Summary of Recent Studies of Dowel Alignment for DBI vs. Basket Installations

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December 12, 2012

Introduction

The following summarizes recent studies that have examined the relative alignment accuracies of concrete paving dowels installed using Dowel Bar Inserter (DBI) equipment and traditional dowel baskets. It is limited primarily to informal works done in New York and West Virginia using the MIT-SCAN2 magnetic tomography imaging equipment and related software, but also includes a 2003 study from Missouri that was performed using GPR technology, a study done in 1988 in Wisconsin using pavement cores to verify dowel location, and references work done even earlier in Texas.

Missouri US 60 near Van Buren

A five-mile divided highway, the eastbound lanes were reconstructed in 2002 using DBI (as an experiment – MoDOT had not allowed DBIs on highway projects prior to this time) while the westbound lanes were reconstructed using dowel baskets.

The investigation started with the selection of 10 joints spaced at 400-m intervals in each direction. A hand-held GPR unit was used to compare dowel bar placement accuracy for the two installations, and a hand-held pachometer (magnetic steel locator) was used to measure dowel bar depths at one joint in each direction to provide calibration data for the GPR. The GPR was used to provide accurate measures of horizontal and vertical skew, transverse translation and depth. Measurements were obtained at 4.5 and 9 inches on either side of the transverse joint. Details of the test equipment and protocol are included in Donahue (2003).

Results – Skew

The results of the MoDOT US 60 dowel measurements are summarized in Tables 1 through 3 below. Table 1 shows that the DBI produced slightly less average horizontal skew than did the dowel baskets (0.41 inches vs. 0.48 inches). Much of this lower average for the DBI can be attributed to the 40 percent reduction in highly skewed (>1 inch rotational misalignment) dowels. The MoDOT report noted the similarity of these results to those of a 1988 Texas study, which found average horizontal skews of 0.49 inches and 0.51 inches for the DBI and basket installations, respectively (Okamoto, 1988).

Table 1. Horizontal Skew Comparison for MoDOT US 60

Type	Number of Dowels	Mean Horizontal Skew (in)	% ≤ ½"	½" < % ≤ 1"	% > 1"
DBI	360	0.41	67.2	23.9	8.9
Basket	368	0.48	60.9	23.9	15.2

Table 2 shows that much lower levels of vertical skew were observed for both installation types and that neither installation type had significant incidence of vertical skew > 1 inch. Again, the DBI had slightly lower average overall skew (0.23 inches vs 0.27 inches) while the baskets had a slightly higher percentage within 0.5 inches of true.

Table 2. Vertical Skew Comparison for MoDOT US 60

Type	Number of Dowels	Mean Vertical Skew (in)	% ≤ ½"	½" < % ≤ 1"	% > 1"
DBI	360	0.23	88.9	10.6	0.5
Basket	368	0.27	92.7	6.8	0.5

It was noted that oppositely misaligned dowels are more critical to joint function than uniform misalignment. Table 3 shows that, on this project, the DBI produced about 10 percent fewer oppositely horizontally skewed dowel pairs (>0.5 inches each) than did the basket installation. The DBI resulted in no oppositely vertically skewed dowel pairs (>0.5 inches each), while the baskets resulted in 3 oppositely vertically skewed dowel pairs.

Table 3. Oppositely Skewed Dowel Summary Comparison for MoDOT US 60

Type	Horizontal Oppositely Skewed Pairs (> ½" each)	Horizontal Oppositely Skewed Pairs (> 1")	Vertical Oppositely Skewed Pairs (> ½")	Vertical Oppositely Skewed Pairs (> 1")
DBI	22	5	0	0
Basket	25	5	3	0

Results – Translation and Depth

Longitudinal translation was difficult to assess because of the limited number of GPR runs performed. The symmetry of surrounding dowels at any given joint indicated that, in most cases, any longitudinal misalignment was minor and probably due to slight operational drift in the DBI or a slight distortion in the dowel basket. There was one case in each installation sample where it appeared that a single dowel was longitudinally misplaced beyond acceptable tolerances; it was determined that these cases were due to mislocation of the joint mark or sawing and were not a result of inherent flaws in the DBI or baskets themselves.

Significant horizontal (side-to-side) translation was not observed.

Dowel depth was considered difficult to assess comparatively because of the accuracy limitations of the GPR (± 1/8 inch for depth) and the differences in placement reference plane for the two dowel installation techniques (installations are performed at depths relative to the top surface for

the DBI and at heights relative to the subbase surface for the baskets, which can result in varying concrete cover). It was observed that the DBI depth standard deviation was much less (0.22 inches) than that of the baskets (0.37 inches), which is what would be expected because of the differences in placement reference. Because of GPR accuracy issues and variations in slab thickness, it was impossible to know exactly how close the DBI and dowel basket installations were to the actual slab mid-depth, but it was concluded that they were both reasonably close to MoDOT specifications.

Based on the results of this experiment, MoDOT began to allow the use of DBI on their paving jobs.

West Virginia SR48 and SR9 – April 2012

MIT-SCAN measurements were obtained for several transverse joints of a single travel lane at each of three locations: 19 joints of an unground section of SR48 where a dowel bar inserter (DBI) was used in construction; 6 joints of a diamond-ground section of SR48 where a DBI was used in construction; and 22 joints of an unground section of SR9 where dowel baskets were used in construction. These measures were obtained during an MIT-SCAN training session by WVDOT staff. A summary of the results of these measurements, as they apply to comparing the relative quality of alignment of the DBI and dowel basket sections, is presented in Table 4 below.

Table 4. Summary of West Virginia Dowel Alignment Data (all measures in mm)

	Depth	Measured Depth minus Plan Depth	"SideShift" (longitudinal translation)	Overall Misalignment	Horizontal Misalignment	Vertical Misalignment	Minimum Cover
DBI Location 1 (no grind)							
Average	132.0	5.0	26.9	12.2	0.5	-4.4	111.3
SD	7.0	7.0	34.8	11.8	7.7	14.5	9.1
DBI Location 2 (diamond ground)							
Average	130.1	3.1	12.0	11.2	3.1	-1.3	109.8
SD	5.0	5.0	22.2	11.0	9.2	12.3	6.2
Dowel Basket Location							
Average	131.8	4.8	2.3	14.1	11.5	0.2	111.8
SD	11.9	11.9	14.5	7.3	6.2	9	9.4

The table above leads to the following observations concerning the relative alignment of dowels recently installed in West Virginia using DBI and dowel baskets:

- The average depth of dowel placement was essentially the same for the DBI sections and the dowel basket section, although the variability of depth was nearly double for the dowel basket section. This is not unexpected because the MIT-SCAN estimates distance to mid-

dowel from the pavement surface and DBIs place dowels at depths relative to the pavement surface while dowel baskets provide a constant height above the surface upon which the baskets are placed and the depth from the surface may vary with normal variations in pavement thickness.

- Deviations in dowel depth from planned depth averaged 5mm or less for all three test sites, and the standard deviation of these values ranged from 5 – 12 mm. These numbers suggest that most dowels placed using either DBI or baskets would be within the WV specified range (+/- 25mm) of the planned vertical location when measured from the surface. 5 – 10 percent of the dowels placed using baskets would be expected to fall outside of this range (mainly due to basket height being referenced to the bottom of the slab while MIT-SCAN measures are referenced to the top surface of the concrete slab.
- The average "side shift" (longitudinal translation or distance from joint location to center-of-dowel) was much higher in the DBI sections (12 – 27mm) than in the dowel basket section (2.3mm), and the variability was 50 – 140 percent higher in the DBI sections. The side shift values measured do not suggest a cumulative error in dowel insertion location, so this suggests that the contractor on this job had more difficulty in accurately locating and marking and saw cutting the exact center of the dowels when using the DBI.
- Average total misalignment values were generally higher for the basket-placed dowels than for the DBI dowels, but the variability in the DBI dowel misalignment was at least modestly higher in all cases (i.e., 7 – 9 mm for the baskets vs. 7.7 – 14.5 mm for the DBI dowels). The horizontal misalignment component was, on average, much higher for the basket dowels than for the DBI dowels. Conversely, the average vertical misalignment component was negligible (0.2mm) for the basket dowels but was 1.1 to 4.4 mm for the DBI dowels.

New York State DOT Work – various locations

Cold Spring Construction has constructed several projects on Interstate 90 in NY, Rte 219 near Springville, NY and I-86 near Sherman, NY in New York using a DBI; portions of Rte 219 and I-86 were constructed using dowel baskets, and an additional project on Rte 78 near Williamsville, NY (a local road) was also constructed using dowel baskets. Cold Spring Construction measured dowel alignment using the MIT-SCAN device on all of these projects and provided the data summaries that follow to document the quality of alignment obtained with both construction techniques.

Tables 5 and 6 summarize aggregated dowel alignment data from these projects for DBI and dowel basket installations, respectively. Nearly 19,000 DBI-placed dowels were evaluated in eight 500-ft test sections, while nearly 1300 basket-placed dowels were evaluated on the 4 projects described previously.

For these projects, maximum allowable misalignment levels were considered to be 15mm total rotational misalignment, 50mm side shift (longitudinal misplacement, and 25mm vertical translation. Table 7 summarizes the percentages of dowels placed using each technique that met these criteria and shows that the DBI provided overall better alignment results in all modes of alignment. It must again be pointed out that the vertical translation issues with the dowel baskets are most likely due to the placement of fixed-height baskets on a prepared foundation layer with

subsequent measurement with respect to the finished pavement surface (a different plane of reference).

At the time this report was prepared, raw data was not available for computing either overall or project-specific averages and standard deviations for the Cold Spring Construction project data.

Table 5. Summary of Dowel Alignment Data for Available NYSDOT DBI Projects
(data summary provided courtesy of Cold Spring Construction)

Data comes from 8 - 500 m Test Strips on the 3 projects in which DBI was used

Resultant Misalignment

Misalignment Ranges (mm)	Counts				Percentages
	I-90	Rte. 219	I-86	Total	
d ≤ 10	9691	1122	1333	12146	64%
10<d≤15	3400	823	869	5092	27%
15<d≤20	882	280	224	1386	7%
20<d≤25	158	72	34	264	1%
d > 25	37	13	4	54	0%
				18942	

Sideshift

Misalignment Ranges (mm)	Counts				Percentages
	I-90	Rte. 219	I-86	Total	
d ≤ 10	7340	1561	1071	9972	53%
10<d≤20	4371	594	801	5766	30%
20<d≤30	1748	129	402	2279	12%
30<d≤40	517	24	137	678	4%
40<d≤50	138	2	37	177	1%
50<d	54	0	16	70	0%
				18942	

Vertical Translation

Misalignment Ranges (mm)	Counts				Percentages
	I-90	Rte. 219	I-86	Total	
d ≤ 10	10719	1416	2125	14260	75%
10<d≤15	2184	575	259	3018	16%
15<d≤20	873	246	65	1184	6%
20<d≤25	251	58	11	320	2%
d > 25	141	15	4	160	1%
				18942	

Table 6. Summary of Dowel Alignment Data for Available NYSDOT Dowel Basket Projects (data summary provided courtesy of Cold Spring Construction)

Dowel Bar Alignment Statistics for Baskets

Data comes from Hand-Formed section on Rte.78 and Slip-Formed on Rte.78, Rte. 219, and I-86 in Sherman

Resultant Misalignment

Misalignment Ranges (mm)	Counts					Percentages
	Rte. 78 Slip	Rte. 78 Hand	Rte. 219	I-86 Sherman	Total	
d ≤ 10	110	116	107	338	671	52%
10<d≤15	89	54	52	196	391	30%
15<d≤20	30	19	31	52	132	10%
20<d≤25	15	12	16	10	53	4%
d > 25	16	10	14	4	44	3%
					1291	

Sideshift

Misalignment Ranges (mm)	Counts					Percentages
	Rte. 78 Slip	Rte. 78 Hand	Rte. 219	I-86 Sherman	Total	
d ≤ 10	53	73	107	365	598	46%
10<d≤20	63	45	51	168	327	25%
20<d≤30	57	40	32	43	172	13%
30<d≤40	39	31	17	19	106	8%
40<d≤50	30	18	10	5	63	5%
50<d	18	4	3	0	25	2%
					1291	

Vertical Translation

Misalignment Ranges (mm)	Counts					Percentages
	Rte. 78 Slip	Rte. 78 Hand	Rte. 219	I-86 Sherman	Total	
d ≤ 10	1	81	23	514	619	48%
10<d≤15	11	28	34	63	136	11%
15<d≤20	23	40	32	17	112	9%
20<d≤25	57	33	39	5	134	10%
d > 25	168	29	92	1	290	22%
					1291	

Table 7. Alignment Summary for Cold Spring Construction NYS Projects

	Total Rotational Misalignment <15mm	Side-Shift <50mm	Vertical Translation <25mm
	Percentages Meeting Above Criteria		
DBI	91	100	99
Basket-placed	82	98	78

Wisconsin, Various Locations
A 1989 study by the Wisconsin Department of Transportation examined the alignment of 294 DBI-placed dowels and 272 basket-placed dowels on 6 different projects that were constructed on major Wisconsin highways in 1987 and 1988. Dowel alignment was verified by coring the ends of each selected dowel and measuring the depth and lateral offsets of the dowel ends.

The project report included the following conclusions:

- The dowel bar inserter is capable of consistent satisfactory placement of dowel bars with respect to vertical translation (average depth), vertical rotation (difference in depth between two ends of dowel), and horizontal rotation (difference in transverse position between two ends of dowel) .
- The initial set-up of the dowel bar inserter with respect to depth of dowel placement is critical at the start of each project, and dowel depths should be verified by probing through the fresh concrete.
- The construction procedures currently used for marking and sawing joints need improvement both for inserter and basket projects, to consistently and accurately align the sawn joints with the midpoints of the dowel bars.
- Ride quality has improved on each successive inserter project, and on the latest project, the South Madison Beltline, a project PSI of 4.6 was achieved with minimal diamond grinding.
- Improved concrete consolidation around the dowels is needed both on inserter and basket projects, and quality control coring is needed to assess future progress in solving the problem of voids around the dowel bars.
- Problems with missing dowel bars on existing inserter projects appear to be infrequent and isolated, but this problem should be monitored on future projects.

The primary general recommendation from the study was to accept the DBI as an equal alternate to dowel baskets for future doweled WisDOT concrete pavement construction projects. This recommendation was accepted and DBIs have been used successfully (and, now, almost exclusively) on WisDOT construction projects for more than 20 years.

West Virginia SR9 New Construction – May 2012
A section of SR9 near Charles Town, WV was constructed by Golden Triangle Construction during the late spring and early summer of 2012. All construction was performed using a Guntert and Zimmerman paving system with a DBI. The contractor monitored and measured dowel alignment along three separate sections and provided that data (representing more than 2100 DBI-placed dowels) for consideration here. There were no basket-placed sections for comparison.

Horizontal Skew/Vertical Tilt:
Total rotational misalignment averaged 0.36 inches with a standard deviation of 0.24 inches, with average horizontal and vertical misalignments of 0.22 and 0.24 (absolute values), respectively. About 10 percent of the measurements indicated total rotational misalignment exceeding 0.6 inches (which is comparable to the 90% compliance rate for 15mm cited in the NY measurement studies).

Longitudinal Translation/Side Shift:
Total longitudinal translation (absolute value) averaged 0.67 inches with a standard deviation of 0.62 inches. About 3 percent exceeded 2 inches of misplacement and less than 1 percent exceeded 3 inches. This is a higher level than was observed in the New York field study, but is still not excessive or critical. It is not known whether the source of side shift was due to joint location difficulties in sawing or a placement error by the paver (or errors in measurement).

Vertical Translation:
Total vertical translation (absolute value) averaged 0.50 inches with a standard deviation of 0.25 inches. About 2 percent exceeded 1 inch of vertical misplacement, slightly higher than the 1 percent reported in the New York study. None would have exceeded the cover requirements cited in ACPA's new draft dowel alignment guidelines.

Summary and Conclusions
Data from studies going back to the 1980s and from field measurements conducted as recently as 2012 generally suggest that DBI-placed are generally as well-aligned (and, in some cases better aligned) than those that are placed in baskets. This is particularly true for the rotational misalignment, which is the type of misalignment that has the greatest potential for causing joint lockup and related distresses. This is probably due to the fact that DBI installations eliminate the potential for basket sliding and tipping due to the approaching concrete head when basket anchoring is inadequate.

References
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Unpublished MIT-SCAN2 data from West Virginia, provided by Golden Triangle Construction.

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