Comparison of Marshall and SUPERPAVE™ Level I Mix Design for Asphalt Mixes

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ABSTRACT

Mix designs were conducted on 14 different mixtures categorized as: Conventional; wet process asphalt rubber (manufacturer preblended); dry process rubber asphalt and polymer modified mixes. These designs were developed using both the Marshall procedure and the SUPERPAVE™ gyratory Level I procedure. This paper presents a comparison between the design asphalt contents results obtained by the two procedures. The SUPERPAVE designs were conducted at a traffic level compared to traffic for the 75 blow Marshall procedure and for three climatic regions representative of cool to warm conditions.

Major problems were encountered with the SUPERPAVE gyratory approach for five mixtures within the dry process rubber asphalt groups. These problems appear to be related to the high resiliency of the rubber aggregate during the gyratory compaction process coupled with time dependent swell of these mixtures directly after compaction. It is concluded that the SUPERPAVE Level I mix design approach is not applicable to those mixtures.

For the other three groups of mixtures studied, differences between the binder contents from the Marshall and SUPERPAVE were found to be a function of the group type. Differences in design content obtained from the SUPERPAVE gyratory were found to be about 1.0% more asphalt as the climatic regions went from warm to cool conditions. This finding was true for all types of mixtures studied.

In general, the conventional mixtures and manufacturer preblended rubber asphalts gave similar design values between the Marshall and "warm" SUPERPAVE climatic region. In contrast, 0.5% to 0.8% less asphalt was found for the SUPERPAVE design, in warm conditions, compared to the Marshall design for the polymer modified asphalts investigated

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INTRODUCTION

The main objective of the laboratory mix design process for asphalt mixtures is to determine the combination of binder and aggregate that, when properly constructed, will yield an asphalt mixture that will withstand loading and environmental distress throughout the intended design and performance period.

The two most common mix design procedures used in the United States are the Marshall and Hveem procedures with the former being the most widely used. In 1993, SHRP presented the SUPERPAVE^{TM} laboratory mix design procedure which is based upon a gyratory compaction device (5). Conceptually, the SUPERPAVE^{TM} laboratory testing procedure is intended to be applicable for all types of asphalt mixtures : virgin and recycled hot mixtures, with or without modified binders even though SHRP research almost universally focused upon conventional asphalt mixtures and binders.

The SUPERPAVE^{TM} mix design procedure recommends three distinct hierarchical levels of design termed Level I. II and III, which are dependent upon the anticipated traffic volume. Also, under each design level, the influence of the project site climatic conditions (related to design air temperature) are also combined in the mix design process. Table 1 presents SUPERPAVE^{TM} guidelines for the number of design gyrations to be used under design Level I for different design air temperatures and traffic (ESAL's). This design number of gyrations. coupled with the specific mixture gyratory densification curves developed for each mix under different asphalt contents, can be used to determine the design asphalt content. In summary, it can be observed that the final design asphalt (binder) content will depend upon: traffic level and environmental conditions.

In contrast to the proposed SUPERPAVE^{TM} gyratory mix design approach, the Marshall mix design uses an impact hammer to achieve the design level of compaction (air voids) as a basis for establishing the design asphalt content. The compaction energy is controlled by the number of blows the specimen will be subjected to in the compaction process. The majority of agencies using the Marshall, specify 35, 50 or 75 blow compaction consistent with the anticipated traffic level ($\leq 10^4$; $10^4 - 10^6$; $> 10^6$

respectively). For this widely used mix design process, it can be recognized that the final design asphalt (binder) content will depend only upon traffic level.

STUDY OBJECTIVES

The major objectives of this study were twofold. The first objective was to obtain quantitative information on the difference in design asphalt contents determined by the Marshall design and SHRP-SUPERPAVE gyratory Level I procedure for a variety of mixtures. The second objective was to develop a preliminary assessment of the applicability of the SUPERPAVE Level I design to several types of non-conventional (rubber and polymer modified) mixtures.

It should be clearly recognized by the reader, that the pursuit of these objectives should not be misconstrued to show that the final design asphalt contents from one approach are much better than another as this can only be accomplished, in the authors' opinion, by a rigorous lab study encompassing more fundamental test procedures (e.g., moduli, permanent deformation, fatigue) on a given mix, at a unique combination of air-asphalt binder percentage. Nonetheless, the study presented does serve a very useful purpose in that it provides, for the first time, some knowledge of the anticipated differences in design asphalt content between the two major compaction process evaluated. Because of the limited number of the mixtures evaluated, it is hoped, however, that other agencies will conduct similar type studies to broaden the data base, results and implications of this study.

MIXTURES INVESTIGATED

A total of 14 different mixtures were evaluated in the initial phase of the comparative mix design study. These mixtures have been classified into the four major groups identified in Table 2. Additional work is currently being pursued in the second study phase (not reported in this paper). The major groups investigated were: Group 1 : Conventional Mixtures; Group 2 : Wet Process Asphalt Rubber (Manufacturer Preblended); Group 3 : Dry Process Rubber Asphalt and Group 4 : Polymer Modified.

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Future (stage 2) work will involve mix design comparisons for six separate mixtures to be categorized as Group 5 : Wet Process Asphalt Rubber (Plant Blended).

For all mixtures investigated , the aggregate type, source, stockpile gradations and maximum nominal size were identical except for the two Plus Ride mixtures. A MSHA dense aggregate grading with maximum nominal size of 12.5mm (1/2") were used for all mixes except the Plus Ride mixtures where an open grading was used with a maximum nominal size of 12.5mm (1/2") and 19.0mm (3/4") for Plus Ride No. 12 and No. 16 respectively. Table 3 summarizes the job mix gradation for all of the mixes studied.

SELECTION OF MIXING AND COMPACTION TEMPERATURES

Lab mixing and compaction temperatures for all mixtures were selected in accordance with viscosity criteria stated by the Asphalt Institute in MS-2 ([1]). For each mix, the same mix/compaction temperatures were used for both the Marshall and SUPERPAVE[TM] Level I mix design procedures. Mixing temperatures were selected at a binder viscosity range of 150-190 centistokes while the compaction temperature range corresponded to a binder viscosity range of 250-310 centistokes. Viscosity - temperature relationships for each binder were developed using the relationship:

$$\log \log \eta \ (cp) = A_i + VTS_i \log T_R$$

where : η (cp) - viscosity in centipoise

T_R - temperature in degrees Rankine

A_i, VTS_i - regression constants

In general, these binder relationships were developed from Penetration data at : 39.2, 50, 77, 90 $^\circ$F; Softening Point; Kinematic and absolute viscosity tests as well as Brookfield viscosity results. A summary of the binder A_i and VTS_i values; as well as the resulting backcomputed mixing and compaction temperatures is shown in Table 4.

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MARSHALL MIX DESIGN

Test Procedure

The Marshall test method ,as described in The Asphalt Institute (TAI) manual (MS-2) (1), was used to select the "optimum/design" binder contents for all the mixes investigated in this study. Some modifications were made for the use of the Marshall procedure on the dry process asphalt rubber mixes (Group 3). For all mixtures investigated in this study, 3 - 4 different binder content percentages were selected for the Marshall stability analysis. Binder percentages progressed in 1.0 percent increments to cover an air void range between 3.0% to 5.0% . with three replicates at each binder content. The aggregates were first combined in general accordance with the Job Mix Formula (JMF) and then manually separated according to sieve sizes after blending. The specific amount required for each size was then calculated to form an aggregate blend of 1200 gm. conforming as close as possible to the JMF.

For the of asphalt rubber dry processed mixes. crumb rubber was added to the hot aggregate at the calculated mixing temperature and according to its percentage in the total mix. The binder , at the calculated mixing temperature was then added to the aggregate/aggregate rubber blend by an amount according to its percent in the mix. The mix was then wet mixed. for about 2 minutes. at the mixing temperature. in order to insure that the aggregate/rubber particles were completely and uniformly coated by the binder.

Upon mixing, the loose mixture was then placed in an oven. at 320° F. for a time period of one hour. This aging process was used to simulate the short term aging during mixing and laydown conditions. After that, samples were compacted. at the calculated compaction temperature. using an automatic Marshall hammer with 75 blows per side. To prevent expansion of the rubber compacted mixes (dry process) in the molds during the cooling period; immediately after compaction, two plugs were placed under and above the specimen. in the molds, and then at least a 10 pound weight was placed above the specimen. After the specimens cooled to room temperature, they were removed from the molds and their height and weight in air and in water were recorded. The specimens were then immersed in a water bath maintained at 140° F and after 30 - 40 minutes they were removed from the water bath and tested

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immediately using the Marshall apparatus. Stability and the flow values were recorded. Bulk density, Specific Gravity, Voids (air), Voids in mineral aggregate. Voids filled with asphalt, and the stability/flow values were calculated for each specimen and the average for the replicates at the same binder content were also calculated.

Selection of Design Binder Contents

Design binder contents were selected, for each mixture, at air void levels of 3.0%, 4.0% and 5.0%. These results, for 75 Blow Marshall study, are shown in Table 5. From this table, it can be observed that only insignificant changes are shown for the Group I (Conventional) mixtures. For the Group 2 (Asphalt Rubber Manufacturer Preblends); asphalt contents for the two 10% rubber blends (SAR 10/10 and Ecoflex) are essentially the same and are about 0.5% more than the 5% rubber preblended (SAR 10/5).

The dry process rubber asphalt generic mixtures shown in Group 3, indicates that the demand for the total asphalt content, at any air void level, is increased by approximately 1.3 - 1.7% for each 1% increment of rubber (also see Chevron AC-20); Group 1 - Conventional for 0% rubber). For the Group 4 Polymer modified mixtures, the asphalt contents are about 0.3% more for the EVALAST modifier and are about 0.7% more for the DuPont ELVALOY mixtures.

SHRP- GYRATORY COMPACTION

Test Procedure

The SUPERPAVE level I mix design method requires specimen compaction with a gyratory compactor capable of providing a consolidation pressure of 0.60 MPa with an angle of gyration of 1.25 degrees and speed of gyration of 30.0 rpm. Cylindrical molds are also required to accommodate specimen size of 100 mm to 150 mm in diameter and with height ranges of 60 - 100 mm and 90 - 150 mm respectively. The gyratory compactor can continously monitor the increase in specimen density (expressed as a percent of its theoretical maximum specific gravity) with increasing compactive effort. For all mixes

investigated in this study, specimens were compacted in the 100 mm diameter mold using a Rainhart gyratory compactor for a number of gyration up to 200 gyrations. Two replicates were prepared at each of the three binder contents used in the Marshall mix design. Also, mixing and compaction temperatures were maintained the same as those used in the Marshall tests. Specimen height versus number of gyrations were saved in a computer files to be used for generating the corrected density curves.

Uncorrected Density Curves

The density, at any point in the compaction process, can be computed from the weight of the specimen and its height. This is termed the uncorrected density (C_{ux}), where:

$$C_{ux} = \frac{w}{\frac{\pi d^2 H}{4}} \times \frac{1}{G_{mm}}$$

W = the weight of the specimen; gm

H = the height of the specimen at any number of gyrations; cm

d = the diameter of the specimen; cm

G_{mm} = the theoretical maximum specific gravity of the tested specimen.

To generate final densification curves, the uncorrected values of the theoretical maximum specific gravity must be corrected using the final height recorded at the end of compaction (H_{eoc}) and the measured bulk specific gravity of the specimen after the end of compaction (G_{mb}).

Corrected Density Curves

After the compaction of the specimens, the final heights were recorded and the bulk specific gravities were measured in accordance to (AASHTO T-166). The corrected density (C_{cx}) at any number of gyrations is calculated as follows:

$$C_{cx} = C_{ux} \times \frac{G_{mb}}{\frac{\pi d^2 H_{eoc}}{w}}$$

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Figure 1 represents the typical densification curves obtained for a conventional mix (AC-20 Chevron) under 4.0%, 5.0%, and 6.0% binder content. Each curve in this Figure represents the average corrected density values for two replicates at the same binder content.

Selection of Design Binder Contents

The first step to determine the design binder content was to select a traffic level expected on the pavement as well as the average design air temperature for the pavement site. Once these two factors are selected, the design number of gyrations (N_{design}) can be determined from Table 1. The design binder content will be the one that produces a densification curve passing through 96.0% of theoretical maximum specific gravity (i.e. $V_a = 4.0\%$) at the design number of gyrations. SUPERPAVE manual for mix design recommends values of N_{design} under each design air temperature level/range and traffic level. These values of N_{design} are shown in Table 1.

In this study, a traffic level less than 1×10^7 ESALs was selected in order to be consistent with the Marshall 75 blow traffic level ($>1 \times 10^6$ EAL). The design air temperature ranges were selected to represent different climatic conditions. Thus, three design air temperature levels/ranges were selected to represent the lowest temperature level, a medium range, and the highest temperature range recommended by SHRP procedure. These design air temperatures were $\leq 34^0$ C, 37 - 38° C, and 43 - 44° C. The corresponding N_{design} values were 67, 96, and 119 number of gyrations. In addition, in lieu of simply determining the design binder content at one level of $V_a = 4.0\%$; binder contents were also evaluated at the 3.0; 4.0 and 5.0% air void levels conducted for the Marshall Analysis. The summary of these results is shown in Table 6.

In Table 6, it can be seen that design asphalt contents are summarized for mixtures only in Groups 1, 2 and 4. These values are not shown for the Group 3 Dry Process Rubber Asphalt mixtures. The reason for this is because significant problems were found with these mixtures, with the SUPERPAVE [TM] Gyratory device. These problems, in the authors' opinion, preclude their applicability with SUPERPAVE[TM] Gyratory device and design specifications to select design asphalt contents under the

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<u>Level I approach.</u> A more detailed discussion of these findings is presented in ensuing sections of this paper.

COMPARISON BETWEEN MARSHALL AND SUPERPAVE RESULTS

Approach

Tables 5 and 6 provide summaries of the design binder content for the Marshall and Superpave Gyratory procedures. These results are shown for $V_a = 3.0$; 4.0 and 5.0%. Marshall results are based on 75 blow while the gyratory designs have been selected to represent a comparable traffic level to the 75 blow compaction and at three levels of temperature to simulate : cool (< 34 ^oC); moderate (37 - 38 ^oC) and warm (43 - 44 ^oC) climatic regions.

The comparison of the design asphalt contents is presented in two approaches. The first approach uses the difference in asphalt contents between the SUPERPAVE^{TM} Level I and Marshall. This parameter is referred to as the d(AC) value or:

$$d(AC) = AC\% \text{ (SUPERPAVE)} - AC\% \text{ (Marshall)}$$

The second approach was to determine the equivalent number of gyrations. for the 75 blow Marshall results. that when used in the SUPERPAVE procedure will yield the same design binder content as determined by the Marshall approach. This parameter is referred to as the N_{eq} value.

Using the information shown in Tables 5 and 6. Table 7 is a summary of the d(AC) and N_{eq} values for the mixtures evaluated in Group 1. 2 and 4. Figure 2 graphically presents the d(AC) results while Figure 3 shows the N_{eq} values obtained in the comparison study.

Results

As noted in Table 7 and Figures 2 and 3; mix subgroups have been developed for the Group 2 and Group 4 categories to facilitate the ensuing discussions. Based upon an examination of the information shown. the following conclusions can be drawn:

1. For each specific mixture evaluated, there is little (if any) variation of the d(AC) values, within a given mix, at the three levels of V_a examined. This implies that the d(AC) is independent of the target air void level used to establish the design binder content (within the normal V_a design range of 3 to 5%).

2. As would be expected, the SUPERPAVE design asphalt content is increased as the design climatic condition becomes cooler (i.e. less asphalt is required for warmer conditions). This finding was observed for all mixtures evaluated. Quite interestingly, the increase in design asphalt content by the SUPERPAVE, between the warm (43/44 $^\circ$C) and cool (< 34 $^\circ$C) condition is equivalent to nearly 1.0% more asphalt, irrespective of the mix type and group (i.e. finding is true for conventional, wet blend rubber and polymer modified asphalt mixtures).

3. Within a given SUPERPAVE climatic region, there are no consistent trends in the d(AC) values between the various groups (subgroups) identified. In general, the d(AC)-climatic trends for the two Neste SAR (Wet Process-Manufacturer Preblends) are very similar to those found for all three of the conventional (Group 1) mixes studied. For the warm SUPERPAVE region, Level design asphalt contents are almost equivalent to those found by the Marshall procedure. In contrast, for the cold SUPERPAVE region, the SUPERPAVE designs require about 1.o% more binder content than the Marshall.

The Ecoflex (Bitumar) wet asphalt rubber binder appeared to be intermediate in d(AC) values to the Conventional (Group 1) and Polymer Modified (Group 4) mixtures. Both Polymer Modified subgroups (DuPont ELVALOY and Neste EVALAST) resulted in SUPERPAVE asphalt contents that were significantly less (-0.5 to -0.8%), for the warm SUPERPAVE condition, compared to Marshall derived asphalt contents.

4. The average N_{eq} values for the Conventional (Group 1), Wet Blend SAR and Wet Blend Ecoflex (Group 2) were found to be 130, 132 and 128 respectively. This implies that the probable response of the wet blends investigated are not dissimilar to conventional mixtures. The overall average of these groups (N_{eq} = 130) is not greatly different from the SUPERPAVE design gyration value, for warm climatic conditions, of N_{eq} = 119. In contrast, the Polymer Modified materials (ELVALOY and EVALAST) resulted in N_{eq} values of 76 and 92 respectively, indicating that equivalent SUPERPAVE and Marshall design binder contents occur for colder SUPERPAVE climatic regions.

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GYRATORY BEHAVIOR OF DRY PROCESS RUBBER ASPHALT MIXTURES

General Problem Discussion

As noted in Table 2, the study of the Group 3 (Dry Process Rubber Asphalt Mixtures) involved the Marshall and SUPERPAVE[TM] Level I analysis of five separate mixtures (three being a generic mix developed at the UMD and two PLUS-RIDE mixes. As alluded to several major obstacles developed with the implementation of the SUPERPAVE[TM] Level I approach for the Group 3 mixtures that have led the authors to conclude that the SUPERPAVE[TM] approach is completely inappropriate to select design binder contents for the Group 3 mixtures.

These problems and limitations regarding the SUPERPAVE[TM] approach are a direct result of two unique properties of the dry rubber asphalt mixtures. The first property of these mixtures is related to the highly resilient nature of the rubber particles used as aggregate within the mix. During the gyratory compaction process, the change in sample height (i.e. volumetric change) is primarily an elastic compression due to the high resilience of the rubber particles themselves. After the gyratory process is completely a significant instantaneous rebound may occur in the specimen. This process is best viewed as having the gyratory device simply compact a series of elastic springs.

The second characteristic of these mixtures is related to the swelling of the sample after the compaction process stops. This positive (increase) volume change is a time dependent phenomena whose magnitude is related to the complex interaction of rubber type/gradation, percentage of rubber as well as asphalt cement and the temperature during the compaction process.

These two volumetric change properties of the Group 3 mixtures are directly responsible for the accurate interpretation of lab results for use with the SUPERPAVE[TM] Level I mix design procedure currently used (especially the N_{gyr} criteria of Table 1), The schematic influence of these volume change is shown in Figure 4. Directly after compaction, if the mix has no volume change potential, the height of the specimen (and subsequently the measurement of the sample bulk density) is identical to end of compaction conditions. If the specimen exhibits volume change, the final height at the end of compaction and the measured bulk specific gravity after the sample cools, cannot be used to correct the density curves   (i.e.

obtain (C_{cx}) because the specimen volumes differ between the G_{mb} measurement and the end of compaction process. Thus, even though "corrections" can be computed, they will always be in error and consequently provide erroneous plots of gyrations versus air voids (or percent of maximum theoretical gravity). In contrast, accurate estimates of the densification curve can be obtained for mixtures with little to no volume change after the compaction process.

Typical Results

Figure 5 illustrates results of the "corrected" densification curves for the PLUS RIDE No. 12 mixture at three binder contents. All five of the Group 3 mixtures evaluated resulted in very similar types of relationships. The difference in gyratory response for this mix is quite obvious in comparison to the Group 1 (Conventional) mix response shown in Figure 1. As a general rule, the "computed" (erroneous) maximum theoretical density was achieved within 20 to 50 gyrations for all 15 mix-binder content combinations evaluated in Group 3. As noted, the major reason associated with the rapid "densification" of dry rubber asphalt mixtures is due to the large resilient (elastic) deformations within the rubber particles themselves and is not due to permanent densification of the specimen due to compaction process.

The inapplicability of the SUPERPAVE[TM] densification curves developed for all five mixtures in Group 3 can also be viewed relative to the N_{eq} parameter introduced in the previous section of this paper. Table 8 summarizes for the Group 3 mixtures, the Marshall design asphalt content and the equivalent SUPERPAVE[TM] gyratory repetitions necessary to achieve equivalent binder contents. Of special importance is the fact that each of the five mixtures were successfully placed in MSHA field demonstration projects during the fall of 1993 at design Marshall asphalt contents shown in the table at air voids between 3 and 4%. The SUPERPAVE[TM] N_{eq} values (average) (67; 22; 13; 8 and 15) are somewhere near the Table 1 (SUPERPAVE[TM]) recommendations of $N_{des} = 67$, 96 and 119 to represent the various gyratory climatic regions used in this study. In fact the difference is so large that it was impossible to obtain design binder contents for all five mixtures from the SUPERPAVE[TM] criterion shown in Table 1.

In order to evaluate the influence of the time dependent volume change increase immediately upon the completion of the gyratory compaction process, the gyratory machine itself was used to determine the time dependent height change observed during the volume change process. This process involved the preparation of an additional replicate, at each binder content, and compacting the specimens in the gyratory device to 200 gyrations. Directly after the end of compaction, the ram pressure was released to a zero level and the height of the specimen recorded at various time increments (generally 10 measurements during the first 30 minutes, starting at 30 seconds, 1 - 2 hours; 3 - 4 hours and 16 - 20 hours).

The measurement of volume change was computed by two approaches involving the process in which the G_{mb} values were obtained. In the "approach, the specimens were left in the gyratory mold for 16 - 20 hours after the end of the compaction process. Bulk density measurement were obtained on the specimen after completion of the volume change measurements. For the "unconfined" approach; samples were extruded from the molds after about 1.5 hours from the end of the compaction and allowed to expand volumetrically for 16 hours before the bulk gravity was measured.

Figure 6 illustrates a typical volume change (as denoted by the air voids) pattern measured during the study. The combined influence of the nearly instantaneous and time dependent swell pattern on this mix is clearly shown. It can also be observed that a volume change, equivalent to an air void change, dV_a, of nearly 6.0% was observed.

Figure 7 graphically summarizes the average dV_a values (computed by both the "confined" and "unconfined" approaches) for all mixtures and binder contents evaluated and not limited to the Group 3 mixtures). While dV_a values were recorded for Groups 1, 2 and 4: their magnitude is not considered to be significant relative to the dV_a values obtained on the Group 3 (Dry Process Rubber Asphalt Mixtures). Figure 8 shows the relationship between dV_a and rubber percentage (by binder weight) for all five mixtures within Group 3. Within any given mix, the dV_a is shown to greatly increase as the rubber percentage is increased (i.e. binder content is decreased). Or, at a given percent (by total mix weight) the dV_a (volume change) is decreased with increasing asphalt content.

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SUMMARY AND CONCLUSIONS

This study focused on the comparison of Asphalt Mix designs between the 75 blow Marshall SUPERPAVE[TM] Gyratory Level 1 approach. A total of 14 different mixtures were evaluated, categorized into four (4) major mix groups. Based upon the results of this study the following conclusions have been developed.

1. Of the four mix groups evaluated, it is the conclusion of the authors that the SUPERPAVE[TM] gyratory Level I design cannot be used to evaluate Dry Process : Rubber Asphalt mixtures. The reasons for this are to the high resilience of the rubber particles during the compaction process and the time dependent swelling , upon compaction completion, of these mixtures. This suggests, that problems with SUPERPAVE[TM] approach implementation may occur on any mixture possessing these abnormal characteristics.

2. The design process for all other mixtures investigated posed no similar type of problem and demonstrated the potential advantages and benefits of the SUPERPAVE[TM] gyratory approach.

3. Relative to the comparison of design asphalt content differences between both mix design procedures, it was found that :

   a. Within any specific mix type, the difference in asphalt contents, between approaches, is independent of the target air void level selected (V_a = 3.0 to 5.0%) to develop the design value.

   b. As the SUPERPAVE[TM] climatic regions changes from warm to cool, an increase of approximately 1.0% more asphalt will be required from the Level I approach. This finding was found to be true for all mix types/groups studied.

   c. Within a given SUPERPAVE[TM] climatic region, no consistent trends in design asphalt contents, between the type of mix design procedure used, were found between mixtures. In general, design asphalt contents for the conventional and wet process asphalt rubber mixes, were equivalent between the Marshall and the warm SUPERPAVE[TM] climatic region. For identical traffic and climatic conditions, the

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SUPERPAVE^{TM} Level I designs for polymer modified mixtures. were about 0.5% to 0.8% less than the Marshall analysis.

ACKNOWLEDGMENTS

REFERENCES

1. Asphalt Institute Manual Series NO. 2 (MS-2) Sixth Edition. Mix Design Methods for Asphalt Concrete and Other Hot -Mix Types. Lexington. Kentucky, 1993.

2. L. Von Quintus. J. A. Scherocman. C. S. Hughes. and T. W. Kennedy, Asphalt Aggregate Mixture Analysis System. National Cooperative Highway Research Program Report 338. Transportation Research Board. Washington D.C.. March 1991.

3. M. W. Witczak. M. W. Mirza. I. Hafez. and X. Qi, Laboratory Characterization of Neste Oil Asphaltic Mixtures. Department of Civil Engineering, University of Maryland at College Park, Maryland, June 1994.

4. Richard May. Ph. D. Dissertation. An Analysis System for Evaluating the Structural Performance of Asphalt Concrete Pavement, Department of Engineering, University of Maryland at College Park, Maryland, 1991.

5. Strategic Highway Research Program (SHRP), The SUPERPAVE^{TM} Mix Design Manual for New Construction and Overlays, National Research Council, March 1993.

6. University of Maryland, Department of Civil Engineering, Mix Design of Rubber Modified Asphalt Concrete (RUMAC) for Generic-Dense Graded Mixtures (Dry Rubber Process), Maryland State AW0-093-360-046, Development of Demonstration Projects with Scrap Tire Rubber in Highway Pavements within the State of Maryland, University of Maryland at College Park, Maryland. September 1993.

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7. University of Maryland, Department of Civil Engineering, The Design and Testing of Rubber Modified Asphalt Mixtures (Dry Process) by the Marshall Method, MSMT Designation 405-RMAC-T, University of Maryland at College Park, Maryland, June 1993.

Table 1
SUPERPAVE™ Design Number of Gyrations

Traffic (ESALs)	Average Design Air Temperature (° C)					
	≤ 34	35 – 36	37 – 38	39 – 40	41 – 42	43 – 44
$< 3x10^5$	50	59	68	74	78	82
$< 1x10^6$	55	65	76	83	88	93
$< 3x10^6$	61	73	86	95	100	105
$< 1x10^7$	67	81	96	106	113	119
$< 3x10^7$	74	92	109	121	128	135
$< 1x10^8$	84	105	126	139	146	153
$\geq 1x10^8$	93	118	143	158	165	172

Source: SUPERPAVE™ mix design manual for new construction and overlays. SHRP. 1993

Table 2
Summary of Asphalt Mixture Group Evaluated

Group	Description	Mix Identification	UM Project
1	Conventional	Chevron AC-20	MSHA Rubber Project
		Neste AC-20	Neste Oil Study
		Conoco AC120/150	DuPont Study
2	Wet Process Asphalt Rubber	Neste SAR 10/5	Neste Oil Study
	(Manufacturer Preblended)	Neste SAR 10/10	MSHA Rubber Project
		Ecoflex (Bitumar)	MSHA Rubber Project
3	Dry Process Rubber Asphalt	Generic: Chevron AC-20 (1% R)	MSHA Rubber Project
		Generic: Chevron AC-20 (2% R)	MSHA Rubber Project
		Generic: Chevron AC-20 (3% R)	MSHA Rubber Project
		Plus Ride No.12 (3% R)	MSHA Rubber Project
		Plus Ride No.16 (3% R)	MSHA Rubber Project
4	Polymer Modified	Neste EVALAST	Neste Oil Study
		ELVALOY (Con 120/150 +1.5% Mod)	DuPont Study
		ELVALOY (Con 120/150 + 2.0% Mod)	DuPont Study

Table 3
Summary of Mix Aggregate Properties

Sieve	Job Mix Gradation (% Pass)		
mm (#)	All Mixes	Plus Ride No. 12	Plus Ride No. 16
25.40 (1")	100.0	100.0	100.0
19.00 (3/4")	100.0	100.0	96.0
12.70 (1/2")	96.0	94.0	67.0
9.50 (3/8")	82.0	69.0	50.0
4.75 (#4)	58.4	28.0	32.0
2.36 (#8)	40.9	20.0	23.0
1.18 (#16)	24.0	17.0	18.0
0.60 (#30)	14.7	16.0	15.0
0.30 (#50)	9.1	15.0	14.0
0.15 (#100)	5.5	14.0	12.0
0.75 (#200)	5.5	11.0	9.2
S.G (C.A)	2.637	2.711	2.722
S.G (F.A)	2.647	2.669	2.698
S.G (M.F)	2.760	2.788	2.819
Bulk S.G. (Combined)	2.661	2.712	2.725

Table 4
Summary of Binder A_i, VTS_i Parameters

Mix Type	Binder	A	VTS	Mixing Temp (^{0}F)	Compaction Temp (^{0}F)
Conventional	Chevron AC-20	10.72596	-3.59598	310	290
	Neste AC-20	10.93286	-3.67221	305	285
	Conoco 120/150	11.22030	-3.78738	285	265
Wet Process Asphalt Rubber (Manufacturer Preblended)	Neste SAR 10/5	9.21569	-3.05231	340	320
	Neste SAR 10/10	9.49318	-3.14280	350	330
	Ecoflex (Bitumar)	10.06920	-3.35609	325	305
Dry Process Rubber Asphalt	Generic: Chevron AC-20 (1%, 2%, 3% R)	10.72596	-3.59598	310	290
	Plus Ride No. 12 & No. 16	10.72596	-3.59598	310	290
Polymer Modified	Neste EVALAST	8.70081	-2.84582	400	375
	ELVALOY (Conoco 120/150 + 1.5% Modifier)	10.31936	-3.45168	310	290
	ELVALOY (Conoco 120/150 + 2.0% Modifier)	9.41115	-3.11800	345	325

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Table 5
Summary of Design Asphalt Content (Marshall)

Group	Description	Mix Identification	A.C. at Temp./Vair		
			Va = 3%	Va = 4%	Va = 5%
1	Conventional	Chevron AC - 20	5.1	4.8	4.4
		Neste AC - 20	5.1	4.7	4.3
		Conoco AC 120/150	5.1	4.8	4.4
2	Wet Process (Manufacturer Preblended)	Neste SAR 10/5	5.3	4.7	4.3
		Neste SAR 10/10	5.8	5.3	4.7
		Ecoflex (Bitumar)	5.7	5.3	4.8
3	Wet Process (Manufacturer Preblended)	Generic: Chevron AC-20 (1% R)	6.2	5.7	5.5
		Generic: Chevron AC-20 (2% R)	8.0	7.3	6.8
		Generic: Chevron AC-20 (3% R)	9.0	8.2	7.7
		Pluse Ride No. 12 (3% R)	10.0	8.9	7.5
		Pluse Ride No. 16 (3% R)	7.4	6.4	-
4	Polymer Modified	Neste EVALAST	5.5	5.1	4.6
		ELVALOY (Conoco 120/150 + 1.5% Mod)	5.8	5.3	4.8
		ELVALOY (Conoco 120/150 + 2.0% Mod)	5.9	5.5	5.1

Table 6
Summary of Design Asphalt Content (SUPERPAVE™ Level I)

Group	Description	Mix Identification	Va (%)	A.C. at Temp./Vair		
				34 °C	37 - 38 °C	43 - 44 °C
1	Conventional	Chevron AC - 20	3.0	-	5.6	5.3
			4.0	5.8	5.2	4.9
			5.0	5.3	4.8	4.5
		Neste AC - 20	3.0	-	5.4	5.1
			4.0	5.6	5.0	4.7
			5.0	5.1	4.6	4.3
		Conoco AC 120/150	3.0	5.9	5.5	5.3
			4.0	5.6	5.2	4.9
			5.0	5.3	4.6	-
2	Wet Process (Manufacturer Preblended)	Neste SAR 10/5	3.0	-	5.7	5.4
			4.0	6.0	5.2	4.9
			5.0	5.4	4.7	4.5
		Neste SAR 10/10	3.0	-	-	5.8
			4.0	-	5.6	5.3
			5.0	5.7	5.1	4.7
		Ecoflex (Bitumar)	3.0	-	5.7	5.4
			4.0	5.8	5.3	5.0
			5.0	5.4	4.8	4.5
4	Polymer Modified	Neste EVALAST	3.0	-	5.5	5.1
			4.0	5.9	4.9	4.6
			5.0	5.1	4.4	4.1
		ELVALOY (Conoco 120/150 + 1.5% Mod)	3.0	5.7	5.2	5.0
			4.0	5.3	4.8	4.5
			5.0	5.0	4.4	4.1
		ELVALOY (Conoco 120/150 + 2.0% Mod)	3.0	-	5.7	5.1
			4.0	-	4.9	4.7
			5.0	5.2	4.6	4.4

Table 7
Summary of Design Binder Comparison Analysis

Group	Description	Mix Identification	Design V_a (%)	d(AC) Value*			Marshall N_{eq}
				Cool	Mod	Warm	
1	Conventional	Chevron AC - 20	3.0	-	0.5	0.2	138
			4.0	1.0	0.4	0.1	140
			5.0	0.9	0.4	0.1	148
		Neste AC - 20	3.0	-	0.3	0.0	120
			4.0	0.9	0.3	0.0	128
			5.0	0.8	0.3	0.0	124
		Conoco AC 120/150	3.0	0.8	0.4	0.2	145
			4.0	0.8	0.4	0.1	122
			5.0	0.9	0.2	-	104
		Group Average		**0.9**	**0.4**	**0.1**	**130**
2	Wet Process (Manufacturer Preblended)	Neste SAR 10/5	3.0	-	0.4	0.1	127
			4.0	1.3	0.5	0.2	142
			5.0	1.1	0.4	0.2	152
		Neste SAR 10/10	3.0	-	-	0.0	124
			4.0	-	0.3	0.0	120
			5.0	1.0	0.4	0.0	128
		Subgroup Average		**1.1**	**0.4**	**0.1**	**132**

* a. d(AC) Value = AC% (SUPERPAVE) - AC % (Marshall)
   b. SUPERPAVE Climatic Regions

        Cool : Temp ≤ 34 °C   ; N_{des} = 67
        Mod : Temp = 37 - 38 °C ; N_{des} = 96
        Warm : Temp = 43 - 44 °C ; N_{des} = 119

Table 7 (Cont'd)
Summary of Design Binder Comparison Analysis

Group	Description	Mix Identification	Design Va (%)	d(AC) Value[a]			Marshall Neq
				Cool	Mod	Warm	
2	Wet Process (Manufacturer Preblended)	Ecoflex (Bitumar)	3.0	-	0.0	-0.3	133
			4.0	0.5	0.0	-0.3	122
			5.0	0.6	0.0	-	130
		Subgroup Average		0.6	0.0	-0.3	131
4	Polymer Modified	Neste EVALAST	3.0	-	0.0	-0.4	104
			4.0	0.8	-0.2	-0.5	89
			5.0	0.5	-0.2	-0.5	84
		Subgroup Average		0.7	-0.1	-0.5	92
		ELVALOY (Conoco 120/150 + 1.5% Mod)	3.0	-0.1	-0.6	-0.8	68
			4.0	0.0	-0.5	-0.8	72
			5.0	0.2	-0.4	-0.7	77
		ELVALOY (Conoco 120/150 + 2.0% Mod)	3.0	-	-0.2	-0.8	91
			4.0	-	-0.6	-0.8	80
			5.0	0.1	-0.5	-0.7	67
		Sugroup Average		0.1	-0.5	-0.8	76

[a]. d(AC) Value = AC% (SUPERPAVE) - AC % (Marshall)

b. SUPERPAVE Climatic Regions

Cool : Temp $\leq 34\ ^{\circ}C$; $N_{des} = 67$
Mod : Temp $= 37 - 38\ ^{\circ}C$; $N_{des} = 96$
Warm : Temp $= 43 - 44\ ^{\circ}C$; $N_{des} = 119$

Table 8
Equivalent Marshall Gyrations for Group 3 Dry Process Rubber Asphalt Mixes

Group	Description	Mix Identification	Va (%)	AC % Marshall	Marshall Neq
3	Dry Process Rubber Asphalt	Generic: Chevron AC-20 (1% R)	3.0	6.2	72
			4.0	5.7	71
			5.0	5.5	59
		Group Average			67
		Generic: Chevron AC-20 (2% R)	3.0	8.0	23
			4.0	7.3	22
			5.0	6.8	21
		Group Average			22
		Generic: Chevron AC-20 (3% R)	3.0	9.0	16
			4.0	8.2	10
			5.0	7.7	13
		Group Average			13
		Plus Ride No. 12 (3% R)	3.0	10.0	6
			4.0	8.9	8
			5.0	7.5	11
		Group Average			8
		Plus Ride No. 16 (3% R)	3.0	7.4	14
			4.0	6.4	16
			5.0	-	-
		Group Average			15

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FIGURE 1 PERCENT OF THEORETICAL MAXIMUM SPECIFIC GRAVITY VERSUS THE NUMBER OF GYRATIONS UNDER DIFFERENT ASPHALT CONTENT @ Pr=0.0% (AC - 20 Chevron)
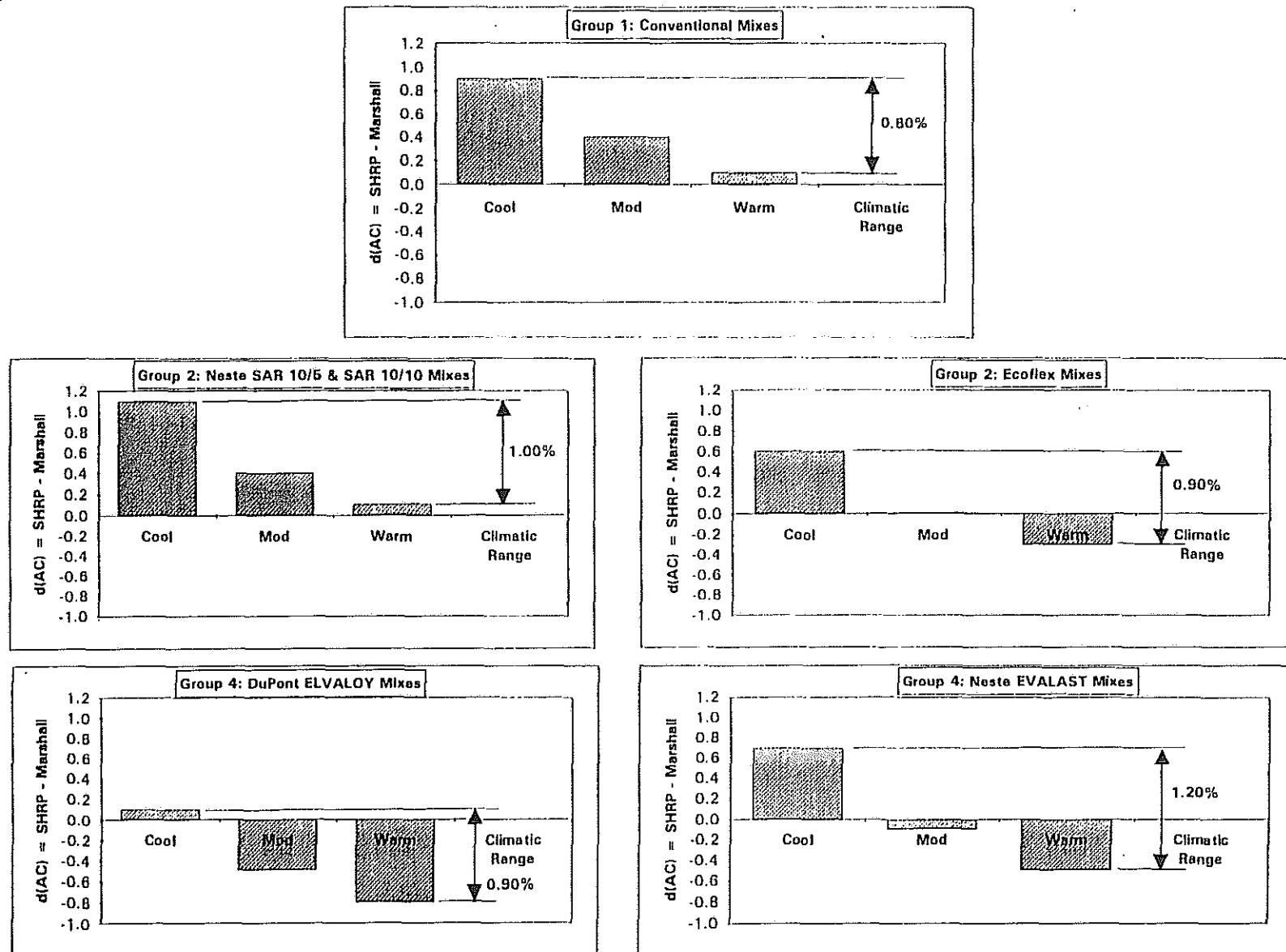
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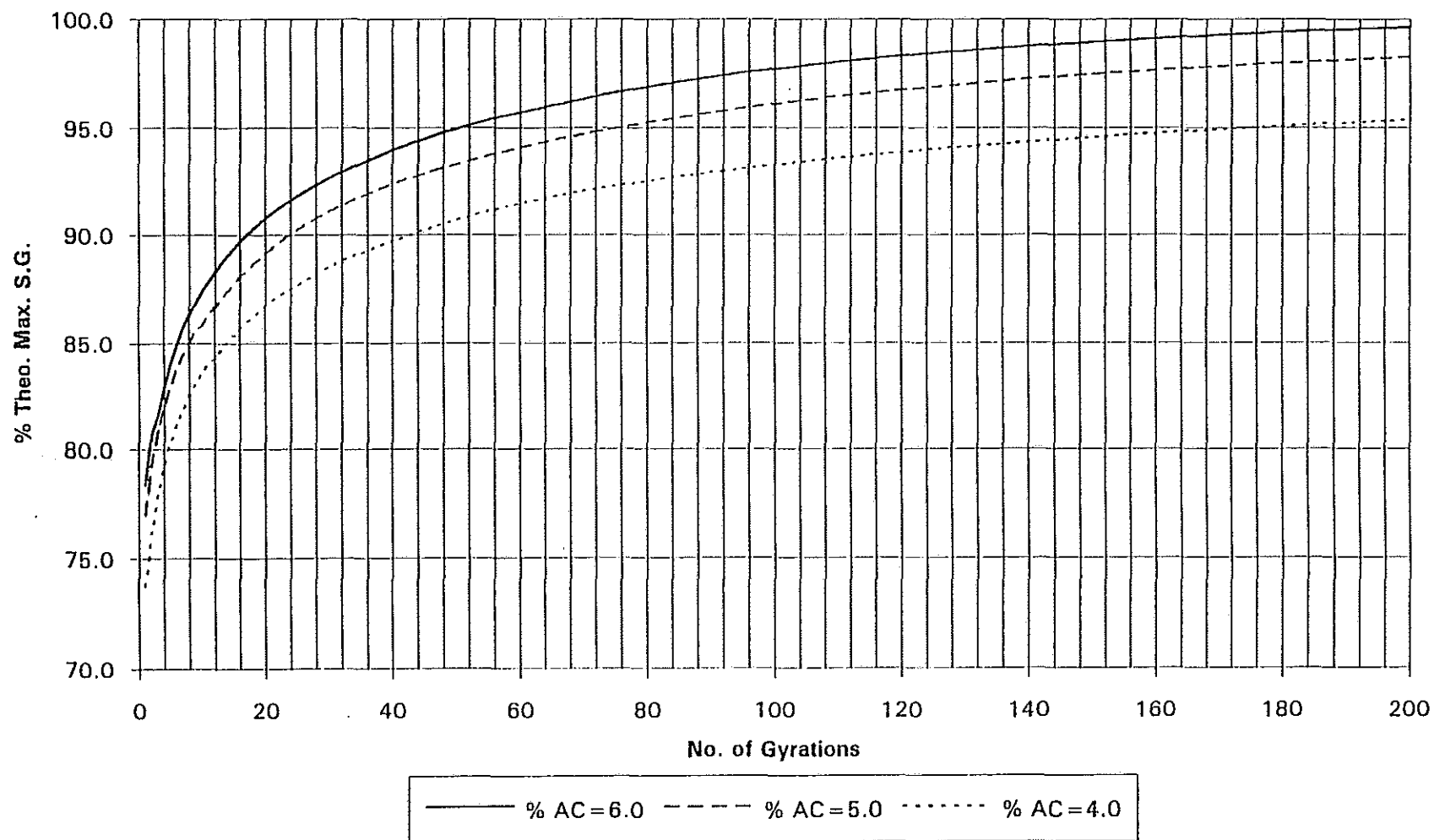
FIGURE 2 DESIGN AC% DIFFERENCES (SUPERPAVE - MARSHALL) FOR MIX GROUPS INVESTIGATED

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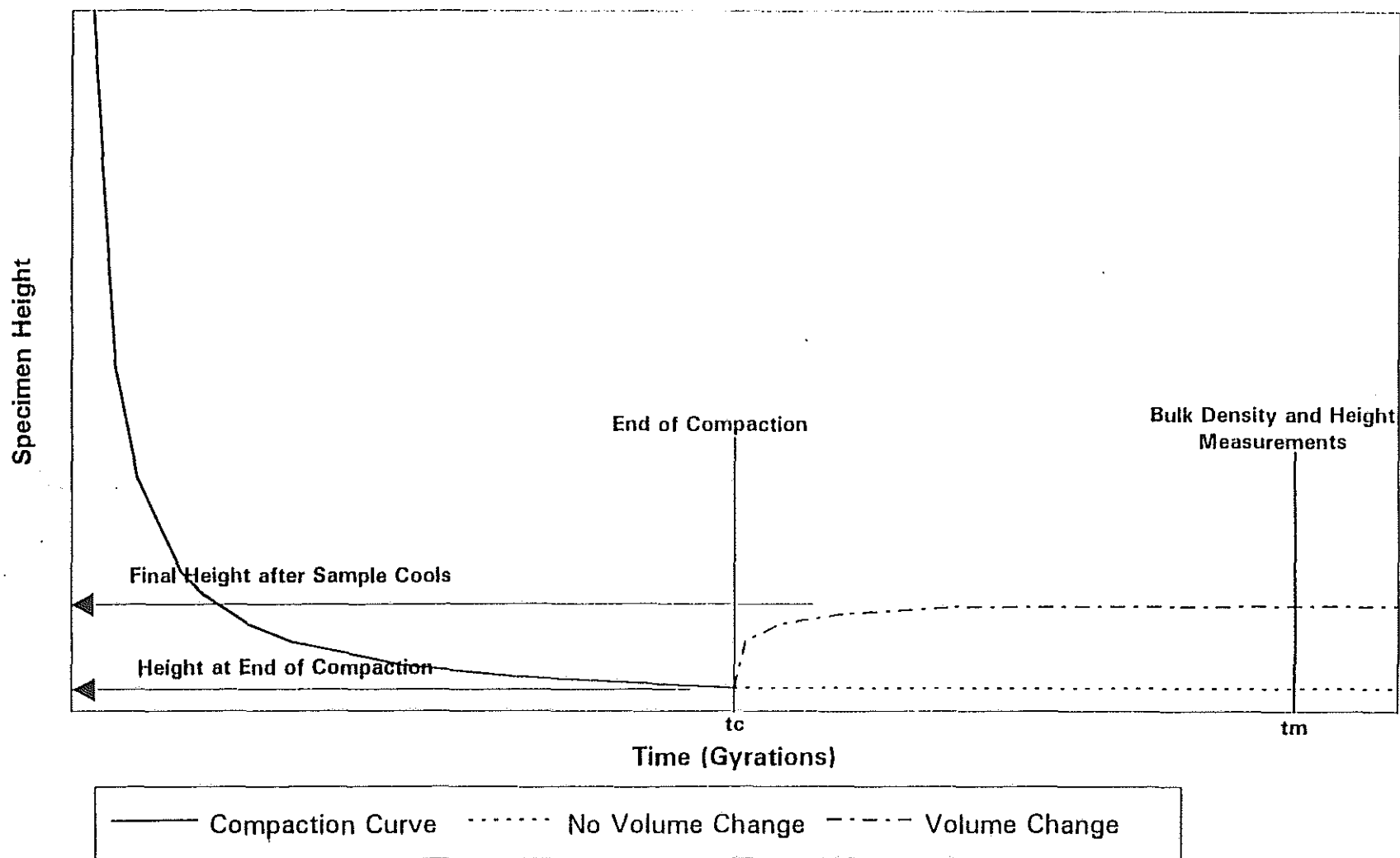
FIGURE 3 EQUIVALENT NUMBER OF GYRATIONS FOR MIXES INVESTIGATED

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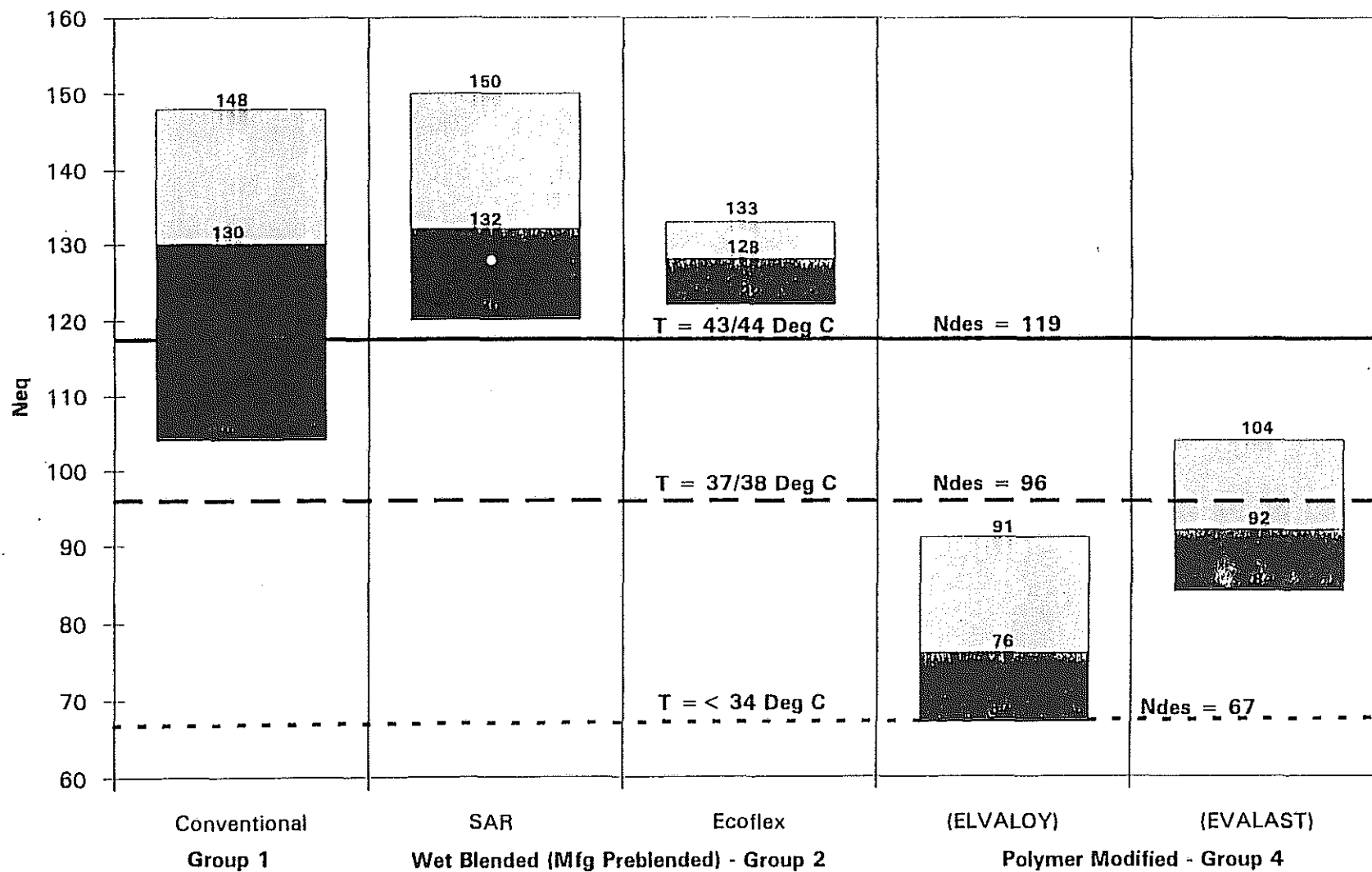
FIGURE 4 VARIATION OF SAMPLE HEIGHT DURING AND AFTER SUPERPAVE GYRATORY COMPACTION

Specimen Height (y-axis)

End of Compaction

Bulk Density and Height Measurements

Final Height after Sample Cools

Height at End of Compaction

t_c

t_m

Time (Gyrations)

——— Compaction Curve   ······· No Volume Change   —·—·— Volume Change

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FIGURE 5 PERCENT OF THEORETICAL MAXIMUM SPECIFIC GRAVITY VERSUS NUMBER OF GYRATIONS
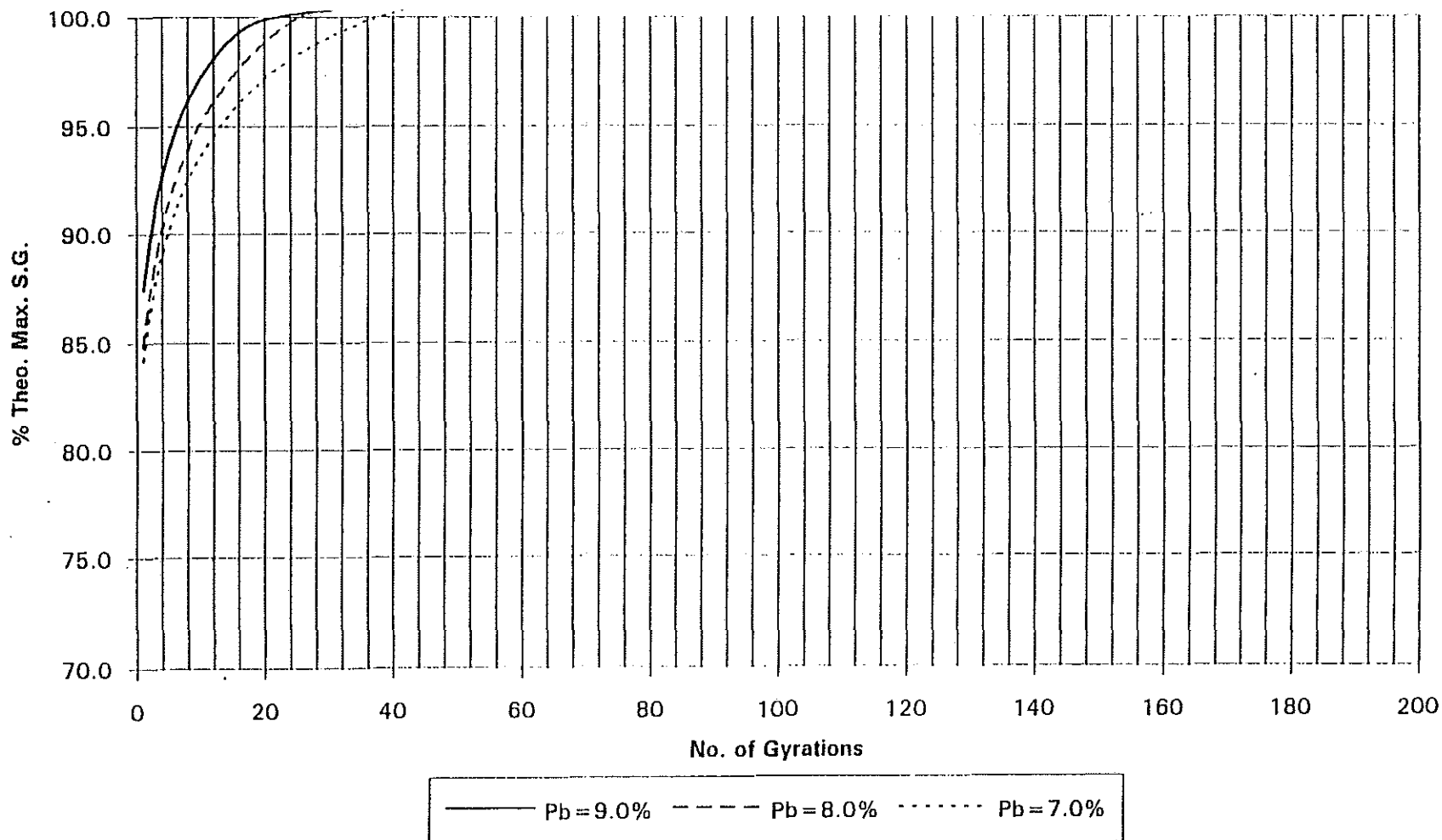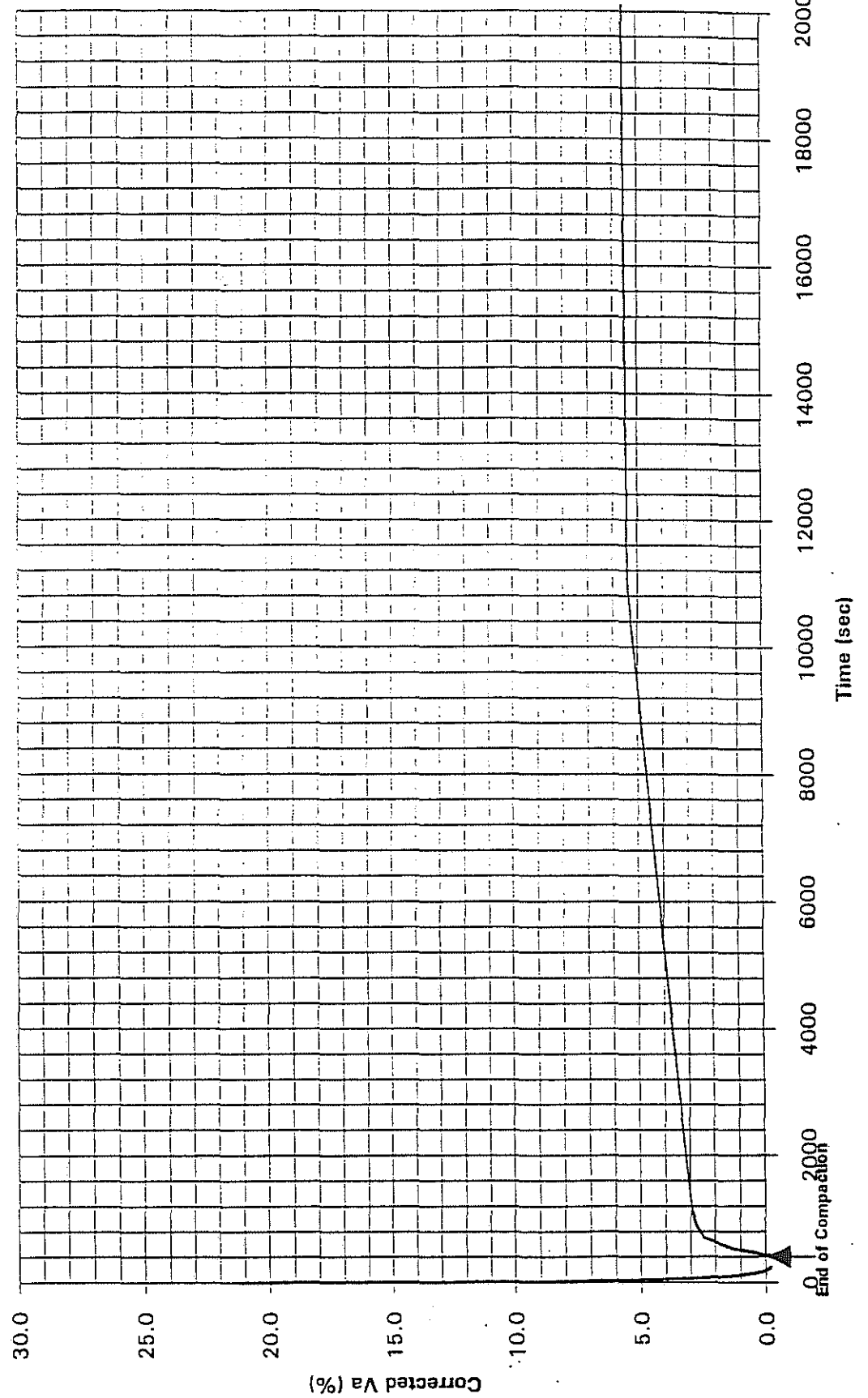UNDER DIFFERENT ASPHALT CONTENT (PLUS RIDE # 12 MIX)

FIGURE 6 CORRECTED AIR VOIDS VERSUS TIME (RUBBER MODIFIED ASPHALT MIXES @ Pb = 7.0% & Pr = 2.0%)

FIGURE 7 AVERAGE VOLUME CHANGE (dVa) VALUES AFTER GYRATORY COMPACTION BY MAJOR MIX GROUPS
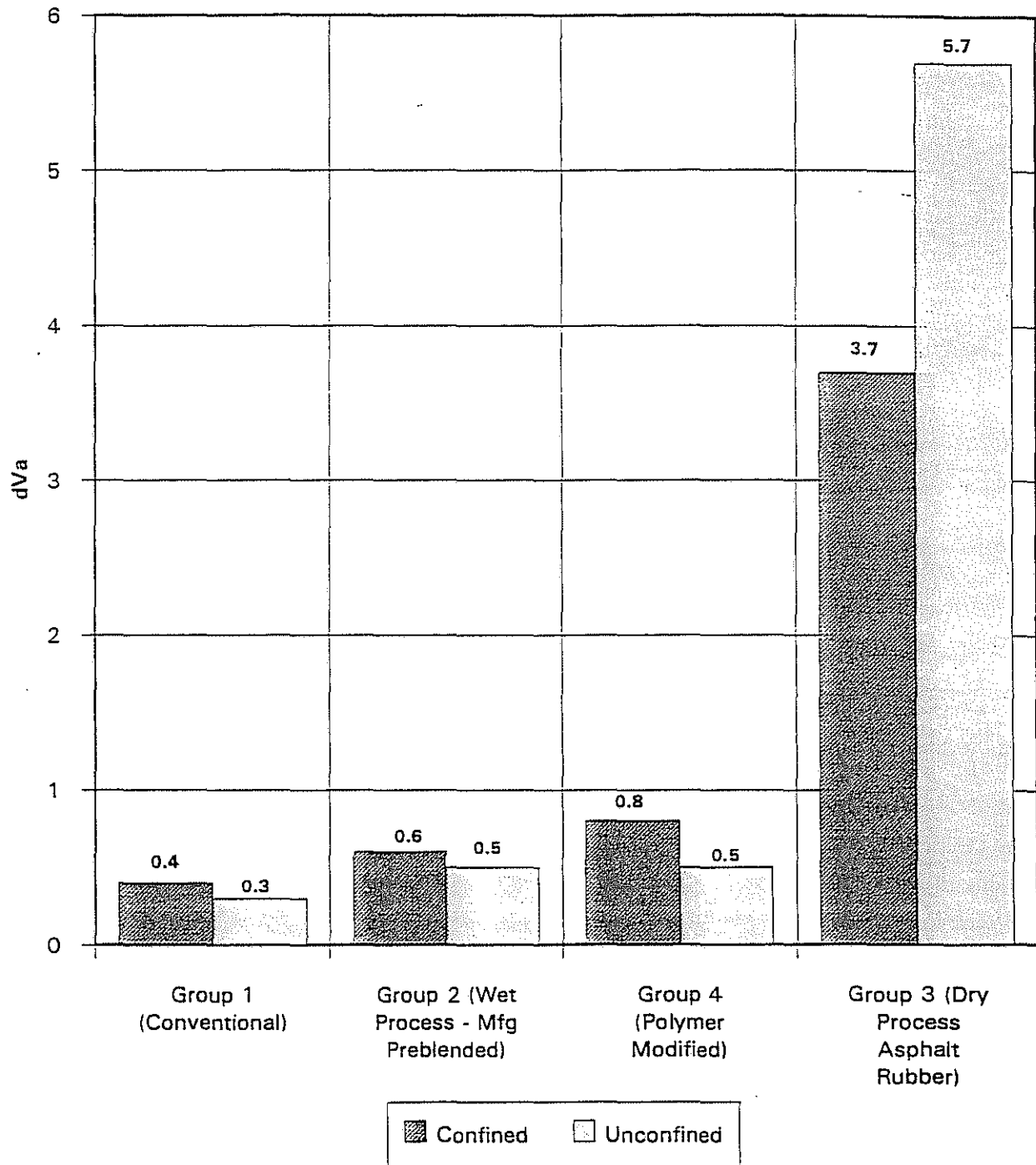
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FIGURE 8 INCREASE IN AIR VOIDS AFTER GYRATORY COMPACTION VERSUS PERCENT RUBBER (BY BINDER WEIGHT) FOR GROUP 3 MIXTURES - CONFINED CONDITION