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New Jersey 08405

# Review of Recent Research on Using Gyratory Compaction to Design Hot Mix Asphalt for Airfield Pavements

November 2013

Final Report



U.S. Department of Transportation
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16. Abstract

This document is a critical review of three recent reports detailing research on the appropriate level of design gyrations to use when preparing hot mix asphalt (HMA) mix designs for airfield pavements using the gyratory compactor. Research performed at the U.S. Army Corp of Engineers Engineering Research and Development Center (ERDC) recommended using 70 gyrations when designing HMA for airfield pavements using the gyratory compactor. The results from research using a similar approach, sponsored by the Federal Aviation Administration (FAA) and performed by SRA International, Inc. (SRA) and several other contractors, concurred that 70 gyrations was an appropriate compaction level. This research also found that HMA designed using 75-blow Marshall compaction and 70 gyrations exhibited similar levels of rut resistance and fatigue resistance when evaluated in laboratory tests. A third study, Airfield Asphalt Pavement Technology Program (AAPTP) Project 04-03, also examined the issue of using gyratory compaction to design HMA for airfield pavements. In this project, it was recommended that design gyrations should increase with increasing tire pressure. For example, the AAPTP 04-03 report recommended that, for HMA subject to aircraft tire pressures in excess of 200 $lb/in^2$, 80 gyrations should be used in preparing specimens during the mix design process. Although the concept of linking design gyrations to aircraft tire pressure has merit, the performance test used in developing these recommendations was not calibrated to actual pavement performance. Therefore, it is recommended that 70 gyrations be used in preparing mix designs for HMA for airfield pavements, in accordance with the ERDC and FAA/SRA reports.

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| | |
|---|---|
| AAPTP | Airfield Asphalt Pavement Technology Program |
| AAT | Advanced Asphalt Technologies, LLC |
| ACY | Atlantic City International Airport, New Jersey |
| APA | Asphalt Pavement Analyzer |
| CHO | Charlottesville Albemarle Airport, Virginia |
| EHE | Equivalent highway ESAL |
| ELM | Elmira Regional Airport, Elmira, New York |
| ERDC | Engineer Research and Development Center |
| ESAL | Equivalent single axel load |
| FAA | Federal Aviation Administration |
| HMA | Hot mix asphalt |
| JFK | John F. Kennedy International Airport, New York |
| JMF | Job mix formula |
| LEX | Blue Grass Airport, Lexington, Kentucky |
| NAPTF | National Airport Pavement Test Facility |
| NCHRP | National Cooperative Highway Research Program |
| NTU | Oceana Naval Airfield Station, Virginia Beach, VA |
| PG | Performance grade |
| SRA | SRA International, Inc. |
| VMA | Voids in the mineral aggregate |

## EXECUTIVE SUMMARY

Recently, three reports dealing with the use of gyratory compaction in designing hot mix asphalt (HMA) for airfield pavements have been published:

- "Development of $N_{design}$ Criteria for Using the Superpave Gyratory Compactor to Design Asphalt Pavement Mixtures for Airfields," by J.F. Rushing, U.S. Army Engineer Research and Development Center (ERDC), Geotechnical and Structures Laboratory, Vicksburg, Mississippi, December 2009.

- "Implementation of Superpave Mix Design for Airfield Pavements, Vol. I: Research Results," Final Report, by L.A. Cooley, B.D. Prowell, E.R. Brown, and A. Kvasnak, Airfield Asphalt Pavement Technology Program (AAPTP) Project 04-03, March 2009.

- "Final Report, FAA/SRA Gyratory Compaction Project," by D.W. Christensen, T. Bennert, R. Bonaquist, H. Brar, and R.D. McQueen, September 2010.

This document is a critical review of these three reports and present conclusions and recommendations based on this review.

The ERDC research, as detailed in J.F. Rushing's report, focused on determining the number of gyrations required to achieve the same air void content as produced using 75-blow Marshall compaction. A wide range of mixes were included in this research. Aggregates used included Alabama limestone, Arkansas granite, and Mississippi chert/gravel. Three aggregate sizes were used and the aggregates were blended into coarse, fine, and center gradations. The mixes were designed with and without 10% natural sand. Two different binders were used: a performance grade (PG) 64-22 and a polymer-modified PG 76-22. The various combinations of aggregate type, size, gradation, natural sand content, and binder resulted in a total of 52 different mix designs. When compacted to 3.5% air voids using 75-blow Marshall compaction, all the mixes made using the PG 64-22 binder met Federal Aviation Administration (FAA) P-401 requirements (included in Advisory Circular 150/5370-10). However, a number of the mixes made using the PG 76-22 binder failed the flow number requirement of P-401; one mix had an air void content above the minimum requirements of this standard. In the ERDC study, the average value of N-equivalent was found to be 69 gyrations. Most of the factors evaluated had an effect on N-equivalent, as expected. Rushing recommended that 70 gyrations be used to compact specimens in the gyratory compactor when designing HMA for airfield pavements.

In the AAPTP 04-03 project, researchers looked at N-equivalent, but also examined how the mixes selected for the study compacted under traffic, and how much compaction effort was needed to provide adequate rut resistance for the intended application. Eleven primary mixes were used in the study, including seven designed using Marshall compaction and four designed using gyratory compaction. These mixes replicated mixes used in existing airfield pavements from a wide geographic area, and represented a variety of aggregate types, sizes, gradations, and binders. The 95% confidence interval for N-equivalent for 75-blow Marshall compaction was 43 to 55 gyrations, significantly lower than in the ERDC study. Ultimately, the AAPTP 04-03 researchers based their recommendations on the relationship between the number of gyrations and rutting resistance, as measured using the flow number test, as performed on the asphalt mixture performance tester. Specimens were prepared using two to four gyration levels with varying binder contents, and were then subjected to the flow number test. From these data, the minimum number of gyrations required to prepare specimens passing the flow number test was determined. The final recommendations were given in table form, giving design gyrations as a function of aircraft tire pressure. At tire pressures below 100 $lb/in^2$, 50 gyrations are to be used; at tire pressures from 100 to 200 $lb/in^2$, 65 gyrations are to be used; and at tire pressures above 200 $lb/in^2$, 80 gyrations are to be used in preparing specimens.

In the FAA/SRA study, an approach similar to the ERDC study was used, in that much of the work focused on determining N-equivalent for a range of mixtures. However, in the FAA/SRA study, all the mixes used to determine N-equivalent were based on HMA designs used in airfield pavements that have exhibited good performance (mixes used in the ERDC study were not based on ones from actual airfield pavements). Furthermore, the FAA/SRA study performed laboratory tests to compare the rut resistance and fatigue resistance of mixes designed using both Marshall and gyratory compaction. In the FAA/SRA study, the average value of N-equivalent was 62; the researchers recommend using 70 gyrations to prepare specimens, since the difference between 62 and 70 gyrations is probably negligible. The rutting resistance of mixes designed using 70 gyrations was found to be slightly better overall than the same mixes designed using 75-blow Marshall compaction. The fatigue resistance of the mixes designed using the two procedures was found to be similar.

Comparing the three studies, the ERDC and FAA/SRA efforts used similar approaches and produced an identical primary recommendation: HMA for airfield pavements should be designed using 70 gyrations. The N-equivalent range found in the AAPTP 04-03 project was significantly lower than this value, but it should be noted that many of the mixes used in this project had marginal or even poor performance records. More weight should, therefore, be given to the ERDC and FAA/SRA recommendations to use 70 gyrations. The concept of using higher gyration levels to compact HMA intended for use in airfield pavements subject to high tire pressure, as presented in the AAPTP 04-03 report, has merit. However, the performance test used to develop the specification recommendations for design gyrations has not been calibrated or otherwise linked to actual pavement performance. Additional research may be warranted to further evaluate linking design gyrations to aircraft tire pressure.

## 1. INTRODUCTION.

This report presents the results of a review of recently completed research on the use of gyratory compaction to design hot mix asphalt (HMA) for airfield pavements. Reports detailing the results of three different projects were reviewed:

- "Development of $N_{design}$ Criteria for Using the Superpave Gyratory Compactor to Design Asphalt Pavement Mixtures for Airfields," by J.F. Rushing [1].

- "Implementation of Superpave Mix Design for Airfield Pavements, Vol. I: Research Results," by L.A. Cooley, B.D. Prowell, E.R. Brown, and A. Kvasnak [2].

- "Final Report, FAA/SRA Gyratory Compaction Project," by D.W. Christensen, T. Bennert, R. Bonaquist, H. Brar, and R.D. McQueen [3].

The results of these projects were somewhat consistent. Although there is good agreement between Rushing's report [1] (hereafter called the Engineer Research and Development Center (ERDC)) and the report by Christensen, et al. [3] (herein referred to as SRA International, Inc. (SRA)/Advanced Asphalt Technologies, LLC (AAT)/Soiltek), the findings by Cooley, et al., [2] in Airfield Asphalt Pavement Technology Program (AAPTP) Project 04-03 differ substantially from those of the other two reports. This report summarizes the research described in these three projects, presents a short critical review, and makes several conclusions and recommendations on the basis of this review. It should be noted that the author of this review is the primary author of the FAA/SRA/ report.

## 2. THE ERDC RESEARCH ON GYRATORY COMPACTION FOR HMA AIRFIELD PAVEMENTS.

The ERDC report [1] was published in December 2009. The research was performed at the U.S. Army ERDC in Vicksburg, Mississippi. The research was specifically designed to determine the appropriate gyration level to use in designing HMA for airfield pavements.

### 2.1 GENERAL APPROACH.

The general approach used was to design a variety of mixtures according to P-401 specifications from Advisory Circular (AC) 150/5370-10 [4] using Marshall compaction and a design air void content of 3.5%. Several aggregates and binders were used, and some mixtures contained natural sand, while others did not. Most of the mixtures tested met P-401 requirements, but some did not. These mixtures were then compacted with the gyratory compactor using several different levels of compaction; the data was analyzed to determine the number of gyrations needed to obtain an air void content of 3.5%, i.e., the N-equivalent, and indicated the $N_{design}$ value providing equivalent compaction to 75-blow Marshall compaction.

## 2.2 MATERIALS.

Two asphalt binders were used in this research: a performance grade (PG) 64-22 and a PG 76-22 polymer-modified binder, both supplied by Ergon Asphalt and Emulsion, Inc. The following aggregates were used:

- A limestone aggregate supplied by Vulcan Materials in Alabama
- A granite from the McGeorge Corp. quarry in Arkansas
- A chert gravel from Green Bros. Gravel Co. in Mississippi

These aggregates were combined in a wide array of blends, all meeting P-401 specifications. The aggregate gradations used are listed in table 1. Note that these aggregate blends were not based on existing airfield HMA mix designs. In the initial Marshall stability test, the fine and coarse chert/gravel designs with the PG 64-22 binder failed to meet stability criteria. Therefore, an intermediate aggregate gradation was used in place of the fine and coarse gradations for this aggregate. Table 2 summarizes the Marshall mix designs made using the PG 64-22 binder, indicating that all mixes met P-401 requirements. Table 3 is the corresponding table for mixes made using the PG 76-22 binder; in this case, many of the mix designs failed to meet the Marshall flow criteria (flow >14) established in P-401. Also, the 3/4″ coarse mix without mortar sand made with the limestone aggregate had air voids that were slightly high (4.3% >4.2% maximum).

Table 1. Aggregate Blends Used in ERDC Study

| Aggregate Size | Gradation | Mortar Sand Content Wt. % | Aggregate Type | | |
|---|---|---|---|---|---|
| | | | Limestone | Granite | Chert Gravel |
| 1/2″ | Center | 0 | --- | --- | XXX |
| | | 10 | --- | --- | XXX |
| | Fine | 0 | XXX | XXX | --- |
| | | 10 | XXX | XXX | --- |
| | Coarse | 0 | XXX | XXX | --- |
| | | 10 | XXX | XXX | XXX |
| 3/4″ | Fine | 0 | XXX | XXX | XXX |
| | | 10 | XXX | XXX | XXX |
| | Coarse | 0 | XXX | XXX | XXX |
| | | 10 | XXX | XXX | XXX |
| 1″ | Fine | 0 | --- | XXX | --- |
| | | 10 | --- | XXX | --- |
| | Coarse | 0 | --- | XXX | --- |
| | | 10 | --- | XXX | --- |

Table 2. Marshall Mix Designs Using PG 64-22 Binder

| Aggregate Size | Gradation | Mortar Sand Content (Wt. %) | Aggregate Type/Did Mix Meet P-401 Requirements? | | |
|---|---|---|---|---|---|
| | | | Limestone | Granite | Chert Gravel |
| 1/2″ | Center | 0 | --- | --- | Yes |
| | | 10 | --- | --- | Yes |
| | Fine | 0 | Yes | Yes | --- |
| | | 10 | Yes | Yes | --- |
| | Coarse | 0 | Yes | Yes | --- |
| | | 10 | Yes | Yes | --- |
| 3/4″ | Fine | 0 | Yes | Yes | Yes |
| | | 10 | Yes | Yes | Yes |
| | Coarse | 0 | Yes | Yes | Yes |
| | | 10 | Yes | Yes | Yes |
| 1″ | Fine | 0 | --- | Yes | --- |
| | | 10 | --- | Yes | --- |
| | Coarse | 0 | --- | Yes | --- |
| | | 10 | --- | Yes | --- |

Table 3. Marshall Mix Designs Using PG 76-22 Binder

| Aggregate Size | Gradation | Mortar Sand Content (Wt. %) | Aggregate Type/Did Mix Meet P-401 Requirements? | | |
|---|---|---|---|---|---|
| | | | Limestone | Granite | Chert Gravel |
| 1/2″ | Center | 0 | --- | --- | Flow high |
| | | 10 | --- | --- | Flow high |
| | Fine | 0 | Flow high | Yes | --- |
| | | 10 | Yes | Yes | --- |
| | Coarse | 0 | Flow high | Yes | --- |
| | | 10 | Yes | Yes | --- |
| 3/4″ | Fine | 0 | Flow high | Yes | Flow high |
| | | 10 | Yes | Yes | Yes |
| | Coarse | 0 | Flow high<br>Voids high | Yes | Flow high |
| | | 10 | Yes | Yes | Yes |
| 1″ | Fine | 0 | --- | Yes | --- |
| | | 10 | --- | Yes | --- |
| | Coarse | 0 | --- | Yes | --- |
| | | 10 | --- | Yes | --- |

2.3 RESULTS.

Table 4 lists the N-equivalent values determined in the ERDC study for each combination of aggregate type, aggregate size, aggregate gradation, mortar sand content, and binder grade. Note that each value, in general, is the average of two individual determinations on a compacted specimen. A few values shown in the table are the average of three determinations. Figure 1 is a histogram of the N-equivalent values using individual determinations—hence, there are more than double the number of observations in the histogram as in table 4.

Table 4. N-equivalent Values Determined in ERDC Study

| Aggregate Type | Maximum Aggregate Size | Gradation | Mortar Sand Content (Wt. %) | Asphalt Grade PG 64-22 | Asphalt Grade PG 76-22 |
|---|---|---|---|---|---|
| Granite | 1/2″ | Fine | 0 | 80 | 125 |
| | | | 10 | 50 | 99 |
| | | Coarse | 0 | 85 | 125 |
| | | | 10 | 43 | 65 |
| | 3/4″ | Fine | 0 | 30 | 125 |
| | | | 10 | 94 | 104 |
| | | Coarse | 0 | 45 | 81 |
| | | | 10 | 40 | 76 |
| | 1″ | Fine | 0 | 65 | 106 |
| | | | 10 | 35 | 80 |
| | | Coarse | 0 | 43 | 67 |
| | | | 10 | 68 | 79 |
| Limestone | 1/2″ | Fine | 0 | 93 | 86* |
| | | | 10 | 35 | 52 |
| | | Coarse | 0 | 61 | 60* |
| | | | 10 | 39 | 53 |
| | 3/4″ | Fine | 0 | 76 | 55* |
| | | | 10 | 49 | 66 |
| | | Coarse | 0 | 68 | 75** |
| | | | 10 | 42 | 61 |
| Chert Gravel | 1/2″ | Center | 0 | 62 | 61** |
| | | | 10 | 21 | 46** |
| | 3/4″ | Fine | 0 | 54 | 44 |
| | | | 10 | 39 | 38 |
| | | Coarse | 0 | 35 | 52* |
| | | | 10 | 25 | 49* |

*These mixes had flow values above the maximum of 14.
**This mix had a flow value above the maximum of 14, and an air void content above the maximum value of 4.2.

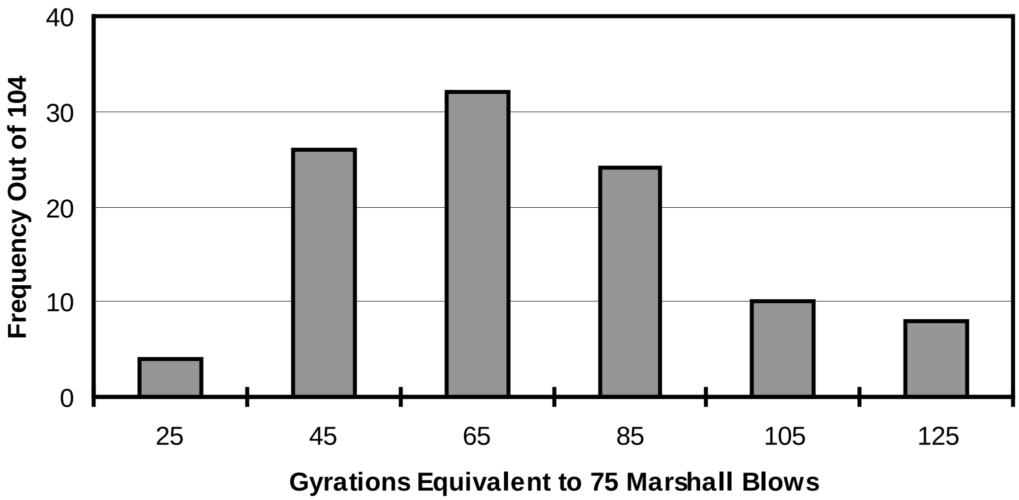


Figure 1. Histogram of N-equivalent Values From ERDC Study

The ERDC authors concluded (on the basis of figure 1) that the data were not normally distributed; therefore, the methods of statistical analyses used were not dependent on the assumption of normality. However, an analysis of the data in table 4 suggests that the data follow a log-normal distribution. Figure 2 is a normal probability plot of the data in table 4, in which observed values of N-equivalent are plotted against expected z-values, calculated assuming a log-normal distribution. The data plot, as a nearly perfect straight line, strongly indicating a log-normal distribution.

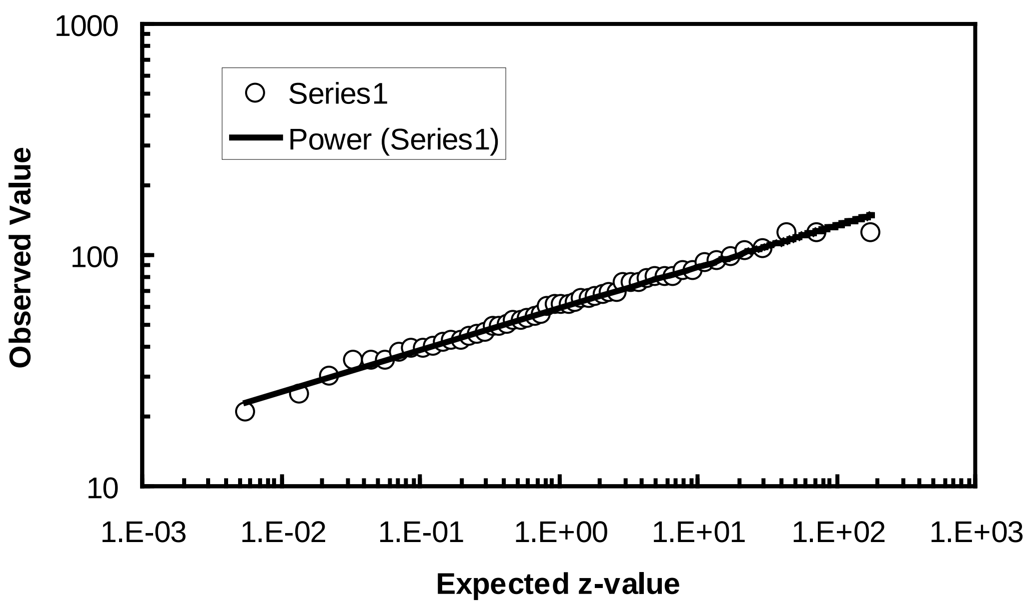


Figure 2. Observed N-equivalent Value Plotted Against Expected z-Value Calculated on the Assumption of a Log-Normal Distribution

## 2.4 STATISTICAL FINDINGS OF ERDC STUDY.

### 2.4.1 Effect of Mortar Sand.

The N-equivalent values for mixes with mortar sand were significantly less than for those without mortar sand (average values 59 and 75, respectively). The method of statistical analysis used was the Mann-Whitney rank sum test, which can be used to evaluate data that are not normally distributed.

### 2.4.2 Effect of Aggregate Type.

The Kruskal-Wallis one-way analysis of variance by ranks was used to evaluate the effect of aggregate type on N-equivalent. Median values were 50, 84, and 69 for the chert gravel, granite, and limestone aggregates, respectively, with the differences being highly significant. Dunn's method of comparison indicated that the pairwise differences between each set of aggregates were always significant.

### 2.4.3 Effect of Aggregate Size.

The Kruskal-Wallis one-way analysis of variance by ranks was used in this case also. The differences among the three aggregate sizes were not statistically significant; however, it should be mentioned that the p-value was 0.051, which is only slightly higher than the level of 0.05 normally used as a cutoff for statistically significance in engineering analysis. A p-value of 0.05 indicates that an effect is highly significant, not merely significant. Using such a low p-value in this case minimizes the chance of wrongly concluding that an effect is significant when it is in fact not, but creates a greater chance of making the opposite error—concluding a factor is not significant when in fact it is. A more conservative and logical conclusion here would be that aggregate size is likely a significant factor that affects the N-equivalent.

### 2.4.4 Effect of Aggregate Gradation.

The Mann-Whitney rank sum test was used to determine if there is a difference in N-equivalent for fine versus coarse aggregate gradations. The results showed that there was, in fact, a significant difference ($p = 0.047$), with the fine aggregate being somewhat more difficult to compact in the gyratory (N-equivalent of 80 versus 69 for the fine and coarse gradations, respectively).

### 2.4.5 Effect of Binder Grade.

The Mann-Whitney rank sum test was again used to determine the effect of binder grade on N-equivalent. The median value of N-equivalent was 62 and 66 for the PG 64-22 and PG 76-22 binders, respectively, and this difference was found to be statistically significant at $p = 0.027$.

The overall mean value for N-equivalent was found to be 69. The authors recommended using 70 gyrations in the design of HMA for airfield pavements. The authors also evaluated the effect of the number of gyrations on average air void content; the results are shown in table 5.

Table 5. The Effect of Number of Gyrations on Air Void Content in ERDC Study

| Number of Gyrations | Effect on Air Void Content Relative to 70 Gyrations (%) |
|---|---|
| 50 | +0.93 |
| 60 | +0.42 |
| 70 | 0.00 |
| 80 | -0.035 |
| 90 | -0.065 |

2.5 CONCLUSIONS OF THE ERDC STUDY.

The following conclusions were made.

- When using Marshall compaction, no significant difference was found in the design asphalt binder content for mixes with PG 64-22 binders and those with PG 76-22 binders.
- The value of N-equivalent was affected by aggregate type, aggregate gradation, mortar sand content (0% versus 10%), and binder grade. Note: although the authors concluded aggregate size did not affect N-equivalent, it probably does.
- The mean value of N-equivalent was 69. Changing N-design by 10 gyrations resulted in an average air void content change of less than 0.5%.
- A large percentage of the mixtures studied failed to meet requirements for both N-initial and N-max, as described in Engineering Brief 59A [5].

2.6 RECOMMENDATIONS.

An N-design value of 70 should be used for designing HMA for airfield pavements subject to aircraft with a gross weight greater than 60,000 lb. There should be no requirements for N-initial or N-max. Additional research is needed to further evaluate N-initial and N-max, and also to evaluate the field performance of HMA for airfield pavements designed using Superpave methods. A laboratory performance test should be adopted for evaluating mixtures. Airfield pavements made using modified binders should be monitored to determine if they are achieving the same ultimate density as mixes made using non-modified binders. A lower value for N-design might be needed for mixtures containing a polymer-modified binder.

3. THE AAPTP PROJECT 04-03.

The AAPTP Project 04-03 report [2] was published in March 2009, prior to the publication of the ERDC report. It should be noted that the objective of this research was to develop and recommend a method of designing HMA for airfield pavements using the gyratory compactor. Thus, determination of $N_{design}$ was a relatively small part of this research.

## 3.1 GENERAL APPROACH TO DETERMINING N-equivalent.

Three approaches were used to evaluate the relationship between Marshall and gyratory compaction: (1) comparing compaction under traffic loading, (2) comparing density achieved in laboratory compaction, and (3) determining the compaction level needed to provide adequate rut resistance.

## 3.2 MATERIALS.

The mix designs used in the AAPTP 04-03 study are summarized in table 6. A total of 14 mixes from 13 airfield pavements were included in the study. Note that the last three mixes listed in table 6 were described by the researchers as ancillary. Therefore, there were eleven primary mix designs—seven 75-blow Marshall designs and four Superpave designs. The traffic levels and performance of the 11 primary mix designs/airfield pavements are listed in table 7. Note that the pavements exhibited a wide range in performance levels and a variety of distresses.

Table 6. The HMA Mix Designs Used in the AAPTP 04-03 Study

| Airfield | Location | Marshall Blows | Gyrations | Binder Grade | Aggregate Type | Aggregate Size | Air Void Content (Vol. %) | VMA (Vol. %) |
|---|---|---|---|---|---|---|---|---|
| Jacqueline Cochran Regional | Thermal, CA | 75 | --- | AR-4000 | Granite | 3/4″ | 3.8 | 15.2 |
| Mineral County Memorial | Creede, CO | --- | 76 | PG 58-34 | Low Gs/ High Abs/ Crushed Gravel/ NS | 12.5 mm | 4.0 | 15.0 |
| Oxford-Henderson | Henderson, NC | --- | 75 | PG 64-22 | Granite Gneiss/RAP | 9.5 mm | 4.0 | 17.1 |
| Little Rock Air Force Base | Jacksonville, AR | --- | 139 | PG 70-22 | Sandstone | 12.5 mm | 4.0 | 15.1 |
| Naval Air Station-Oceana | Virginia Beach, VA | 75 | --- | PG 70-22 | Granite/20% RAP/ 20% NS | 3/4″ | 3.7 | 17.4 |
| Volk Field | Camp Douglas, WI | --- | 109 | PG 64-28 | Limestone/ 15% NS | 12.5 mm | 2.9 | 14.2 |
| | | 75 | --- | | | 3/4″ | 3.7 | 14.9 |
| Jackson International | Jackson, MS | 75 | --- | AC-30 | Limestone/NS | 19.0 mm | 3.5 | 15.2 |
| Newark Liberty International | Newark, NJ | 75 | --- | PG 64-22 | Granite Gneiss | 3/4" | 4.0 | 16.3 |
| Palm Springs International | Palm Springs, CA | 75 | --- | AC 20P | Granite | 3/4″ | 3.0 | 14.0 |
| Spokane International | Spokane, WA | 75 | --- | AR 4000W | Crushed Gravel/ 13% NS | 3/4″ | 4.0 | 16.0 |
| John Bell Williams | Bolton, MS | 75 | --- | PG 67-22 | Crushed Gravel/ Limestone/11% NS | 19 mm | 3.6 | 15.2 |
| Mid-Delta Regional | Greenville, MS | 75 | --- | AC 30 | Crushed Gravel/ Limestone/10% NS | 12.5 mm | 3.5 | 15.4 |
| Portland International | Portland, OR | --- | 100 | PG 70-22 | Not Specified | 19 mm | 4.0 | 13.7 |

VMA = Voids in the mineral aggregate
NS = Natural sand
RAP = Recycled asphalt pavement
Abs = Absorption
Gs = Specific gravity

Table 7. Traffic Levels and Performance of Airfield Pavements Included in AAPTP 04-03 Study

| Airfield | Traffic Level | Performance |
|---|---|---|
| Jacqueline Cochran Regional | Light | Excellent |
| Mineral County Memorial | Light | Light transverse cracking; raveling |
| Oxford-Henderson | Light | Minimal longitudinal cracks |
| Little Rock Air Force Base | Medium | Some rutting, raveling, and cracking |
| Naval Air Station-Oceana | Heavy | Significant rutting |
| Volk Field | Heavy | Limited transverse and longitudinal cracks |
| Jackson International | Medium | Some cracking at joints; limited raveling |
| Newark Liberty International | Medium | Moderately severe transverse cracks; raveling |
| Palm Springs International | Medium | Excellent |
| Spokane International | Medium | Severe transverse cracking; longitudinal cracking; pop-outs; raveling |

## 3.3 RESULTS.

### 3.3.1 Compaction Under Traffic Loading.

The average in-place air void for the well-performing Marshall mixes was 3.2%, which is typical for the design air void level for the Marshall mix design method. The average in-place air void content for the mixes designed using the Superpave method was 5.6%, more than 2.0% higher than the well-performing Marshall mixes. However, because the sample was so small, no specific conclusions were made on the basis of these observations.

It should be noted that in research performed as part of the National Cooperative Highway Research Program (NCHRP) Projects 9-25 and 9-31 [7], a wide range of pavements designed using both the Marshall method and the Superpave procedure was analyzed; it was concluded that HMA pavements made with mixes designed using the Marshall method exhibited significantly lower in-place air voids than pavements made with Superpave mixes. This was attributed to several factors: (1) higher asphalt binder content for the Marshall mixes; (2) smaller aggregate sizes for the Marshall mixes; (3) finer aggregate gradations for the Marshall mixes; and (4) widespread use of some natural sand in Marshall mixes. During the past 5 to 10 years, the trend in Superpave mix design has been to avoid large aggregate sizes and coarse gradations in surface coarse mixtures. This change, along with additional contractor experience, has probably resulted in a somewhat decreased level of in-place air voids for Superpave pavements, but it is generally accepted that this is still a problem.

### 3.3.2 Comparison of Laboratory Compaction.

As in the ERDC study, a wide range of N-equivalent values were observed in the AAPTP 04-03 research. All mixes included in the study were compacted with the Marshall hammer using both 50 and 75 blows. It was found that the 95% confidence interval for the mean value of N-equivalent was 43 to 55 gyrations for 75-blow Marshall compaction and 32 to 40 gyrations for 50-blow Marshall designs. It should be noted that this analysis assumed that the distribution of N-equivalent values was normal, whereas analysis of the ERDC data, as discussed above, strongly suggested that N-equivalent data follow a log-normal distribution. On the other hand, the data set used in the AAPTP 04-03 study was constructed in a much different fashion compared to the ERDC study, so it is possible that the data were in fact normally distributed. The small size of the AAPTP 04-03 data set made testing of normality problematic.

### 3.3.3 Performance Tests.

All mix designs were compacted from two to four different gyration levels and tested using the flow number test. Note that the asphalt binder content varied, depending on the gyration level—the higher the gyrations, the lower the asphalt binder content. Furthermore, as gyrations increase and asphalt binder content decrease, rut resistance increases. The general approach to the performance tests was to determine the maximum asphalt content at which a given mix would pass the flow number test. Conditions for this test were 50 $lb/in^2$ confining pressure and deviator stress levels of 100, 200, and 350 $lb/in^2$. The test temperature varied, depending on the climate in which the mix was used. The test was performed to a maximum of 20,000 cycles. If the mix did not exhibit tertiary flow within 20,000 cycles, it was determined to have passed the test; if it failed prior to 20,000 cycles, it was considered a failed test. Specific flow number values were not reported, only whether a given mix passed or failed under the specific set of conditions. The results of the performance tests are summarized in table 8; N-equivalent values ranged from 35 to 75 gyrations, and in general, varied with tire pressure—the greater the tire pressure, the greater the N-equivalent value.

Table 8. N-equivalent Values Determined From Performance Tests in AAPTP 04-03

| Airfield | Maximum Gross Wt. (lb) | Maximum Gross Wt. per Tire (lb) | Tire Pressure ($lb/in^{2)}$) | Estimated N-equivalent |
|---|---|---|---|---|
| Jacqueline Cochran Regional | 20,000 | 10,000 | 75 | 50 |
| Mineral County Memorial | 12,500 | 6,250 | 90 | 50 |
| Oxford-Henderson | 30,000 | 15,000 | 75 | 35 |
| Little Rock Air Force Base | 155,000 | 38,750 | 105 | 50 |
| Naval Air Station-Oceana | 66,000 | 33,000 | 240 | 75 |
| Volk Field | 42,500 | 21,250 | 215 | 75 |
| Jackson International | 890,000 | 55,625 | 200 | 35 |
| Newark Liberty International | 873,000 | 54,563 | 200 | 35 |
| Palm Springs International | 800,000 | 52,500 | 200 | N/A |
| Spokane International | 400,000 | 100,000 | 200 | N/A |

## 3.4 RECOMMENDATIONS.

The final recommended levels for gyratory compaction were based largely upon the results of the performance tests. However, the gyration levels necessary for adequate performance, according to the flow number test, were quite low—significantly lower than currently used in designing either highway or airfield pavements. Therefore, the gyration levels were increased to maintain some consistency with current practice. The final recommended gyration levels are given in table 9.

Table 9. N-design Values Recommended in AAPTP Project 04-03 Final Report

| Tire Pressure ($lb/in^2$) | N-design |
|---|---|
| <100 | 50 |
| 100 to 200 | 65 |
| >200 | 80 |

3.5 DISCUSSION OF AAPTP 04-03.

The recommendations given as part of AAPTP Project 04-03 were based almost entirely on the results of rut resistance tests—that is, the flow number test. The approach used was to evaluate rut resistance of the test mixes designed as different compaction levels and to determine the minimum compaction level at which the mixes exhibited adequate rut resistance. There are three problems with this approach.

- Although lowering binder content can increase rut resistance, this can sometimes result in mixes with voids in the mineral aggregate (VMA) values that are too low, resulting in compaction problems, permeability issues, and poor durability. These mixes were not evaluated to determine if the altered binder content was adequate to ensure good durability.

- This approach assumes that the correct binder grade was used in each mix for the given application. This also is not clear. Since traffic mixes were not described for the facilities included in the AAPTP study, the issue of whether the correct binder grade was used in the mix designs cannot be addressed.

- Most importantly, the flow number test, as used in the AAPTP 04-03 project, has not been calibrated in any way to relate to actual pavement performance, either for highway pavements or airfield pavements. The test certainly provides a relative indication of rut resistance, but there are no criteria for characterizing the mixes on a pass/fail basis on the results of this test.

It appears that little confidence can be given to the AAPTP 04-03 report recommendations . One aspect of the recommendations that should be considered is the concept of using different compaction levels in designing airfield pavements. It should be noted that the increase in gyrations with traffic level in the Superpave system was not necessarily meant to ensure lower binder content for mixes with heavy traffic. In fact, many engineers have acknowledged that because of the high cost of asphalt binders, many technicians currently design all their HMA mixes closely to the minimum allowable binder content, regardless of the compaction level. What is perhaps more important is that, as gyration levels increase, it becomes more difficult for soft aggregates to resist breakdown during compaction. At the highest N-design levels, soft aggregates in general, cannot be used because they break down and proper air void content cannot be obtained. This approach is of special interest in airfield pavements because of the extreme high tire pressures used in some aircraft. However, it should be noted that P-401 includes requirements for Los Angeles abrasion (ASTM C 131 [6]), whereas Superpave does not. Thus, P-401 already has requirements to help ensure against aggregate breakdown under traffic. Furthermore, it appears that using a single level of Marshall compaction (75 blows) to design airfield pavements in the past has not resulted in a significant number of pavements in which aggregate breakdown is a problem. Nevertheless, the issue of whether or not to include a second, higher level of gyrations for designing HMA for airfield pavements subject to high tire pressures should probably be addressed.

## 4. THE SRA/AAT/SOILTEK GYRATORY COMPACTION PROJECT.

This research project used a similar approach to the ERDC report, in that much of the effort revolved around determining N-equivalent for a number of mixes. However, in this case, the mixes used were actual HMA designs used in constructing a range of airfield pavements, most of which had a good record of performance. In Phase II of the project, performance tests were performed to ensure that using gyratory compaction (as opposed to Marshall compaction) did not significantly reduce the performance of the mixtures. An interesting feature of this work was the degree of replication—two laboratories replicated the work involved in determining N-equivalent, and each determination was replicated within those two laboratories. Therefore, there is a good indication of the variability involved in the determination of N-equivalent. In Phase I of the project, AAT and Soiltek independently determined N-equivalent values for the eight different airfield HMA mixes listed in table 10. Note that these were properly designed FAA mixes with a good record of field performance. Volumetric data for the job mix formulae (JMF) for these mixes are listed in table 11.

Table 10. Mixes Used in Phase I Test Plan of SRA/AAT/Soiltek Study

| Mix Name/ Code | Airport | Aggregate Type | FAA Maximum Aggregate Size (mm) | Original Binder Grade |
|---|---|---|---|---|
| JFK93 | JKF, New York, NY | Gneiss | 19 | AC 20 |
| JFK97 | JFK, New York, NY | Dolomite | 25 | PG 82-22 |
| JFK96 | JFK, New York, NY | Dolomite/ granite gneiss | 25 | PG 82-22 |
| ACY | ACY, Atlantic City International, NJ | Basalt | 19 | PG 64-22 |
| LEX | LEX, Lexington, KY | Limestone | 19 | PG 70-22 |
| ELM | ELM, Elmira, NY | Crushed gravel | 25 | PG 64-28 |
| NAPTF | NAPTF, Atlantic City International Airport, NJ | Argillite | 19 | PG 64-22 |
| CHO | CHO, Charlottesville Albemarle, NC | Diabase | 25 | PG 64-22 |

ACY = Atlantic City International Airport
CHO = Charlottesville Albemarle Airport
ELM = Elmira Regional Airport
LEX = Blue Grass Airport
JFK = John F. Kennedy International Airport
NAPTF = National Airport Pavement Test Facility

Table 11. The JMF Volumetric Data for the Mixes in the SRA/AAT/Soiltek Study

| Mix Name/ Code | Asphalt Content (Wt. %) | Air Void Content (Vol. %) | VMA (Vol. %) |
|---|---|---|---|
| JFK93 | 5.2 | 3.9 | 16.3 |
| JFK97 | 4.7 | 4.0 | 15.2 |
| JFK96 | 4.7 | 4.0 | 15.4 |
| ACY | 5.0 | 3.5 | 15.7 |
| LEX | 5.7 | 3.8 | 15.7 |
| ELM | 5.8 | 3.4 | 14.0 |
| NAPTF | 5.2 | 3.5 | 15.7 |
| CHO | 5.2 | 3.2 | 16.7 |

ACY = Atlantic City International Airport
CHO = Charlottesville Albemarle Airport
ELM = Elmira Regional Airport
LEX = Blue Grass Airport
JFK = John F. Kennedy International Airport
NAPTF = National Airport Pavement Test Facility

The eight Marshall mix designs in table 11 were independently verified by both AAT and Soiltek. In some cases, this resulted in a change in the design asphalt binder content, but aggregate gradations were generally not changed. However, the aggregates obtained for reproducing the John F. Kennedy International Airport (JFK) designs were apparently somewhat different from those used in the original mix design, so some alteration of the aggregate gradation for these mixes was required. The procedure used in the SRA/AAT/Soiltek study for determining N-equivalent is shown in figure 3. This is essentially the same procedure used in the ERDC study; note that the air void content used to determine the N-equivalent was determined in verification and not the air void content of the JMF. To evaluate the effect of binder grade and type on N-equivalent, three binders were used for each mix design: a PG 64-22 binder, a PG 76-22 binder modified with Novophalt (plastomeric modification), and a PG 76-22 binder modified with styrene-butadiene-styrene (elastomeric modification). Figure 4 summarizes the results, showing the N-equivalent values for the resulting 24 mix designs for each laboratory. This figure includes error bars that represent ±2 standard deviation limits, based on a pooled standard deviation.

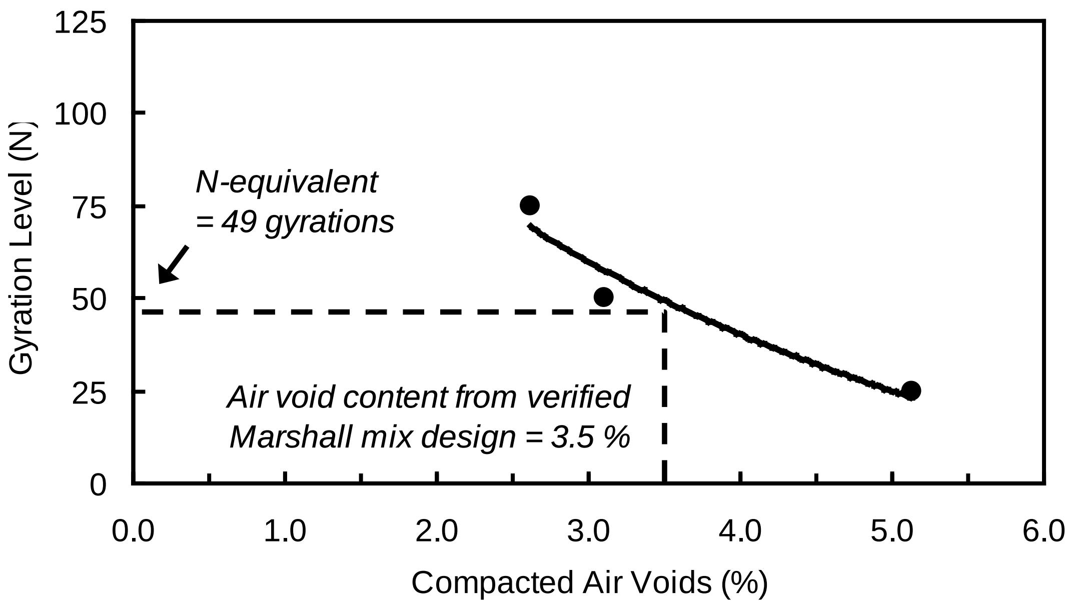


Figure 3. Determination of N-equivalent for the Second Replicate of the ACY Mix Design, as Evaluated in the AAT Laboratory

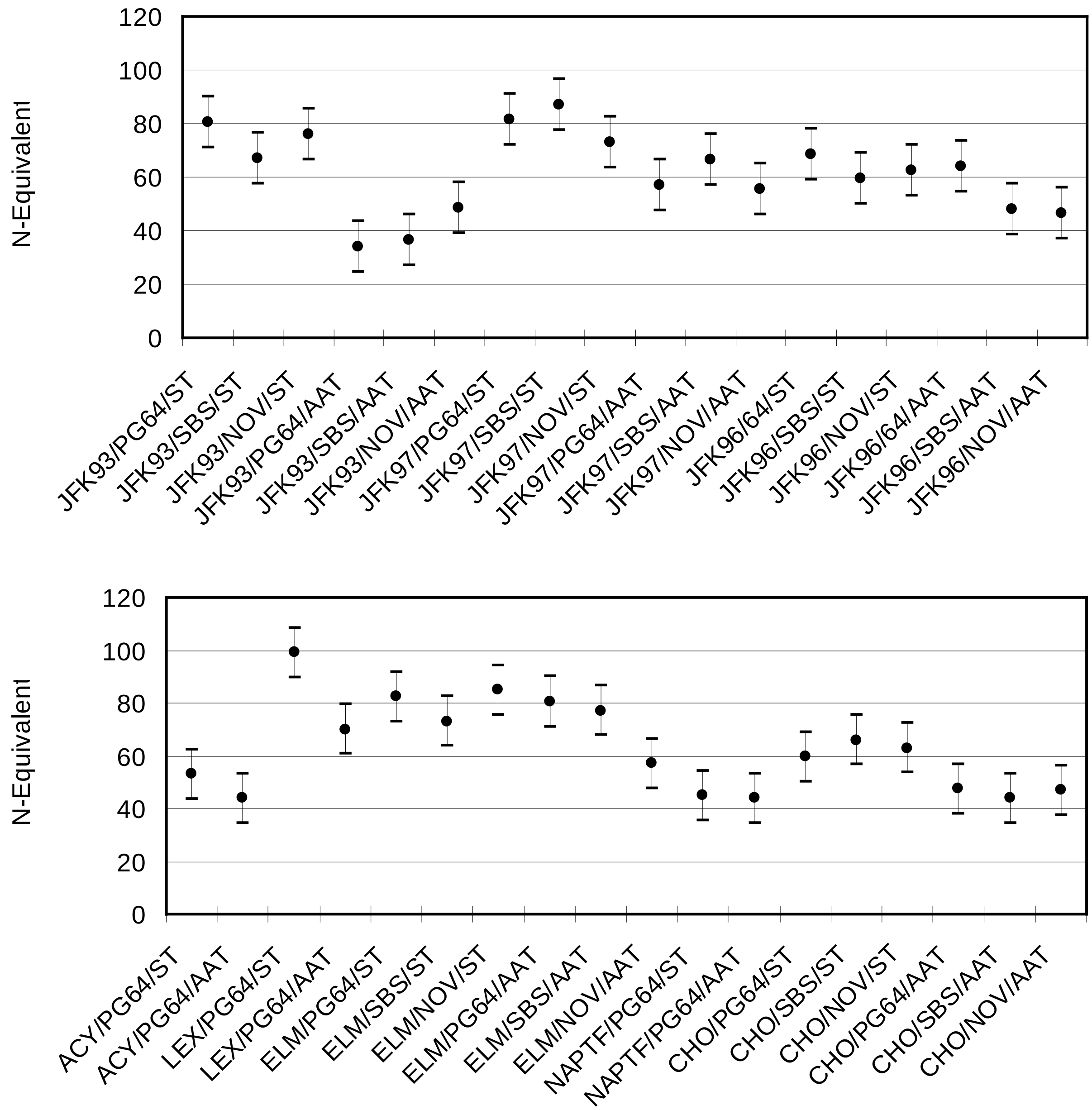


Figure 4. Plot of N-equivalent Values (Error bars show pooled ±2 standard deviation limits for the average value of N-equivalent.)

One question raised by the ERDC study is whether the distribution of N-equivalent values is normal, log-normal, or follows some other distribution. Two probability plots were generated to evaluate the distribution of N-equivalent values. Figure 5 shows a probability plot for the N-equivalent values determined in the SRA/AAT/Soiltek values; the AAT and Soiltek values are plotted separately. Included for comparison are the ERDC values for the N-equivalent. As figure 5 shows, the Soiltek values are normally distributed, but there is a discrepancy in the AAT values; however, the $R^2$ value is still quite high, and the deviation from normality does not appear as significant as for the ERDC data. Figure 6 is a plot of the same three data sets, but in this case, the log of the N-equivalent values has been used. Figure 6 clearly shows that the data in all three sets does, in fact, follow a log-normal distribution. It also appears that the variability for the AAT and Soiltek data are similar, but the mean value is different. This discrepancy was discussed in the final report [3], and was mostly the result of differences in the asphalt binder content of the verified Marshall designs rather than in differences in the gyratory compaction for the two laboratories. The variability in the ERDC study appears to be considerably greater than in the SRA/AAT/Soiltek data (based upon the steeper slope of the ERDC data in the probability plot), but this is not surprising, given that the structure of the experiment in the two studies was substantially different.

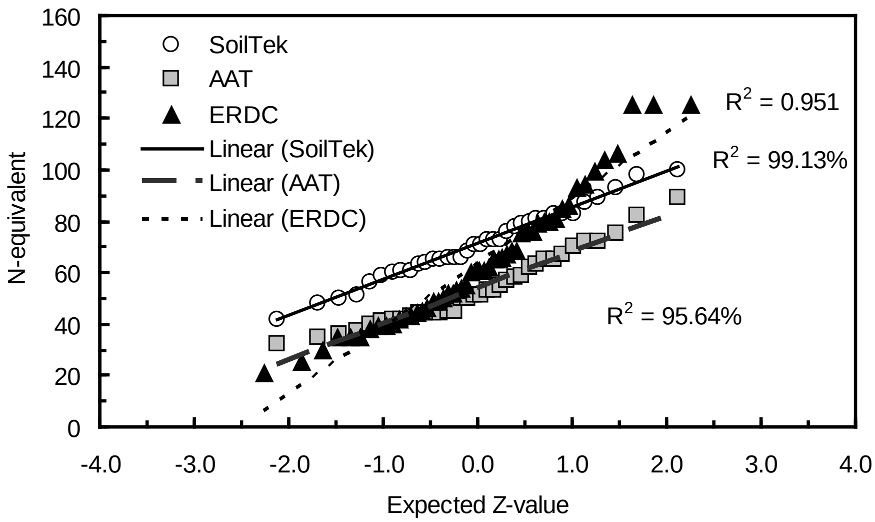


Figure 5. Normal Probability Plot for N-equivalent Values From the ERDC and SRA/AAT/Soiltek Studies

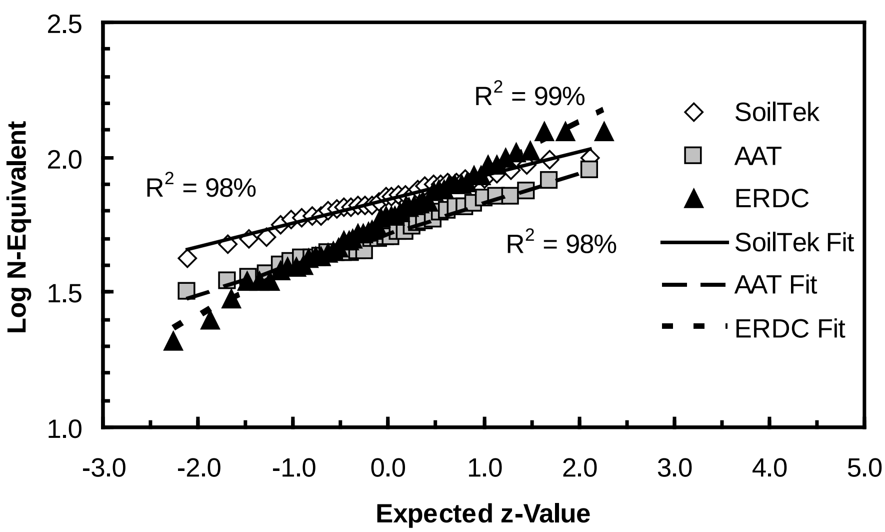


Figure 6. Normal Probability Plot for the Log of N-equivalent Values for the ERDC and SRA/AAT/Soiltek Studies

The conversion of the eight Marshall mix designs into equivalent gyratory mix designs resulted in significant variations in N-equivalent. This suggests that significant differences in binder content and/or aggregate gradation sometimes exists in mix designs performed using the two methods. In Phase II of the SRA/AAT/Soiltek study, performance tests were done to evaluate the rut resistance and fatigue resistance of selected mixes from Phase I of the study. These mixes are listed in table 12. Note that one additional mix from the Oceana Naval Airfield Station in Virginia Beach, VA (NTU), which was not included in Phase I, was subjected to performance testing. This mix was included in the AAPTP 04-03 study and in the performance testing because it was decided that at least one poorly performing mix should be included in the Phase II tests to determine if the performance tests could correctly identify it as potentially exhibiting poor performance.

Table 12. Summary of Mix Designs Subjected to Phase II Performance Tests

| Airport Code | Aggregate Type | FAA Aggregate Size (mm) | Superpave Aggregate Size (mm) | Design Compaction Method | Design Gyrations[a] | Design Binder Content (Wt.%) | Air Void Content (Wt.%) | VMA (Wt. %) | Binder Grade |
|---|---|---|---|---|---|---|---|---|---|
| JFK | Granite Gneiss | 19 | 12.5 | Marshall[b] | 40 | 5.6 | 3.7 | 15.4 | PG 64-22 |
| | | | | Marshall[c] | 74 | 6.7 | 3.8 | 18.4 | PG 64-22 |
| | | | | Gyratory | 70 | 5.2 | 4.1 | 15.0 | PG 64-22 |
| JFK | Dolomite | 25 | 25 | Both | 70 | 5.1 | 4.1 | 15.4 | PG 82-22 |
| | | | | Both | 70 | 5.1 | 3.8 | 15.2 | PG 64-22 |
| ACY | Basalt | 19 | 12.5 | Marshall | 53 | 5.0 | 3.5 | 14.8 | PG 64-22 |
| | | | | Gyratory | 70 | 4.9 | 3.5 | 14.6 | PG 64-22 |
| LEX | Limestone | 19 | 12.5 | Both | 70 | 5.7 | 3.8 | 16.4 | PG 70-22 |
| ELM | Crushed Gravel | 25 | 19 | Both | 70 | 6.2 | 3.6 | 15.5 | PG 64-28 |
| NAPTF | Argillite | 19 | 12.5 | Marshall | 45 | 5.6 | 3.7 | 17.8 | PG 64-22 |
| | | | | Gyratory | 70 | 5.4 | 3.7 | 17.3 | PG 64-22 |
| CHO | Diabase | 25 | 19 | Marshall | 46 | 5.2 | 3.3 | 16.6 | PG 64-22 |
| | | | | Gyratory | 70 | 4.8 | 2.8 | 15.0 | PG 64-22 |
| NTU | Granite | 12.5/19[d] | 19 | Marshall | 50 | 6.6 | 3.5 | 16.7 | PG 70-22 |
| | | | | Gyratory | 70 | 6.2 | 3.8 | 16.0 | PG 70-22 |

[a] For gyratory designs, 70 gyrations were used, representing the average number of gyrations required to produce compaction equivalent to that achieved with 75 blows per side of a standard Marshall compaction hammer. For Marshall designs, the design gyrations is the specific gyration for that mix required to produce compaction equivalent to that achieved in the 75-blow Marshall design; if the equivalent gyrations for a given mix design was within 10 gyrations of 70, the Marshall and gyratory designs were assumed to be equivalent.

[b] Designed by AAT

[c] Designed by Soiltek

[d] This gradation was between FAA 19- and 12.5-mm specifications.

Two performance tests were used to evaluate the rut resistance of the mixtures: the flow number test, using the asphalt mixture performance tester, and the Asphalt Pavement Analyzer (APA). The flow number test involves repeated loading of a cylinder prepared in the gyratory compactor; the flow number represents the number of loading cycles the specimen can withstand before tertiary creep begins. In the APA test, a short, cylindrical specimen cut from a gyratory specimen is repeatedly loaded with a wheel rolling over a pressurized hose on top of the specimen. The APA is normally run at a hose pressure of 100 $lb/in^2$, but in this case, to better simulate the high tire pressures used for many aircraft, a special APA with a hose pressure of 250 $lb/in^2$ was used. The results are typically given in terms of rut depth after 8000 loading cycles. Both tests were run at the average 7-day maximum pavement temperature 20 mm below the surface, at 50%

reliability, as determined using LTPPBind version 3.1. The APA tests were performed by Soiltek; the APA test was run at the FAA's laboratory at National Airport Pavement Test Facility (NAPTF) in Atlantic City International Airport, NJ, on specimens prepared by Soiltek.

The rut test results are shown in figures 7 (flow number) and 8 (APA). Note that in interpreting these figures, an increased rut resistance is indicated by a higher flow number and a lower APA rut depth. In both series of rut resistance tests, the mixes designed with gyratory compaction appeared to have similar, but slightly better, rut resistance compared to the mixes designed using Marshall compaction. Preliminary guidelines for interpreting the flow number test were developed as part of NCHRP Project 9-33; these guidelines were evaluated by the SRA/AAT/Soiltek researchers by applying methodologies developed in AAPTP Project 04-02 for calculating equivalent highway ESALs (EHE) for airfield pavements where ESALs stands for equivalent single-axel loads (ESAL. They concluded that the NCHRP 9-33 flow number guidelines appeared reasonable for use on airfield HMA mixes. However, it must be noted that the NCHRP 9-33 guidelines are very preliminary in nature, and the SRA/AAT/Soiltek tests were performed on a limited number of mixes.

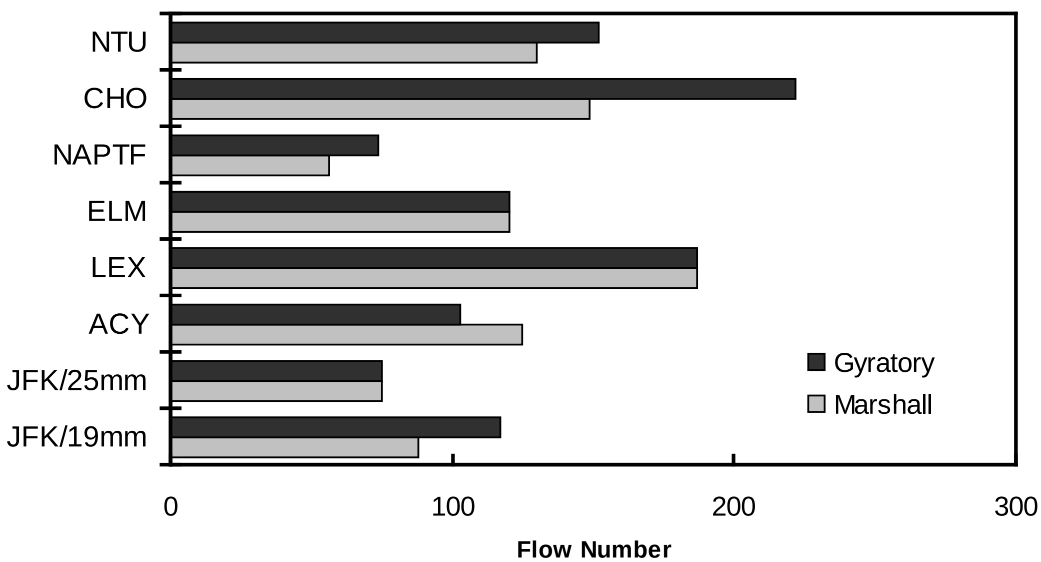


Figure 7. Results for the Flow Number Tests for Phase II Mixes
(excluding JFK/25 mm with PG 82-22)

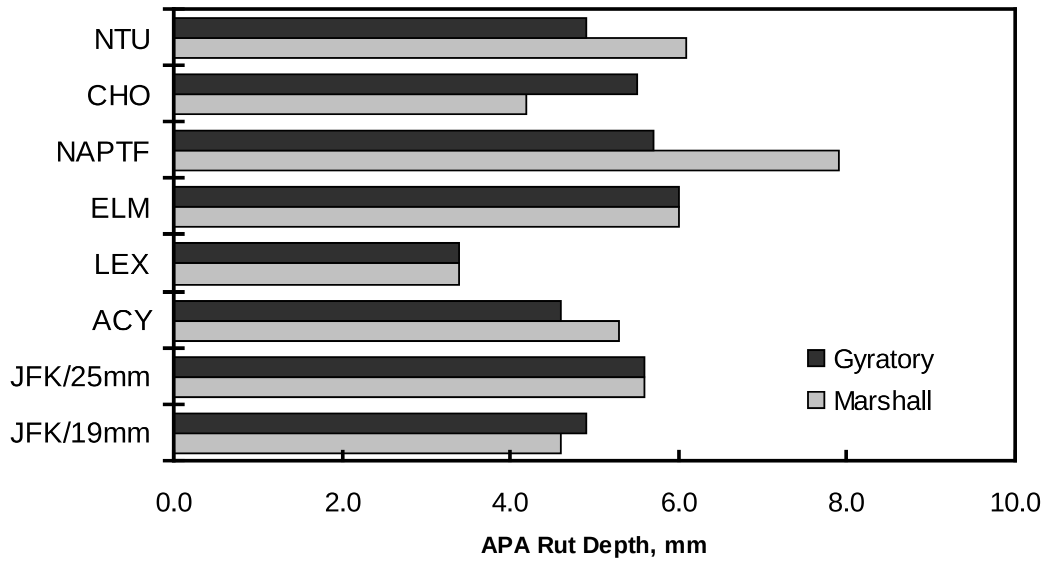


Figure 8. Results for the APA Rut Depth Test for Phase II Mixes (excluding JFK/25 mm with PG 82-22)

Although guidelines for interpreting the APA test were also developed during NCHRP 9-33, these guidelines only applied to the standard hose pressure of 100 $lb/in^2$, and not to the 250 $lb/in^2$ pressure used in the SRA/AAT/Soiltek project. The researchers, therefore, attempted to develop a set of preliminary guidelines for interpreting the APA test run at the higher hose pressure. As with the flow number analysis, the AAPTP 04-02 methodology was used to estimate EHEs and was then related to the observed rut depth. Table 13 lists the recommended APA rut depth value as a function of EHEs, as given in the SRA/AAT/Soiltek report.

Table 13. Preliminary Maximum Rut Depths for the APA Test Run at 250 $lb/in^2$ for Evaluating HMA for Airfield Pavements

| Traffic Level (Million ESALs) | Maximum Rut Depth (mm) |
|---|---|
| <3 | --- |
| 3 to <10 | 8 |
| 10 to <30 | 6 |
| 30 to <100 | 5 |
| 100 to <300 | 4 |
| ≥300 | 3 |

A second set of performance tests were conducted in the SRA/AAT/Soiltek study to evaluate fatigue resistance. The procedure used was based on continuum damage principles as developed by Christensen and Bonaquist [8]. Uniaxial fatigue tests were performed on the mixes at 20°C and 4°C. The results were analyzed to given parameters describing the damage curves. These results were then used, along with modulus values determined during the test, to estimate fatigue life in thick and thin pavements at both test temperatures. The results are shown in figure 9. There was little difference in the observed fatigue resistance of the mixes designed with the Marshall and gyratory compactors.

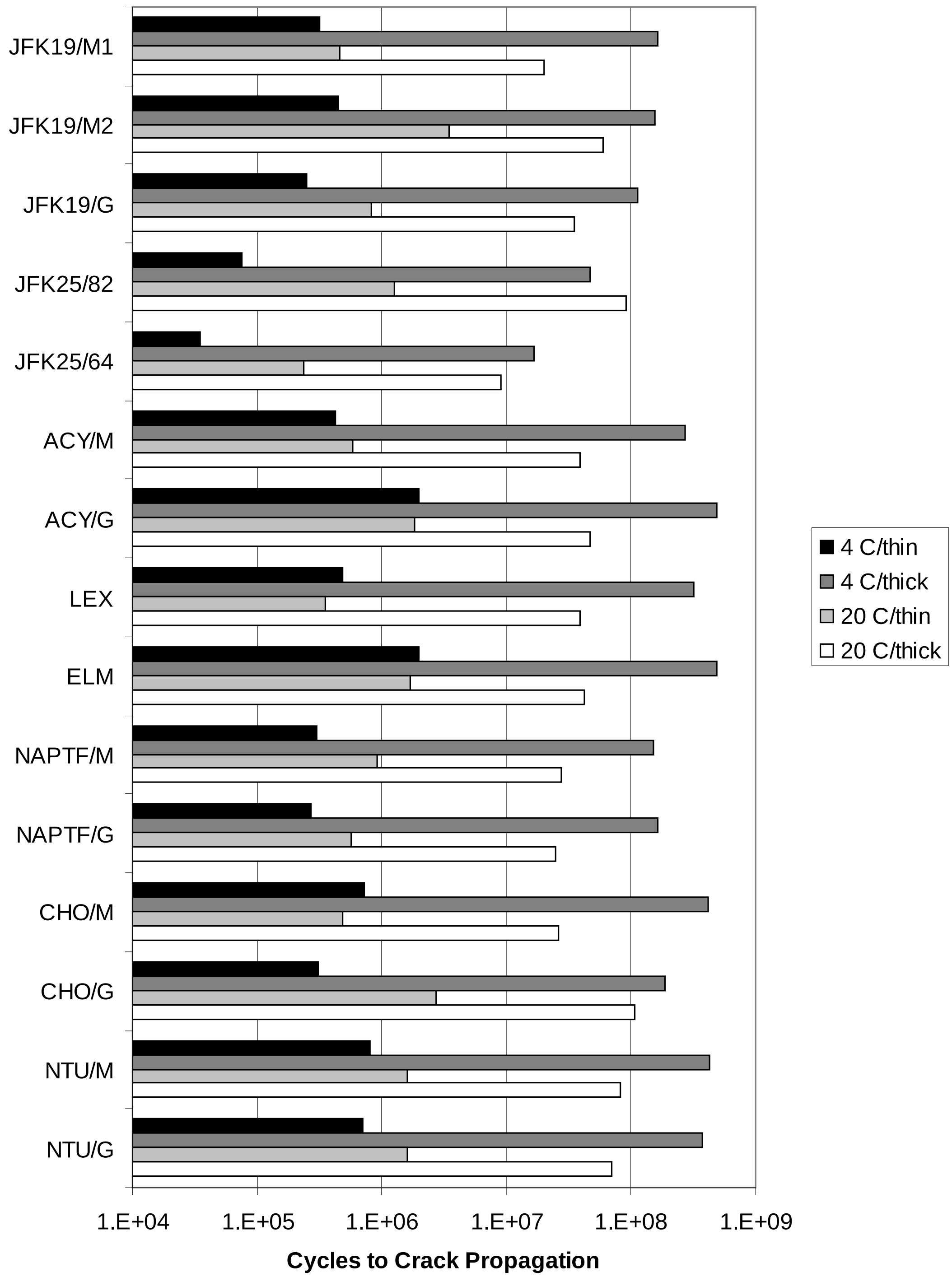


Figure 9. Estimated Cycles to Crack Propagation for Phase II Mixes for Different Temperatures and Pavement Structures

The most important conclusions of the SRA/AAT/Soiltek report were as follows:

- When designing airfield HMA mixes with the Superpave gyratory compactor, a compaction level of 70 gyrations will provide similar volumetrics on average to that produced with 75 blows of a Marshall compaction hammer. However, there is significant variation in the relationship between Marshall and gyratory compaction for airfield HMA mixes.

- In many cases, converting an existing Marshall design for airfield HMA mix to a gyratory design can be done with a slight adjustment in the asphalt binder content. However, in some cases, adjustment of the aggregate gradation may be needed to achieve a mix design that meets all FAA requirements using gyratory compaction.

- In laboratory tests conducted during this research, mixes designed using the gyratory compactor with $N_{design}$ = 70 achieved slightly better rut resistance on average than companion 75-blow Marshall designs. This was most likely the result of slightly lower binder contents for the gyratory mix designs. In practice, it should be expected that there will be little or no difference in the rut resistance of airfield HMA mixes designed using 75-blow Marshall and $N_{design}$ = 70 gyratory compaction.

In laboratory tests conducted during the SRA/AAT/Soiltek research, airfield HMA mixes designed using gyratory compaction with $N_{design}$ = 70- and 75-blow Marshall compaction exhibited similar levels of fatigue resistance as indicated by uniaxial, continuum damage fatigue tests.

## 5. DISCUSSION.

Based upon the summaries presented above, the approach used by ERDC and by SRA/AAT/Soiltek in determining N-equivalent was quite similar and produced similar results, with ERDC reporting an average N-equivalent value of 69 and SRA/AAT/Soiltek reporting an average N-equivalent value of 62. The difference of 7 gyrations should not be considered significant. The method used in these two projects was to determine at what gyration level mixes prepared using the gyratory compactor had the same air void content as those prepared using 75-blow Marshall compaction. The approach used in the AAPTP 04-03 project was much different, and was mostly based on the results of a performance test that has not been calibrated to either highway or airfield HMA performance. The results of this research should therefore not be considered in evaluating N-equivalent. The only data that should be considered is the ERDC and SRA/AAT/Soiltek data. The ERDC recommended that a gyration level of 70 be used in designing airfield HMA pavements, and SRA/AAT/Soiltek agreed that their findings were consistent with this recommendation.

A second issue raised in the review of the three research projects is that of how the N-equivalent data are distributed statistically. The ERDC concluded that their N-equivalent data did not follow a normal distribution, but the data was skewed, and they selected their statistical analysis methods accordingly. Analyses performed as part of this review suggest that N-equivalent data from both the ERDC and the SRA/AAT/Soiltek projects follow a log-normal distribution rather than a normal distribution. However, the practical implications of this finding are not significant. One ramification, for example, is that the average value of N-equivalent should be calculated not as an arithmetic average, but as an average of the log transform. Because the authors of this review did not have access to the complete set of ERDC data (individual replicate determinations were not reported), this calculation could not be made; but using the average N-equivalent data (reported by the ERDC) to calculate the logarithmic average suggests that the average value of N-equivalent calculated would be closer to 60 rather than 70 gyrations. This suggests that perhaps the gyration level selected for designing airfield pavements should be lowered from 70 to 60 gyrations. The effect of this change would not be large, but may result in mixes that would be slightly easier to compact in the field. This could ensure good durability for airfield HMA pavements designed using the gyratory compactor.

A third issue that arose in the review of the three research projects dealing with N-equivalent was whether to include a higher gyration level for use in designing airfield HMA for use in pavements subject to high tire pressure, e.g., above 200 or 250 $lb/in^2$. Such an approach would ensure that mixes used in such applications would not be prone to aggregate breakdown. However, it is not clear if this would be necessary or even beneficial. It is suggested that this issue be addressed in the ongoing research on high tire pressure being conducted by SRA/AAT/Soiltek. Specifically, the question can be posed in terms of whether to keep a single gyration level of 70 for all airfield HMA pavements, or to adopt a system of two gyration levels, 60 for pavements subject to low to moderate tire pressure, and 80 or 90 for pavements subject to high tire pressure.

## 6. CONCLUSIONS AND RECOMMENDATIONS.

The research at the Engineer Research and Development Center (ERDC) and the SRA International, Inc. (SRA)/Advanced Asphalt Technologies, LLC (AAT)/Soiltek research on gyratory compaction used similar approaches and came to similar conclusions, suggesting that 70 gyrations is a suitable compaction level to use in the design of hot mix asphalt (HMA) for airfield pavements. The Airfield Asphalt Pavement Technology Program (AAPTP) 04-03 project used a different approach, relying on an uncalibrated performance test to relate compaction level to tire pressure. The recommendations of AAPTP 04-03 are, therefore, questionable, and the recommendations of ERDC and SRA/AAT/Soiltek to use 70 gyrations appears reasonable.

There is some logic in using two gyration levels in the design of HMA pavements—one level for pavements intended for low to moderate tire pressures and a higher gyration level for pavements subject to high tire pressures. This approach should be evaluated to determine if it will help better ensure the performance of HMA pavements used by aircraft with high tire pressures ($>250\ lb/in^2$).

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