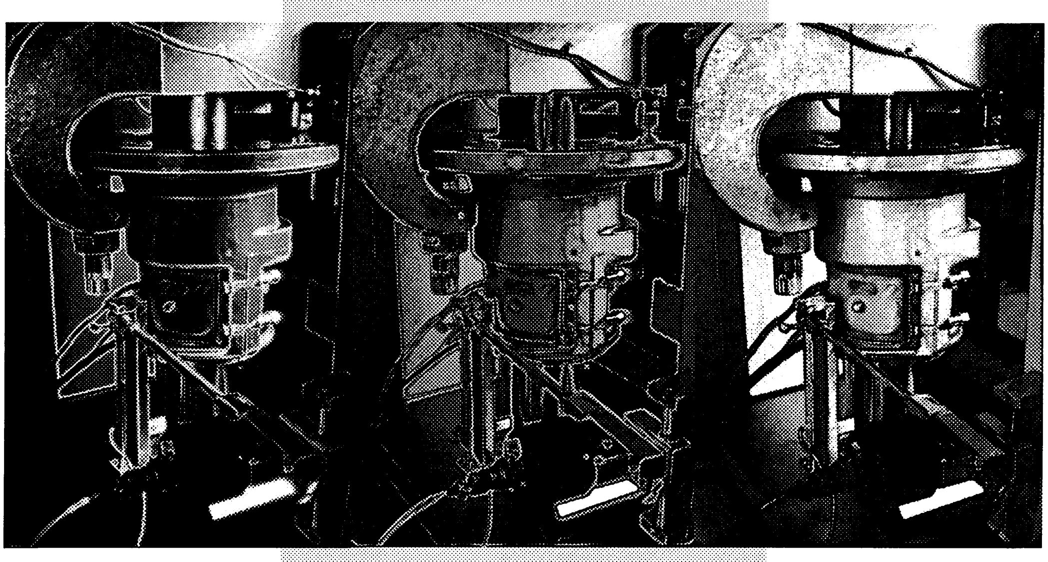
FINAL REPORT

DETERMINING THE COMPACTIVE EFFORT REQUIRED TO MODEL PAVEMENT VOIDS USING THE CORPS OF ENGINEERS GYRATORY TESTING MACHINE



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16. Abstract

Various agencies have used the Corps of Engineers gyratory testing machine (GTM) to design and test asphalt mixes. Materials properties such as shear strength and strain are measured during the compaction process. However, a compaction process duplicating void levels in the pavement after traffic has not been clearly defined when using the oil-filled roller. The intent of this project was to determine the laboratory compactive effort for the GTM that duplicates the voids in pavement after being exposed to traffic.

Samples of asphalt mix were obtained during construction of ten field projects and tested in the laboratory with six different compactive efforts using various angles of gyration and vertical pressures. Voids were also measured in pavement immediately after construction and after several years of exposure to traffic. Regressions were then developed to allow the prediction of pavement voids from the voids obtained by the laboratory compaction procedures. A high correlation between voids obtained in the laboratory and pavement voids after several years of traffic was obtained with the gyratory testing machine at two combinations of gyratory angle and vertical pressure; however, the degree of correlation was mostly dependent on the inclusion of the post-construction voids.

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ABSTRACT

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Samples of asphalt mix were obtained during construction of ten field projects and tested in the laboratory with six different compactive efforts using various angles of gyration and vertical pressures. Voids were also measured in pavement immediately after construction and after several years of exposure to traffic. Regressions were then developed to allow the prediction of pavement voids from the voids obtained by the laboratory compaction procedures. A high correlation between voids obtained in the laboratory and pavement voids after several years of traffic was obtained with the gyratory testing machine at two combinations of gyratory angle and vertical pressure; however, the degree of correlation was mostly dependent on the inclusion of the post-construction voids.

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INTRODUCTION

The gyratory testing machine (GTM), developed by the Corps of Engineers, is used to design asphalt mixes for heavy-duty airfield pavements. Murfee and Manzione indicate that the GTM is still preferable to the Marshall method of mix design for pavements subjected to very heavy loads.[1] Mississippi, Maine, and Kansas have also used the Corps GTM to analyze and design asphalt mixes.

One of the earliest models of the GTM, located at Purdue University, has been used in several laboratory studies.[2,3] This model found that bituminous mixtures could be effectively designed based on their compaction and shear strain properties. The GTM can be used as a traffic simulation device to measure changes in compaction and shear strain properties of mixtures when they are placed in service. The sensitivity of mixtures with respect to variations in gradation and asphalt content also can be studied.

After considerable research using a GTM with an air roller instead of the oil-filled roller, Ruth concluded, "The gyratory compaction and densification testing procedure provides rapid assessment of a mixture's shear resistance as related to changes in asphalt content, aggregate gradation, and density."[4] The apparatus measures the shear resistance necessary to resist rutting type deformation. Ruth identified a compactive effort for the air-filled roller to simulate the density achieved by the construction process and that following traffic.

Although the compactive effort has been identified for the air-filled roller, it has not been clearly distinguished for the oil-filled roller. Three compaction variables define the compactive effort: the angle of gyration, vertical pressure, and the number of revolutions. The vertical pressure is usually taken as the tire pressure representing the traffic that will be on the mixture, commonly 827 kPa. Although a 17.45 mrad angle of gyration often has been used, lesser angles are believed to simulate traffic better. Typical values for the number of gyrations used for evaluation have been 30 and 60 revolutions. However, the GTM manufacturer has indicated a preference for evaluation at a point when the rate of compaction decreases to a minimum value of 16 $kg/m^3/100$ revolutions.

The author used the recommended compactive effort (achieved by the combination of 17.45 mrad angle of gyration, 827 kPa vertical pressure, and evaluation when the rate of compaction reaches 16 kg/m^3/100 revolutions) on various mixes he sampled in Virginia shortly after acquisition of the GTM. There were indications that this compactive effort was too severe, resulting in low air voids. The researcher concluded that he needed to determine which combination of compaction variables yielded the same densities reached in pavement after subjection to traffic.

PURPOSE AND SCOPE

The purpose of this study was to identify the compactive effort for the Corps of Engineers gyratory testing machine that produces approximately the same void level as that reached in pavement after being exposed to traffic. The study involved the following activities: 1) the sampling of mix from 10 paving projects; 2) construction of laboratory samples with the GTM at various compactive efforts; and 3) the sampling of the paving projects after exposure to traffic to determine the void level.

RESEARCH METHOD

The researcher obtained samples of surface mix from ten resurfacing projects. Each of these projects was then cored after 28 to 44 months to determine void levels after traffic. Although some densification may have continued on some of the projects, it is believed that the void level had nearly stabilized by then.

The researcher took samples of mix from each project to the laboratory, where he performed gyratory shear tests at differing levels of compaction by varying the angle of gyration and vertical pressure. Six combinations of angle of gyration and vertical pressure were used. The angle of gyration was varied from 8.72 to 26.18 mrad, and the vertical pressure used was either 689 kPa or 827 kPa. The researcher then determined the voids total mix (VTM) on the compacted specimens.

The researcher attempted to develop a correlation between the voids achieved at each compaction level and the voids in the pavement after being subjected to traffic. Other factors, such as total traffic level and post-construction pavement void level, were also considered in the correlations. The degree of correlation was one of the primary considerations in selecting the most satisfactory compaction level.

Procedures

Sampling Mixes and Coring

The researcher attempted to locate projects on primary and interstate highways where traffic would have a significant effect on the compaction of the pavement. The compaction by traffic to a critical level is a primary cause of the instability and ultimate shear failure in permanent deformation types of distress. Since one of the projects was on a secondary route with very high traffic, a measurement of the amount of truck traffic was not readily available. For this reason, this project was not included in the part of the data analysis incorporating traffic.

The researcher obtained samples of plant mix from each project and recorded their location so that cores could be taken at a later date. Pavement samples were also removed by dry-sawing immediately after construction to identify the post-construction void levels. If the pavement received insufficient compaction during construction, it would definitely have a major influence on the final void level after traffic.

Laboratory Compaction

The researcher compacted the plant mix samples in the GTM using each of the test combinations shown in Table 1.

Table 1. Combinations of Angle of Gyration and Vertical Pressure

Compaction Level	Angle of Gyration, mrad	Vertical Pressure, kPa
1	8.72	689
2	872	827
3	13.09	827
4	17.45	689
5	17.45	827
6	26.18	689

With several modifications, the researcher used the ASTM "Standard Test Method for Compaction and Shear Properties of Bituminous Mixtures by Means of the U.S. Corps of Engineers Gyratory Testing Machine (GTM)" to compact each specimen.[5] Instead of keeping the angle of gyration constant at 17.45 mrad, it was varied from 8.72 to 26.18 mrad to yield different compactive efforts. Also, instead of recording the shear strength and shear strain at 30 and 60 revolutions and then concluding the test, these values were recorded at regular intervals until the rate of densification decreased to 16 kg/m^3/100 rev. The equipment manufacturer suggested this evaluation point. At that point, the research team stopped the compaction, measured the wall friction, and removed the specimen from the machine. The researcher measured bulk specific gravities and defined the resultant VTM, calculating the ultimate voids.

Since the Virginia Department of Transportation (VDOT) has used the Marshall test method for many years, the researcher used this test to compact the mixes to see how well it would predict the final void level of the pavement. Because these mixes were placed under what were considered to be fairly heavy traffic conditions, a 75-blow compactive effort was used. In retrospect, this effort was too high. The current thinking of the state paving industry and departmental engineers supports a 75-blow effort only for very heavy traffic. Some of the projects that used the 75-blow effort should probably have used the 50-blow effort instead, as it might have better simulated the compaction effect of average traffic.

RESULTS

Pavement Voids

A summary of test results for each project is presented in Table 2. The void levels achieved during the construction process before the pavement was exposed to traffic were relatively high. The only project to achieve single digit voids was the secondary route mentioned above, which was not included in part of the analysis because of the lack of traffic data. Certainly the post-construction void level, which ranged from 7.3 to 15.0 percent in this study, should have had an influence on the magnitude of voids reached after the sampled pavement areas were exposed to traffic. The "final" voids, after exposure to several years of traffic, ranged from 3.1 to 7.7 percent. Traffic reduced the post-construction voids on average by approximately half.

Table 2. Traffic and Void Data Results

Route	Mix	Total 18 kip ESAL x 10^3	Post Const VTM	Final VTM	75-blow Marshall VTM	VTM at Various Compactive Efforts Angle (mrad)/Vertical Pressure (kPa)					
						8.72/689	8.72/827	13.09/827	17.45/689	17.45/827	26.18/689
58	SM-2C	137	12.2	7.2	4.7	6.3	5.5	3.2	1.9	1.7	0.6
I-64H	S-10M	877	10.3	5.5	4.4	5.6	5.9	3.7	2.4	2.4	1.2
29	SM-2C	982	10.1	4.6	5.0	6.9	6.6	3.6	2.2	1.7	2.1
01	SM-2C	513	13.3	7.6	6.1	9.4	6.6	4.3	4.9	3.0	2.0
28	SM-2C	250	15.0	7.7	5.8	8.0	6.7	4.0	2.5	2.3	1.2
I-64NK	SM-2C	1066	13.2	7.2	5.1	6.6	6.2	3.6	2.5	2.4	1.2
I-66	SM-2C	1176	11.9	5.5	5.0	8.1	7.8	5.0	3.4	3.0	1.2
I-77	SM-2C	2160	11.1	5.6	3.2	6.4	6.0	4.1	3.1	2.4	----
I-81	SM-2C	2931	11.0	6.6	5.4	6.9	6.1	2.9	1.8	1.0	0.1
663	SM-3C	----	7.3	3.1	4.2	4.3	5.4	3.1	1.2	1.4	0.2

Effects of Angle of Gyration and Vertical Pressure

The compaction curves for each of the ten mixes are shown in Figures 1-10. The curves at different compaction efforts appear to be parallel for a specific mix. As expected, increases in the angle of gyration and vertical pressure yield a higher compactive effort, shifting the curves downward. By comparing the voids at different levels of compactive effort, the effect of both the gyratory angle and vertical pressure can be observed.

Figures 1–6. Laboratory Voids Varying Angle of Gyration and Vertical Pressure

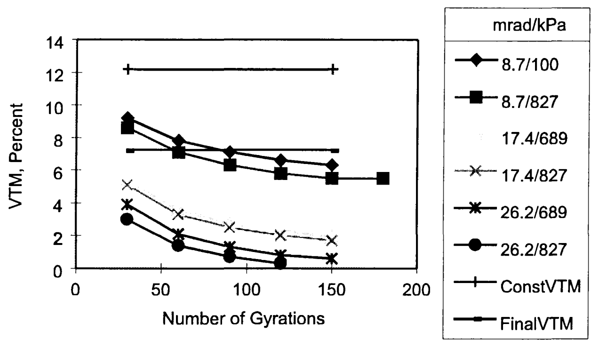

Figure 1. Route 58

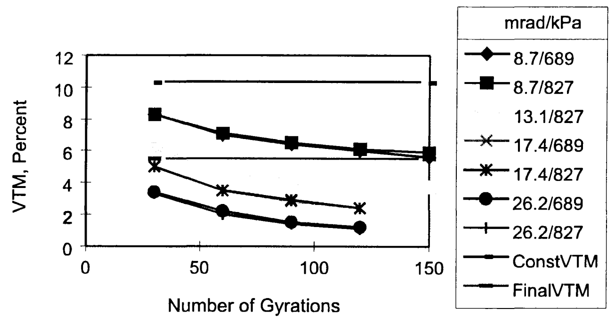

Figure 2. I-64H

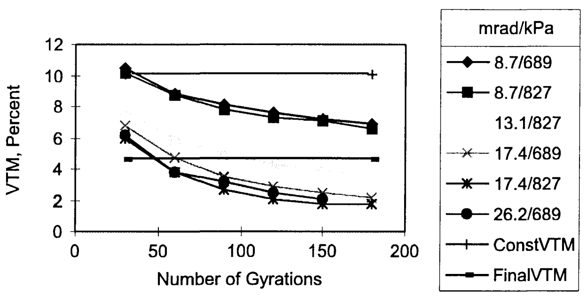

Figure 3. Route 29

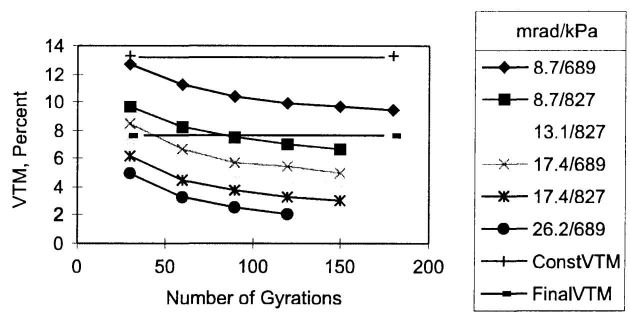

Figure 4. Route 1

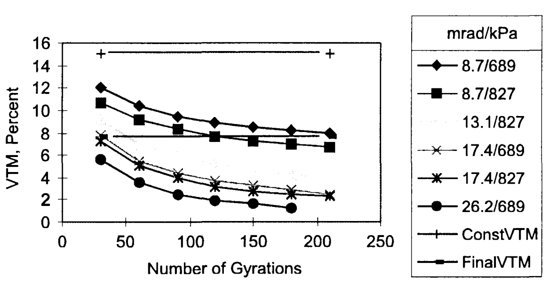

Figure 5. Route 28

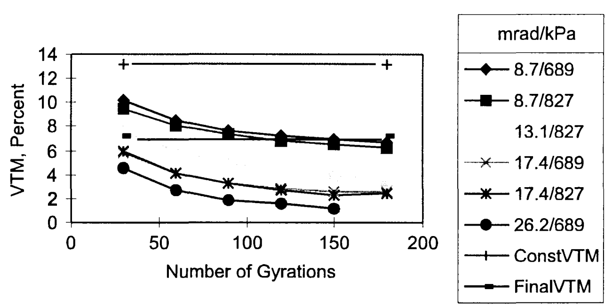

Figure 6. I-64NK

Figures 7-10. Laboratory Voids Varying Angle of Gyration and Vertical Pressure

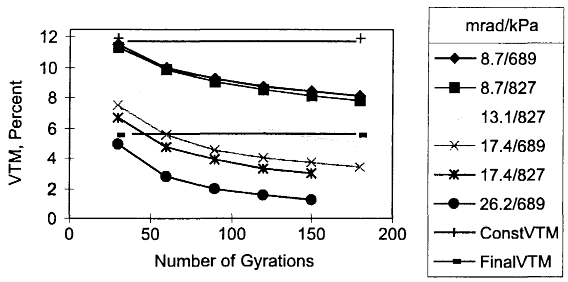

Figure 7. I-66

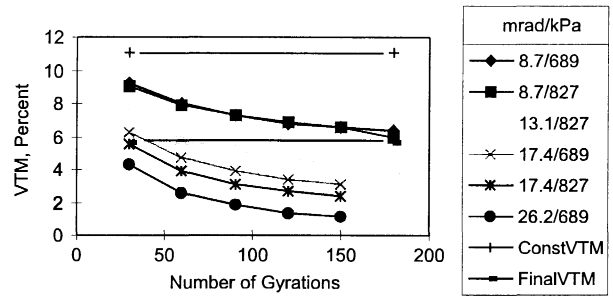

Figure 8. I-77

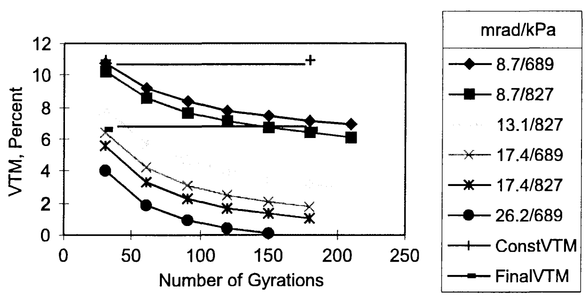

Figure 9. I-81

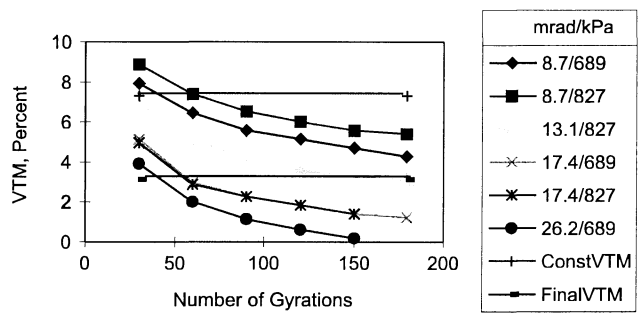

Figure 10. Route 663

Generally, an increase in vertical pressure from 689 kPa to 827 kPa tended to reduce the void level approximately one percent; however, in some instances the change was negligible. It is thought that the vertical pressure is analogous to the tire pressure of traffic traveling on the pavement. Although vertical pressure may correlate with the degree of loading exerted by tires, the gyratory shear test is not an exact duplication of what takes place on the roadway. One cannot be sure that a test performed at a certain vertical pressure will duplicate the behavior of the mix on the roadway exposed to the same tire pressure.

The researcher made a similar comparison of voids obtained at different angles of gyration, but at the same vertical pressure for each of the ten mixes. A change in the angle of 8.7 mrad generally produced a change in the void level of at least 2 percent. The researcher found that dependable results could be achieved only by making sure the angle did not vary significantly from test to test.

Development of Regressions

The coefficients for the multiple linear regressions developed to predict pavement voids after traffic by using voids from the gyratory shear tests are listed in Table 3.

Table 3. Multiple Regression Results

	Coefficients of Independent Variables and Constant Values for Regression Equations to Predict Final Pavement Voids						
				VTM at Various GTM Compactive Efforts (mrad/kPa)			
Regression R^2	Total ESAL x 10^{-7}	Post Const. VTM	75-blow Marshall VTM	8.72/689	8.72/827	13.09/827	Constant
0.74	1.44	0.686		-0.128			-1.10
0.88	1.62	0.694			-0.668		2.12
0.86	0.61	0.673				-0.675	0.81
0.74	1.46	0.581	0.175				-1.62
0.86[a]		0.690		-0.0889			-1.29
0.92[ab]		0.730			-0.591		1.34
0.92[a]		0.726				-0.656	0.14
0.86[a]		0.617	0.118				-1.64

a - The Route 633 project was included because unavailable traffic data was not necessary.
b - Example of regression: Pavement VTM = 0.730 (Post Const. Voids) - 0.591 (GTM voids) + 1.34

The first series was developed using 80 kN (18 kip) equivalent axle loads (ESAL) of total traffic, post construction voids, and ultimate voids. The independent variables were obtained by the laboratory method; pavement voids acted as the dependent variable. The second series was developed excluding traffic but including post-construction voids. Voids obtained by the laboratory method acted as the independent variable. The researcher observed that inclusion of the traffic variable tended to decrease rather than increase the degree of correlation. This result indicates that the effect of traffic was not represented properly by ESALs. Also, other factors such as poor traffic estimates and speed of traffic may have had a significant influence on the results.

The regressions developed with an 8.72 and 13.09 mrad angle of gyration and 827 kPa vertical pressure, but containing no traffic variable, both had high R-square terms (0.92). This value indicates a good correlation. The standard error of estimate was 0.48 percent voids, which is reasonable. A closer examination of the effects of the two independent variables on the degree of correlation was revealing. The post-construction voids had a major effect on the degree of correlation that was achieved. An R-square of approximately 0.85 was achieved for the correlation, using only post-construction voids as an independent variable. These numbers indicate that the GTM was not very useful in predicting final pavement air voids.

Prior to the initiation of this project, VDOT began to use 75-blow Marshall designs and a higher design void content of three to six percent for the SM-2C mixes used in this field study. It has been observed that most of these mixes now are "dry;" even though rutting is no longer a problem, durability has suffered. The author also believes that the dry mixes may have influenced the degree of correlation in this study between the compaction method and the final pavement voids. The dry mixes are difficult to compact during construction; therefore, the void contents tend to be high. The high voids probably resulted in stiffening of the asphalt cement, which possibly prevented the field mixes from reaching the void levels achieved in the laboratory with fresh asphalt.

From visual observations, it appears that the voids of specimens using the gyratory shear test with an angle of 8.72 mrad and 827 kPa vertical pressure most closely approximated the absolute final pavement voids. The correlations developed using the 75-blow Marshall voids were not quite as good as the correlations with the gyratory shear test.

CONCLUSIONS

1. A good correlation was obtained between pavement voids and voids obtained in the laboratory with the gyratory shear test; however, the degree of correlation was highly dependent on inclusion of post-construction voids as an independent variable. Although the GTM contributed to the correlation, its performance was somewhat disappointing.

2. A slightly lower degree of correlation was obtained between pavement voids and voids obtained with the 75-blow Marshall compactive effort.

3. Total traffic in terms of ESALs did not aid the degree of correlation obtained, although it is known to have a significant influence on the final voids. The estimation and inclusion of traffic effects needs to be refined further.

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