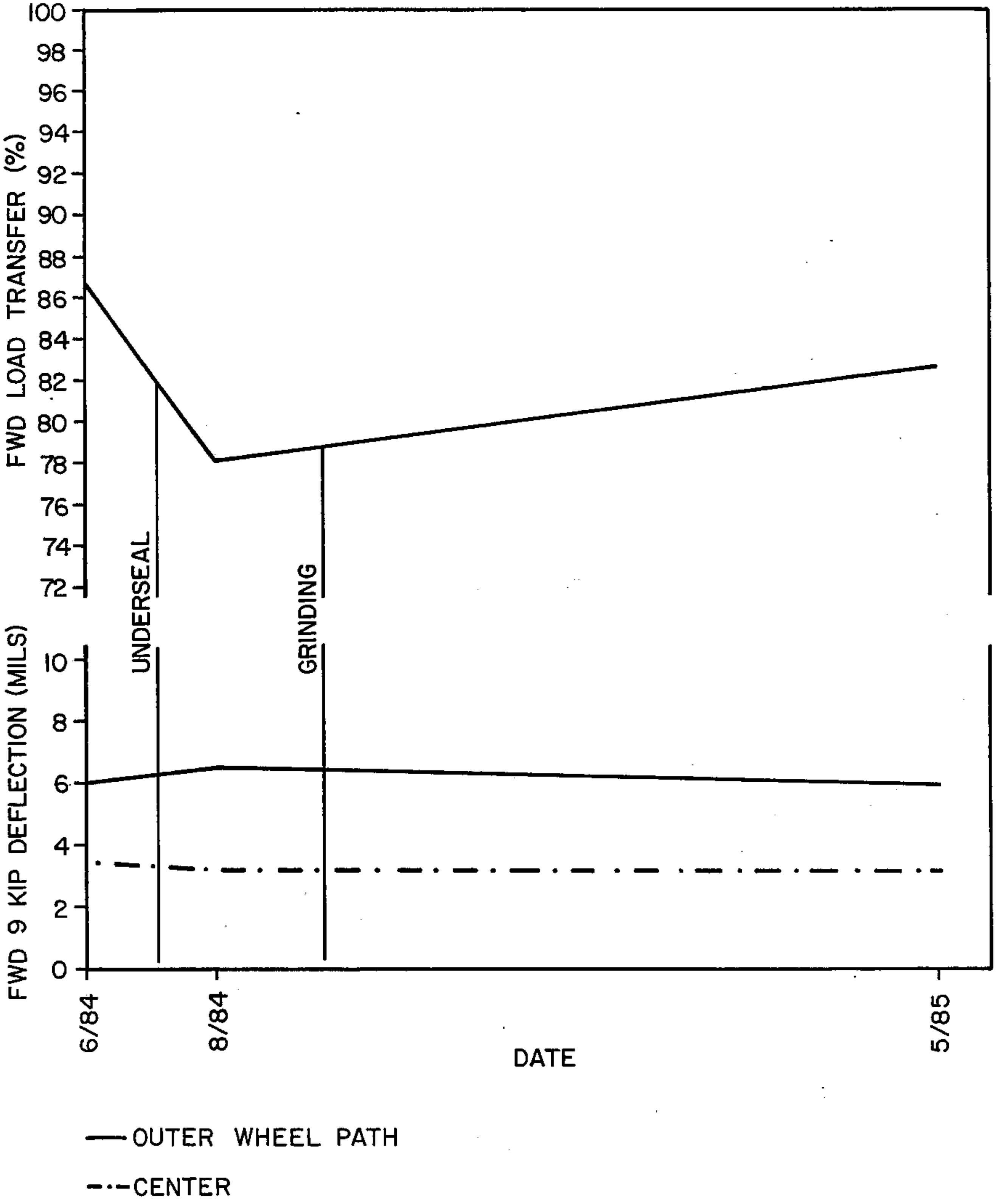

Figure 13. Deflection and Load Transfer History of Undersealing on Project Number 5

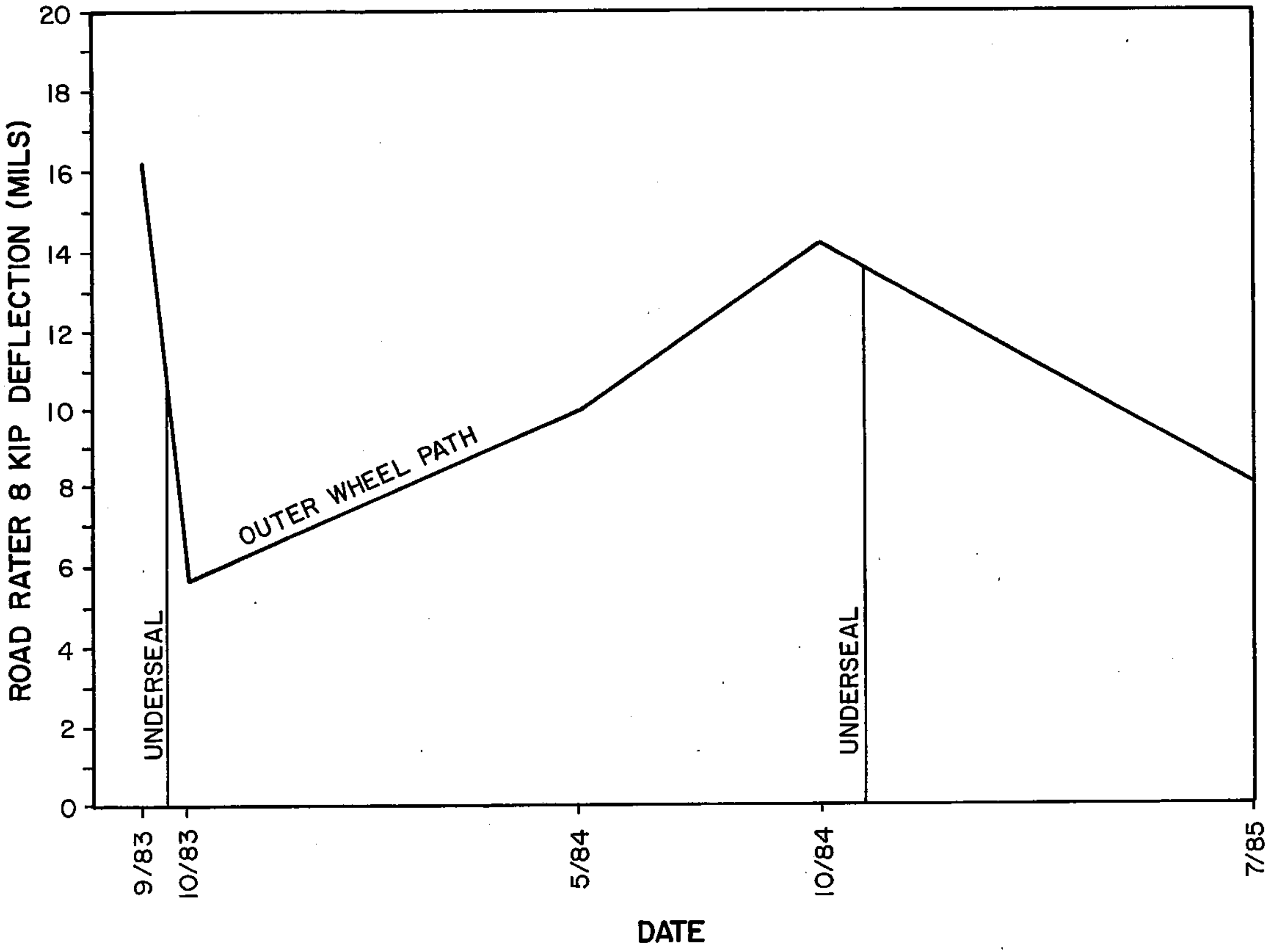

Figure 14. Deflection History of Patch Undersealing on Project Number 1

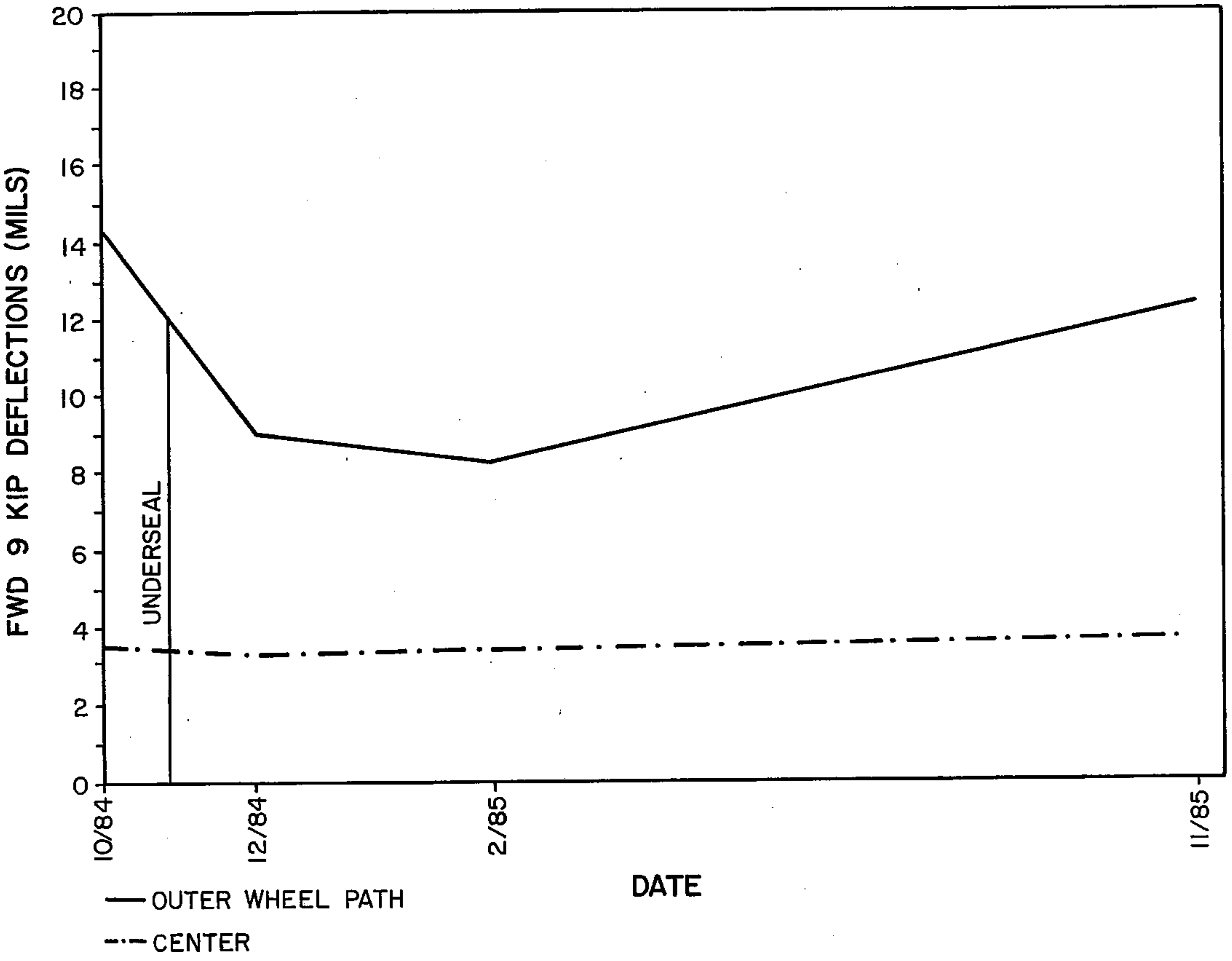

Figure 15. Deflection History of Patch Undersealing on Project Number 3