Evaluation of Bonding Strength of Grout Used in Intact Pavement Core Replacement

Report to

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RESEARCH SUMMARY

Title	Evaluation of Bonding Strength of Grout Used in Intact Pavement Core Replacement

Performing Agency	Gas Technology Institute (GTI)
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Objective

An ongoing project is being carried out at Southern California Gas Company (SoCal Gas) to support the development of the keyhole operations process. A major objective of this work was the development of a reliable method for the replacement of the intact cores. Up to this stage, grouting has been used in the field with mixed success. Two major concerns in grouting, as applied to the core replacement process were:

- The mixing of the grout and the measurement process was arbitrary and overly complicated for use by field crew.
- The bond strength between the core and the surrounding pavement was inconsistent and the cores separated in some cases.
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This report addresses these issues and presents the laboratory and field-testing programs which evaluated the strength of several grouts, and the mixing procedure. The implementation of this research should result in a successful and consistent installation process.

Approach

Laboratory and field tests were carried out in order to evaluate several types of grouts for use in intact core replacement. The tests evaluated five types of grouts commonly used or had a potential success in pavement repair and rehabilitation. Three of these grouts were evaluated in a comprehensive laboratory-testing program. The other two grouts were evaluated in a limited number of lab and field tests in order to determine their shear strength.

Shear tests in the lab were performed on 4-inch cores, which were pre-drilled in slabs of aged asphalt and then rebounded in place using the grout under test. These tests determined the shear strength of the grouts, the gain of strength with time, and the optimal water content ratio (essentially the water: grout ratio) of the mix.

A pavement test section was constructed in order to perform traffic-load tests on full-scale cores. SIMCO drilling equipment was used in drilling the 18-inch diameter test cores. The quantity of the grout needed in the field was estimated as the sum of grout needed to fill the voids around any irregularly shaped core while allowing some excess grout to squeeze out of kerf. This quantity can be obtained from the chart and the table presented in Chapter 2 for various thicknesses of cores.

Wheel loads were applied on the cores using the "Accelerated Pavement Loading Equipment' at GTI. The testing machine allowed the application of repetitive truck wheel-loads using full-scale tires. Wheel loading was uni-directional, with loading being applied only on the forward stroke. The tire assembly was raised in the return stroke in order to avoid contact with the surface. This loading configuration simulated real one-direction field traffic condition. Short-term settlement in the pavement was evaluated after 300 load cycles. The tires ran continuously over the core for 3,700 load cycles in one test in order to evaluate the long-term performance of the grout.

Results

Laboratory test results showed that the shear strengths of the grouts "Rapid Set DOT'', ''CeraCrete'', and ''Enbridge'' reached the required strength after one-hour setting time. The consistency of the ''CeraCrete'' grout, however, needed to be modified to produce less flowable mix during installation in order to restrain core settlement. The shear strength of the ''Rapid Set DOT'' mix was higher than that of ''Enbridge'' when tested at the same temperature.

Extensive laboratory and field tests were accordingly conducted on the ''Rapid Set DOT" grout in order to evaluate its optimal mix design and the effect of various parameters (e.g. additives, temperature, and mixing time) on its performance. A water content ratio of 1 lb of grout to 0.16 lb of water provided the optimum shear strength for this grout. This ratio is approximately equivalent to a mix of one 55 lb bag of grout to one gallon of water. Water contents less than 0.15 resulted in dryer mixes and did not provide sufficient flow of grout during installation.

Field and lab tests showed that the ''Rapid Set DOT'' grout reached the required strength after ½ hour setting time when mixed at temperature of 85^{o}F. This strength, accordingly, would allow opening the street for traffic at this period.

The results of field tests have demonstrated the effect of temperature on the setting time of the grout. Field tests on the ''Rapid Set DOT'' grout, mixed at temperature of 50^{o}F, did not have sufficient strength to carry traffic loads after one-hour of grout setting. However, the grout performed well in one-hour tests when mixed at higher temperatures.

The addition of the ''Fast'' additive accelerator, distributed by Rapid Set, resulted in shortening the setting time of the grout when the temperature was between 50^{o}F and 70^{o}F. The mixing ratio of the additive was 2 bags of additive to one 55 lb bag of grout. Using the additive at temperatures higher than 70^{o}F may shorten the setting time to the extent that the mix starts to harden before the core installation is complete.

The performance of the grout in the field was also evaluated by monitoring the settlements under the cores and in the adjacent pavement after applying wheel loads. The settlements of the cores with the ''Rapid Set DOT'' were negligible (less than 0.05 inch) and were comparable to the performance of the adjacent pavement.

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Laboratory Tests on Grouted Intact Core Replacement Samples

A. INTRODUCTION

The objective of the laboratory-testing program was to evaluate the performance of several grouts for use in intact core replacement in keyhole operations. Three types of grouts were evaluated in a comprehensive testing program in the lab. Two additional types of grout were later added to the testing program and were evaluated in a limited number of tests. These five types of grouts are currently used in various applications in highway pavements and in core replacement in keyhole applications. The evaluation tests focused on determining their strength properties, their interface shear strength after a pre-determined setting time, their fresh consistency, and the mixing process in field conditions.

The scope of the laboratory-testing program was to test the effect of the following parameters:

- Interface shear strength after one hour, and gain of strength with time,
- Change of water content ratio of the mix,
- Effect of additives on the grout performance,
- Effect of mixing time,
- Effect of temperature on setting time of grout.

This chapter presents the laboratory testing program and the results of the tests performed on the five grouts. The testing equipment and procedures are presented in section C of this chapter. The results of the shear and compression tests are shown in section D while section E presents a conclusion of the laboratory tests.

B. GROUT SELECTION CRITERIA

The selection of the appropriate grout for use in intact core replacement depends on many criteria:

- The grout should provide the shear strength required to transfer the traffic load from the core to the adjacent pavement structure.
- The grout should reach its target strength at an adequate setting time to allow fast opening to traffic. Most of the tests were performed to evaluate the grouts at a setting time of one hour. Shear strength at a target setting time of ½ hour was also evaluated for one grout.
- The consistency should be of medium viscosity such that it allows flow of access grout through the core sides and; on the other hand, it prevents settlement of the core under its own weight.
- The grout should be readily available in the market at an economical cost.

The amount of shear strength required for transferring the vertical load to the adjacent pavement can be estimated by applying a half-axle wheel load of 9 Kips on the top of the core. This value presents the maximum load on the pavement under the standard ''Equivalent Single Axle Load'' (ESAL) of 18 Kips. It should be noted that this amount of load results in a conservative estimation of shear strength as the surrounding pavement usually carries a part of wheel load when dual tires run on cores of smaller than 18-inch diameter.

The portion of wheel load, which is transferred by the grout to the adjacent pavement, depends mainly on the thickness of the core. In thin cores, most of the load is carried out by the base soil under the core. In thicker cores, the load is primarily carried out by shear stress along the kerf. The maximum shear strength carried out at the interface (τ_{max}) can be calculated from the following equation:

$$\tau_{max} = (\alpha \times 9{,}000) / (\pi D H) \qquad \text{(in psi)}$$

Where 'α' is the percentage of wheel load carried by shear stress along the kerf of the core, 'D' is the diameter of the core, and 'H' is its height in inches.

Assuming that the core transfers the load uniformly, it can be assumed that 40% of the load is carried out by shear for cores of 6 in. depth, with the ratio of α increasing to 90% for thicker cores of 12 inches deep (Figure 1). For a core of 18-inch diameter, the equation yields an average shear strength (τ_{max}) value of 12 psi for this range of core thickness. This value was used as the target shear strength for the acceptance of grouts in laboratory tests.

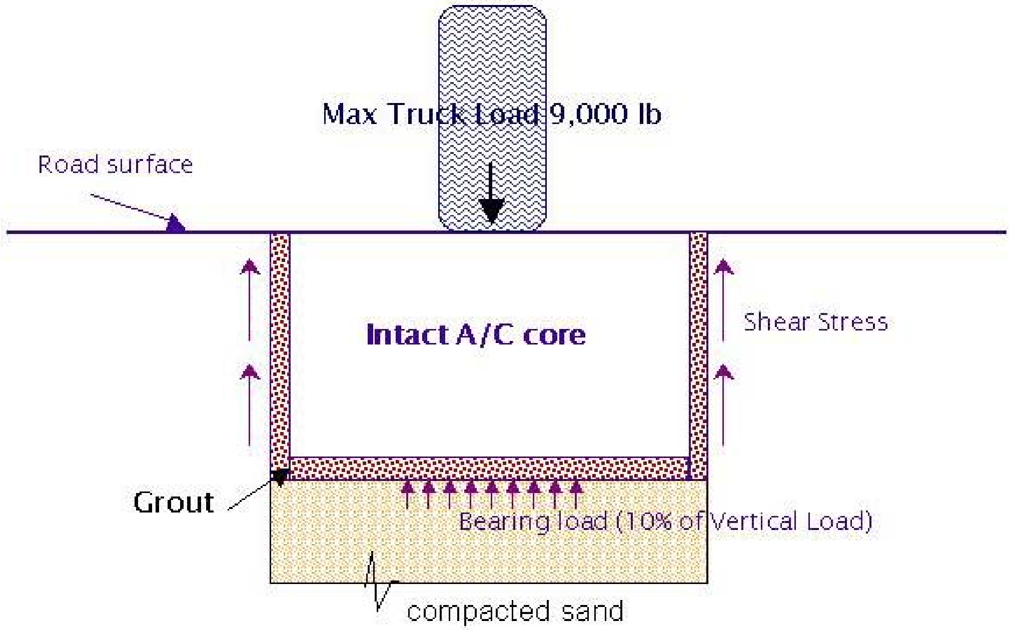


Figure 1. The grout is assumed to transfer up to 90% of the wheel load in thick cores

C. TESTING PROCEDURE

The types of grouts used in the laboratory tests are presented in Table 1. A comprehensive testing program was performed on the first three grouts in the table in order to evaluate their performance at various mixing ratios and setting times. The last two types of grouts (namely CeraCrete and Enbridge grouts) are commonly used in pavement repair and in core replacement. A limited number of tests were performed on these two grouts in order to evaluate their performance in comparison to the other grouts.

Laboratory tests were performed on 4-inch diameter asphalt cores with an average height of 5 inches. The cores were drilled from aged asphalt slabs obtained from streets in the Chicago area. The cores were then re-bonded in place using the grout under test. Figures 2 and 3 show the drilling of the cores from the asphalt samples.

Table 1. List of Grouts used in the testing program

Material		Description	Distributor/Manufacturer
1	Duratop®	Polymer-Reinforced Repair Mortar. Two-components, cement based mortar system.	L&M Construction Chemicals, Inc. 14851 Calhoun Road Omaha, NE 68152 Phone: 402-453-6600 Fax: 402-453-0244
2	Rapid Set® Cement All	Dry blend of non-shrink cementitious material and sand in 55 lb "Blue" bag.	CTS Cement Manufacturing Company 11065 Knott Ave. Suite A Cypress, CA 90630 Phone: 800-929-3030 Fax: 714-379-8270
3	Rapid set® DOT Repair Mix	A blend of Rapid Set cement, specially graded sand , and performance additives in 55 lb "Orange" bags.	CTS Cement Manufacturing Company
4	CeraCrete®	A blend of components that include Magnesium Oxide, phosphate and coal ash.	CeraTech, Inc. 2425 Grenoble Road Richmond, VA 23294 Phone: (804) 264-7810
5	Enbridge Grout	Cement based grout used by Enbridge Tech. in core replacement.	Enbridge Technology Inc. 10303 Jasper Ave., Suite 502 Edmonton, AB T5J 2J9 Canada Phone: (780) 412-6461

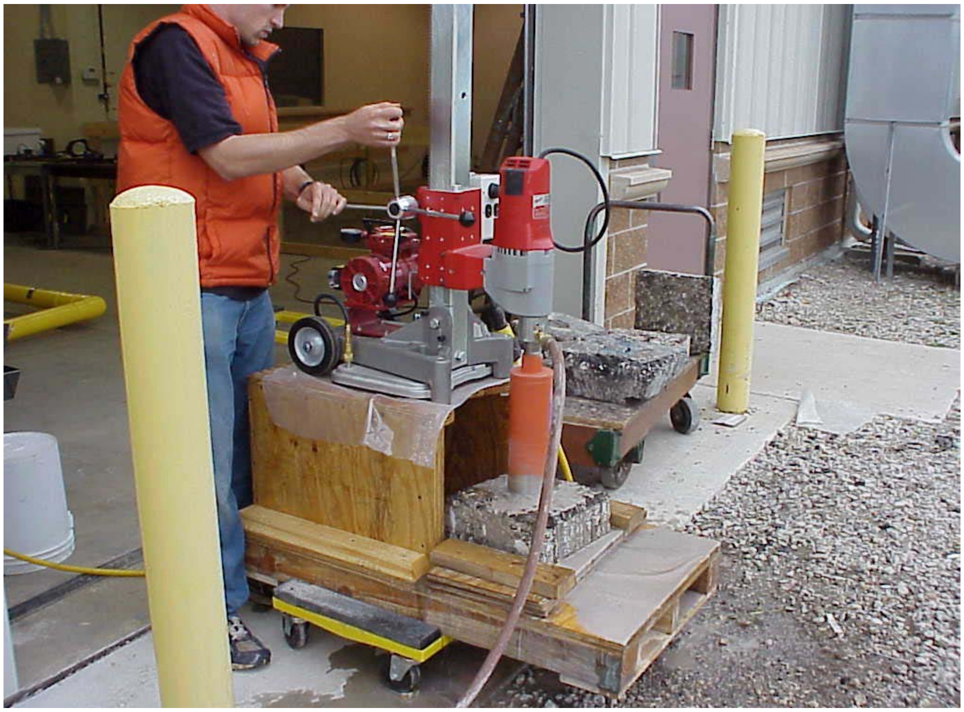


Figure 2. Drilling of the 4-inch core samples from the aged asphalt specimens

Figure 3. Retrieving the core sample from the drilling machine

The grouts were mixed with various water content ratios and were tested after a setting time of one hour. Various samples were tested at longer setting periods to evaluate the strength gain of the grout with time. Figure 4 shows grout samples mixed at various water content ratios.

Figure 4. View of several samples prepared with various water content ratios

Shear tests were performed by applying vertical loads over the 4-inch grouted cores. The shear resistance at the grout interface and the displacement of the core were measured during load application. Figure 5 shows a schematic of the shear test. All the tests were performed at a constant shear rate of 0.15 inch/min (4 mm/min). The tests were performed using the MTS compression-testing machine at GTI’s ASTM Lab. Figure 6 shows the asphalt test sample in the MTS machine and Figure 7 shows a detail of the core sample during the test.

Compression tests were also performed on cylindrical grout specimens of 1.6-inch diameter and 2.5-inch length. These tests were performed in order to evaluate the gain of the grout’s compression strength with time. Figure 8 shows the cylindrical grout sample in a compression test.

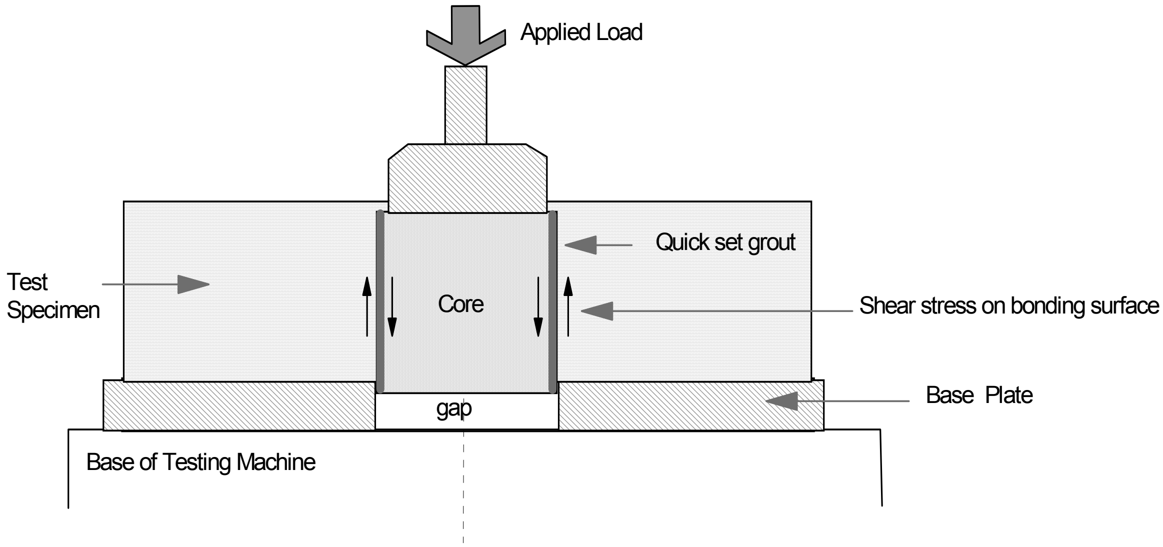


Figure 5. Schematic diagram of the shear test

Figure 6. Performing the shear test using the MTS testing machine

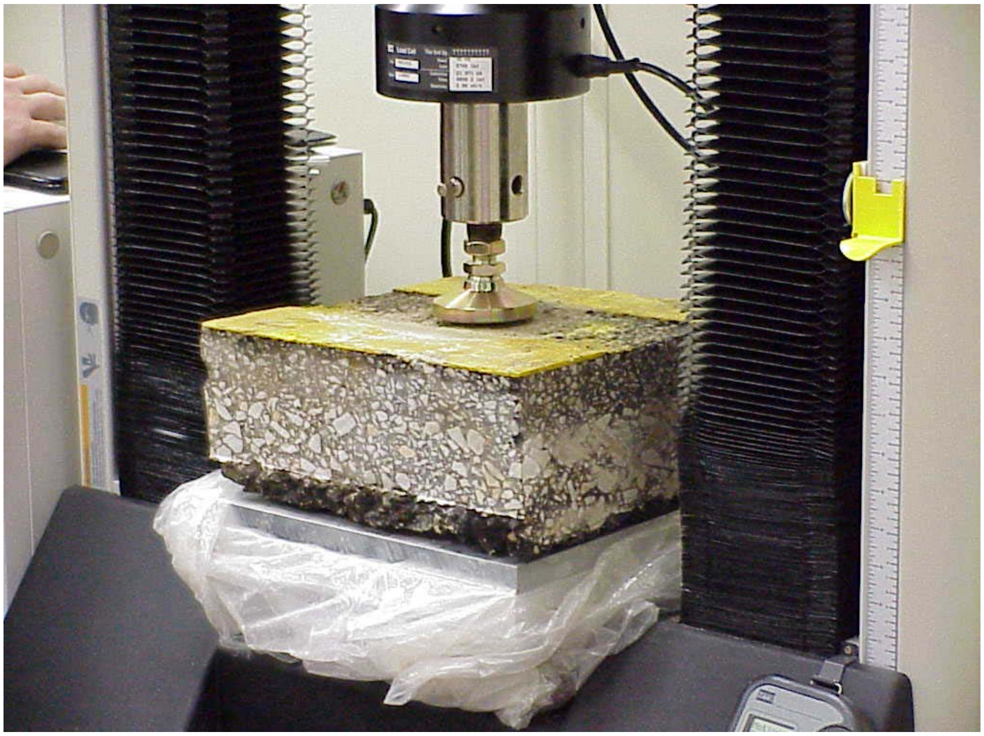


Figure 7. Application of the vertical load on the core of the asphalt sample

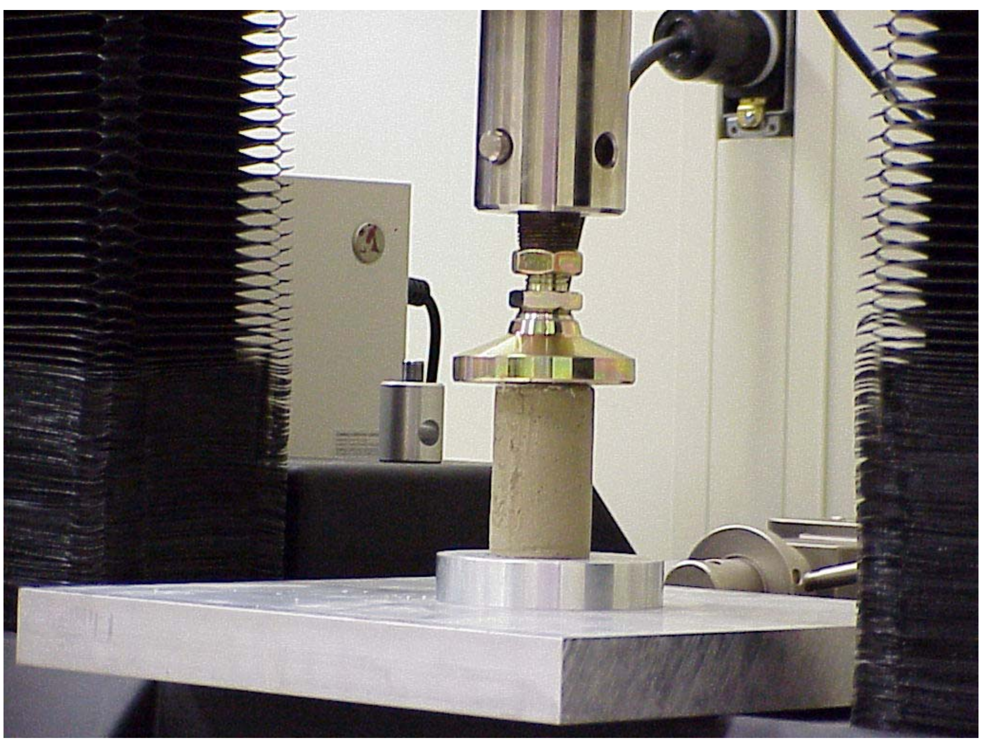


Figure 8. View of the cylindrical grout sample in a compression test

D. TEST RESULTS

D.1 Duratop Grout:

This grout is a mix of component A: a 50 lb bag of graded aggregates, cement, and admixtures; and component B: a container of co-polymer liquid (Figure 9). The manufacturer suggested a mixing ratio of one bag of component A to one container of component B. This ratio was equivalent to 1:0.2 mixing ratio of both components respectively, and it was used in mixing the grout in lab tests. The tests consisted of evaluating the gain of shear strength with time and table 2 shows the testing program. The mixing of this grout was performed in the lab in a controlled temperature.

The results of the shear tests are plotted in figure 10. The increase of shear strength with time is also shown in Figure 11. The figure shows that the setting time of 4 hours was not sufficient to reach the target shear strength value of 12 psi in order to carry the anticipated loads in the field. As the results showed that the performance of this grout was below the target value, it was decided to proceed with the evaluation of the other grouts.

Figure 9. The two components mix of the Duratop grout

Table 2. Shear testing program on the Duratop

Test	Mixing Ratio (Component A:B by weight)	Mixing time (min.)	Mixing Temperature (^{O}F)	Setting Time (hour)	Shear Strength (psi)
1	1: 0.2	2	65	1	0.41
2	1: 0.2	2	65	2	0.75
3	1: 0.2	2	65	3	1
4	1: 0.2	2	65	4	1.5
5	1: 0.2	2	65	24	40

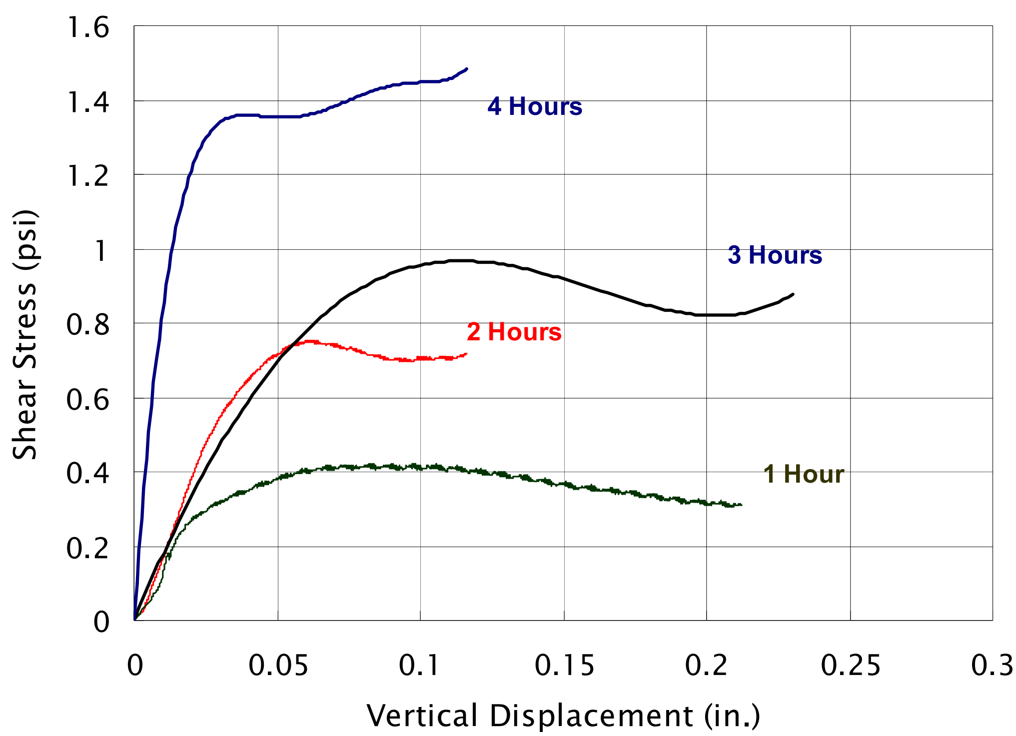


Figure 10. Results of shear tests on the Duratop

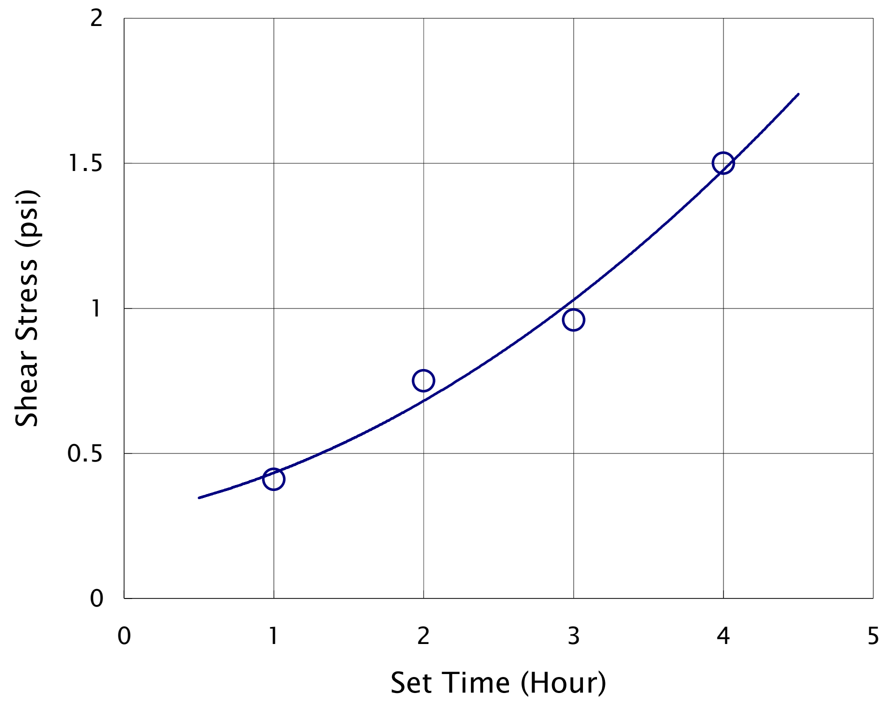


Figure 11. Increase of shear stress with time for the Duratop grout

D.2 Rapid Set® Cement All (Blue Bag):

This grout is a dry blend of non-shrink cementitious material and sand in 55 lb bags (Figure 12). The suggested mix ratio of this grout is ¾ to 1- ¼ gallon of water to the 55 lb bag. The grout was tested with a water mix ratio of 1 lb grout to 0.2 lb water.

The grout was mixed in the lab in a controlled temperature and with the mixing parameters shown in Table 3. The results of the shear tests on the grouted cores are shown in Figure 13. Figure 14 shows the increase of shear strength with setting time. The results show that the grout reached acceptable shear strength of about 12 psi after a setting period of about 1½ hour.

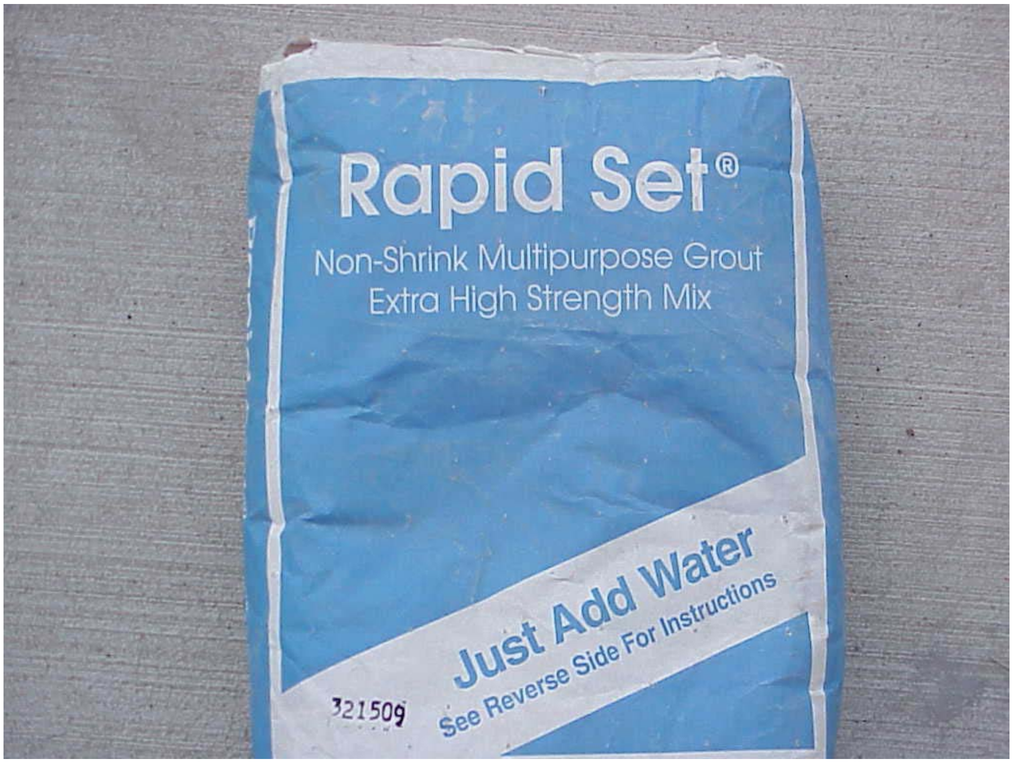


Figure 12. The Rapid Set® Cement All (Blue Bag)

Table 3. Shear testing program on the Rapid Set (Blue)

Set	Mixing Ratio (Grout: water ratio)	Mixing Time (sec)	Mixing Temperature (°F)	Set Time (Hour)	Additives	Shear Strength (psi)
1	1:0.2	1	65	1	None	7.6
2	1:0.2	1	65	2	None	19.5
3	1:0.2	1	65	4	None	38.5

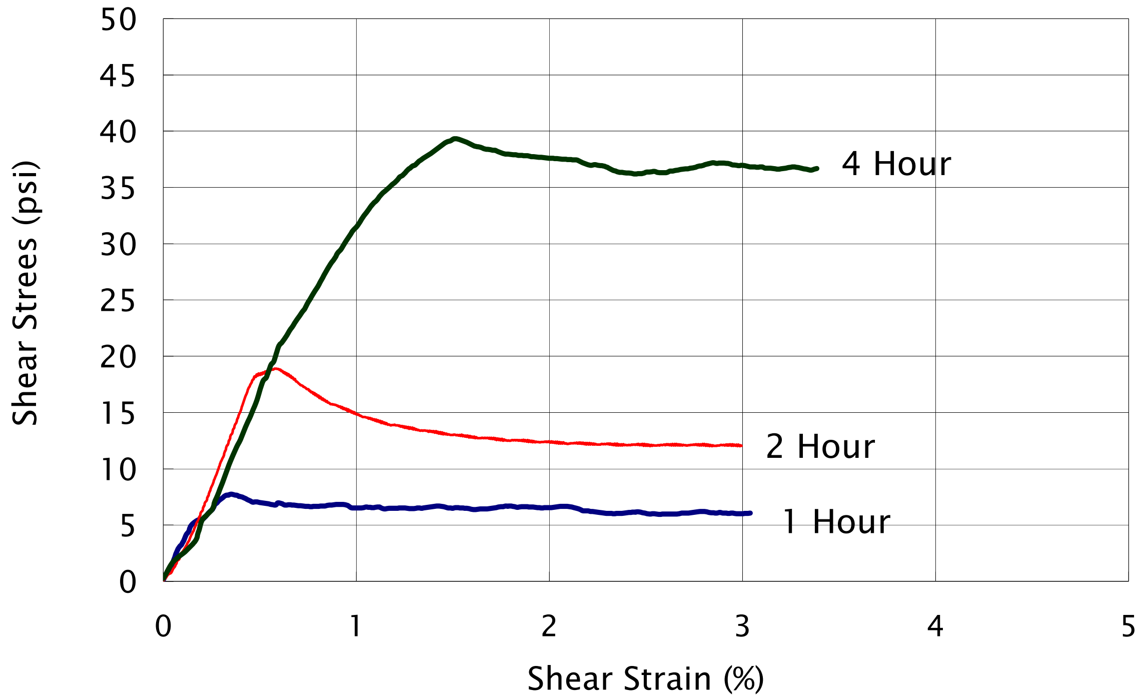


Figure 13. Results of shear stress tests on the Rapid Set (Blue)

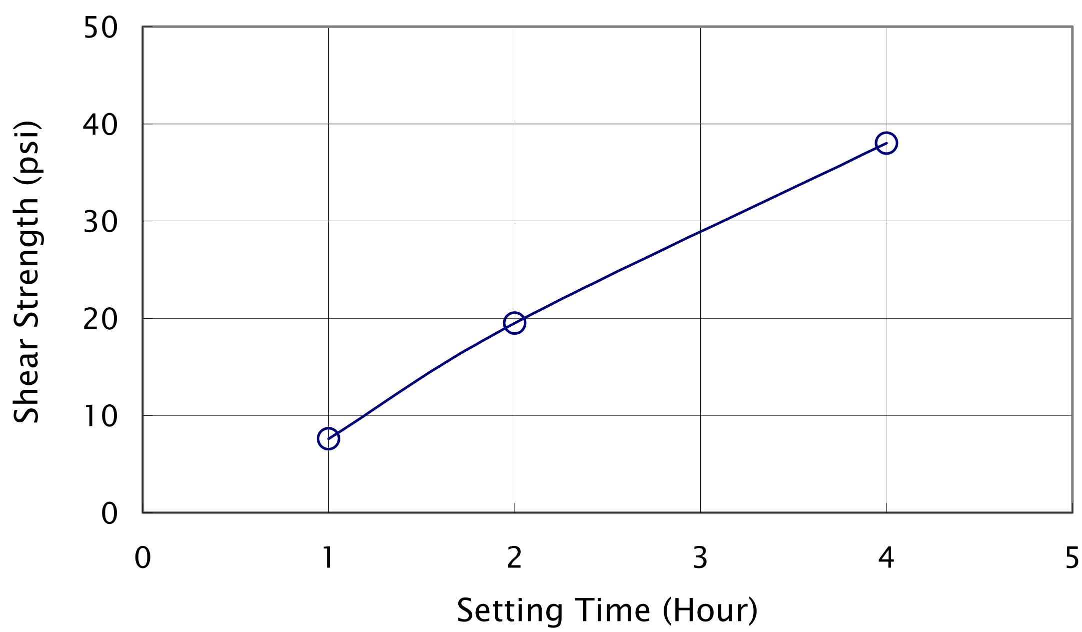


Figure 14. Increase of shear strength with time for the Rapid Set (Blue)

D.3 Rapid Set DOT Repair Mix:

This grout is similar to the previous one with the exception of adding specially graded sand fill and other performance additives for use in highway rapid repairs. It comes in 55 lb bags with an orange label (Figure 15). The results of the shear tests showed a better performance of this grout and, accordingly, an extensive testing program was performed in order to evaluate the effect of the change of water ratio, mixing time, setting time, and additives on its shear strength. Table 4 shows a list of the tests performed on this grout.

The tests of <u>set 1</u> were performed in order to evaluate the repeatability of the results under the same testing conditions. Grout mixing of these tests was performed in a controlled lab temperature and the testing parameters are shown in table 4. The results of these tests are plotted in Figure 16 and they show comparable performance for all tests with average shear strength of 12 psi.

The tests of <u>set 2</u> were performed to evaluate the increase of shear strength with time. These tests were performed after a grout setting times of 1, 2 and 4 hours. The results in Figure 17 show the increase of grout shear strength with the increase of setting time.

The effect of the change of water content ratio is evaluated by comparing the results of test <u>sets 3, 4, and 5</u> of table 3. These tests were performed with various water contents, no additives, mixing time of 35 sec., and at a setting time of one hour. The results of these tests (Figures 18 and 19) show that water content ratio of 0.16 yielded a higher shear strength value than the water ratio of 0.18. It should be noted that the mix ratio in the field is typically between these two values. A typical mix of one gallon of water to a 55 lb bag is approximately equivalent to the water ratio of 0.16.

The tests in <u>sets 4 and 5</u> also evaluated the shear strength of the grout with and without the addition of ''Dark'' additives. The results (Figures 20 and 21) show that the addition of the additive did not have a significant effect on the shear strength of the grout. The additive of carbon black has the effect of darkening the grout line from gray-white to relatively dark gray, which tends to be less noticeable in asphalt core replacement.

Figure 15. The Rapid Set® DOT Mix (Orange Bag)

The manufacturer recommends the ‘Fast’ additive when faster setting time is desired and when mixing the grout at a temperature lower than 60^{o}F. Figure 22 shows the results of the one-hour setting time tests with the additive (set No. 6). The results show a significant increase in shear strength equivalent to 2.5 times the shear strength of the grout without the additive.

The shear test of set 8 was performed on the grout at ½-hour setting time. The grout was mixed in the field at temperature of 85^{o}F. The results in Figure 23 show high shear strength of the grout. The results demonstrate the effect of elevated temperature on accelerating the setting time of the grout. It also shows that the ½-hour setting time at this temperature is an adequate time to allow traffic loads over the cores.

Table 4. Shear testing program on the Rapid Set DOT Mix (Orange).

Set	Mixing Ratio (Grout: Water)	Mixing Time	Set Time (Hour)	Mixing Temperature (^{O}F)	Additives	Shear Strength (psi)
1	1:0.18	35 sec	1 1 1	65	None	12.1 12.0 11.5
2	1:0.18	2.5 min	1 2 4	65	None	14 24.7 50
3	1:0.19	35 sec	1 2	65	None	13 48.7
4	1:0.18	35 sec	1 1	65	None Black	11.6 10.9
5	1:0.16	35 sec	1 1	65	None Black	15.5 14.4
6	1:0.18	35 sec	1 1	65	Fast+ Black Fast+ Black	38.2 35.6
7	1:0.16	35 sec	2	65	None	34
8	1:0.18	35 sec	1/2	85 (field mix)	Black	35

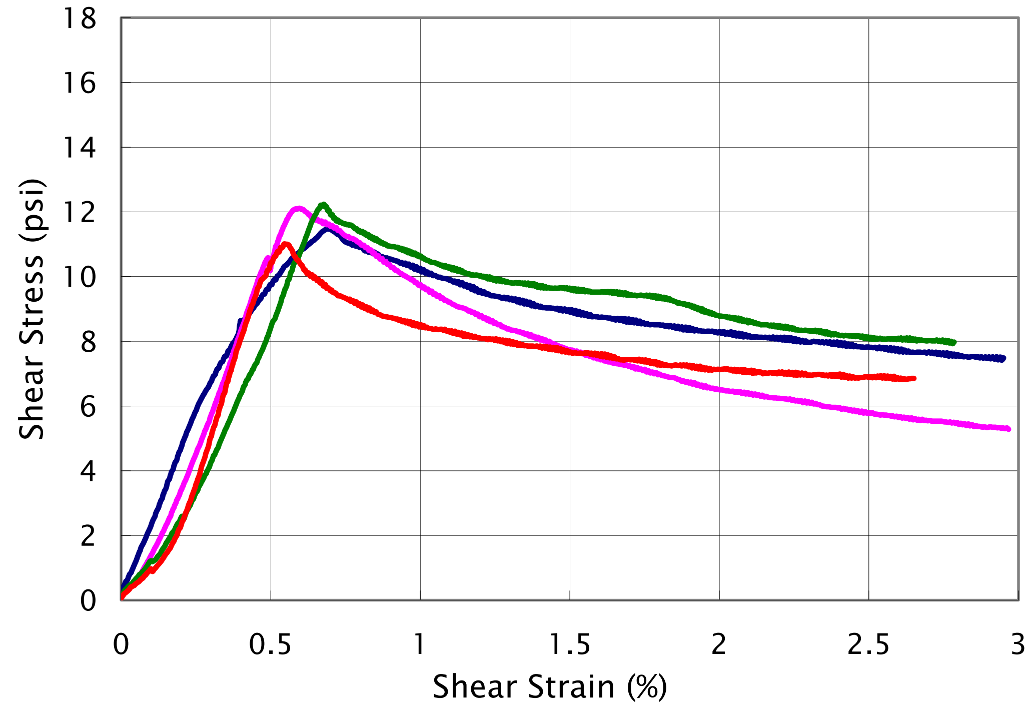


Figure 16. Shear stress results at 1-hour set time of the grout (water ratio 0.18, no additives)

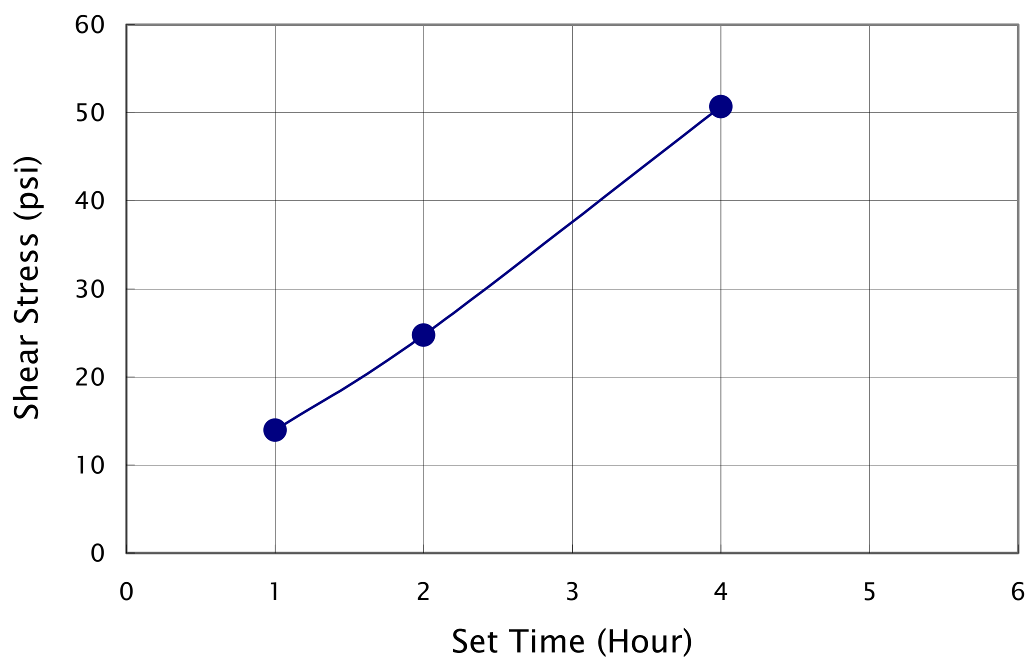


Figure 17. Increase of shear stress with setting times (water ratio 0.18, no additives)

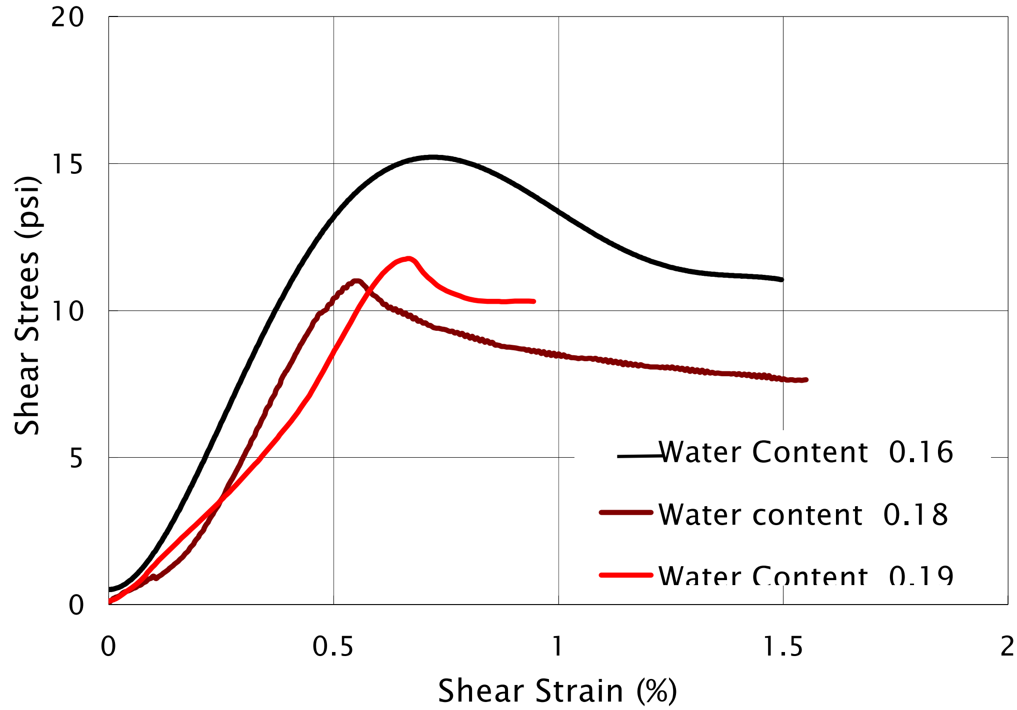


Figure 18. Results of shear tests on grouts mixed at various water contents (no additives)

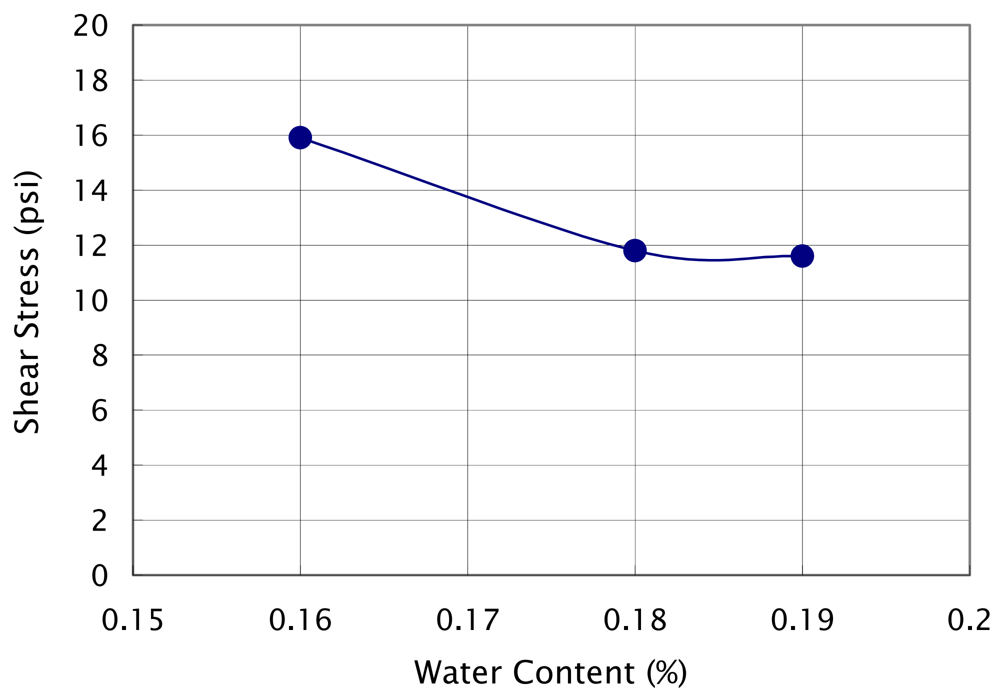


Figure 19. Effect of water content on the shear strength of grout

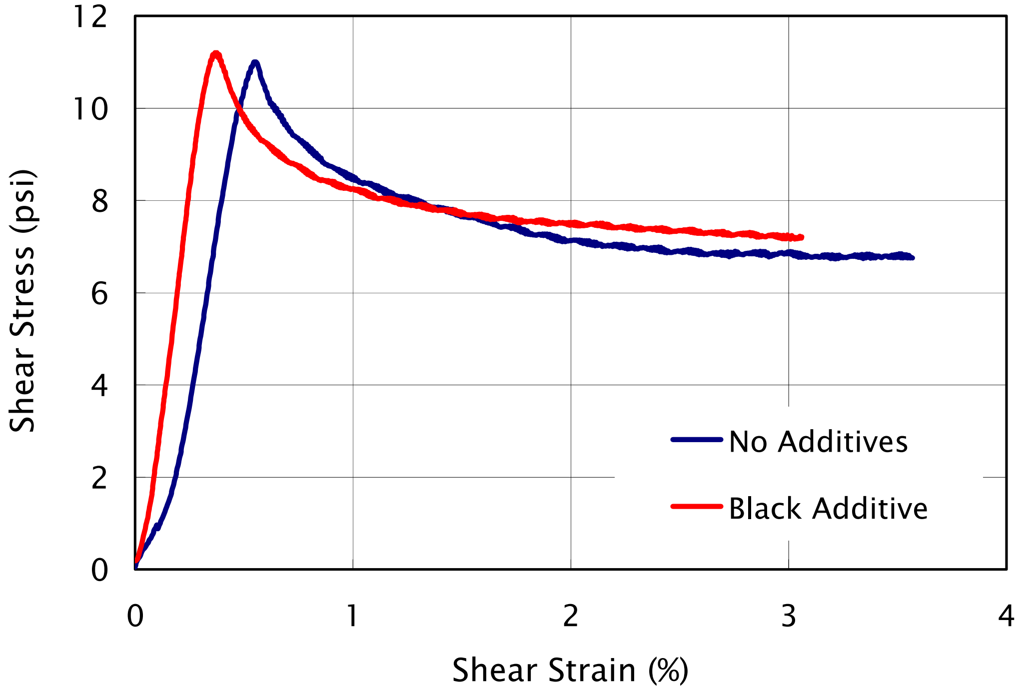


Figure 20. Test results of Set No. 4

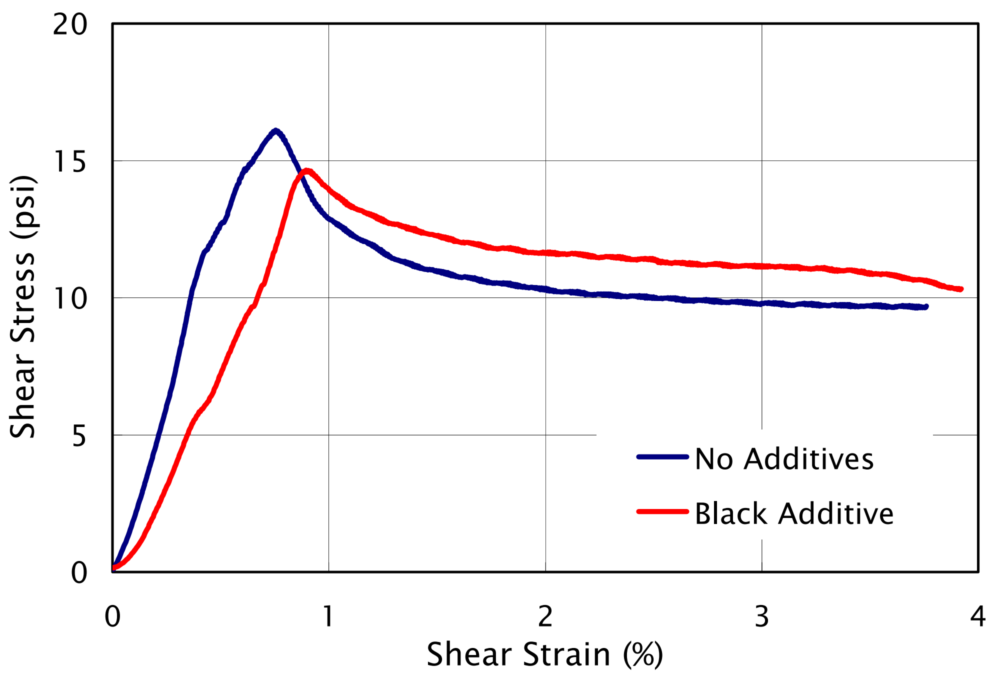


Figure 21. Test results of set No. 5

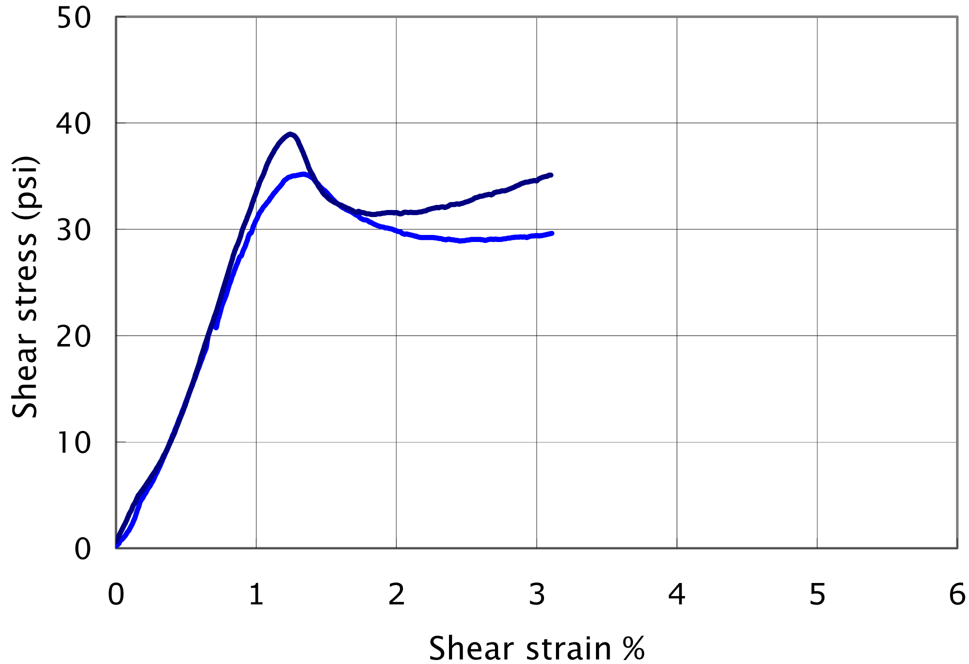


Figure 22. One-hour shear strength of the grout with 'Fast' additive

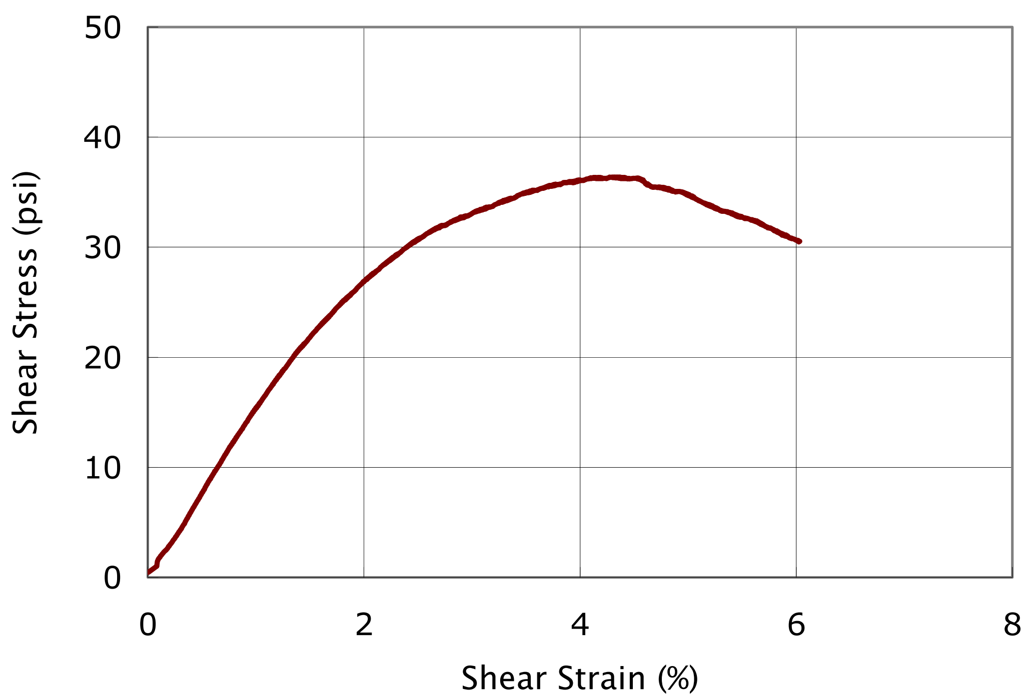


Figure 23. Shear strength after ½ hour setting time
(water content 0.18, no additives)

Compression Tests were also performed on this type of grout in order to validate strength gain and the effect of the water content ratio. These tests were performed on cylindrical specimens of 1.6 in diameter and 2.5 inch high (see figure 8). The grout samples were mixed at various water contents as shown on table 5. The results are shown in figures 24 and 25 and show a significant decrease in the grout compression strength at high water content of 21 percent. The effect of the increase of water ratio on the reduction of shear strength is comparable to the conclusion from the shear test results on the effect of water content.

Table 5. Compression tests on the Rapid Set DOT Mix (Orange).

Set	Mix Ratio (Grout: water)	Mix Time (sec.)	Set Time (Hour)	Stress at 1% strain (psi)	Max. strength At set time (psi)
1	1: 0.16 1: 0.18 1: 0.21	25	1	64 53 30	146 127 45
2	1: 0.16 1: 0.16 (with Black)	35	1	34 33	66 (very high)
3	1: 0.18 1: 0.18 (with Black)	35	1	33 40	54 56

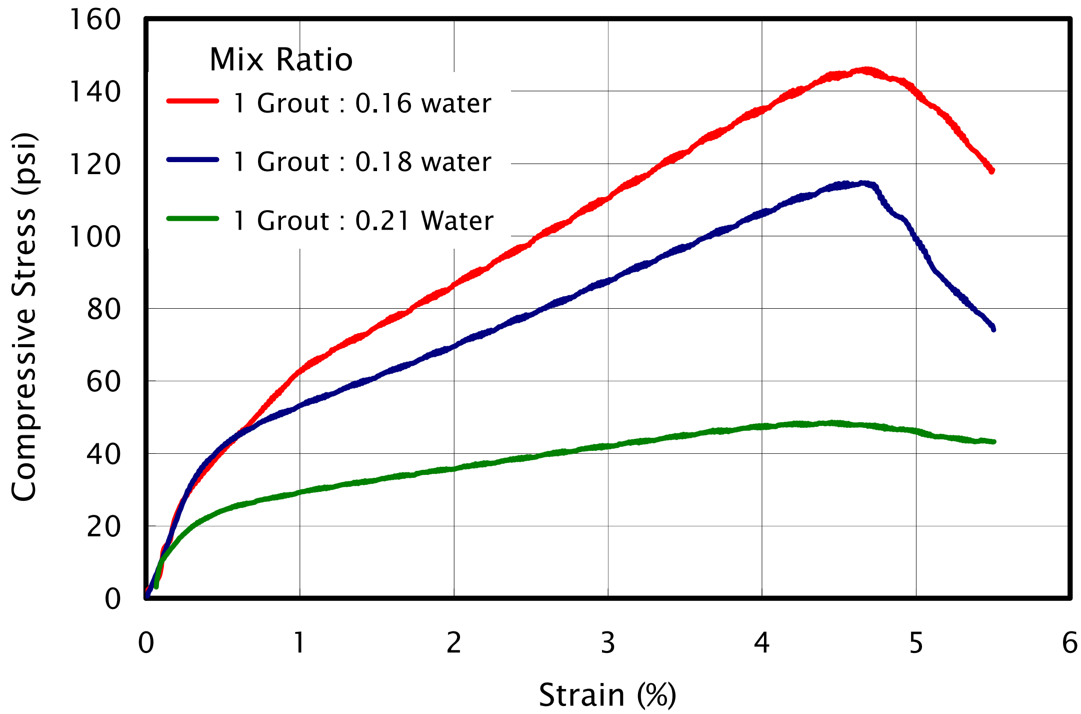


Figure 24. Compression strength of the grout at various water contents

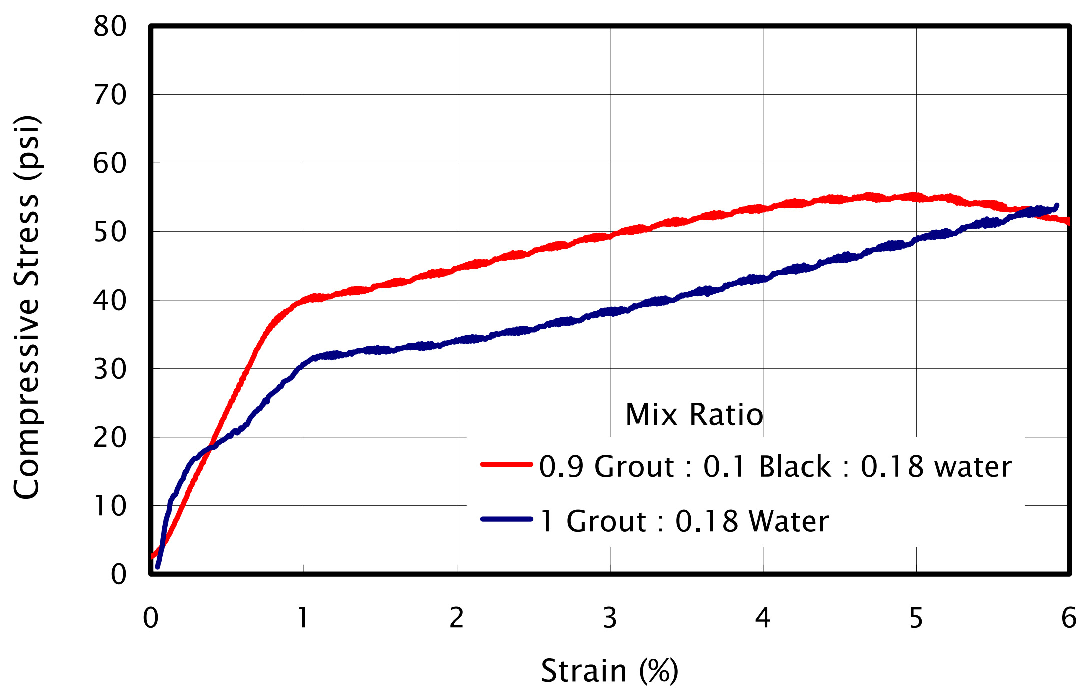


Figure 25. Compression strength of the grout with and without the ''Black'' additive

D.4 CeraCrete Grout:

This grout is a blend of mineral aggregate components and coal ash that has been used in pavement repair, specifically rapid repair of bomb-crater damage in military airfields. The grout demonstrated high compression strength after one-hour setting time. Figure 26 shows the results of compression tests on grout mixed at 0.16 water content ratio, a mixing time of 4.5 min, and at one-hour setting time.

The result of shear test on the grout yielded shear strength of 13 psi as shown in Figure 27. This value of shear strength was comparable to that of the ‘‘Rapid Set D.O.T.’’ grout. The figure shows shear strength of grout mixed at water content ratio of 0.17 and at one hour setting time.

Although the grout demonstrated a significantly high compressive strength, it had low viscosity during installation and most of the mix seeped through the core sides in field tests. The manufacturer is working on modifying the aggregate ratio of the grout in order to improve its consistency for use in this application. It may be also helpful to operate this grout at lower water content as the present recommended values were designed to facilitate easy flow of grouts in crack repair applications.

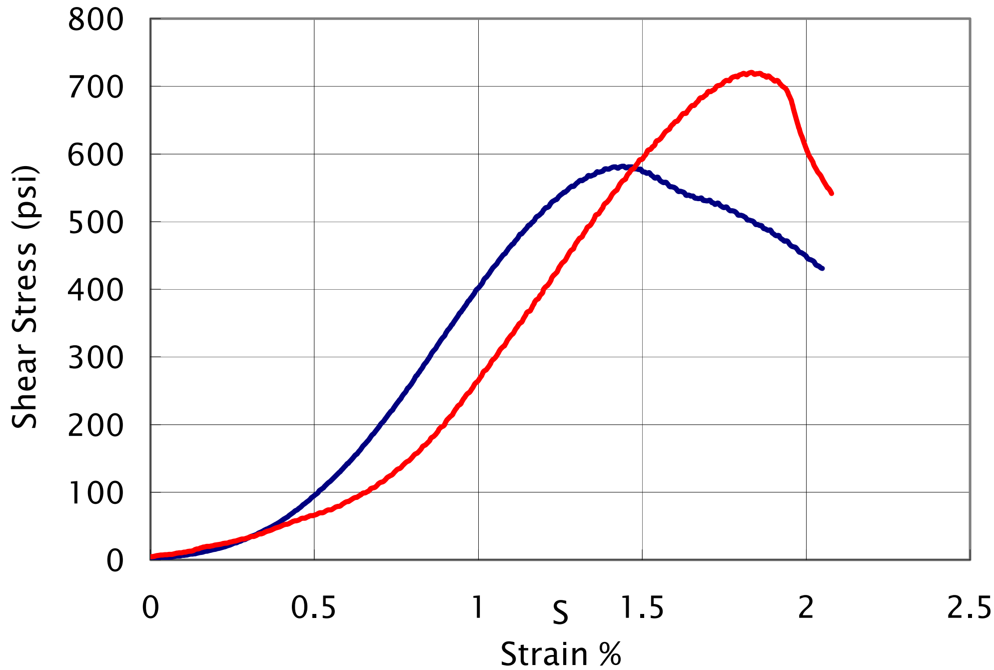


Figure 26. Compression test results of the CeraCrete

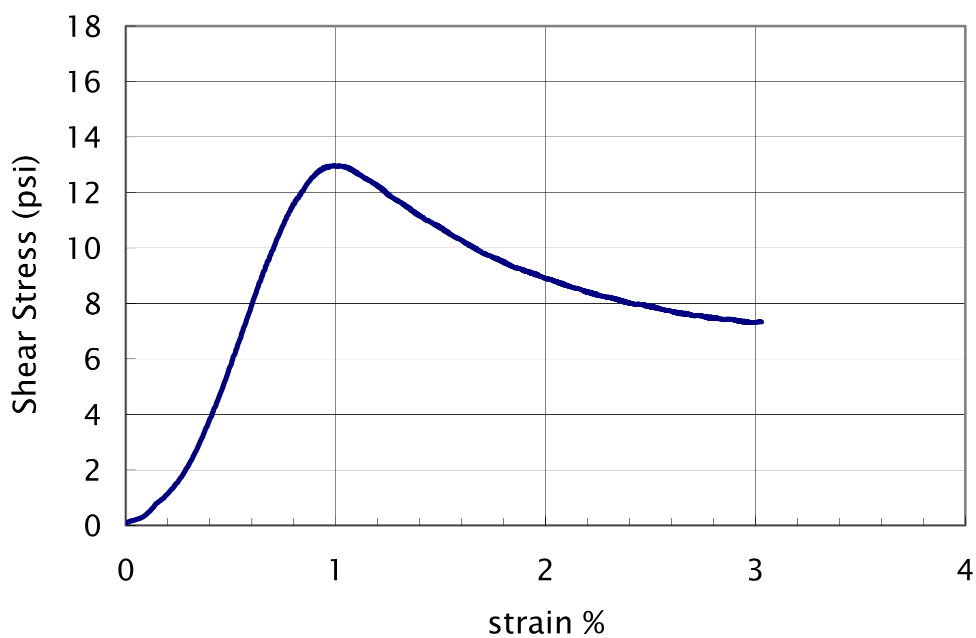


Figure 27. Result of shear test on the CeraCrete grout

D.5 Enbridge Grout

This grout is used by Enbridge Technology in the replacement of intact cores in keyhole operations. The grout was evaluated in a field test and a single shear test was performed in the lab using the same grout mix.

The shear test in the lab was performed on a grout mixed with a water ratio of 0.2, a mixing time of 30 sec., and at a temperature of 85°F. The sample was tested after a setting time of one hour and the test result is shown in Figure 28. The result shows an acceptable shear strength value of 20 psi at a one-hour setting time at this temperature. This shear strength, however, was less than the shear strength of the ''Rapid Set DOT'' mix of 35 psi that was attained after ½ hour setting time at the same temperature and shown in figure 23.

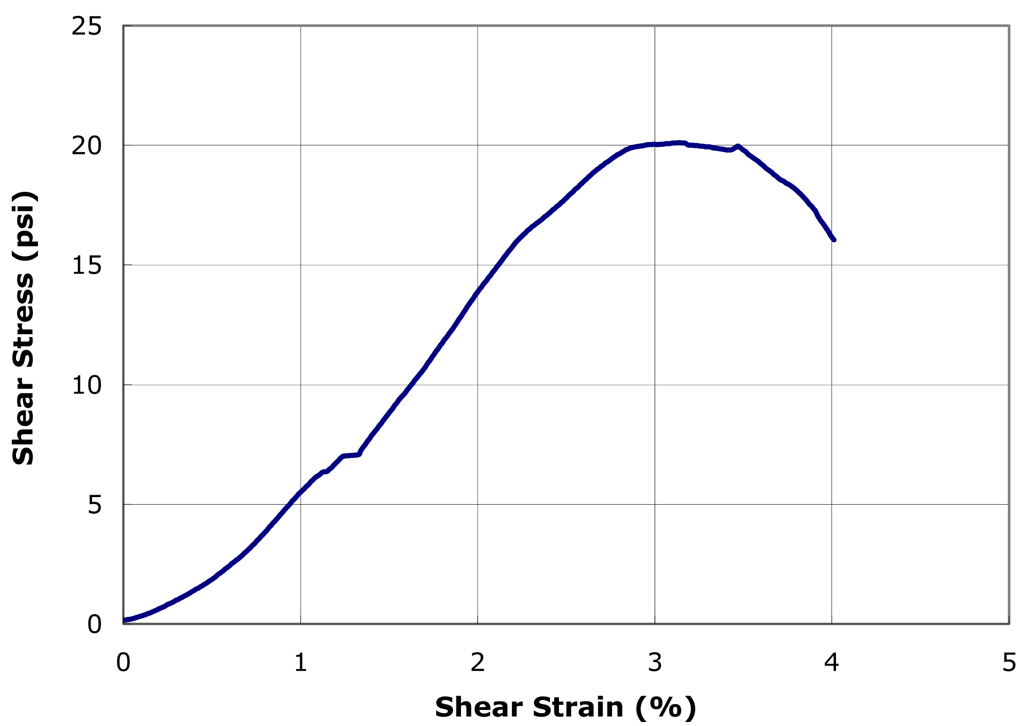


Figure 28. Shear test result on the Enbridge grout (one-hour setting time)

E. CONCLUSIONS

The following conclusions summarize the results of the laboratory-testing program:

- The shear strengths of the grouts ''Rapid Set DOT'' and ''Enbridge'' were sufficient to carry the anticipated wheel loads after a setting time of one-hour. The shear strength of the ''Rapid Set DOT'' was higher than that of the ''Enbridge'' grout when both were mixed at temperature of 85°F.

- Although the shear strength of the ''CeraCrete'' was comparable to that of the "Rapid Set DOT", the consistency of the ''CeraCrete'' grout needed to be modified in order to produce a less flowable mix and to restrain the settlement of the core under its own weight.

- The determination of the target value of shear strength was based on assuming a maximum capacity of 9000 lb wheel load over the core. Less setting time is permissible when traffic loads are not expected to reach such high values during the first hours after installation or when the core diameter is less than 18 inches to the extent that only a part of the wheel load is applied on the core.

- The shear strength of the ''Rapid Set DOT'' grout at ½-hour setting time and a temperature of 85°F was sufficient to carry the wheel loads and, accordingly, it allows opening the street for traffic at this period.

- High ambient temperature accelerates the setting time of the grout. The ½-hour shear strength of ''Rapid Set DOT'' grout, mixed at temperature of 85°F, was equivalent to the two-hour shear strength of the grout mixed at 65°F. The effect of temperature will further be investigated in field tests.

- The shear strength was sensitive to the water content ratio. A water ratio of 0.16 (1 lb of grout to 0.16 lb of water) was found to provide the highest shear strength for the ‘‘Rapid Set D.O.T.’’ mixes. This ratio is approximately equal to one gallon of water to the 55 lb bag of grout. When the ‘‘Fast’’ additives was added to the mix, a mixing ratio of two bags of ‘‘Fast’’ to the 55 lb bag of grout was used.

- A mixing time of about 2 minutes provided slightly higher shear strength than the grouts mixed for 35 seconds. When ‘‘Fast’’ additive is added to the mix, the short mixing time is recommended so that the placement of the core is speedy enough before the grout starts setting.

- The ‘‘Black’’ additive provided a grout with a darker color that resulted in a closer match to the color of the asphalt. The additive did not have a measurable effect on the shear strength of the grout.

Chapter 2
Field Tests on Full-Scale Core Sections

A. INTRODUCTION

Field tests on full-scale keyhole cores were performed in order to evaluate mixing process and grout performance under field conditions. The objectives of the tests were to:

- Improve the estimate of the amount of grout needed in the field,
- Develop a procedure for the mixing process in the field,
- Evaluate the effect of field conditions and temperature on the setting time of the grout,
- Evaluate grout performance and core settlement under wheel loads.

The results of the laboratory-testing program have demonstrated that the ‘‘Rapid Set DOT’’ grout had the highest shear strength in direct shear tests. Accordingly, most of field tests were performed on this grout in order to further investigate its field performance under varying temperature and field conditions. Additionally, two tests were performed on the ‘‘CeraCrete’’, and ‘‘Enbridge’’ grouts in conjunction with their laboratory evaluation program.

Field tests were performed on 18-inch cores in a paved test section at the GTI outdoor testing facility. The paved section consisted of an 8-inch asphalt concrete (AC) layer on the top of 12-inch aggregate base layer. The section was constructed in October 2001 and was left to age till the cores were drilled on March 2002. The cores were drilled by ’’SIMCO’’ using a keyhole rig similar to those in service by SoCal Gas. Field tests were performed during the spring season in April and May 2002. The test section and testing procedure are presented in sections D and E of this chapter.

Repeated wheel loads of 3 to 6 Kips were applied on the grouted cores after one hour of installation. The loads were applied using the “Accelerated Pavement Loading Equipment (APLE)” at GTI. Settlements were monitored after the application of loads and the results are presented in section F of this chapter.

B. DETERMINATION OF GROUT WEIGHT

The determination of the grout unit weight of the ''Rapid Set'' grout was performed according to AASHTO T121-86: "Standard Method of Test for Weight per cubic foot, Yield, and Air Content of Concrete". The results of the unit weight were used in determining the weight of the dry grout and total weight of mix for any given core size. The procedure is summarized as follows:

1. A grout container (measure) of volume of 1/30 ft^3 was calibrated according to AASHTO T19 procedure "Methods of Sampling and Testing". A calibration factor of the measure was calculated.
2. A freshly mixed grout sample was obtained.
3. The grout mix was placed in the measure. No rodding or tamping was performed as required by the standard in order to represent the installation procedure of pouring the grout in the keyhole.
4. The top of the grout was leveled off at the top edge of the measure.
5. The net weight of the grout (W_g) was determined by subtracting the weight of the measure from the gross weight.
6. The unit weight of the grout (γ_g) was calculated by multiplying the net weight (W_g) by the calibration factor of the measure.

The procedure yielded the following values for a grout mix ratio of 1 Ib of grout to 0.16 Ib of water:

Unit weight of dry grout = 85 Ib/ft^3

Unit weight of mix (γ_g) = 140 Ib/ft^3

These values were used in the determination of the weight of the mix required for core replacement.

C. DETERMINATION OF THE QUANTITIES OF MATERIALS

The quantity of the grout should be sufficient to fill the voids under the core and the space between the core and the surrounding pavement as shown in Figure 29. Access grout should squeeze out of the core in order to insure that all the voids are filled. The excess grout should not be too much to cause a run off into the street drainage system.

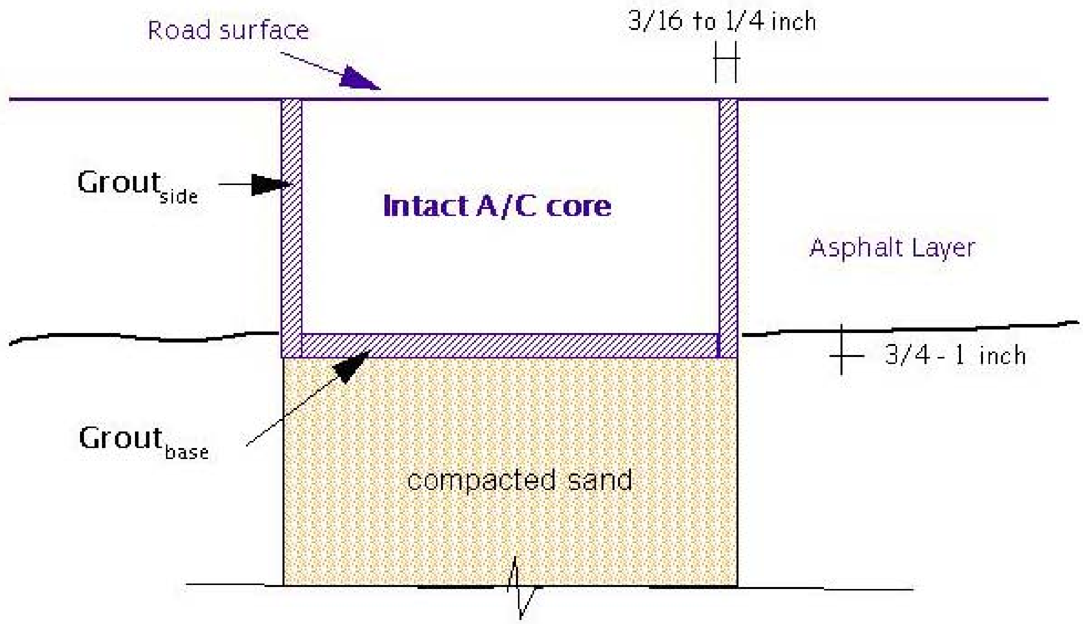


Figure 29. Ideal configuration of the grouted core

The thickness of the grout at the perimeter (Grout side) varies from 3/16 to 1/4 inch while the thickness of the grout at the base (Grout base) is typically about one inch. In the proceeding calculations of the quantity of grout, values of 1/4 and one- inch were used for the side and base thickness, respectively.

The calculation of the optimum amount of grout, which fills the volume of voids shown in figure 29, is straightforward. However, some grout is usually lost in the container during mixing and additional quantity is needed to squeeze out of the core during placement. Furthermore, the shape the core can be irregular and may require more grout to level the bottom of the core (Grout core). Figure 30 shows a more realistic geometry of the grouted core system.

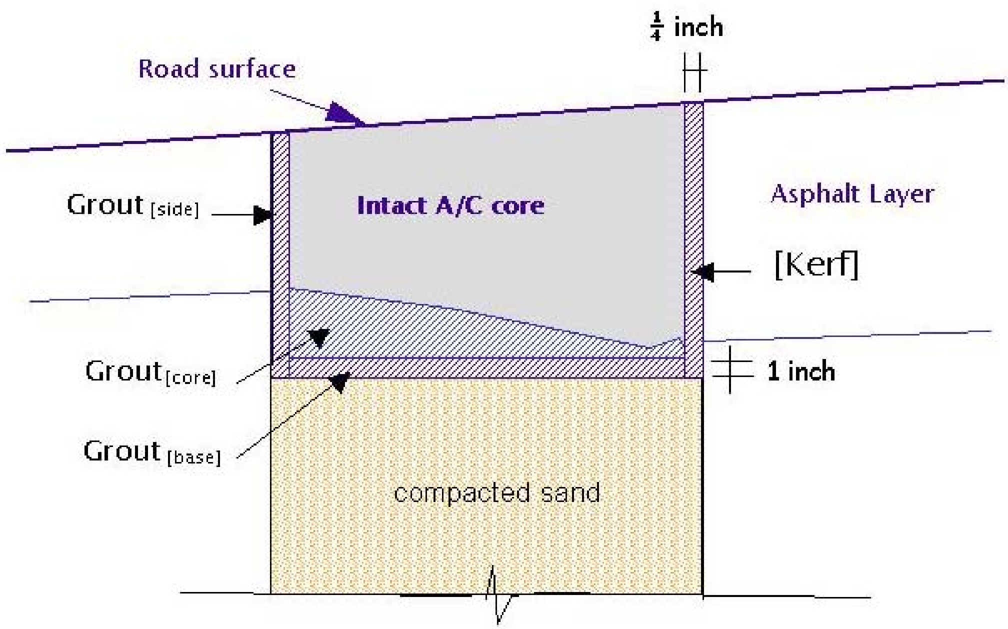


Figure 30. Typical geometry of the grout-core system

Accordingly, The amount of grout required for core replacement (V_{total}) is the sum of the following:

$$V_{total} = V_{side} + V_{base} + V_{core} + V_{access} + V_{loss} \qquad (1)$$

Where V_{side} = volume of grout at the perimeter (kerf)

V_{base} = volume of grout at the base

V_{core} = volume of grout required to fill irregular cores

V_{access} = volume of access grout squeezed of the surface

And V_{loss} = volume of unused grout mix.

Based on observations in field tests, $\underline{V_{loss}}$ can be assumed to be about 10 percent of total volume. The amount of access grout ($\underline{V_{access}}$) can reasonably be 15 to 20 percent of the total volume. Additionally, the volume required to fill the bottom of irregular core ($\underline{V_{core}}$) can be approximated to be equal to the volume shown in figure 31 (b).

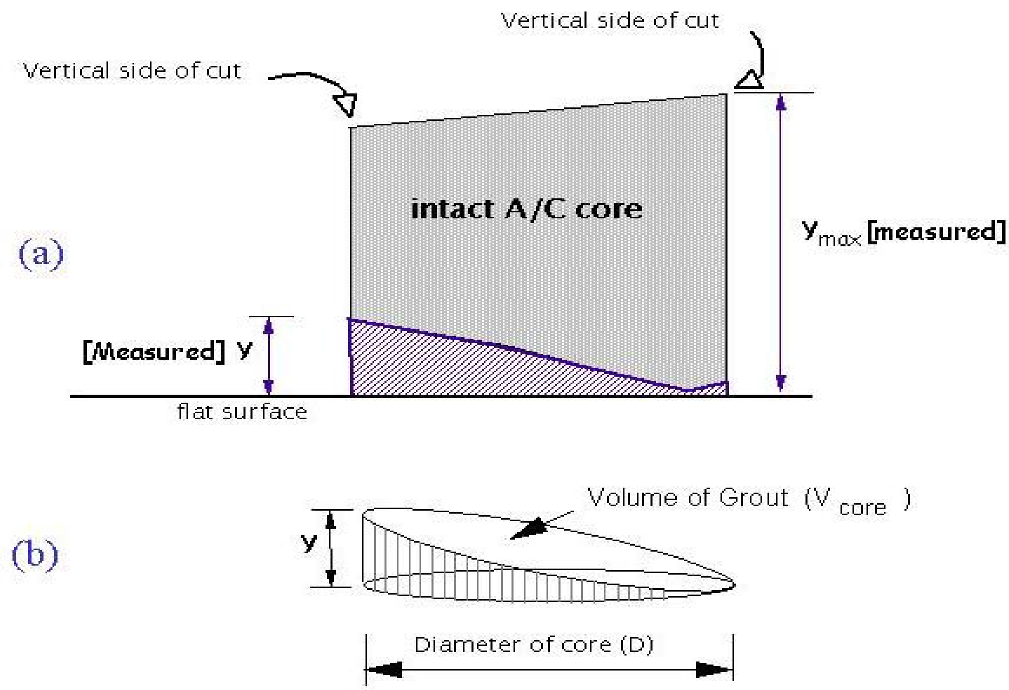


Figure 31. Estimation of quantity of grout needed for irregular base (V_{core})

The value of y in figure 31 is determined in the field by placing the core in a vertical position on a flat horizontal surface and measuring the largest gap at the bottom of the irregular core.

Equation (1) was used in determining the required weights of the dry grout in field installation. The weights of the dry grouts needed for cores of 10-inch and 18-inch diameters are shown in Figures 32 and 33, respectively. The calculations were based on water content ratio of 0.16, grout unit weight of 140 lb/ft^3, and various core depths from 6 to 18 inches. The figures also show the weights of dry grout needed to fill irregular cores up to a 'y' value of 2 inches.

For all practical purposes, Table 6 can also be used in estimating the weight of grout needed for a regular core. The table is based on the results in figures 32 and 33 for y<= one inch. The table can also be used to determine the height of the grout in the hole (Hg) in order to insure that a sufficient quantity of grout squeezes out of the core. Figure 34 shows a schematic of the grout height Hg.

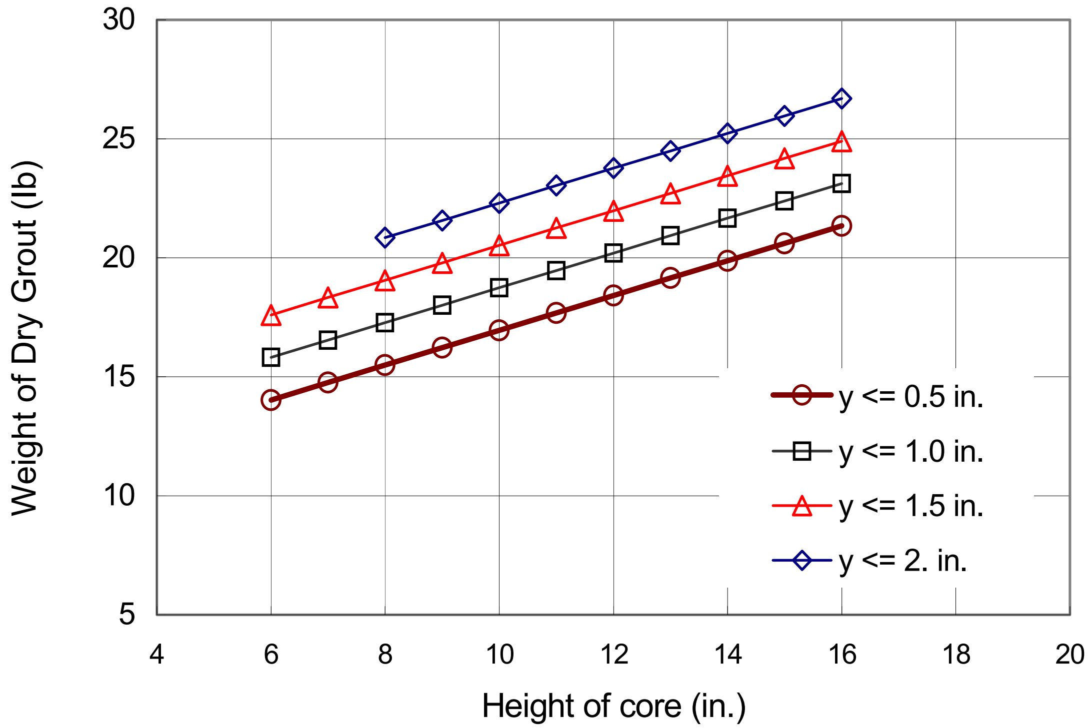


Figure 32. Weight of dry grout for 10-inch diameter cores

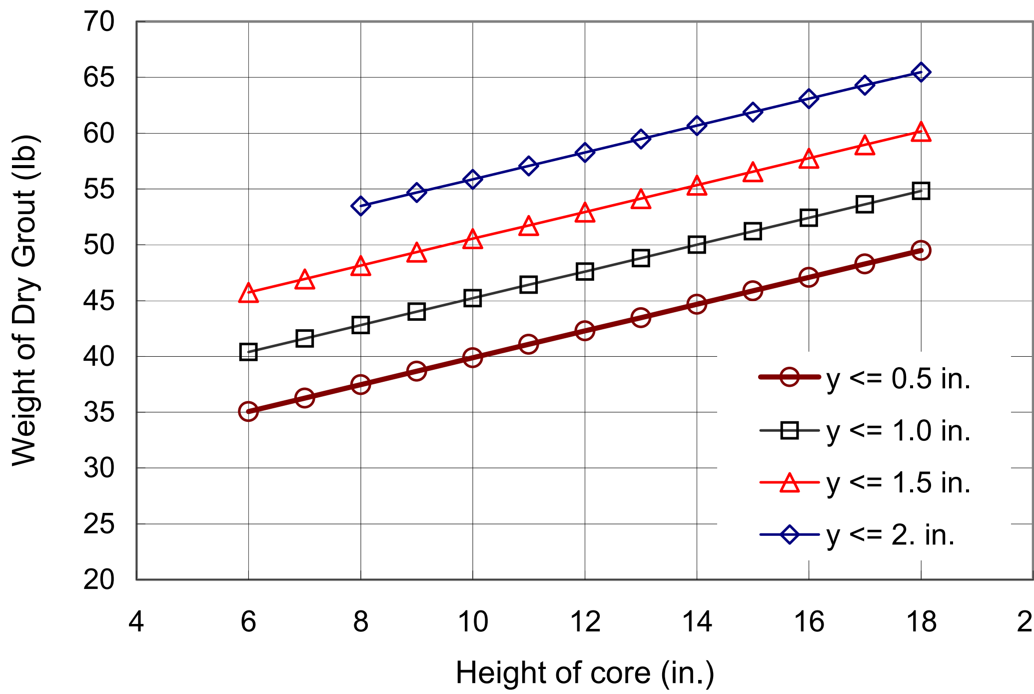


Figure 33. Weight of dry grout for 18-inch diameter cores

Table 6. Estimating weight of dry grout, water, and height of grout in hole

Core Diameter (inch)	Core height Inch)	Weight of Dry Grout (lb)	Weight of Water (lb) Ratio = 0.16	Height of grout in the hole, Hg (inch)
10	<= 8 inches	16	2.6	2.5
	9 to < 12	18	2.9	3
	12 to <15	22	3.5	3.5
18	<= 8 inches	36	5.8	2
	9 to < 12	45	7.2	2.2
	12 to <15	50	8.0	2.6

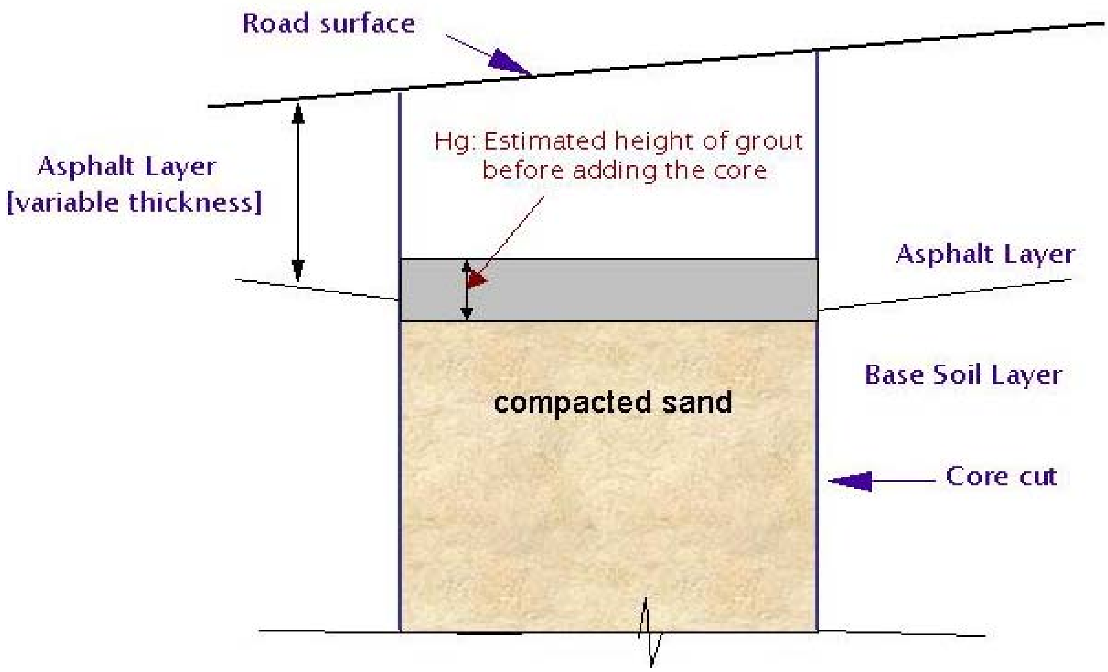


Figure 34. Use of Table 6 to estimate the height of grout (Hg)

D. OUTDOOR TEST SECTION

The outdoor test section was constructed at GTI in order to evaluate the grout performance in full-scale core samples. The section is 20 ft wide by 24 ft long section paved with bituminous concrete pavement (AC) layer. The pavement was about 8 inches thick and consisted of a 6-inch bituminous binder course layer, and a 2-inch bituminous surface cover layer. A base course layer was placed under the asphalt and consisted of 12 inches of compacted crushed stone. The base course was compacted in two lifts of 6 inches thick. Material and construction were according to standard Illinois DOT specifications section 406.

Nine cores of 18-inch diameter were drilled in the AC section. Figure 35 shows the layout of the test site. Figure 36 shows the construction of the test section and Figure 37 shows the drilling of the 18-inch cores in the test section using the SIMCO drilling machine.

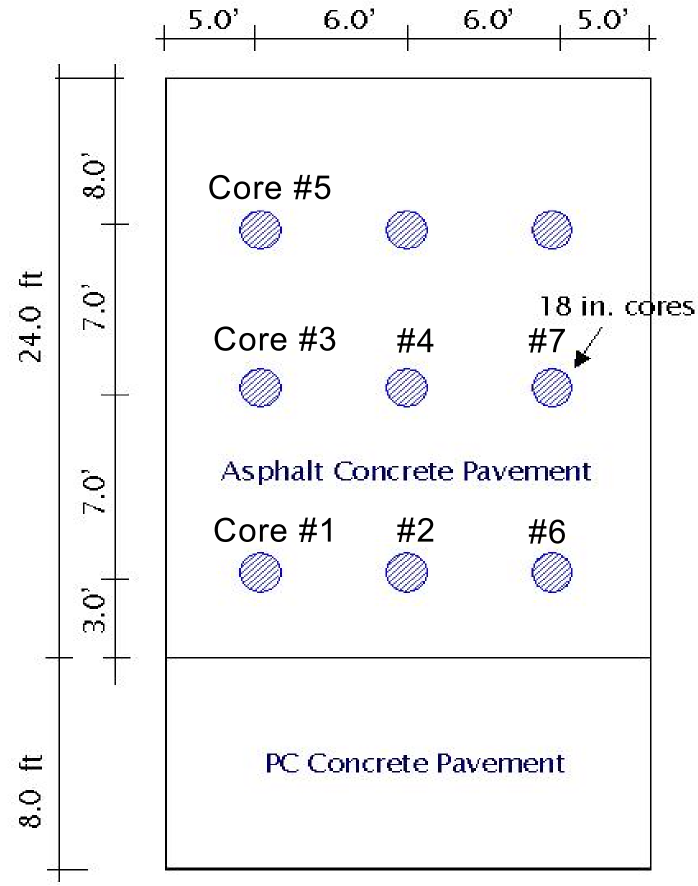


Figure 35. Layout of the field test section and locations of cores

Figure 36. Construction of the asphalt layer in the outdoor test section

Figure 37. Drilling the 18-inch cores using the ''SIMCO'' Drilling machine

E. PROCEDURE OF CORE PLACEMENT IN THE FIELD

The procedure of grouting and core placement was performed as follows:

1. The cores were marked in order to place them at their initial position after grouting (Figure 38). The cores were drilled at the center and were provided with an anchored eyebolt for ease of handling. A steel rod was used for lifting and placing the cores. The eyebolt was removed after the core had been set in place and the eyebolt hole was grouted.

2. The side-surface of the cores and the hole were cleaned with a wet cloth (Figure 39).

3. A sand layer of about 3 inches was placed and compacted under the core in order to represent the compacted backfill material. The sand was leveled so that a thickness of 0.5 to 0.75 inches was left for the base grout (Grout $_{base}$) under the core. For irregular cores in the field, a larger thickness of about

one inch may be left under the core in order to insure proper leveling of the core surface.

Figure 38. Pre-marking and anchoring the core

Figure 39. Cleaning the surface of the cores.

4. Before adding the grout, the core was placed on the sand backfill and the difference between the ground level and core was measured (Figure 40) in order to insure that the thickness of the grout base is uniform under the core.

5. Spacers were used in order to center the core and insure uniform kerf thickness around the core. Figure 38 shows the spacers placed around the core during placement.

6. The height of the core was measured at various locations along its perimeter. All the cores had a uniform height of about 8 inches. Table 6 can be used to determine the weight of dry grout. A dry grout of about 35 Ib was used since the cores had a regular surface at the base and the amount of grout loss was controlled in the lab-mixing environment. The mix was sufficient to fill the voids, with some excess grout at the surface (Figure 41).

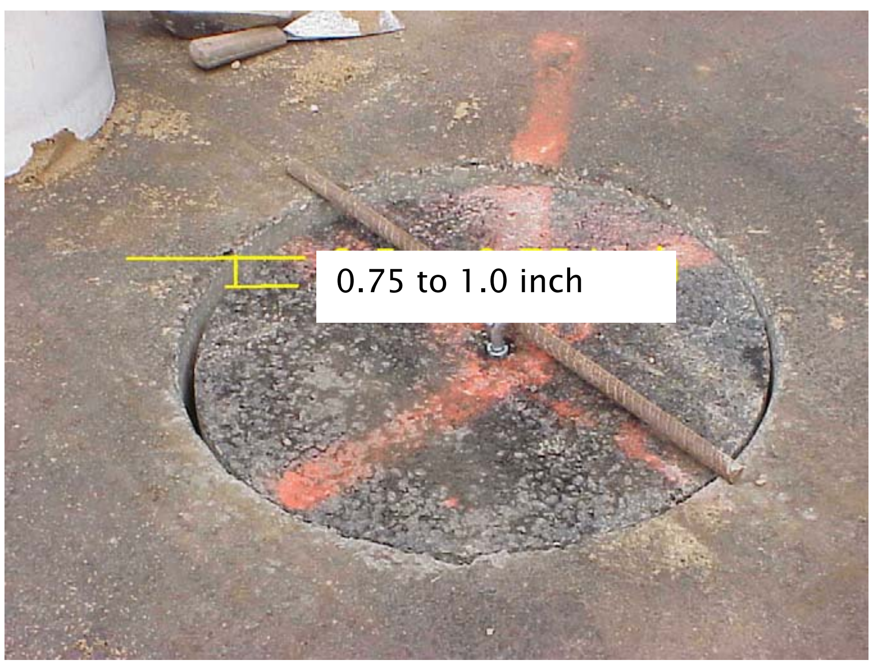


Figure 40. A uniform grout bed of 0.5-0.75 inch was set by placing the core on top of backfill before adding the grout.

Figure 41. Scooping out the excess grout after core placement.

F. EVALUATION OF CORE PERFORMANCE

Repeated wheel loads were applied on the grouted cores at a predetermined time after installation. The loads were applied using the "Accelerated Pavement Loading Equipment" (APLE) at GTI. This is a full scale testing machine that applies moving wheel loads using standard single or dual tires. Figure 42 shows a view of the APLE machine.

The wheel travels across pavement sections of 16 ft at controlled speeds and the machine is capable of applying constant loads up to single ESAL load of 9 Kips. The wheel load can be applied unidirectional and bi-directional on the pavement section. In the field tests, wheel loading was uni-directional, with the tire assembly being raised in the return stroke in order to avoid contact with the surface. This loading configuration simulated real one-directional field traffic conditions.

The wheel loads were applied using the dual tires, with one tire running over the grouted core while the other tire was running over the adjacent old pavement. This configuration enabled the assessment of the differential displacement between the core and the pavement. A front view of the dual tire system is shown in Figure 43.

The loading tests were performed on several cores prepared with various mixing ratios and at various temperatures. Table 7 shows grout types, mix ratios, additives used, and the testing conditions for each test. Repetitive wheel loads of 3 kips were applied over cores #1 to #4 and wheel loads of 6 kips were applied on cores #5, #6, and #7.

Figure 42. View of the Accelerated Pavement Loading Equipment

Figure 43. Front view of the APLE showing the dual tire loading on the core section

Table 7. List of the Testing parameters and conditions of the field cores

Core No.	Grout type	Wt. of dry grout (lb)	Water ratio (%)	Additives (per bag)			Temp (°F)	Mixing Time (min)	Set Time (Hr)
				Flow	Fast	Black			
1	Rapid Set (DOT MIX)	30	0.16	½	0	½	50	2	1
2		35	0.18	0	1	1	50	2	1
3		35	0.18	0	0	0	80	1	1
4		35	0.18	0	1	0	60	3/4	1
5	CeraCrete	35	0.16	0	0	0	70	5	1
6	Rapid Set (DOT Mix)	30	0.18	0	0	0	85	1	½
7	Enbridge	30	0.2	0	0	0	85	1	1

The short-term performance of the core was evaluated by comparing the settlement of the core with the settlement of the adjacent pavement after the setting time of the grout. Figure 44 shows the locations of tire loads over the core and the adjacent pavement. In short-term tests, settlements were measured after the application of 300 cycles of wheel loads. Long-term performance of the grout was evaluated in core 3 by measuring the settlement after the application of 3,700 cycles of loads over the core.

Settlements were measured across the pavement cross section using a depth profiler (Figure 45). The profiler gauge measured the displacement before and after the application of loads at every 6 inches across the cross section. Figure 46 shows a schematic of the locations of the settlement measurements around the core and figure 47 shows a view of the settlement reading using the depth gauge.

Figure 44. Location of the applied wheel load on the core

Figure 45. Measurement of core settlement using the depth profiler

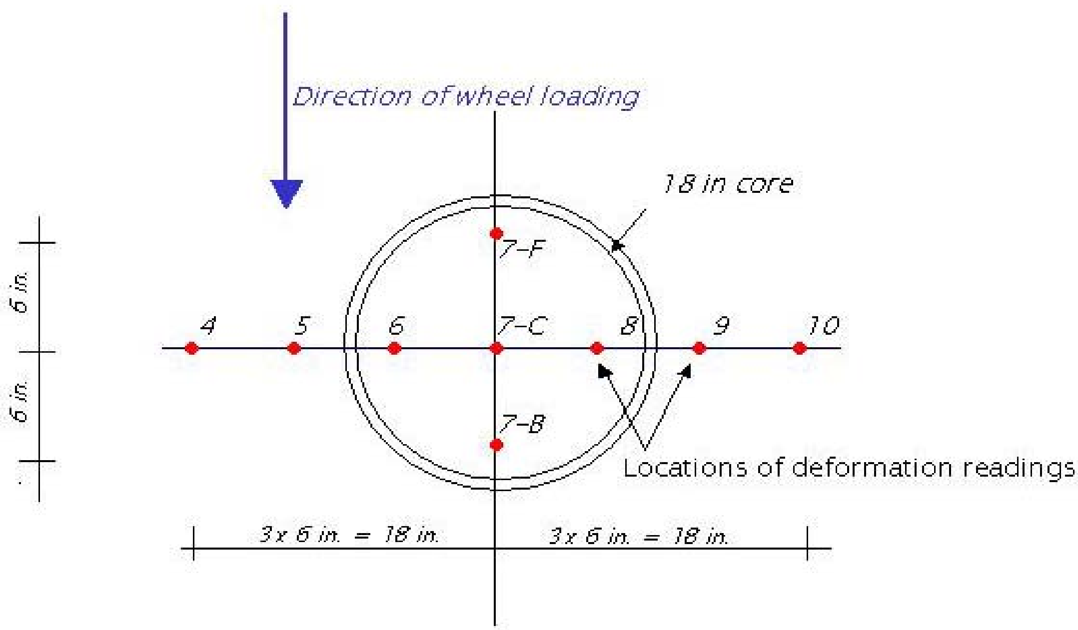


Figure 46. Locations of settlement measurements around the core

Figure 47. View of depth measurement using the depth gauge

The settlement measurements along the cross sections of the cores and adjacent pavement are shown in Figures 48 to 54 for cores #1 to #7, respectively. Testing parameters and settlements measurements of these tests are also shown in Appendix A.

The test in core #1 was performed on the ‘‘Rapid Set DOT’’ grout with the ‘‘Flow’’ and ‘‘Black’’ additives. The grout was mixed at a cold temperature of 50^{o}F and it required longer setting time before it could develop sufficient strength. Accordingly, the core could not carry the applied wheel load at one-hour setting time and relatively large differential settlement (in the range of 0.2 inches) was measured at the center of the core as shown in Figure 48.

The test of core #2 was performed on the grout mixed at the same temperature of 50^{o}F with the ‘Fast’ additive added to the mix in order to accelerate the grout setting. Grout stress at one-hour setting time was adequate to carry the wheel load and no significant settlement was measured at this core (Figure 49).

Loading continued on core #3 for up to 3,700 cycles in order to evaluate the long-term performance of the grout. The core was mixed at a temperature of 80^{o}F and no additives were added to the mix. The settlement of the core increased with the increase of number of passes. However, the maximum settlement at the center of the core (point 8) was less than 0.1 inch and was comparable to the settlement of the adjacent asphalt pavement at point 6. Settlement measurements of the core are shown in Figure 50.

Core #4 was mixed with the same type of grout and ''Fast'' additive. The grout setting was fast and started during the installation of the core in the ground. No significant settlement was measured after applying the wheel load (Figure 51).

The ''CeraCrete'' grout was tested at one hour setting time in core #5. The grout had no significant settlement (Figure 52). The consistency of the mix, however, was flowable and could not carry the weight of the core during installation.

The ''Rapid Set DOT'' grout was tested at ½ hour setting time in core #6. The results in Figure 53 show that the grout had acceptable performance with no significant settlement at the mixing temperature of 85^{o}F.

The ''Enbridge'' grout was evaluated in core #7. Wheel loading was applied to the core at one-hour setting time and the settlement measurements are shown in Figure 54. The results show no significant displacement (less than 0.05 inch) after the application of the 300 passes of the wheel load. The comparison between the measurements of the Rapid set grout (Figure 53) and the ''Enbridge'' grout (Figure 54) shows that the settlement of the Rapid set at ½ hour setting time was less than that of the ''Enbridge'' grout at one-hour setting time. Both grouts were mixed at temperature of 85^{o}F with no additives.

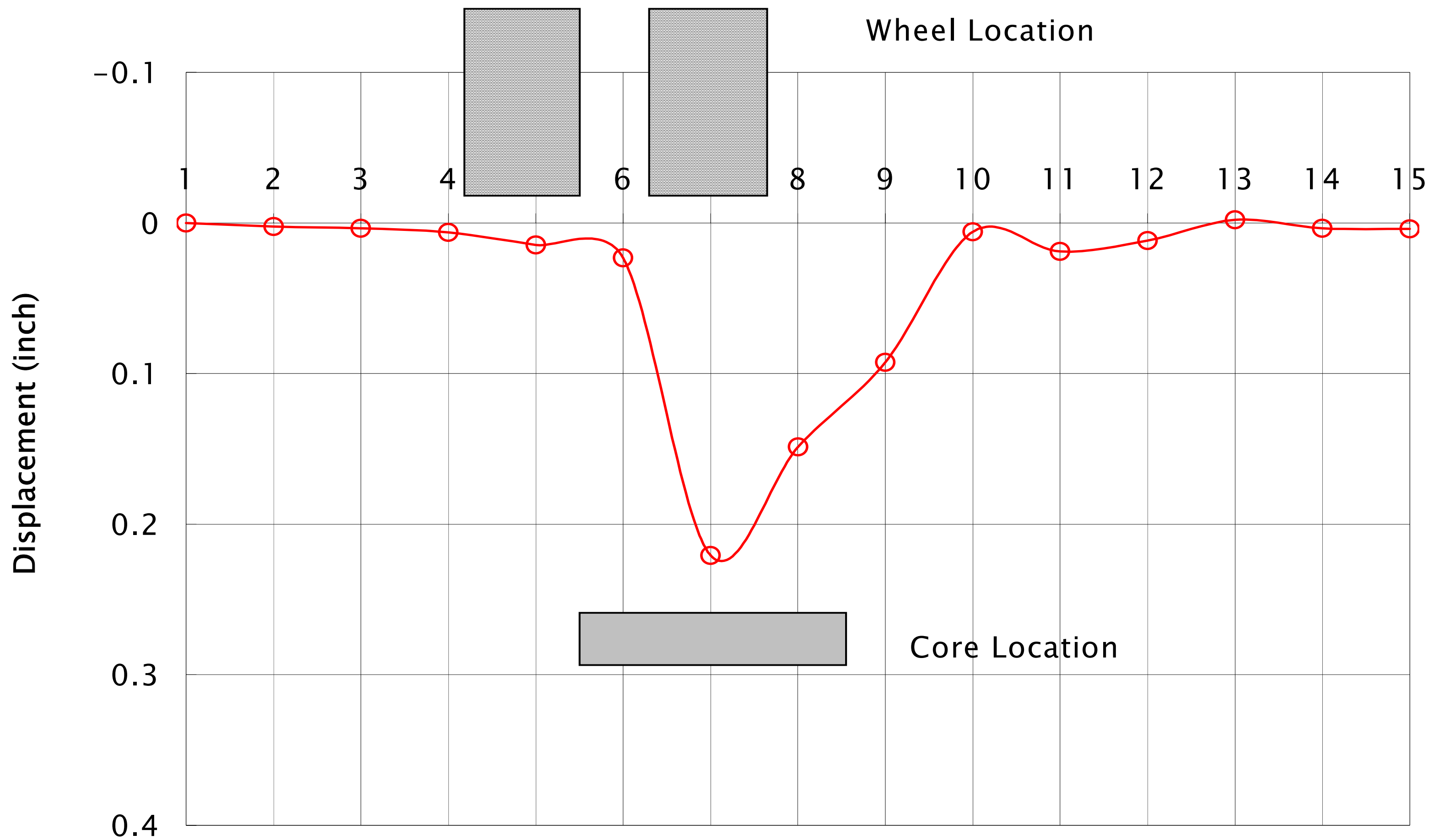


Figure 48. Displacement of core #1 section after 300 wheel passes

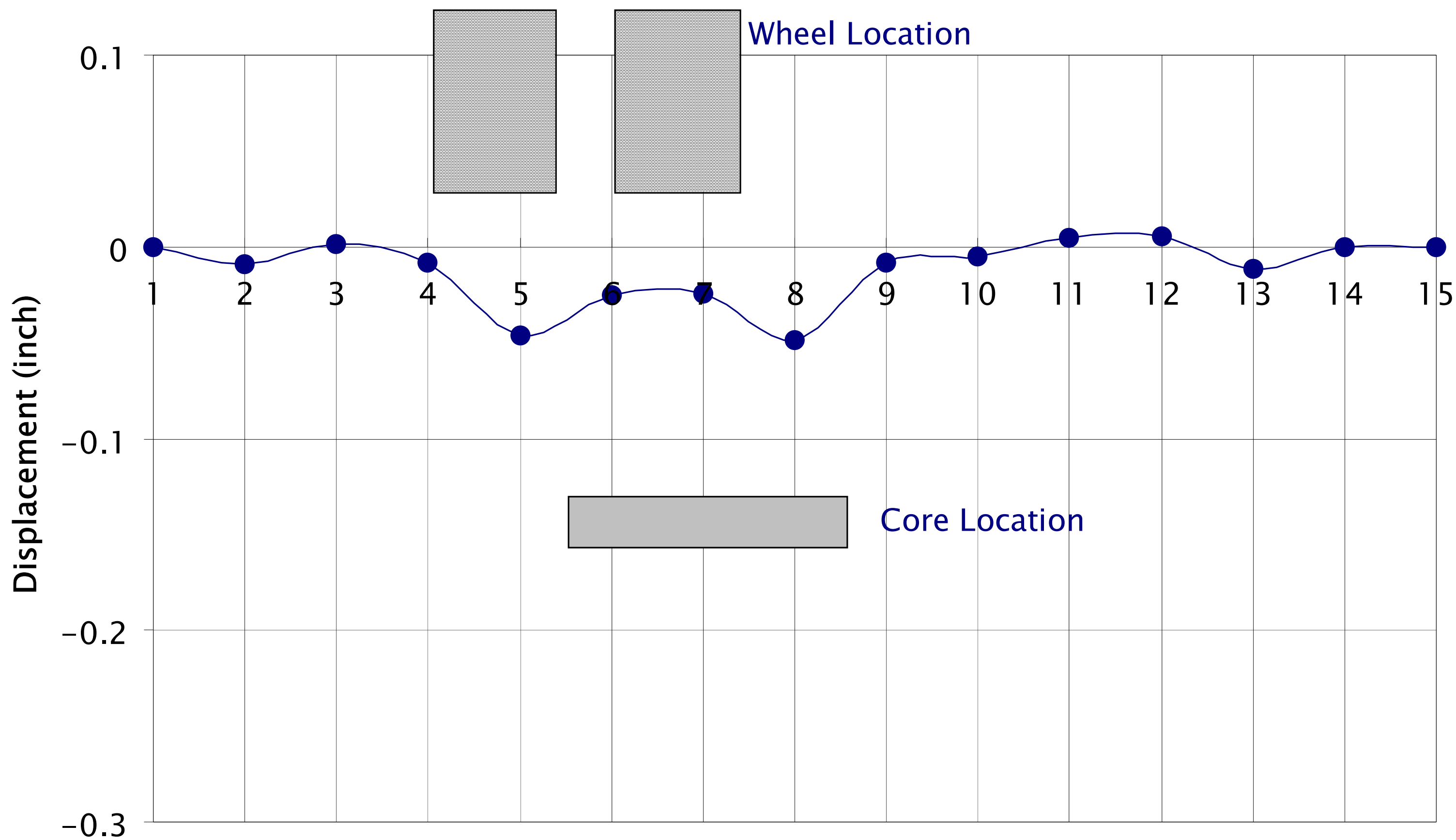


Figure 49. Displacement of core #2 section after 300 wheel passes

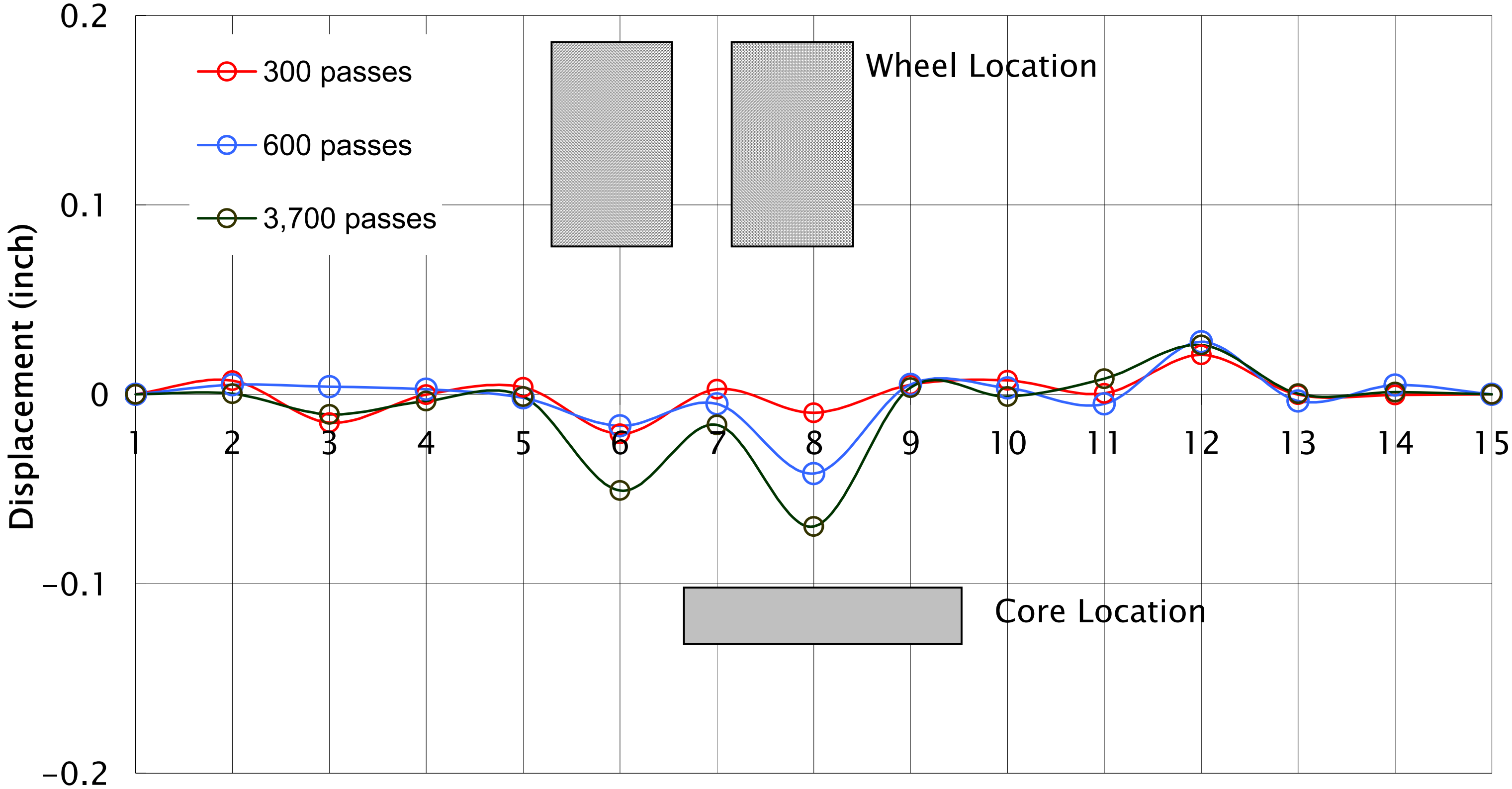


Figure 50. Long-term Displacement of core #3 section

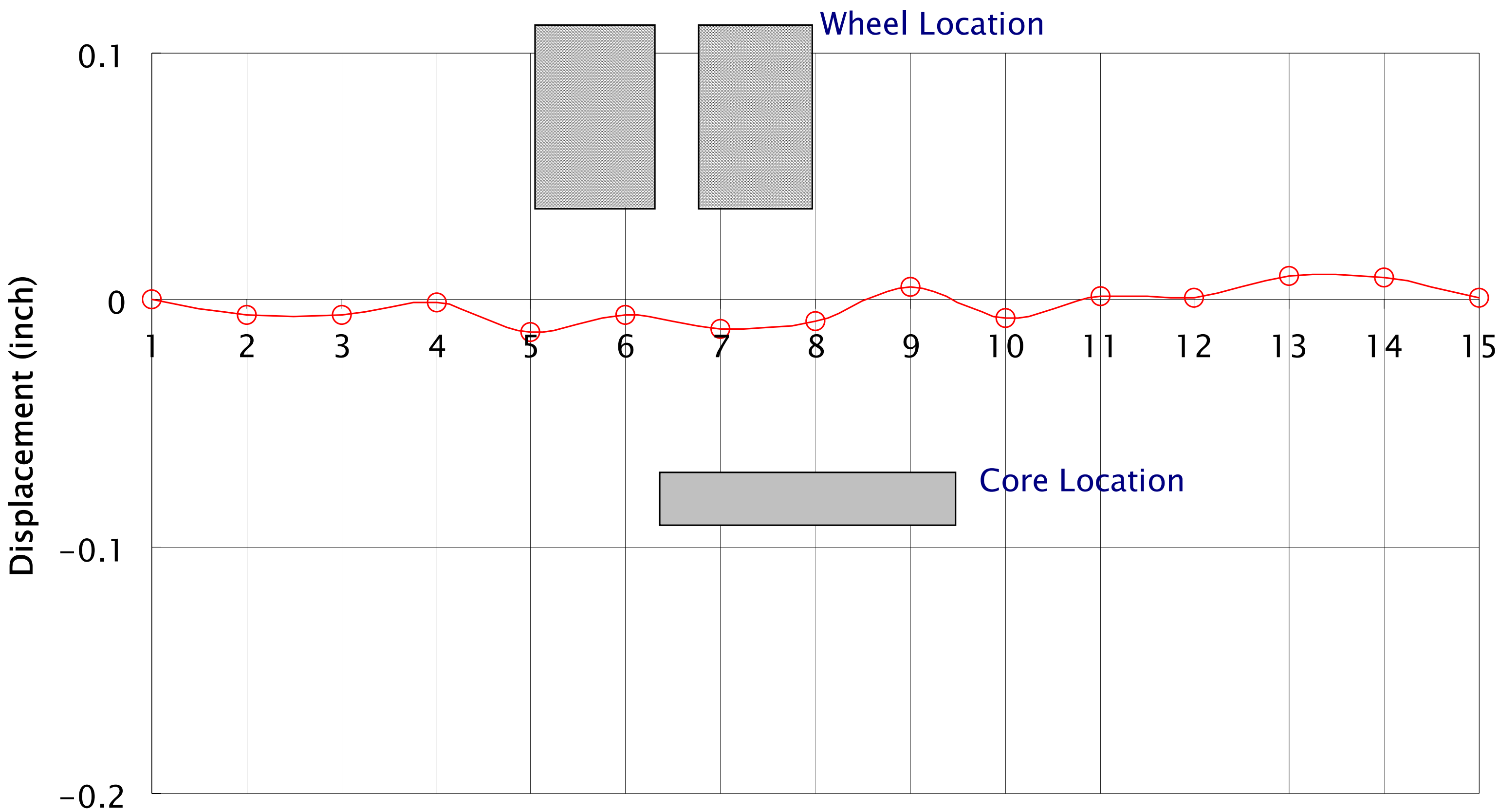


Figure 51. Displacement of core #4 section after 300 wheel passes

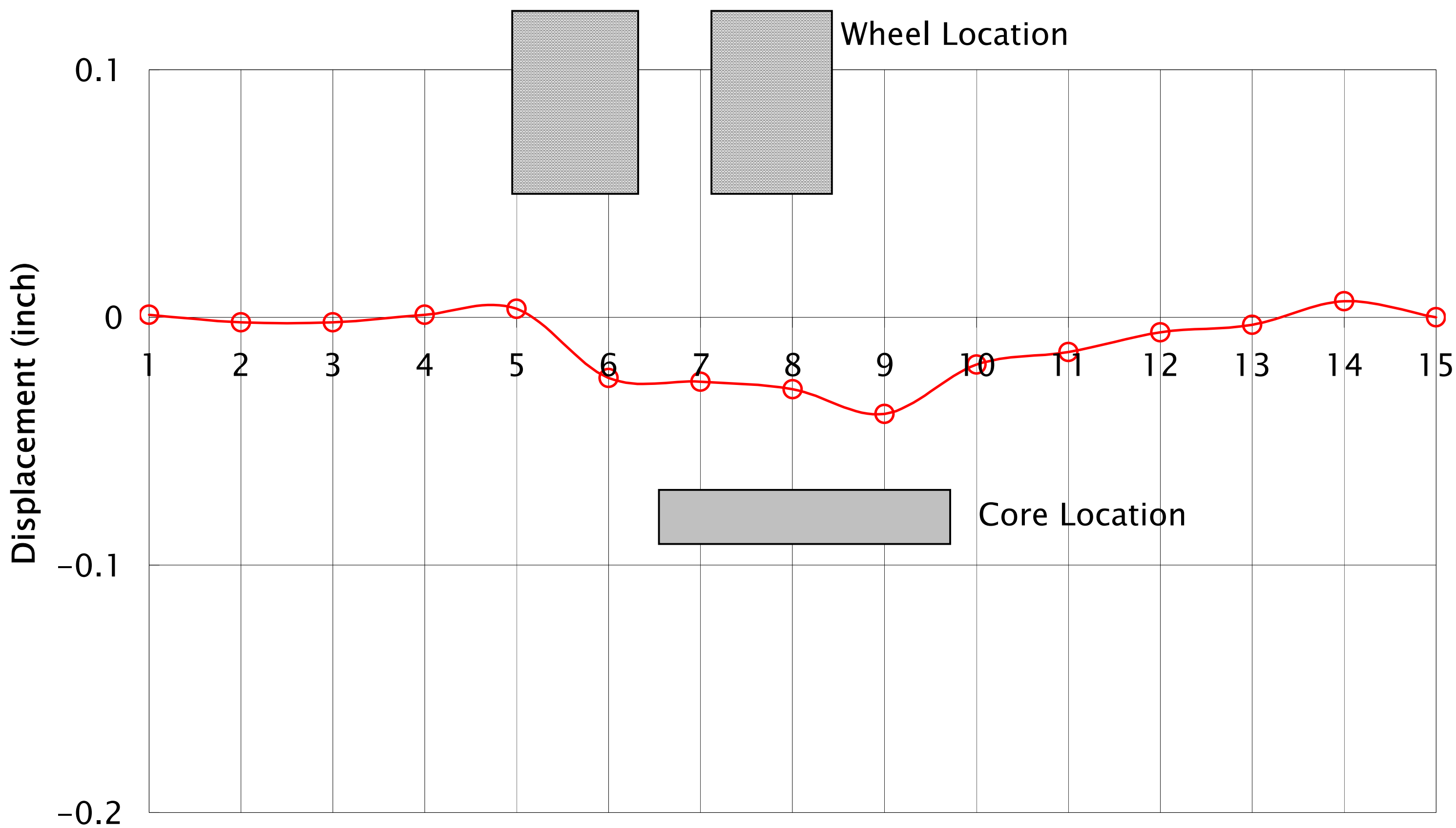


Figure 52. Displacement of core #5 section after 300 wheel passes

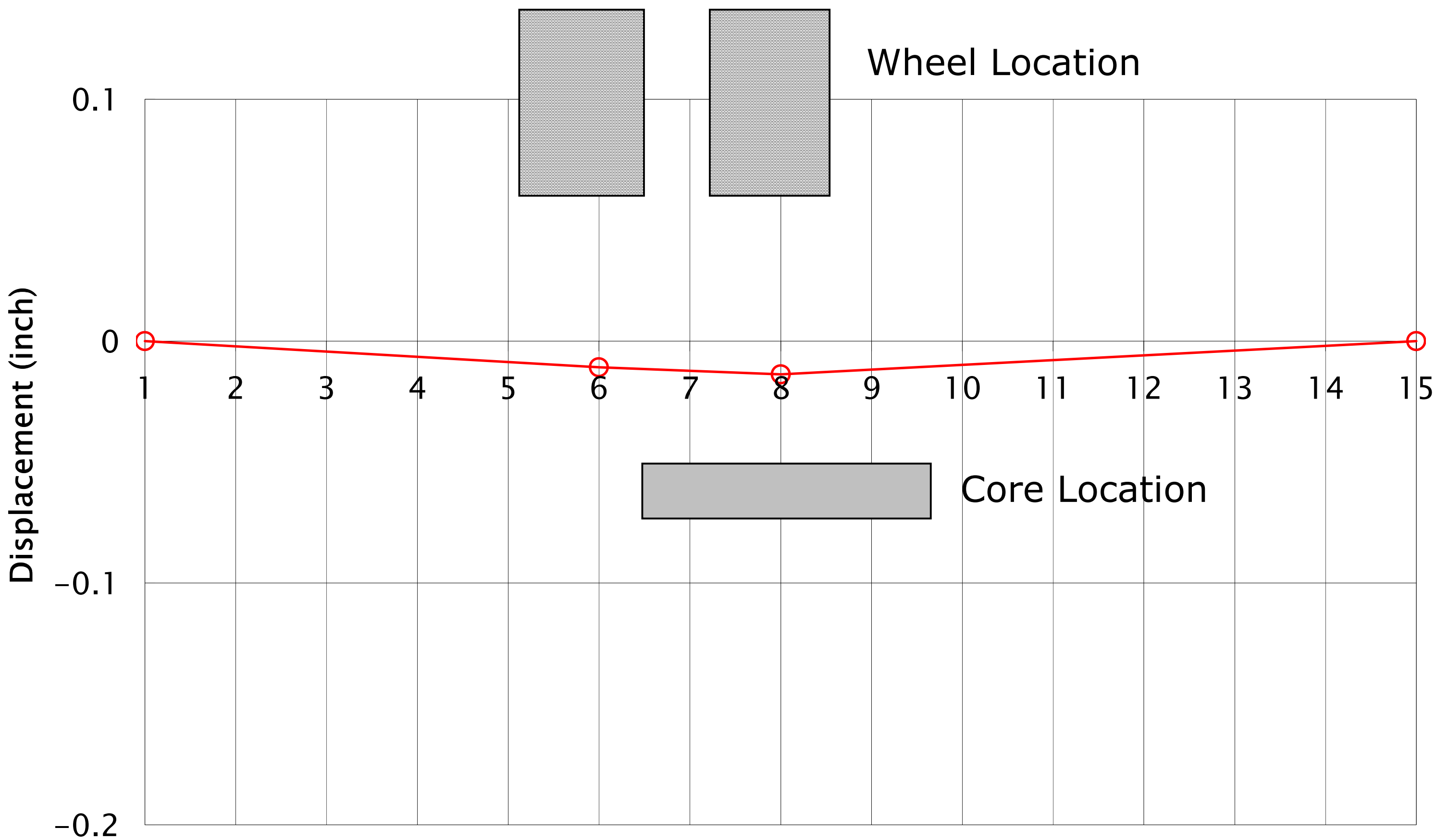


Figure 53. Displacement of core #6 section after 300 wheel passes

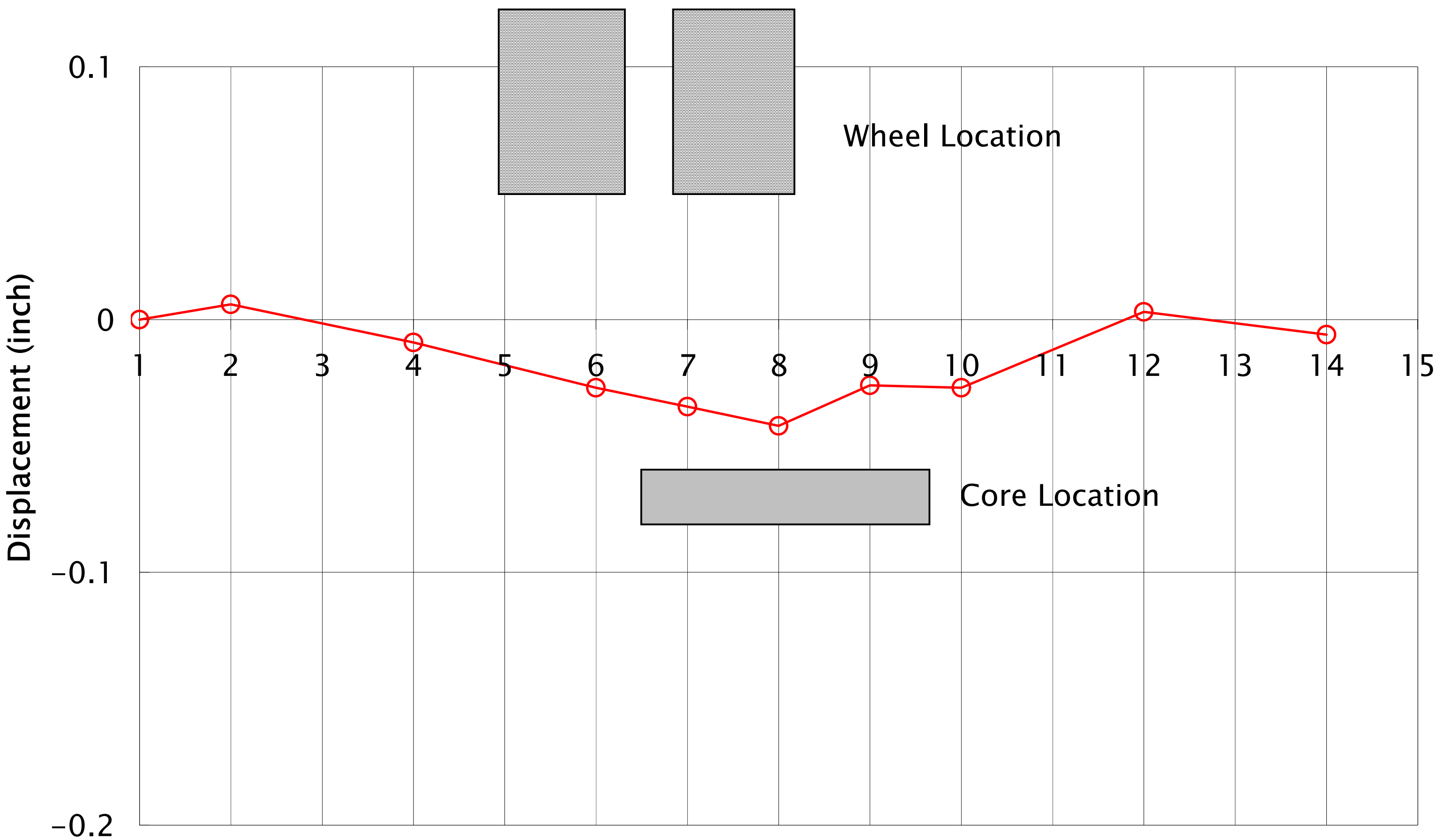


Figure 54. Displacement of core #7 section after 300 wheel passes

G. CONCLUSIONS

- The mix ratios of the “Rapid Set DOT’’ were established for core diameters of 10 inches and 18 inches. Table 6 can be used in estimated the mix ratios for various core heights and for a grout thickness of one inch under the core. Figures 32 and 33 can be used in estimating the mix ratios for larger thickness (y) under the core.

- Settlement measurements after applying repeated wheel loads showed that the short-term settlements of the cores with “Rapid Set DOT’’ mix (cores #2, #3, #4, and #6) were small (less than 0.05 inches) and were comparable to the ones of the adjacent pavement. However, the grout mixed at temperature of 50^{o}F required longer setting time and did not carry the wheel load after one-hour of installation (core 1).

- In colder temperatures, adding the ‘‘Fast’’ additive to the mix resulted in accelerating the setting time of the grout (cores #2 and #4). The use of ‘‘Fast’’ additive is recommended when the ambient temperature is between 50^{o}F and 70^{o}F. Using the additive at temperatures higher than 70^{o}F may shorten the setting time to the extent that the mix starts to harden before core installation is complete.

APPENDIX A

RESULTS OF FIELD LOADING TESTS

Field Test on Core-1

Mix Ratio

Grout:	Raspid Set - Orange [DOT Mix]		
Grout:		27	lb
water [0.16 %]		4.32	lb
Mixtures	1/2 Flow	0.0725	lb
	1/2 Black	0.16	lb

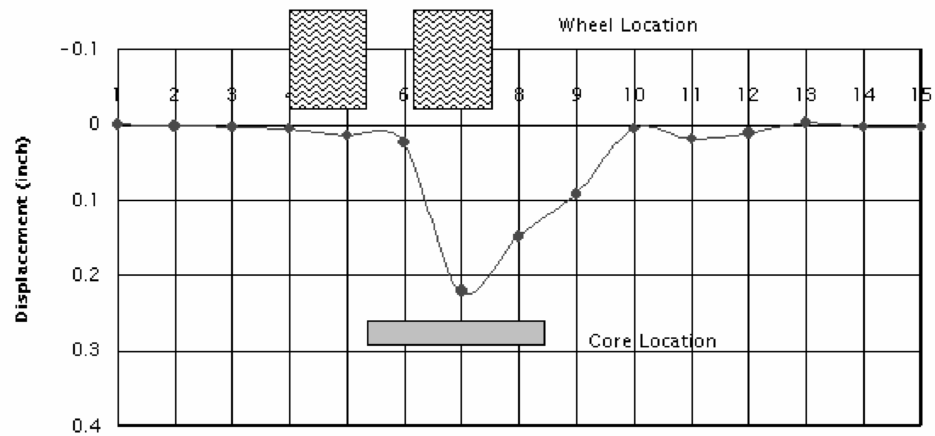
Accelerated Pavement Loading Machine (APLM)

Applied Vert. pressure	20	psi
Applied Vert. Load	3140	lb
No. of Runs [uni-directional]	300	

Core Dimensions

Core Diam.	18 in
Outer Diam	18.5 in
Depth	8 in

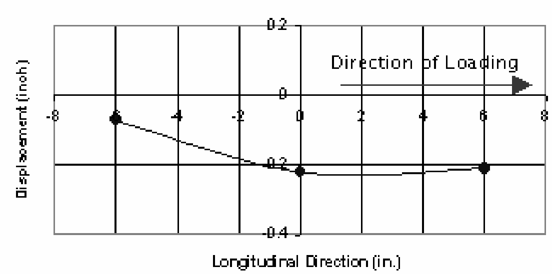
Notes: Core and cut surface were cleaned before installation
Grout thick. Beneath core = 1/2 inch
A/C Temp 45 F
Mixing time 2 min
Curing time 1 hour



Longitudinal Direction
Date 3/28/02

Location	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
initial Reading	0	-1.22	-0.4	-1.8	-3.44	-6.06	-9.27	-12.07	-16.17	-16.53	-15.42	-6.04	0.81	-0.08	-0.36
After 300 passes	0	-1.16	-0.31	-1.64	-3.07	-5.47	-3.66	-8.29	-13.82	-16.38	-14.94	-5.74	0.76	0.01	-0.26
Displ (mm)	0	0.06	0.09	0.16	0.37	0.59	5.61	3.78	2.35	0.15	0.48	0.3	-0.05	0.09	0.1
Displ (in.)	0	0.00236	0.00354	0.0063	0.01457	0.02323	0.22087	0.14882	0.09252	0.00591	0.0189	0.01181	-0.002	0.00354	0.00394

Cross-Direction	7-F	7-M	7-B
	-6	0	6
initial Reading	-9.78	-9.27	-11.4
After 300 passes	-8.02	-3.66	-6.06
	-1.76	-5.61	-5.34
	-0.0693	-0.2209	-0.2102

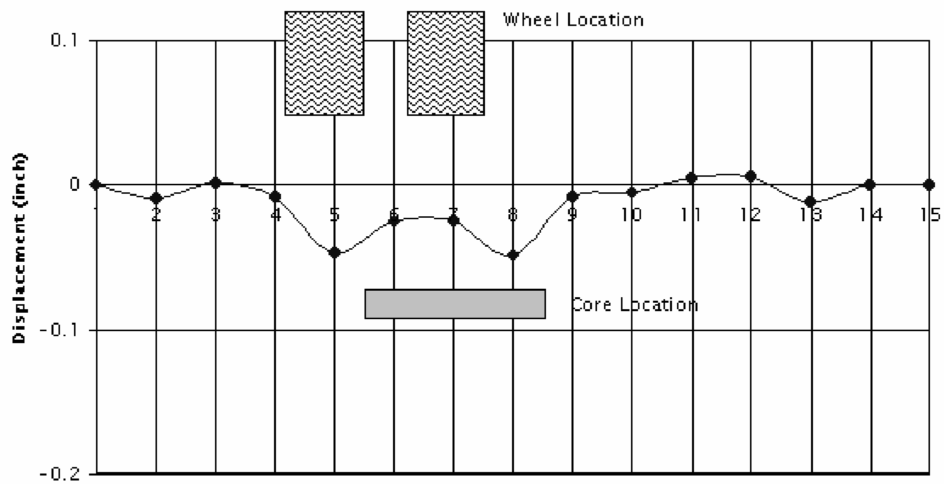


Notes
* Points are across the direction of loading and 6 in. apart
* Pts. 6,7, 8 are inside core
* Point 7-M at centerline of core
* Points 7-Front and 7-Back are 6 in from 7-M in direction of wheel loading

Field Test on Core-2

Date 4/8/02
Mix Ratio

Grout:	Raspid Set - Orange [DOT Mix]		
Grout:		27	lb
water [0.18 %]		4.86	lb
Mixtures	Flow	0	lb
	1 Fast	0.18	lb
	1 Black	0.32	lb



Accelerated Pavement Loading Machine (APLM)

Applied Vert. pressure	20	psi
Applied Vert. Load	3140	lb
No. of Runs [uni-directional]	300	

Core Dimensions

Core Diam	18	in
Outer Dian	18.5	in
Depth	8	in

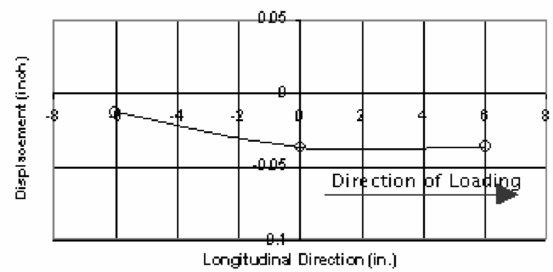
Notes: Core and cut surface were cleaned before installation
Grout thick. Beneath core = 1/2 inch
A/C Temp 50 F
Mixing time 2 min
Curing time 1 hour

Longitudinal Direction

Location	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
initial Reading	0	0.45	1.6	1.84	2.24	0.87	-2.45	-4.33	-1	-1.73	-1.37	-0.15	-0.2	0.13	-2.33
After 300 passes	0	0.13	1.51	1.46	0.84	-0.03	-3.38	-5.91	-1.6	-2.3	-1.72	-0.53	-1.06	-0.48	-2.98
Displ (mm)	0	-0.32	-0.09	-0.38	-1.4	-0.9	-0.93	-1.58	-0.6	-0.57	-0.35	-0.38	-0.86	-0.61	-0.65
Displ (in.)	0	-0.0126	-0.00354	-0.01496	-0.05512	-0.03543	-0.03661	-0.0622	-0.02362	-0.02244	-0.01378	-0.01496	-0.03386	-0.02402	-0.02559
Re-distributed	0	-0.00919	0.001575	-0.00814	-0.04659	-0.0252	-0.02467	-0.04856	-0.00827	-0.00538	0.004987	0.005512	-0.01168	-0.00013	0

Cross-Direction

	-6	0	6
initial Reading	-4.22	-2.45	-1.54
After 300 passes	-4.55	-3.38	-2.46
Displ (mm)	-0.33	-0.93	-0.92
Displ (in.)	-0.01299	-0.03661	-0.03622



Notes
* Points are across the direction of loading and 6 in. apart
* Pts. 6,7, 8 are inside core
* Point 7-M at centerline of core
* Points 7-Front and 7-Back are 6 in from 7-M in direction of wheel loading

Field Test on Core-3

Mix Ratio

Grout:	Raspid Set - Orange [DOT Mix]		
Grout:		27	lb
water [0.18 %]		4.86	lb
Mixtures	Flow	0	lb
	0 Fast	0	lb
	0 Black	0	lb

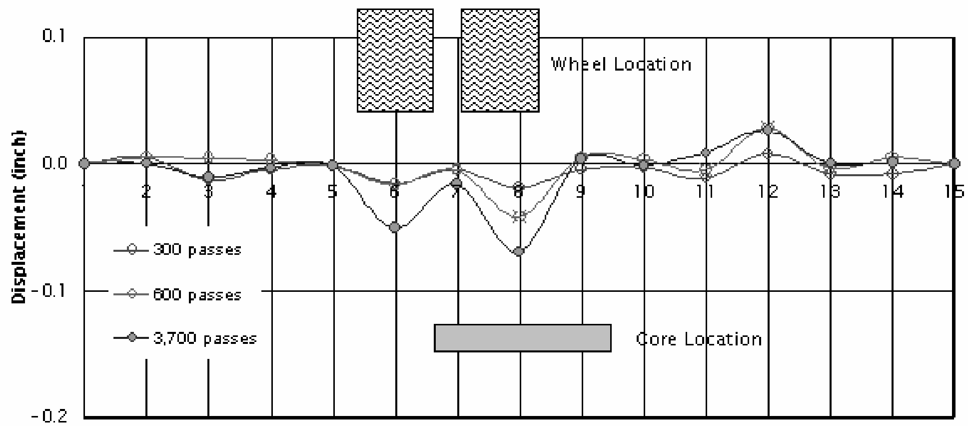
Accelerated Pavement Loading Machine (APLM)

Applied Vert. pressure	20	psi
Applied Vert. Load	3140	lb

Core Dimensions

Core Diam	18	in
Outer Dian	18.5	in
Depth	8	in

Notes: Core and cut surface were cleaned before installation
Grout thick. Beneath core = 1/2 inch
Temp 85 F
Mixing time 1 min
Curing time 1 hour

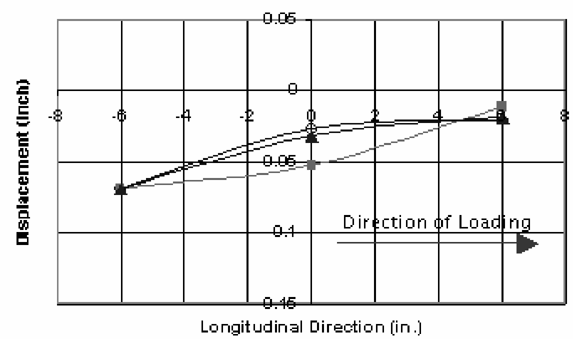


Longitudinal Direction
Test 4/16/02

Location	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
initial Reading	0	9.1	12.84	15.31	17.59	17.57	11.51	8.72	5.77	6.5	6.39	7.28	6.06	4.11	0.07
After 300 passes	0	8.87	13.01	15.22	17.38	17.66	11.28	8.79	5.43	6.08	6.12	6.47	5.6	3.6	-0.28
Displ (mm)	0	0.23	-0.17	0.09	0.21	-0.09	0.23	-0.07	0.34	0.42	0.27	0.81	0.46	0.51	0.35
Displ (in.)	0.0000	0.0091	-0.0067	0.0035	0.0083	-0.0035	0.0091	-0.0028	0.0134	0.0165	0.0106	0.0319	0.0181	0.0201	0.0300
Re-distributed	0.0000	0.0051	-0.0127	-0.0045	-0.0017	-0.0155	-0.0049	-0.0188	-0.0046	-0.0035	-0.0114	0.0079	-0.0079	-0.0079	0.0000

Cross-Direction

	-6	0	6
initial Reading	7.55	8.72	12.45
After 300 passes	9.3	9.41	12.98
Displ (mm)	-1.75	-0.69	-0.53
Displ (in.)	-0.0689	-0.02717	-0.02087



Notes
* Points are across the direction of loading and 6 in. apart
* Pts. 7, 8 and 9 are inside core
* Point 8-M at centerline of core
* Points 8-Front and 8-Back are 6 in from 8-M in direction of wheel loading

Field Test on Core-3 [continued]

Test 5/2/02

Longitudinal Direction

Location	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
initial Reading	0	9.1	12.84	15.31	17.59	17.57	11.51	8.72	5.77	6.5	6.39	7.31	6.06	4.11	0.07
After 600 passes	0	9.14	12.99	15.58	18.06	18.5	12.23	10.46	6.4	7.26	7.45	7.62	7.25	5.17	1.34
Displ (mm)	0	-0.04	-0.15	-0.27	-0.47	-0.93	-0.72	-1.74	-0.63	-0.76	-1.06	-0.31	-1.19	-1.06	-1.27
Displ (in.)	0	-0.00157	-0.00591	-0.01063	-0.0185	-0.03661	-0.02835	-0.0685	-0.0248	-0.02992	-0.04173	-0.012205	-0.04685	-0.041732	-0.05
Re-distributed	0	0.005092	0.004094	0.002703	-0.00184	-0.01661	-0.00501	-0.04184	0.005197	0.003412	-0.00507	0.027795	-0.00352	0.004934	0

Cross-Direction

	-6	0	6
initial Reading	7.55	8.72	12.4
After 600 passes	9.3	10.06	12.7
Displ (mm)	-1.75	-1.34	-0.3
Displ (in.)	-0.0689	-0.05276	-0.01181

Test 5/10/02

Longitudinal Direction

Location	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
initial Reading	0	9.1	12.84	15.31	17.59	17.57	11.51	8.72	5.77	6.5	6.39	7.31	6.06	4.11	0.07
After 3,700 passes	0	8.85	12.75	14.92	17.02	18.14	11.08	9.53	4.6	5.33	4.86	5.21	4.49	2.4	-1.73
Displ (mm)	0	0.25	0.09	0.39	0.57	-0.57	0.43	-0.81	1.17	1.17	1.53	2.1	1.57	1.71	1.8
Displ (in.)	0	0.009843	0.003543	0.015354	0.022441	-0.02244	0.016929	-0.03189	0.046063	0.046063	0.060236	0.0826772	0.061811	0.0673228	0.0708661
Re-distributed	0	0.000394	-0.01063	-0.00354	-0.00118	-0.05079	-0.01614	-0.06969	0.003543	-0.00118	0.008268	0.025984	0.000394	0.001181	0

Cross-Direction

	-6	0	6
initial Reading	7.55	8.72	12.4
After 3700 passes	9.3	9.53	12.88
Displ (mm)	-1.75	-0.81	-0.48
Displ (in.)	-0.0689	-0.03189	-0.0189

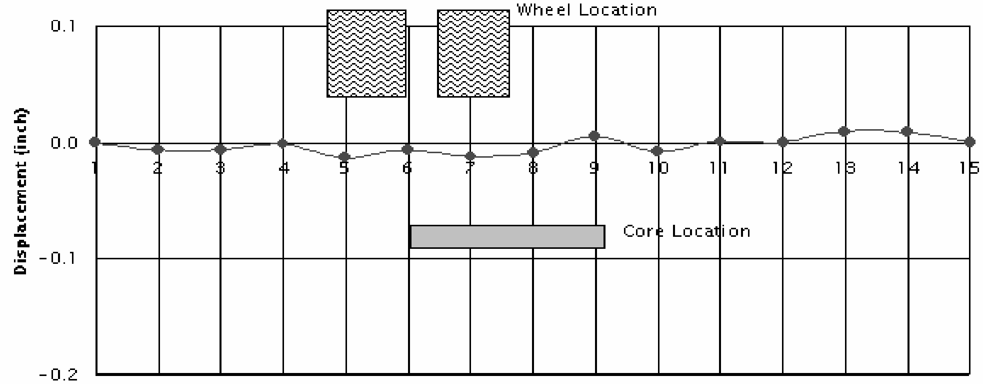
Field Test on Core-4

Date 4/16/02
Mix Ratio
Grout: Raspid Set - Orange [DOT Mix]
Grout: 27 lb
water [0.18 %] 4.86 lb
Mixtures Flow 0 lb
1 Fast 0.18 lb
0 Black 0 lb

Accelerated Pavement Loading Machine (APLM)
Applied Vert. pressure 20 psi
Applied Vert. Load 3140 lb
No. of Runs [uni-directional] 300

Core Dimensions
Core Diam 18 in
Outer Dian 18.5 in
Depth 8 in

Notes: Core and cut surface were cleaned before installation
Grout thick. Beneath core = 1/2 inch
Temp 55
Mixing time 45 sec
Curing time 1 hour

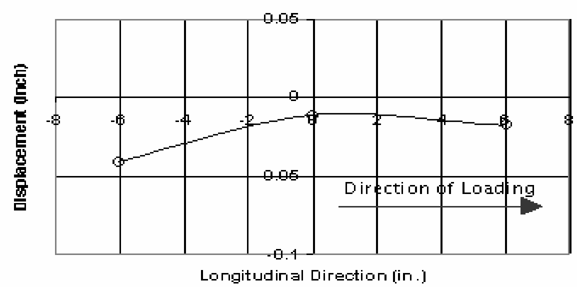


Longitudinal Direction

Location	1	2	3	4	5	6	7	8-M	9	10	11	12	13	14	15
initial Reading	0	0.28	1.78	0.56	1.16	-0.03	-8.02	-8.56	-8.36	-0.53	2.94	2.26	2.65	2.26	1.6
After 300 passes	0	0.12	1.62	0.53	0.83	-0.19	-8.32	-8.78	-8.22	-0.72	2.97	2.28	2.9	2.49	1.62
Displ (mm)	0	-0.16	-0.16	-0.03	-0.33	-0.16	-0.3	-0.22	0.14	-0.19	0.03	0.02	0.25	0.23	0.02
Displ (in.)	0.0000	-0.0063	-0.0063	-0.0012	-0.0130	-0.0063	-0.0118	-0.0087	0.0055	-0.0075	0.0012	0.0008	0.0098	0.0091	0.0008

Cross-Direction

	-6	0	6
initial Reading	-1.46	-8.49	-13.65
After 300 passes	-2.5	-8.78	-14.1
Displ (mm)	-1.04	-0.29	-0.45
Displ (in.)	-0.04094	-0.011417	-0.01772



Notes * Points are across the direction of loading and 6 in. apart
* Pts. 7, 8 and 9 are inside core
* Point 8-M at centerline of core
* Points 8-Front and 8-Back are 6 in from 8-M in direction of wheel loading

Field Test on Core-5

Mix Ratio

Grout:	Ceratech	
Grout:	30	lb
water [0.16 %]	4.8	lb
No Additives		

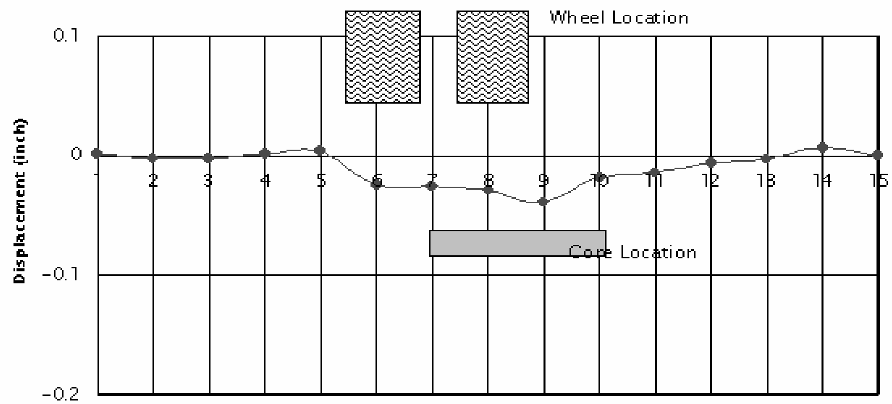
Accelerated Pavement Loading Machine (APLM)

Applied Vert. pressure	38	psi
Applied Vert. Load	6000	lb
No. of Runs [uni-directional]	300	

Core Dimensions

Core Diam.	18 in
Outer Diam	18.5 in
Depth	8 in

Notes: Core and cut surface were cleaned before installation
Grout thick. Beneath core = 1/2 inch
A/C Temp 65 F
Mixing time 5 min
Curing time 1 hour

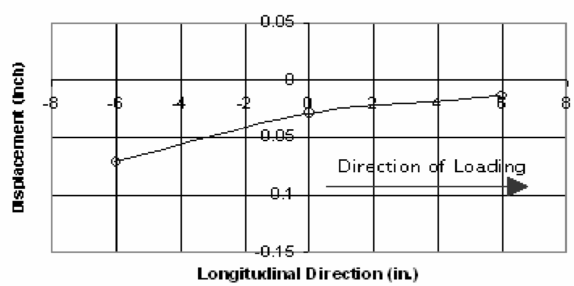


Longitudinal Direction

Location	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
initial Reading	-0.0575	-0.04	-0.082	-0.158	-0.335	-0.4525	-0.326	-0.303	-0.223	-0.174	-0.117	-0.075	-0.02	-0.0265	0
After 300 passes	-0.0565	-0.042	-0.084	-0.157	-0.3315	-0.477	-0.352	-0.332	-0.262	-0.193	-0.131	-0.081	-0.023	-0.02	0
Displ (in)	0.001	-0.002	-0.002	0.001	0.0035	-0.0245	-0.026	-0.029	-0.039	-0.019	-0.014	-0.006	-0.003	0.0065	0

Cross-Direction

Location	-6	0	6
initial Reading	-0.232	-0.303	-0.256
After 300 passes	-0.303	-0.332	-0.27
Displ (in)	-0.071	-0.029	-0.014



Field Test on Core-6

Mix Ratio

Grout:	Raspid Set - Orange [DOT Mix]	
Grout:	30	lb
water [0.18%]	5.4	lb
No Additives		

Accelerated Pavement Loading Machine (APLM)

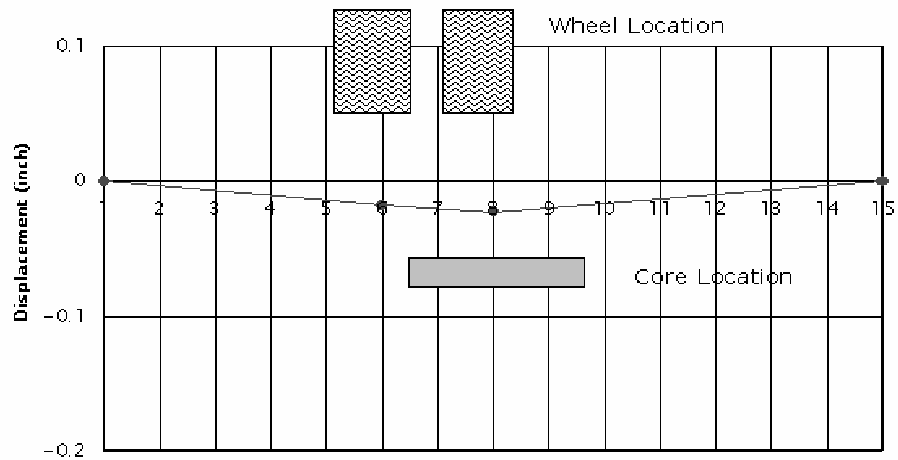
Applied Vert. pressure	38	psi
Applied Vert. Load	6000	lb
No. of Runs [uni-directional]	400	

Core Dimensions

Core Diam.	18	in
Outer Diam	18.5	in
Depth	8	in

Notes: Core and cut surface were cleaned before installation
Grout thick. Beneath core = 1 inch

A/C Temp.	85	F
Mixing time	30	sec
Curing time	1/2	hour



Longitudinal Section

Location	1	6	8	15
initial Reading	0	-0.01	-0.01	-0.11
After 400 passes	0	-0.02	-0.022	-0.09
Displ (in)	0	-0.01	-0.012	0.02
correction for pt. 15	0	-0.008	-0.011	-0.02
Absolute Displ (inch)	0	-0.018	-0.023	0

Field Test on Core-7
Date 7/25/2002

Mix Ratio

Grout:	Ambridge Mix	
Grout:	30	lb
water [0.2%]	6	lb
No Additives		

Accelerated Pavement Loading Machine (APLM)

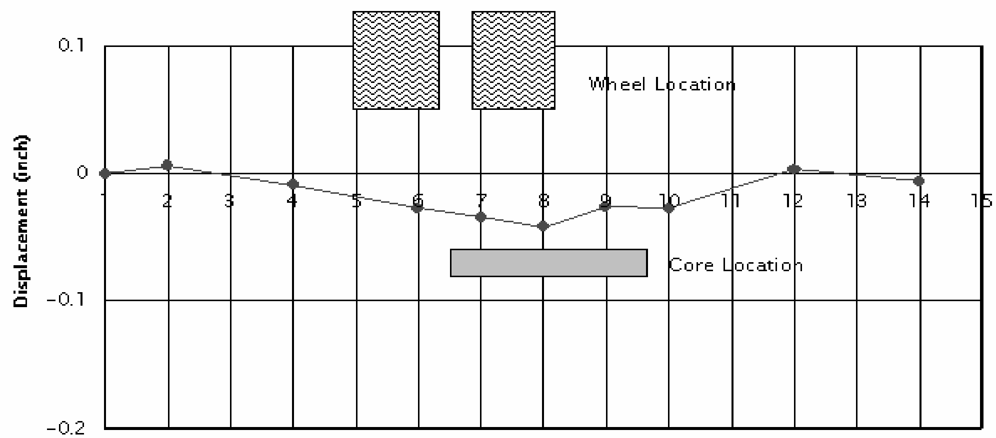
Applied Vert. pressure	38	psi
Applied Vert. Load	6000	lb
No. of Runs [uni-directional]	300	

Core Dimensions

Core Diam.	18 in
Outer Diam	18.5 in
Depth	8 in

Notes: Core and cut surface were cleaned before installation
Grout thick. Beneath core = 0.75 inch

A/C Temp.	85	F
Mixing time	30	sec
Curing time	1	hour



Longitudinal Section

Location	1	2	4	6	7	8	9	10	12	14
initial Reading	0	-0.14	-0.189	-0.233	-0.298	-0.34	-0.222	-0.118	-0.027	-0.03
After 300 passes	0	-0.146	-0.18	-0.206	-0.263	-0.298	-0.196	-0.091	-0.03	-0.024
Displ (in)	0	0.006	-0.009	-0.027	-0.035	-0.042	-0.026	-0.027	0.003	-0.006

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