EVALUATION OF DOWEL PLACEMENT USING A DOWEL BAR INSERTER

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This paper presents the results of several field investigations to evaluate the effectiveness of automatic dowel bar inserter equipment to properly place dowel bars in rigid pavements. Results of three studies using the ground penetrating radar technique to measure dowel bar misalignment are summarized. Two investigations were sponsored by the Demonstration Projects Division of the Federal Highway Administration. The third radar survey was sponsored by the Wisconsin Department of Transportation, Madison, Wisconsin. A commercially available radar system capable of locating steel embedded in concrete was used. The system produces a real time graphic recording and that indicates the horizontal position and relative depth of the embedded steel. Cores were obtained to calibrate the graphic recordings and to obtain the actual embedded depth of the steel bars. In two of the three studies dowel bar alignment using the radar technique was measured along a section where a Guntert and Zimmerman dowel bar inserter was used and where dowels were placed in wire basket assemblies. Overall, the dowel bar inserter performed well compared to the basket assembly construction. Dowel depth, misalignment (vertical and horizontal), and longitudinal displacement are generally comparable

This paper presents the results of several field investigations conducted to evaluate the effectiveness to properly place dowel bars in rigid pavements. Results of three nondestructive test surveys of dowel bar alignment using the radar technique which were conducted in 1986 and 1987 are discussed. Evaluations of dowel bar alignment were conducted at three projects where the dowel bar inserter was used in the states of Idaho, Texas, and Wisconsin. The investigations in Idaho and Texas were sponsored by the Demonstration Projects Division of the Federal Highway Administration (FHWA) and in Wisconsin by the Wisconsin Department of Transportation.

Background

The use of round steel dowel bars for load transfer at rigid pavement joints is currently a standard practice. Bar diameter is generally one-eighth of slab thickness, dowel spacing is 12-in. and length is 18 in. Dowel bars are placed at mid-depth of the pavement and require care in placement to minimize the detrimental effects of misalignment.

Traditionally, dowel bars have been positioned in wire basket assemblies which in turn are pinned to the subbase or subgrade prior to paving. Recently a new method of dowel placement is being used with automatic dowel bar inserter (implanter) equipment inserting dowels directly into the plastic concrete. These inserters are described by manufacturers as being capable of accurate dowel placement and proper finishing of concrete after insertion without disturbing the inserted dowel bars.

For satisfactory long-term performance of rigid pavements, it is required that dowel bars be placed as parallel as practical to the longitudinal axis and the horizontal plane of the pavement. The reason for dowel bar placement tolerance specifications is to minimize problems associated with locked joints. Pavement slabs should be free to expand and contract with changes in slab temperature and moisture. Resistance to movement is provided by subbase friction and locked joints. For slabs up to 20 ft. resistance due to subbase friction is not a major problem. The magnitude of restraint caused by locked joints depends on the degree of dowel misalignment, number of misaligned dowel bars, and degree of dowel corrosion. Locked joints may result in transverse cracking, corner breaks, and spalling at the concrete face around the dowel. Once a spall occurs around a dowel, load transfer effectiveness of the dowel may decrease. The different categories of dowel misalignment and their possible effects on pavement behavior are illustrated in Figure 1.

Generally, limits on permissible tolerances are specified individually by state highway agencies. In the past, maximum allowable alignment error of 1/4 in. per 18 in. length of the dowel bar was commonly specified. Recently, many state agencies have been revising the allowable tolerance levels. For example, the Georgia Department of Transportation specifies an allowable tolerance of 3/8 in. per foot in both the horizontal and vertical directions, and several other state agencies specify an allowable

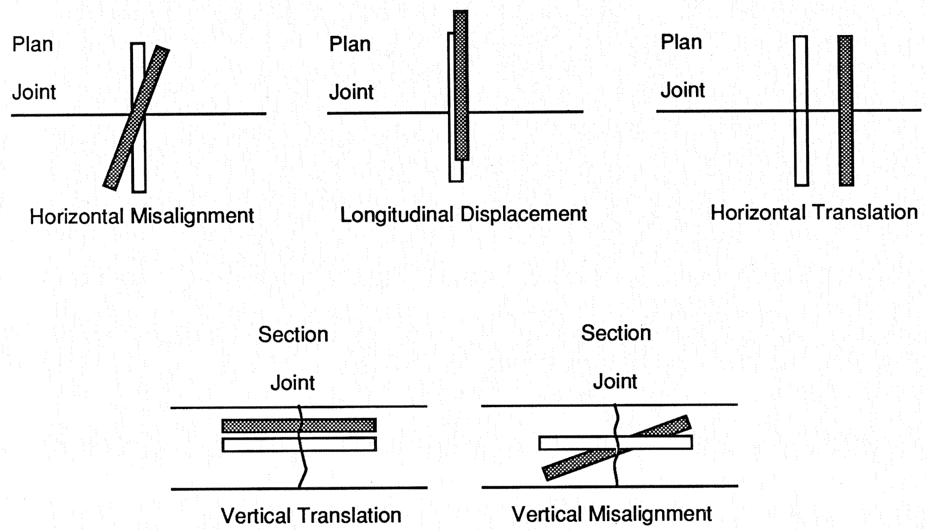

FIGURE 1 Classification of Dowel Bar Misalignment

tolerance of 1/4 in. per foot in both the horizontal and vertical directions.

It should be noted that no clear consensus exists as to the level of practical limits on dowel placement tolerances.(1) In addition, in the past, it has been a very slow process to determine levels of misalignment after the pavement was constructed. Dowel bar alignment in fresh concrete was determined by carefully exposing both dowel bar ends immediately after placement of concrete and directly measuring misalignment. In hardened concrete dowel alignment can be measured using a pachometer to locate the dowel bars and taking partial depth cores near the dowel ends. Currently, use is being made of ground penetrating radar devices (GRR) to determine accuracy of dowel placement.(2,3,4)

Objectives

The objectives of each of the three investigations discussed in this paper were as follows:

Interstate 86 - State of Idaho (Sponsored by the Federal Highway Administration, 1986)

1. Perform lab study on application of ground penetrating radar to locate and determine depth of dowel bars in hardened concrete.

2. Evaluate the effectiveness of using the radar technique for measuring dowel bar misalignment in the field.

3. Determine vertical and horizontal misalignment of dowel bars placed with a Gomaco automatic dowel bar inserter.

Interstate 45 - State of Texas (sponsored by the Federal Highway Administration, 1987)

1. Measure dowel bar alignment using ground penetrating radar equipment at joints along a pavement section where dowel baskets were used and along a section of pavement where a Guntert and Zimmerman dowel bar inserter (implanter) was used.

2. Evaluate the effectiveness of the radar technique for measuring dowel bar misalignment in the field.

3. Evaluate the effectiveness of an automatic dowel bar inserter to properly place dowel bars in rigid pavements by comparing radar results from both types of joints.

Interstate 90 - State of Wisconsin (Sponsored by the Wisconsin Department of Transportation, 1987)

1. Measure dowel alignment using ground penetrating radar at joints along a section where a Guntert and Zimmerman dowel bar inserter was used and along a section where dowel basket assemblies were used.

2. Evaluate the effectiveness of an automatic dowel bar inserter for properly placing dowel bars in rigid pavements by comparing radar results from both types of joints.

Radar Rebar Locator

A commercially available ground penetrating radar unit owned and operated by Construction Technology Laboratories, Inc. (CTL) was used to locate and measure the depth of dowel bars. The radar unit, SIR System-4R, manufactured and sold by Geophysical Survey Systems, Inc. (GSSI) has been successfully used by CTL to quickly and easily locate reinforcing bars and other embedded steel in concrete.

By measuring the depth near the ends of the dowels the magnitude and direction of vertical misalignment (tilt) can be accurately determined. The dowel bars can also be located in the horizontal plane to detect horizontal skew and displacement.

The GSSI radar system includes the following items:

1. Radar control unit
2. Transducer (antenna)
3. Graphic recorder
4. Transducer control cable
5. Remote marker switch

High frequency electromagnetic pulses are propagated into the concrete by a hand held transducer. The pulses are reflected by the reinforcing bars (or other embedded steel) back to the transducer which are then sent to the radar control unit for signal processing and fed to a line-scan graphic recorder. As the transducer is moved along the concrete surface, a real time graphic recording is automatically generated showing the location and relative depths of all the steel bars along the transect line. Cores or known steel bar depths are used to calibrate the graphic recording to obtain actual embedded depths of the steel bars.

Project Details

Interstate 86 - State of Idaho

An eleven mile section of Interstate 86 in Idaho between the Raft River and Rockland Junction West of American Falls constructed in 1986. The eastbound two lanes are a 10-in. thick plain concrete pavement placed over an asphalt treated base. The pavement is 38 ft. wide and incorporates an 8.5-ft. wide inside shoulder. The random joint spacing is 13, 15, 16, and 14 ft.

Project specifications required the use of epoxy-coated 18-in. long, 1-1/4-in. diameter dowel bars spaced at 12 in. Maximum allowable misalignment specified was 1/4 in. per 12 in. in any direction. Project specifications allowed the option of using dowel basket assemblies or an automatic dowel bar inserter manufactured by Guntert and Zimmerman or approved equal. A dowel bar inserter supplied by Gomaco was approved for this project.

Interstate 45 - State of Texas

A 6.2 mile pavement section of Interstate 45 replaced south of Dallas, Texas (winter of 1986-87). This plain jointed concrete pavement is primarily 10.0 in. thick except near bridge approaches, underpasses, etc. where the nominal thickness was increased to 12 in.

Dowels were used at right angle transverse joints spaced every 15 ft. for load transfer. Project specifications required use of lead painted, 22 in. long, 1-1/4 in. diameter bars spaced at 12 in. The outside lane (truck lane) is 14-1/2 ft wide and the inside lane (passing lane) is 12-1/2 ft wide. The full 27 ft wide section was placed in single pass by a Guntert & Zimmerman paver. Dowels were placed using dowel basket assemblies for a portion of the project. The dowel basket assembly specified used wire gage No. 1/0 (0.306 in. diameter) with bars alternately welded on one end. For the remainder of the project, a Guntert & Zimmerman dowel bar inserter was used to place dowels in the plastic concrete.

Interstate 90 - State of Wisconsin

A 5 mile pavement section of Interstate 90 recently constructed near Janesville, Wisconsin (summer and fall of 1987). The westbound lanes were constructed as a 10-in. thick plain jointed concrete pavement. The eastbound lanes were constructed as a 10-in. thick continuously reinforced concrete pavement (CRCP). Dowel baskets were used in a 1000 ft plain concrete pavement section in the eastbound lanes.

Dowels were used for load transfer at skewed transverse joints spaced at 12, 13, 18, and 19 ft. Project specifications required use of 18 in. long, 1-1/4 in. diameter bars spaced at 12 in. Specified dowel depth to the center of the dowel was 5 in. (mid-depth) plus or minus 1 in. Specified maximum allowable horizontal and vertical misalignment (skewness and tilt) was plus or minus 1/2 in. per 18 in. Specified horizontal dowel spacing specified was 12 in. plus or minus 1 in. Both the outside lane (truck lane) and the inside lane (passing lane) are 12 ft wide. The full 24 ft wide section was placed in a single pass by a Guntert & Zimmerman paver. The slipform paver was equipped with a Guntert & Zimmerman dowel bar inserter for placing dowels in the plastic concrete.

Test Procedure

The evaluation procedure at each selected joint was done by making a pass with the radar transducer 6-in. away from each side of the joint as shown in Figure 2. Thus, the difference in dowel bar depth between two corresponding readings gave vertical misalignment over a length of 12 in. The output for each pass was simultaneously recorded graphically for future interpretation. A typical graphic output is shown in Figure 3.

To evaluate horizontal dowel displacement and skew, a triggering mechanism when manually activated causes a reference mark to be printed on the radar recording. In Idaho, the transducer was pulled along the tined surface and reference marks manually triggered every foot. To estimate horizontal position the dowel positions had to be interpolated between one foot marks on the radar output. Because of the relatively nonuniform

FIGURE 2 Radar Pass at Transverse Joint

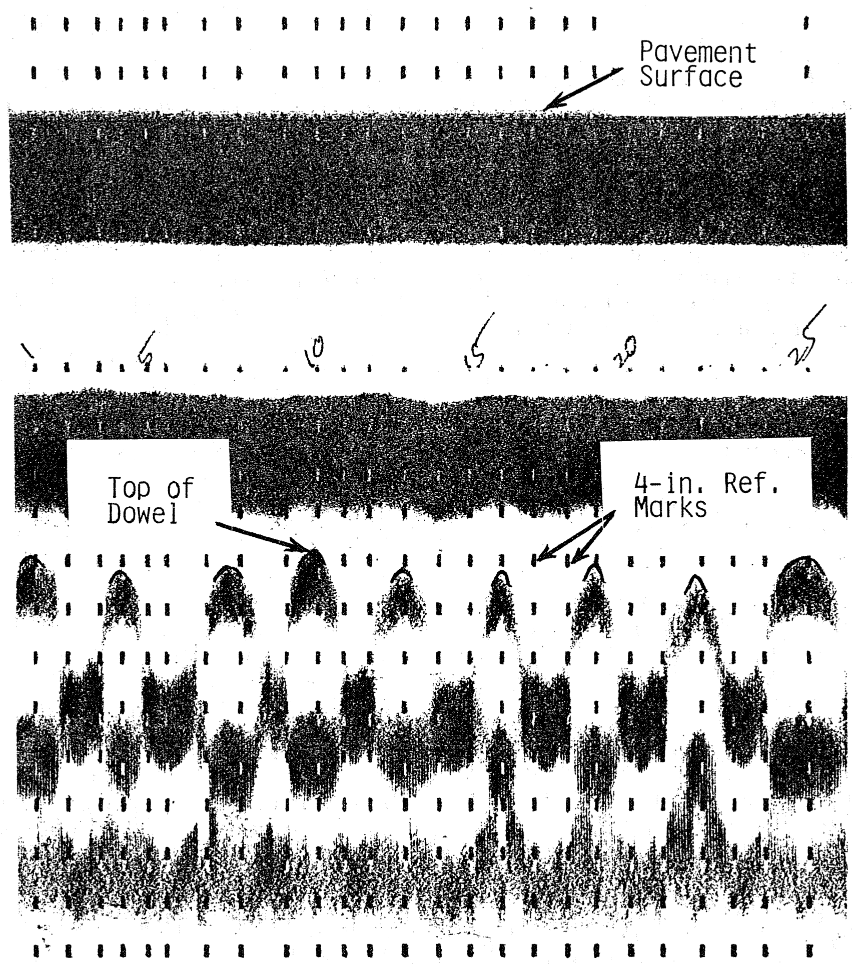

FIGURE 3 Radar Graphic Output

travel rates along the surface, determination of horizontal misalignment was only approximate. Only gross misalignment or horizontal translation could be detected. To improve estimates of horizontal displacement and skew a 3/8 in. thick plexiglass guide was used in the Texas and Wisconsin investigations.

The transducer was passed on top of the 15-ft. long plastic guide between two rails. The guide served several purposes including:

1. Allowing dowel depths to be determined at a constant offset distance from the joint.

2. Facilitating uniform travel rate along the joint to allow for horizontal displacement and skew estimation.

3. Providing a template for triggering reference marks on radar output.

A triggering mechanism was assembled and attached to the transducer. Studs mounted on the plastic guide at uniform 4-in. spacings triggered the marker. The guide was consistently placed in the same position to allow for estimation of horizontal position and misalignment levels.

Based on experience from the three investigations, it was determined when the transducer passed very near or over the end of the dowel, a relatively weaker return signal was received resulting in a lighter gray recording. In such instances, to eliminate additional subjective variance in interpolating output, the test was repeated at a 4-in. offset. This repetition also allowed for qualitative verification that the dowel embedment lengths were at least 4-in.

Based on laboratory testing and the Idaho investigation, the water content in freshly placed concrete decreased to a level where the radar could penetrate a minimum of 5 in. down to the dowels when the concrete was between 24 and 48 hours old. The penetration depth of radar signals is directly dependent upon the dielectric constant of concrete which can be greatly affected by the presence of salts or water. The evaluation of misalignment in Texas was done weeks after paving when the water content had sufficiently decreased allowing dowels to be easily located.

In Wisconsin it was planned to measure alignment of dowel bars placed with the inserter as soon as possible after concrete placement. The radar survey was first attempted when the concrete age ranged from one to five days. The reflected dowel radar signals were not clearly processed by the control unit. Dowel traces were only received and processed when the radar antenna was passed directly over the sawed joints. This indicated that the signals were not penetrating the concrete to the depth of dowels at locations away from the saw cuts. Recent attempts by the radar manufacturer, GSSI, to use both a different antenna and modified antenna to evaluate dowel depth within 24 hours of concrete placement were not successful. The evaluation was completed several weeks later when the water content had sufficiently decreased allowing dowels to be easily located. This suggests that the minimum time required for the water content to sufficiently decrease to allow dowels to be easily located can range from one day to two weeks depending on the specific concrete mix, aggregate type, salt content, and moisture content.

Radar Calibration

During the investigations, cores were obtained to calibrate the output at dowel locations identified by the radar. The number of cores varied from 15 in Idaho to 39 in Wisconsin. An additional 123 calibration points were used in the analysis of data from Wisconsin. The additional calibration points were provided when four joints were removed and replaced for dowel bar alignment and depth verification, as required by contract specifications. As the number of data points increases, the calibration of output generally improves. From the calibration data, the graphic recordings are calibrated to obtain the actual dowel bar depths (top of steel).

Previous laboratory testing during the Texas investigation indicated the degree of influence the plastic guide exerted on test results was proportional (rather than constant) to the depth of the dowel. To reduce any proportional influence of the plastic guide, a calibration factor dependent on the depth of steel was developed for the Texas and Wisconsin study. A least squares linear regression analysis was performed on the data used for calibration of the radar. The radar paper depth of the dowel was regressed on measured dowel depths as shown in Figure 4. The paper depth of the dowel was determined by measuring the distance on the graphic output from slab surface to peak of dowel signal. This "paper depth" was input into the regression equation to determine the estimated dowel depth. Separate calibration curves were developed for the Wisconsin data. Attempts to use the regression equation derived from inserter joint data on the basket assembly data were not successful. On average, the predicted dowel depths for basket joints using the inserter regression equation underestimated actual depths by 0.4 in. Differences probably occurred due to the differing ages of concrete during the separate radar evaluations. In the Texas study the same calibration curve was used. This suggests that the calibration curve is dependent on concrete age. As the time between paving and radar testing increases to several days, concrete age is not a variable.

The regression analysis of actual dowel depth on radar output depth in the Wisconsin study yielded a coefficient of determination (R-squared) of 0.95 and 0.41 for inserter and basket joints, respectively. For the Texas calibration data the coefficient of determination was 0.88. The value of R-squared varies from zero (no statistical power of explanation) to one (complete explanation of sample variability) and is a measure of how well the derived curve fits the sample data. This indicates that the resulting calibration curve explains 88% of the observed Texas sample variability in dowel depth. The prediction error is defined as the absolute difference between the measured dowel depth (top of steel) and predicted

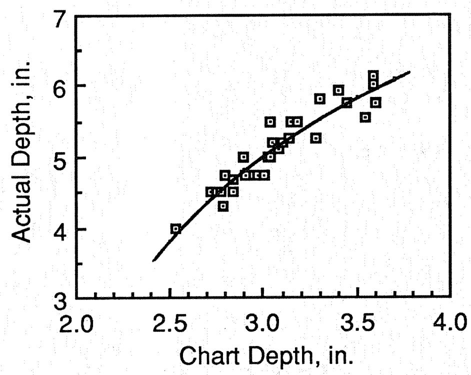

FIGURE 4 Calibration Graph

dowel depth from regression equation. For the relatively large number of calibration points from the Texas and Wisconsin data, most of the sample prediction errors were less than 0.2 in. This error is the observed sample error at given point estimates (paper depth). At most individual point estimates the 95% confidence interval is plus or minus 0.1 in. This indicates that while the sample error is plus or minus 0.2 in. or less for a given paper depth, for the population this error is 0.1 in. or less 95% of the time.

Variability Associated With Radar Measurements

The depth derived from radar testing is not an absolute measurement. Because of several factors, there is a variability associated with each measurement. These factors include operator experience, quality of calibration, and equipment operation.

An analysis of the regression residuals (observed minus predicted dowel depth) indicated that the semi-logarithmic linear regression models used for the Wisconsin and Texas evaluations are quite appropriate. A chi-squared goodness-of-fit test on the residuals demonstrated that the normal distribution is a valid model at the 5% significance level. Since the residuals are assumed to be normally distributed, the predicted dowel depths will also be normally distributed about the regression line with a common variance. The variance (standard deviation squared) of vertical misalignment is twice the regression error variance assuming that the two estimated dowel depths are statistically independent. The standard deviation (square root of the variance) of the difference in depth between two points along the dowel bar, S_v, is given as follows:

variance $S_v^2 = 2S^2$

standard deviation $Sv = 1.414S$

where S = standard deviation of predicted dowel depth, in.
S_v = standard deviation of predicted vertical misalignment, in.

The probability of a dowel being misaligned vertically given an allowable level of misalignment, can then be calculated using statistical procedures. The probabilities for dowels being misaligned for several allowable levels of misalignment are shown in Figure 5. This figure was derived from the Wisconsin calibration data from dowels at inserter joints using a variance of 0.0925 sq. in. (predicted dowel depth). Given an estimated vertical misalignment of 3/4 in./ft and specified allowable misalignment of 1/3 in./ft, the probability of the dowel being out of specification is 0.84. The probability of detecting a dowel exceeding specified allowable vertical misalignment increases with decreasing calibration variance, increasing measured misalignment, and decreased allowable misalignment. Similar results were obtained for the Idaho and Texas data.

Summary of Data

Detailed dowel bar alignment data are presented elsewhere.(2,3,4) A total of 16 joints were evaluated in alternating inside and outside lanes during the Idaho investigation. Dowels were placed at all 16 joints with a Gomaco dowel bar inserter. The evaluation in Texas compared alignment data from 51 two-lane joints where basket assemblies were used to data from 52 two-lane joints where the Guntert and Zimmerman dowel bar inserter was used. Similar to the Texas study, data from 50 joints where a Guntert and Zimmerman dowel bar inserter was used was compared to 30 joints where conventional basket assemblies were pinned to the subbase.

Average Depth

Using data obtained from both sides of the joint, the average depth to the top of each dowel was calculated. Average depth was calculated to compare the effectiveness of the inserter to place dowels at the proper depth. Dowels with excessive vertical translation from slab mid-depth can cause joints to spall. The capability of the dowel to transfer loads across the joint can also be reduced when dowels have large levels of vertical translation. Loss of load transfer can increase

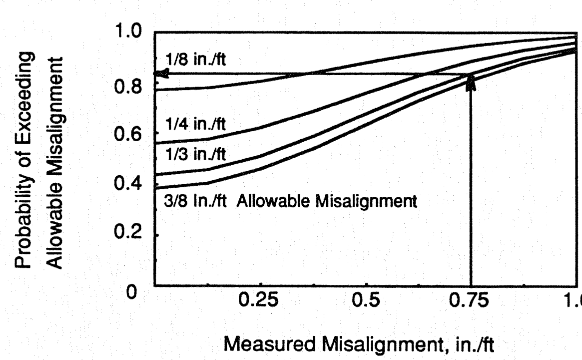

FIGURE 5 Probability of Exceeding Allowable Misalignment

slab deflections under load causing pumping and loss of subbase support. This can then cause premature joint and corner cracking.

Dowel bar depth was generally consistent for both types of construction. Results of the Wisconsin investigation are summarized in Table 1. Average depth (top of dowel bar) was generally maintained to within plus or minus one inch of slab mid-depth. In the Texas study dowels tended to be deeper than design mid-depth at both types of joints. The results in the Idaho Study were similar to those of the basket assemblies in Wisconsin. Although average dowel depths are similar for both joint types in the Wisconsin study, the basket joint dowels exhibited slightly higher within-joint uniformity. The within-joint range of dowel depths at individual joints averaged 0.8 and 0.4 in. for inserter and basket joints respectively. These values represent the within-joint variation in dowel bar depths. In the Texas investigation the uniformity was similar for both types of joints.

Vertical Misalignment

Using the depth data obtained from both sides of the joint, the vertical misalignment (tilt) over a 12 in. dowel length can be calculated. Dowels with excessive vertical misalignment can prevent the joint from opening and closing easily. Dowels should be placed as parallel as practical to the longitudinal axis to prevent the joint from locking as adjacent slabs move due to both temperature change and shrinkage of concrete. Vertical misalignment can cause joint spalling, joint cracking, corner cracking, and a reduction in load transfer capability. Loss of load transfer can cause premature joint and corner cracking. The degree of deterioration depends on both the magnitude of vertical misalignment as well as the number of misalignment dowels per joint.

Vertical misalignment was generally consistent for both types of construction. Average magnitude of misalignment ranged from 0.1 to 0.2 in. per foot. Results of the Texas evaluation are summarized in Table 2. The percentage of dowels exceeding specified misalignment tolerances ranged from 9 to 15% for the three studies. In the Wisconsin study the percentage of dowels out of specification was lower at joints where basket assemblies were used due to above average construction control and a smaller size sample for comparison.

The distribution of misalignment was generally symmetric around zero for dowels at joints where basket assemblies were used. At joints where the inserters were used the distribution of misalignment indicates the dowels are tilted forward in the direction of paving. The distribution of misalignment for the Wisconsin evaluation is shown in Figure 6. The theoretical normal distribution, derived using calculated averages and standard deviations, are also shown. Both distributions are clustered around the sample mean indicating that compared to the normal distribution, good control was maintained for both types of construction. There is a definite skew to the distribution indicating the direction of misalignment may not be independent of paving direction when inserters are used.

The percentage of dowels tilted forward or backward relative to paving direction is summarized in Table 3. At joints where the inserter equipment was used approximately 60% of all misaligned dowels were tilted either in the forward or backward direction indicating that vertical misalignment may be dependent on paving direction. At joints where baskets were used the difference is significantly less than the difference at inserter joints. Although dowels tend to be misaligned forward in the direction of paving using the inserter, the percentage of dowels exceeding specified allowable misalignment appears to be comparable to that using basket assemblies.

Horizontal Misalignment

Using data from both sides of the joint, horizontal misalignment over 12 in. (skew) can be evaluated. The horizontal position was estimated

TABLE 1 Summary of Dowel Depth for Wisconsin I-90 Project

	Inserter	Baskets
No. of Dowels	1145	719
Minimum, in.	2.7	3.8
Maximum, in.	5.9	5.2
Average, in.	4.3	4.6
Std. Deviation, in.	0.41	0.22
Ave. Range per Joint, in.	0.8	0.4
Shallower than Spec., %	0.7	0
Deeper than Spec., %	4.5	0

Note: Dowel depth to top of steel

TABLE 2 Summary of Vertical Misalignment for Texas I-45 Project

	Inserter	Baskets
No. of Dowels	1329	1367
Maximum, in./ft	0.6	1.1
Average, in./ft	0.1	0.1
Ave. Range per Joint, in./ft	0.3	0.5
More than 1/4 in./ft, %	14	15

Note:
Misalignment statistics based on absolute magnitudes of misalignment.

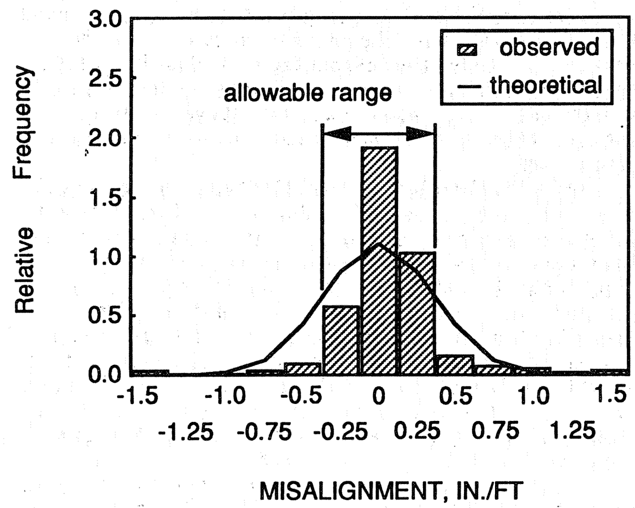

FIGURE 6 Distribution of Inserter Vertical Misalignment

by interpolating dowel location relative to the reference marks on the recordings. In the Texas and Wisconsin evaluations reference marks, automatically printed on the radar output, represented an actual spacing of 4-in. Horizontal alignment was not evaluated in Idaho. Dowels with excessive horizontal misalignment can prevent the joint from easily opening and closing. Dowels should be placed as parallel as practical to the horizontal plane to prevent the joint from locking up as adjacent slabs move due to both temperature change and shrinkage of concrete. Horizontal dowel misalignment, like vertical misalignment, can lead to joint spalling, joint cracking, corner cracking, and a reduction in load transfer capability. Loss of load transfer can increase slab deflections under load causing pumping and loss of subbase support. This can then cause joint and corner cracking. The degree of joint deterioration depends on both the magnitude of horizontal misalignment as well as the number of misaligned dowels per joint.

The accuracy of horizontal misalignment is estimated at approximately 1/4 to 1/2 in./ft. There is more subjective interpretation involved in determining horizontal position than dowel depth. Errors can also be introduced during the radar evaluation. The guide, over which the radar antenna was passed, is placed in the same position relative to the outside shoulder. Any errors is consistently placing the guide at the same reference point introduces a constant horizontal offset for each dowel at that particular joint. Placement errors are also introduced when there is significant slump at the edge of the slipformed pavement and when the 6-in. joint offset for the radar pass is not maintained. Even though the accuracy in determining horizontal dowel position magnitudes may not be accurate and it is intuitive that dowels tend to be misaligned more in the vertical plane due to forward movement of the concrete during paving, the distribution of misalignment can still be examined for relative comparison purposes.

The distribution of misalignment was generally symmetrical for both studies where horizontal misalignment was evaluated. The percentage of dowels skewed in either direction relative to the paving direction was approximately equal in the Wisconsin study for both types of construction. This suggests that the direction of paving does not affect the direction of misalignment. For the Texas evaluation the distribution of horizontal skew was more asymmetrical. This difference may be attributed to the relatively smaller sample size evaluated. Similar to the results from Wisconsin, there is no significant difference in the distributions where the inserter was used and where basket assemblies were used.

Longitudinal Displacement

Longitudinal dowel displacement was qualitatively evaluated in the Texas and Wisconsin

TABLE 3 Distribution of Vertical Misalignment

Project	Inserter, percent		Baskets, percent	
	Forward	Backward	Forward	Backward
Idaho Interstate 86	38	62	NA	NA
Texas Interstate 45	61	39	52	48
Wisconsin Interstate 90	63	37	54	46

Note:
Positive misalignmentindicates that the dowel bar is tilted forward in the direction of paving.

NA indicates no construction using basket assemblies.

investigations. Significant displacement can significantly reduce the capability of the dowel to transfer load across the joint. Loss of load transfer allows increased slab deflections which can lead to joint pumping and erosion of subbase material. Loss of subbase support can then cause premature joint and corner slab cracking. Any longitudinal displacement detected may not necessarily be due to dowel placement techniques. Displacement can be introduced if the joint location for sawing is not correctly marked or the sawcut does not follow the marked joint location.

Longitudinal data from coring operations in Texas and Wisconsin for radar output calibration indicated that displacement could be qualitatively evaluated based on radar output strength. When the relative signal strength was weaker the dowel embedment length was considered less than one half the dowel bar length. The criteria used in evaluating longitudinal displacement was verified in the Wisconsin study. Coring data used for calibration of output at joints where basket assemblies were used indicated that only one case was misinterpreted for longitudinal position. Nine dowels were qualitatively evaluated to be longitudinally displaced. Coring verified that the ends of the dowels ranged from 9 in. (optional) to 3-5/8 in. and averaged 7-1/4 in. away from the joint. At the other sixteen dowel bar locations where the radar did not indicate any gross longitudinal displacement only one core was over the end of the dowel indicating less than an optional 9 in. embedment length.

The number of dowels at inserter joints displaced relative to the sawed joints was similar to that where baskets were used. In Wisconsin the percentage of dowels displaced was 9.3 and 7.5% for inserter and basket joints, respectively. This does not include joints where more than 2/3 of the dowels appeared to be longitudinally displaced. It was assumed that when more than 2/3 of the dowels at a given joint were displaced that the joint location was not properly marked or that the joint was sawed at an offset. The percentage of dowels longitudinally displaced in the Texas evaluation was similar with the percentage of dowels slightly less at joints where basket assemblies were used. The percentage drops to 2.7 and 1.8% for the Texas data for inserter and basket joints, respectively. The overall percentage drops since the test was run at a 6-in. joint offset in both studies but the dowels in Texas were 22-in. long compared to 18-in. long in Wisconsin. Also the joints in Wisconsin were skewed amplifying longitudinal displacement if the joint locations were not correctly marked or the sawcut does not follow the marked joint location.

Summary

Overall, the dowel bar inserter performed well compared to the basket assembly construction. Based on dowel depth, longitudinal displacement, vertical tilt, and horizontal skew there does not appear to be any significant differences between the two types of construction. The percentage of dowels vertically misaligned is similar for both types of construction. The distribution of tilt is more symmetrical for basket joints than inserter joints indicating that vertical misalignment may not be independent of paving direction. Horizontal misalignment appears to be independent of paving direction. At present there exists a need for improvement in the radar technique to estimate horizontal skew. Longitudinal displacement relative to the joint was estimated qualitatively. Due to variability in radar output interpretation and operator experience the presence of displacement rather than degree or magnitude can only be estimated. The occurrence of longitudinal displacement was similar for both types of joints. Any longitudinal displacement detected may not be necessarily due to dowel placement techniques used. Displacement can be introduced if the joint location for sawing is not correctly marked or the sawcut does not follow the correctly marked joint location.

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The opinions and findings expressed or implied in this paper are those of the authors. They are not necessarily those of the Idaho Department of Transportation, Texas State Department of Highway and Public Transportation, Wisconsin Department of Transportation, or Federal Highway Administration.

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