VIBRATION STUDY FOR CONSOLIDATION OF PORTLAND CEMENT CONCRETE

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Vibration Study for Consolidation of
Portland Cement Concrete

Final Report
for Iowa DOT
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8. ABSTRACT

The Iowa Department of Transportation has noticed an increase in the occurrence of excessively vibrated portland cement concrete (PCC) pavements. The over consolidation of PCC pavements can be observed in several sections of PCC highways across the state of Iowa. Also, excessive vibration is believed to be a factor in the premature deterioration of several pavements in Iowa. To address the problem of excessive vibration, a research project was conducted to document the vibratory practices of PCC slipform paving in Iowa and determine the effect of vibration on the air content of pavement. The primary factors studied were paver speed, vibrator frequency, and air content relative to the location of the vibrator. The study concluded that the Iowa Department of Transportation specification of 5000 and 8000 vibrations per minute (vpm) for slipform pavers is effective for normal paver speeds observed on the three test paving projects. Excessive vibration was clearly identified on one project where a vibrator frequency was found to be 12,000 vpm. When the paver speed was reduced to half the normal speed, hard air contents indicated that excessive vibration was beginning to occur in the localized area immediately surrounding the vibrator at a frequency of 8000 vpm. Analysis of variance testing indicated many variables and interactions to be significant at a 95 percent confidence level; however, the variables and interactions that were found to be significant varied from project to project. This affirms the complexity of the process for consolidating PCC.

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INTRODUCTION

Portland cement concrete has provided durable highway pavements for decades in the state of Iowa. When properly designed and constructed, the expected service life is 40 years according to Iowa DOT design standards. In some cases a PCC pavement may suffer premature deterioration due to poor design, materials, or construction procedures.

Excessive vibration of PCC during placement can lead to premature deterioration in a portland cement concrete pavement. Excessive vibration of PCC will cause coarse aggregate to segregate, and it will decrease the entrained air content of the concrete. The reduced entrained air content compromises the air void system that protects the PCC from damage caused by the freezing and thawing of moisture within the concrete. The air voids allow the pressures that develop during the freezing of moisture within the concrete to be reduced (1, 19). The segregation of the PCC may initiate abnormal cracking during the hydration of the cement (1). The cracking is caused by differential drying shrinkage between areas of differing paste and aggregate contents.

BACKGROUND INFORMATION

This section covers some of the basic concepts of paving with portland cement concrete. These concepts include the basics of PCC, consolidation, and slipform paving.

Portland Cement Concrete

Portland cement concrete is primarily a mixture of aggregate and paste. The aggregates are usually separated into two classes. These classes are fine aggregate and coarse aggregate. The paste is composed primarily of portland cement, water, and mineral admixtures. The cement paste for Iowa DOT pavement mixes is approximately one third of the total concrete mix by volume (2). Portland cement is a hydraulic cement that hardens by reacting with water. Thus the paste acts like a glue by binding together the aggregate in the PCC.

The fine aggregates are sometimes referred to as the sand portion of the PCC mix. The fine aggregate is usually considered to be an aggregate whose gradation will pass through a 9.5 mm (3/8 inch) sieve (1). The coarse aggregate is usually an aggregate with a gradation that is almost completely retained on a 1.18 mm (number 16) sieve and has aggregate particles that normally range up to a maximum size of 25 or 38 mm (1 or 1 ½ inches) in nominal diameter (1).

Air Voids

The paste in the PCC will contain air voids. The air voids are separated into two classifications. The classifications are entrapped air voids and entrained air voids. Entrapped air is generally considered to have a diameter larger than 1 mm (0.04 inches) (1, 17). Entrapped air voids do not provide adequate protection from freeze-thaw cycles. Entrapped air voids are actually detrimental to the concrete, since they reduce the strength of the PCC (3). In addition they are a potential reservoir for water that can later freeze inside the concrete. Entrained air voids are very small in size. Entrained air ranges from 10 μm to 1000 μm (0.0004 to 0.04 inches) in diameter. These bubbles significantly improve the resistance of concrete to freezing and thawing (1).

Entrained air is formed by the adding an air entraining agent to the portland cement concrete as it is being mixed. The air entraining agent is a surfactant that helps to stabilize the microscopic bubbles that form during mechanical mixing of PCC. Uniform dispersion of the entrained air is important for effective resistance to freeze-thaw cycles (1,19) . Without an air entraining agent portland cement concrete will only have an entrained air content of approximately 1.5 percent (1). For environments that are subjected to numerous freeze-thaw cycles an entrained air content of about 6 percent is desired in the hardened concrete. The desired air content is determined by severity of exposure, availability of water, use of deicing chemicals, and the nominal maximum aggregate size (1).

Mechanics of Consolidation and Vibration

Consolidation of PCC is the removal of entrapped air voids by hand or mechanical methods. Most mechanical methods utilize some form of vibratory energy. In nearly all large PCC operations mechanical vibrators are used for consolidation. Vibration can be either internally or externally applied to the PCC.

Slipform pavers use internal vibrators to consolidate concrete. Internal vibrators are immersed in the concrete and consolidate by direct physical contact with the plastic concrete (4). Internal vibrators have an external housing that protects a rotating eccentric weight. This eccentric weight causes the vibrator to rotate in a circular orbit. The amplitude or size of the orbit depends on the total weight of the vibrator, the weight of the eccentric, the frequency of the vibrator, and the eccentric weights moment (4, 5). The orbiting vibrator induces a simple harmonic wave to the concrete.

The frequency of the vibrator is measured by the number of rotations of the eccentric weight per minute. This frequency is termed vpm (vibrations per minute). The frequency effects the radius of action of the vibrator. The radius of action is the distance from the vibrator that the vibrator delivers enough force to reduce internal friction so entrapped air voids may be removed. Generally the radius of action is increased as the frequency of the vibrator is increased (4).

Low slump concrete is required for slipform paving. This indicates a slump of less than three inches when tested according to ASTM C 143 - 90a. Low slump concrete, as defined by American Concrete Institute (ACI), tends to have an entrapped air content of 5 to 20 percent (4). Consolidation by vibration attempts to remove the entrapped air. When plastic concrete is vibrated, it passes through two stages. The first stage is the slumping of the concrete. The harmonic vibration causes the particles to behave as a near liquid. This behavior is caused by the reduction of internal friction in the concrete. During this stage the unstable mix becomes denser, and it will flow as a viscous liquid to reach a lower level. The second stage is the deaeration of the concrete. In this stage the entrapped air voids rise toward the surface of the concrete. The concrete should be vibrated until nearly all of the entrapped air is released, this level of consolidation usually will leave an entrapped air content of approximately 1.5 percent (10).

However, care should be taken not to excessively vibrate the concrete. Excessive vibration of the concrete will cause the entrained air to be vibrated out of the mix. The effect of the vibration on a mix is dependent on the vibrator frequency, amplitude, length of vibration time, and the distance from the vibrator (5).

Most slipform pavers utilize a vibrator with a diameter of 50 to 90 mm (2 to 3 ½ inches) (4). The force of the vibration is typically in the range of 3100 to 8900 N (700 to 2000 lbs) (4). All vibrators observed on Iowa DOT projects during this research had a diameter of 60 mm (2 3/8 inches) and a centrifugal force of either 5560 or 7870 N (1250 or 1770 lbs) at 10000 vpm.

The American Concrete Institute recommends that vibrators of this size and eccentric moment operate at a frequency of 8000 to 12000 vpm (4). This frequency range is intended to result in a radius of action of 180 to 360 mm (7 to 14 inches). This size of vibrator is recommended for use in stiff plastic concrete with a slump of less than 80 mm (3 inches). The ACI recommends this class of vibrators for slipform paving. There are some recommendations that these vibrators should be used at a frequency of 6000 to 9000 vpm (15).

Methods of Measuring Vibrator Frequency

The vibrators on pavers do not have a device that indicates their frequency. Each vibrator is controlled by a needle valve. The valve regulates the flow of hydraulic fluid that drives the vibrator. However, these valves do not give a reliable indication of the vibrator's frequency. In fact a valve may be set for maximum fluid flow, but the vibrator may not be vibrating if its bearings or seals are worn out. Therefore, external means are required to monitor the frequencies of vibrators. A vibrating reed can be used to determine the frequency of the vibrator. Two types of reeds are commonly used. These are an adjustable single reed vibration indicator like a "Vibra-tak™" (Appendix D), or a multiple reed vibration indicator like a "Standco™" vibrating reed tachometer (Appendix D).

Neither type of reed can be placed on the vibrator since the vibrator will be submerged in the concrete. The vibrators amplitude is too large for continuous contact to be made between the vibrator and a vibrating reed. Often these problems are overcome by using a rod attached to a vibrating reed (Figure 1, Appendix A). The end of the rod is placed against the hydraulic hose or on the protective covering of the hose near the vibrator. The hose has a much smaller amplitude, and it vibrates with the same frequency as the vibrator it is attached to.

Currently, vibrator manufactures are experimenting with digital displays for vibrators. Some of these prototype displays have already been field tested in Iowa, but they are not yet currently used in normal paving operations.

Slipform Pavers

The slipform paver is an extrusion process for forming a concrete pavement. An example of extrusion that everyone can relate to is toothpaste. When a tube of toothpaste is squeezed, the toothpaste is extruded onto the tooth brush. The toothpaste is in the shape of the mold. Pavement is molded in a similar manner with a slipform paver. However a pavement is much larger and the concrete is much heavier than toothpaste, so more energy is required to extrude the pavement.

A slipform paver utilizes the standard procedure of striking off, vibrating, tamping, and finishing the concrete. But a slipform paver completes all these procedures in a single pass (15). The slipform paver takes the concrete that is placed in front of the paver and spreads it with an auger. A strike-off plate then levels the concrete. A set of gang mounted vibrators consolidate the concrete. The vibrators are generally spaced at approximately 0.3 to 0.6 m (12 to 24 inch) centers (15). A tamper bar then tucks the larger aggregate particles below the pan of the paver. The pan and side forms mold the concrete. A finishing pan or screed completes the slipform process. The entire slipform process is contained on one piece of equipment, and it is moved by large hydraulic tracks. The slipform paver is a continuous operation. The paver moves forward over the concrete placed in front and an extruded pavement is produced out of the rear of the paver.

Effect of Vibration on Air Content

The effect of vibration on air content of PCC has long been an area of interest for researchers and practitioners. The Bureau of Reclamation studied the effect of vibration time on air content as far back as 1949 (18). Since that time many efforts have been made to determine the radius of action of vibrators and the impact of vibration on air content.

Few of these efforts have looked at the use of vibration in slipform paving. The fact that the vibrators slide through the pavement parallel with the extruded pavement makes it different than other vibrators that are vertically inserted into concrete. In addition the PCC used in slipform paving is very stiff when compared to the PCC used in many other applications. Also, the fact that there are many vibrators being used simultaneously makes slipform pavers a special case of vibration. Some states such as Colorado (12), Kansas (13) and Illinois (21) initiated studies into the impact of vibratory consolidation. The FHWA initiated a National Experimental and Evaluation Program (NEEP) study of consolidation for slipform paving (22). However these studies researched the density and relative strength of the concrete. The objective was to find out how much vibration was required to obtain a desired strength or density. The exception to this was the Illinois study. It suggested the possibility of segregation when a large vibratory force was applied to the PCC (21). But the study still did not evaluate low entrained air content as part of the excessive vibration. Because of these early studies, paver manufactures began building larger and more powerful pavers. This ensured that enough vibration energy could be provided to consolidate the pavement.

The more is better approach is not always the best. A new problem emerged from these larger pavers. The possibility of excessive consolidation now became the concern, rather than the lack of consolidation (19). The excessive vibration usually resulted in the excessive removal of entrained air voids and the segregation of the portland cement concrete mix.

PREMATURE PAVEMENT FAILURES IN IOWA

Vibratory consolidation of PCC became an area of interest to the Iowa Department of Transportation (DOT) when excessive vibration was identified as a factor in the premature deterioration of US Highway 20 in Webster and Hamilton counties (6)

Deterioration of US 20 was initially noticed in May of 1990. The deterioration was unexpected since the pavement was only three years old. The characteristics of the early stages of the deterioration were similar to the staining and cracking associated with D-cracking. Initially the cracks were tight and had dark stains. Investigators originally identified the primary source of the deterioration as either ettrignite formation in the air voids or alkali-silica reactivity (7, 8). Later work identified that the air void system may have been compromised (20). The deterioration continued at a rapid rate. In 1998 the PCC pavement had to be resurfaced with asphalt cement concrete because traffic was causing portions of the pavement to crumble, and large areas of the pavement were completely map cracked.

Cores of the US 20 pavement revealed many instances where the hardened concrete contained air contents of less than three percent (6). Many of the cores that had low air contents came from longitudinal cracks in the pavement (Figure 2, Appendix A). The minimum desired entrained air content for the hardened concrete was six percent according to Iowa DOT specifications for the project. The deficiency of entrained air is believed to have accelerated the deterioration of the pavement (6, 7, 20). Researchers hypothesized the probable cause of the low air content was excessive vibration during paving.

A similar deterioration was noticed in 1992 in Interstate 80 in Dallas county. One of the similarities in the cracking pattern between the two projects were longitudinal cracks (Figure 2 and 3, Appendix A). The cracks were spaced at intervals of approximately 0.6 m (2 feet). This spacing is very similar to the spacing of the vibrators on the slipform pavers used in the construction of the PCC pavements. In Dallas county, cores taken from the longitudinal cracks in the pavement contained entrained air contents of approximately of 3 percent in the top half, and 6 percent in the bottom half (11). The longitudinal cracking pattern and the reduced air content indicate the possibility of excessive vibration; since, the vibrators were positioned near the surface of the pavement.

In other areas of the state, longitudinal trails were observed in the surface of some PCC pavements. These trails were parallel to each other with a spacing similar to that of gang mounted vibrators on slipform pavers (Figure 4, Appendix A). These longitudinal disconformities of the pavement were termed vibrator trails, if they could be seen on the surface of the pavement. Vibrator trails have also been called post holing, when they are below the surface of the pavement.

Vibrator trails are formed by the excessive vibration of the concrete. The excessive vibration causes coarse aggregate to separate from the paste. This leaves a localized region of increased paste content near the vibrator. This zone of increased paste may allow the tines of the tine texturing machine to penetrate deeper into the surface of the pavement. This creates a longitudinal distortion of the pavement surface (Figure 5, Appendix A). Vibrator trails can be found below the surface of the pavement when taking cores. If the vibrator trail is slightly below the surface, it can be exposed by diamond grinding the PCC pavement (Figures 6 & 7, Appendix A). In this case the exposed surface has longitudinal bands where the pavement has a reduced coarse aggregate content from excessive vibration.

PURPOSE OF RESEARCH

As a result of the observations made while investigating slipform pavers, a research project was initiated in 1995 to evaluate the practices of vibration during slipform PCC paving and to determine the effect of a new vibration specification for the frequency of vibrators. The new specification limited the frequency of vibrators to a range of 5,000 to 8,000 vpm. Prior to this specification there were no limits on the frequency of vibrators.

The primary factors studied for their effect on entrained air content were vibrator frequency, paver speed, and distance from the vibrator. The research was conducted on three interstate paving projects. On each project a test section was paved where the paver speed was recorded and vibrator frequencies were set to known values. The lateral distance between each vibrator was carefully measured, so the relative position of the vibrator to the location of a core would be known.

EXPERIMENT DESIGN

The experiment was designed to be a matrix of paver speed and vibrator frequency. The test sections were a matrix of two paver speeds and three vibrator frequencies. The speeds selected were normal paver speed and a slow speed which was set at half the normal paver speed. Because the normal speed for the pavers was found to be 1.2 to 2.1 m (4 to 7 feet) per minute, the normal paver speed was set at 1.5 m (5 feet) per minute. The three vibrator frequencies were 5000, 6500, and 8000 vpm. This range covered the Iowa DOT specification for internal vibrators on slipform pavers. This range was established to prevent the formation of vibrator trails and was based on preliminary work conducted during the summer of 1994 by the Iowa DOT Materials Research Section.

A consecutive pair of vibrators was selected to be controlled at the indicated test frequency. This allowed cores to be taken in the vibrator trail and at the midpoint between the two controlled vibrators (Figure 8, Appendix A). The other vibrators on the paver were maintained at their normal operational frequency set by the contractor. The frequency of these vibrators was also recorded. In some instances this allowed a comparison between a vibrator set within specification limits and vibrators that were found to be operating outside the specification.

Three cores were taken from both the vibrator trail and between the vibrator trails in each division of the design matrix. The cores were cut into thirds to determine the air content of the top, middle, and bottom of the core. Air content results were obtained through high pressure testing by the Iowa Department of Transportation test method number Iowa 407-B. A vertical slice was taken from each core prior to the high pressure air test for possible image analysis testing.

Careful measurements were taken of the vibrator spacing, vibrator location relative to the edge of the pavement, and vibrator location relative to the edge of the pavers pan. The brand and model of each vibrator was documented. In addition the mix design, weather conditions, type of paver, tilt of the vibrators relative to the pavement surface, type of base, pavement design thickness, and slump were recorded. These factors were held as constant as possible for each individual project.

The result of this research is a design matrix that treats cores as independent samples. The cores each come from a separate load of concrete taken to the project. The treatments that affect the core are vibrator frequency, paver speed, and location relative to the vibrator (in or between the vibrator trails). Nested within each core is the top, middle, and bottom air content. This results in a 2x3x3 factorial design of 12 treatment combinations with three additional treatment levels nested inside each of the 12 treatment combinations. Three repetitions were taken for each treatment, so a total of 108 air tests were performed for each project. Table 1 in Appendix B lists the resulting experimental design.

PROJECTS

Three projects were selected for the experiment. The projects are identified as A, B, and C. Each project was paved by a different paving contractor. Each contractor had a different methodology on how to utilize vibration to consolidate the concrete. The spacings and consolidating forces of the vibrators used by each paver are in Table 2 (Appendix B). All the vibrator trail cores were taken from the path of the second vibrator from the pavement edge. The between vibrators were taken between the second and third vibrators from the edge. Appendix E lists the edge of slab the cores were measured from, the distance from the edge of the slab to the center of the core, and the station of the core. Table 3 (Appendix B) lists the high pressure air testing results of all cores. Appendix E contains all the raw data for the high pressure testing.

Project A

Project A was in Jasper County on Interstate 80. Project A had three separate research test sections. These sections were named A1, A2, and A3. A1 and A2 were in the west bound lanes. A3 was in the east bound lanes.

The first test section, A1, was a limited trial of the experiment. This trial section was paved on June 16, 19, and 20 of 1995. This section had all the variables used in the experiment design except for paver speed. Only the normal paver speed was used. Cores 1 through 31 were taken from this project. The data from these cores were not analyzed in this research, but this test run showed that this research was feasible. This initial trial refined procedures of measuring and recording paver speed, vibrator frequency, and location of the vibrators.

The second section, A2, was the first complete test. Section A2 was paved on July 13, 1995. Cores 32 through 67 are from this project. The contractor for this section had the top of the vibrators parallel with the paving pan.

Project A3 was nearly a duplicate of project A2 except for the position of the vibrators. The contractor lowered the vibrators 100 mm (4 inches) below the paving pan. Section A3 was paved on August 9, 1995. Cores 68 through 109 were taken from this portion of project A.

Project B

This section was conducted on the southbound lanes of Interstate 29 in Pottawattamie County. The test section was paved on August 14, 1995. The vibrators for project B had a smaller eccentric force than projects A and C and had the largest spacing for the test vibrators (Table 2, Appendix B). This project has the smallest vibrator consolidation energy for the research test sections. The top of the vibrators were positioned level with the paving pan. Cores 110 through 146 were from this project.

Project C

This test section was on the west bound lanes of Interstate 80 in Scott County. The test section was paved on September 12, 1995. Additional cores were also taken from the paving of September 14. A complete test section was not possible for this project. At low vibration frequencies the pavement surface was excessively open in the area between the vibrators. At the request of the contractor the test sections were stopped. Half of the test sections were completed. The completed test sections were the slow paver speed at 8000 vpm and the normal paver speed at 5000 vpm and 8000 vpm.

However, a vibrator on this project was found operating at a frequency of 12000 vpm. This allowed comparisons to be made between the controlled test conditions and the 12000 vpm vibrator. Cores from the vibrator trail revealed the vibrator was 125 mm (5 inches) below the surface. This was clearly evident by the vibrator trail in the cores (Figure 11, Appendix A). These cores allowed for a comparison of consolidation in a vibrator trail at 12000 vpm, in a vibrator trail at 8000 vpm, and cores between 12000 vpm and 8000 vpm vibrators. An analysis of variance is not possible for these cores since the vibrator is located 5 inches lower for the 12000 vpm vibrator than the 8000 vpm vibrator. However, for cores that paver speed and vibrator frequency are known some basic comparisons can be made.

Cores 147 - 191 were from this test section. Not all of these cores were analyzed in the research. Some of the cores were extra cores that were taken while trying to locate the exact path of the vibrator that was operating at 12000 vpm. Cores 164 through 191 were taken from the paving on September 14. These cores were taken to compare vibrators that were operating at 12000 and 8000 vpm. As indicated, these cores will be used as a separate test section.

OBSERVED PCC CONSOLIDATION PRACTICES

The paving practices of each of the three contractors was observed prior to the construction of the test sections. The most carefully observed items were the number and location of vibrators, the types of vibrators used, the operating frequency of the vibrators, and the speed of the paver. This allowed an opportunity to observe and compare the normal paving operations of the contractors.

Vibrator Frequencies

Vibration readings were found to vary substantially on each of the pavers. A difference of 3000 vpm from the lowest vibrator frequency to the highest vibrator frequency was typical. The hydraulic control valves of individual vibrators commonly allowed a variation of several thousand vpm for valves at the same numeric setting. Vibration readings were often found to be outside the specification limits of 5000 to 8000 vpm. In most cases when the frequency was outside the specification, the vibrator was operating above the specification limit. In one instance a vibrator was found to be operating at 12000 vpm.

Vibrator Positioning

Inspection of the pavers revealed that in most cases the vibrators were positioned at the level of the pavering pan and in a horizontal position. However, some pavers had a large variation in horizontal position of the vibrators. In one case the center of the vibrators ranged from 50 mm (2 inches) above the pan to 75 mm (3 inches) below the pan (Figure 9, Appendix A). In another case, a paver operator indicated the vibrators were level with the pan; however, evidence from cores showed the vibrators were as far as 125 mm (5 inches) below the pan. The change in position can occur from an inaccurate position indicator, sag due to oil leakage in the hydraulic system that holds the gang mounted vibrators in position, or loose bolts that hold an individual vibrator in position.

Placing the vibrators parallel to the pavement surface minimizes the frontal area or cross sectional area of the vibrator. In this position the possibility of excessive vibration is probably increased since all the available energy from a vibrator is applied to a minimal cross sectional area of concrete.

RESULTS

The results of this research are categorized into two primary areas. The first is visual observations. All the cores from the project were carefully inspected for consolidation and aggregate distribution. The second area is the results of the hard air tests used to determine the entrained air content of the concrete.

Visual Observations of the Cores

Observations from cores taken in and between the vibrator trails indicate the radius of effective consolidation from the vibrator may be smaller than indicated by the American Concrete Institute in Report 309R-87. The cores commonly show significant entrapped air within 100 mm (4 inches) of the vibrator location. One noticeable case of this was on project B (Figure 10, Appendix A). The vibrator was positioned at the top of the slab. The test variables used in this case were a slow paver speed, vibrator frequency of 8000 vpm, and the core was taken in the vibrators trail. This section had the condition of maximum consolidation energy for the project. The three cores taken from this test section show an area of aggregate separation approximately 1 inch below the top of the cores. This segregation is an example of the beginning of a vibrator trail. However, this consolidation effort still is leaving entrapped air only a few inches from the area of segregated concrete. Similarly, on project C where a vibrator was operating at a frequency of 12000 vpm, entrapped air is located within four inches of areas of excessive vibration (Figure 11, Appendix A). In this case the vibrator was five inches below the pavement surface. A vibrator trail can be clearly seen passing through the core, yet entrapped air can be found in the bottom third of the cores taken in this vibrator trail.

Visual observations also revealed that the cores from the 5000 vpm test sections had significantly more entrapped air than the 6500 and 8000 vpm test sections, especially under the test conditions of normal paving speed. The impact of the increased entrapped air was not studied, but it appears that the frequency of a vibrator should not be below 5000 vpm to ensure adequate consolidation.

Iowa High Pressure Air Test

Iowa DOT test method number Iowa 407-B is the "Method of Test for Determination of Air Content of Portland Cement Concrete Cores Using a High Pressure Air Meter." (Appendix D) The test estimates the entrained air content of the hardened PCC. This is done by first oven drying the hardened PCC concrete and weighing the specimen. The oven dry PCC is then soaked in water and weighed in water and air. The water that penetrates into the PCC during this time fills the voids in the PCC that are accessible to water. This void space is capillary pores and entrapped air that are not going to allow for the additional volume of the water as it freezes. The specimen is then submerged in a pressure tank, and a pressure of 34.47 MPa (5000 psi) is applied to the specimen. The volume change of the pressure chamber is recorded. This volume change is then used to calculate the additional voids that water can penetrate when pressure is applied. This volume also estimates the volume of entrained air that is in the PCC concrete. This method is not as exacting as linear traverse or image analysis, and it does not indicate void size distribution and spacing. However the Iowa DOT has had success in correlating plastic air tests with the high pressure test over an extended period of time. This test method allows for a higher rate of test production and has a lower cost for each test.

Raw Data

The results of the high pressure testing of the PCC cores are in Appendix E. The results of the high air pressure test yield four responses. The primary response is the estimated entrained air content. The test also yields an estimate of the entrapped air content, the density of the core with all air voids, and the density of the core with only the entrained air voids. These statistics are all listed in Appendix E. However, this research will only look at the estimated entrained air content.

Project A2

The mean percent entrained air of the 108 samples for project A2 was 8.653 with a standard deviation of 1.629. The entrained air contents ranged from 5.37 to 12.16 percent. Table 3 (Appendix B) lists the average entrained air contents by statistic. Graph 1 (Appendix C) displays the data.

Portion of core and paver speed appear to have the most significant effect on the entrained air content. A slow paver speed had an average decrease of 1.069 percent air when compared to the normal paver speed. The top of the cores had an average decrease in air content of more than 2 percent when compared to the middle and bottom of the cores.

The interaction graphs of the main variables are displayed in Graph 2 (Appendix C). The graphs indicate that an interaction may be occurring between the paver speed and the portion of the core and between the vibrator frequency and the portion of the core. Both of these graphs seem to indicate that the bottom of the cores is interacting differently with these variables. It may be that the distance from the top of the cores is far enough that the vibrators or another variable is not affecting the bottom of the PCC slab.

The analysis of variance of this data is complicated by the nesting of the portion of core variable. The portion of the core is the top, middle, and bottom thirds. This variable is designated as TMB. The analysis that includes the nesting effect results in two different error terms. The terms in the analysis that have a TMB term have a different mean squared error than the terms that do not have a TMB term. The adjustment in the two error terms results in essentially a split experiment. Table 4 (Appendix B) lists a complete analysis of variance that accounts for the nesting effect. All the analysis of variances use the coding listed at the bottom of Table 4 (Appendix B).

The analysis of variance indicates that the paver speed, location relative to the vibrator, and portion of the core terms were found to be significant at a 95 percent confidence interval. The air content increases as the paver speed increases. The entrained air content also increases when the cores are between the vibrators instead of in the vibrator trails. The air content was also found to increase with depth in the pavement slab. In addition the following interactions were also found to be significant at the 95 percent confidence interval: paver speed and vibrator frequency, paver speed and portion of core, and vibrator frequency and portion of core. In addition the three way interaction of paver speed, vibrator frequency, and portion of the core was significant at a 95 percent confidence level.

Project A3

The average percent entrained air of the 108 samples for project A3 was 8.537 with a standard deviation of 1.531. The entrained air contents ranged from 5.010 to 13.150 percent. Table 5 (Appendix B) lists the average entrained air content by variable. Graph 3 (Appendix C) displays this data.

The vibration frequency and portion of core appear to have the greatest impact on the entrained air content. The average entrained air content for the vibration frequency ranges from 8.010 for 8000 vpm to 9.525 for 5000 vpm. The average entrained air contents for the portion of core range from 7.316 for the top of the core to 9.614 for the bottom of the core.

The interaction graphs are displayed in Graph 4 (Appendix C). The graphs indicate that the paver speed and vibrations per minute may be interacting. The location of the core and the vibrator frequency also gives some indication of a possible interaction.

The analysis of variance of this data is shown in Table 6 (Appendix B). The analysis of variance indicates that the location of the core, vibration frequency, and portion of the core were significant at a 95 percent confidence level. The entrained air content increases when the core is taken between the vibrator trails. The air content decreases as the vibrator frequency increases. And the air content increases with depth of the pavement. In addition the interaction between paver speed and the portion of the core was found to be significant at a 95 percent probability level.

Project B

The average percent entrained air of the 108 samples for project B was 7.069 with a standard deviation of 1.279. The entrained air contents ranged from 4.400 to 11.230. Table 7 (Appendix B) lists the average entrained air contents by variable. Graph 5 (Appendix C) displays the data.

Location of the core, vibrator frequency, and portion of the core all appear to effect the entrained air content. Each of these has a change of about 1 percent from the low to the high level of the variable.

The interaction graphs of the variables are displayed in Graph 6. The graphs indicate that the core location and vibrator frequency may have a possible interaction. However this interaction is not strong, and it does not follow the expectations of vibratory energy and entrained air content.

Table 8 (Appendix B) lists the complete analysis of variance. The analysis indicates that the core location and portion of core have a probability greater than 95 percent of being significant. The vibrator frequency has a probability of 0.055. This is very close to being significant at the 95 percent level. In addition the following interactions were significant at a 95 percent probability level: paver speed, location of core, and portion of core; and paver speed, location of core, vibrator frequency, and portion of core. The fact that a third level and a fourth level interaction are statistically significant at a 95 percent probability is very interesting. It reveals some of the complexity in the process of vibrating PCC.

Project C

For the partial experiment conducted on September 12 the average percent air of the 54 samples was 7.431 with a standard deviation of 0.910. The entrained air contents ranged from 4.900 to 9.980. Table 9 (Appendix B) lists the average air contents by test treatment. The air contents in the vibrator trail are lower for the 5000 vpm and 8000 vpm sections. By just looking at the top portion of the cores an even further reduction of the air contents is revealed (Table 10, Appendix B). The average air contents of 5.510 for the normal paver speed and 5.173 for the slow paver speed is approaching an entrained air content that may not provide effective freeze thaw protection.

Because of the low air contents a more detailed look was taken at only the 8000 vpm core samples. The average air contents for the experiment variables is in Table 11 (Appendix B) and Graph 7 (Appendix C). The top of the cores and the in trail cores show a reduction in air of more than 1 percent. An analysis of variance using only the 8000 vpm cores was calculated (Table 12, Appendix B). The analysis indicated that the paver speed, location relative to the vibrator, and portion of the core were significant at greater than 95 percent probability. Also, the interactions between paver speed and portion of core; location of the core and portion of core; and paver speed, location of core and portion of core were significant at greater than a 95 percent probability. This indicates a very complex interaction in the consolidation of this mix.

The second portion of project C involves the cores obtained from the paving of September 14. Table 13 (Appendix B) and Graph 8 (Appendix C) have the entrained air contents by core location, paver speed, and portion of the core. The top of the cores from the 8000 vpm vibrator trail has an air content of 5.550 percent. This is similar to the top of the core at 8000 vpm from September 12. This air content is more than 1 percent lower than the rest of the core on the vibrator trail and more than 2 percent lower than the cores from between the vibrators.

However, the reduction in air content at 12000 vpm and in the vibrator trial is even more dramatic. The top of these cores have an average air content of 4.032 percent and the middle of these cores have an average air content of 1.610 percent. The fact that the middle has the lowest entrained air content is due to the vibrator being 125 mm (5 inches) below the pan. This puts the vibrator trail in the top of the middle portion of the core.

Comparisons of All Projects

A summary of the analysis of variances for all the projects is given in Table 14 (Appendix B). This table indicates if a treatment had a 95 percent or greater probability of being significant. The vibrator location and the portion of the core were the only variable to be found significant for all four of the projects. Each of the variables was found to be significant on at least one project. Four of the six two way interactions were found to be significant on at least one project. Two of the four three way interactions were found to be significant on at least one project and the four variable interaction was significant on one project.

Project A2 and A3 are an interesting comparison. By lowering the vibrators into the slab the paver speed was not significant on project A3 as it was for A2. Conversely, the vibrator frequency was significant for A3 and not for A2. In addition only the interaction of paver speed and vibrator frequency was significant for both projects. Actually this was the only interaction that was significant for A3, compared to A2 that had four different interactions that were significant.

Project B is very interesting; because, only four treatments were significant, but two of these treatments were a three and four variable interaction. The fact that the interaction of all the variables was found to be significant shows the complexity of vibrator consolidation.

Project C found many variables to be significant. Even though the vibrator frequency variable was not included in the analysis of this project, the other three variables were significant and two of the four interactions were significant.

The variability in which treatments were significant might be in the other uncontrolled variables in this experiment. Each project (A, B, C) had a different paver with different vibrators and spacing. The materials used in the PCC for each project was different. But, these variables exist in real life and any potential method of controlling pavement consolidation must account for these types of variables. In addition variability in the entrained air content may be effected by variation in mix production, aggregate gradation, mix proportions, personnel, test methods, temperature, humidity, head in grout box, pavement depth, pavement base, vibrator eccentric weight, amplitude of vibrator, diameter of vibrator, vibrator shape, and vibrator positioning.

PHASE II

A second phase of this research project was scheduled in the summer of 1996. This research involved side by side comparisons of vibrators of different amplitude, diameter, shape, mounting angle, and spacing. The research was conducted on two separate paving projects. More than one hundred cores were taken from these two projects.

However, phase II was terminated during the core evaluations due to a laboratory equipement malfunction. The high pressure air test is a destructive test, so retesting the samples was not possible. The malfunction presented a bias that could not be accounted for in the analysis of the cores. Thus, none of the results of phase two are included in this research report.

CONCLUSIONS

Excessive vibration of PCC can cause vibrator trails that have low air contents, but the specification of 5000 to 8000 vpm did prevent the formation of vibrator trails at normal paver speeds. However, at 8000 vpm the possibility of excessive vibration begins to increase with a decrease in paver speed. This is evident in both the visual observations and entrained air contents of projects B and C.

The variable of vibrator frequency did not have as much impact on the air content of the pavement as the location of the core and the portion of the core did in the range of 5000 to 8000 vpm. But, testing on project C indicates that the vibrator frequency may greatly effect the entrained air content at a frequency of 12000 vpm.

The variability in the analysis of variance affirms the complexity of the vibratory consolidation of PCC. To overcome this complexity the number of variables introduced into the consolidation process should be minimized by a contractor. The contractor should try to have a uniform vibrator frequency, spacing and paver speed. This will allow the contractor to have a better opportunity to control the consolidation and entrained air content of the PCC.

ADDITIONAL RESEARCH

More research needs to be conducted to find ways to more uniformly consolidate PCC pavements and to reduce the occurrence of excessive vibration and the associated loss of entrained air. The following areas need to be researched in greater detail to determine their impact on pavement consolidation.

1) Tilting the vibrators at an angle of 10 to 20 degrees from the horizontal plane of the pavement surface to increase the area of influence of the vibrator.
2) Develop a maximum vibrator spacing to ensure that the slab is uniformly consolidated based on a study of vibrator spacings.
3) Determine the effect of vibrator diameters and amplitudes on the consolidation of PCC for slipform paving.
4) Determine the relationship between mix design and the vibratory consolidation of PCC.

ADDITIONAL DEVELOPMENTS

Since the completion of this research, the Iowa DOT has been working to develop an electronic vibratory frequency measuring device. The device will be directly linked to each vibrator, and it will digitally display the vibrator frequency of each vibrator. These electronic devices will be required on some paving projects in 1999. This will help contractors and inspectors reduce the likelihood of excessive consolidation.

Also, research is continuing in the area of consolidation effort and its effect on entrained air contents. James Cable of Iowa State University is conducting a research project that involves looking at the impact of using electronic vibration monitoring devices to control the entrained air content of PCC in slipform paving. Image analysis is being used to determine the entrained air in the concrete.

REFERENCES

1. Portland Cement Association, Design and Control of Concrete Mixtures, Thirteenth Edition, 1988

2. Iowa Department of Transportation, Office of Materials Instructional Memorandum 527, May 1998

3. Ken Hover, "Why is there air in concrete?", Concrete Construction, January 1993, pages 11-15.

4. American Concrete Institute, "Guide for Consolidation of Concrete", ACI 309R-87, 1987

5. American Concrete Institute, "Behavior of Fresh Concrete During Vibration", ACI 309.1R-93, 1993

6. K. Jones, "Evaluation of Deterioration on US 20 in Webster County", Final Report for Iowa DOT Research Project MLR-91-1, Ames, Iowa, January 1991.

7. V.J. Marks and W.G. Dubberke, A Different Perspective for Investigation of PCC Pavement Deterioration," Interim Report for Iowa DOT Research Project HR-2074, January 1995

8. D. Starks, "Investigation of Pavement Cracking in US 20 and I-35 in Central Iowa," Construction Technologies Laboratories, Inc. , September 1992.

9. L. Forssblad ans Stif Sallstrom, "Concrete Vibration - What's Adequate?", Concrete International, September 1995, pages 42-48

10. Walker, H. N. 1992, Petrographic Methods of Examining hardened Concrete: A Petrographic Manual, VTRC Report No. 92-R14, Virginia Transportation Research Council

11. Iowa Department of Transportation Test Reports, John Lane P.E., 1993

12. Lawrence C. Bower and Burrell B. Gerhardt, The Effect of Good Vibration on the Durability of Concrete Pavement, HRR No. 357, Highway Research Board, 1971

13. W.A. Legge, Slipform Concrete pavement Consolidation Study, Bureau of Materials and Research, Kansas Department of Transportation, 1982

14. Efficient Consolidation of Concrete Using the Resonance Phenomenon, Innotech International, Inc, April 1996

15. B. Risser, Understanding Slipform Pavers, Concrete Construction, June 1995, pages 521-530

16. C. Sipherd, Role of Internal Vibration and the Extrusion Process Slipform Paver in Consolidation, Transportation Research Board, Committee A2F01, January 22-28, 1995

17. Treval Powers, The Properties of Fresh Concrete, John Wiley and Sons, Inc., 1963

18. Effect of Vibration Time Upon Loss of Entrained Air from Concrete Mixes, Materials Laboratories report No. C-461, United States Department of the Interior, 1949

19. David Stark, Effect of Vibration on the Air-Void System and Freeze-Thaw Durability of Concrete, Portland Cement Association Report RD092.01T, 1986

20. Paul Stutzman, NIST, Presentation to Iowa DOT, June 12, 1998

21. Robert Elliot, Effect of Internal Vibration of Portland Cement During Paving, Physical Research Report No. 53, Illinois Department of Transportation, Bureau of Materials and Physical Research, 1974

22. H. A. Lindberg, Proper Vibration of Portland Cement Concrete Pavements, National Experimental and Evaluation Program, Project No. 8, FHWA Notice, 1975

APPENDIX A
FIGURES

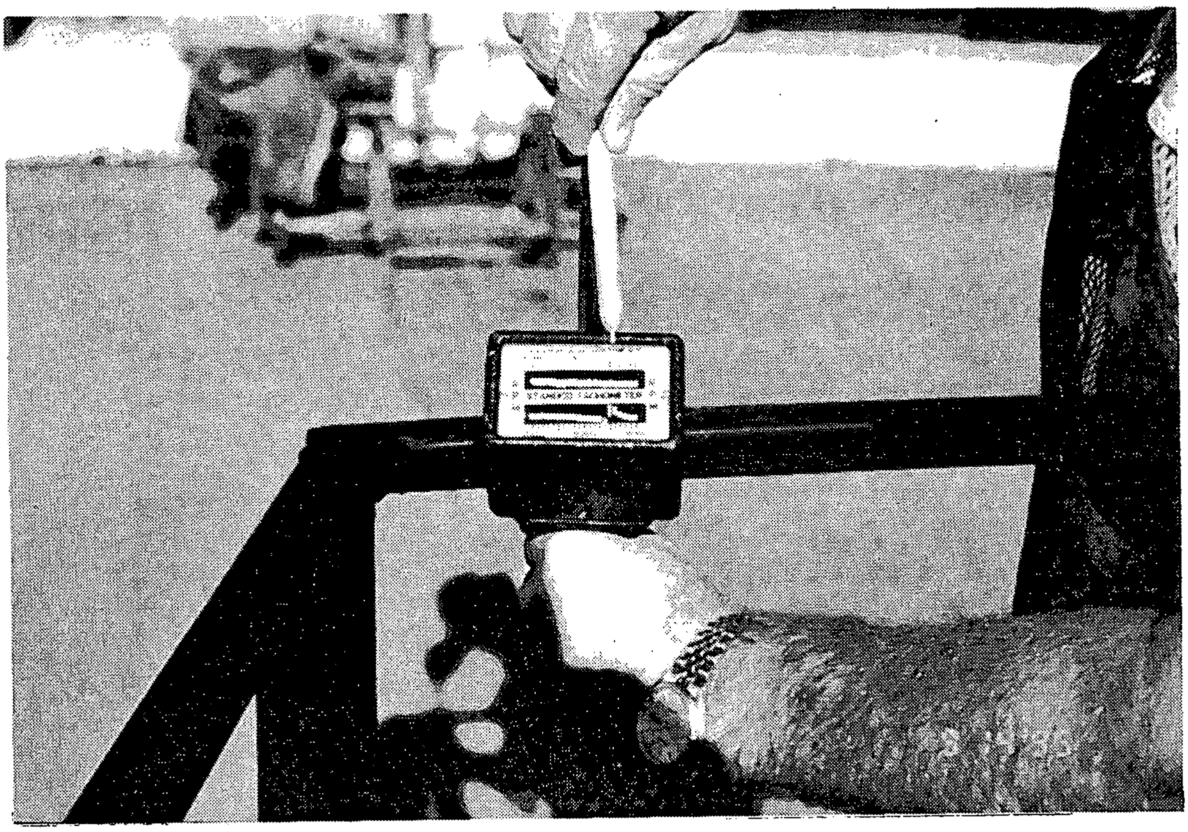


FIGURE 1 Vibrating reed tackometer attached to steel rod.

FIGURE 2 Longitudinal and joint cracking on US 20 in Webster County.

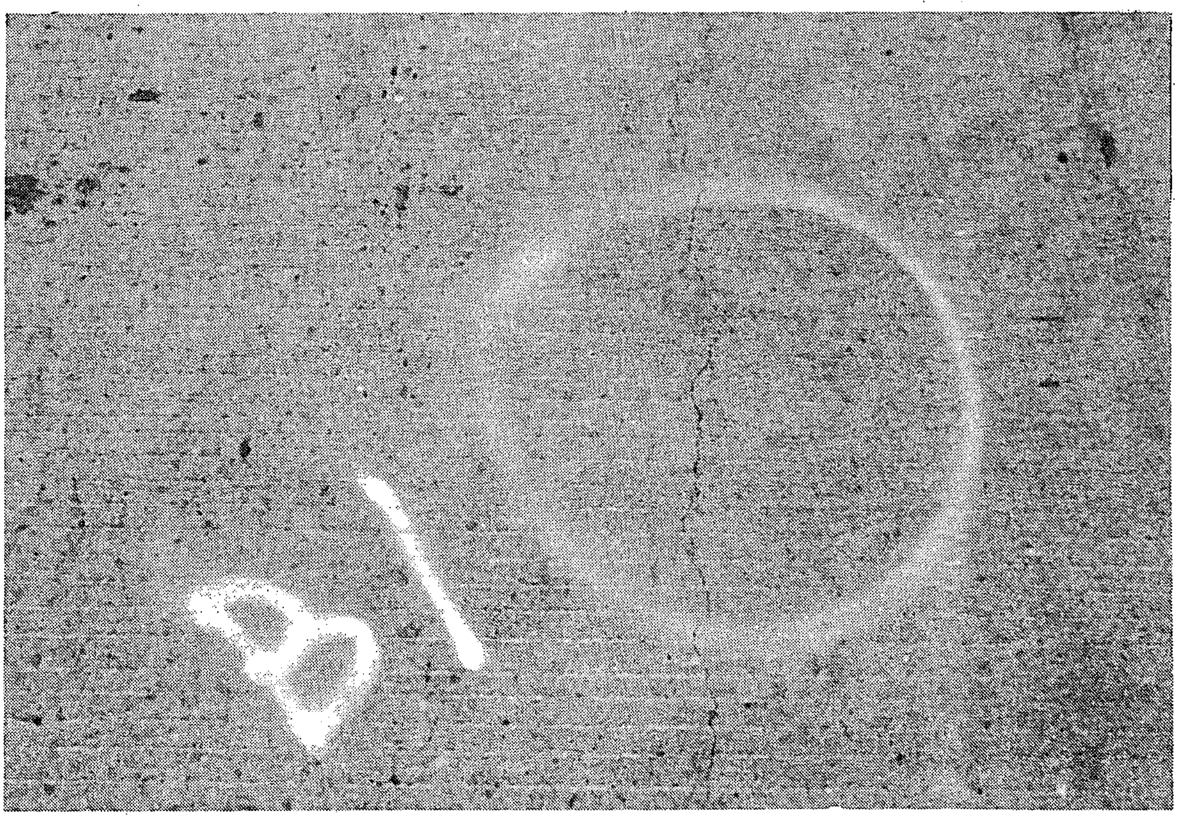


FIGURE 3 Longitudinal crack on I-80 in Dallas County.

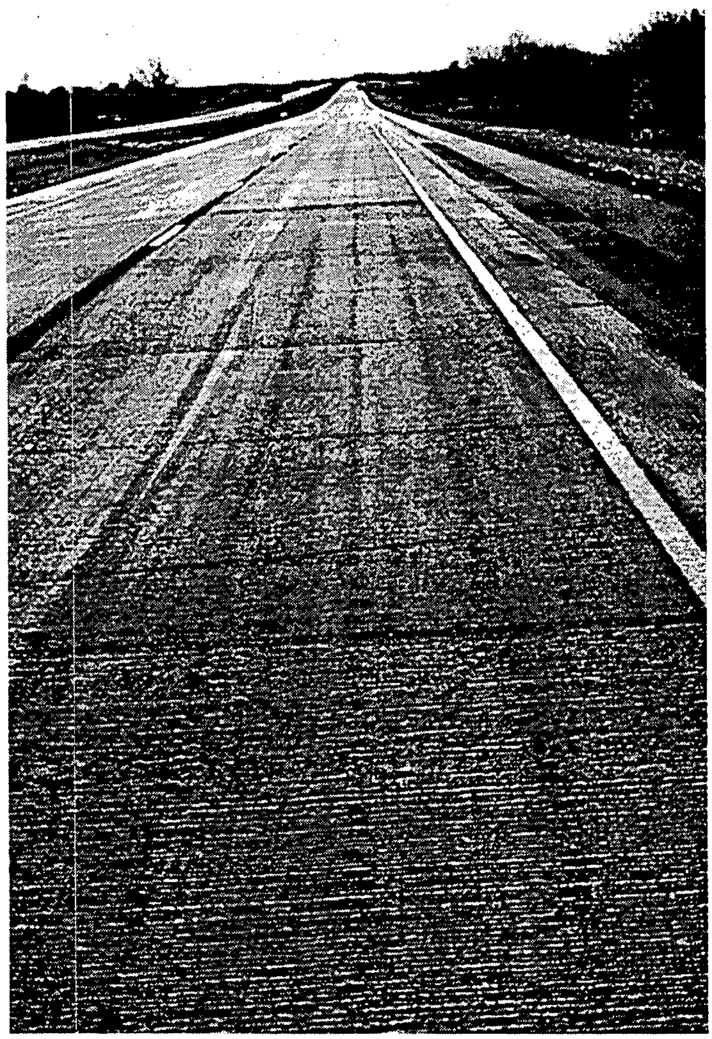


FIGURE 4 Vibrator trails in pavement surface on US 65 in Polk County.

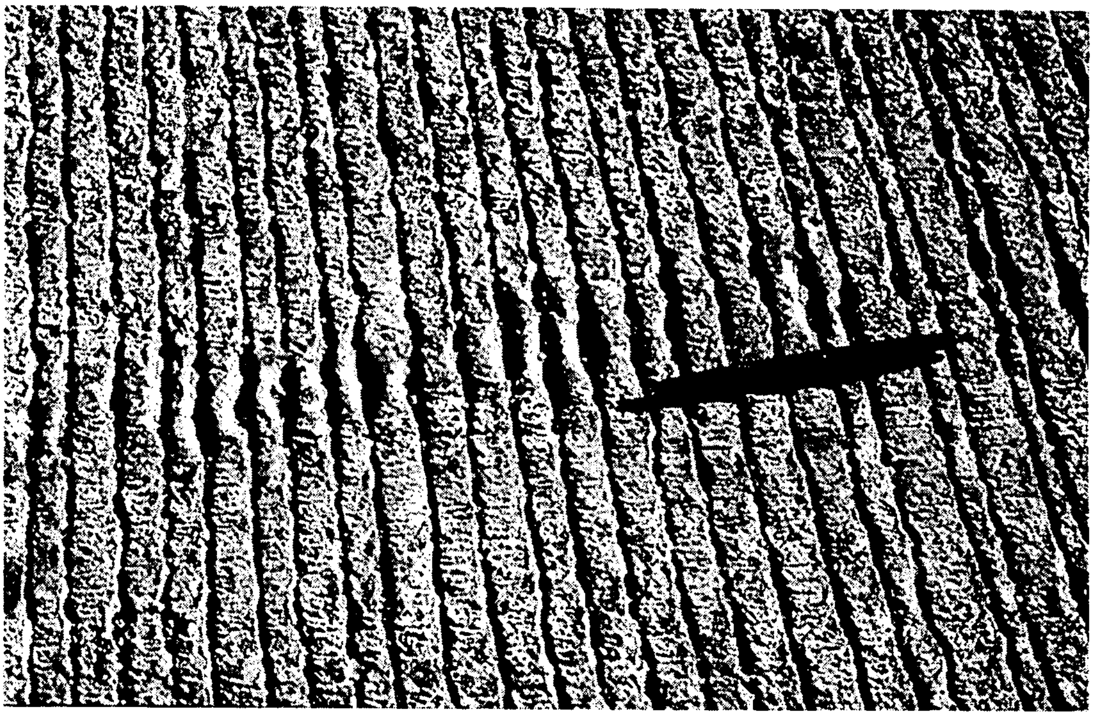


FIGURE 5 Distortion of pavement surface in a vibrator trail.

FIGURE 6 Longitudinal distortion in the surface of a diamond ground pavement

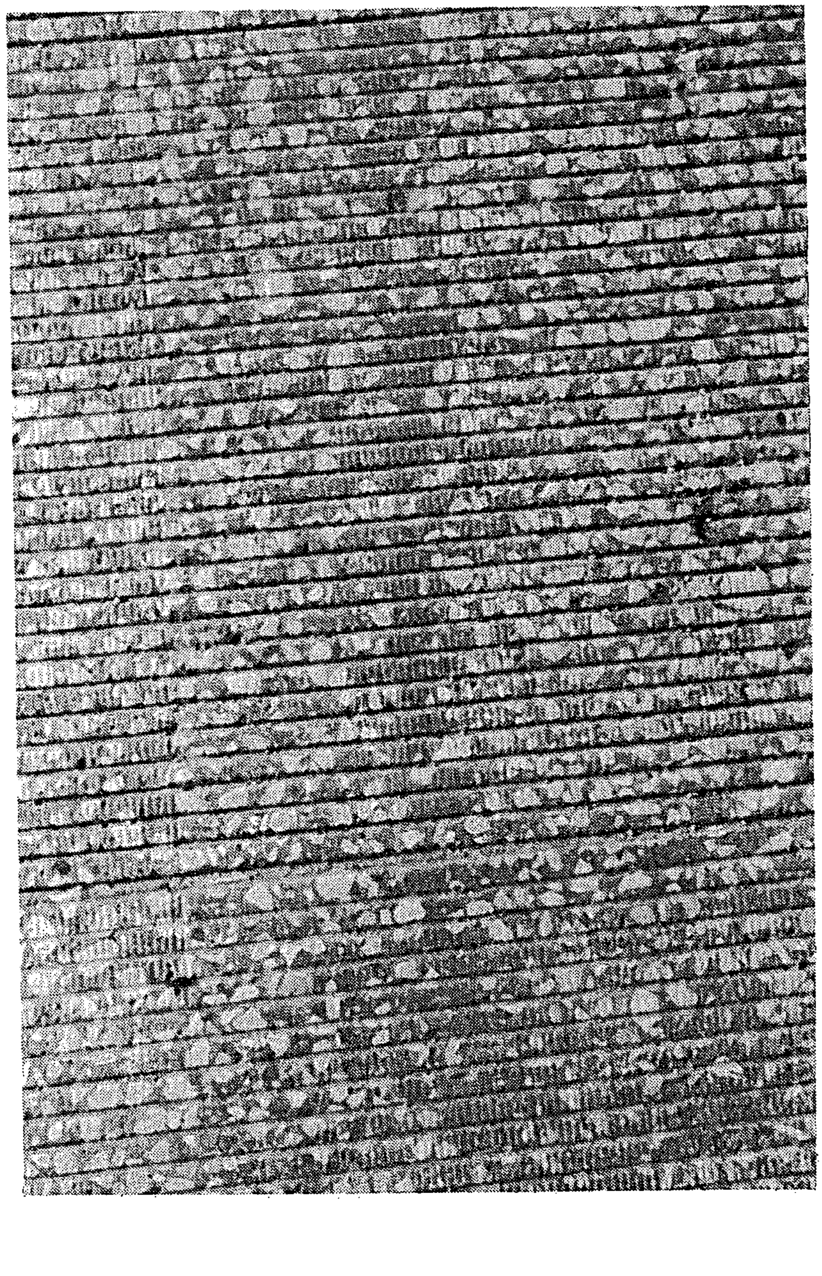


FIGURE 7 Aggregate separation in the vibrator trail of a diamond ground pavement.

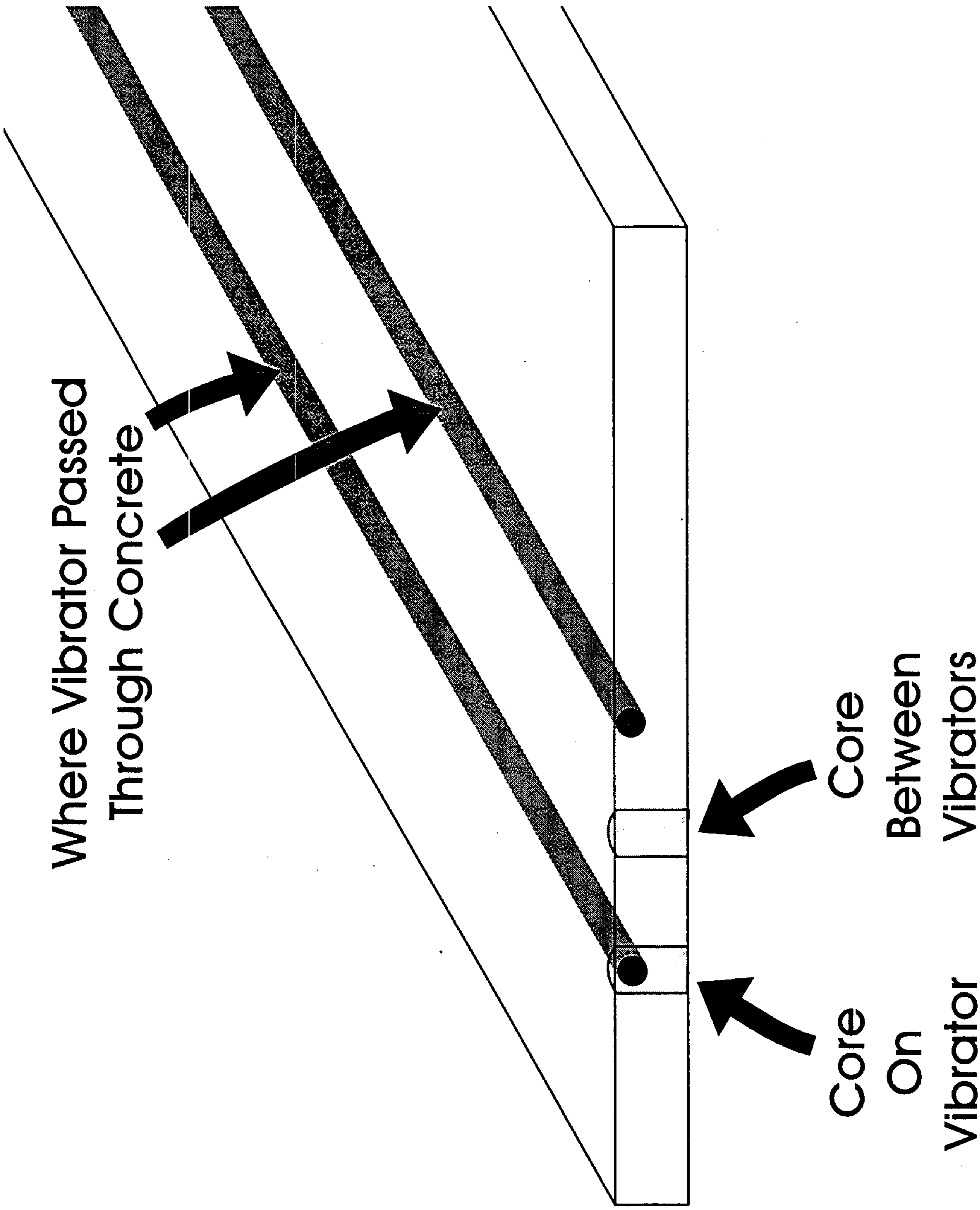


FIGURE 8 Location of cores relative to vibrator trails.

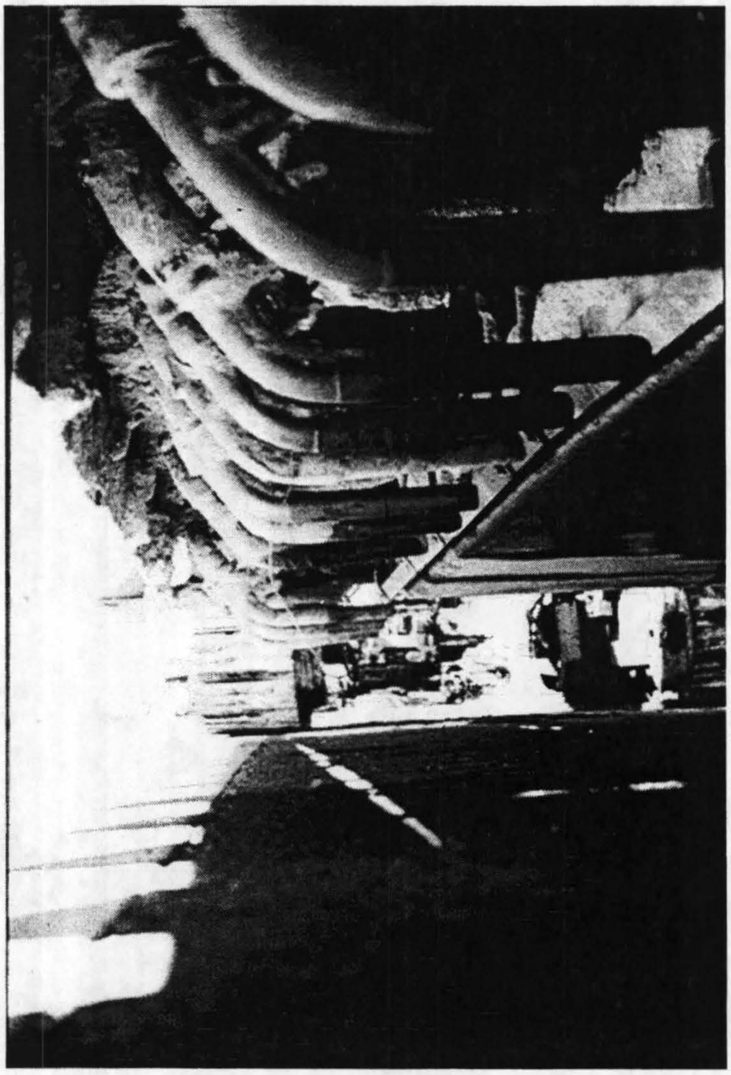


FIGURE 9 Variation in elevation of vibrators relative to paving pan.

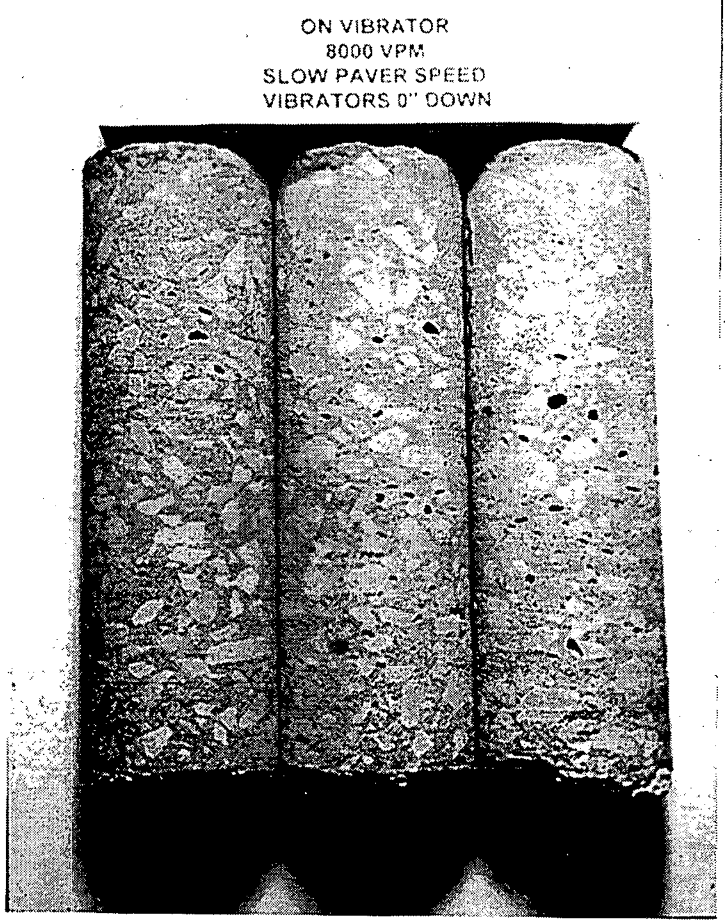


FIGURE 10 Cores from project B showing aggregate segregation near the top.

FIGURE 11 Cores from project C revealing a vibrator trail.

APPENDIX B
TABLES

TABLE 1
Experimental Design

Treatment	Paver Speed	Location Relative to Vibrator Trail	Vibrator Frequency (vpm)	Portion of Core (Nested)	Repetitions (n)
1	Slow	In	8000	Top Middle Bottom	3 3 3
2	Slow	In	6500	Top Middle Bottom	3 3 3
3	Slow	In	5000	Top Middle Bottom	3 3 3
4	Slow	Between	8000	Top Middle Bottom	3 3 3
5	Slow	Between	6500	Top Middle Bottom	3 3 3
6	Slow	Between	5000	Top Middle Bottom	3 3 3
7	Normal	In	8000	Top Middle Bottom	3 3 3
8	Normal	In	6500	Top Middle Bottom	3 3 3
9	Normal	In	5000	Top Middle Bottom	3 3 3
10	Normal	Between	8000	Top Middle Bottom	3 3 3
11	Normal	Between	6500	Top Middle Bottom	3 3 3
12	Normal	Between	5000	Top Middle Bottom	3 3 3

TABLE 2
Paver and Project Data

	Project A-2	Project A-3	Project B	Project C
Number of vibrators	22	22	17	15
Maximum spacing between vibrators (mm)	460	460	660	740
Minimum spacing between vibrators (mm)	230	230	360	360
Spacing between test vibrators (mm)	410	380	660	360
Vibrator centrifugal force at 10000 vpm (N)	7870	7870	5560	7870
Vibrator elevation below paver pan (mm)	0	100	0	0
Design thickness of pavement (mm)	300	300	300	300
Design width of pavement (m)	7.9	7.9	7.9	7.9
Iowa Mix design number	C-3WR-C20	C-3WR-C20	C-4WR-C20	C-3WR-C20

TABLE 3
Descriptive Statistics of Entrained Air For Project A2

Variable	Level	N	Mean	Standard Deviation
Paver Speed	Normal Slow	54 54	9.175 8.106	1.306 1.708
Location of Core	In Trail Between Trails	54 54	8.426 8.855	1.623 1.622
Vibrator Frequency	8000 6500 5000	36 36 36	8.657 8.702 8.563	1.967 1.401 1.508
Portion of Core	Top Middle Bottom	36 36 36	6.913 9.097 9.911	0.897 1.266 0.875
All Cores		108	8.641	1.629

TABLE 4
ANOVA for Project A2

Source	DF	SS	MS	Error	F Ratio	P
NS	1	30.8054	30.8054	0.6869	44.85	0.000
INBET	1	4.9580	4.9580	0.6869	7.22	0.006
VPM	2	0.3585	0.1792	0.6869	0.26	0.757
TMB	2	173.0215	86.5107	0.3095	279.52	0.000
NS*INBET	1	0.1365	0.1365	0.6869	0.2	0.796
NS*VPM	2	6.3624	3.1812	0.6869	4.63	0.014
NS*TMB	2	9.9749	4.9874	0.3095	16.11	0.000
INBET*VPM	2	1.4703	0.7351	0.6869	1.07	0.329
INBET*TMB	2	0.3180	0.1590	0.3095	0.51	0.582
VPM*TMB	4	13.2932	3.3233	0.3095	10.74	0.000
NS*INBET*VPM	2	0.0816	0.0408	0.6869	0.06	0.939
NS*INBET*TMB	2	0.2788	0.1394	0.3095	0.45	0.629
NS*VPM*TMB	4	8.9761	2.2440	0.3095	7.25	0.000
INBET*VPM *TMB	4	0.8567	0.2142	0.3095	0.69	0.672
NS*INBET*VPM *TMB	4	1.7979	0.4495	0.3095	1.45	0.211
ERROR FOR TREATMENTS	24	16.4845	0.6869			
ERROR FOR NESTING TMB	48	14.8577	0.3095			
TOTAL	107	284.0320				

NS = Paver Speed (Normal or Slow)
INBET = Core Location Relative to the Vibrator (In Vibrator Trail or Between Vibrators)
VPM = Vibration Level (Low 5000 vpm, Medium 6500 vpm, High 8000 vpm)
TMB = Portion of Core (Top 1/3, Middle 1/3, and Bottom 1/3)

TABLE 5
Descriptive Statistics of Entrained Air For Project A3

Variable	Level	N	Mean	Standard Deviation
Paver Speed	Normal Slow	54 54	8.594 8.481	1.441 1.627
Location of Core	In Trail Between Trails	54 54	8.252 8.823	1.464 1.557
Vibrator Frequency	8000 6500 5000	36 36 36	8.010 8.168 9.434	1.516 1.441 1.241
Portion of Core	Top Middle Bottom	36 36 36	7.316 8.683 9.614	0.916 1.631 0.959
All Cores		108	8.537	1.531

TABLE 6
ANOVA for Project A3

Source	DF	SS	MS	Error	F Ratio	P
NS	1	0.3389	0.3389	0.6868	0.49	0.438
INBET	1	8.8008	8.8008	0.6868	12.81	0.001
VPM	2	43.8678	21.9339	0.6868	31.94	0.000
TMB	2	96.1802	48.0901	0.9753	49.31	0.000
NS*INBET	1	0.7617	0.7617	0.6868	1.11	0.213
NS*VPM	2	12.3397	6.1699	0.6868	8.98	0.001
NS*TMB	2	2.6391	1.3195	0.9753	1.35	0.255
INBET*VPM	2	3.0155	1.5077	0.6868	2.20	0.112
INBET*TMB	2	0.7423	0.3712	0.9753	0.38	0.675
VPM*TMB	4	1.4226	0.3556	0.9753	0.36	0.696
NS*INBET*VPM	2	4.0159	2.0080	0.6868	2.92	0.059
NS*INBET*TMB	2	1.2359	0.6179	0.9753	0.63	0.523
NS*VPM*TMB	4	9.0683	2.2671	0.9753	2.32	0.098
INBET*VPM *TMB	4	2.3900	0.5975	0.9753	0.61	0.700
NS*INBET*VPM *TMB	4	0.6948	0.1737	0.9753	0.18	0.509
ERROR FOR TREATMENTS	24	16.4843	0.6868			
ERROR FOR NESTING TMB	48	46.8134	0.9753			
TOTAL	107	250.8112				

NS = Paver Speed (Normal or Slow)
INBET = Core Location Relative to the Vibrator (In Vibrator Trail or Between Vibrators)
VPM = Vibration Level (Low 5000 vpm, Medium 6500 vpm, High 8000 vpm)
TMB = Portion of Core (Top 1/3, Middle 1/3, and Bottom 1/3)

TABLE 7
Descriptive Statistics of Entrained Air For Project B

Variable	Level	N	Mean	Standard Deviation
Paver Speed	Normal	54	7.028	1.235
	Slow	54	7.110	1.331
Location of Core	In Trail	54	6.672	1.109
	Between Trails	54	7.466	1.323
Vibrator Frequency	8000	36	6.566	0.934
	6500	36	7.291	1.383
	5000	36	7.350	1.349
Portion of Core	Top	36	6.461	1.271
	Middle	36	7.264	1.076
	Bottom	36	7.483	1.277
All Cores		108	7.069	1.279

TABLE 8
ANOVA for Project B

Source	DF	SS	MS	Error	F Ratio	P
NS	1	0.179	0.179	2.281	0.08	1.339
INBET	1	17.009	17.009	2.281	7.46	0.005
VPM	2	13.710	6.855	2.281	3.01	0.055
TMB	2	20.863	10.431	0.643	16.23	0.000
NS*INBET	1	0.017	0.017	2.281	0.01	3.928
NS*VPM	2	4.342	2.171	2.281	0.95	0.371
NS*TMB	2	0.689	0.345	0.643	0.54	0.573
INBET*VPM	2	6.051	3.026	2.281	1.33	0.255
INBET*TMB	2	0.845	0.423	0.643	0.66	0.508
VPM*TMB	4	2.315	0.579	0.643	0.90	0.572
NS*INBET*VPM	2	2.215	1.108	2.281	0.49	0.594
NS*INBET*TMB	2	4.133	2.067	0.643	3.21	0.043
NS*VPM*TMB	4	4.230	1.058	0.643	1.64	0.244
INBET*VPM *TMB	4	4.262	1.066	0.643	1.66	0.238
NS*INBET*VPM *TMB	4	8.480	2.120	0.643	3.30	0.025
ERROR FOR TREATMENTS	24	54.742	2.281			
ERROR FOR NESTING TMB	48	30.859	0.643			
TOTAL	107	174.940				

NS = Paver Speed (Normal or Slow)
INBET = Core Location Relative to the Vibrator (In Vibrator Trail or Between Vibrators)
VPM = Vibration Level (Low 5000 vpm, Medium 6500 vpm, High 8000 vpm)
TMB = Portion of Core (Top 1/3, Middle 1/3, and Bottom 1/3)

TABLE 9
Average Entrained Air Contents by Treatment for Project C

Vibrator Frequency (vpm)	Paver Speed	Location Relative to Vibrator(s)	Number of Samples	Average	Standard Deviation
5000	Normal	All In Trail Between	18 9 9	7.698 7.454 7.942	0.578 0.544 0.532
8000	Normal	All In Trail Between	18 9 9	7.498 6.901 8.094	1.007 1.073 0.451
8000	Slow	All In Trail Between	18 9 9	7.098 6.713 7.483	1.017 0.637 1.207

TABLE 10
Average Entrained Air Contents for the Top of the Cores In Project C

Frequency (vpm)	Paver Speed	Number of Samples	Average	Standard Deviation
5000	Normal	3	7.317	0.318
8000	Normal	3	5.510	0.244
8000	Slow	3	5.173	0.257

TABLE 11
Descriptive Statistics of Entrained Air for Project C at 8000 vpm

Variable	Level	N	Mean	Standard Deviation
Paver Speed	Normal	18	7.498	1.007
	Slow	18	7.098	1.017
Location of Core	In Trail	18	6.807	1.112
	Between Trails	18	7.789	0.621
Portion of Core	Top	12	6.453	1.301
	Middle	12	7.597	0.432
	Bottom	12	7.845	0.461
All Cores		36	7.298	1.018

TABLE 12
ANOVA for Project C at 8000 vpm

Source	DF	SS	MS	Error	F Ratio	P
NS	1	1.436	1.436	0.219	6.56	0.010
INBET	1	8.673	8.673	0.219	39.60	0.000
TMB	2	13.239	6.620	0.096	68.96	0.000
NS*INBET	1	0.403	0.403	0.219	1.84	0.112
NS*TMB	2	1.665	0.832	0.096	8.67	0.001
INBET*TMB	2	6.966	3.483	0.096	36.28	0.000
NS*INBET*TMB	2	0.564	0.282	0.096	2.94	0.060
ERROR FOR TREATMENTS	8	1.753	0.219			
ERROR FOR NESTING TMB	16	1.541	0.096			
TOTAL	35	36.240				

NS = Paver Speed (Normal or Slow)
INBET = Core Location Relative to the Vibrator (In Vibrator Trail or Between Vibrators)
TMB = Portion of Core (Top 1/3, Middle 1/3, and Bottom 1/3)

TABLE 13
Entrained Air Content Sorted by VPM and Portion of Core for Slow Paver Speed
Project C, September 14

Treatment	Top of Core	Middle of Core	Bottom of Core
Between Vibrators	8.383	8.810	7.933
In Trail at 8000 vpm	5.550	7.460	7.013
In Trail at 12000 vpm	4.032	1.610	5.610

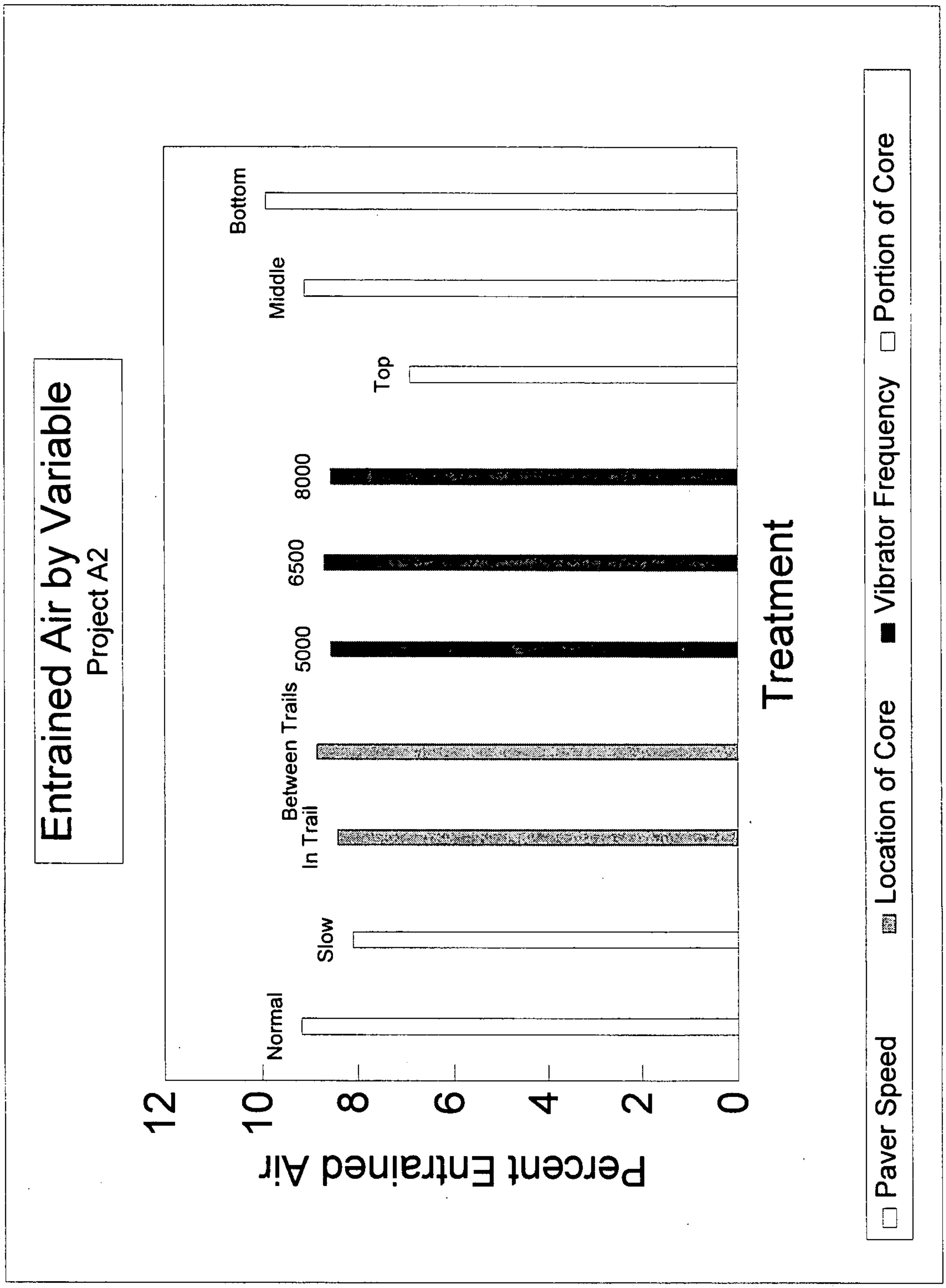
TABLE 14
95 Percent Probability of Significance for All Projects

	PROJECT A2	PROJECT A3	PROJECT B	PROJECT C (8000 vpm)
NS	YES	NO	NO	YES
INBET	YES	YES	YES	YES
VPM	NO	YES	NO	*
TMB	YES	YES	YES	YES
NS*INBET	NO	NO	NO	NO
NS*VPM	YES	YES	NO	*
NS*TMB	YES	NO	NO	YES
INBET*VPM	NO	NO	NO	*
INBET*TMB	NO	NO	NO	YES
VPM*TMB	YES	NO	NO	*
NS*INBET*VPM	NO	NO	NO	*
NS*INBET*TMB	NO	NO	YES	NO
NS*VPM*TMB	YES	NO	NO	*
INBET*VPM*TMB	NO	NO	NO	*
NS*INBET*VPM*TMB	NO	NO	YES	*

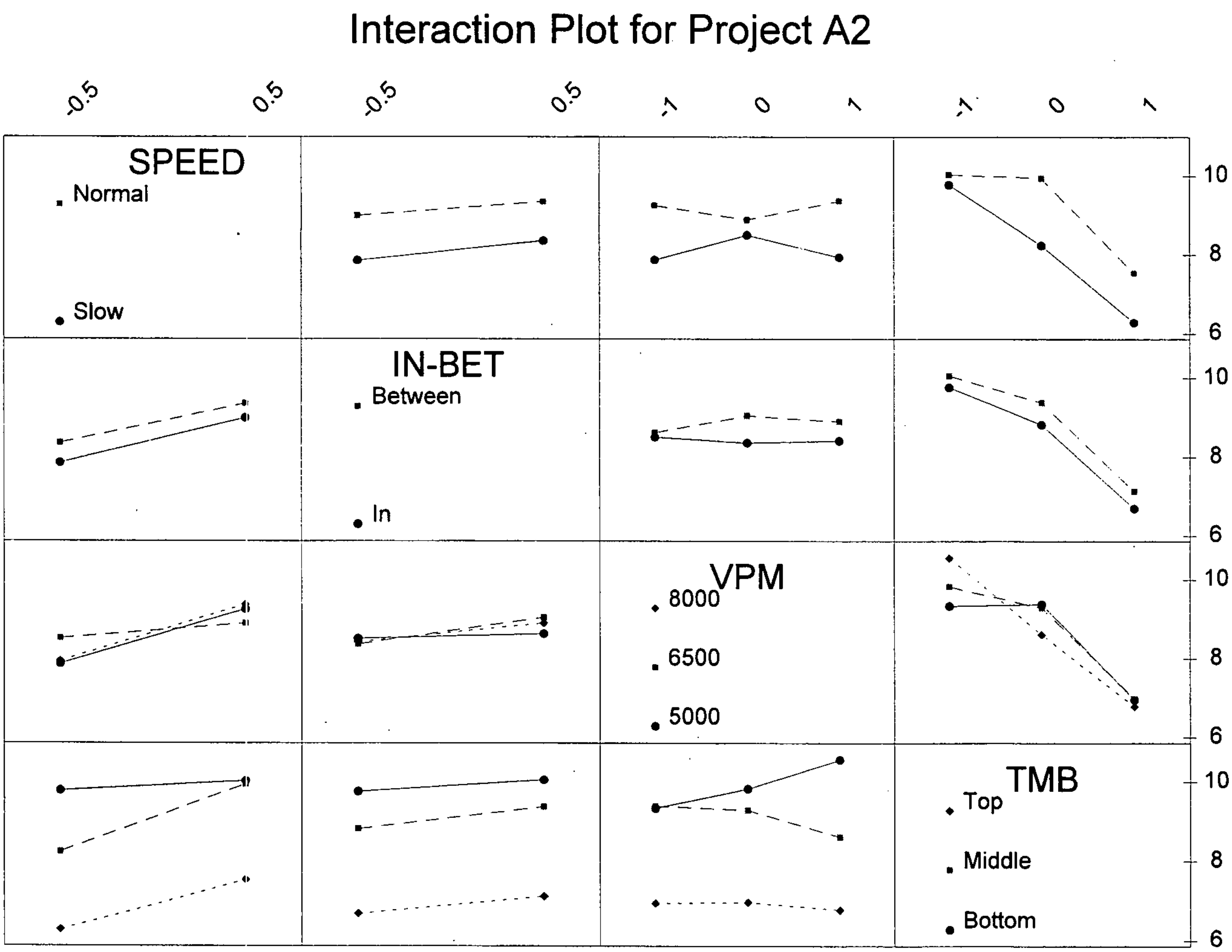
* Variable not tested

NS = Paver Speed (Normal or Slow)
INBET = Core Location Relative to the Vibrator (In Vibrator Trail or Between Vibrators)
VPM = Vibration Level (Low 5000 vpm, Medium 6500 vpm, High 8000 vpm)
TMB = Portion of Core (Top 1/3, Middle 1/3, and Bottom 1/3)

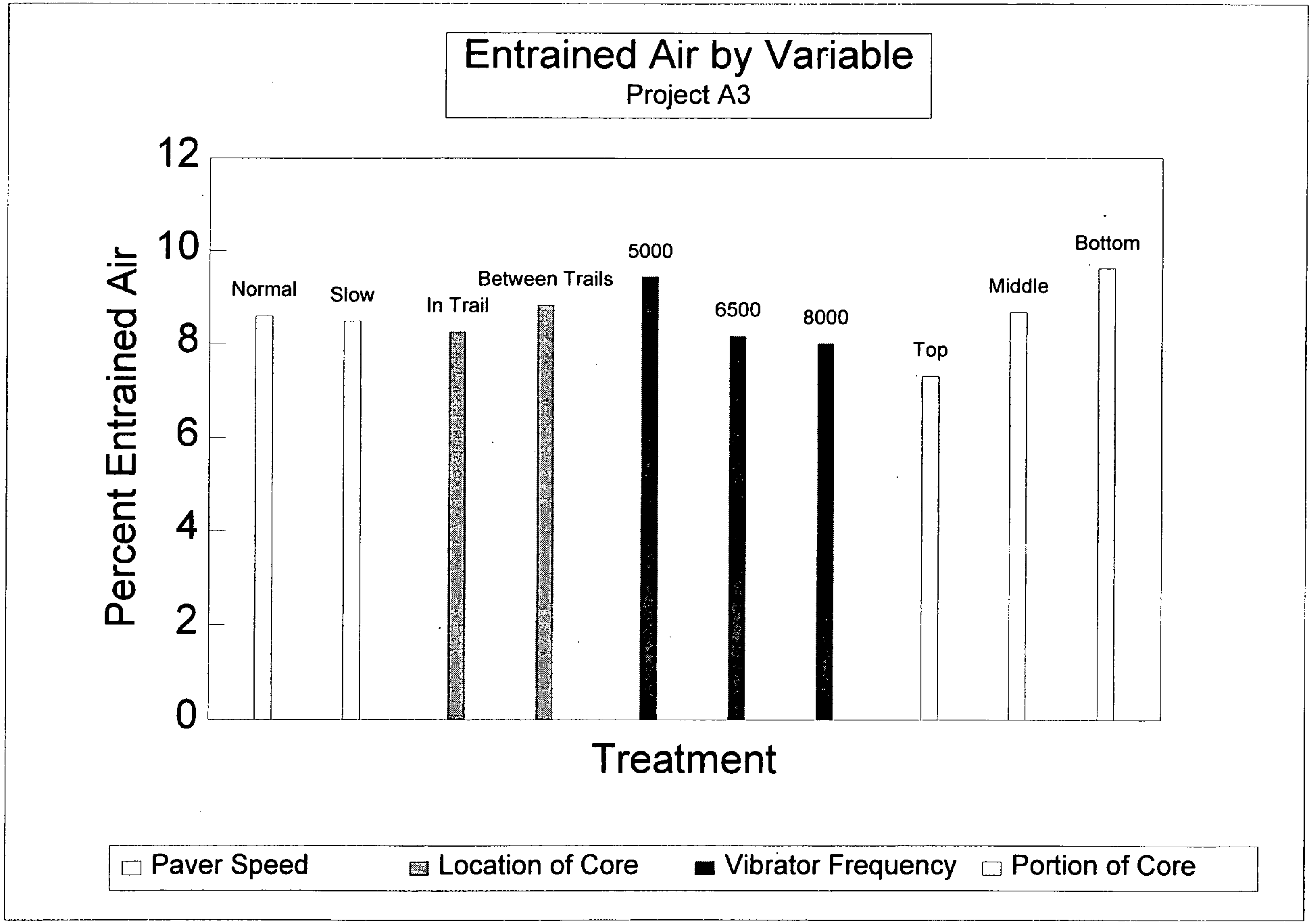
APPENDIX C
GRAPHS



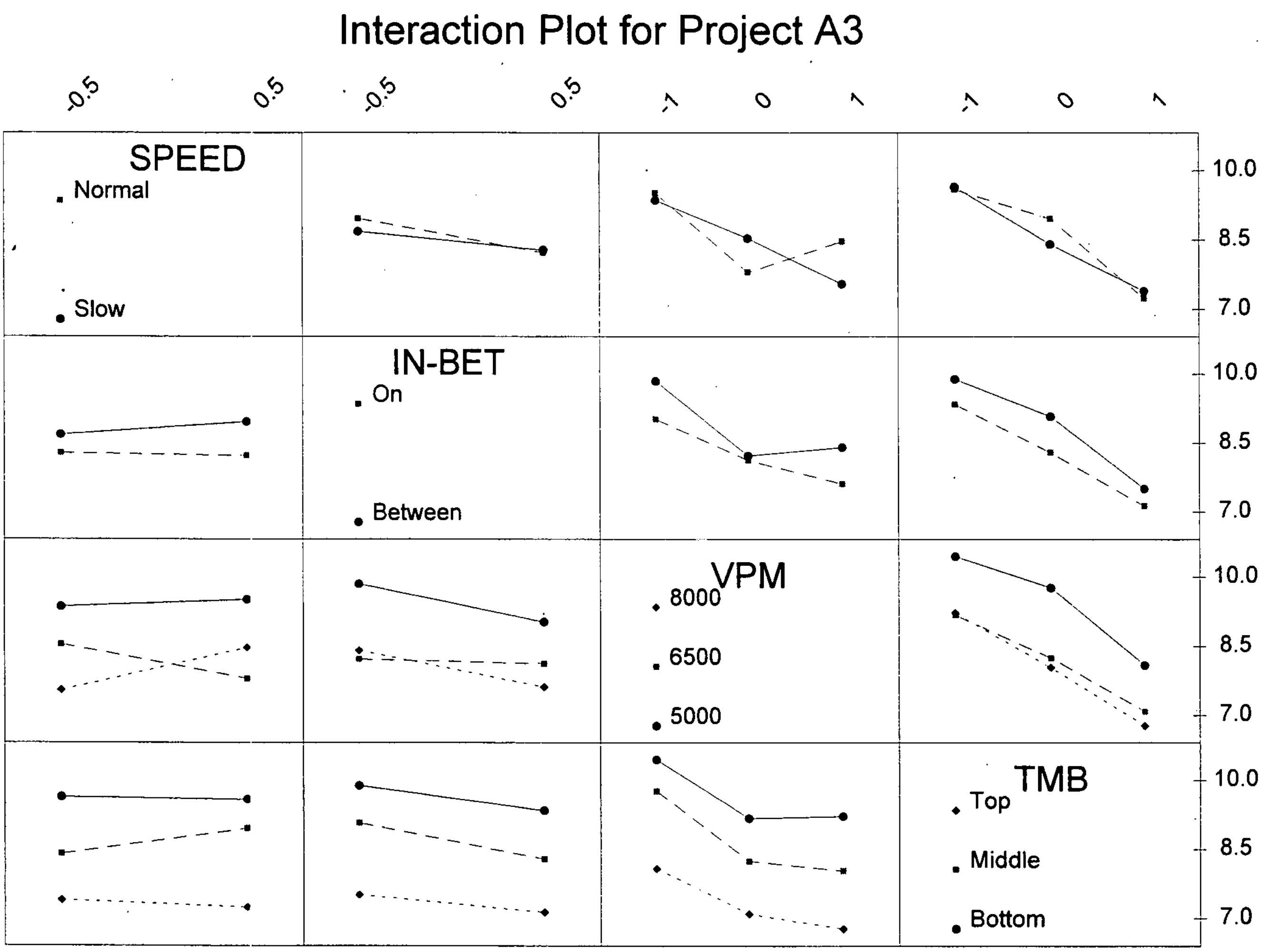
GRAPH 1 Average entrained air content by variable for project A2.



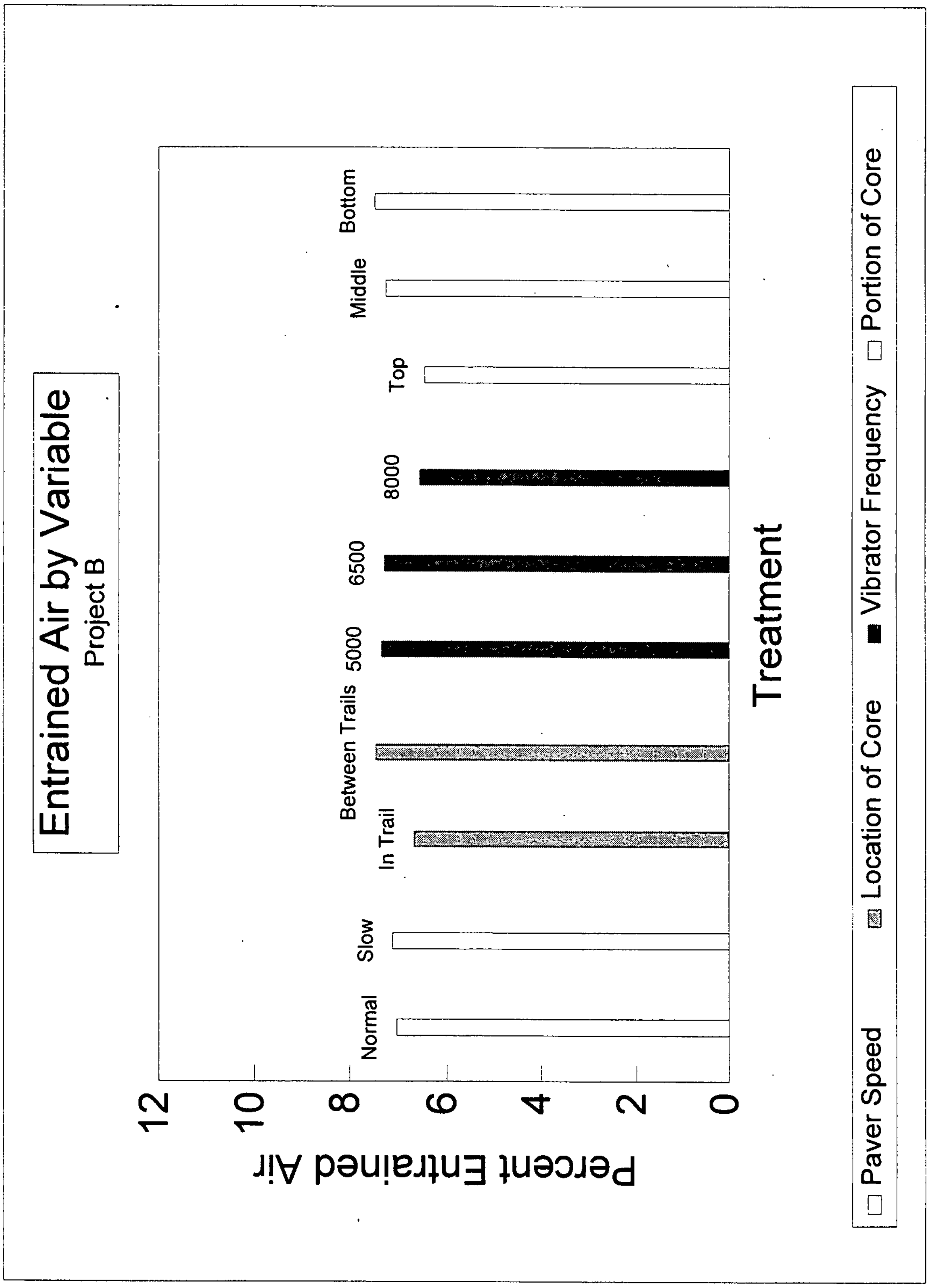
GRAPH 2 Interactions of variables for project A2.



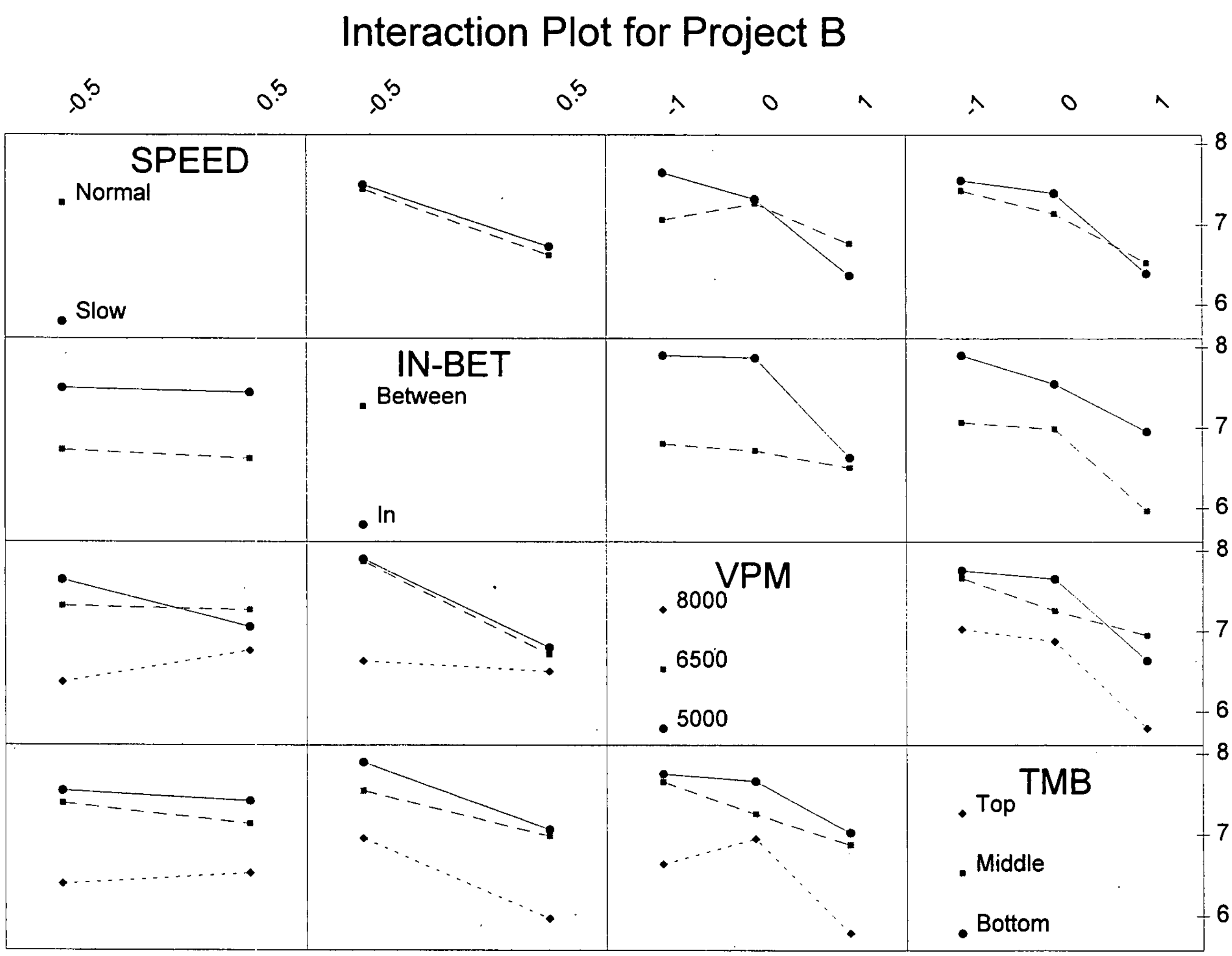
GRAPH 3 Average entrained air contents by variable for project A3.



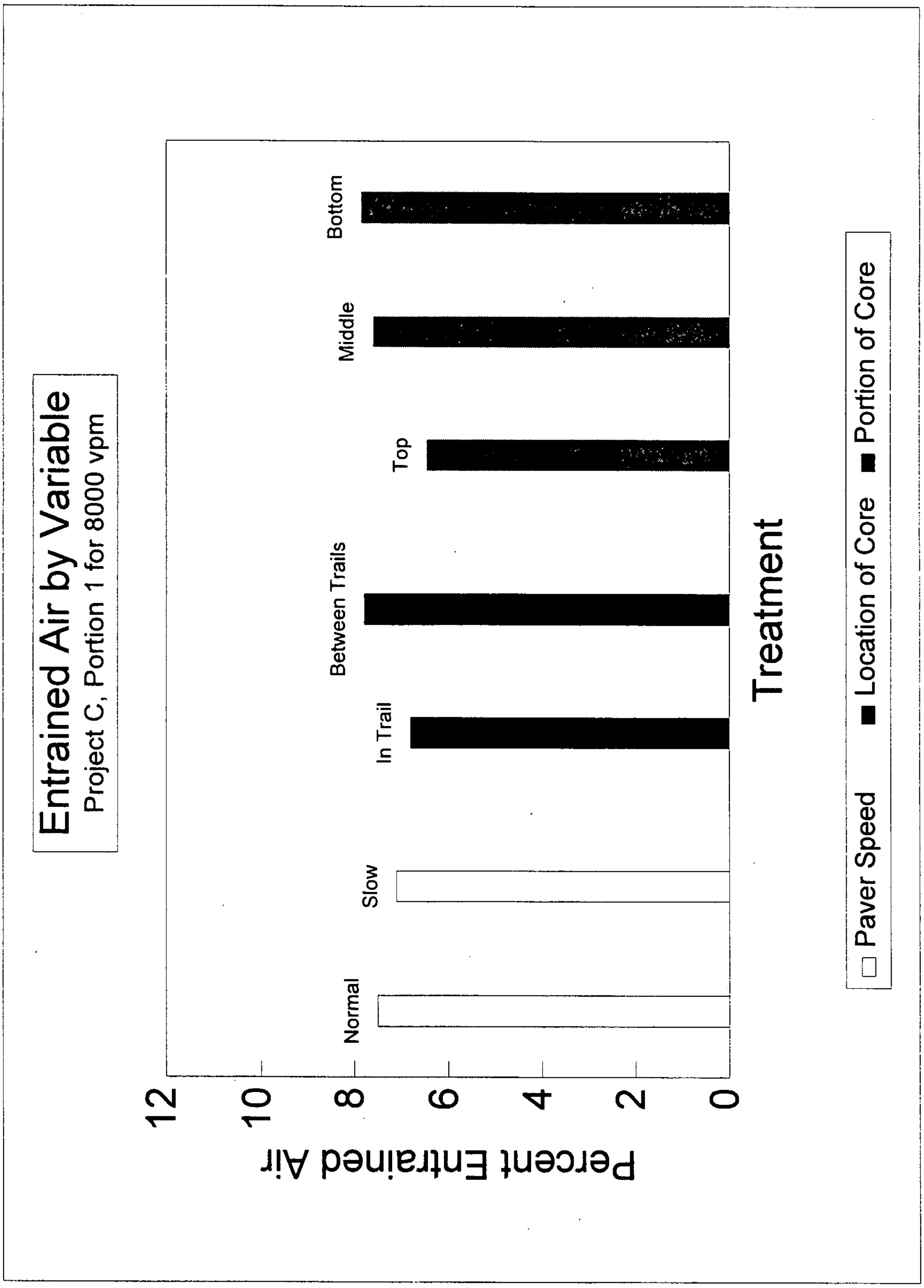
GRAPH 4 Interactions of variables for project A3.



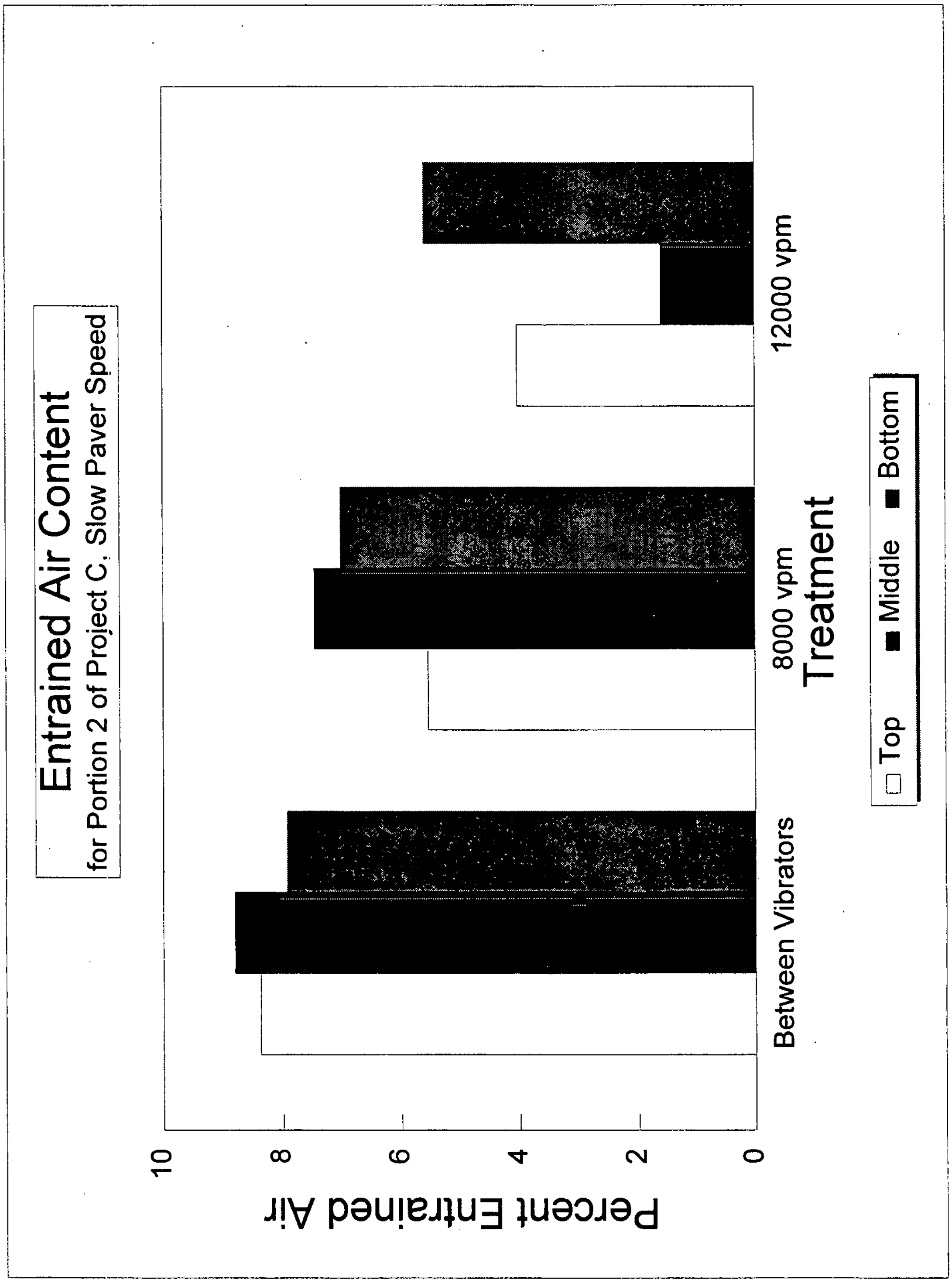
GRAPH 5 Average entrained air contents by variable for project B.



GRAPH 6 Interactions of variables for project B.



GRAPH 7 Average entrained air for portion 1 of project C at 8000 vpm.



GRAPH 8 Average entrained air contents for portion 2 of project C.

APPENDIX D
TEST METHODS

IOWA DEPARTMENT OF TRANSPORTATION
HIGHWAY DIVISION

Office of Materials

METHOD OF TEST FOR DETERMINATION OF AIR CONTENT OF PORTLAND CEMENT CONCRETE CORES USING A HIGH PRESSURE AIR METER

PART I, AIR CONTENT OF CONCRETE CORES

Scope

The amount of air in portland cement concrete is a factor that can result in longer life, greater versatility, and better economy. The proper amount of air content will greatly improve the quality, appearance, and placeability of concrete. The air content of cores drilled from pavement, pavement widening, bridges, etc., is determined by a high pressure air meter. In addition, water absorption in paste by volume of the core can also be determined.

A. Apparatus and Materials

1. High pressure air meter (Fig. 1 and 2).
2. Specimen stirrup for lowering the specimen into the compression chamber.
3. Core soaking container.
4. Liquid solution of 20 grams sodium borate, 5 gram sodium chromate, and one gallon water.
5. Oven (300^{o} F.).
6. Scale (capacity = 7,000 grams, accuracy = 0.5 gram).

B. Test Record Forms

1. Data and calculation sheet (Fig. 3).
2. "P.C.C. core strength - air - absorption" coding sheet.
3. Strength and air field book with columns of core number, dry weight, absorbed weight, weight in water, zero reading, and observed dial reading.

C. Test Procedure

1. Dry the core specimen in an oven at 300^{o}F. for a period of 72 hours.
2. Cool the specimen at room temperature for a period of approximately 3 hrs.
3. Weigh the specimen in air.
4. Soak the specimen in the soaking container for a period of 48 hours.
5. Weigh the specimen in water.
6. Wipe the excess water off the specimen using an absorbent cloth.
7. Weigh the specimen in air (absorbed weight).
8. Using the stirrup, lower the specimen into the compression chamber.
9. Close the elliptical lid tightly, such that one-quarter to one-half inch of liquid remains on the top.
10. Remove the trapped air as follows: with a small head pressure, let the liquid flow into the chamber at the low side valve and out of the chamber at the high side valve. Be sure that all the trapped air is removed by checking for air bubbles in the beaker which is used as a receiver of the liquid from the high side valve.
11. When all the trapped air is out of the compression chamber, close both valves tightly.
12. Turn the transmission switch to the (D) down position. The cylinder piston will begin to move downward, the distance of which is indicated by the dial reading. When there is no further visual movement of the dial, note the pressure gauge, and use a correction of 0.05 divisions of the dial for every 100 psi. differential from 5,000 psi. Thus, if the dial reading is 4.81 revolutions and the pressure gauge reads 4,900 psi., the recorded dial reading should be 4.86 revolutions. If the pressure gauge reads 5,060 psi., the recorded reading would be 4.78 revolutions.
13. Loosen the lid screw a half-turn to prevent it from locking up.

14. Turn the transmission switch to the (U) up position. When the pressure has dropped below 1000 psi., open the high side valve and remove the elliptical lid. Make sure that the dial has returned to the zero position.

15. Remove the specimen from the compression chamber by lifting the stirrup.

16. Before and after each series of cores that are tested, a dial reading should be recorded with nothing but the stirrup in the compression chamber. This is the zero reading and is recorded for each core in the field book.

D. Calculations

1. Computer Calculating

a. Computer calculating of the resulting air content can be gained by transferring the relevant data from the field book to the coding sheet labeled "P.C.C. Core Strength - Air - Absorption" Form 909. The coding sheet is then sent to the data processing center for computation.

2. Hand Calculating

a. The calculation sheet shown in Fig. 3 can be used to calculate the air content when the computation is carried out by laboratory personnel.

3. Computer Terminal Calculating

a. The Materials Laboratory computer terminal will calculate the air content when the program login (dpctl, dp01), load (air) is supplied with the requested core data.

E. Reporting the Results

1. The computer print-out and the calculation sheet both present the air content as a percent by volume of the concrete core specimen. The water absorption in paste by volume of a core is determined by the same computer program as air content. All aggregate and mix data should be included on the coding sheet. The water absorption in paste is specified on the print-out.

F. Note

The high pressure air meter is similar to an original design by the Illinois Division of Highways (Highway Research Board Proceedings Vol. 35, "Illinois Develops High Pressure Air Meter For Determining Air Content of Hardened Concrete", pp. 424-435). See also ISHC R-168.

PART II, CALIBRATION

Scope

It is recommended that at least once-a-year the high pressure air meter be calibrated to determine the effects of wear on its performance. These effects are reflected by the two air meters constants which are used in calculating the air content of concrete specimens. The first constant determined is the solid slope-factor which is a correction for the expansion of the equipment and compressibilities of the liquid. The second constant is the volume of air displaced by liquid per dial revolution.

A. Apparatus and Materials

1. High pressure air meter.

2. Liquid solution of 20 grams sodium borate, 5 grams sodium chromate and one gallon water.

3. Two standardized steel volume specimens marked "565 cc" and "1180 cc" along with a threaded rod used to transport the specimens.

4. Complete set of steel air displacement specimens that include:

a. Two steel cylinders marked "50 cc".

b. One steel cylinder marked "100 cc".

c. One cylindrical cup with lid marked "240 cc steel - 250 cc air".

B. Test Report Form

1. Data and calculation sheet labeled "Large High Pressure Air Meter Calibration" (Fig. 4).

C. Calibration Procedure

1. Fill the compression chamber with the liquid solution and close the elliptical lid tightly such that one-quarter to one-half inch of liquid remains on the top.

2. Remove the trapped air as described in item number 10 under the test procedure of Part I, Air Content of Concrete Cores.

3. Close both valves tightly.

4. Turn the transmission switch to the (D) down position and record the 5000 psi. corrected dial reading.

5. Loosen the lid screw a half-turn.

6. Turn the transmission swith to the (U) up position. When the pressure has dropped below 1000 psi. open the high side valve, remove the elliptical lid, and make sure the dial has returned to the zero position.

7. The remainder of the calibration procedure requires that dial readings be recorded for various amounts of steel and air within the compression chamber. These amounts are specified on the data sheet, and can all be gained by using different combinations of the steel specimens and the air measuring cup. Thus, steps 1 through 6 are repeated for the various combinations until the twenty-four corrected dial readings have been recorded on the data sheet.

D. Calculations and Reporting of Results

1. The calculations are made directly on the data sheet under the format presented. The results (solid-slope-factor and cubic centimeters per dial revolution) are recorded on the first page of the high pressure air meter file R-168. A comparison of previous results will indicate the nature of the air meter wear, and will serve as a basis for any repairs.

PART III, AGGREGATE AIR CORRECTION

Scope

Before the air content of a concrete specimen can be computed, a correction for the air within the coarse aggregate must be determined. Since the amount of air within the coarse aggregate is not included in the final results, it is subtracted from the observed air content of the concrete core.

A. Apparatus and Materials

1. High pressure air meter.

2. Soaking container.

3. 500 cc beaker.

4. Specimen stirrup for lowering beaker into the compression chamber.

5. Liquid solution of 20 grams sodium borate, 5 grams sodium chromate and one gallon water.

6. Scale (capacity = 1000 gm., accuracy = 0.2 gm.).

B. Test Record Form

1. Data and calculation sheet labeled "Aggregate Air Correction Using the High Pressure Air Meter" (Fig. 5).

C. Aggregate Correction Procedure

1. Soak a representative aggregate sample of approximately 1000 grams at room temperature for 48 hours.

2. Wipe the excess water of the aggregate using an absorbent cloth (saturated-surface-dry-condition).

3. Weigh a sample having a weight that is equivalent to 100 times the specified gravity in grams.

4. Place the weighed sample in the 500 cc beaker and lower it (by the stirrup) into the compression chamber.

5. Close the elliptical lid tightly, such that one-quarter to one-half inch of liquid remains on the top.

6. Remove the entrapped air as described in item number 10 under the test procedure of Part I, Air Content of Concrete Cores.

7. Close both valves tightly.

8. Turn the transmission to the (D) down position and record the 5000 psi. corrected dial reading.

9. Loosen the lid screw a half-turn.

10. Turn the transmission switch to the (U) up position. When the pressure has dropped to below 1000 psi., open the high side valve, remove the elliptical lid, and make sure the dial has returned to the zero position.

11. Record a zero reading (stirrup, beaker and water in chamber) for each sample.

12. Repeat items 3 through 11 until 3 samples of a given aggregate have been tested and reported.

D. Calculations and Reporting of Results

1. The calculations are made directly on the aggregate correction data sheet (Fig. 5). The results (avg. percent air in aggregate and cc air in standard specimen) are recorded in Table II, "Aggregate Characteristics", which is a listing of air content, specific gravity, and absorbed weight of all aggregates previously tested. Any additions or corrections to Table II should be made available to the data processing center so that future computer calculations can be kept up-to-date.

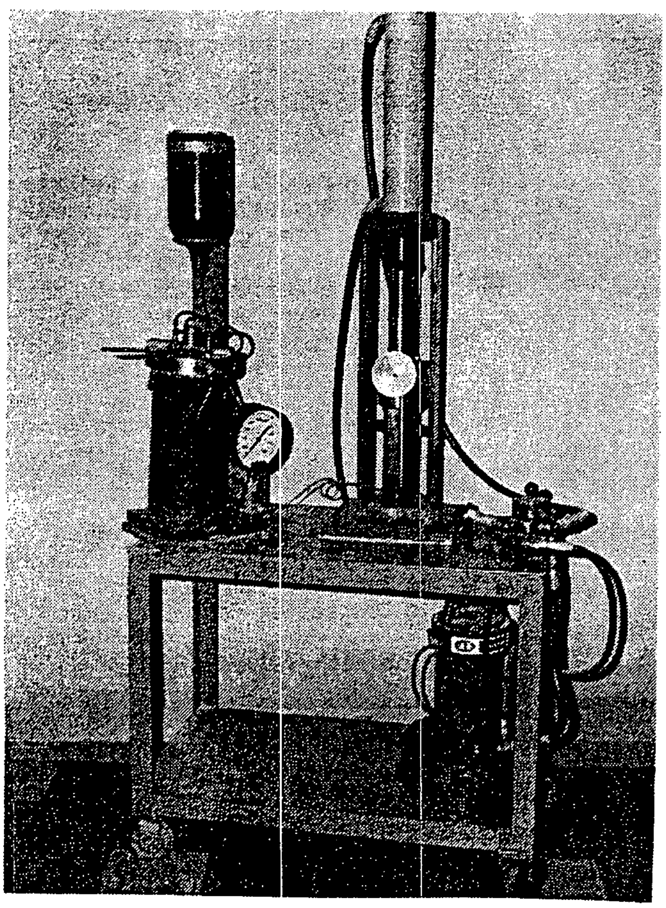


Figure 1
High Pressure Air Meter

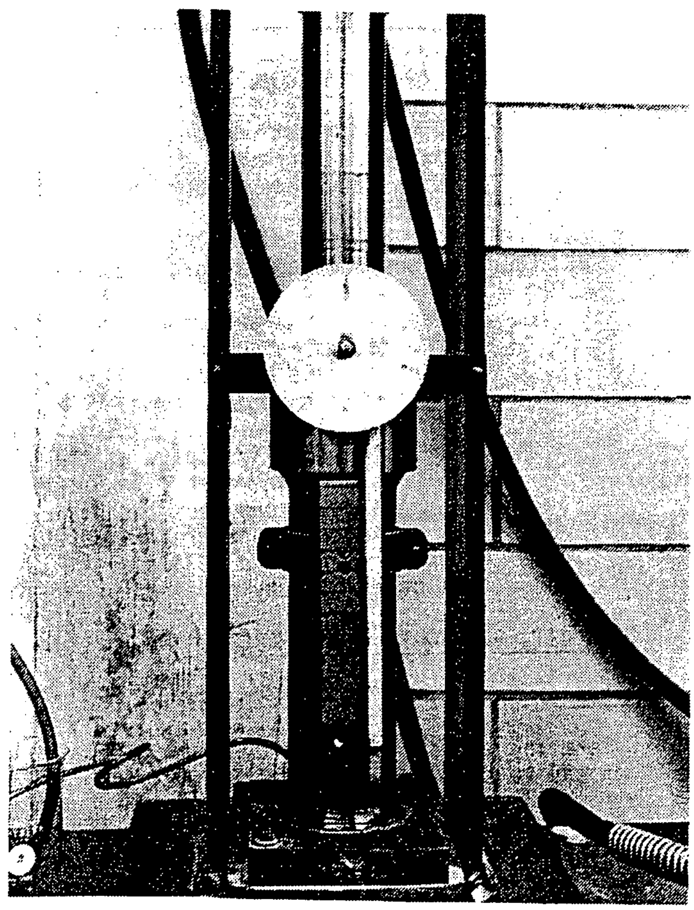


Figure 2
Close-Up of Dial on High Pressure Air Meter

FIGURE 3

ENTRAINED AIR DETERMINATION OF CORE SPECIMENS USING THE HIGH PRESSURE AIR METER-DATA AND CALCULATION SHEET

Project No. 5-1105(6)-50-39 County GUTHRIE

Date 3/23/71 By S. CAREY

Core No. 6991 Lab. No. 3127

Location STA. 101+00

Coarse Aggregate HALLET, GILMORE CITY HUMBOLDT COUNTY Mix B-4

Air Meter Characteristics (Most Recent):

A) Solid Slope Factor, K = 0.00041

B) Volume of Air Per Dial Revolution, V = 36.88

C) Use Pressure Correction of 0.05 Revolutions Per 100 PSI Differential from 5,000 PSI.

Specimen Reference	1					
1. Dry Weight of Specimen, gm. (72 hr. in oven)	2300					
2. Absorbed Wt. of Specimen, gm. (48 hr. soak)	2478					
3. Weight in Water, gm.	1394					
4. Volume of Specimen, $Cm^3 = (2-3)$	1084					
5. Zero Dial Reading (Water & Stirrup)	2.40					
6. Volume Absorbed Water = (2-1)	178					
7. Volume Solids + Air = (4-6)	906					
8. Observed Dial Reading	4.06					
9. Adj. Zero Reading = [5-(Kx7)]	2.03					
10. Net Revolutions = (8-9)	2.03					
11. Observed Vol. Air = (10)(V)	74.87					
12. % Vol. Coarse Agg. (Table I)	34.51					
13. Vol. Coarse Agg. = $\frac{(4)(12)}{100}$	374.09					
14. % Vol. Air in Agg. (Table II)	0.3					
15. Agg. Correction = $\frac{(13)(14)}{100}$	1.12					
16. Vol. Entrained Air = (11-15)	73.75					
17. % Air = (16/4)	6.8%					

DATE TESTED: 3-18-87
TESTED BY: M. Coles

IOWA DEPARTMENT OF TRANSPORTATION - MATERIALS LABORATORY

LARGE HIGH PRESSURE AIR METER CALIBRATION

DATA AND CALCULATION SHEET

VOLUME OF STEEL IN TEST SPECIMEN -CUBIC CENTIMETERS	VOLUME OF AIR IN CONTAINER -CUBIC CENTIMETERS		DIAL READING №	DIAL READING AT 5000 PSI -REVOLUTIONS (SEE NOTE 1)
0	0		1	2.39
565	0		2	2.14
1180	0		3	1.87
1745	0		4	1.65
440	50	1	5	3.54
1005	50	2	6	3.34
1620	50	3	7	3.09
2185	50	4	8	2.84
390	100	1	9	4.95
955	100	2	10	4.72
1570	100	3	11	4.48
2135	100	4	12	4.32
340	150	1	13	6.46
905	150	2	14	6.20
1520	150	3	15	5.94
2085	150	4	16	5.79
290	200	1	17	7.92
855	200	2	18	7.70
1470	200	3	19	7.49
2035	200	4	20	7.31
240	250	1	21	9.07
805	250	2	22	8.88
1420	250	3	23	8.66
1985	250	4	24	8.41

SOLID SLOPE FACTOR (K)

$K = \dfrac{\text{DIAL READING №1} - \text{DIAL READING №4}}{1745}$

$K = \dfrac{2.39 - 1.65}{1745} = \dfrac{.74}{1745}$

$K = 0.000424$

CALCULATIONS TO DETERMINE AIR DISPLACEMENT PER DIAL REVOLUTION

NOTE: $D.R._2$ = DIAL READING AT DIAL READING № 2

REVOLUTION CHANGE EQUAL TO STEEL AT 0 VOLUME OF AIR (Z)	A	B	C	D	E	F
$Z_1 = (440)(K)$; $Z_1 = .187$	$A_1 = Z_1 + DR_8$; $A_1 = 3.03$	$B_1 = A_1 - DR_4$; $B_1 = 1.38$	$C_1 = 50/B_1$; $C_1 = 36.23$	$D_1 = Z_1 + DR_7$; $D_1 = 3.28$	$E_1 = D_1 - DR_3$; $E_1 = 1.41$	$F_1 = 50/E_1$; $F_1 = 35.54$
$Z_2 = (390)(K)$; $Z_2 = .165$	$A_2 = Z_2 + DR_{12}$; $A_2 = 4.48$	$B_2 = A_2 - DR_4$; $B_2 = 2.83$	$C_2 = 100/B_2$; $C_2 = 35.34$	$D_2 = Z_2 + DR_{11}$; $D_2 = 4.65$	$E_2 = D_2 - DR_3$; $E_2 = 2.78$	$F_2 = 100/E_2$; $F_2 = 36.04$
$Z_3 = (340)(K)$; $Z_3 = .144$	$A_3 = Z_3 + DR_{16}$; $A_3 = 5.93$	$B_3 = A_3 - DR_4$; $B_3 = 4.28$	$C_3 = 150/B_3$; $C_3 = 35.05$	$D_3 = Z_3 + DR_{15}$; $D_3 = 6.08$	$E_3 = D_3 - DR_3$; $E_3 = 4.21$	$F_3 = 150/E_3$; $F_3 = 35.60$
$Z_4 = (290)(K)$; $Z_4 = .123$	$A_4 = Z_4 + DR_{20}$; $A_4 = 7.43$	$B_4 = A_4 - DR_4$; $B_4 = 5.78$	$C_4 = 200/B_4$; $C_4 = 34.60$	$D_4 = Z_4 + DR_{19}$; $D_4 = 7.61$	$E_4 = D_4 - DR_3$; $E_4 = 5.74$	$F_4 = 200/E_4$; $F_4 = 34.83$
$Z_5 = (240)(K)$; $Z_5 = .102$	$A_5 = Z_5 + DR_{24}$; $A_5 = 8.51$	$B_5 = A_5 - DR_4$; $B_5 = 6.86$	$C_5 = 250/B_5$; $C_5 = 36.44$	$D_5 = Z_5 + DR_{23}$; $D_5 = 8.76$	$E_5 = D_5 - DR_3$; $E_5 = 6.89$	$F_5 = 250/E_5$; $F_5 = 36.27$

TOTAL C = 177.66
AVERAGE C = 35.53

TOTAL F = 178.28
AVERAGE F = 35.66

G	H	I	J	K	L
$G_1 = Z_1 + DR_6$; $G_1 = 3.53$	$H_1 = G_1 - DR_2$; $H_1 = 1.39$	$I_1 = 50/H_1$; $I_1 = 36.05$	$J_1 = Z_1 + DR_5$; $J_1 = 3.73$	$K_1 = J_1 - DR_1$; $K_1 = 1.34$	$L_1 = 50/K_1$; $L_1 = 37.40$
$G_2 = Z_2 + DR_{10}$; $G_2 = 4.89$	$H_2 = G_2 - DR_2$; $H_2 = 2.75$	$I_2 = 100/H_2$; $I_2 = 36.43$	$J_2 = Z_2 + DR_9$; $J_2 = 5.12$	$K_2 = J_2 - DR_1$; $K_2 = 2.73$	$L_2 = 100/K_2$; $L_2 = 36.70$
$G_3 = Z_3 + DR_{14}$; $G_3 = 6.34$	$H_3 = G_3 - DR_2$; $H_3 = 4.20$	$I_3 = 150/H_3$; $I_3 = 35.68$	$J_3 = Z_3 + DR_{13}$; $J_3 = 6.60$	$K_3 = J_3 - DR_1$; $K_3 = 4.21$	$L_3 = 150/K_3$; $L_3 = 35.60$
$G_4 = Z_4 + DR_{18}$; $G_4 = 7.82$	$H_4 = G_4 - DR_2$; $H_4 = 5.68$	$I_4 = 200/H_4$; $I_4 = 35.19$	$J_4 = Z_4 + DR_{17}$; $J_4 = 8.04$	$K_4 = J_4 - DR_1$; $K_4 = 5.65$	$L_4 = 200/K_4$; $L_4 = 35.38$
$G_5 = Z_5 + DR_{22}$; $G_5 = 8.98$	$H_5 = G_5 - DR_2$; $H_5 = 6.84$	$I_5 = 250/H_5$; $I_5 = 36.54$	$J_5 = Z_5 + DR_{21}$; $J_5 = 9.17$	$K_5 = J_5 - DR_1$; $K_5 = 6.78$	$L_5 = 250/K_5$; $L_5 = 36.86$

TOTAL I = 179.89
AVERAGE I = 35.98

TOTAL L = 181.94
AVERAGE L = 36.39

AVERAGE DISPLACEMENT PER DIAL REVOLUTION	
AVERAGE C	35.53
AVERAGE F	35.66
AVERAGE I	35.98
AVERAGE L	36.39
TOTAL AVERAGE	143.56
FINAL AVERAGE = TOTAL AVE / 4 =	35.89

NOTES:

1. USE PRESSURE CORRECTION OF 0.05 REVOLUTIONS FOR EVERY 100 PSI DIFFERENCE FROM 5000 PSI AS READ ON THE PRESSURE GAUGE.
2. STIRRUP SHOULD BE IN AIR METER WHENEVER POSSIBLE BEFORE RECORDING A DIAL READING.

RESULTS:

SOLID SLOPE FACTOR 0.000424

CUBIC CENTIMETERS PER DIAL REVOLUTION ______

FIGURE 5

AGGREGATE AIR CORRECTION USING THE HIGH PRESSURE
AIR METER-DATA AND CALCULATION SHEET

Project No. AAC9-464 County BLACK HAWK

Date 12/12/69 By DEWEES POTTHOFF

Aggregate RAYMOND QUARRY LIMESTONE Location SE 1/4 36-89-12

Specific Gravity 2.674

Air Meter Characteristics:

A) Solid Slope Factor, K = 0.00042

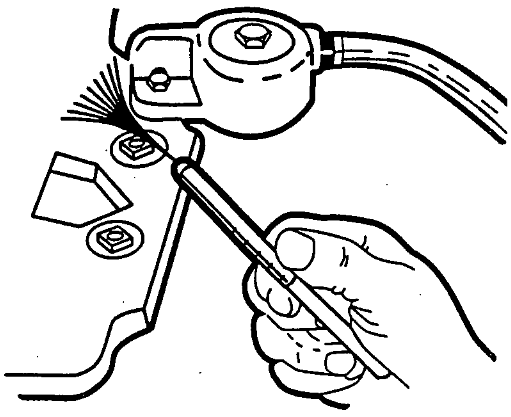
B) Volume of Air Per Dial Revolution, V = 34.3

C) Use Pressure Correction of 0.05 Revolutions Per 100 PSI Differential from 5,000 PSI.

1) Specimen Reference	1	2	3		
2) Sat. Surface Dry Wt. (100 x S. Gr.) gms.	267	267	267		
3) Total Volume, cm^3	100	100	100	100	100
4) Dial Reading (Stirrup, Beaker, Liquid)	2.32	2.32	2.32		
5) Observed Dial Reading	2.31	2.30	2.30		
6) Adjusted Zero Reading = [4 - (K)(3)]	2.28	2.28	2.28		
7) Net Revolutions = (5 - 6)	0.03	0.02	0.02		
8) Observed CC Air = (7)(V)	1.03	0.69	0.69		
9) % Air in Agg. = 8 as %	1.03%	.69%	.69%		
10) Average Percent Air in Agg. (Use for Hand Calculating Entrained Air)	→	0.80%	←		
11) CC Air in Standard Specimen = $\frac{(10)(470)}{100}$ (Use for Computer Calculating Entrained Air)	→	3.8	←		

NOTE: Items 10 and 11 are to be added to Table II.

Check speed of vibration quickly, easily, and accurately



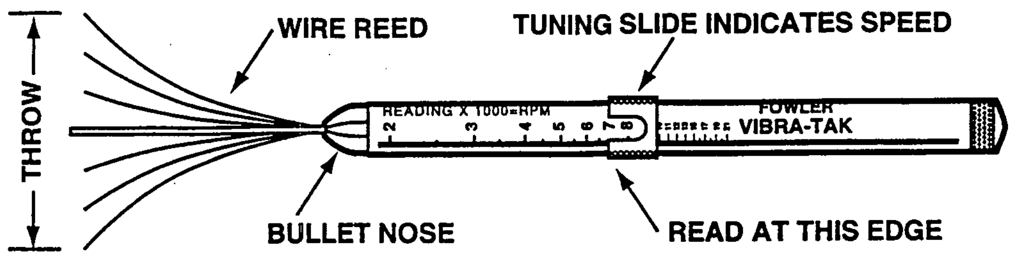
Indicates speed of vibration on match plate

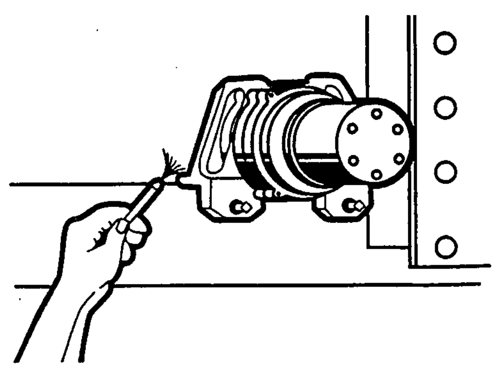
MARTIN®
VIBRA-TAK™
Vibration Indicator

The "Slide Rule" that:

- Finds vibrations per minute
- Helps locate the source of unwanted vibration
- Finds "dead spots" on vibration equipment

This MARTIN® VIBRA-TAK™ vibration indicator is a simple, easy to use tool for accurately measuring the speed of a vibrating object.





Locate hopper car vibration rpm to help correct dangerous overspeed and inefficient underspeed.

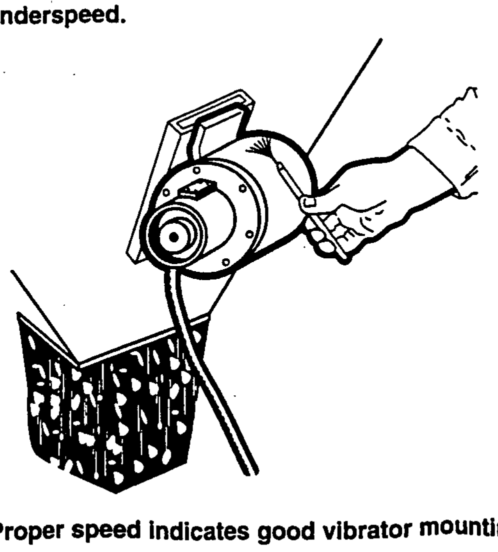
How To Use:

1. Move tuning slide down scale until wire reed is fully extended outside of housing.
2. Press the bullet nose against the vibrating object.
3. Move tuning slide up scale until the wire reed reaches its maximum throw.
4. Multiply scale reading by 1,000 to find vibration cycles per minute, or shaft speed rpm.
5. The arc through which reed "throws" is in direct proportion to speed and stroke. Each 1/2" of "throw" equals .001" stroke.

Two Models Available

Low Speed - 200 to 2,000 rpm P/N 14831
High Speed - 2,000 to 21,000 rpm P/N 14830.

(Higher speeds do register and can be closely estimated.)



Proper speed indicates good vibrator mounting.

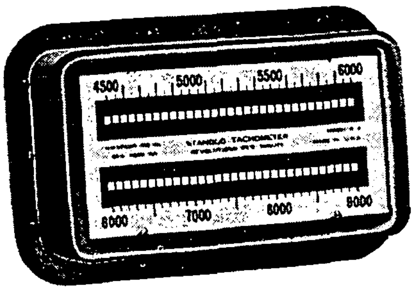
MARTIN ENGINEERING
One Martin Place
Neponset, Illinois 61345-9766 USA
1-800-544-2947 or 309-594-2384
FAX: 309-594-2432

 Form No. 1191-12/94CP

INSTRUCTIONS

"STANDCO" Vibrating Reed Tachometers

...... *For Stationary Mounting*



"Standco" Vibrating Reed Tachometers operate on the well-known and time-tested principle of resonance. They measure speed of rotating machinery by picking up the rate of vibration on accurately calibrated reeds. These reeds are set in motion by the slight vibration of the rotating element. The RPM or vibrations per minute are indicated on the scale of these instruments by the visual pattern formed by one or more reeds while vibrating. See attached Bulletin No. 770C.

HOW TO INSTALL STATIONARY TACHOMETERS ......

1. **Mount the Tachometer on its bracket.** Various types of brackets are available and should be carefully selected from our literature. If the Tachometer has been received without brackets, we recommend that brackets best suitable be ordered (at extra cost).

2. **After the Tachometer has been secured to the bracket,** hold it at or near the desired permanent location for a rough check of reed indication and the amplitude of the swing of the reeds. It is best to select a spot where the reeds which are in motion will show maximum vibration.

3. **When a location has been found** on the machine where the reeds vibrate at normal amplitude, fasten the bracket securely in that spot. It is recommended that the machine speed be then varied over the full range of the Tachometer to see that the reeds vibrate at the proper amplitude over the entire range.

4. **It is recommended** that the reeds are not allowed to vibrate continuously at an excessive amplitude. Usually the amplitude should not be greater than the scale opening which is usually 5/8″ to 3/4″. For high speeds, that is over 5000 or 6000 RPM, it is recommended that the amplitude should be less, or about 1/2″ to 3/8″, and still less for still higher speeds. Do not exceed these amplitudes under ordinary conditions.

5. **If the vibration amplitude of the reeds is excessive,** it is recommended that the instrument be cushioned by a suitable material, either between the instrument and bracket or between bracket and machine.

6. **If the machine for which the Tachometer is intended has very little vibration,** it is recommended that the Tachometer be tried at various locations as it is usually possible to find a point on the machine where the vibration is more pronounced than at other points.

7. In such cases where this should not be possible, **vibration of the reeds can be increased** by using a Type T Mounting Bracket and attaching the Tachometer to a 3/4″ steel rod 1-2 feet long, which in turn is secured to the machine. By lowering or raising the Tachometer, the best spot on the rod for maximum reed vibration is easily determined.

8. **As a general rule,** vibration of the reeds in any Tachometer is usually best if the reed row is parallel to the axis of the machine. Internal amplitude stimulators can be supplied if any of the other methods do not give satisfactory results.

HARMONICS—*see reverse page . . .*

INSTRUCTIONS

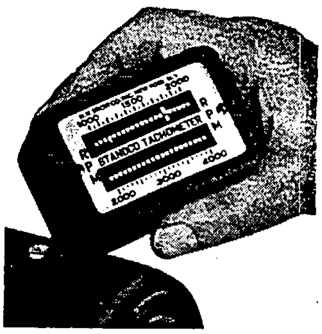
81

H.H. STICHT CO.
57 FRONT ST.
BROOKLYN NY 11201

770-I

"STANDCO" Vibrating Reed Tachometers

...... *Hand Type, for portable use*



"Standco" Vibrating Reed Tachometers operate on the well-known and time-tested principle of resonance. They measure speed of rotating machinery by picking up the rate of vibration on accurately calibrated reeds. These reeds are set in motion by the slight vibration of the rotating element. The RPM or vibrations per minute are indicated on the scale of these instruments by the visual pattern formed by one or more reeds while vibrating. See attached Bulletin No. 770C.

REVOLUTIONS PER MINUTE . . . .

"Standco" Vibrating Reed Hand Tachometers do not require brackets or any other accessories. These instruments are ideal for checking speeds of totally enclosed electrical equipment. Just hold the tachometer against the motor, turbine, pump, vacuum cleaner, compressor, outboard motor, sewing machine, or other similar equipment *anywhere* and read the speed. Speeds can be measured from 600 RPM to 100,000 RPM (in different models).

If vibration is excessive, cushion the Tachometer by a pad of rubber or cotton or with the hand. If vibration is insufficient, try different parts of the machine until a perfect pickup is made. Usually pickup is best if the row of reeds is parallel to the axis of the machine.

VIBRATIONS PER MINUTE . . . .

Since the reeds reflect vibrations as well as RPM, the instruments can be used as vibration indicators.

EXCESSIVE VIBRATION . . . .

With pneumatic equipment or other equipment where vibrations are severe, it is not recommended to hold the instrument directly against vibrating metal parts but to apply it to air hoses or other parts of the equipment. If this vibration is still too severe place hand on machine or hose and hold instrument against forearm and the vibration will be transmitted to the instrument reeds.

HARMONICS . . . .

Since all Vibrating Reed Tachometers operate on the principle of resonance, it is frequently the case that if a machine is running at let us say 1800 RPM another reed tuned at 3600 RPM may also respond, but at less amplitude. When a machine is running at 3600 RPM, however, a reed tuned at 1800 is not likely to respond.

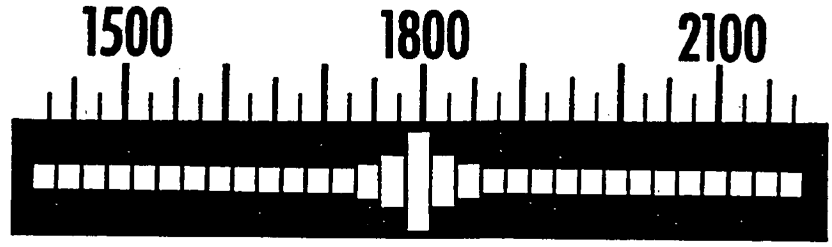
HOW TO READ VIBRATING REED TACHOMETERS

RPM or Vibrations per Minute are indicated on the scale of these instruments by the visual pattern formed by one or more reeds while vibrating. The following illustrations show how simple it is:

This is a typical scale of a "STANDCO" Vibrating Reed Tachometer (slightly reduced size) with a range from 1425-2175 RPM, designed for equipment with a normal speed of 1800 RPM. Interval between reeds is 25 RPM.

EVEN PATTERN:

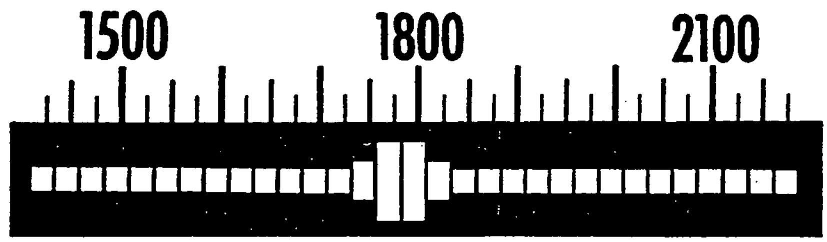
1800 RPM



One Reed has maximum amplitude, adjoining reeds on both sides have less but equal amplitude and form a similar pattern on both sides.
Speed is 1800 RPM.

TWO REEDS WITH SAME AMPLITUDE

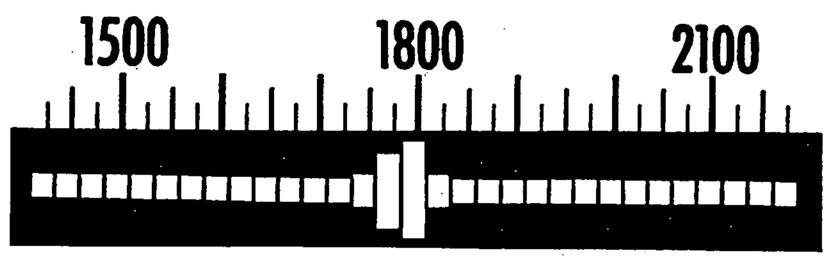
1788 RPM



Two adjoining reeds at 1800 RPM and 1775 RPM have same amplitude.
Speed is halfway between the two reeds=1788 RPM.

UNEVEN PATTERN BELOW 1800

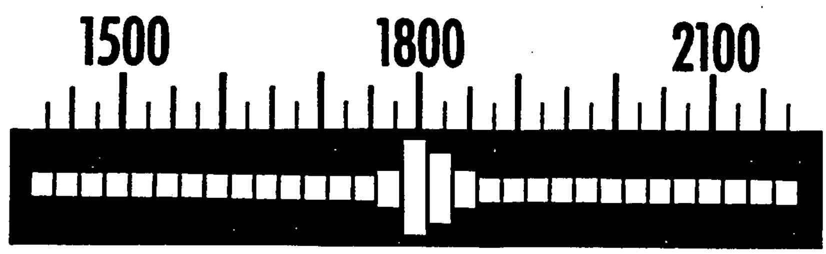
1794 RPM



One reed has maximum amplitude at 1800 RPM. Adjoining reed 1775 RPM vibrates almost as much. Other adjoining reeds below 1800 taper off proportionately.
Speed is one-quarter between 1800 and 1775=1794 RPM.

UNEVEN PATTERN ABOVE 1800

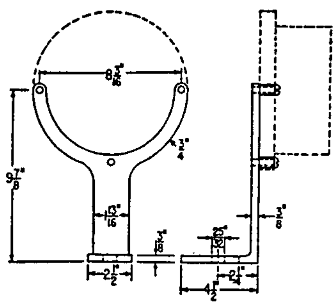
1806 RPM

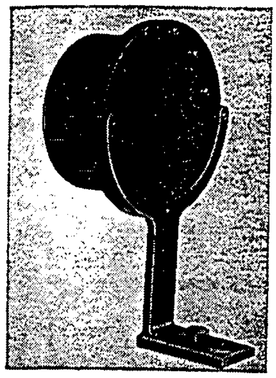


This is the same pattern as above but on the high side of 1800 RPM.
Indicated speed is one-quarter between 1800 and 1825=1806 RPM.

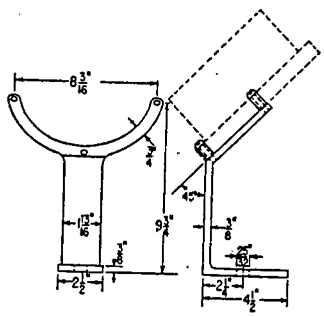
VARIOUS STYLES OF MOUNTING BRACKETS

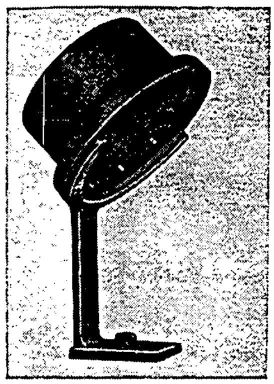
For Round Type Cases M-1 and M-2



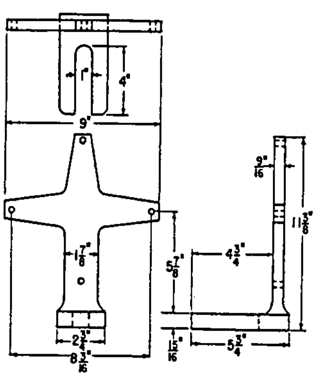


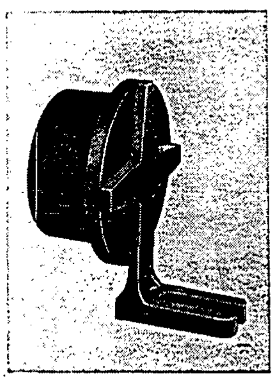
Type V Cat. No. 5400 — Vertical Mounting



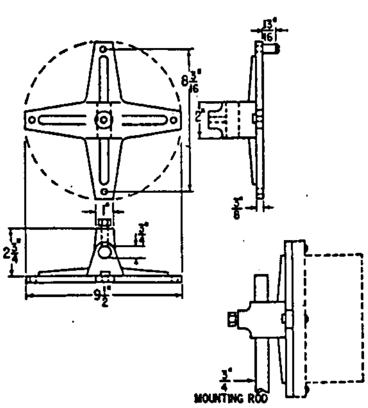


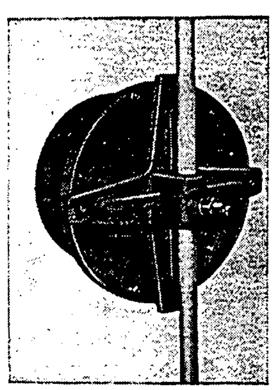
Type W Cat. No. 5401 — 45° Mounting





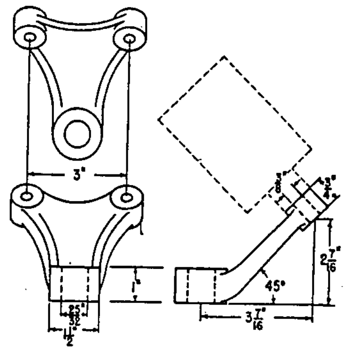
Type Z Cat. No. 5402 — Vertical, heavy duty



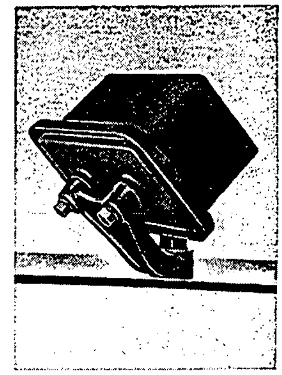


Type T Cat. No. 5403 — For mounting on 3/4" round rod (adjustable)

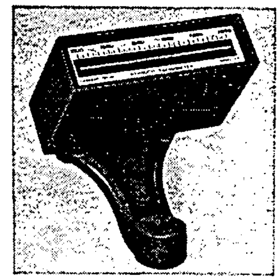
For Rectangular Cases



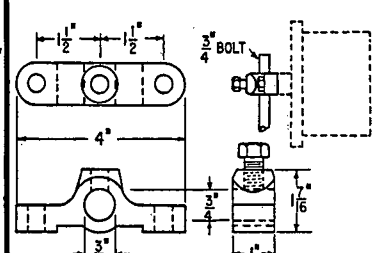
Type R Cat. No. 8400
45° Mounting



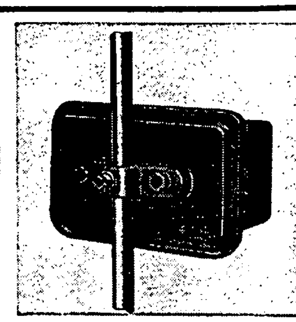
With Splashproof case instrument Types R-1 and R-2



With Rectangular Hand Type case with lugs Types H1-B and H2-B

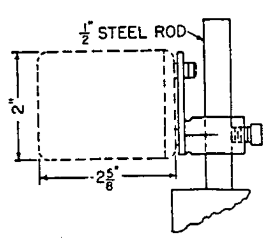


Type S Cat. No. 8401

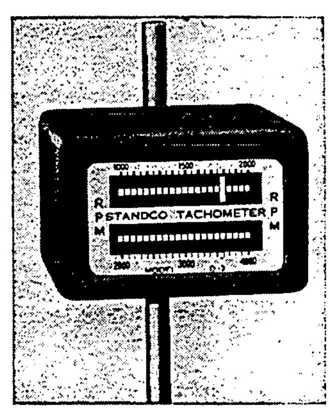


Adjustable Mounting on steel rod

For "DWARF" Type Instruments



Cat. No. 9401 90° Bracket



Adjustable Mounting on steel rod

APPENDIX E
RAW DATA

SUMMARY OF CORE DATA

Core #	Project	Station	Paver Speed	Actual Speed (in./min.)	Vibrator	Target Frequency (vpm)	Actual Frequency (vpm)	
							2	3
1	A1	2418+35	Normal	64	In	5000	5100	5100
2	A1	2418+32	Normal	64	Between	5000	5100	5100
3	A1	2418+14	Normal	64	Between	5000	5100	5100
4	A1	2418+10	Normal	64	In	5000	5100	5100
5	A1	2415+49	Normal	64	Between	5000	5100	5000
6	A1	2415+46	Normal	64	In	5000	5100	5000
7	A1	2415+28	Normal	64	In	5000	5100	5000
8	A1	2415+25	Normal	64	Between	5000	5100	5000
9	A1	2415+00	Normal	64	Between	5000	5100	5000
10	A1	2414+96	Normal	64	In	5000	5100	5000
11	A1	2391+87	Normal	60	In	6500	6500	6500
12	A1	2391+80	Normal	60	Between	6500	6500	6500
13	A1	2389+90	Normal	61	Between	6500	6400	6400
14	A1	2389+87	Normal	61	In	6500	6400	6400
15	A1	2389+70	Normal	61	Between	6500	6400	6400
16	A1	2389+66	Normal	61	In	6500	6400	6400
17	A1	2387+70	Normal	59	In	6500	6500	6500
18	A1	2387+65	Normal	59	Between	6500	6500	6500
19	A1	2364+80	Normal	69	In	8000	7500	7500
20	A1	2364+76	Normal	69	Between	8000	7500	7500
21	A1	2362+60	Normal	65	In	8000	7500	7500
22	A1	2362+50	Normal	65	Between	8000	7500	7500
23	A1	2360+94	Normal	63	Between	8000	7600	7600
24	A1	2360+90	Normal	63	In	8000	7600	7600
25	A1	2360+84	Normal	63	Between	8000	7600	7600
26	A1	2360+80	Normal	63	In	8000	7600	7600
27	A1	2359+59	Slow	48	Between	8000	7500	7500
28	A1	2359+55	Slow	48	In	8000	7500	7500
29	A1	2415+05	Normal	64	In	5000	5100	5000
30	A1	2394+00	Normal	60	In (Dead)	0	Dead	Dead
31	A1	2366+25	Normal	69	In (Dead)	0	Dead	Dead
32	A2	2140+62	Slow	35	In	5000	5000	5000
33	A2	2140+56	Slow	35	Between	5000	5000	5000
34	A2	2140+50	Slow	35	In	5000	5000	5000
35	A2	2140+38	Slow	35	Between	5000	5000	5000
36	A2	2140+35	Slow	35	In	5000	5000	5000
37	A2	2140+30	Slow	35	Between	5000	5000	5000
38	A2	2140+20	Normal	68	In	5000	5000	5000
39	A2	2140+14	Normal	68	Between	5000	5000	5000
40	A2	2140+00	Normal	68	In	5000	5000	5000
41	A2	2139+94	Normal	68	Between	5000	5000	5000
42	A2	2139+80	Normal	68	In	5000	5000	5000
43	A2	2139+72	Normal	68	Between	5000	5000	5000

SUMMARY OF CORE DATA

Core #	Project	Station	Paver Speed	Actual Speed (in./min.)	Vibrator	Target Frequency (vpm)	Actual Frequency (vpm) 2	Actual Frequency (vpm) 3
44	A2	2138+80	Slow	36	In	6500	6500	6500
45	A2	2138+74	Slow	36	Between	6500	6500	6500
46	A2	2138+68	Slow	36	In	6500	6500	6500
47	A2	2138+60	Slow	36	Between	6500	6500	6500
48	A2	2138+54	Slow	36	In	6500	6500	6500
49	A2	2138+48	Slow	36	Between	6500	6500	6500
50	A2	2138+40	Normal	53	In	6500	6500	6500
51	A2	2138+34	Normal	53	Between	6500	6500	6500
52	A2	2138+28	Normal	53	In	6500	6500	6500
53	A2	2138+20	Normal	53	Between	6500	6500	6500
54	A2	2138+14	Normal	53	In	6500	6500	6500
55	A2	2138+08	Normal	53	Between	6500	6500	6500
56	A2	2137+60	Slow	35	In	8000	7100	7700
57	A2	2137+54	Slow	35	Between	8000	7100	7700
58	A2	2137+48	Slow	35	In	8000	7100	7700
59	A2	2137+40	Slow	35	Between	8000	7100	7700
60	A2	2137+34	Slow	35	In	8000	7100	7700
61	A2	2137+28	Slow	35	Between	8000	7100	7700
62	A2	2137+05	Normal	72	In	8000	7100	7700
63	A2	2136+98	Normal	72	Between	8000	7100	7700
64	A2	2136+90	Normal	72	In	8000	7100	7700
65	A2	2136+85	Normal	72	Between	8000	7100	7700
66	A2	2136+78	Normal	72	In	8000	7100	7700
67	A2	2136+72	Normal	72	Between	8000	7100	7700
68	A3	2999+90	Normal	74	In	8000	7400	8100
69	A3	2999+84	Normal	74	Between	8000	7400	8100
70	A3	2999+70	Normal	74	In	8000	7400	8100
71	A3	2999+64	Normal	74	Between	8000	7400	8100
72	A3	2999+50	Normal	74	In	8000	7400	8100
73	A3	2999+44	Normal	74	Between	8000	7400	8100
74	A3	2999+12	Normal	73	In	6500	6500	6500
75	A3	2999+02	Normal	73	Between	6500	6500	6500
76	A3	2998+92	Normal	73	In	6500	6500	6500
77	A3	2998+82	Normal	73	Between	6500	6500	6500
78	A3	2998+72	Normal	73	In	6500	6500	6500
79	A3	2998+62	Normal	73	Between	6500	6500	6500
80	A3	2998+28	Slow	35	In	8000	7600	8100
81	A3	2998+22	Slow	35	Between	8000	7600	8100
82	A3	2998+14	Slow	35	In	8000	7600	8100
83	A3	2998+08	Slow	35	Between	8000	7600	8100
84	A3	2998+02	Slow	35	In	8000	7600	8100
85	A3	2997+95	Slow	35	Between	8000	7600	8100
86	A3	2997+28	Slow	37	In	6500	6500	6500

SUMMARY OF CORE DATA

Core #	Project	Station	Paver Speed	Actual Speed (in./min.)	Vibrator	Target Frequency (vpm)	Actual Frequency (vpm)	
							2	3
87	A3	2997+22	Slow	37	Between	6500	6500	6500
88	A3	2997+14	Slow	37	In	6500	6500	6500
89	A3	2997+08	Slow	37	Between	6500	6500	6500
90	A3	2997+02	Slow	37	In	6500	6500	6500
91	A3	2996+95	Slow	37	Between	6500	6500	6500
92	A3	2996+81	Normal	74.5	In	5000	5000	5000
93	A3	2996+73	Normal	74.5	Between	5000	5000	5000
94	A3	2996+68	Normal	74.5	In	5000	5000	5000
95	A3	2996+63	Normal	74.5	Between	5000	5000	5000
96	A3	2996+53	Normal	74.5	In	5000	5000	5000
97	A3	2996+43	Normal	74.5	Between	5000	5000	5000
98	A3	2996+10	Normal	73	In	8000	7500	7800
99	A3	2996+02	Normal	73	Between	8000	7500	7800
100	A3	2995+92	Normal	73	In	8000	7500	7800
101	A3	2995+87	Normal	73	Between	8000	7500	7800
102	A3	2995+82	Normal	73	In	8000	7500	7800
103	A3	2995+75	Normal	73	Between	8000	7500	7800
104	A3	2995+42	Slow	43.5	In	5000	5000	5000
105	A3	2995+36	Slow	43.5	Between	5000	5000	5000
106	A3	2995+30	Slow	43.5	In	5000	5000	5000
107	A3	2995+22	Slow	43.5	Between	5000	5000	5000
108	A3	2995+16	Slow	43.5	In	5000	5000	5000
109	A3	2995+12	Slow	43.5	Between	5000	5000	5000
110	B	381+46	Normal	59	In	5000	5100	5100
111	B	381+35	Normal	59	Between	5000	5100	5100
112	B	381+28	Normal	59	In	5000	5100	5100
113	B	381+20	Normal	59	Between	5000	5100	5100
114	B	381+12	Normal	59	In	5000	5100	5100
115	B	381+06	Normal	59	Between	5000	5100	5100
116	B	380+54	Slow	40	In	5000	5000	5000
117	B	380+48	Slow	40	Between	5000	5000	5000
118	B	380+42	Slow	40	In	5000	5000	5000
119	B	380+32	Slow	40	Between	5000	5000	5000
120	B	380+26	Slow	40	In	5000	5000	5000
121	B	380+21	Slow	40	Between	5000	5000	5000
122	B	378+88	Slow	39	Between	6500	6500	6500
123	B	378+80	Slow	39	In	6500	6500	6500
124	B	378+72	Slow	39	Between	6500	6500	6500
125	B	378+63	Slow	39	Between	6500	6500	6500
126	B	378+59	Slow	39	In	6500	6500	6500
127	B	378+50	Slow	39	In	6500	6500	6500
128	B	377+82	Slow	41	In	8000	8000	8100
129	B	377+76	Slow	41	Between	8000	8000	8100

SUMMARY OF CORE DATA

Core #	Project	Station	Paver Speed	Actual Speed (in./min.)	Vibrator	Target Frequency (vpm)	Actual Frequency (vpm)	
							2	3
130	B	377+69	Slow	41	In	8000	8000	8100
131	B	377+63	Slow	41	Between	8000	8000	8100
132	B	377+57	Slow	41	In	8000	8000	8100
133	B	377+47	Slow	41	Between	8000	8000	8100
134	B	372+60	Normal	68	Between	6500	6500	6500
135	B	372+54	Normal	68	In	6500	6500	6500
136	B	372+45	Normal	68	Between	6500	6500	6500
137	B	372+36	Normal	68	In	6500	6500	6500
138	B	372+04	Normal	68	Between	6500	6500	6500
139	B	371+93	Normal	68	In	6500	6500	6500
140	B	370+45	Normal	74	Between	8000	8000	8000
141	B	370+30	Normal	74	In	8000	8000	8000
142	B	370+24	Normal	74	Between	8000	8000	8000
143	B	370+09	Normal	74	In	8000	8000	8000
144	B	370+00	Normal	74	Between	8000	8000	8000
145	B	369+88	Normal	74	In	8000	8000	8000
146	B	370+00	Normal	74	Middle	8000	8000	8000
147	C	240+38	Normal	70	In	8000	8000	8000
148	C	240+34	Normal	70	Between	8000	8000	8000
149	C	240+27	Normal	70	In	8000	8000	8000
150	C	240+21	Normal	70	Between	8000	8000	8000
151	C	240+15	Normal	70	In	8000	8000	8000
152	C	240+08	Normal	70	Between	8000	8000	8000
153	C	239+39	Slow	35	In	8000	8000	8000
154	C	239+35	Slow	35	Between	8000	8000	8000
155	C	239+28	Slow	35	In	8000	8000	8000
156	C	239+22	Slow	35	Between	8000	8000	8000
157	C	239+16	Slow	35	In	8000	8000	8000
158	C	239+06	Slow	35	Between	8000	8000	8000
159	C	238+88	Normal	72	In	5000	5000	5000
160	C	238+85	Normal	72	Between	5000	5000	5000
161	C	238+80	Normal	72	In	5000	5000	5000
162	C	238+75	Normal	72	Between	5000	5000	5000
163	C	238+67	Normal	72	In	5000	5000	5000
164	C	238+61	Normal	72	Between	5000	5000	5000
165	C-2	205+78	Slow	41	In	8000	8000	8000
166	C-2	205+75	Slow	41	Between	8000	8000	8000
167	C-2	205+71	Slow	41	In	8000	8000	8000
168	C-2	205+66	Slow	41	Between	8000	8000	8000
169	C-2	205+60	Slow	41	In	8000	8000	8000
170	C-2	205+56	Slow	41	Between	8000	8000	8000
171	C-2	203+96	*	*	In	#	12000	8000
172	C-2	203+88	*	*	In	#	12000	8000

SUMMARY OF CORE DATA

Core #	Project	Station	Paver Speed	Actual Speed (in./min.)	Vibrator	Target Frequency (vpm)	Actual Frequency (vpm) 2	3
173	C-2	203+79	*	*	In	#	12000	8000
174	C-2	239+39	Slow	35	In #8	#	12000	8000
175	C-2	239+36.5	Slow	35	Between	#	12000	8000
176	C-2	239+28	Slow	35	In #8	#	12000	8000
177	C-2	239+23	Slow	35	Between	#	12000	8000
178	C-2	239+16	Slow	35	Left of #8	#	12000	8000
179	C-2	239+11	Slow	35	Right of #8	#	12000	8000
180	C-2	205+78	Slow	41	In #8	#	12000	8000
181	C-2	205+73	Slow	41	Between	#	12000	8000
182	C-2	205+66	Slow	41	In #8	#	12000	8000
183	C-2	205+63.5	Slow	41	Between	#	12000	8000
184	C-2	205+58.5	Slow	41	Left of #8	#	12000	8000
185	C-2	205+56	Slow	41	Right of #8	#	12000	8000
186	C-2	203+96	*	*	In #8	#	12000	8000
187	C-2	203+93.5	*	*	Between	#	12000	8000
188	C-2	203+88	*	*	In #8	#	12000	8000
189	C-2	203+86.5	*	*	Between	#	12000	8000
190	C-2	203+81.5	*	*	Left of #8	#	12000	8000
191	C-2	203+79	*	*	Right of #8	#	12000	8000

NT = Not Tested
* = Not Measured
# = No Target Established

Summary of High Pressure Air Testing

	Entrained Air (%)			Estimated Total Voids (%)			Core Density-1 (gm/cm^3)			Core Density-2 (gm/cm^3)			Permeable Voids (%)		
Core #	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom
1	10.87	9.89	9.31	17.64	16.55	15.61	2.41	2.45	2.43	2.07	2.10	2.11	6.77	6.66	6.30
2	9.74	10.84	10.29	16.35	17.25	16.40	2.44	2.41	2.44	2.10	2.09	2.13	6.61	6.41	6.11
3	9.31	10.94	10.94	15.79	17.35	17.44	2.47	2.41	2.40	2.13	2.09	2.08	6.48	6.41	6.50
4	8.78	11.11	11.47	15.42	17.50	17.82	2.46	2.39	2.39	2.12	2.08	2.08	6.64	6.39	6.35
5	9.56	10.71	11.10	15.78	17.19	17.32	2.46	2.42	2.40	2.13	2.09	2.09	6.22	6.48	6.22
6	7.92	9.93	10.17	14.27	16.39	16.51	2.49	2.43	2.43	2.15	2.10	2.11	6.35	6.46	6.34
7	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
8	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
9	8.03	10.11	10.42	14.41	16.74	16.64	2.49	2.45	2.43	2.15	2.11	2.11	6.38	6.63	6.22
10	9.91	8.49	9.62	20.40	14.76	15.65	2.70	2.47	2.45	2.10	2.14	2.14	10.49	6.27	6.03
11	6.82	9.54	10.84	13.53	15.73	16.92	2.52	2.47	2.41	2.15	2.14	2.10	6.71	6.19	6.08
12	7.56	10.33	10.49	13.96	16.73	16.50	2.50	2.42	2.42	2.16	2.10	2.12	6.40	6.40	6.01
13	6.80	9.66	10.23	13.29	16.03	16.09	2.52	2.44	2.44	2.16	2.11	2.13	6.49	6.37	5.86
14	6.11	9.05	10.01	12.74	14.47	16.91	2.53	2.43	2.46	2.17	2.15	2.10	6.63	5.42	6.90
15	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
16	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
17	6.71	10.51	10.23	13.65	16.74	16.36	2.52	2.42	2.44	2.15	2.11	2.12	6.94	6.23	6.13
18	7.80	10.35	9.89	14.24	16.94	16.00	2.50	2.43	2.45	2.15	2.09	2.13	6.44	6.59	6.11
19	11.27	9.97	9.94	17.91	16.72	16.36	2.39	2.43	2.43	2.07	2.09	2.10	6.64	6.75	6.42
20	7.10	10.53	10.66	14.42	17.34	16.44	2.51	2.42	2.42	2.12	2.08	2.12	7.32	6.81	5.78
21	7.10	7.61	9.52	14.34	14.66	15.85	2.50	2.50	2.46	2.12	2.13	2.13	7.24	7.05	6.33
22	7.43	7.75	9.77	14.78	14.36	16.65	2.52	2.51	2.45	2.12	2.15	2.10	7.35	6.61	6.88
23	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
24	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
25	9.22	8.31	9.95	16.74	15.02	16.30	2.46	2.49	2.45	2.08	2.14	2.12	7.52	6.71	6.35
26	6.93	9.95	10.21	14.33	17.09	16.60	2.52	2.44	2.43	2.12	2.08	2.11	7.40	7.14	6.39
27	7.09	7.00	12.55	13.21	13.07	18.76	2.52	2.52	2.45	2.18	2.19	2.13	6.12	6.07	6.21
28	8.11	8.46	9.19	14.30	14.32	15.05	2.49	2.48	2.48	2.16	2.17	2.16	6.19	5.86	5.86
29	7.37	7.16	9.35	14.12	13.66	15.55	2.50	2.51	2.46	2.14	2.16	2.13	6.75	6.50	6.20
30	8.19	8.95	7.02	15.02	15.86	13.58	2.49	2.44	2.44	2.13	2.09	2.10	6.83	6.91	6.56
31	11.03	12.38	11.65	17.80	19.13	18.18	2.40	2.38	2.38	2.07	2.05	2.06	6.77	6.75	6.53
32	5.78	8.64	9.08	12.77	15.54	15.73	2.53	2.45	2.45	2.15	2.09	2.10	6.99	6.90	6.65
33	5.37	8.35	8.12	12.26	15.42	14.68	2.54	2.47	2.47	2.16	2.10	2.13	6.89	7.07	6.56
34	5.91	8.89	8.73	12.55	15.75	15.26	2.54	2.45	2.46	2.17	2.10	2.12	6.64	6.86	6.53
35	5.90	8.32	9.09	12.60	15.12	15.73	2.54	2.47	2.45	2.17	2.12	2.10	6.70	6.80	6.64
36	6.11	9.14	9.15	12.77	16.01	15.67	2.52	2.44	2.45	2.16	2.09	2.11	6.66	6.87	6.52
37	6.01	8.92	10.15	12.68	15.86	16.68	2.52	2.46	2.42	2.16	2.10	2.09	6.67	6.94	6.53
38	8.46	8.97	8.26	15.27	15.86	15.21	2.46	2.44	2.45	2.11	2.09	2.09	6.81	6.89	6.95
39	8.33	9.94	8.95	15.22	17.02	15.65	2.48	2.42	2.44	2.12	2.06	2.10	6.89	7.08	6.70
40	7.43	9.69	10.26	14.29	16.51	16.89	2.49	2.42	2.41	2.12	2.08	2.08	6.86	6.82	6.63
41	7.67	10.56	10.00	14.33	17.37	16.94	2.49	2.40	2.42	2.13	2.06	2.07	6.66	6.81	6.94
42	9.21	10.76	10.74	16.08	17.95	17.28	2.44	2.39	2.39	2.09	2.04	2.07	6.87	7.19	6.54
43	7.38	10.48	9.53	13.97	17.39	16.26	2.50	2.40	2.43	2.14	2.06	2.09	6.59	6.91	6.73
44	7.24	10.16	10.23	13.97	17.02	16.71	2.49	2.41	2.42	2.13	2.07	2.09	6.73	6.86	6.48
45	6.44	8.79	9.49	13.04	15.39	15.70	2.51	2.45	2.45	2.16	2.11	2.12	6.60	6.60	6.21
46	7.22	9.91	10.00	13.74	16.52	16.41	2.49	2.43	2.43	2.15	2.09	2.10	6.52	6.61	6.41
47	6.42	8.47	10.96	12.85	14.98	16.68	2.53	2.47	2.43	2.18	2.13	2.13	6.43	6.51	5.72
48	6.45	9.12	9.99	12.79	15.52	16.27	2.53	2.45	2.42	2.18	2.12	2.10	6.34	6.40	6.28
49	6.88	8.43	10.58	10.92	15.10	16.84	2.53	2.46	2.40	2.30	2.12	2.09	4.04	6.67	6.26

Summary of High Pressure Air Testing

	Entrained Air (%)			Estimated Total Voids (%)			Core Density-1 (gm/cm^3)			Core Density-2 (gm/cm^3)			Permeable Voids (%)		
Core #	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom
50	7.52	9.67	9.94	13.96	16.34	16.30	2.51	2.44	2.43	2.16	2.10	2.11	6.44	6.67	6.36
51	7.02	9.46	9.73	13.86	16.11	16.23	2.52	2.45	2.44	2.15	2.10	2.11	6.84	6.65	6.50
52	7.28	10.44	10.52	13.57	17.44	17.03	2.51	2.42	2.41	2.17	2.07	2.08	6.29	7.00	6.51
53	6.57	9.61	9.98	13.17	16.23	16.51	2.53	2.45	2.43	2.17	2.11	2.10	6.60	6.62	6.53
54	7.64	9.56	9.88	14.24	16.37	16.34	2.51	2.45	2.44	2.15	2.10	2.11	6.60	6.81	6.46
55	7.12	8.91	10.04	13.70	15.43	16.39	2.52	2.47	2.43	2.16	2.13	2.11	6.58	6.52	6.35
56	6.01	7.35	9.91	12.31	13.91	16.22	2.55	2.50	2.44	2.19	2.15	2.11	6.30	6.56	6.31
57	5.43	6.19	9.71	11.81	11.88	15.99	2.57	2.51	2.45	2.20	2.20	2.12	6.38	5.69	6.28
58	5.94	6.28	12.16	12.47	12.82	18.35	2.55	2.54	2.44	2.18	2.18	2.12	6.53	6.54	6.19
59	6.36	7.47	11.08	13.00	14.07	17.83	2.55	2.54	2.44	2.18	2.18	2.09	6.64	6.60	6.75
60	7.66	8.10	10.46	14.44	14.97	17.27	2.55	2.50	2.43	2.17	2.13	2.08	6.78	6.87	6.81
61	6.07	6.92	9.80	13.01	13.86	16.49	2.55	2.53	2.45	2.17	2.15	2.11	6.94	6.94	6.69
62	7.41	10.55	10.59	14.09	17.76	17.42	2.52	2.44	2.43	2.16	2.07	2.08	6.68	7.21	6.83
63	6.91	8.86	9.93	13.96	15.76	16.80	2.54	2.49	2.46	2.15	2.12	2.10	7.05	6.90	6.87
64	7.61	11.33	9.94	14.63	18.70	16.77	2.51	2.40	2.45	2.13	2.04	2.10	7.02	7.37	6.83
65	6.53	9.43	11.01	13.65	16.44	18.15	2.55	2.47	2.41	2.16	2.10	2.06	7.12	7.01	7.14
66	7.48	10.21	11.19	14.44	17.17	18.11	2.52	2.45	2.42	2.15	2.09	2.07	6.96	6.96	6.92
67	8.11	10.67	10.98	15.08	17.65	17.98	2.54	2.46	2.45	2.16	2.10	2.09	6.97	6.98	7.00
68	6.91	7.90	8.39	13.50	14.51	14.81	2.52	2.48	2.48	2.16	2.13	2.14	6.59	6.61	6.42
69	6.79	8.96	8.53	13.62	15.82	15.05	2.53	2.47	2.49	2.16	2.11	2.14	6.83	6.86	6.52
70	6.94	8.66	9.58	13.77	15.39	16.19	2.51	2.47	2.44	2.14	2.12	2.10	6.83	6.73	6.61
71	5.85	11.00	10.56	11.09	17.81	16.97	2.58	2.42	2.45	2.28	2.07	2.12	5.24	6.81	6.41
72	6.74	9.32	9.50	13.46	15.86	15.94	2.52	2.45	2.45	2.16	2.11	2.12	6.72	6.54	6.44
73	7.64	9.78	9.40	14.65	16.40	16.29	2.49	2.45	2.46	2.12	2.11	2.10	7.01	6.62	6.89
74	6.12	7.61	7.98	13.06	14.43	14.38	2.55	2.51	2.50	2.17	2.14	2.16	6.94	6.82	6.40
75	6.59	8.77	9.41	13.54	15.72	16.15	2.53	2.49	2.48	2.15	2.13	2.12	6.95	6.95	6.74
76	6.74	8.02	8.97	13.56	14.68	15.47	2.54	2.52	2.49	2.17	2.16	2.14	6.82	6.66	6.50
77	6.81	8.83	8.96	13.86	16.11	15.85	2.53	2.48	2.47	2.14	2.10	2.11	7.05	7.28	6.89
78	6.42	6.65	8.27	13.16	13.41	15.03	2.55	2.54	2.49	2.18	2.17	2.13	6.74	6.76	6.76
79	7.35	7.88	9.03	14.51	14.92	15.69	2.50	2.48	2.46	2.12	2.11	2.11	7.16	7.04	6.66
80	5.87	6.86	8.93	13.39	13.78	15.43	2.59	2.53	2.49	2.17	2.15	2.14	7.52	6.92	6.50
81	5.50	7.17	8.49	12.58	14.12	14.94	2.56	2.52	2.49	2.17	2.14	2.15	7.08	6.95	6.45
82	6.01	5.01	9.10	13.00	11.89	19.27	2.54	2.57	2.57	2.15	2.18	2.03	6.99	6.88	10.17
83	8.09	8.37	9.34	15.42	15.21	16.10	2.51	2.51	2.48	2.12	2.14	2.12	7.33	6.84	6.76
84	7.00	5.73	8.65	14.18	12.55	15.56	2.51	2.56	2.48	2.13	2.18	2.12	7.18	6.82	6.91
85	7.95	7.67	10.17	14.75	14.35	16.86	2.51	2.52	2.45	2.14	2.15	2.11	6.80	6.68	6.69
86	8.50	7.43	9.43	15.92	14.53	16.09	2.48	2.52	2.48	2.10	2.14	2.13	7.42	7.10	6.66
87	7.08	8.59	10.30	14.62	15.73	17.35	2.52	2.48	2.43	2.12	2.11	2.07	7.54	7.14	7.05
88	7.27	13.15	9.39	14.66	19.92	16.18	2.50	2.50	2.45	2.11	2.14	2.10	7.39	6.77	6.79
89	7.76	8.38	10.26	15.22	15.03	16.96	2.49	2.49	2.44	2.10	2.13	2.09	7.46	6.65	6.70
90	7.50	6.30	10.39	15.21	14.04	16.91	2.50	2.53	2.42	2.10	2.11	2.09	7.71	7.74	6.52
91	6.92	7.32	7.68	14.41	14.33	14.31	2.51	2.50	2.49	2.11	2.13	2.14	7.49	7.01	6.63
92	7.94	8.70	9.75	14.76	16.22	16.53	2.49	2.49	2.44	2.13	2.10	2.10	6.82	7.52	6.78
93	9.40	10.48	11.97	16.58	17.41	18.97	2.46	2.44	2.40	2.09	2.09	2.05	7.18	6.93	7.00
94	9.00	9.84	10.85	16.22	16.77	17.79	2.46	2.44	2.41	2.09	2.09	2.06	7.22	6.93	6.94
95	7.91	10.81	10.77	14.84	17.57	17.75	2.50	2.41	2.41	2.13	2.08	2.06	6.93	6.76	6.98
96	9.19	8.50	9.67	16.41	15.18	16.49	2.46	2.49	2.44	2.09	2.13	2.09	7.22	6.68	6.82
97	8.05	9.54	10.93	15.22	16.49	17.83	2.50	2.44	2.41	2.12	2.09	2.07	7.17	6.95	6.90
98	7.07	7.54	9.76	13.85	14.48	16.24	2.54	2.51	2.47	2.17	2.14	2.13	6.78	6.94	6.48

Summary of High Pressure Air Testing

	Entrained Air (%)			Estimated Total Voids (%)			Core Density-1 (gm/cm^3)			Core Density-2 (gm/cm^3)			Permeable Voids (%)		
Core #	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom
99	7.61	10.47	11.03	14.56	17.23	17.35	2.52	2.44	2.43	2.14	2.09	2.11	6.95	6.76	6.32
100	6.47	8.10	9.28	13.20	14.52	15.50	2.53	2.49	2.46	2.16	2.15	2.13	6.73	6.42	6.22
101	7.59	9.51	9.97	14.51	16.42	16.78	2.53	2.47	2.51	2.15	2.11	2.14	6.92	6.91	6.81
102	6.93	8.60	9.44	13.82	14.98	16.08	2.52	2.50	2.47	2.14	2.16	2.12	6.89	6.38	6.64
103	7.73	8.98	9.69	14.28	15.64	16.21	2.51	2.47	2.45	2.16	2.12	2.11	6.55	6.66	6.52
104	7.52	9.17	9.91	14.23	15.83	16.54	2.50	2.47	2.45	2.14	2.12	2.11	6.71	6.66	6.63
105	8.13	9.29	10.85	15.21	16.03	17.24	2.50	2.46	2.44	2.13	2.11	2.11	7.08	6.74	6.39
106	7.20	9.51	9.38	13.58	16.47	16.16	2.49	2.46	2.41	2.15	2.10	2.07	6.38	6.96	6.78
107	8.63	10.11	10.58	15.70	17.18	17.42	2.50	2.45	2.44	2.13	2.09	2.09	7.07	7.07	6.84
108	7.51	10.88	9.96	14.51	14.99	19.29	2.51	2.34	2.52	2.14	2.14	2.04	7.00	4.11	9.33
109	8.65	10.40	10.76	15.70	17.34	17.40	2.48	2.44	2.43	2.11	2.09	2.09	7.05	6.94	6.64
110	4.40	5.87	5.93	10.89	12.76	12.67	2.52	2.47	2.46	2.17	2.11	2.11	6.49	6.89	6.74
111	9.09	9.46	10.28	15.82	16.20	16.65	2.44	2.43	2.41	2.09	2.09	2.09	6.73	6.74	6.37
112	6.45	7.63	7.36	13.03	14.15	13.94	2.52	2.48	2.51	2.16	2.14	2.15	6.58	6.52	6.58
113	6.61	7.45	6.62	13.67	14.38	12.70	2.50	2.48	2.51	2.12	2.11	2.17	7.06	6.93	6.08
114	6.39	6.62	6.16	13.29	13.36	12.63	2.54	2.53	2.54	2.16	2.16	2.18	6.90	6.74	6.47
115	6.20	7.44	7.07	13.23	14.13	13.82	2.53	2.50	2.52	2.15	2.14	2.15	7.03	6.69	6.75
116	7.95	8.33	9.30	14.58	15.18	16.14	2.52	2.47	2.48	2.16	2.11	2.12	6.63	6.85	6.84
117	6.68	7.06	6.99	13.80	13.52	13.70	2.49	2.48	2.47	2.11	2.14	2.12	7.12	6.46	6.71
118	5.52	8.21	7.04	12.11	15.10	20.07	2.54	2.47	2.45	2.17	2.11	1.86	6.59	6.89	13.03
119	7.46	9.03	10.05	14.54	15.63	16.45	2.50	2.46	2.46	2.13	2.11	2.13	7.08	6.60	6.40
120	5.79	6.05	7.41	12.78	12.85	13.70	2.50	2.48	2.44	2.13	2.12	2.12	6.99	6.80	6.29
121	7.11	8.73	8.87	14.21	15.47	15.36	2.51	2.46	2.46	2.13	2.11	2.12	7.10	6.74	6.49
122	6.85	8.95	8.34	13.69	16.13	14.77	2.50	2.45	2.47	2.14	2.09	2.13	6.84	7.18	6.43
123	5.34	8.43	8.27	12.09	15.18	14.53	2.55	2.47	2.49	2.18	2.12	2.15	6.75	6.75	6.26
124	11.23	7.35	8.08	18.05	14.18	14.48	2.52	2.49	2.48	2.15	2.13	2.14	6.82	6.83	6.40
125	6.63	7.81	7.21	13.72	14.69	13.61	2.52	2.48	2.50	2.14	2.12	2.15	7.09	6.88	6.40
126	5.51	7.09	6.47	12.34	14.05	12.84	2.54	2.48	2.52	2.16	2.11	2.17	6.83	6.96	6.37
127	5.32	6.69	6.14	12.31	13.69	12.53	2.55	2.51	2.53	2.16	2.13	2.18	6.99	7.00	6.39
128	4.72	5.97	7.89	10.98	12.68	14.30	2.57	2.51	2.46	2.21	2.15	2.13	6.26	6.71	6.41
129	5.80	7.98	7.67	12.54	14.84	14.25	2.53	2.48	2.48	2.16	2.12	2.13	6.74	6.86	6.58
130	5.43	6.44	6.37	11.99	12.81	12.49	2.55	2.54	2.52	2.18	2.18	2.18	6.56	6.37	6.12
131	5.53	5.71	5.66	11.99	12.19	11.98	2.55	2.53	2.54	2.19	2.18	2.19	6.46	6.48	6.32
132	5.47	6.91	6.48	12.06	13.24	12.80	2.55	2.51	2.51	2.18	2.17	2.16	6.59	6.33	6.32
133	6.76	6.28	6.52	13.61	12.96	12.76	2.50	2.50	2.50	2.14	2.14	2.16	6.85	6.68	6.24
134	7.09	7.78	11.17	13.39	14.51	18.07	2.50	2.46	2.43	2.16	2.11	2.08	6.30	6.73	6.90
135	7.59	6.91	6.00	14.50	13.77	12.88	2.47	2.47	2.45	2.11	2.11	2.10	6.91	6.86	6.88
136	6.79	5.96	7.91	13.69	12.56	14.14	2.50	2.53	2.47	2.13	2.16	2.14	6.90	6.60	6.23
137	7.79	7.40	7.53	14.91	14.15	14.07	2.47	2.48	2.49	2.10	2.13	2.14	7.12	6.75	6.54
138	6.03	7.66	8.80	12.88	14.56	15.55	2.53	2.47	2.47	2.16	2.11	2.11	6.85	6.90	6.75
139	7.24	5.04	6.06	13.66	11.73	12.52	2.52	2.52	2.48	2.17	2.16	2.14	6.42	6.69	6.46
140	6.78	7.26	7.74	13.47	14.18	14.51	2.51	2.49	2.48	2.15	2.12	2.12	6.69	6.92	6.77
141	5.67	6.76	7.22	12.19	13.52	13.85	2.55	2.52	2.50	2.19	2.15	2.15	6.52	6.76	6.63
142	6.30	6.64	6.51	12.67	13.11	12.59	2.51	2.50	2.51	2.17	2.15	2.18	6.37	6.47	6.08
143	5.43	9.24	7.62	12.09	16.00	14.17	2.55	2.50	2.47	2.18	2.14	2.13	6.66	6.76	6.55
144	6.25	7.24	6.69	12.91	13.79	12.98	2.52	2.49	2.51	2.16	2.14	2.17	6.66	6.55	6.29
145	5.38	6.12	6.90	11.62	12.51	13.03	2.56	2.51	2.51	2.21	2.17	2.18	6.24	6.39	6.13
146	8.09	7.57	6.72	14.74	14.18	13.05	2.57	2.50	2.48	2.20	2.15	2.15	6.65	6.61	6.33
147	5.68	7.72	7.31	10.91	13.01	12.19	2.54	2.93	2.49	2.24	2.54	2.22	5.23	5.29	4.88

Summary of High Pressure Air Testing

	Entrained Air (%)			Estimated Total Voids (%)			Core Density-1 (gm/cm^3)			Core Density-2 (gm/cm^3)			Permeable Voids (%)		
Core #	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom
148	7.99	8.12	8.55	13.77	13.56	13.93	2.45	2.45	2.45	2.15	2.16	2.16	5.78	5.44	5.38
149	5.62	7.20	7.83	11.32	12.84	13.19	2.55	2.43	2.46	2.22	2.14	2.18	5.70	5.64	5.36
150	8.75	8.39	7.84	15.09	14.29	13.18	2.47	2.46	2.48	2.14	2.14	2.19	6.34	5.90	5.34
151	5.23	7.68	7.84	10.90	13.12	12.84	2.54	2.47	2.47	2.22	2.18	2.20	5.67	5.44	5.00
152	8.07	7.94	7.20	13.77	13.43	12.24	2.46	2.46	2.48	2.16	2.16	2.20	5.70	5.49	5.04
153	4.90	6.96	7.32	10.74	12.43	12.57	2.18	2.50	2.48	1.94	2.20	2.19	5.84	5.47	5.25
154	6.71	7.19	7.68	12.84	12.63	12.96	2.50	2.48	2.48	2.17	2.19	2.19	6.13	5.44	5.28
155	5.41	7.44	7.96	11.25	13.14	12.81	2.55	2.49	2.48	2.22	2.18	2.21	5.84	5.70	4.85
156	6.92	7.89	8.74	12.85	13.53	14.24	2.50	2.47	2.45	2.18	2.17	2.16	5.93	5.64	5.50
157	5.21	7.23	7.99	10.98	12.96	13.04	2.56	2.49	2.50	2.23	2.18	2.22	5.77	5.73	5.05
158	6.94	7.40	7.88	13.10	12.99	13.14	2.49	2.47	2.47	2.16	2.17	2.19	6.16	5.59	5.26
159	7.42	8.48	6.99	13.12	13.92	12.23	2.48	2.45	2.49	2.17	2.16	2.21	5.70	5.44	5.24
160	7.55	8.13	7.86	13.51	14.14	12.85	2.47	2.45	2.47	2.16	2.14	2.20	5.96	6.01	4.99
161	7.57	8.15	7.44	13.55	13.74	12.64	2.47	2.46	2.48	2.16	2.16	2.20	5.98	5.59	5.20
162	8.13	8.98	8.41	14.04	14.58	13.42	2.45	2.43	2.45	2.14	2.14	2.18	5.91	5.60	5.01
163	6.96	7.12	6.96	12.78	12.77	12.29	2.50	2.48	2.49	2.18	2.17	2.20	5.82	5.65	5.33
164	7.47	7.67	7.28	13.27	13.44	12.47	2.50	2.48	2.49	2.19	2.17	2.20	5.80	5.77	5.19
165	5.98	8.12	7.39	11.24	13.68	12.73	2.54	2.47	2.50	2.24	2.18	2.20	5.26	5.56	5.34
166	8.34	7.46	6.89	13.82	12.90	12.08	2.46	2.48	2.51	2.17	2.18	2.22	5.48	5.44	5.19
167	5.23	7.05	6.75	10.33	12.35	11.83	2.56	2.49	2.51	2.26	2.20	2.22	5.10	5.30	5.08
168	8.87	9.95	8.64	14.49	15.63	14.11	2.46	2.43	2.47	2.16	2.14	2.17	5.62	5.68	5.47
169	5.44	7.21	6.90	10.51	12.60	14.32	2.54	2.44	2.49	2.25	2.15	2.10	5.07	5.39	7.42
170	7.94	9.02	8.27	13.52	14.83	13.65	2.46	2.44	2.45	2.16	2.14	2.17	5.58	5.81	5.38
171	6.18	7.72	7.40	11.24	13.21	12.59	2.52	2.48	2.50	2.23	2.18	2.21	5.06	5.49	5.19
172	6.63	7.77	6.84	12.20	13.54	12.14	2.52	2.48	2.51	2.21	2.17	2.22	5.57	5.77	5.30
173	6.90	7.58	9.75	12.25	12.77	14.92	2.50	2.48	2.43	2.20	2.20	2.16	5.35	5.19	5.17
174	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
175	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
176	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
177	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
178	3.49	1.00	4.14	8.89	6.45	8.83	2.61	2.65	2.58	2.29	2.32	2.30	5.40	5.45	4.69
179	4.72	2.35	5.15	10.26	6.73	10.06	2.57	2.63	2.56	2.25	2.36	2.27	5.54	4.38	4.91
180	4.04	1.32	5.28	9.06	6.24	10.25	2.59	2.66	2.55	2.29	2.35	2.26	5.02	4.92	4.97
181	6.93	8.36	6.58	12.44	13.92	11.62	2.49	2.46	2.50	2.19	2.16	2.22	5.51	5.56	5.04
182	4.63	2.33	6.94	9.73	7.27	12.29	2.58	2.65	2.50	2.28	2.34	2.20	5.10	4.94	5.35
183	7.68	9.61	9.48	13.08	14.96	14.52	2.48	2.43	2.44	2.18	2.15	2.18	5.40	5.35	5.04
184	3.61	0.96	5.70	8.73	6.06	10.51	2.59	2.66	2.54	2.29	2.34	2.26	5.12	5.10	4.81
185	3.70	1.70	3.75	8.83	6.65	9.04	2.59	2.63	2.57	2.29	2.33	2.26	5.13	4.95	5.29
186	3.60	2.20	7.36	8.74	7.64	12.80	2.60	2.63	2.50	2.29	2.30	2.20	5.14	5.44	5.44
187	6.98	9.78	7.67	12.67	15.31	13.05	2.50	2.47	2.48	2.19	2.17	2.19	5.69	5.53	5.38
188	3.41	1.75	6.38	8.62	6.91	11.51	2.60	2.66	2.54	2.29	2.34	2.25	5.21	5.16	5.13
189	6.78	8.05	13.78	12.36	13.85	19.06	2.50	2.47	2.47	2.20	2.16	2.18	5.58	5.80	5.28
190	3.81	1.73	8.52	9.10	7.10	15.24	2.61	2.66	2.50	2.29	2.33	2.14	5.29	5.37	6.72
191	4.74	4.69	8.14	10.33	10.02	13.39	2.59	2.58	2.47	2.26	2.27	2.19	5.59	5.33	5.25

NT = Not Tested