THE EFFECT OF SHEARING DEFORMATIONS ON PULL-OUT RESISTANCE OF STEEL DOWELS EMBEDDED IN CONCRETE

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THE EFFECT OF SHEARING DEFORMATIONS ON PULL-OUT RESISTANCE OF STEEL DOWELS EMBEDDED IN CONCRETE

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ABSTRACT: Laboratory pull-out tests were conducted on 40, 1-1/4-in. diameter steel dowel bars with deformed ends, cast in concrete blocks, and load and bar movements were recorded at various increments. Based on measurements obtained, working definitions of "out-of-roundness" and "burr" deformations were established for use in this study. Since 40 sample bars did not exhibit a sufficient variation of out-of-roundness or burr depth to satisfy the testing requirements, it was necessary to machine deformations on some of the bars. Fifty-three pull-out tests were performed on bars coated with RC 250 liquid asphalt (21 tests), plain uncoated bars (11 tests), and twenty-one were shop-coated with paint. The tests on coated bars gave the most meaningful information about the sliding resistance caused by burrs or out-of-roundness. The average maximum resistance developed by asphalt-coated shear deformed bars with 0.03 in. out-of-roundness was 1250 lbs. Asphalt-coated bars with 0.04 to 0.05 in. machined out-of-roundness developed average maximum pull-out resistance of about 3000 lbs and, with 0.04-in. machined burrs, developed an average maximum resistance of about 2300 lbs. Saw cut bars, coated with asphalt, developed an average maximum resistance of about 150 lbs. The tests of uncoated and painted bars served primarily to emphasize the importance of asphalt coatings. The pull-out loads observed in these tests were erratic and not fully attributable to the out-of-roundness or burrs existing on the bars. The tests showed that the out-of-roundness allowed by Michigan specifications could result in considerable sliding resistance, thus it was recommended that dowels used in contraction joints be saw-cut on the coated end.

KEY WORDS: dowels, testing, concrete, deformation, sliding, sawing, shearing.

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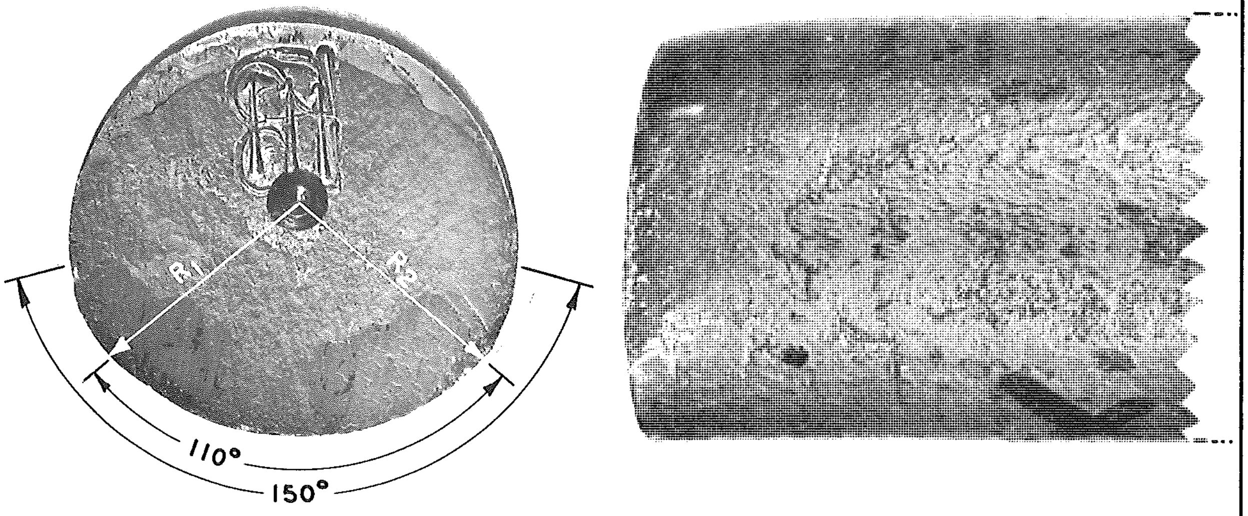
INTRODUCTION

This report covers experiments requested by C. B. Laird, Chief Construction Engineer, subsequent to a meeting held September 13, 1967. The meeting was attended by representatives of the dowel bar manufacturers and the Department's Divisions of Construction, Design, and Testing and Research. Specification requirements were discussed regarding allowable shear deformations. Paragraph 7.16.11 of the Standard Specifications states that: "The bars shall be straight and cut true to length, with ends square and free from burrs. Deformation from true shape caused by shearing shall not exceed 0.04 inch on the diameter of the bar, and such deformation shall not extend more than 0.4 inch from the end of the dowel." The bar manufacturers proposed revising the specification to allow 0.04-in. burr, or shear-drag, in addition to the 0.04-in. variation in diameter.

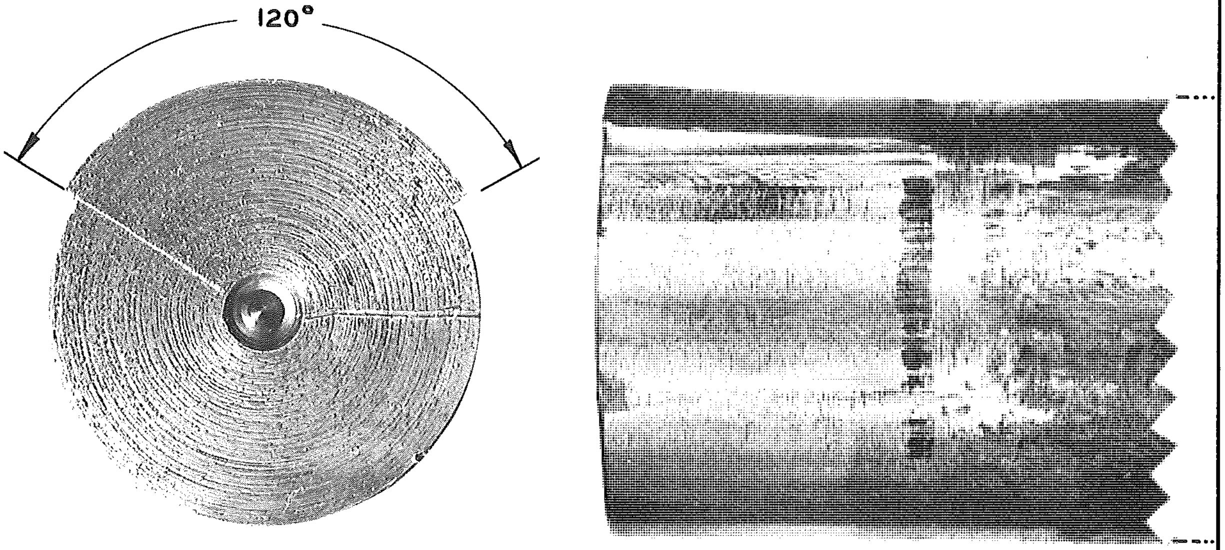
The Research Laboratory conducted tests to determine the effect of end deformation on the pull-out resistance of dowels embedded in concrete. The work was done as a cooperative effort by the Structures Unit and the Concrete and Surface Treatments Unit. Based on the suggestions of those attending the meeting, pull-out tests were made on plain, uncoated dowel bars and bars coated with RC 250 liquid asphalt. Field measurements were made to determine the thickness of asphalt coating currently being used in construction. Laboratory specimens were coated by dipping, and the thickness of coating was found to be typical of those measured in the field. Limited tests were also conducted with uncoated bars in weak, or "green" concrete.

In the case of uncoated bars, bond strength can be quite high and may mask the effect of the bar deformations. Therefore, the test results should emphasize the effect of the bond-reducing asphalt, as well as the effect of the bar deformations.

Pull-out resistance might be expected to be some function of the magnitude of the projections beyond the cylindrical cross-section of the bar. However, the volume of metal that protrudes is certainly a factor also,



Dowel bar end deformed by shearing.



Dowel bar end deformed by upsetting and machining.

Figure 1. Out-of-round dowel bars.

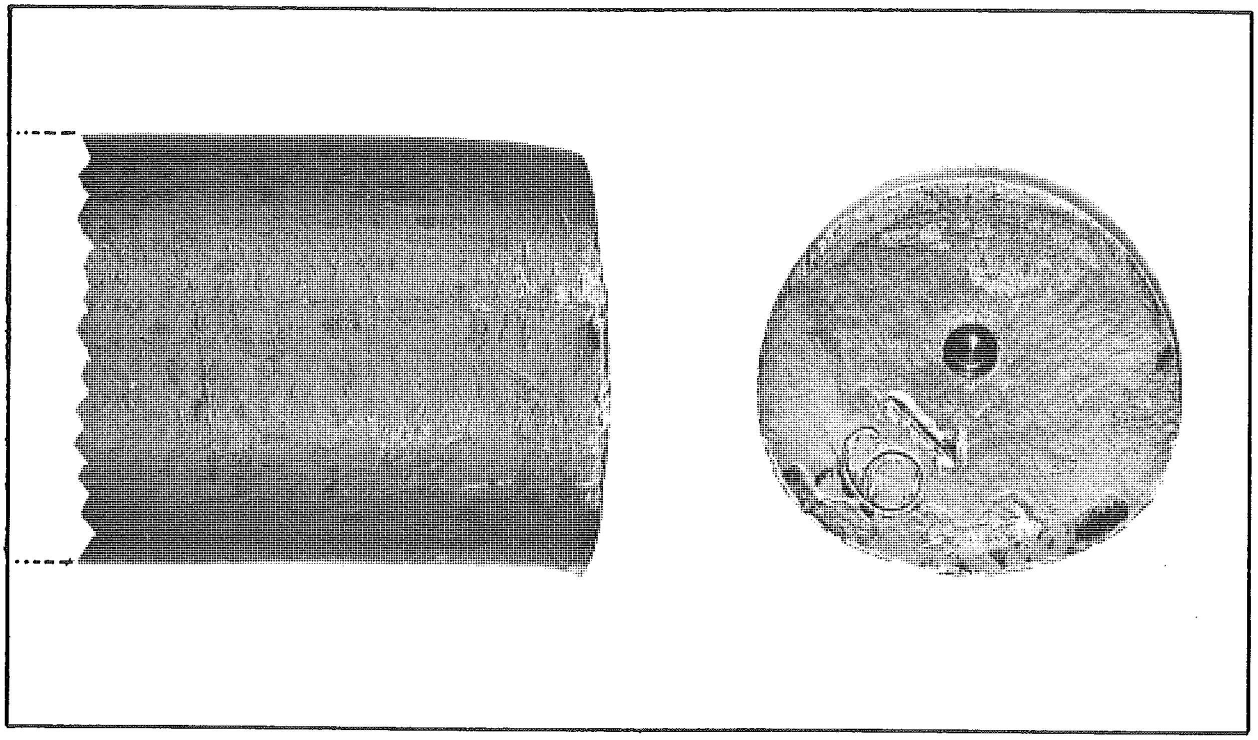
since a fine burr would deform far easier than a bulb-shaped projection of the same radial dimension.

The size and shape of bar deformations can vary considerably, depending on the type, quality, and adjustment of the shear. These variations make it difficult to obtain a precise definition which can be used in the comparative measurement of the deformed portions of the bar. Such definitions are necessary, however, because testing programs require replication of identical samples and also samples with known and controlled variations. A discussion of the methods used for measuring bar deformations is included in the appendix.

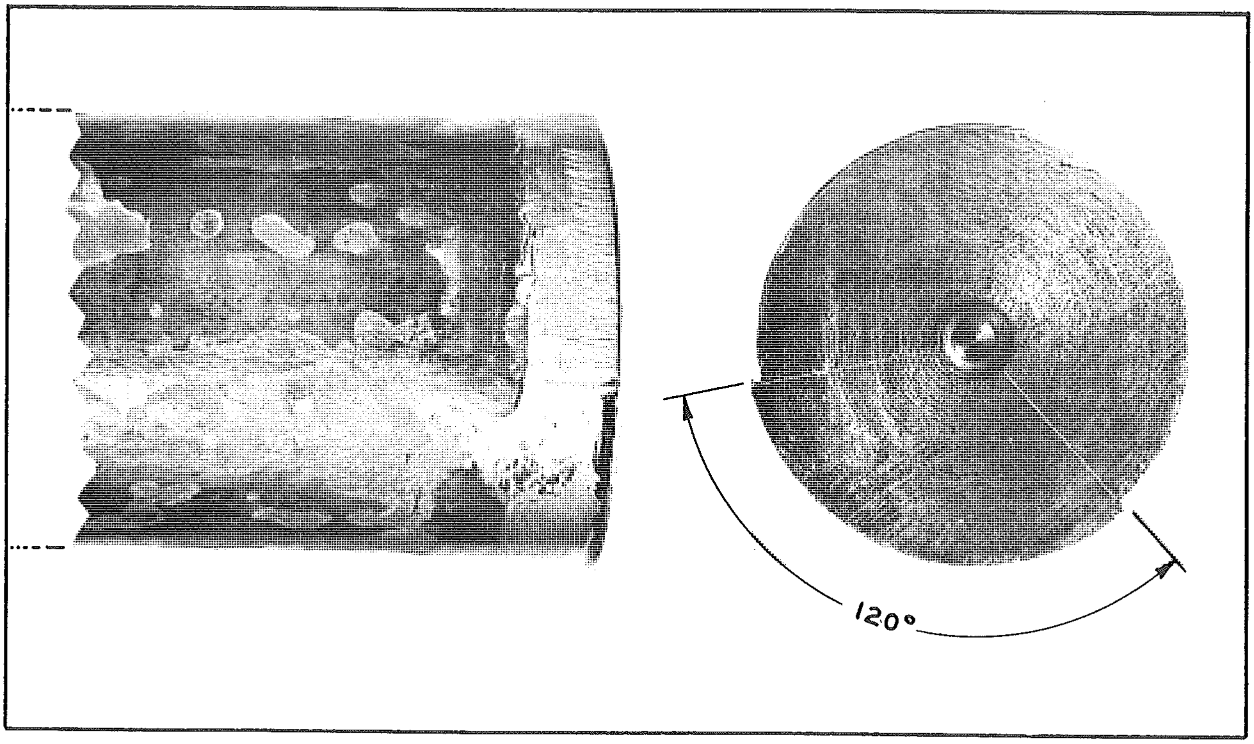
Figure 1 shows an example of one type of deformation that can occur when a bar is shear cut. The enlarged side view of the bar shows that the bar stock is generally pushed downward near the end of the bar. This downward distortion causes the bar to project outside its normal cross-section. The projecting deformation shown in Figure 1 extends about 1 in. longitudinally from the end of bar, and has as average maximum projection of 0.031 in. over a 110° sector between the maximum radii, R_1 and R_2. The end view of the bar shows that the total outward projection covers a sector of about 150°. For the purpose of this study, the type of deformation that extends a considerable distance from the end of the bar is defined as an "out-of-round" deformation. It can be seen that such a deformation would affect the pull-out resistance of an embedded bar because the metal extending outside the normal cross-section would meet interference as the bar is pulled out.

Some of the bars tested were machined out-of-round. It was necessary to fabricate these artificially deformed bars because there was not enough variation in out-of-roundness among the sample bars obtained to provide the desired range of variation for evaluation. The machined bars had a uniform projection covering a 120° sector at the bottom edge of the bar, which decreased linearly to zero projection at a longitudinal distance of 3/4 in. from the end of the bar, (Figure 1). The 120° sector was chosen since it seemed to give a reasonable representation of the variable projection over a larger sector of the deformed bars.

Another type of shearing deformation is shown in Figure 2. On the shear cut bar shown, the bar stock projects 0.02 in. below the normal cross-section at the end of the bar, but this projection decreases to zero within 0.02 in. from the end. The sector of the cross-section covered by this deformation is about 100 degrees on the bar shown. This type of deformation will be called a "burr." As with out-of-roundness, not enough variation in burr size existed in the samples obtained to get the desired



Dowel bar end deformed by shearing.



Dowel bar end deformed by upsetting and machining.

Figure 2. Burred dowel bars.

range for evaluation of this variable. Therefore, it was necessary to prepare samples with machined burrs. Figure 2 shows a sample with a 0.04 in. machined burr. All of the machined burrs were constructed on 120° sectors with projected heights equal to longitudinal extension.

In summary, two types of deformation were evaluated in this study and are referred to in this report as "out-of-roundness" and "burring." Out-of-roundness is defined as a deformation which projects beyond the normal bar cross-section and extends for a distance of 0.4 in. to as much as 0.75 in. longitudinally from the end of the bar. A burr is defined as a deformation which extends along the bar, a distance not greater than its radial projection from the normal bar stock.

TEST PROCEDURE

A total of 53 concrete test blocks were cast, 9 by 9 by 12 in., each containing one bar. Bars were 1-1/4 in. in diameter by 18 in. long. The 53 tests included 21 for effect of burrs, 23 for effect of out-of-roundness on pull-out resistance, and 9 for effect on green concrete. Twenty-one of the bars were coated with liquid asphalt, 11 were plain, uncoated and 21 were shop-coated with paint.

Special steel-faced forms were prepared to maintain dowel alignment perpendicular to the block face (Figure 3). Type III high early strength cement was used in all but the green concrete tests. Cylinders were cast for each group of test blocks and were broken to determine compressive strength of the concrete. Pull-out tests were run at seven days with concrete compressive strengths about 4000 psi at the time of test. Bar deformations of 0.00, 0.04, and 0.08 in. were selected for test purposes.

The pull-out tests were made on a universal testing machine with a dial gage for measurement of relative movement between the bar and block, (Figure 4). Bars were pulled out a total of 1/2 in. in each test. (Data from the Michigan Experimental Transverse Joint Project (Research Report No. R-634) indicated that 1/2 in. is about the maximum joint opening that can be expected of pavements with 71-ft slab lengths).

The samples for tests on green concrete were prepared with ordinary Type I cement. Initial pull-out of 1/8-in. was made at early age, and the blocks were then cured to about 4000 psi compressive strength before pulling the bar an additional 3/8 in.

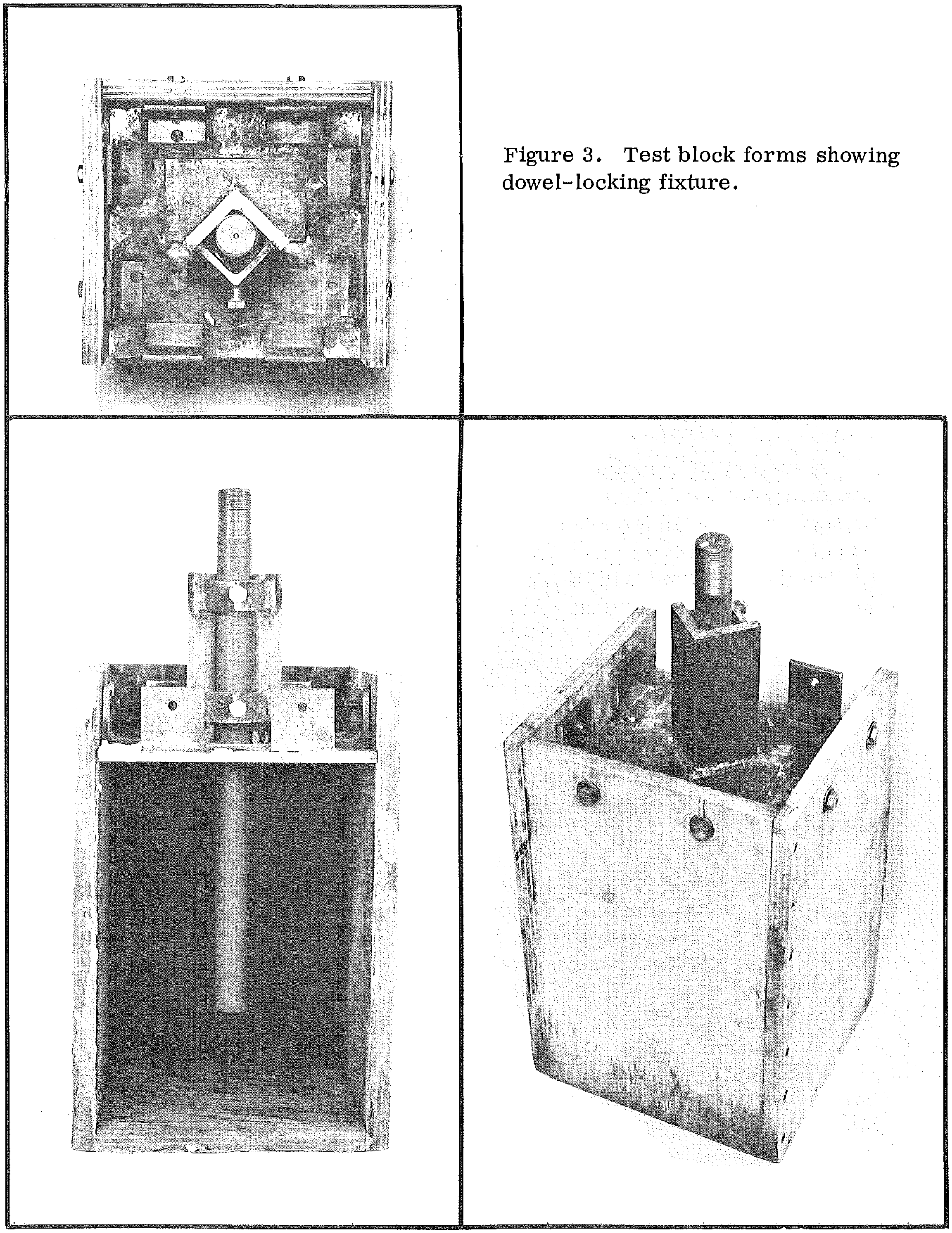


Figure 3. Test block forms showing dowel-locking fixture.

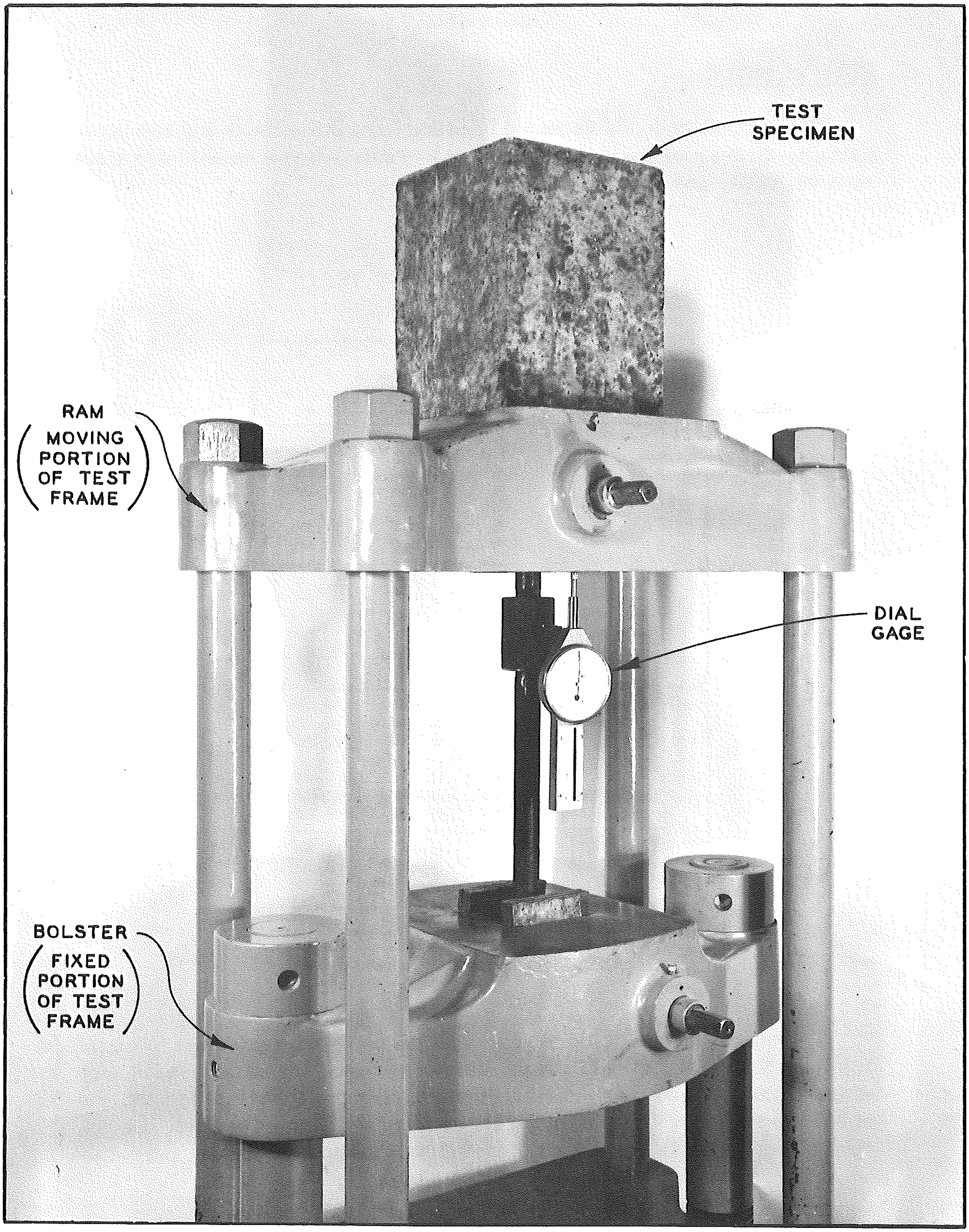


Figure 4. Pull-out test equipment.

TEST RESULTS

Effect of Burrs

These tests included uncoated bars and bars coated with RC 250 liquid asphalt. Results of the tests are shown in Table 1, for nominal burr sizes of 0.00, 0.04, and 0.08 in.

TABLE 1

DATA FROM PULL-OUT TESTS
ON BARS WITH BURRS

	Deformation Process	Burr Depth, in.	Maximum Pull-Out Resistance, lbs	Average Pull-Out Resistance, lbs
Group 1, asphalt coated	Machined	.08	5,800	4,500
		.08	4,450	3,000
		.08	3,900	3,150
		.05	2,300	1,800
		.05	2,350	1,550
		.04	2,150	1,600
	Saw cut and burr removed	---	100	100
		---	100	100
		---	150	100
		---	150	150
		---	100	100
		---	250	200
Group 2, uncoated	Machined(1)	.08	29,400	24,300
		.08	25,000	23,000
		.07	23,500	22,200
	Machined	.04	11,100	9,950
		.03	9,400	8,150
		.04	11,050	9,450
	Machined(1)	.00	17,250(2)	14,200
		.00	18,200(2)	16,250
		.00	13,400(2)	12,900

(1) Same bars with burrs removed for 0.0 burr depth test.

(2) Concrete compressive strength was 5000 psi in these samples. The other samples had strengths of about 4000 psi.

The coated bars with no burrs exhibited pull-out resistance of about 150 lbs, those with nominal 0.04-in. burrs developed a maximum resistance of about 2300 lbs, and the nominal 0.08-in. burred bars developed resistance of 3900 to 5800 lbs. The maximum and average resistance to pull-out developed by each sample are shown in the table. The tests on coated bars discussed here are denoted "Group 1" in the table.

Plain, uncoated bars with burrs were also tested, and the results are given in the table as "Group 2." The tests on uncoated bars showed that considerable resistance is caused by bar features other than the burrs. The tests on plain bars exhibited maximum pull-out resistances from 9400 to 29,400 lbs, far in excess of those obtained in any of the tests on coated bars with burrs. It was observed that bond between the concrete and dowel bar did not appear to be the only important factor that contributed to the pull-out resistance of plain, uncoated bars. The pull-out resistances developed were sustained at high levels for most of the distance the bars were pulled after reaching maximum values at pull-out distances of about 0.1 in. or greater.

In general, it was not possible to accurately evaluate the effect of the burrs on the pull-out resistance of uncoated bars. Other factors affected the pull-out resistance with such magnitude that the effect of the burrs was hidden. However, in one case, a rough estimate of the burr effect can be made. The bars with 0.08 burrs used in Group 2 were removed from the test blocks, machined free of burrs, and then re-cast for testing again. Thus, by subtracting the values of pull-out obtained in the later tests from those obtained in the earlier tests, a rough estimate of the resistance caused by the 0.08-in. burrs could be obtained. This computation gave pull-out resistances due to 0.08-in. burrs of from 6800 to 12,150 lbs. These values are much higher than those obtained using bars coated with RC 250 asphalt where some clearance exists around the bars. However, it should be noted that the surfaces of the bars were altered in the earlier Group 2 tests as several polished areas were evident on the bars. It would thus appear that some of the pull-out resistance that was caused by bar features other than the burrs probably was not developed in the later tests. The rough estimate of the effect of the burrs computed here would therefore appear high.

The tests performed on RC 250 asphalt-coated bars appear to be the most valid evaluations of pull-out resistance attributable to burrs. Moreover, Michigan Specifications require that dowel bars used in concrete pavements be coated with liquid asphalt. Although the effect of the coating may deteriorate in time, it is thought that the tests performed on coated bars better simulated the actual environment in which dowel bars normally function, than did the tests on plain bars. Thus, the tests on asphalt-coated bars provide a good measure of the effective resistance that burrs might develop in service.

Based on these tests, it is concluded that 1-1/4-in. diameter dowel bars coated with RC 250 liquid asphalt and embedded in concrete, develop

TABLE 2
DATA FROM PULL-OUT TESTS ON OUT-OF-ROUND BARS

	Deformation Process	Out-of-Round Depth, in.	Maximum Pull-Out Resistance, lbs	Average Pull-Out Resistance, lbs
Group 1, asphalt coated	Machined	.08	8,400	5,300
		.08	8,800	3,150
		.08	7,500	5,400
		.05	3,000	1,500
		.05	2,750	1,400
		.04	3,050	1,350
	Shear deformed	.03(1)	1,250	750
		.03(1)	1,250	700
		.03(1)	1,250	700
	Saw cut(2) and burr removed, bars	---	100	100
		---	100	100
		---	150	100
	Saw cut and burr removed	---	150	150
		---	100	100
		---	250	200
Group 2, uncoated	Machined	.04	12,900	11,500
	Sheared	.02(1)	9,700	6,550
Group 3, paint coated	Machined	.08	19,800	15,450
		.08	20,250	15,600
		.08	20,700	14,800
		.05	15,700	10,250
	Shear deformed	.03(1)	5,500	4,800
		.03(1)	4,250	4,200
		.01(1)	4,800	3,650
		.00(1)	4,850	3,600
		.00(1)	6,250	4,300
	Saw cut(2) and burrs removed, bars	---	7,000	3,000
		---	6,000	2,700
		---	5,750	2,700

(1) Equivalent machined deformity depth given. (Equivalent $\text{depth} = \dfrac{\text{radially projecting area}}{(\pi/3)(1.25)}$

(2) Same bars used in both tests.

maximum resistances to pull-out of about 150, 2300, and 4700 lbs, respectively, for nominal 0.00, 0.04, and 0.08 in. burr depths.

Effect of Out-Of-Roundness

Asphalt-coated, and shop-painted bars were tested, with ends deformed by shearing and machining. Results of the tests are shown in Table 2. Data on sawed bars with asphalt coating are repeated from Table 1 for easy reference. The geometry of the machined deformations is shown in Figure 1.

The results of this series of tests emphasize again the effect of the asphalt coating in reducing pull-out resistance. The results also indicate that pull-out resistance is about 1250 lbs for asphalt-coated, shear-deformed bars of the maximum size of deformations submitted for test (Group 1, Table 2). The most significant result of the series, however, is that pull-out resistance of asphalt-coated bars can be practically eliminated by sawing the ends.

Effect of deformations on the pull-out resistance of uncoated and painted bars was masked by other factors. Bars with larger deformations resulted in higher pull-out resistance but the results are erratic for tests involving smaller deformations and sawed bars.

Effect on "Green" Concrete

Nine pull-out tests were made on bars embedded in green concrete to simulate the effect of early pavement shrinkage. All bars used in these tests had been shop-coated with paint and were not coated with asphalt. Therefore, the distress should be more severe than would be expected in service. Test results are shown in Table 3. Initial pull-out of 1/8 in. at 1 day was followed by pull-out of an additional 3/8 in. after the concrete had cured 14 and 28 days.

Damage to the blocks was limited to conical surface spalls around the bars. Such failures are caused by concrete bonding to the bars and would not be expected to occur in pavements where the bars are asphalt-coated. The important result of these tests is that bar pull-out resulted in no major fracture of the blocks. Although the support condition is considerably different in the testing machine than in a pavement, the results seem to indicate that green concrete can withstand the distress of pull-out caused by early shrinkage.

TABLE 3
PULL-OUT TESTS TO DETERMINE EFFECT ON GREEN CONCRETE(1)

	Curing Time, days	Maximum Pull-Out Resistance, lbs	Damage to Block	Measured Bar Deformities		Compressive Strength of Concrete, psi
				Burr Depth in.	Out-of-Round(2) Depth, in.	
Shear Deformed Bars	1	2,550	surface spall	.02	.03	1,400
		2,500	small surface spall	.02	.03	1,400
		2,900	shallow crack	.03	.03	1,400
	28	5,100	surface spall	.02	.03	3,900
		5,100	not observed	.02	.03	3,900
		5,450	surface spall	.03	.03	3,900
Saw Cut Bars(3)	1	3,600	small surface spall	---	---	2,000
		3,200	surface spall	---	---	2,000
		4,050	no surface damage	---	---	2,000
	14	3,900	slight spall	---	---	4,200
		4,000	slight spall	---	---	4,200
		4,000	no damage to surface	---	---	4,200
Saw Cut Bars(3)	1	3,500	surface spall	---	---	1,400
		3,500	surface spall	---	---	1,400
		3,550	surface spall	---	---	1,400
	28	5,250	surface spall	---	---	4,700
		5,600	surface spall	---	---	4,700
		5,950	surface spall	---	---	4,700

(1) All bars listed in this table had shop-paint coatings only.
(2) Equivalent machined out-of-roundness depths are listed.
(3) Same bars cast in new blocks.

DISCUSSION AND CONCLUSIONS

Since bars submitted for testing did not have sufficient variation in magnitude of deformation, it was necessary to prepare machined specimens to obtain controlled deformations with size variations sufficient for testing. The machined bars are shaped differently from sheared bars because it is not practical to reproduce the shear-type deformation with the conventional turning or milling operations available in the Laboratory. However, the machined bars are believed to give a reasonable representation of the effect of metal protruding outside the ordinary cross-section of the bar. The shear deformed bars used in the tests, (Group 1, Table 2) had deformations that were near the 0.04-in. limit of present specifications. The deformations resulted in 1250 lbs pull-out resistance when the bars were coated with asphalt before embedment. Although the deformation due to shearing did not result in extremely large values of pull-out resistance, it is suggested that the Department should attempt to install dowels that provide a minimum of resistance to movement of the pavement. If such a policy is adopted, the tests have shown clearly that minimal resistance can be provided by dowels with sawed ends. Sawed dowels also have the advantage of easy inspection since the cylindrical shape of the bar is not affected by the cutting operation.

During this project, measurements were made of deformations on several dowel bars using the methods detailed in the appendix. It is difficult to make a determination of compliance with specifications regarding "deformation from true shape." Shear deformations may extend for nearly an inch from the bar end. Since it is the projection of metal outside the cylindrical shape of the bar that causes increased resistance to pull-out, it is that projection to which the specification and inspection technique should be directed. The major axis of the elliptically shaped shear deformation does not intersect the longitudinal bar axis; the ellipse is displaced downward by the shear. Therefore, measurement of the major axis dimension does not necessarily give the true departure from the cylindrical shape of the bar. Hot-rolled bar stock of 1-1/4 in. diameter may vary in diameter by plus or minus 0.011 in. in standard mill practice. Therefore, a cylindrical "no-go" gage could theoretically allow a 1.239-in. diameter bar to have 0.022 in. more metal projecting beyond the cylindrical surface than would be allowed on a 1.261-in. diameter bar. The use of personal judgment in acceptance of bars would result in variation of the amount of deformation that is acceptable, depending upon the inspector involved. This results in questions from suppliers, and recurring discussions for clarification.

Dowels of acceptable quality can be produced by shearing. However, it appears that if sheared bars are allowed, the pull-out resistance in the joints will vary, depending upon the amount of projecting metal. The amount of projecting metal will depend, in turn, on the quality of the shearing, and that point will undoubtedly be the subject of considerable future controversy. It is suggested, therefore, that sawing at least one end of the bars should be required.

It was mentioned at the meeting concerning dowel assemblies held on September 13, 1967 that saw-cutting dowels would cost about $.05 more per bar than shear cutting. It is thought that most of the fabricators of dowel bars could readily develop, or currently have, the capacity to saw-cut dowel bars. The State of Wisconsin currently specifies that the dowels furnished for use in pavement joints be saw-cut.

Conclusions

1. The effect of burrs and out-of-roundness were found to be of the same order of magnitude for asphalt-coated bars, although the greater volume of protruding metal resulted in somewhat higher pull-out resistance for the out-of-round specimens.

2. Pull-out resistance for plain and painted dowels was affected so strongly by factors other than end deformation that the results were not significant.

3. Bars pulled out of green concrete resulted in no major concrete failure, and it seems unlikely that fracture of pavements would result immediately from dowel movements caused by early pavement shrinkage.

4. The effect of asphalt coating in reducing pull-out resistance has been known for many years. Although this effect was expected, the 28 to 1 ratio of average pull-out loads required for uncoated and asphalt-coated sawed bars is highly significant.

5. Sawed bars exhibit lower pull-out resistance and ease of inspection. Asphalt-coated, shear cut bars with out-of-round deformities slightly less than the maximum allowed by the present specification developed about ten times more pull-out resistance than similarly coated, sawed bars (Table 2, Group 1).

RECOMMENDATIONS

It is recommended that specifications be changed to require dowel bars for contraction joints to be saw-cut on the coated end.

APPENDIX

Measurements of Bar Deformations

Using a micrometer, the maximum and minimum diameters of the cross-section of each bar were measured at distances of 1/16, 1, 3, and 6 in. from the end to be embedded. The radial variation of the bar along certain longitudinal lines was then profiled. The profiling procedure used will be explained further in this section.

The bars were classified with respect to out-of-roundness and burring, based on the longitudinal profiles. These profiling measurements were made with a dial gage as shown in Figure 5. The following several steps were involved in the profiling:

1. First, the bars were centered in a lathe by fastening the bar in the chuck at about 9 in. from the ends of the bar. This process provided centered indentations at each end of the bar coinciding with the undeformed bar axis.

2. Then the bar was fastened in the indexing device shown in Figure 5 by extending the cone-shaped supports of the device into the centered indentations at the ends of the bar. This procedure placed the undeformed axis of the bar parallel to the surface plate.

3. Next, a dial gage was mounted on a stand on top of the surface plate with the stem of the gage oriented perpendicular to the surface plate. The gage was moved to a position in contact with the top surface of the bar 1/16 in. from the deformed end of the bar.

4. The bar was then rotated on the supporting cones and thus the dial reading gave an indication of the variation in bar radius relative to the established bar axis at that cross-section. By observing the dial gage indications, the two largest radii were located and marked on the end of the bar. The minimum radius was also determined and marked. Figure 6 shows the location of these radii on one particular bar. In that figure, R_1 and R_2 denote the major radii and R_3 the minimum radius. The angles between these special radii were then measured. This was done in the following way: First, the bar was oriented with one of the special radii located under the dial gage stem. Then the clutch was fastened to the bar engaging the indexing gear. The bar was then rotated until the dial needle coincided with one of the other marked radii. By observing the movement of the indexing gear, which had teeth at ten-degree intervals, the angle of rotation between the two special radii was measured. In a similar manner, the angles between all of the three special radii were determined. Finally, a fourth radius was established at 180 degrees from the minimum radius, R_3, using the gear device.

5. Next, the bar was locked in position with the dial gage located over one of the four marked radii. Keeping the height of the dial gage fixed, the variation in height of the top of the bar was measured by moving the gage stem to various positions longitudinally along the bar. The vertical variation in the top surface of the bar was measured relative to the height of

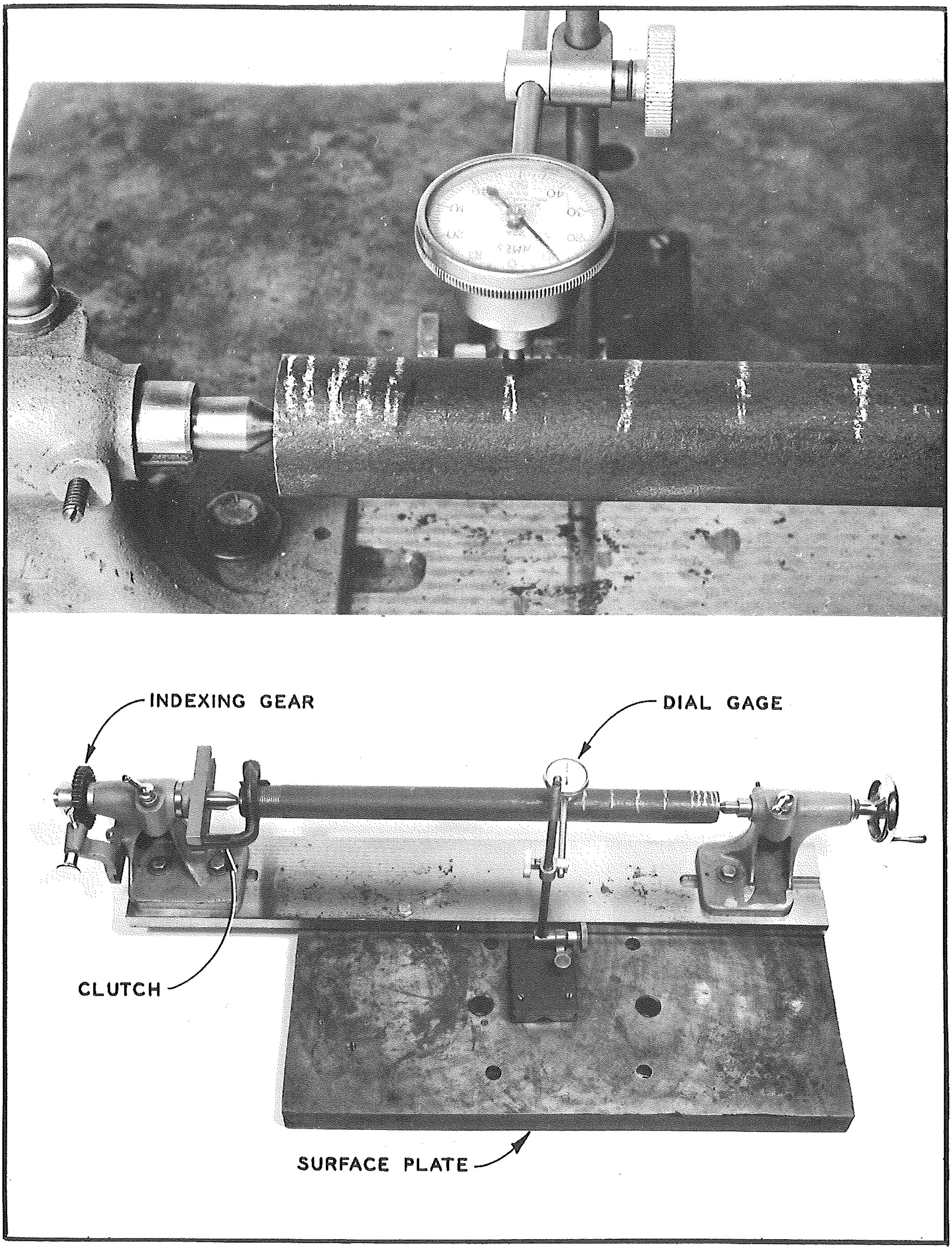


Figure 5. Apparatus used for profiling bar surface variation.

that surface at 1/16 in. from the end. This vertical variation was measured at points along the bar which were 1/8, 1/4, 1/2, 3/4, 1, 2, 3, 4, 5, and 6 inches from the deformed end.

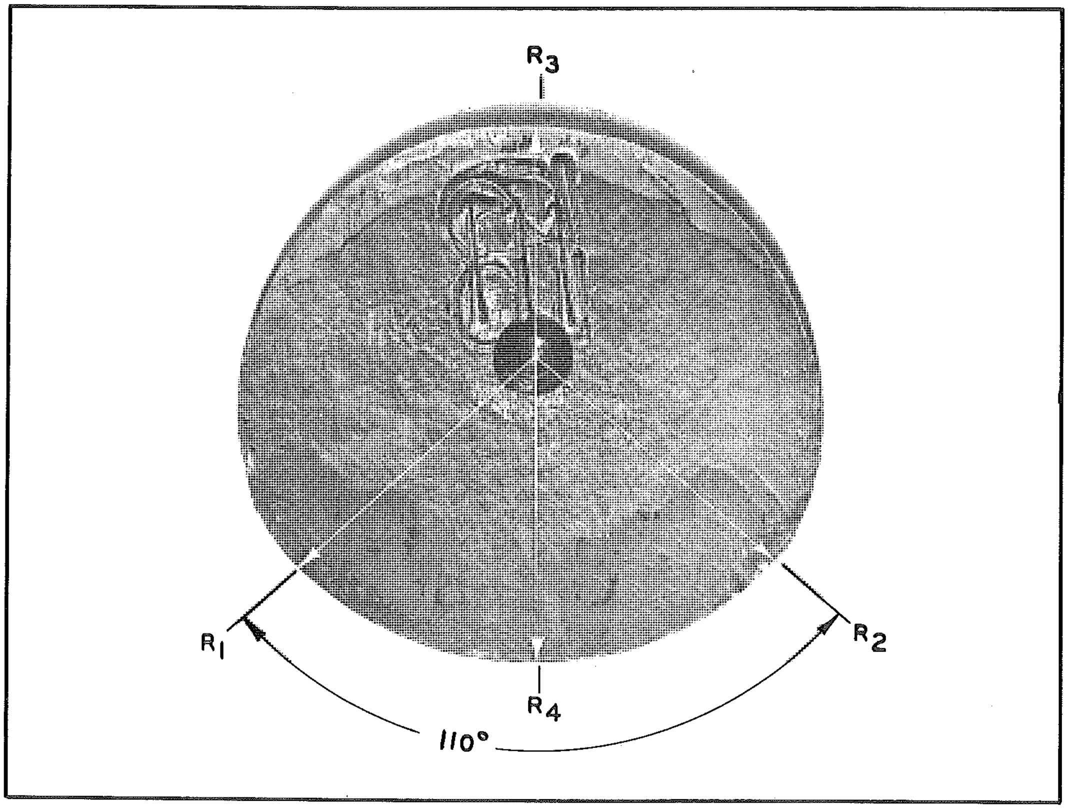
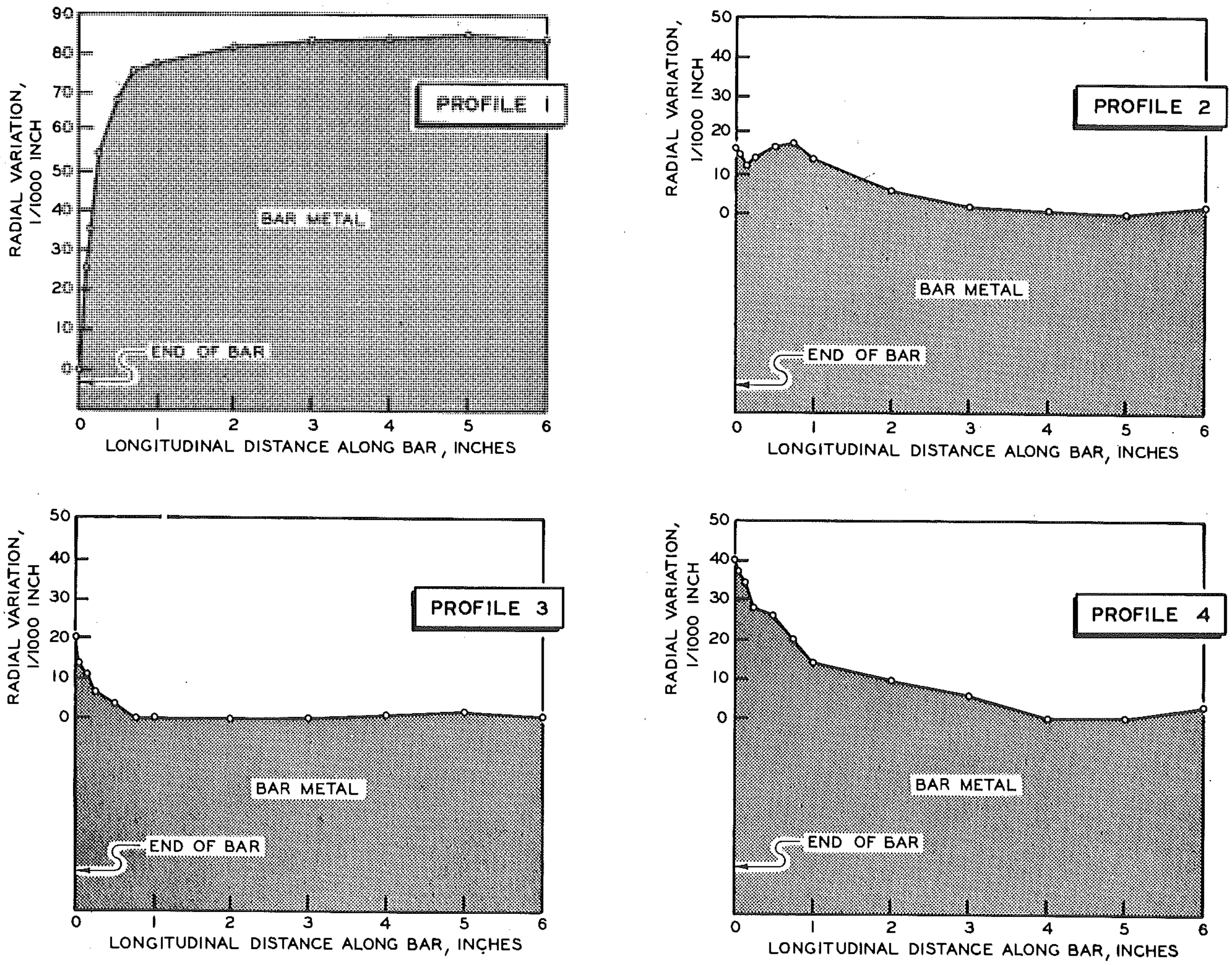


Figure 6. Location of radii on a shear-deformed dowel bar.

6. The measurements described above (5) were then repeated along longitudinal lines coinciding with the other three marked radii at the end of the bar.

Figure 7 is a graphical presentation of the four profiles measured on bar number 10. The profiles 2, 3, and 4 were of primary interest in this study since these indicated the existence of radial projections which would cause drag.



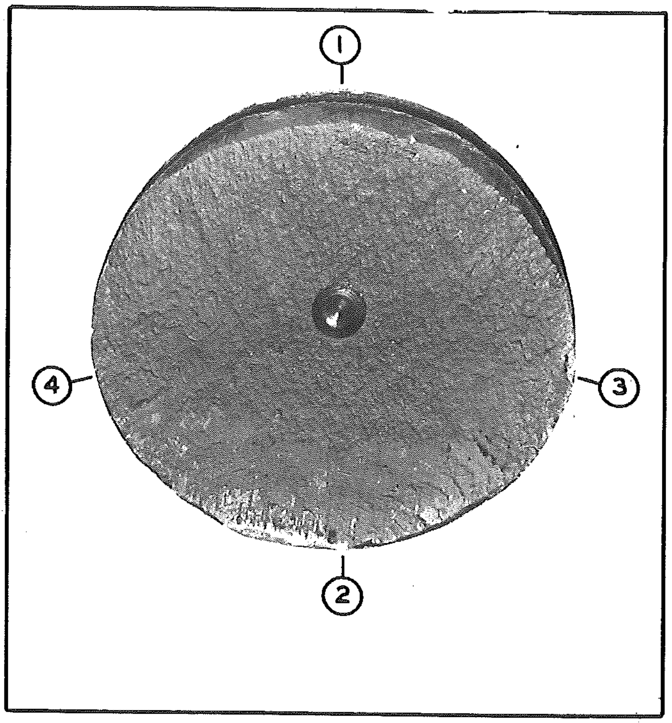


Figure 7. Longitudinal surface profiles of bar no. 10.