INTERIM REPORT ON THE INFLUENCE OF DESIGN, CONSTRUCTION AND TRAFFIC ON COMPACTION OF HOT-MIX ASPHALTIC CONCRETE

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INTRODUCTION

The density of the various layers of a flexible pavement system has always been a problem to highway engineers. The "in place" density requirement is a specification item for most highway foundation work, but the surface layer of asphaltic concrete may not be subject to such requirements. In Texas, the most common specification for asphaltic concrete does not have an "in place" or "field" density requirement; however, job control samples are made in the laboratory and these samples must conform to certain specifications requirements. These laboratory tests are intended to give the engineer needed information about the density of the surfacing material as it ultimately appears on the roadway. However, there is evidence[1] that an increasing number of asphaltic concrete pavements in Texas are reaching higher densities than those obtained in the laboratory design of the paving mixture; and, others are far below the design density.

The density or the amount of air voids in a pavement surface is important to the engineer because it may be a guide to the serviceability of the layer. It is also important to know something of the nature of the rate of densification in service as this is related to construction compaction and time of year the mix is placed. It is desirable to have a certain amount of air voids, in a newly placed pavement layer to allow for thermal changes and additional compaction or consolidation to take place under the traffic loads. But, if the final pavement air voids are too high, the surface may be permeable to air and water, or rutting may appear in the wheel paths. In either case, the pavement surface may be damaged and the expected life may be decreased. Hence, the pavement density can be considered an important factor in the design criterion for flexible pavements.

Some of the primary considerations in the rate and amount of densification of a surface course are:

1. Composition and characteristics of the paving mixture.
2. Construction features (time of year and amount of rolling).
3. Deflection of the pavement structure.

Hence, it is deemed desirable to examine the influence of the above variables of pavement densification and to try to correlate the laboratory and field compactibility of different paving mixtures throughout Texas. This study will also attempt to determine a recommended optimum field density to be obtained during construction.

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[1] Superscript numbers refer to the Reference List.

This recommendation will be made in view of the field compaction equipment and sequence of operation, the compaction temperature, type of material and subsequent traffic volume.

The plan of research to complete these objectives is outlined in detail in the test program.

The data reported herein and the results thus far are based on data taken after four months of traffic. This includes 12 of the 15 test sections planned for the study. A later report will include the other three sections. On four of the 12 test sections reported on, the one-year data have been included. The one-year data for the remaining test sections are scheduled for the late summer and fall of 1967.

SUMMARY OF RESULTS

The following statements briefly summarize the methodology and results of this study. Any conclusions made at this point are tentative and largely reflect the opinions of the researchers.

1. Pavement density was found to increase with service and time. A linear relationship between the total air voids and the logarithm of time was found for all test sections through a four months time period and for a one-year period where data were available.

2. The total air voids in the pavement surfaces under study ranged from 4.1 to 25.9 percent immediately after construction. These data represent the average value of 18 core samples taken from regular construction subsections. Only 16 percent of these core samples had obtained 95 percent laboratory density.

3. Some Texas pavement surfaces attain and even exceed 100 percent laboratory density at an early age, and some never reach this density. It would be desirable to have a field density control so as to produce more nearly uniform, and possibly more durable, surfaces.

4. Texas' method for computing the total air voids in a compacted hot-mix asphaltic concrete sample needs to be revised in order to account for asphalt absorption by the aggregate. Such a procedure would give more realistic values of pavement air voids.

5. During construction, the center of a traffic lane is compacted to a higher density than the edges.

6. An AC-20 grade asphalt cement or its equivalent was used in the hot-mix asphaltic concrete surfaces in this study.

7. There appears to be a linear relationship between the density of specimens compacted using the Texas motorized gyratory shear press and the Corps of Engineers gyratory testing machine. Also, a significant relationship was determined between samples compacted in the Texas motorized press and those compacted by the Marshal procedure.

8. The data indicate that no appreciable aggregate degradation takes place in the laboratory using the motorized press or in the field for the first four months after construction.

TEST PROGRAM

The plan of research can be separated into two phases: (1) the laboratory phase and (2) the field work. The laboratory phase deals with the measurements made in the central laboratory on samples of paving mixture obtained from the test site. Data were also received from the Texas Highway Department district laboratories which made similar measurements on the paving mixtures. The field work included the site selection, preparation, and placing the test section; as well as regular sampling.

Field Work

The test site selection was made on the basis of:

1. Contract work in progress.
2. Traffic volume.
3. Climatic conditions.
4. Materials.
5. Pavement type (flexible or rigid).
6. Construction type (new or overlay).

It was considered that 12 to 15 test sites in four or five highway districts would be adequate to evaluate the study objectives. The sites were chosen such that the grade line was approximately level, there was no ingress or egress from the test sections, and the location was always on a tangent. The approximate location of each test site has been shown in Figure 1. Details for the exact location for the test sites are given in Appendix A-1.

Once the location of the site was established, the test section was dimensioned. Each section was 600 feet in length and one traffic lane in width; the thickness was a variable. The pavement deflection was evaluated by measuring the pavement rebound from an 18,000 lb. axle load with a Benkelman beam. These deflection measurements were made initially, and in selected cases, they were made at regular intervals during the study. The initial measurements were made at 30-foot intervals throughout the test section, and the later measurements were made at the same locations during both the summer and winter months to determine if the

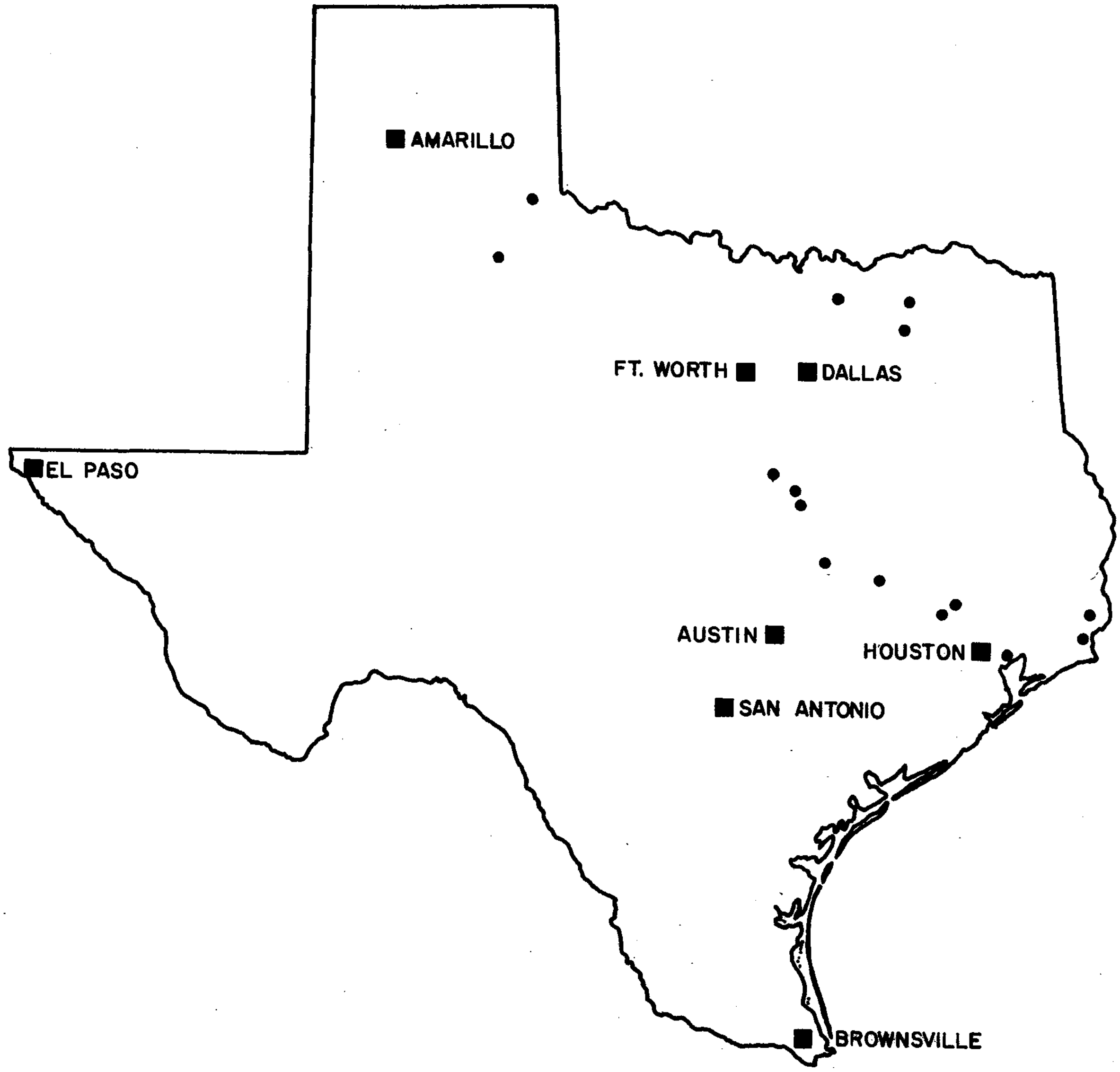


FIGURE 1 TEST SITE LOCATIONS

seasonal variations in the pavement flexibility were a factor influencing the surface compaction. Since freezing subgrade and "spring breakup" are not problems in Texas, only a few additional measurements were considered necessary to reveal any variations that might exist.

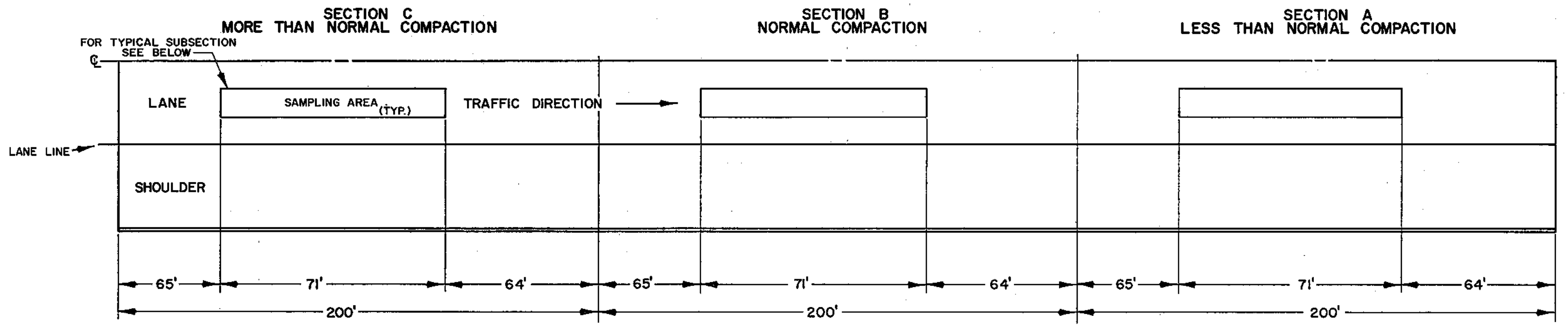
A given location or test section was then subdivided into three parts (A, B, and C) with each part or subdivision receiving a different amount of construction compaction. A typical layout for a given test section is shown in Figure 2. The test cores were removed (as indicated in the figure) from the center portion of each subdivision, and the space between sampling locations was provided so that the rollers would have sufficient maneuvering space.

The test site was prepared for subsequent sampling by placing a number of 18- x 24-inch aluminum foil envelopes on the existing surface or base. These aluminum foil envelopes consist of a single sheet of aluminum foil folded to form an envelope as shown in Figure 3. The three open sides were folded together for ease in handling and placing. The foil envelopes were prepared and packaged in the laboratory before field construction began. They were glued to the pavement with contact cement as shown in Figures 4 and 5. The pressure required to hold the foil in place was applied by an automobile. Figure 6 is a close-up view of an aluminum foil envelope in place on the existing roadway. By viewing Figure 2b and Figure 4 it can be seen that the aluminum foil envelopes are arranged in rows to correspond to the wheel paths of the vehicles with one additional row of envelopes between the wheel paths.

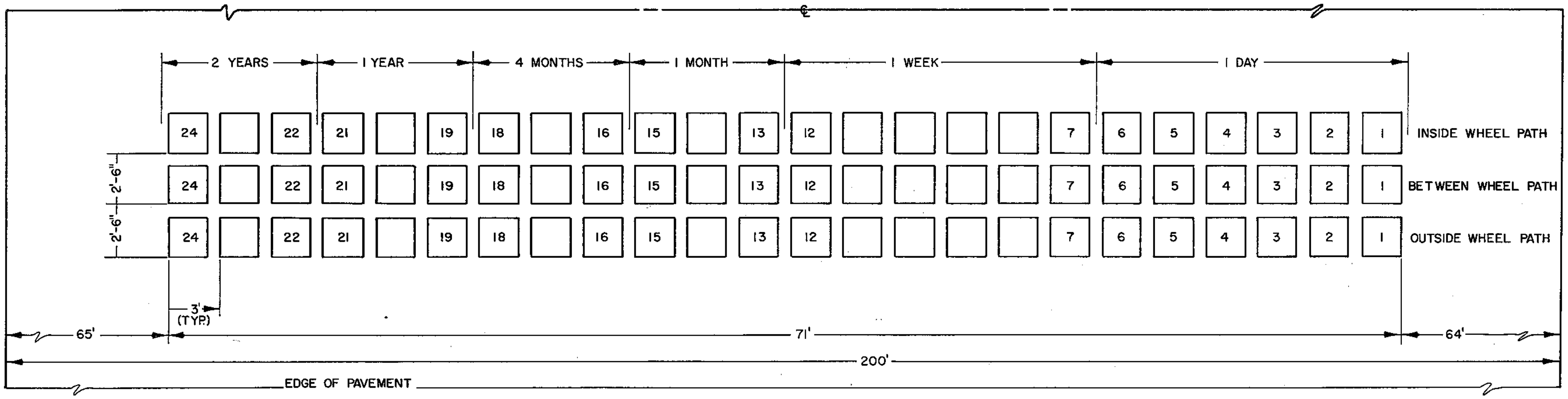
The hot-mix asphaltic concrete was placed on the prepared roadway (Figure 7) in the normal manner with no damage to the foil envelopes. A single 4-inch-diameter core was removed from each prepared location, i.e., one sample per envelope. The number of samples and the sequence of coring is also shown in Figure 2b.

The sampling procedure used in the field was to collect approximately 25 lbs. of loose mixture from the laydown equipment at each subsection for a total of about 75 lbs. of loose mixture. Also the compacted mat was sampled as indicated below:

1 day	18 @ 3 subdivisions = 54
1 week	18 @ 3 subdivisions = 54
1 month	9 @ 3 subdivisions = 27
4 months	9 @ 3 subdivisions = 27
1 year	9 @ 3 subdivisions = 27
2 years	9 @ 3 subdivisions = 27
Total number samples per test site	216



a. OVERALL LAYOUT



b. ENLARGEMENT SHOWING FOIL PLACEMENT & SAMPLE SEQUENCE FOR ONE SUBSECTION

TYPICAL TEST SECTION LAYOUT

FIGURE 2

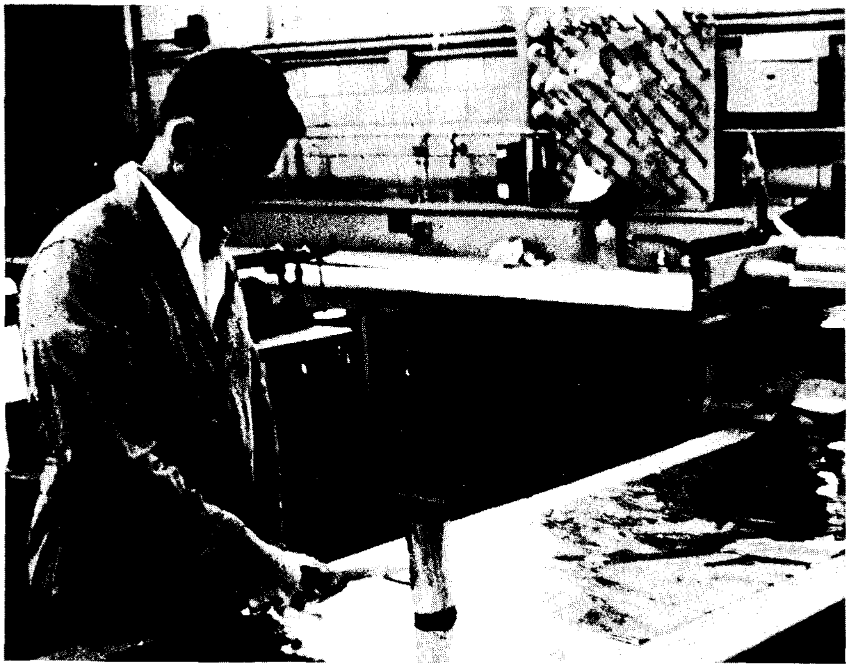


Figure 3. Preparation of aluminum foil envelopes.

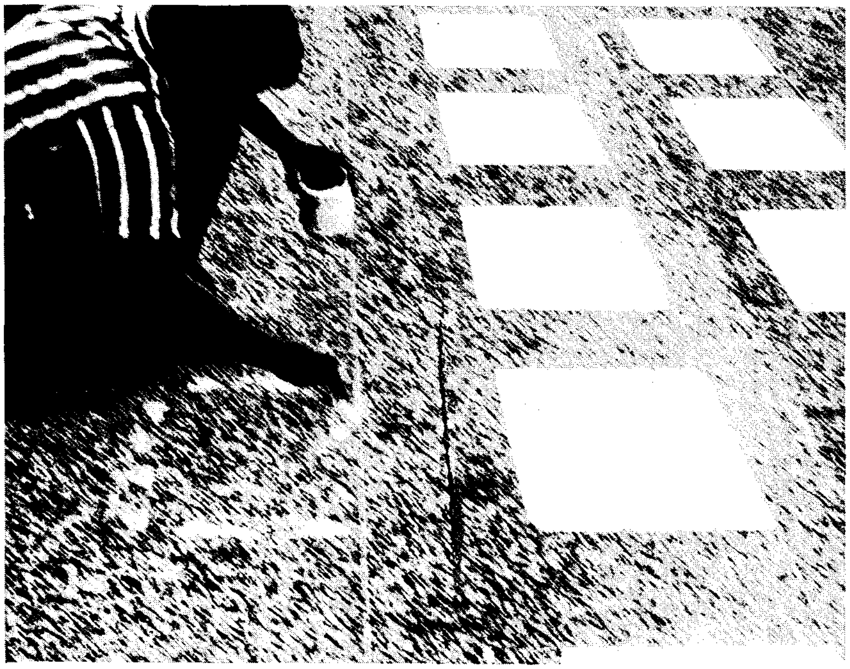


Figure 4. Application of contact cement to the roadway.

Figure 5. Application of aluminum foil envelopes to the roadway.

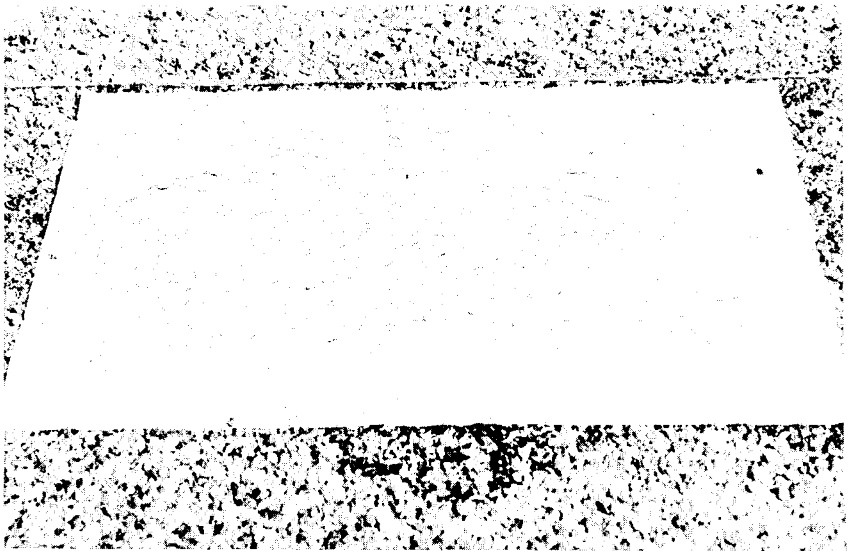


Figure 6. View of aluminum foil envelope in place.

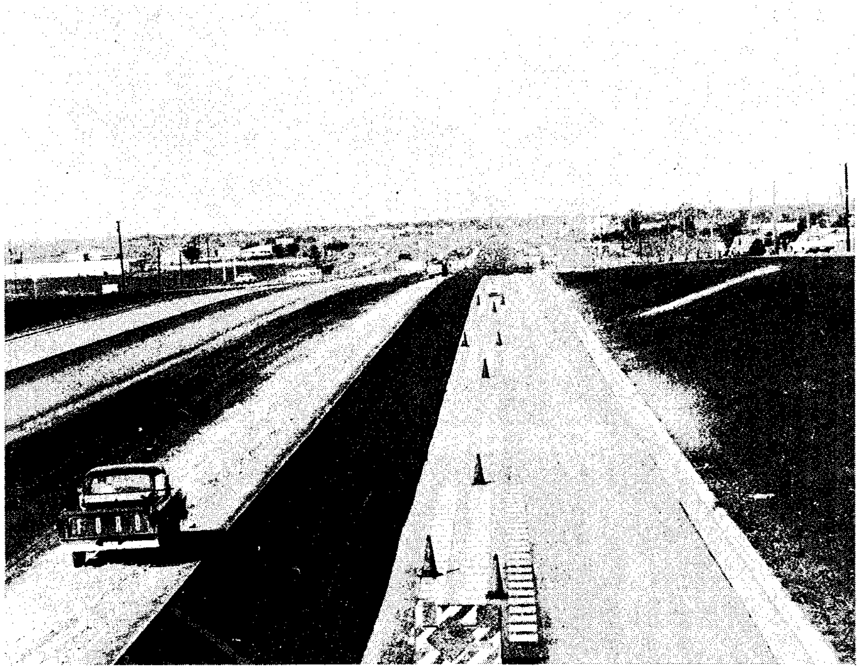


Figure 7. View of completed test section.

The sequence of sampling was always into the direction of traffic as shown in Figure 2b.

As indicated previously, each of the three subdivisions received a different amount of construction compaction. The normal construction rolling for the particular contract was used on subsection B; subsection C received twice as many roller passes as subsection B. Subsection A received half as many passes as subsection B. It was considered that this variation in the total number of roller passes would span the range of current construction practices. Other measurements included the type and weight of the rollers used, tire pressure sequence of roller operations. The temperature of the air and of the compacted mat was recorded at the beginning of the breakdown and final rolling sequence.

Furthermore, the type facility was noted including the thickness of the existing basement structure to be used with the deflection data in evaluating the effect of pavement stiffness on compaction.

Laboratory Work

The loose mixture obtained from the laydown equipment in the field was brought to the central laboratory of the Texas Transportation Institute for further evaluation. Also samples of the mixture were obtained by the Texas Highway Department. The proposed purpose of the duplication of effort was to compare the results of the "field laboratory" and those of the research laboratory so that any recommendations resulting from the study could be translated to Texas Highway Department field conditions. However, this was a secondary objective of the study suggested by the Construction Division of the Texas Highway Department.

The laboratory measurements that were duplicated were those of making and testing job control specimens using the Texas motorized gyratory shear press. The compactive effort was a variable in the study and constituted an attempt to determine the optimum amount of laboratory compaction. The present recommended procedure according to test method Tex-206-F, Part II (tentative)[2] is to apply an initial gage pressure of 50 psi to the specimen to be compacted. The mold containing the loose mix is then tilted 1° of tilt, the mold is leveled and a check is made to determine whether or not the desired compaction has been reached. This is done by making one full stroke on the jack. (This deformation represents approximately 1 percent strain on the compacted specimen). If one stroke of the jack increases the gage pressure to 150 psi or more, the sample is considered to have been satisfactorily compacted. If one stroke on the jack does not increase the pressure to 150 psi, the gage pressure is adjusted to 50 psi, and another set of three gyrations is applied. The procedure is repeated until the designated end point has been reached, then the ends of the sample are leveled or made parallel by applying a leveling force equivalent to 1588 psi on the face of the specimen. The leveling load is then immediately removed. The compacted sample is extruded from the mold and allowed to cool.

Variations in the compactive effort were obtained by changing the starting pressure and the end point pressure. The leveling procedure remained the same. The concensus was that the laboratory density obtained by the standard method (described above) was sufficient for normal roadway construction. Thus, it became necessary to reduce the compactive effort. This was accomplished by reducing the end point from 150 psi (gage) to 100 psi. This is termed for this report the medium compactive effort; whereas, the standard method described previously is called the high compactive effort. This so-called medium effort is the same as the procedure currently being used by the Texas Highway Department for the manual gyratory shear press (Tex-206-F Part I).[2] The low compactive effort was effected by reducing the starting pressure to 40 psi and the end point to 50 psi, otherwise the procedure remained the same.

A second laboratory compactor was also used at three different energy levels to aid in evaluating the compactibility of the asphaltic concrete mixtures. This compactor was the gyratory testing apparatus developed by the U.S. Army Corps of Engineers at Vicksburg, Mississippi and presently patented by the Engineering Development Company (EDCO). This apparatus is similar to the THD motorized gyratory shear press. The standard procedure or compactive effort requires 30 gyrations with the mold inclined at 1° and a constant pressure of 100 psi on the specimen. The compactive effort was varied by changing the constant pressure to 50 and 150 psi and holding the 30 gyrations and 1° of tilt constant.

The laboratory measurements, other than compaction, included a study of the aggregate type and gradation, the asphalt type and amount, viscosity of the original asphalt and asphalt extracted from the pavement cores, and a study of the possible aggregate degradation of the laboratory samples as compared to the aggregate degradation of the mixture compacted in the field.

The TTI laboratory compacted specimens were measured for density, voids, stability, and cohesion. Similarly, the THD compacted specimens were measured by the THD Materials and Test Laboratories in Austin, Texas, for density and stability. All of these measurements were made for comparative purposes and for possible correlation with the field cores which were also measured for density and voids, cohesion, and stability when possible.

TEST RESULTS AND DISCUSSION

Effect of Traffic

Wheel Loads. The density of a pavement surface is affected to a large degree by the traffic on the roadway after the construction compaction. This additional compaction is influenced by the number of vehicles, directional distribution, percentage of trucks, weight of trucks, etc. However, these variables can be reduced to the single variable of equivalent 18,000 lb. axle loads. This information was compiled by the Texas Highway Department and furnished to the Texas Transportation Institute in the form of equivalent 18,000 lb. axle loads applied to the various test sections for the two-year test period. These data are tabulated in Appendix A. Since the data are for a two-year period and the test sections have not yet attained that age, it is impossible, at this point, to determine the specific effects of the wheel loading on pavement density.

Time in Service. The pavement density or the amount of total air voids in a pavement surface is time in service dependent. However, the general variable of time includes a multitude of time related parameters, such as wheel loads and repetitions, viscosity effects, stability and cohesion changes, seasonal variations, etc., but if all of these are included in the time variable a few general statements can be made about the air voids.

It is a generally accepted fact that the density of an in service pavement surface will increase over a period of time. This was one of the hypotheses tested in this study and the data indicated that for all of the pavement surfaces examined the density increased with service time. This hypothesis was accepted at the 99.9 percent confidence level for all the test sections. The supporting analysis of variance is included in Appendix C, Table C-1.

Since the hypothesis that pavement density increased with time in service was accepted a graph was made including the four months' data for the regular or normal constructed "B" sections. Figure 8 shows some typical graphs of the percent air voids plotted as the ordinate and logarithm of time plotted on the absissia. A straight line was fitted to these data using the least squares method and the coefficient of determination, r^2, ranged from 0.98 to 0.60. However, only two of the 12 test sections for which the data were available had coefficients below 0.80. The data are shown in Appendix C, Table C-2. Since the slope was relatively flat, the hypothesis that the slope equaled zero was tested and rejected at the 95 percent confidence level. It should be noted here that the actual pavement voids will not continue to decrease indefinitely as indicated by the regression line, but

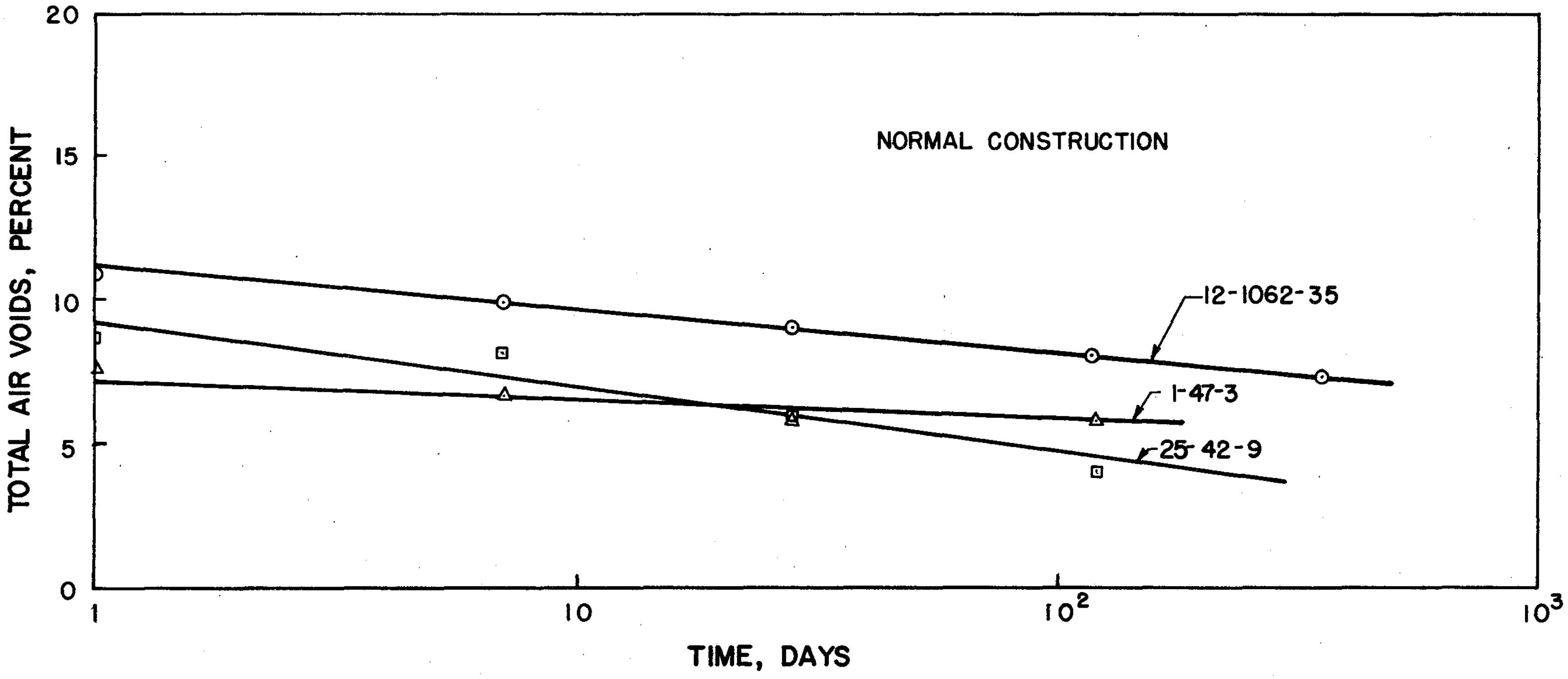


FIGURE 8 PAVEMENT DENSIFICATION WITH TIME

it is expected that the air voids will, in most cases, eventually reach a minimum and stabilize around the 1 to 3 percent range with the possibility of plastic instability. However, the regression line may serve to predict air voids in the early life of the pavement and may be an aid in pavement design criteria. More data will be needed before any definite conclusions can be reached in this respect.

It has been reported by Graham[3] that immediately after construction there exists a significant difference in density between transverse sampling locations, i.e., inner wheel path (IWP), between wheel paths (BWP), and outer wheel path (OWP), and the data presented herein spoke this hypothesis. However, after a time period of at least four months, this hypothesis must be rejected (8 out of 12 cases) at the 95 percent level. That is to say that after four months there are no differences in density in a transverse section of the pavement; however, time and service may change this.

The sampling error for the core samples taken from various construction projects varied from 1.9 to 9.1 percent with one exception which had a variation of 27; but, most of the sampling variability was in the range of about 5 percent. The coefficient of variation or the error in determining the differences in the means for the wheel paths and times is quite high; but, this may be attributed to the non-randomized location of the wheel paths and the wheel load frequency.

Effect of Construction

Rolling. The data indicate that as the construction compaction increases on a given test section the pavement density increases. Figure 9 shows typical data from three different test sites. It can be seen in this figure how the pavement voids are affected by increased rolling, also shown are some of the same data after four months traffic. The sampling stations are labeled OWP and BWP for outer wheel path and between wheel path respectively. The inner wheel path is not shown, but in most cases it is less dense than the other two. It is evident from the curves that the area in the center of the traffic lane receives more construction compaction than the edges. This was true on 65 percent of the test sections placed. Graham[3] found this same tendency for roller operators to favor the center position of the roadway in the New York study. However, he concluded that the inside one-third of the lane was more dense than the outside one-third.

The compactive effort was computed in ton-passes in a manner similar to that described by Graham.[3] Referring again to Figure 9, it will be noted that the rolling of test section 12-508-7 was very light and was not effective until a greater degree of compaction was obtained (in subsection C); whereas, the curves of test section 1-9-13 seem to indicate the optimum compaction was obtained by the normal rolling sequence (in subsection B). Also test section 25-42-9 shows a slight loss in density

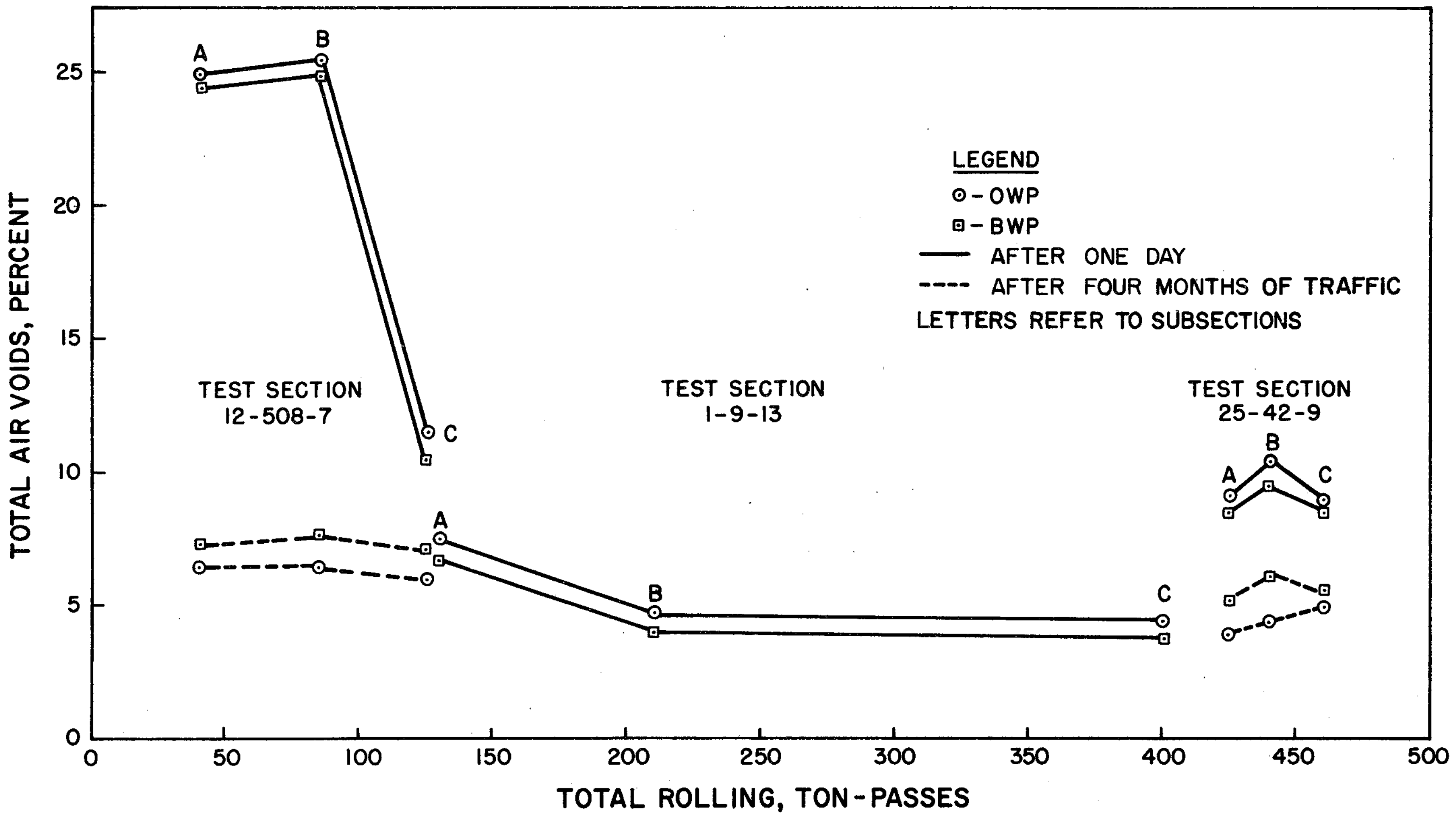


FIGURE 9 EFFECT OF ROLLING ON AIR VOIDS

as the rolling sequence continues. This density loss occurred on about 40 percent of the test sections. It has been reported by Serafin and Kole[4] that the density of pavements subjected to continued rolling will undergo cyclic changes.

Asphalt Viscosity. It has been shown by McLeod[5] that high viscosity asphalt cements increase the resistance of a bituminous mixture to compaction; whereas, the low viscosity asphalt reduces the resistance to compaction by reducing the stability of the mixture at a given temperature. Also Gandhi and Gallaway[6] indicate through triaxial testing that a greater stress is required for failure of specimens containing high viscosity asphalt cement as opposed to those containing low viscosity asphalt. This would serve to reinforce the theory that resistance to compaction, all other things being equal, increases with increasing viscosity of the asphalt cement. However, it has been noted by McLeod[5] that low viscosity asphalt may result in delayed rolling on a hot summer day. Such is the case in Texas. For example, the bituminous surface mat on test section 9-209-1 was placed at 325°F, but the initial or breakdown rolling was not started until the temperature of the mat had reached 180°F. The final roller in the sequence began its operation on the surface some four hours later and the mat temperature was still 120°F. The air temperature during this period was approximately 95 to 100°F and the asphalt cement was of a medium to high viscosity conforming to the Texas specification for AC-20.* The actual viscosity for this particular asphalt was 6.41 poise at 275°F and 2890 poise at 140°F. The asphalt cement used on this particular construction project was fairly typical of the asphalts used on the other test sections. Only three of the fifteen test sites did not use an AC-20, and these three used an asphalt cement of similar absolute viscosity but specified by penetration.

It was anticipated in the beginning that the contract projects selected for this study would use a variety of asphalt cements and that the viscosity would be sufficiently different to permit an evaluation of the effect of viscosity on compaction. However, this was not the case. All of the contractors involved in these tests had used an AC-20 or its equivalent. Since viscosity was not a variable at any particular test site, one cannot draw any definite conclusions concerning these effects. However, in consideration of the above and in view of the present Texas specifications for asphalt cement, it appears that an AC-20 grade asphalt is widely used for hot-mix, hot-laid asphaltic concrete surfaces in Texas.

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*Letter code means Asphalt Cement (AC) with 2000 to 3000 poises absolute viscosity at 140°F.

Laboratory Considerations

Laboratory Samples. Samples were prepared in the laboratory utilizing the Texas gyratory shear press at three compactive efforts. These efforts have been previously discussed, and for convenience were termed low, medium, and high corresponding to the appropriate end point pressure in the compacting procedure.

Apparently, very little can be said about the differences in the air void content for the samples compacted in the TTI laboratory and the THD laboratory. These variations are due to different methods of analysis as already reported by Gallaway[1, 7] and Gallaway and Harper.[8] However, the percent air voids were recomputed to try to eliminate these differences. When these data were analyzed, it was found that differences still existed, but on the average amount to less than 1.5 percentage points. There was, however, less variability in the medium compaction range.

The Hveem stability values of the TTI laboratory compacted specimens were in fair agreement with those of the THD laboratories; however, the TTI values tended to be slightly lower than those of the THD. The compactive effort did not appear to have a definite effect on the Hveem stability. In many cases there was no change in stability with changes in density; but some increased in stability with increasing density. At this point, it may be well to remember that the THD compacted specimens were compacted in field laboratories or central laboratories in each district involved, and each may be regarded as a separate comparison.

Another objective of this study was to examine other methods of forming test specimens for possible correlation and to study the compacting process. The gyratory testing machine and the Marshall method previously described were used to accomplish this goal. If the standard compactive effort for both the gyratory testing machine and the Texas gyratory shear press is used to make test specimens from the same batch of loose mixture, a linear relationship is found to exist with a coefficient of determination 0.74. One can predict with reasonable accuracy the specimen density of samples compacted at the standard effort in the gyratory testing machine from the specimen density of samples compacted in the Texas gyratory shear press. The equation is :

$$D_G = -0.97 + 1.40\ D_T$$

where

D_G = density, g/cc, of specimens compacted in the gyratory testing machine, and

D_T = density, g/cc, of specimens compacted in the Texas gyratory shear press.

Similarly, the relation between the Texas and the Marshall method was examined. In this case the coefficient of determination was 0.88 and the linear equation is:

$$D_M = -0.67 + 1.27\ D_T$$

where

D_M = density, g/cc, of specimens compacted by the Marshall method, 50 blows per face.

These relationships will have to be examined further to determine the performance of the mixture by these methods.

Aggregate Degradation. There has been some concern that the aggregate in the paving mixture undergoes some changes in the mixing and compaction process in the mixing and compacting process in the field as well as in the laboratory. Figure 10 is a typical gradation chart for data from this study. It shows the gradation of the aggregate after a sample of mixture obtained from the field had been compacted in the normal manner and the asphalt cement was removed. Also shown in the figure is the aggregate gradation from a core sample obtained from the field after construction and before traffic was allowed on the surface, and a similar core sample after four months of traffic. The original gradation determined from the THD regular samples of the hot bins is not shown, but it falls in the shaded area between the laboratory and one-day samples. Also the gradation of the one-year sample is not shown, and it too, was found to fall within the shaded region. From these data it is apparent that very little if any aggregate degradation occurs either in the field or in the laboratory. Most of the differences in grading shown in Figure 10 can be attributed to sampling, but those shown are within the normal tolerances for the job mix formula.

It is well to mention that the aggregate type was a factor in the selection of the test sites. This study has included both crushed and uncrushed, rounded and angular aggregates. Also included were limestone, iron ore, wet bottom boiler slag, and silicious materials.

Relationship between Laboratory and Field

Highway engineers are constantly seeking a relationship between laboratory tests and field performance. It is seemingly impossible to determine in a few years the durability and expected pavement life, but it may be possible to determine a few variables that significantly influence the pavement performance. A discussion of the more important variables will follow.

Density. One of the most important factors seems to be the final pavement density or the amount of air voids in the system. According to McLeod[5] and the

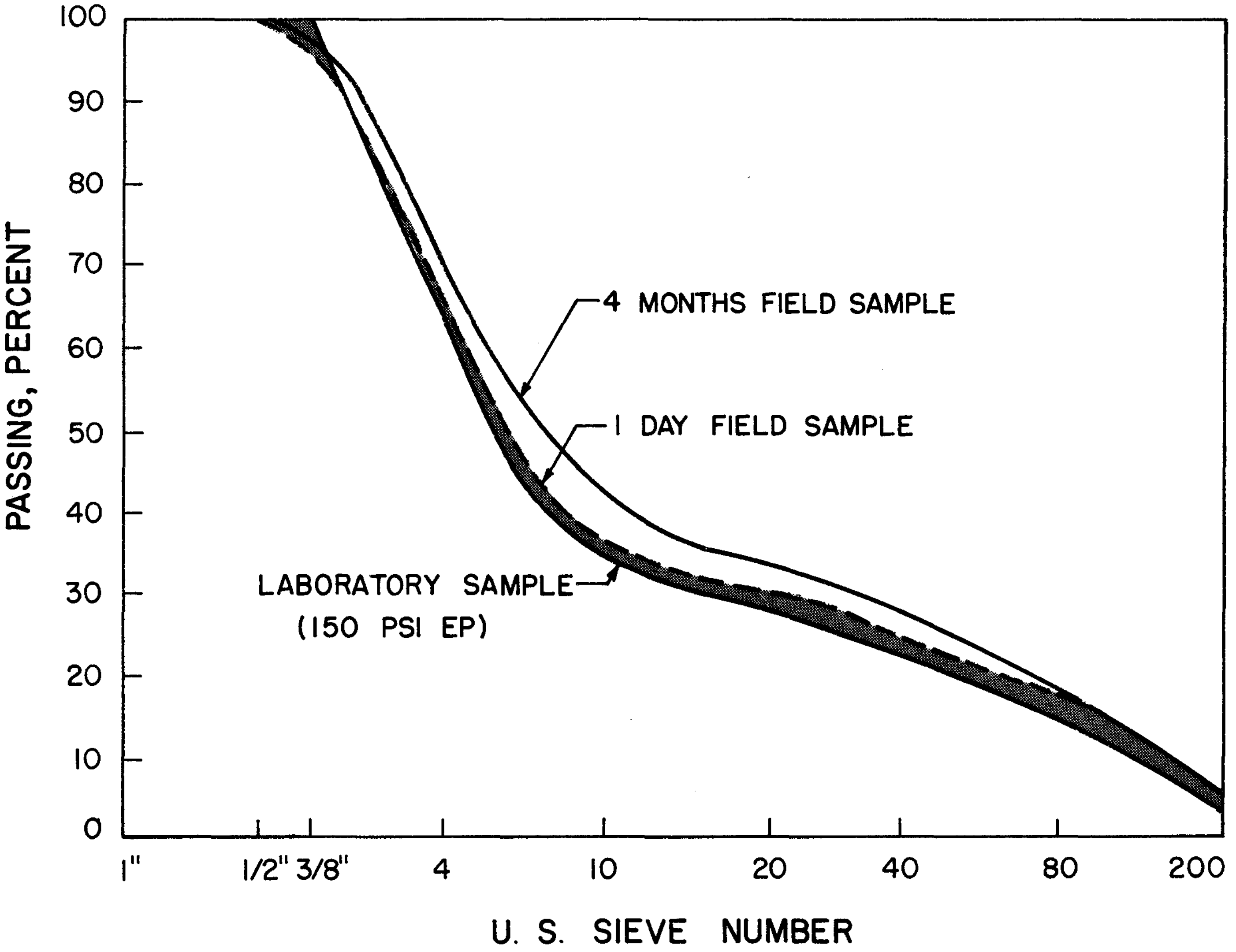

FIGURE 10 AGGREGATE DEGRADATION-TEST SECTION 9-55-8

Texas Highway Department specifications,[9] the desirable amount of air voids in the pavement is in the range of 3 to 7 percent. Plastic instability results when the air voids are below about 3 percent, say in the neighborhood of 1 to 2.5 percent.[5] This can lead to unsafe driving conditions when the pavement is wet. If the air voids are too high, say above 8 to 10 percent, the mixture may be considered "open" and it could be permeable and subject to action of air or water, thus reducing the pavement life.

The pavement air voids for this study were determined by the procedure listed in ASTM D2041-64T. The air voids in the pavement can be compared over a period of time with the laboratory results by bar charts like Figure 11. This figure represents typical data from one of the test sections in the study. It can be observed in this figure that the outer wheel path is generally more dense than the other two transverse sampling locations, and that the pavement density is increasing with time; however, it is impossible to extrapolate the data and predict that the pavement density will eventually attain the laboratory density. Moreover, some pavements such as the one shown in the bar chart of Figure 12 have, for normal construction compaction, attained 100 percent of laboratory density in less than one month. It is also interesting to note in these two figures the relative performance of the various sub-test sections, i.e., A, B, and C. Even though all of the subsections increase in density with time the trend seems to be for the normal construction or "B" subsections to approach the density of the over compacted or "C" subsections. It may be that given enough time all three subsections would approach the same density; however, this is purely conjecture.

From the data presented in Figures 11 and 12, it appears that some of this variability may be reduced by a specification control on the pavement density which would require a certain density or air voids in the surface when the pavement is relased to traffic.

If the data for all fifteen of the test sections are considered collectively, a histogram can be made and a cumulative frequency distribution chart can be plotted. The charts for the relative density before traffic and after four months traffic is shown in Figure 13. From these curves it can be seen that, after construction and before any traffic is allowed on the pavement, 84 percent of the samples from the normal construction operations had not attained 95 percent of the laboratory density. After 1 week of traffic approximately 50 percent of the samples had reached 95 percent laboratory density, and so on, until after four months, 82 percent had reached 95 percent relative density.

Again, the data indicate that a field density requirement would reduce the variability from job to job. This becomes even more evident when it is realized that the total air voids in the pavements under study ranged from 4.1 to 25.9

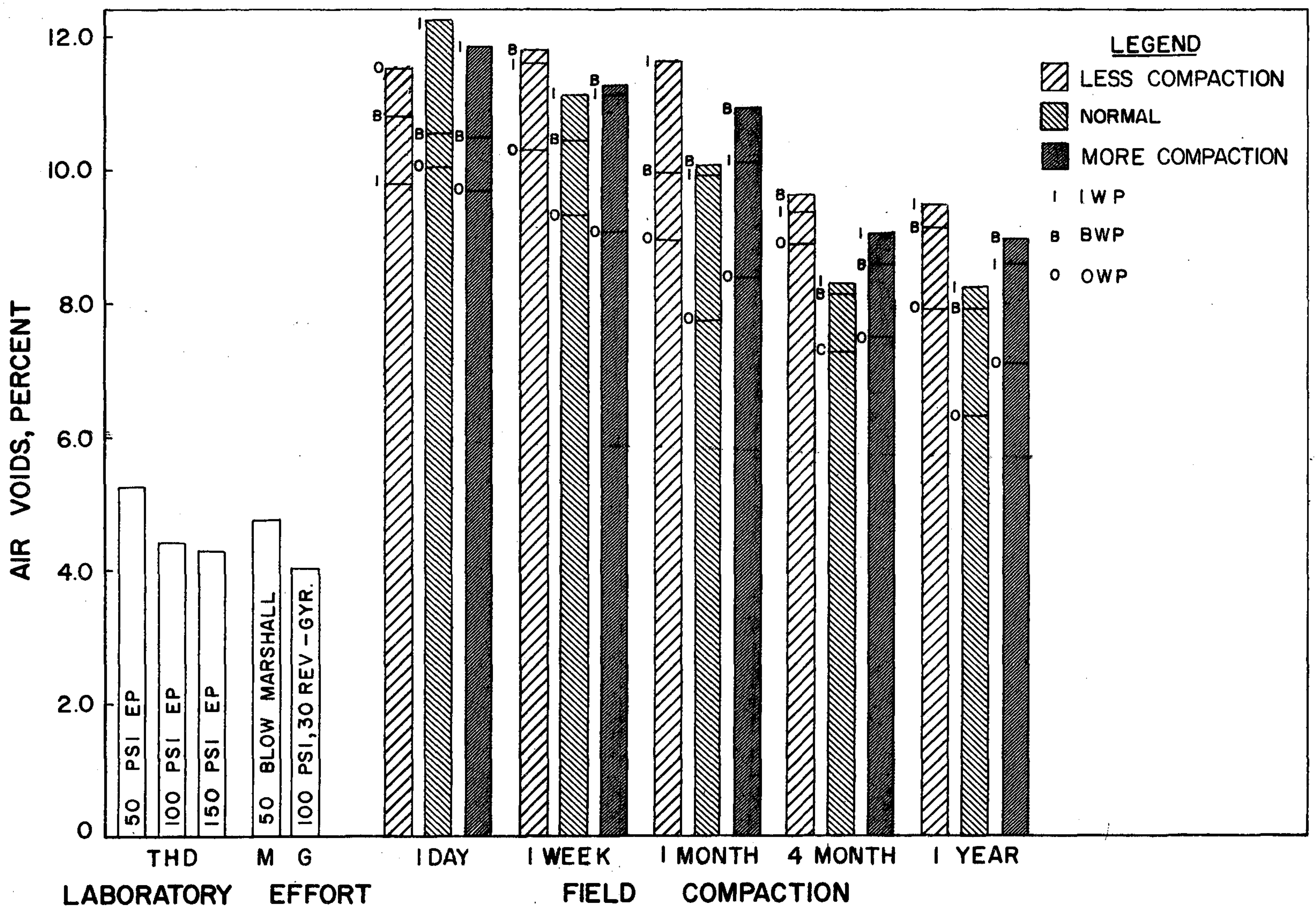

FIGURE 11 AIR VOIDS FOR LABORATORY AND FIELD SAMPLES (TEST SECTION 12-1062-35)

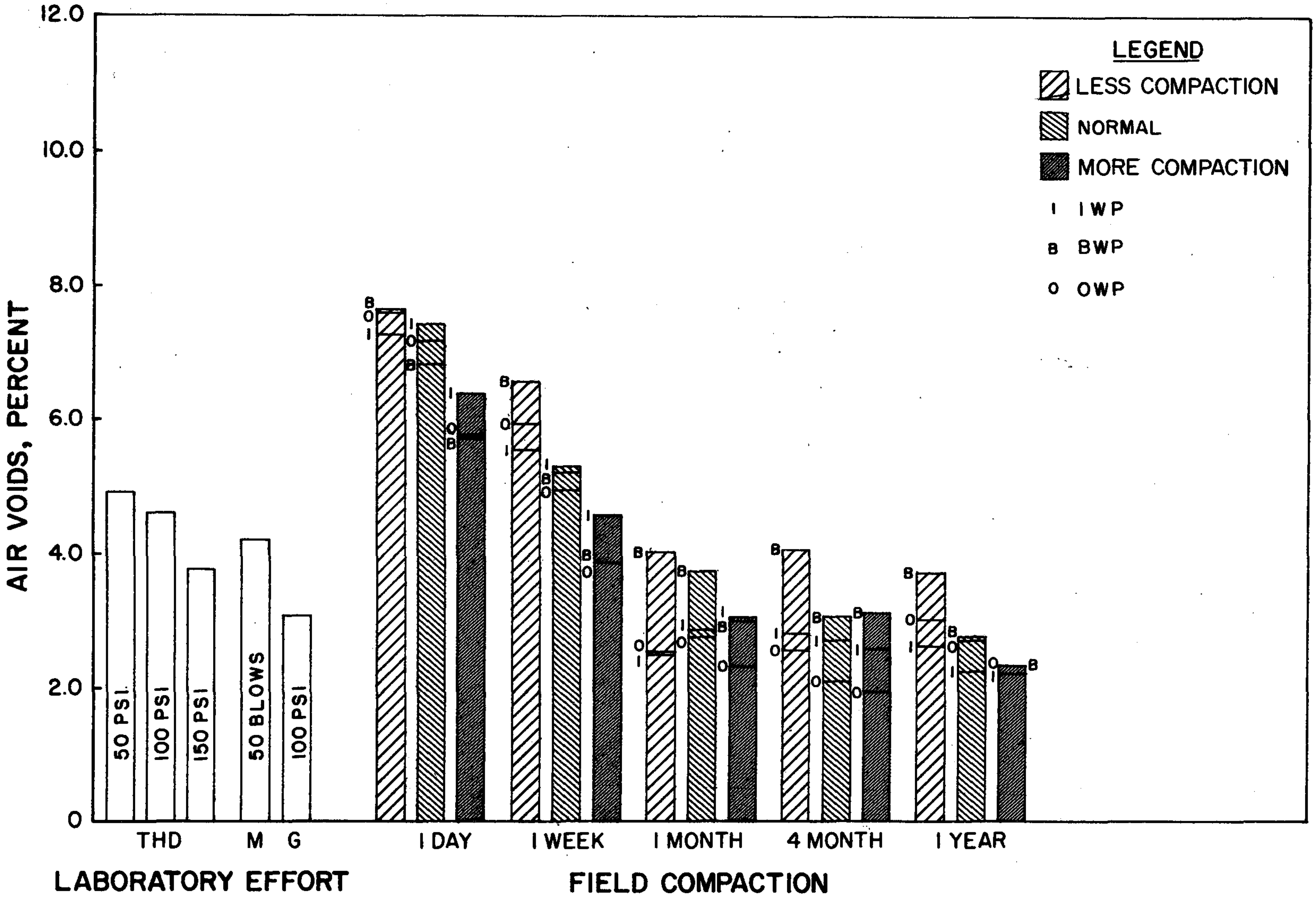

FIGURE 12 AIR VOIDS FOR LABORATORY AND FIELD SAMPLES
(TEST SECTION 9-55-8)

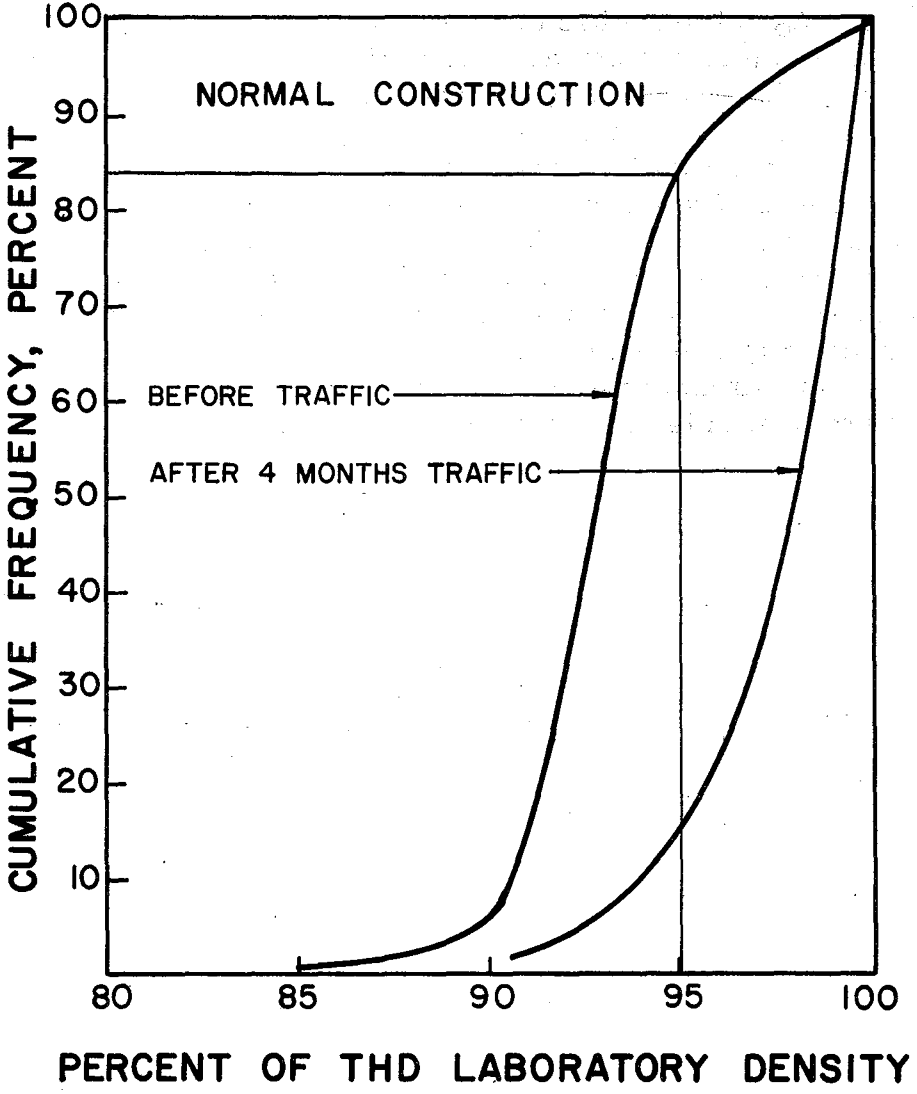

FIGURE 13 CUMULATIVE FREQUENCY RELATIVE DENSITY

percent. This observation is based on an average value from 18 core samples taken from each of 15 subsections. These subsections were the normal operations and the samples were taken before the facility was opened to traffic.

Bending Strength. It has been reported by Jimenez[10] that the static bending strength value, A_o, of asphaltic concrete is related to the viscosity of the asphalt recovered from the test specimens. He further stipulates that the static bending strength is related to the bending strength of asphaltic concrete under repetitive loading conditions. The static bending strength value, A_o, as defined by Jimenez, is derived from a modification of the cohesiometer test. The A_o value has a linear relationship with the Hveem cohesiometer value and the coefficient of determination, r^2, was found to be 0.99 for the laboratory prepared samples used in the subject study. Furthermore, the data indicate that there may be some relationship between laboratory air voids and A_o values from field samples; however, the data are incomplete and no definite conclusions can be made at this time. The main point is that the static bending strength may be an indicator of permanent performance. When all the data are available, a complete analysis will be made.

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APPENDIX A

TABLE A-1

Test Site Details

Test Section Number	Highway	County	Traffic Count 1965 ADT	Equivalent 18 Kip Axle Loads for Test Period	Type of Pavement Structure Surface was Placed on
1-9-13	IH 30, 2 mi. W. of FM 275	Hunt	6,210	188,674	Rigid
1-47-3	US 75, 2.7 mi. N. of Van Alstyne City Limit	Grayson	6,410	202,336	Rigid & Flexible
1-136-3	SH 24, 3 mi. SW of Cooper City Limit	Delta	1,860	37,010	Rigid
9-55-8	US 84, .1 mi. W. of SH 6 Over Pass	McLennan	11,270	106,918	Flexible
9-209-1	US 77, 1.6 mi. N. of Jct. US 77 and FM 2837	McLennan	2,810	111,988	Rigid
9-258-7	SH 6, .1 mi. S. of Jct. SH 6 and FM 217	Bosque	3,060	72,382	Flexible
12-110-4	IH 45, 1.5 mi. S. of West Fork of San Jacinto River	Montgomery	14,180	371,285	Rigid
12-508-7	Spur 330, 3 mi. SE of IH 10	Harris	11,500	266,901	Rigid
12-1062-35	FM 1485, 7 mi. NW of New Caney	Montgomery	810	24,444	Flexible
17-185-4	SH 36, 3 mi. N. of Jct. SH 36 and US 79	Milam	1,720	119,758	Flexible
17-599-1	SH 308, .25 mi. N. of Jct. SH 308 and FM 60	Brazos	7,500	118,244	Rigid
20-306-3	SH 87, .2 mi. S. of Railroad Bridge	Jefferson	8,930	236,729	Flexible
20-499-3	SH 12, .7 mi. E. of Jct. SH 12 and 62	Orange	3,510	105,699	Rigid
25-42-9	US 287, 5.4 mi. NW of Red River Bridge	Hall	3,190	101,378	Flexible
25-145-8	US 70, 3 mi. W. of Matador	Motley	1,170	44,710	Flexible

APPENDIX B

TEX-206-F, Part II

MOTORIZED GYRATORY-SHEAR MOLDING PRESS OPERATING PROCEDURE
(Tentative)

1. Combine aggregates and prepare laboratory bituminous mixtures as described in Test Method Tex-205-F. Hot mix asphaltic concrete mixtures which contain penetration asphalt are mixed and compacted into test specimens at a temperature of 250F. plus or minus 5F. Place cold mix asphaltic concrete mixtures in oven, cure to constant weight at 140F. to remove moisture and/or volatiles and mold at a temperature of 100F. plus or minus 5F. On some projects that specify Item 350 or 352, "Hot-Mix, Cold-Laid Asphaltic Concrete," the Engineer may choose to place the mixture "hot," omitting the addition of water and primer. In these instances it is suggested that the Hveem specimens be molded at 250 ± 5F. rather than the lower temperature specified previously for cold mix asphaltic concrete mixtures.

2. If the design mixture prepared in the laboratory or the mixture obtained from an asphaltic concrete plant contains aggregate larger than 7/8 inch, separate the large size aggregate from the sample by means of a 7/8 inch sieve (or a 1-inch round opening screen). Use the trowel to rub the material through the sieve and scrape off as much of the fines clinging to over size particles as possible.

3. Pre-heat the mold and base plate in an oven to approximately 150F. to 200F. Making certain that the platen is free to turn, connect the motorized gyratory-shear molding press to a 110v. A.C. outlet, push the reset button, and then push the start button, allowing the press to go through one set of gyrations.

4. Remove from oven and wipe the inside of the mold with a rag lightly moistened with kerosene. Insert the base plate into the mold with the large diameter up, and place a paper gasket over the base plate.

5. By means of the bent spoon and wide mouthed funnel, transfer the laboratory mixtures or a weighed quantity of plant-mixed material, heated to the proper molding temperature, into the mold. Place approximately 1/3 of the mixture into the mold and use the spoon to press the material down lightly. Use the small spatula to move any large aggregate which might be touching the side of the mold. Add another one-third of the material, press down and move large aggregate away from the edge. Place the remainder of the sample into the mold move the large particles a small distance away from the mold wall as before, and level the surface of the specimen while pressing the material down. Place a paper gasket on top of mixture. Be careful to avoid loss of material and segregation of particles while placing the mixture into the mold. The vertical

side of the specimen should be smooth to prevent damage to diaphragm of stabilometer; since the top and bottom surface need not be exceptionally smooth, do not arbitrarily place fine material on the bottom or top of the sample.

6. Quickly place a small amount of light-weight oil in the center of the motorized press platen and a drop or two on the surface of the lower bearing. (This is the bearing that "cocks" the mold and gives or creates the gyratory action.)

7. Squirt a small ring of oil around the periphery of the mold on the top surface of the hardened steel ring. This ring of oil should be in the path that the upper bearing will follow during gyration. Do not use an excessive amount of oil in making this ring.

   When molding a number of Hveem specimens, steps 6 and 7 should be repeated every 10 to 15 specimens or as appears necessary when wearing surfaces become dry.

8. Steps 6 and 7 should be done quickly without delay. Then slide the hot mold and contents to the edge of the work table, and with gloved hand holding the base plate in place transport the mold to the platen of the press.

9. Slide the mold onto the platen and center it in molding position beneath the ram of the press.

10. Slip the handle onto the cam-lever, move the lever on the control valve to the forward or positive position, and pump the ram down into the center of the mold. Continue pumping until the low pressure gauge registers 50 psi.

11. Immediately pull the handle on the cam-lever down to the horizontal position, cocking the mold to the proper angle for gyration. Be certain that the cam-lever is pulled all the way down.

12. REMOVE THE HANDLE FROM THE CAM-LEVER.

13. Push the reset button and then the start button.

14. As soon as the last gyration is completed, slip the handle onto the cam-lever and raise the handle into a vertical position, leveling the mold.

15. Once again pump the pressure up to 50 psi, lower the cam-lever to the horizontal position, remove the handle, push the reset button, and then push the start button.

    Experience has revealed that the smoothest operating procedure, and certainly the safest, is for the operator to keep the right hand on the pump handle at all times while operating the cam-lever, push buttons, and control valve with the left hand.

16. Continue steps 13 and 14 until one smooth, but not violent, stroke of the pump handle will cause the low pressure gauge to indicate a pressure of 150 psi or more.

    During molding when one stroke of the pump handle causes the gauge to come to rest between 50 and 150 psi, drop the pressure below 50 psi by shifting the lever on the control valve all the way back and immediately returning it to the forward position. Then pump the pressure back up to 50 psi. NEVER begin to gyrate with any pressure (either more or less) other than a pressure of 50 psi.

17. When this end point of 150 psi is reached, remove the handle from the cam-lever, reverse it and slip the large end onto the pump handle. Bring the pump handle down slowly until the automatic gauge protector valve cuts the low pressure gauge out of the system. Now, at approximately one stroke per second, pump the pressure up to 2500 psi, as measured on the high pressure gauge.

18. As soon as the gauge registers 2500 psi, stop pumping with the right hand, and with the left hand very carefully release the pressure by slowly reversing the lever on the control valve to the backward position. Watch large capacity gauge when releasing pressure to prevent damage to low pressure gauge due to sudden, violent release of pressure.

19. Then pump the ram up and out of the mold.

20. Slide the mold out of the press, remembering to place a gloved hand beneath the mold to keep the base plate from falling out.

21. Allow the base plate to drop out of the mold onto the work table and remove the specimen from the mold with a converted arbor press or some similar device.

22. Clean the mold on the inside with a kerosene rag before molding another specimen.

23. When all molding is completed, disconnect the press from the electrical outlet, clean the unpainted parts of the press, the mold and base plate with a lightly moistened kerosene rag and coat with a thin coating of lightweight oil. This cleaning and oiling is an absolute necessity if the press is expected to continue functioning properly. Wipe the painted parts of the press with a clean dry rag. In areas of high dust concentration it is suggested that the press be kept covered.

APPENDIX C

TABLE C-1

Analysis of Variance

Test Section	Source of Variation	Degrees of Freedom	Mean Squares
1-47-3	Total	161	
	Sections (Sect)	2	13.44
	Wheelpaths (WP)	2	29.26
	Time	3	46.42
	Sect x WP	4	1.24
	Sect x Time	6	0.29
	WP x Time	6	2.67
	Sect x WP x Time	14	0.81
	Error	124	0.42
9-55-8	Total	188	
	Sect	2	13.80
	WP	2	4.54
	Time	4	137.43
	Sect x WP	4	.21
	Sect x Time	8	1.32
	WP x Time	8	1.32
	Sect x WP x Time	16	0.12
	Error	144	0.12
9-209-1	Total	161	
	Sect	2	41.06
	WP	2	9.62
	Time	3	41.47
	Sect x WP	4	4.52
	Sect x Time	6	3.14
	WP x Time	6	6.25
	Sect x WP x Time	14	0.87
	Error	124	0.22
9-258-7	Total	161	
	Sect	2	19.99
	WP	2	3.98
	Time	3	30.37
	Sect x WP	4	0.74
	Sect x Time	6	0.75
	WP x Time	6	2.93
	Sect x WP x Time	14	0.52
	Error	124	0.27

TABLE C-1
(Continued)

Test Section	Source of Variation	Degrees of Freedom	Mean Squares
12-110-4	Total	161	
	Sect	2	16.41
	WP	2	3.76
	Time	3	313.47
	Sect x WP	4	1.53
	Sect x Time	6	3.40
	WP x Time	6	6.05
	Sect x WP x Time	16	1.17
	Error	124	0.29
12-508-7	Total	188	
	Sect	2	155.79
	WP	2	1.93
	Time	4	1606.96
	Sect x WP	4	0.31
	Sect x Time	8	205.12
	WP x Time	8	5.53
	Sect x WP x Time	16	0.30
	Error	144	0.11
12-1062-35	Total	188	
	Sect	2	13.53
	WP	2	38.76
	Time	4	51.21
	Sect x WP	4	3.77
	Sect x Time	8	1.82
	WP x Time	8	2.38
	Sect x WP x Time	16	1.50
	Error	144	0.19
17-185-4	Total	161	
	Sect	2	19.89
	WP	2	5.69
	Time	3	55.69
	Sect x WP	4	2.32
	Sect x Time	6	1.85
	WP x Time	6	2.91
	Sect x WP x Time	14	1.07
	Error	124	0.25

TABLE C-1
(Continued)

Test Section	Source of Variation	Degrees of Freedom	Mean Squares
17-599-1	Total	188	
	Sect	2	29.08
	WP	2	24.21
	Time	4	65.72
	Sect x WP	4	4.15
	Sect x Time	8	4.10
	WP x Time	8	5.77
	Sect x WP x Time	16	1.41
	Error	144	1.06
20-306-3	Total	161	
	Sect	2	17.73
	WP	2	4.46
	Time	3	176.07
	Sect x WP	4	6.43
	Sect x Time	6	1.73
	WP x Time	6	4.34
	Sect x WP x Time	14	1.26
	Error	124	0.21
20-449-3	Total	161	
	Sect	2	6.06
	WP	2	36.95
	Time	3	148.05
	Sect x WP	4	0.90
	Sect x Time	6	18.34
	WP x Time	6	2.56
	Sect x WP x Time	14	1.68
	Error	124	0.36
25-42-9	Total	161	
	Sect	2	17.80
	WP	2	8.73
	Time	3	147.53
	Sect x WP	4	1.09
	Sect x Time	6	1.91
	WP x Time	6	3.03
	Sect x WP x Time	14	0.34
	Error	124	0.17

TABLE C-2

Data for Linear Regression for Pavement Voids and Log Time*

equation #: $V = V_o + S \log t$

Test Section	V_o Voids Intercept	S Slope	r^2 Coefficient of Determination
12-1062-35	11.1	-1.439	0.98
12-508-7	21.4	-7.248	0.81
9-55-8	6.7	-1.850	0.91
17-599-1	18.0	-0.863	0.60
25-42-9	9.3	-2.242	0.91
20-306-3	12.9	-2.386	0.85
20-499-3	10.5	-2.205	0.89
12-110-4	12.0	-2.953	0.95
9-258-7	8.9	-1.022	0.90
9-209-1	8.6	-1.176	0.75
1-47-3	7.3	-0.673	0.81
17-185-4	20.6	-1.473	0.83

*Normal sections including four months time period.

#V = predicted voids and t = time in days.