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16. Abstract

A comparative study was performed to compare the maximum theoretical specific gravities of asphalt-aggregate paving mixtures obtained using several methods. The study included experimental work and analysis of the resulting data. The agreement between results obtained using the Texas C-14 method and the Rice method were excellent. Results obtained by backcalculating theoretical maximum densities from a single Rice test were also found to be satisfactory. Theoretical approach based on bulk specific gravity of aggregate is not recommended because of significantly low theoretical maximum specific gravities and high relative densities.

The C-14 method results in lower design asphalt content than the Rice method if the latter is not corrected for water absorption. This case occurs if the design asphalt content is selected at 97% relative density for both methods. However, the design asphalt contents from the two methods will be much closer if the asphalt content is selected at 97% relative density based on the C-14 method, and 96% based on the Rice method.

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# EVALUATION OF METHODS OF DETERMINING THE THEORETICAL MAXIMUM SPECIFIC GRAVITY OF ASPHALT CONCRETE PAVING MIXTURES

by

Mansour Solaimanian
Thomas W. Kennedy

## Research Report Number 468-2

Research Project 3-9-85/8-468

Field Evaluation to Obtain Density in Asphalt Mixtures

conducted for

**Texas State Department of Highways and Public Transportation**

in cooperation with the

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by the

**CENTER FOR TRANSPORTATION RESEARCH**

Bureau of Engineering Research

THE UNIVERSITY OF TEXAS AT AUSTIN

April 1989

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily represent the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

# PREFACE

This is the second report in a series of reports dealing with the findings of a research project concerned with density of asphalt mixtures. This report summarizes the findings of a study comparing methods of determining the theoretical maximum specific gravity of asphalt mixtures.

The work required to develop this report was provided by many people. Special appreciation is extended to Messrs. James N. Anagnos and Eugene Betts for their assistance in the testing program. Also, the assistance of personnel from the various districts is acknowledged. In addition, the authors would like to express their appreciation to Messrs. Billy R. Neeley and Paul Krugler of the Texas State Department of Highways and Public Transportation, to Peter A. Kopac of the pavement division, HNR-20, and to William E. Elmore of the Center for Transportation Research for their suggestions, encouragement, and assistance, and to other district personnel who provided data and information. Appreciation is also extended to the Center for Transportation Research staff who assisted in the preparation of the report. The support of the Federal Highway Administration, Department of Transportation, is acknowledged.

Mansour Solaimanian
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April 1989

# LIST OF REPORTS

Report No. 468-1, "Evaluation of the Troxler Model 4640 Thin Lift Nuclear Density Gauge," by Mansour Solaimanian, Richard J. Holmgreen, Jr., and Thomas W. Kennedy, is an evaluation of the Troxler Model 4640 Thin Lift Nuclear Gauge's ability to predict core densities. July 1990.

Report No. 468-2, "Evaluation of Methods of Determining the Theoretical Maximum Specific Gravity of Asphalt Concrete Paving Mixtures," by Mansour Solaimanian and Thomas W. Kennedy, summarizes a study comparing methods of estimating the theoretical maximum specific gravity of asphalt mixtures. April 1989.

# ABSTRACT

A comparative study was performed to compare the maximum theoretical specific gravities of asphalt-aggregate paving mixtures obtained using several methods. The study included experimental work and analysis of the resulting data. The agreement was excellent between results obtained using the Texas C-14 method and the Rice method. Results obtained by backcalculating theoretical maximum densities from a single Rice test were also found to be satisfactory. A theoretical approach based on bulk specific gravity of aggregate is not recommended because of significantly low theoretical maximum specific gravities and high relative densities.

The C-14 method results in lower design asphalt content than the Rice method if the latter is not corrected for water absorption. This case occurs if the design asphalt content is selected at 97 percent relative density for both methods. However, the design asphalt contents from the two methods will be much closer if the asphalt content is selected at 97 percent relative density based on the C-14 method and 96 percent based on the Rice method.

# SUMMARY

This report summarizes the results of a comparative study of different methods for determining the theoretical maximum specific gravity of asphalt-aggregate mixtures. Six different methods are compared: (1) Rice method with results not corrected for water absorption, (2) Rice method with results corrected for water absorption, (3) SDHPT method as outlined in Construction Bulletin C-14, hereinafter designated as the C-14 method, (4) theoretical method which uses the bulk specific gravity of aggregates, (5) backcalculated theoretical maximum specific gravity at different asphalt contents from one Rice test at a certain asphalt content with results not corrected for water absorption, and (6) backcalculated theoretical maximum specific gravity at different asphalt contents from one Rice test at a certain asphalt content with results corrected for water absorption. The effect of different design asphalt content is also investigated.

Thirteen asphalt-aggregate mixtures from construction projects were selected. Experiments were performed and the data were analyzed. Results indicated excellent agreement between the theoretical maximum densities obtained using the C-14 and Rice methods. The backcalculation method also gives promising results. The result from the theoretical approach is not reliable and generally yields a significantly higher relative density and lower calculated air voids. Design asphalt content from the C-14 method is slightly lower than that from the uncorrected Rice method. Values were found to be closer for design asphalt content when the corrected Rice method is compared with the C-14 method.

# IMPLEMENTATION STATEMENT

The Rice method of determining the maximum theoretical specific gravity of an asphalt mixture is generally accepted as the best method currently available. This study indicated that excellent agreement exists between values obtained using the Rice method and the Texas-C-14 method. Nevertheless, the C-14 method generally will produce values indicating higher relative densities and lower air voids in the compacted mixture. Thus, the Rice method should definitely be used for compaction control.

In terms of mixture design, using the current Texas design procedure, which selects the asphalt content corresponding to 3 percent air voids, the Rice method will generally yield a higher asphalt content than the C-14 method. In order to obtain the same asphalt content, an air void content of about 4 percent should be used with the Rice method.

Backcalculation of maximum specific gravities at other asphalt contents based on a measured Rice specific gravity at a given asphalt content produces acceptable results. The calculation of maximum specific gravity using the specific gravity of the asphalt cement and the bulk specific gravity of the aggregate is not acceptable and definitely should not be done.

# CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are made based on the data analyzed in this study:

(1) The theoretical maximum specific gravities from the theoretical approach ($G_t$) are, in general, significantly lower than those obtained from other methods, and therefore yield the highest relative densities.

(2) The theoretical maximum specific gravities from the uncorrected Rice approach ($G_{ru}$) are the highest and result in the lowest relative densities compared to other methods.

(3) Relatively good agreement exists between the theoretical maximum specific gravities from the C-14 method ($G_{C14}$) and those from the uncorrected Rice method ($G_{ru}$).

(4) The best agreement is observed between $G_{C14}$ values and the corrected Rice method ($G_{rc}$) values.

(5) Backcalculating theoretical maximum specific gravity ($G_{max}$) values from one single Rice test is also promising, and backcalculated $G_{max}$ values compare well with those directly from the Rice tests.

(6) Design asphalt content at 97 percent relative density based on $G_{C14}$ is smaller than that at 97 percent relative density based on $G_{ru}$.

(7) Relatively good agreement exists between design asphalt contents when 96 percent relative density is used based on $G_{ru}$ and 97 percent relative density is used based on $G_{C14}$.

(8) In this study it was found that the largest differences between the specific gravities measured by the two methods generally do not exceed 2 percent. This difference causes the relative density based on the corrected Rice method to be about 1 to 2 percent less than that based on the uncorrected Rice method. The Rice method is gaining widespread acceptance both at national and at state levels.

(9) An additional consideration should be stated in the C-14 method. If saturation for a specimen is going to be considered complete following the peak, the relative density of that specimen based on the theoretical approach must exceed 100 percent; otherwise erroneous results will occur.

# TABLE OF CONTENTS

# CHAPTER 1. INTRODUCTION

Past experience and studies have shown that density is considered to be among the most important factors affecting engineering characteristics, service life, and performance of hot mix asphalt concrete pavement. Proper density of the pavement is decided based on the amount of air voids. The amount of air voids is calculated from the relative density of the pavement structure and is reported as a percent of the total volume. Relative density is defined as the ratio of the bulk specific gravity of the compacted mixture to the zero-air-void specific gravity (i.e., specific gravity of the mixture when no voids are present). Texas specifications require the air voids to be between 8 and 3 percent (92 and 97 percent relative density when based upon the Rice method). The whole criterion for evaluating density in the mix depends on the values obtained for the zero-air-void specific gravity or the theoretical maximum specific gravity. The Texas method of mixture design (Item 340) selects the design asphalt content which produces a specimen at 3 percent air voids (97 percent relative density) provided that Hveem stability of the specimen satisfies the minimum requirements based on laboratory tests. It is the purpose of this report to evaluate and compare different methods of determining the theoretical maximum specific gravity ($G_{max}$), and to analyze their effects on selecting the design asphalt content. First, the methods will be briefly described; a presentation of experimental data then follows. The results obtained from the tests are discussed and analyzed, and a conclusion is made.

This comparative study is performed on the maximum specific gravities, the effective specific gravities, and the relative densities obtained from different methods. The effect of varying the design asphalt content is investigated. The relationship between the differences in the maximum specific gravity and percent asphalt absorption is also studied.

# CHAPTER 2. METHODS OF DETERMINING THE THEORETICAL MAXIMUM SPECIFIC GRAVITY

Currently, there are three methods which have been or are being used in Texas to estimate the theoretical maximum density (zero air void density), $G_{max}$. These methods are:

(1) Rice method (Test Method Tex-227-F, Ref 1),
(2) SDHPT method as outlined in Construction Bulletin C-14 (Ref 2), and
(3) theoretical method based on the bulk specific gravity of the aggregate.

These methods, along with a fourth method (backcalculation method), will be briefly discussed later.

In the C-14 and backcalculation methods, the effective specific gravity of aggregates is used to determine the theoretical maximum specific gravity. Therefore, before discussing the above methods, the effective specific gravity and its difference from other specific gravities of aggregates are briefly explained.

## SPECIFIC GRAVITIES OF AGGREGATES

The specific gravities of aggregates are required to calculate the theoretical maximum specific gravity of the mixture. However, there are three different specific gravities, all of which will result in different values of the theoretical maximum specific gravity of the mixture. Thus, it is very important to distinguish clearly between different specific gravities of aggregates and their effects on the estimated theoretical maximum specific gravity of the mixture. Figure 1 illustrates the different types of specific gravities which can be calculated for the aggregate. The bulk and apparent specific gravities are obtained directly from tests on the aggregates. However, the effective specific gravity is obtained only through tests on asphalt-aggregate mixtures. The effective specific gravity is greater than the bulk specific gravity. The difference between the bulk and effective specific gravities increases as the amount of absorbed asphalt increases.

### *THE RICE METHOD*

This method (Texas Test Method Tex-227-F and its equivalent, ASTM D-2041) was developed by James Rice (Ref 3), and thus is commonly known as the Rice method. In this method, a measured amount of asphalt-aggregate mixture is placed in a pycnometer and submerged in water. A vacuum is then applied to remove entrapped air at room temperature. The pycnometer is then filled with water and weighed. The weight of the pycnometer filled with water (without presence of the aggregate) is also determined. The volume of the mixture is calculated based on these weight measurements. The theoretical maximum specific gravity is calculated using the dry weight and the volume of the mixture.

For mixtures containing porous aggregates or aggregates which are not completely coated, it is recommended that the saturated surface dry weight be used to determine the volume rather than the dry weight, to correct for errors introduced during testing by water absorption. The higher the water absorption, the greater the difference between the corrected and uncorrected values. The following factors contribute to water absorption into the mixture during the Rice test (Ref 1): (a) insufficient or very thin coating of aggregates by asphalt, (b) very porous aggregate, and (c) excessive vacuum applied and excessive time used for vacuum.

In this report, the Rice specific gravity based on dry weight is referred to as the "uncorrected Rice Specific Gravity," $G_{ru}$. If saturated-surface-dry mixture is used to calculate volume, the gravity is termed "corrected Rice Specific Gravity," $G_{rc}$. The corrected gravity is always smaller than the uncorrected gravity and thus will result in a higher relative density. The uncorrected Rice method is generally used to determine the theoretical maximum specific gravity.

### *TEXAS SDHPT METHOD, C-14*

This procedure is outlined in the Construction Bulletin C-14 (Ref 2). In this method, the effective specific gravity of the aggregate is first determined. Then, the effective specific gravity is used to calculate the theoretical maximum specific gravity using the following formula:

$$G_{C\text{-}14} = \frac{100}{\frac{\%Agg}{G_e} + \frac{\%AC}{G_{ac}}}$$

where

$G_{C\text{-}14}$ = theoretical maximum specific gravity,
%Agg = percentage of aggregate in mix by weight,
%AC = percentage of asphalt in the mix by weight,
$G_e$ = effective specific gravity of the combined aggregates, and
$G_{ac}$ = specific gravity of asphalt.

Thus, the effect of asphalt absorption is taken into account through the use of the effective specific gravity.

This method is unique in the way it determines the effective specific gravity of the aggregate. A series of specimens are compacted at different asphalt contents and their bulk specific gravities are measured. Generally, the bulk specific gravity of the specimens increases as the asphalt content increases until all voids are filled with asphalt (saturated) and then decreases with additional asphalt. Specific gravity of the compacted specimens with one increment more asphalt cement than the compacted specimens with the highest specific gravity ($G_{cs}$) is used to calculate the effective specific gravity of the combined aggregate using the following formula:

$$G_e = \frac{100 - \%AC}{\frac{100}{G_{cs}} + \frac{\%AC}{G_{ac}}}$$

where

$G_{cs}$ = specific gravity of the compacted specimens with one increment more asphalt cement than the compacted specimens with the highest specific gravity.

### *THEORETICAL METHOD*

In this method, the bulk specific gravity of the combined aggregates (which is measured according to Test Method Tex-201-F) is used to calculate the theoretical maximum specific gravity through the following equation:

$$G_t = \frac{100}{\frac{\%Agg}{G_b} + \frac{\%AC}{G_{ac}}}$$

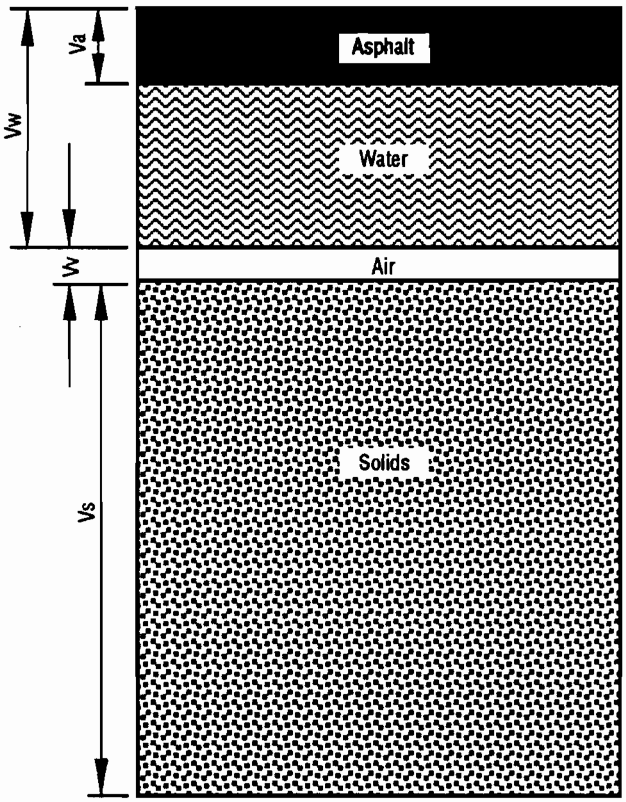
where

$G_b$ = bulk specific gravity of the combined aggregates.

The aggregate potential for asphalt absorption is ignored when bulk specific gravity is used. Therefore, this method yields a lower theoretical maximum specific gravity, higher relative density, and lower optimum asphalt content compared to the first two methods.

### *RICE BACKCALCULATION METHOD*

Another approach, in addition to the three methods mentioned above, is the Rice backcalculation approach, which is similar to the method used in C-14. In this method, only one Rice test is performed on one mixture. Generally, a mixture with a high asphalt content is selected to ensure complete coating of aggregates. The theoretical maximum specific gravity from the Rice test is used to calculate the effective specific gravity of the aggregate, which is then used to calculate $G_{max}$ at other asphalt contents. This method takes significantly less time to find the maximum specific gravities at various asphalt contents than actually performing the Rice test at those asphalt contents. It is reasonable to believe that the effective specific gravity is independent of the amount of asphalt content as long as coating of aggregates with asphalt is complete and the same type of asphalt is used. However, the chances of making errors in performing the Rice test increase at very high asphalt contents, mainly because part of the asphalt can easily be lost by its sticking to the pan and other implements.




Apparent specific gravity:

$$G_a = \frac{Ws}{(Vs + Vv)} \cdot \frac{1}{\gamma_w}$$

Bulk specific gravity:

$$G_b = \frac{Ws}{(Vs + Vv + Vw)} \cdot \frac{1}{\gamma_w}$$

Effective specific gravity:

$$G_e = \frac{Ws}{(Vs + Vv + Vw - Va)} \cdot \frac{1}{\gamma_w}$$

Gb < Ge < Ga

Vs = Volume of solids
Vw = Volume of voids permeable to water
Va = Volume of voids permeable to asphalt cement
Vv = Volume of voids never filled with water or asphalt cement
Ws = Weight of solids
$\gamma_w$ = Unit weight of water

**Fig 1. Graphics representation to indicate different types of specific gravities of aggregates.**

# CHAPTER 3. EXPERIMENTAL PROGRAM

Thirteen projects were selected for this study. The aggregates included limestone and silicious materials. The asphalt cements were either AC-20 or AC-10 for all mixtures. The asphalts and aggregates, their specific gravities, and the asphalt sources are summarized in Appendix Table A.1. Data were obtained from tests conducted by project and district personnel.

All data for projects one, two, and three were from the corresponding districts, and all data for projects six through thirteen were from tests conducted by project personnel. For projects four and five, the data concerning Rice specific gravities at different asphalt contents, and the specific gravities of compacted specimens, were obtained from the corresponding districts; however, the Rice specific gravities at design asphalt content or at a high asphalt content—and the bulk specific gravities of aggregates—were determined by project personnel.

For projects six through eleven, Rice specific gravities were determined at design asphalt content and at a high asphalt content. However, for projects twelve and thirteen, both corrected and uncorrected Rice specific gravities were determined at six to eight different asphalt contents.

## LABORATORY TESTING

The laboratory testing included determination of

- specific gravities of the aggregate,
- Rice specific gravities of mixtures, and
- specific gravities of compacted specimens.

### *AGGREGATE SPECIFIC GRAVITY*

The bulk specific gravities of the coarse portion of the aggregates (retained on No. 80 sieve) were determined according to Texas Test Method Tex-201-F. The apparent specific gravities of the fine portion (passing No. 80 sieve) were determined according to Texas Test Method Tex-202-F.

### *MIXTURE-SPECIMEN SPECIFIC GRAVITIES*

Two groups of asphalt-aggregate mixtures were prepared at various asphalt contents for each individual project for which asphalt and aggregate were available. The mixtures were divided into two batches. The mixtures from batch one were used to determine the corrected and uncorrected Rice specific gravities of the mixture according to Texas Test Method Tex-227-F.

Mixtures from batch two were compacted into specimens using the Texas gyratory compactor according to Texas Test Method Tex-206-F. The specific gravities of the compacted specimens were then determined in accordance with Texas Test Method Tex-207-F. The specific gravities of these compacted specimens were used in the C-14 method.

## CALCULATIONS

The results of the laboratory tests and the data obtained from the districts were used to calculate the different parameters as follows:

(1) Corrected and uncorrected Rice specific gravities obtained at various asphalt contents were used to calculate the effective specific gravities of the aggregates.

(2) The combined bulk specific gravities of aggregates were used to calculate the maximum theoretical specific gravities of the mixtures at various asphalt contents.

(3) The specific gravities of compacted specimens and the maximum theoretical specific gravities calculated in step (2) above were used in the C-14 method to determine the effective specific gravities of the aggregates and the maximum specific gravities of mixtures.

(4) The effective specific gravities from the corrected and uncorrected Rice specific gravity at optimum asphalt content or at a high asphalt content were used to backcalculate the maximum specific gravities at other asphalt contents.

(5) Four types of relative densities at various asphalt contents were calculated. The relative densities were calculated based on four types of maximum specific gravities mentioned before.

(6) The amount of asphalt absorbed for different asphalt aggregate mixtures was calculated with the aid of the effective specific gravities of aggregates.

## ANALYSIS

The following parameters were compared and evaluated:

(1) The effective specific gravities obtained from corrected and uncorrected Rice specific gravities at various asphalt contents.

(2) The effective specific gravities at optimum asphalt content obtained from different maximum specific gravities.

(3) The maximum specific gravities at optimum asphalt content from different procedures.

(4) The maximum specific gravities at various asphalt contents for each individual project.

(5) The relative densities based on different maximum specific gravities.

(6) The amount of asphalt absorptions determined from different procedures.

# CHAPTER 4. DISCUSSION OF RESULTS

## EFFECTIVE SPECIFIC GRAVITY

The effective specific gravity ($G_e$) of the combined aggregates for each project was backcalculated from the Rice specific gravities at different asphalt contents. The results, on a distorted scale, are shown in Fig 2. There is no consistent trend between the backcalculated specific gravity and asphalt content at which the Rice gravity was determined. In addition, the variations are small. The maximum difference between the backcalculated effective specific gravities for the same project does not exceed 2 percent of the average $G_e$ for all cases.

Table A-2 gives numerical values for $G_e$ backcalculated using different methods for different projects, and Table A-3 presents a statistical summary on differences in $G_e$ values from various approaches. It can be seen that average difference between $G_e$ values from uncorrected Rice and C-14 methods is 0.021 (less than 1 percent). Much closer agreement exists between $G_e$ values from the corrected Rice method and those from the C-14 method. Table A-3 indicates that, in this case, average difference and standard deviation are about 0.004 and 0.013, respectively, when algebraic values are used. The difference, in no case, exceeds 0.023.

Effective specific gravities from different methods are also compared in the scatter plots of Fig 3. $G_e$ values from the Rice tests are obtained from tests at design asphalt content. Each point is representative of one project. In almost all cases, $G_e$ values from the C-14 method are smaller than those from the uncorrected Rice method. However, in the case of the corrected Rice method, almost half of the values from the Rice method are larger than those from the C-14 method.

It is also worth noting that the $G_e$ value calculated directly from the Rice test at design asphalt content is very close to the one backcalculated from another Rice test at a different asphalt content (Fig 3 and Table A-2).

## THEORETICAL MAXIMUM SPECIFIC GRAVITY

Table A-4 presents numerical values obtained for the theoretical maximum specific gravity ($G_{max}$) for different projects at different asphalt contents, and Table A-5 gives a statistical summary on differences between $G_{max}$ values from different projects. In almost all cases, the uncorrected Rice method yields a higher $G_{max}$ than the C-14 method, as can be seen in Fig 4. Average difference in $G_{max}$ from the C-14 and the uncorrected Rice method is 0.015 (less than 1 percent of typical $G_{max}$ values). However, the agreement is significantly better in the case of the corrected Rice method. The difference in $G_{max}$ obtained from the C-14 and from the corrected Rice method has an average value of 0.003 when algebraic values are used and of 0.011 when absolute values of differences are used (Table A-5). The standard deviation is 0.013 in the former case and 0.007 in the latter case. Figure 5 indicates that differences are both positive and negative. Notice that both C-14 and Rice methods give significantly higher values for $G_{max}$ than the theoretical approach, which uses the bulk specific gravity of aggregate and does not take into account the effect of asphalt absorption (refer to Fig 4 and Tables A-4 and A-5). A summary of $G_{max}$ values at design asphalt content for different projects, and differences between them, are given in Tables A-6 and A-7, respectively. Good agreement exists between the C-14 and uncorrected Rice methods at design asphalt content. However, the agreement is better when the corrected Rice method is compared with the C-14 method. Figure 4 supports this conclusion. The theoretical approach, as expected, yields significantly lower values for $G_{max}$ than other methods (Fig 4).

Figures A-1 through A-6 indicate differences between $G_{max}$ values from various methods in the case of projects for which Rice specific gravities at different asphalt contents are available. In all cases except for project twelve, $G_{max}$ from uncorrected Rice approach is higher than that from C-14 method. There are only two projects (twelve and thirteen) for which both corrected and uncorrected Rice specific gravities are available, and these two suggest that very close agreement exists between the corrected Rice method and the C-14 method. In one case, $G_{max}$ from the C-14 method is higher than that from the corrected Rice, and in the other case, the inverse is true. The figures also indicate that backcalculation values of $G_{max}$ from one Rice test compare very well with those obtained from the Rice test directly.

## RELATIVE DENSITIES

Figures A-7 through A-12 and Tables A-8 and A-9 were developed from the data available on $G_{max}$ values and specific gravities of compacted specimens. Relative densities based on different approaches are given in these figures. It can be seen that, because maximum theoretical specific gravities from the C-14 method are smaller than those from the uncorrected Rice method, the former results in higher relative densities than the latter.

Notice that backcalculation methods yield good results compared to the C-14 and Rice methods. Relative

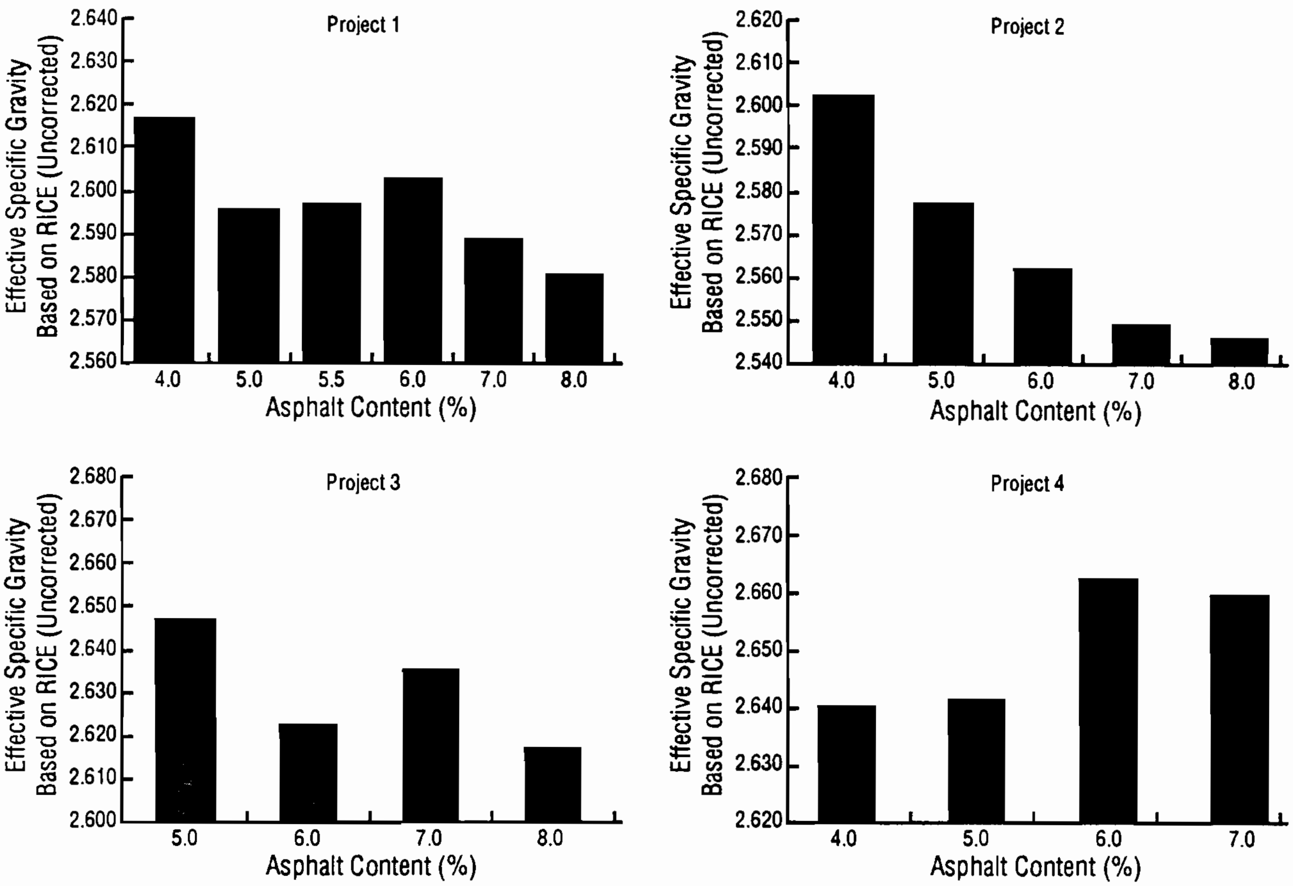



**Fig 2. Effective specific gravities of aggregates obtained from Rice test at different asphalt contents.**

densities based on the corrected Rice method are given only for projects twelve and thirteen. In most cases, except one, the difference between relative densities from the Rice and C-14 methods does not exceed 1 percent, even when the uncorrected Rice specific gravity is compared with that from the C-14 method.

## DESIGN ASPHALT CONTENT

Texas specifications require the design asphalt content to be selected at 97 percent relative density. Because the relative density from the C-14 method is higher than that from the uncorrected Rice method, the former is expected to yield a lower design asphalt content than the latter (Fig 6a). For this reason, in Fig 6b the asphalt content at 96 percent relative density based on the uncorrected Rice method is compared with the asphalt content at 97 percent relative density based on the C-14 method. In this case, better agreement is observed. Since the C-14 method generally yields a drier mix than the uncorrected Rice method at 97 percent relative density, equivalent mixes are expected if design asphalt content is selected at 97 percent based on the former and at 96 percent based on the latter. Unfortunately, sufficient data are not available for the corrected Rice method to compare with data from the C-14 method. However, the design asphalt contents from these two methods are generally expected to be very close.

## ASPHALT ABSORPTION

To investigate the existence of a meaningful relationship between the amount of asphalt absorption and the difference in maximum specific gravities, Fig 7 was provided. The abscissa in this figure is the average percent absorption for each project, which is found based on percent absorptions at different asphalt contents. The average difference in maximum specific gravities also presents the average of differences at different asphalt contents. The data are scattered and do not suggest any meaningful correlation.

## A WORD OF CAUTION CONCERNING THE C-14 METHOD

As mentioned before, in the C-14 method, the assumption is that no air voids exist in the compacted specimen when the saturation point is reached, and

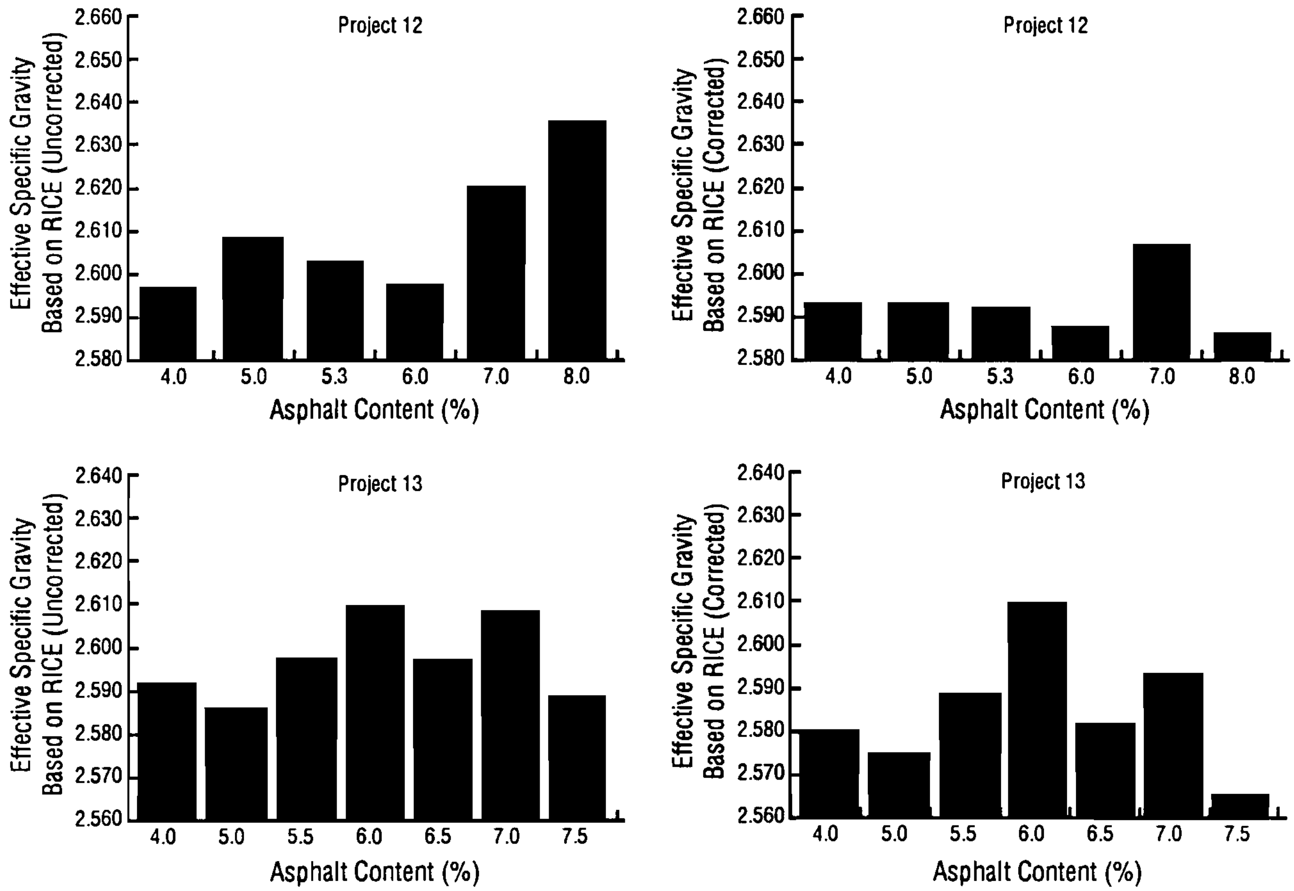



**Fig 2 (continued). Effective specific gravities of aggregates obtained from Rice test at different asphalt contents.**

increasing the asphalt content beyond this point causes reduction in the specific gravity of the specimen. The specific gravity of the specimen following the highest specific gravity is used to find the effective specific gravity of the combined aggregates, because experience indicates that the specimen with the highest specific gravity may have not reached saturation yet and that complete saturation is probably achieved at the asphalt content of the specimen following the peak. It was found that in almost all cases, the relative densities of the specimens with specific gravities following the peak are equal to or exceed 100 percent when $G_{max}$ is calculated based on the bulk specific gravity of the aggregates (i.e., when the theoretical approach is used). No problem is imposed as long as such is the case. However, a review of a number of projects in districts where the C-14 method was used revealed that in some projects, the set of specimens with specific gravity following the peak yielded a relative density less than 100 percent. Assuming that the bulk specific gravity of the aggregates was correct, the only way that the relative density could be less than 100 percent was that saturation was not complete and there were still some voids left in the specimen. There is no way that, on one hand, the specimen could have a lower density than 100 percent based on the theoretical approach, and, on the other, be saturated. Because of this problem, these projects reported effective specific gravities less than the bulk specific gravity, which is impossible, and obtained negative asphalt absorptions.

If theoretical maximum specific gravities are calculated based on the bulk specific gravity, the mix design will yield a mix with less asphalt than could be obtained by any other method. However, erroneous values for the effective specific gravity from the C-14 method will cause this method to yield a mix with even less asphalt content than what should be obtained from the theoretical approach. During the field density control stage, relative densities calculated based on the theoretical approach are generally not conservative. Erroneous results from the C-14 method may indicate significantly higher relative densities than actually exist.

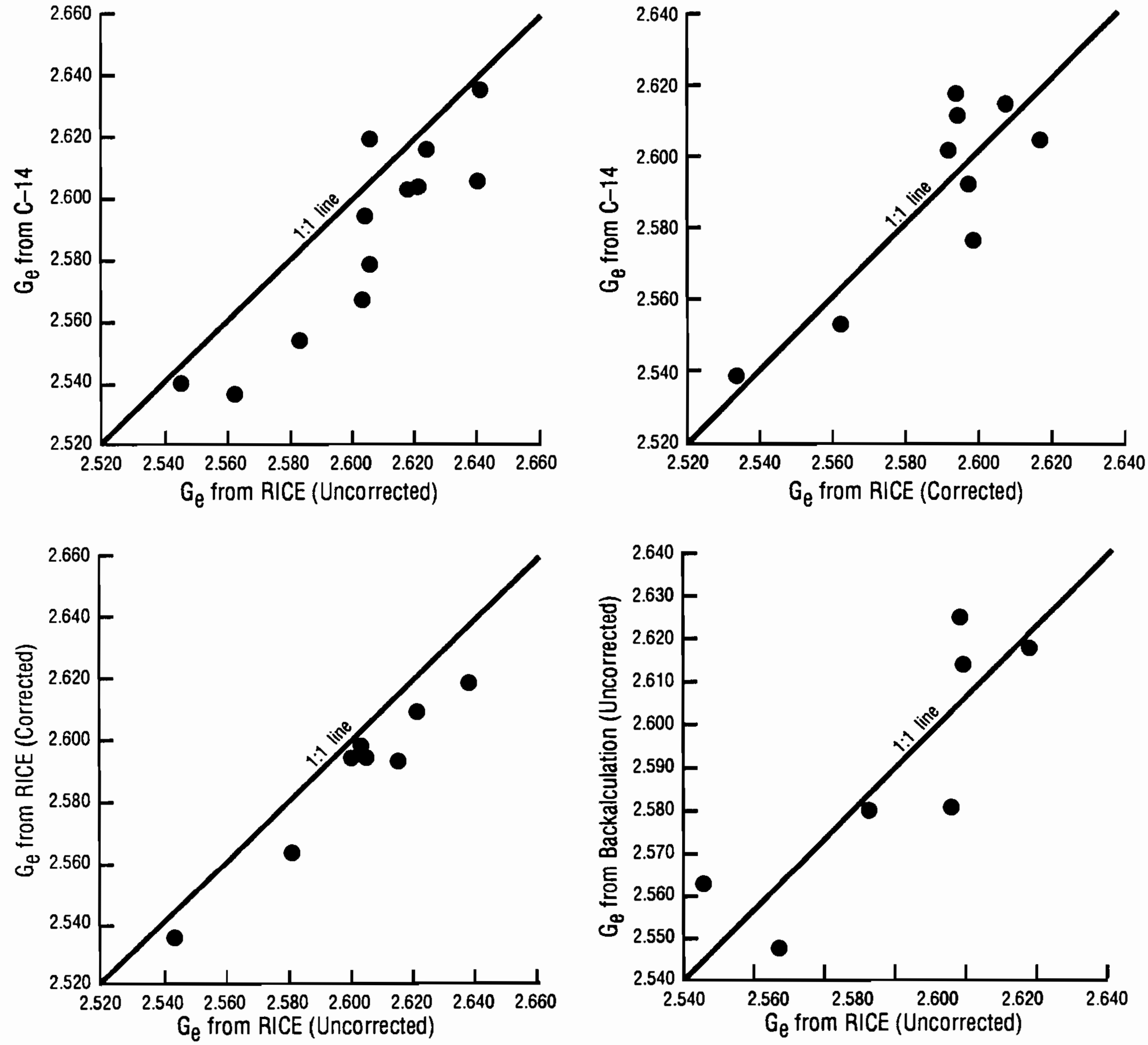



**Fig 3. Comparing effective specific gravities from different methods at design asphalt content.**

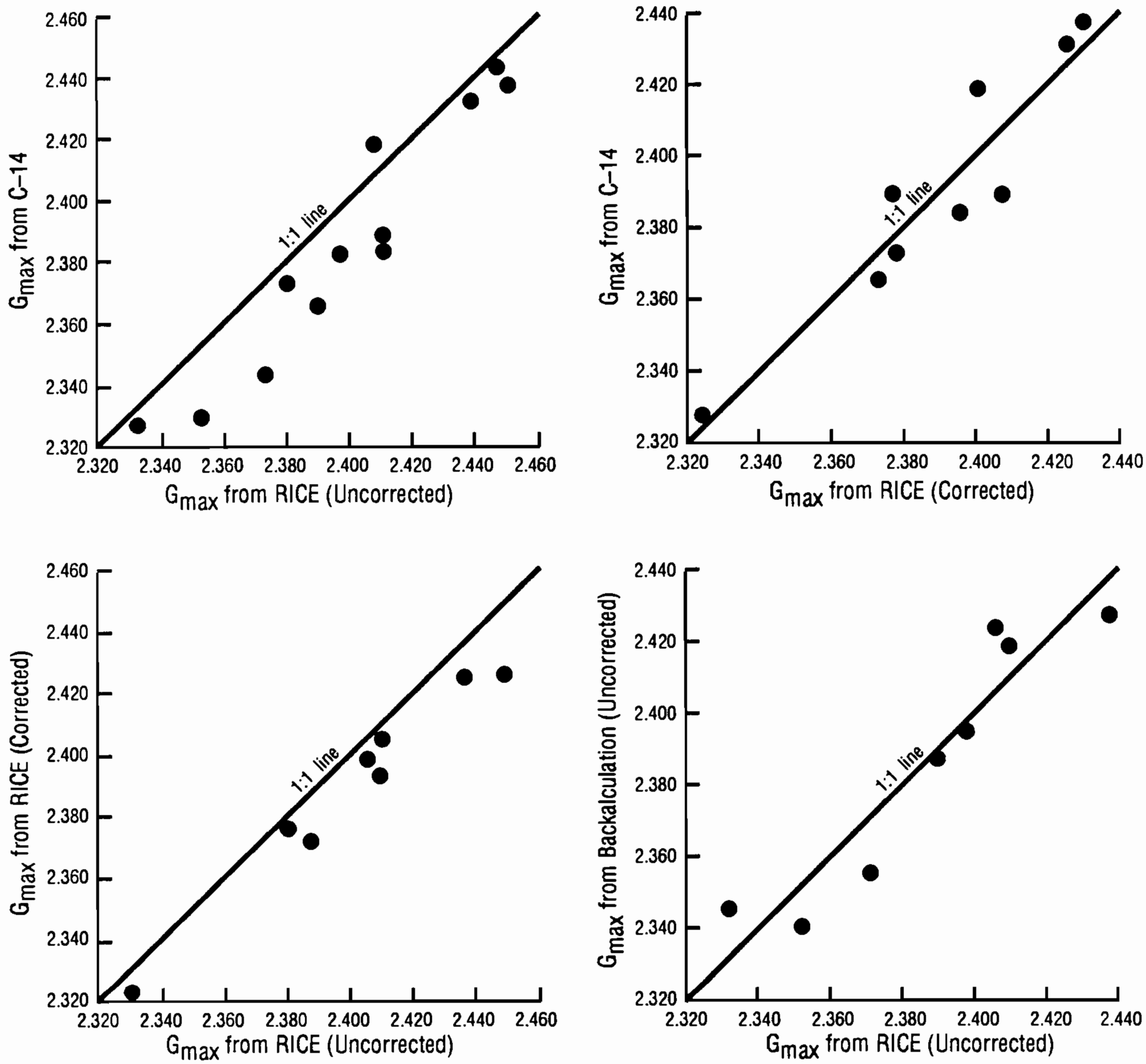



**Fig 4. Comparing theoretical maximum specific gravities from different methods at design asphalt contents.**

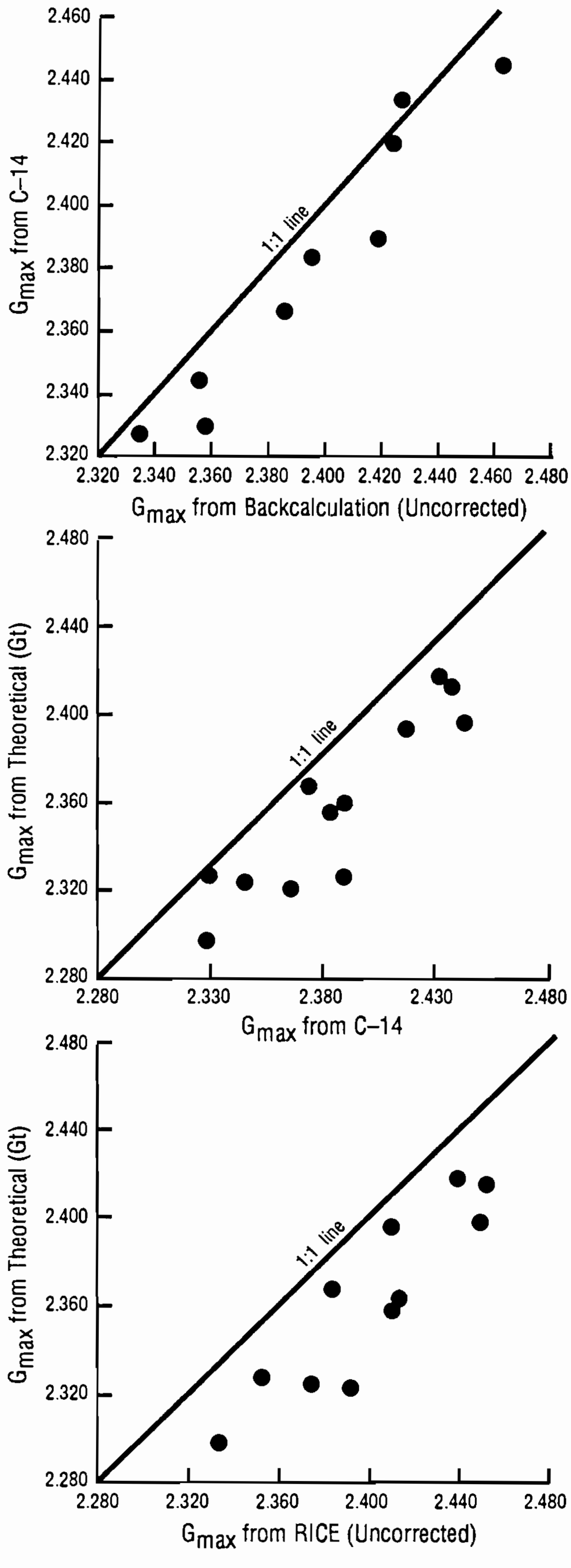



**Fig 4 (continued). Comparing theoretical maximum specific gravities from different methods at design asphalt contents.**

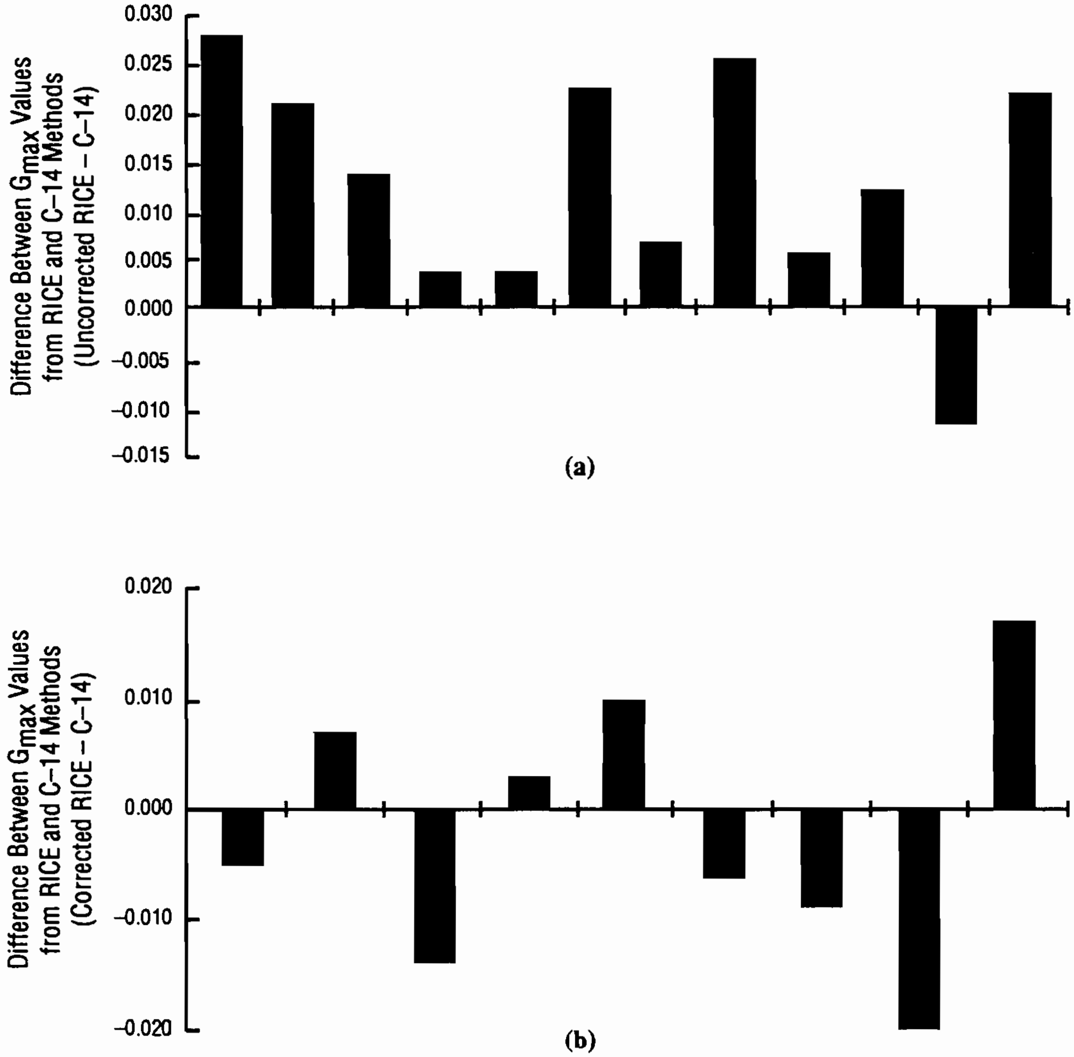



**Fig 5. Differences between values of the theoretical maximum specific gravities from (a) C-14 and uncorrected Rice methods and (b) C-14 and corrected Rice methods.**

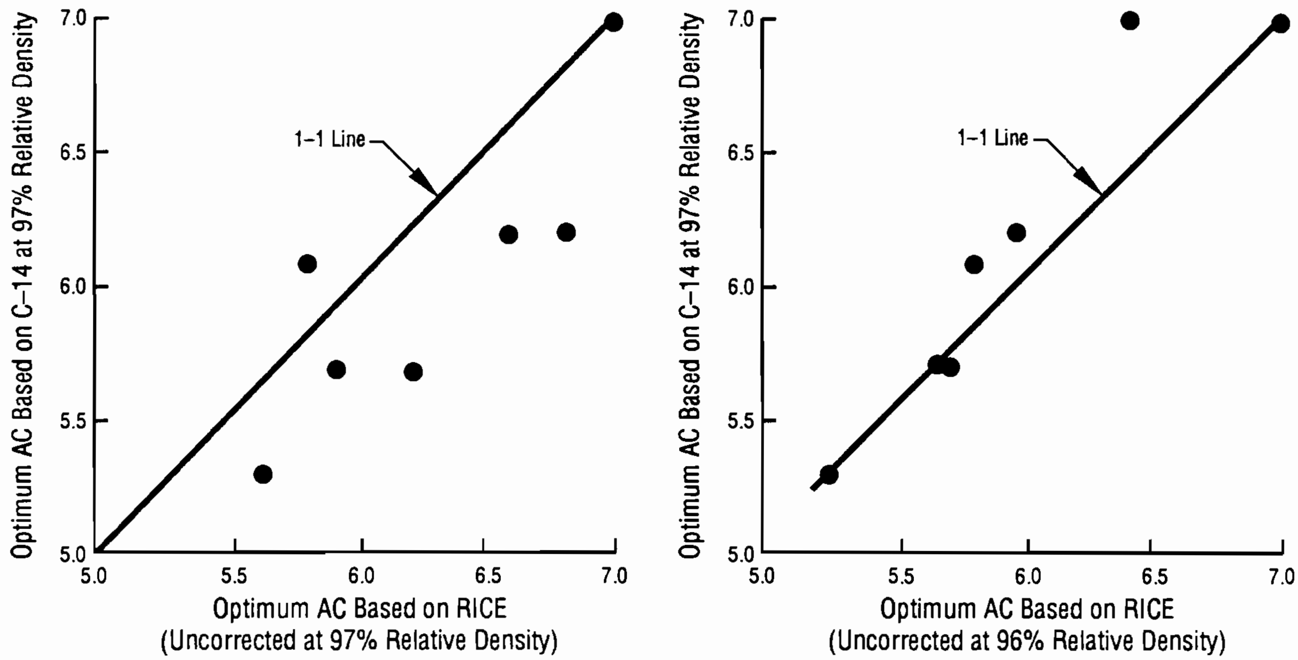



**Fig 6. Comparing design asphalt contents selected based on C-14 and Rice methods.**

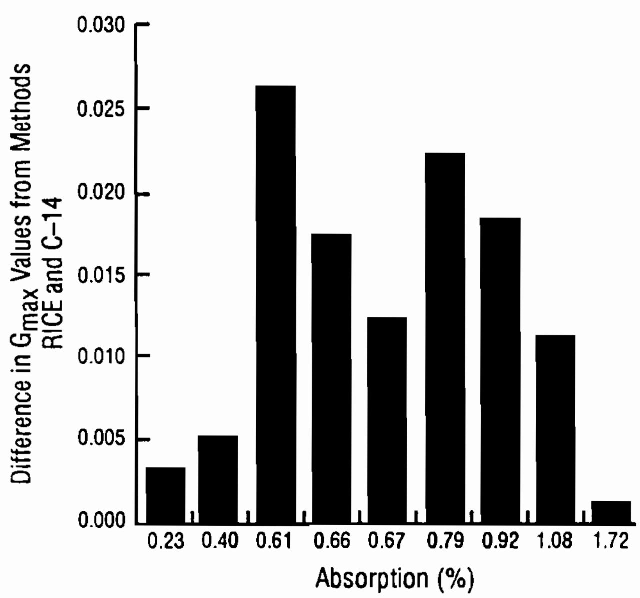



**Fig 7. Difference in $G_{max}$ values from Rice and C-14 methods versus percent of asphalt absorption.**

# CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are made based on the data analyzed in this study:

(1) The theoretical maximum specific gravities from the theoretical approach ($G_t$) are, in general, significantly lower than those obtained from other methods, and therefore, yield the highest relative densities.

(2) The theoretical maximum specific gravities from the uncorrected Rice method ($G_{ru}$) are the highest and result in the lowest relative densities compared to other methods.

(3) Relatively good agreement exists between the theoretical maximum specific gravities from the C-14 method ($G_{C14}$) with those from the uncorrected Rice method ($G_{ru}$).

(4) The best agreement is observed between $G_{C14}$ values and $G_{rc}$ values.

(5) Backcalculating theoretical maximum specific gravity ($G_{max}$) values from one single Rice test is also promising, and backcalculated $G_{max}$ values compare well with those directly from the Rice tests.

(6) Design asphalt content at 97 percent relative density based on $G_{C14}$ is lower than that at 97 percent relative density based on $G_{ru}$.

(7) Relatively good agreement exists between design asphalt contents when 96 percent relative density is used based on $G_{ru}$ and 97 percent relative density is used based on $G_{C14}$.

(8) In this study it was found that the largest differences between the specific gravities measured by the two methods generally do not exceed 2 percent. This difference causes the relative density based on the corrected Rice method to be about 1 to 2 percent less than that based on the uncorrected Rice method. The Rice method is gaining widespread acceptance both at national and at state levels.

(9) An additional consideration should be stated in the C-14 method. If saturation for a specimen is going to be considered complete following the peak, the relative density of that specimen based on the theoretical approach must exceed 100 percent; otherwise erroneous results will occur.

# REFERENCES


1. Manual of Testing Procedures, Volume 2, Texas State Department of Highways and Public Transportation, Austin, Texas, 1982.
2. Construction Bulletin C-14, "Hot Mix Asphaltic Concrete Pavement," Design of Laboratory Mixes, Texas State Department of Highways and Public Transportation, Austin, Texas, April 1984.
3. Rice, J. M., "Maximum Specific Gravity of Bituminous Mixtures by Vacuum Saturation Procedure," ASTM Special Technical Publication No. 191, June 1956.

# APPENDIX. FIGURES AND TABLES

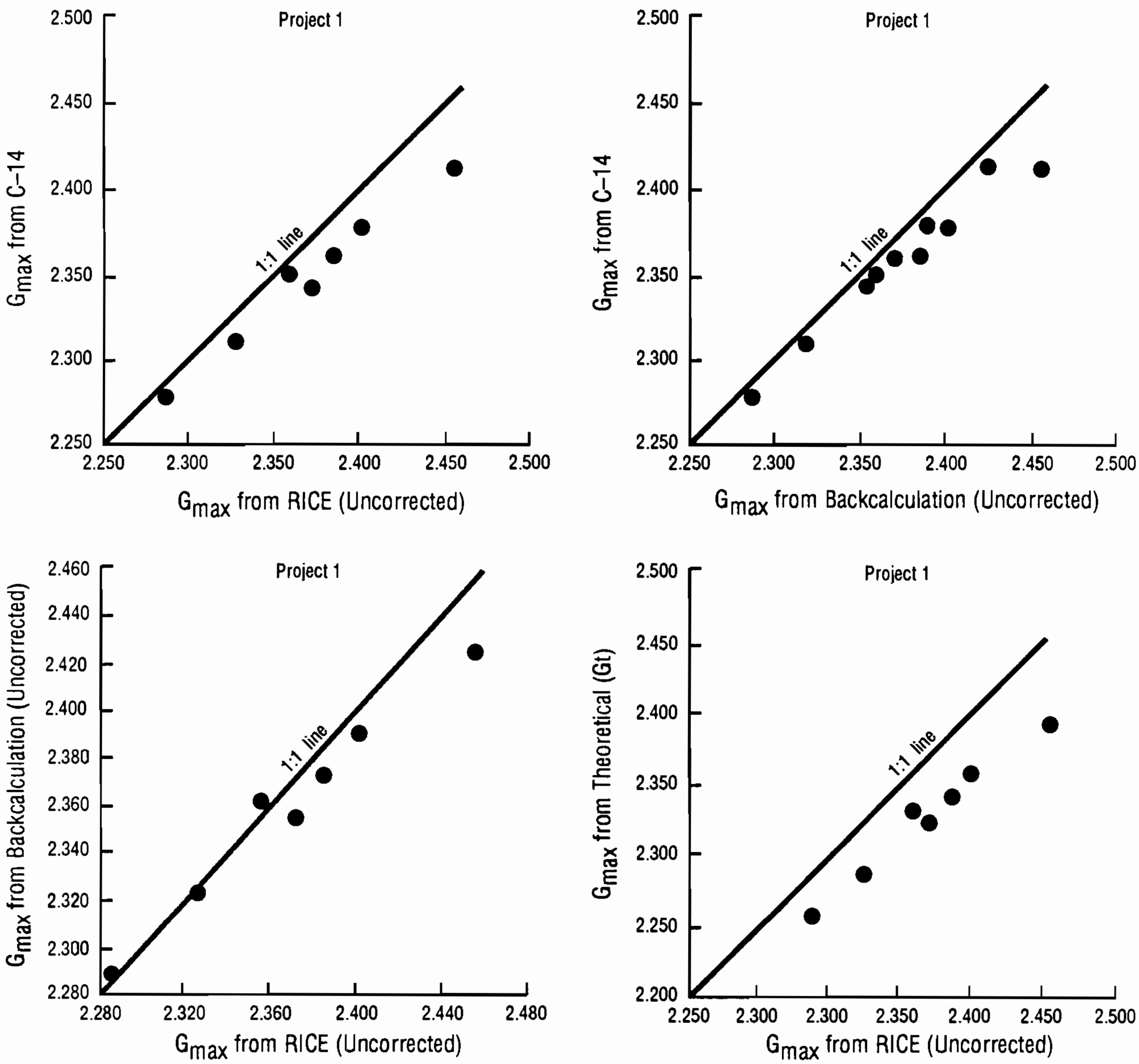



**Fig A-1. Theoretical maximum specific gravity from different methods for Project 1.**

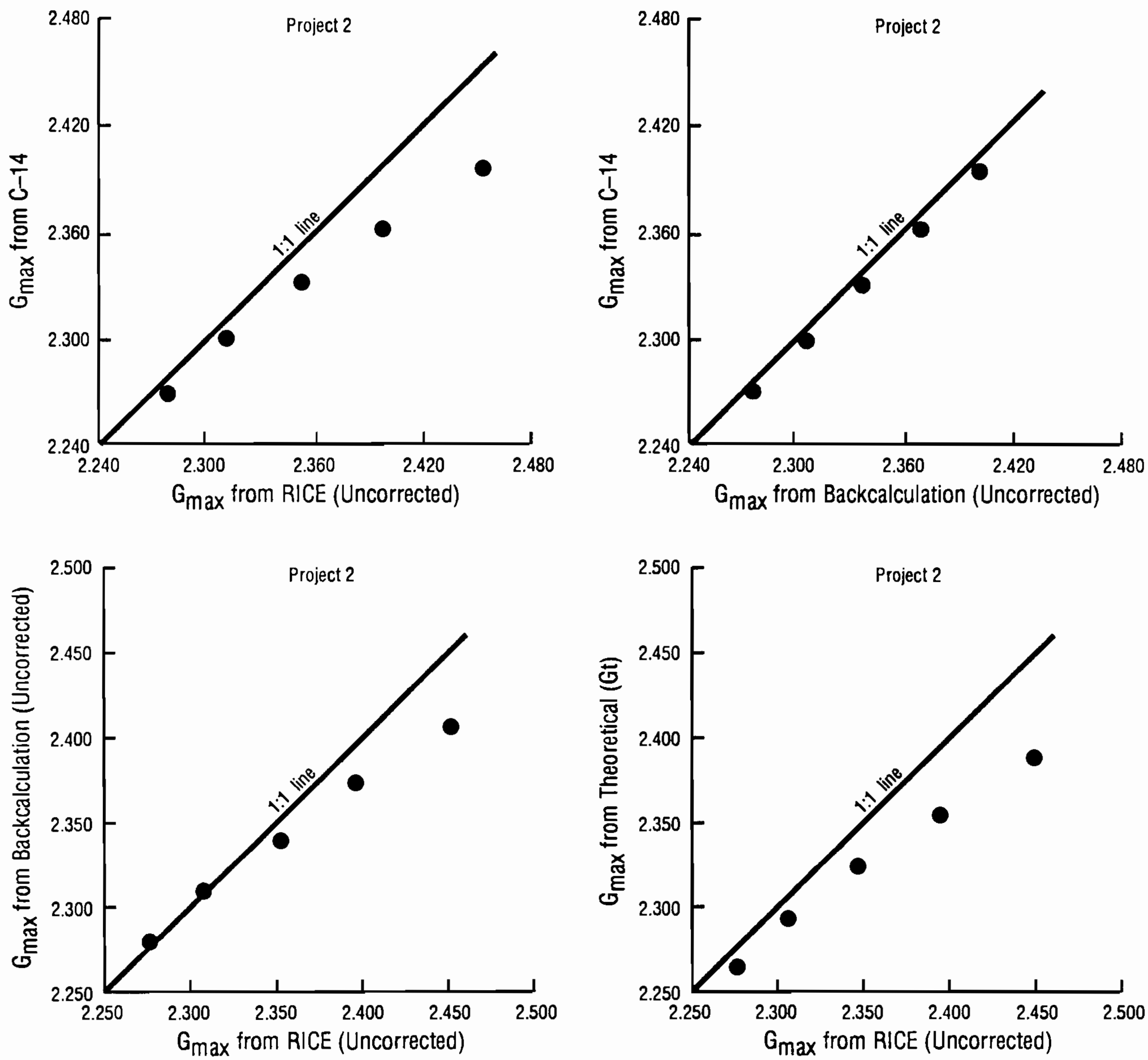



**Fig A-2. Theoretical maximum specific gravity from different methods for Project 2.**

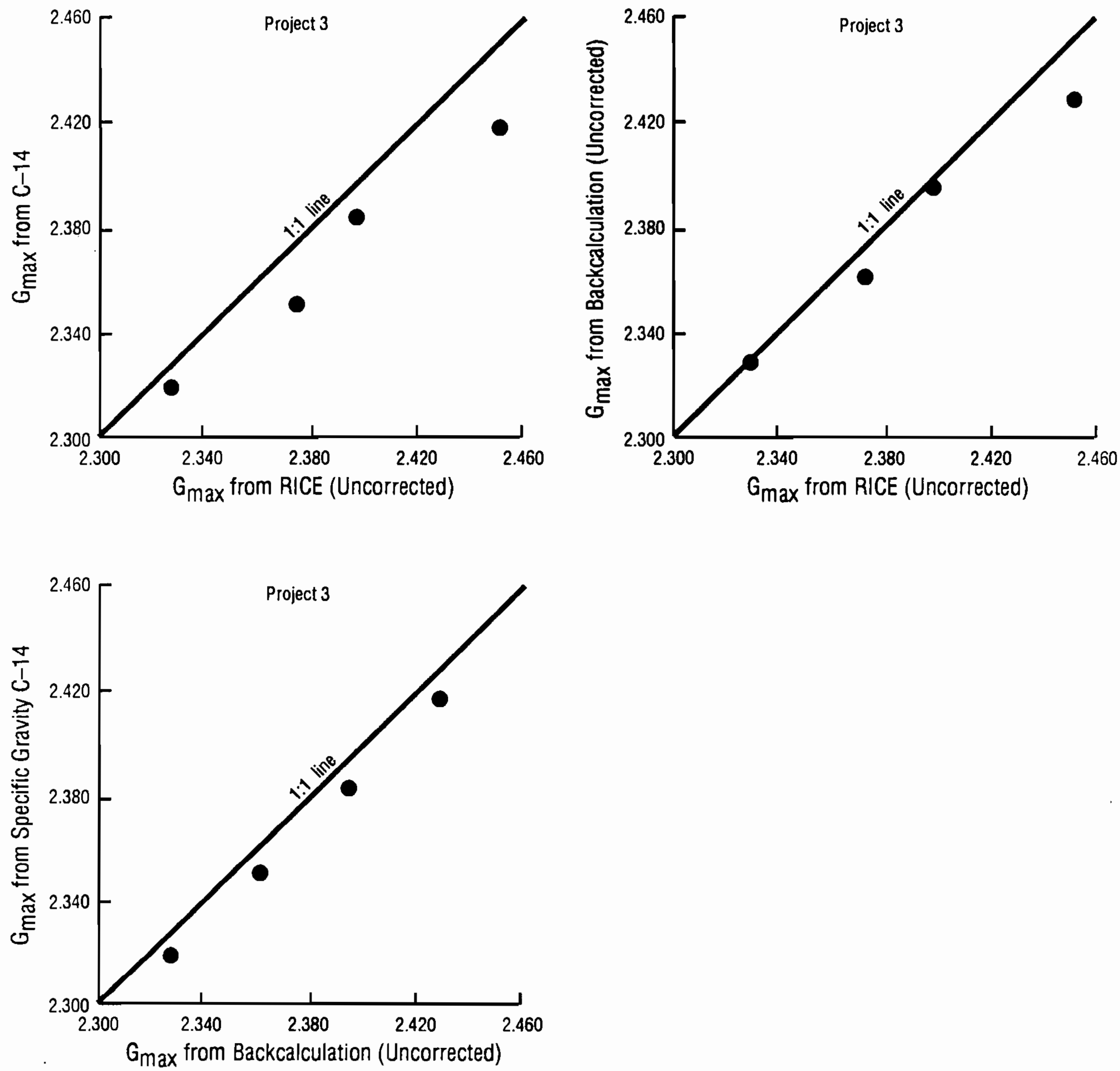



**Fig A-3. Theoretical maximum specific gravity from different methods for Project 3.**

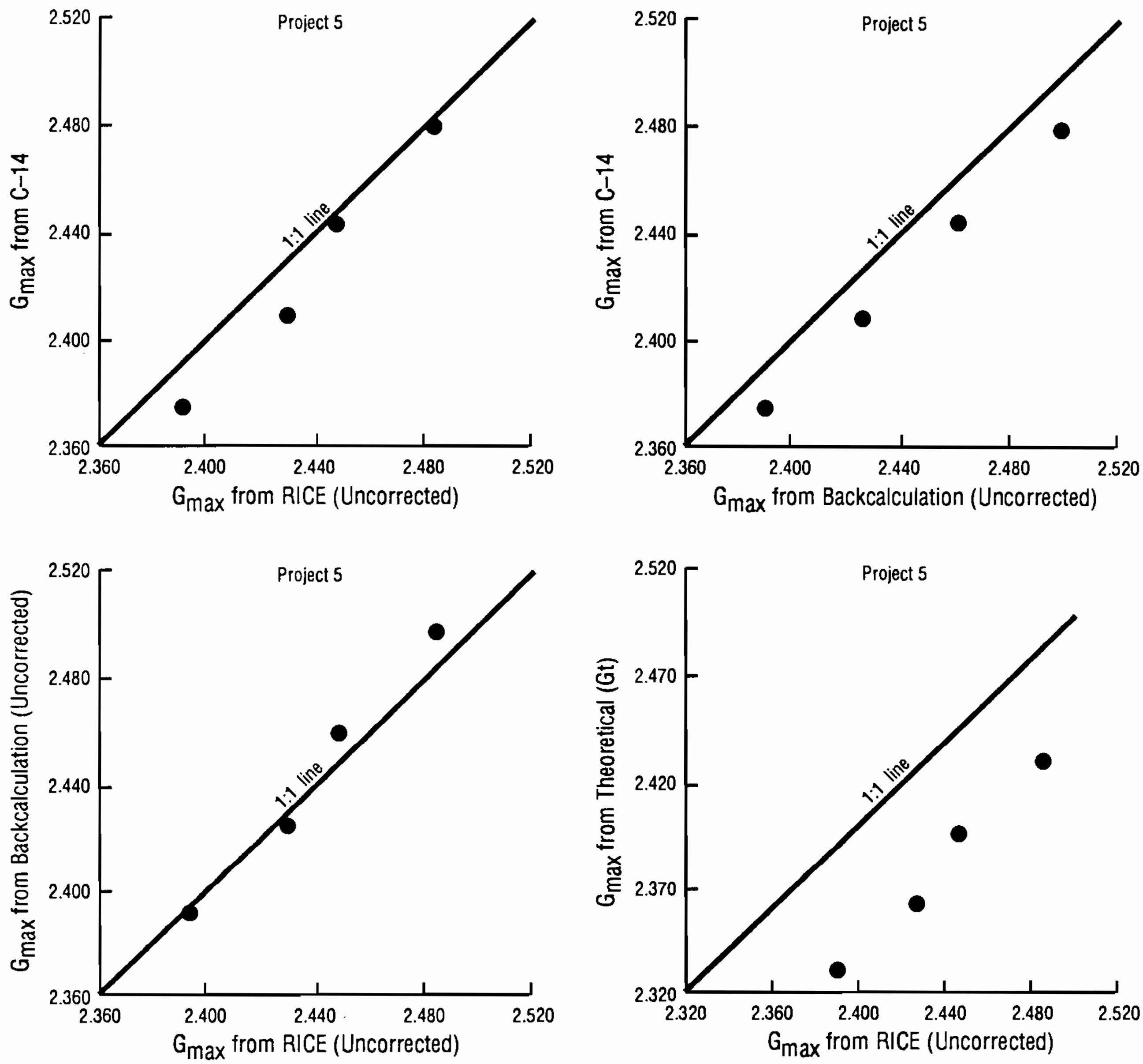



**Fig A-4. Theoretical maximum specific gravity from different methods for Project 4.**

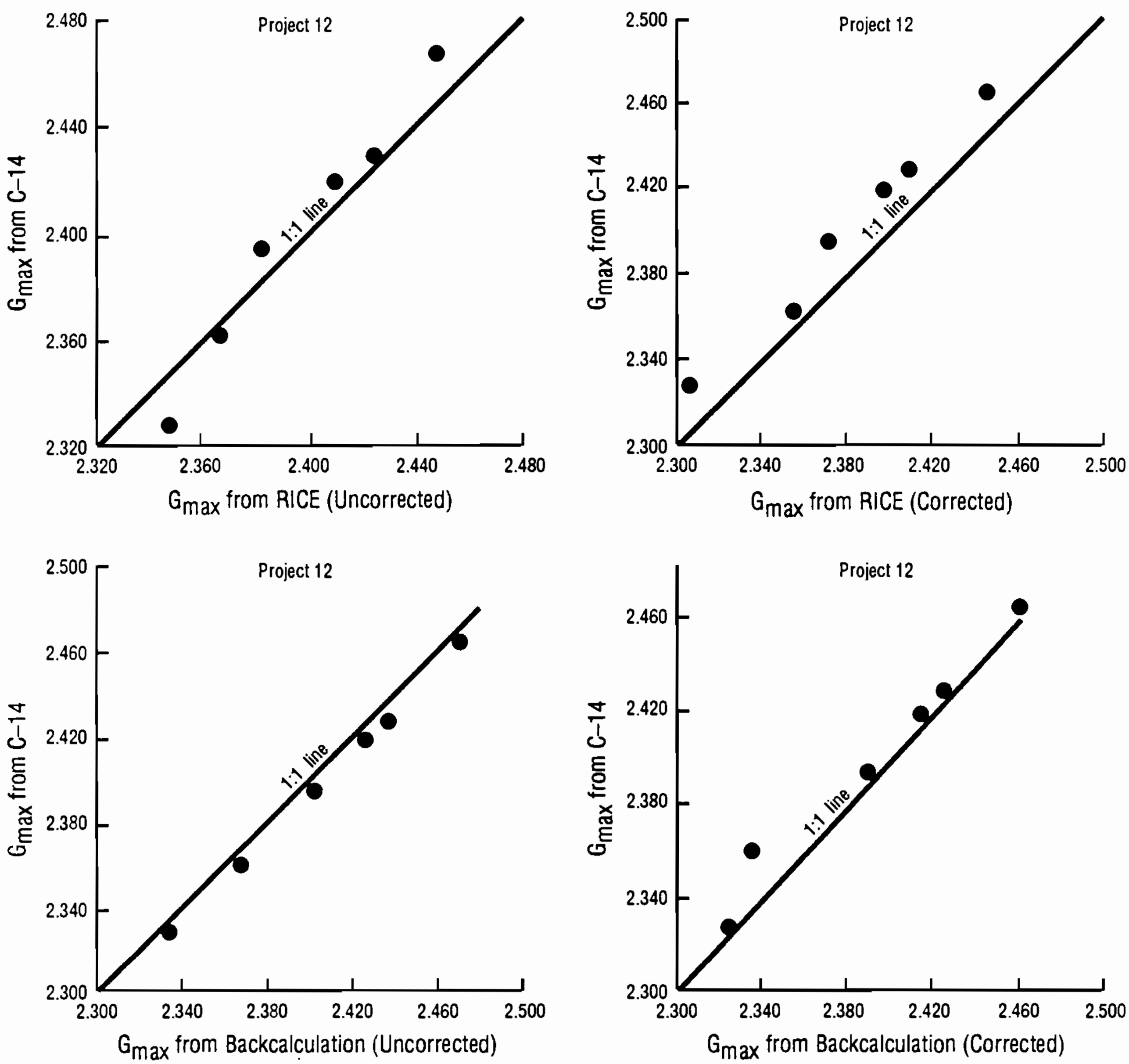



**Fig A-5. Theoretical maximum specific gravity from different methods for Project 12.**

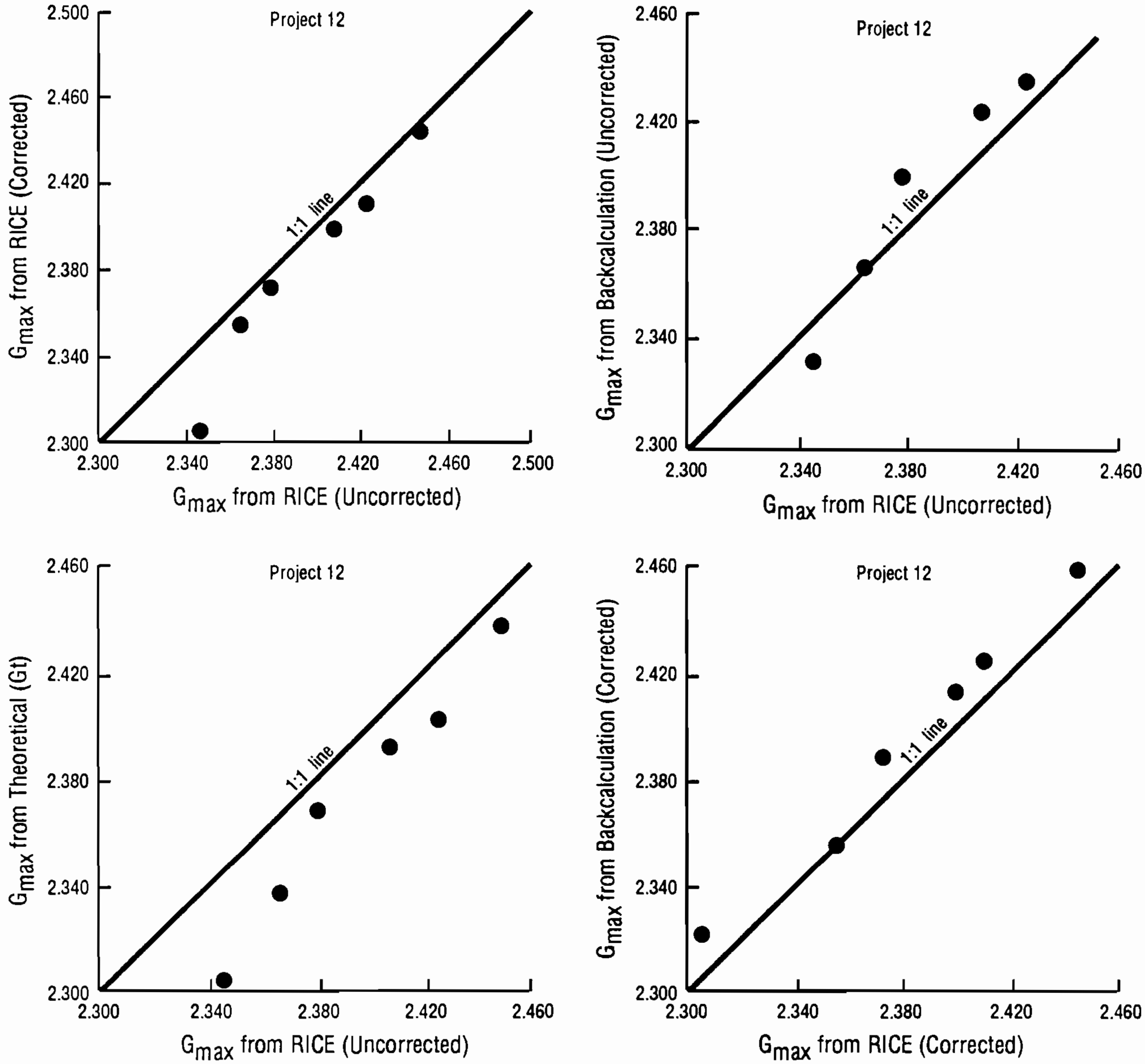



**Fig A-5 (continued). Theoretical maximum specific gravity from different methods for Project 12.**

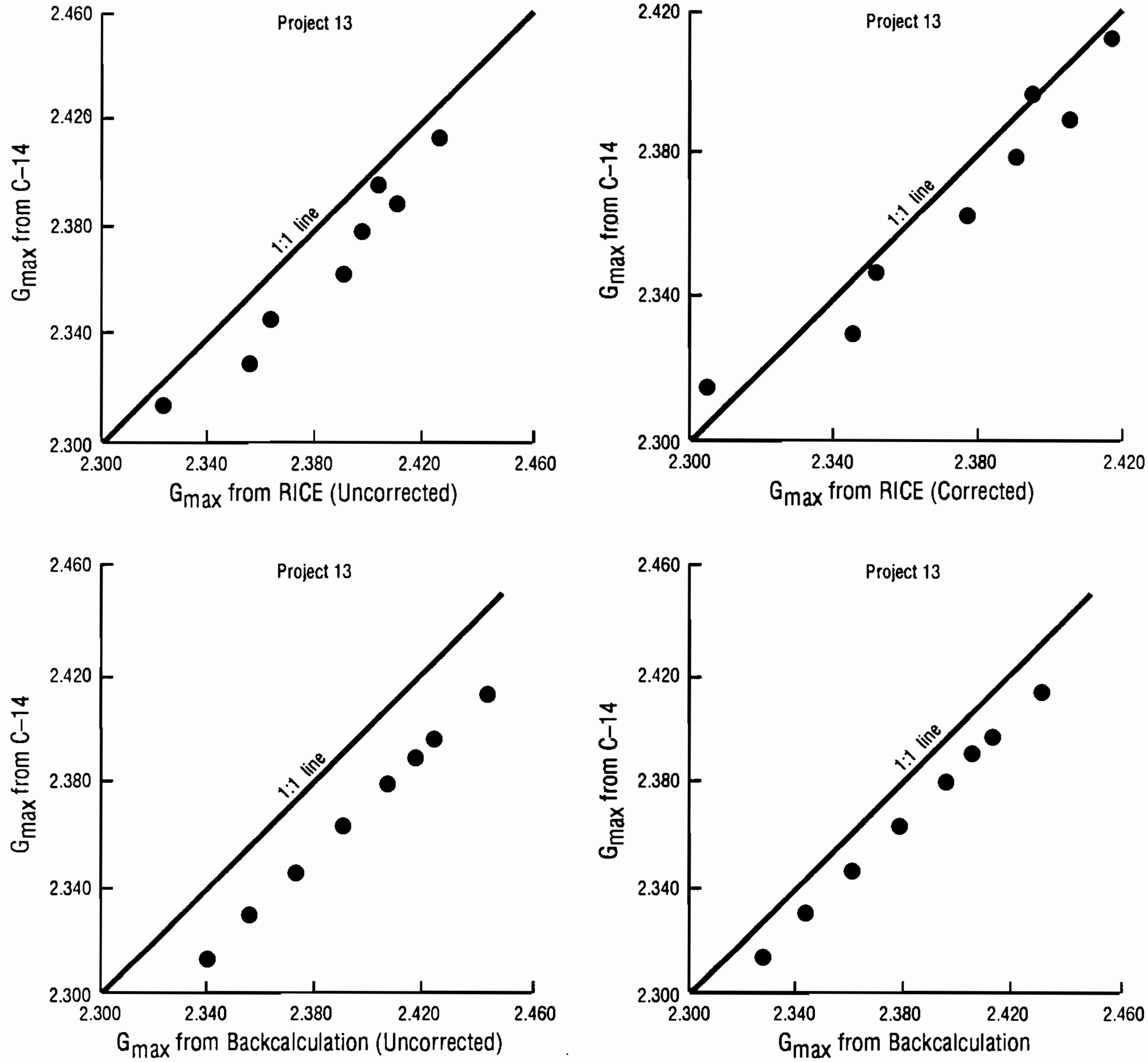



**Fig A-6. Theoretical maximum specific gravity from different methods for Project 13.**

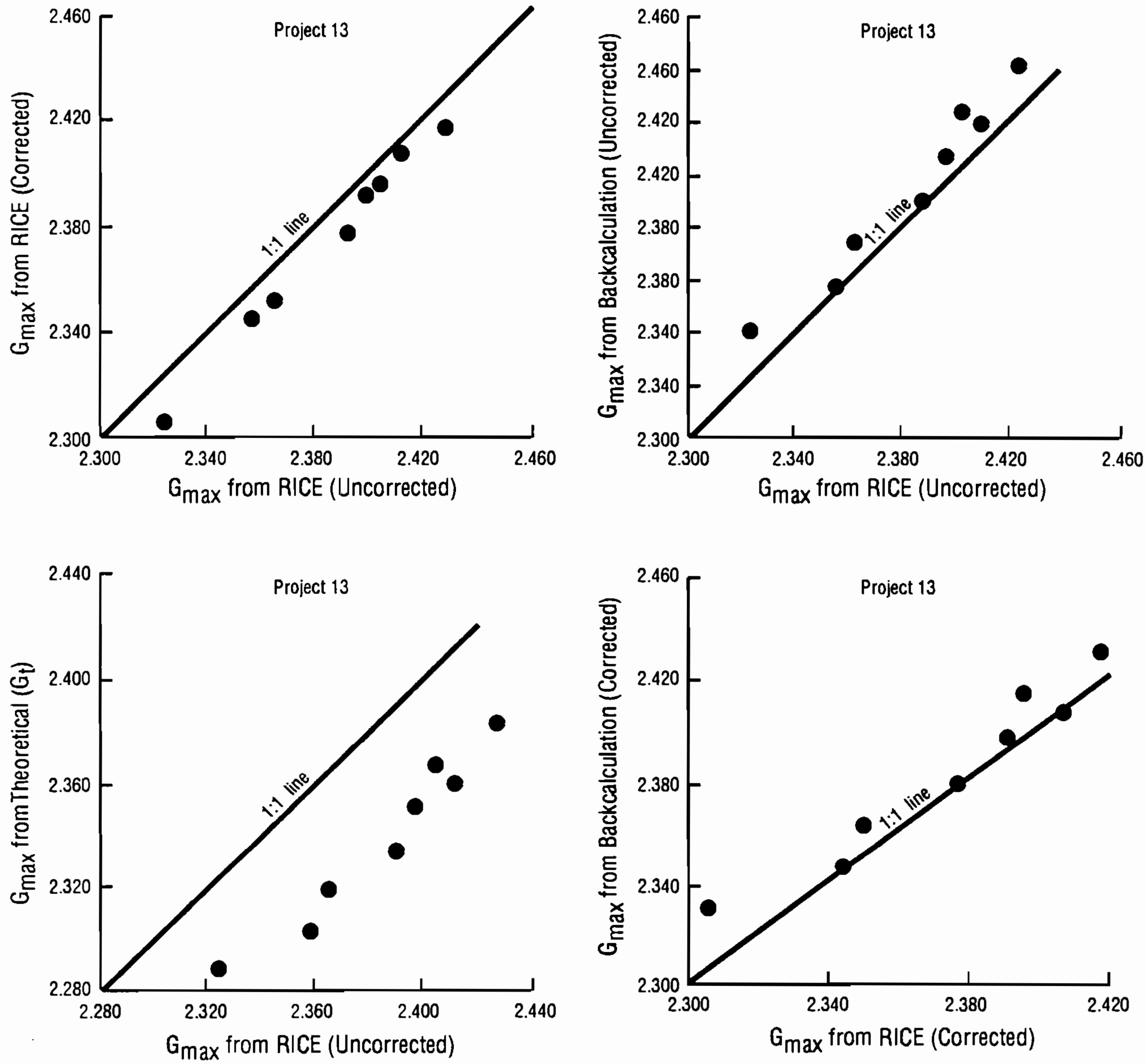



**Fig A-6 (continued). Theoretical maximum specific gravity from different methods for Project 13.**

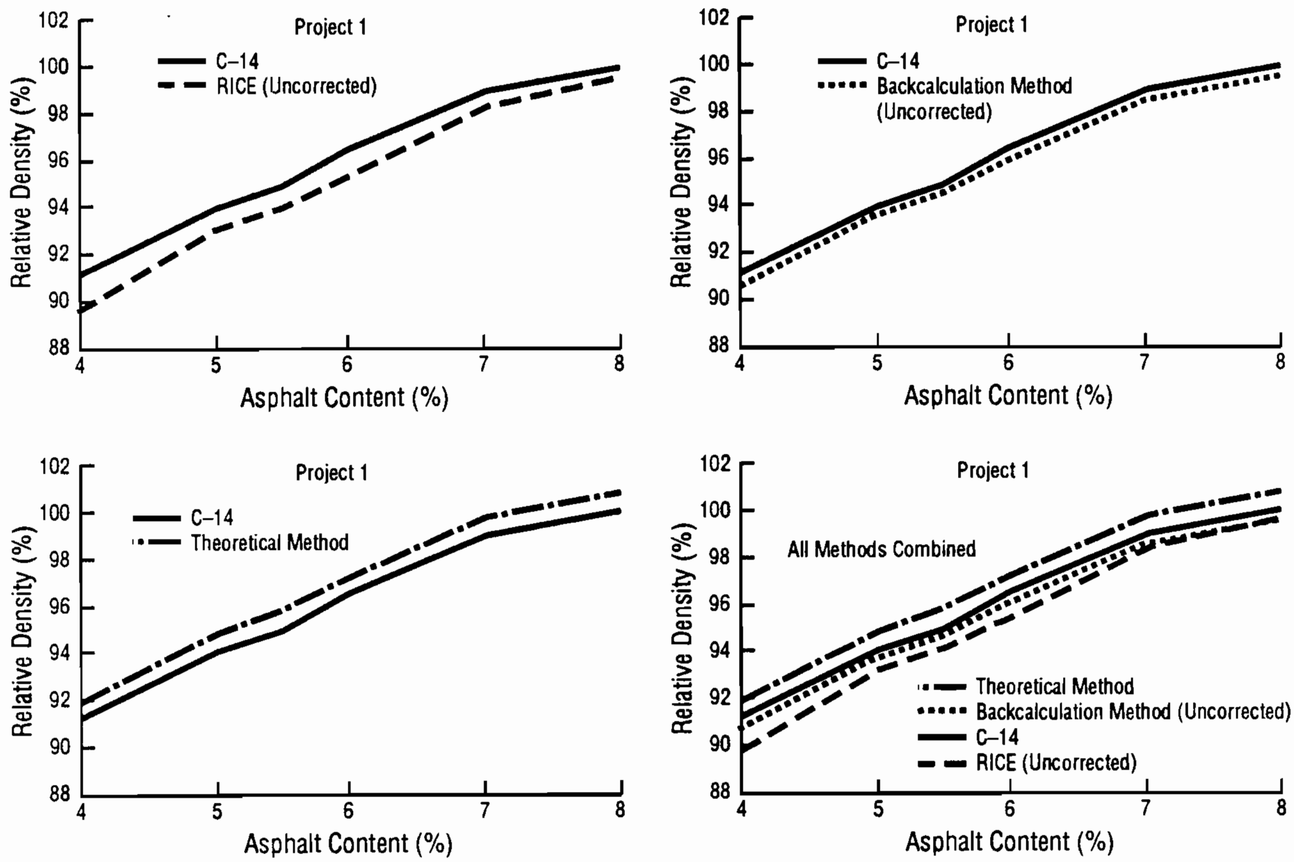



**Fig A-7. Relative densities based on different methods for Project 1.**

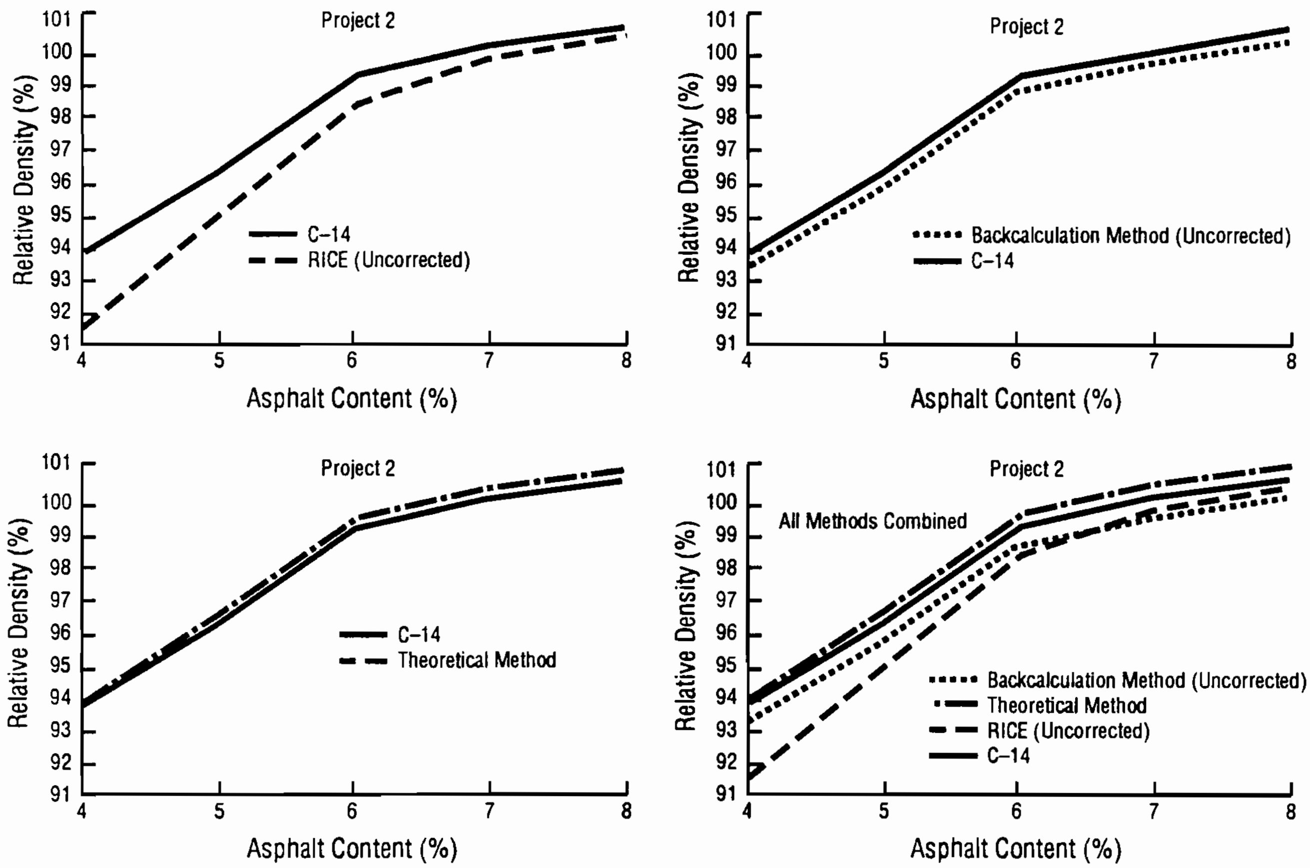



**Fig A-8. Relative densities based on different methods for Project 2.**

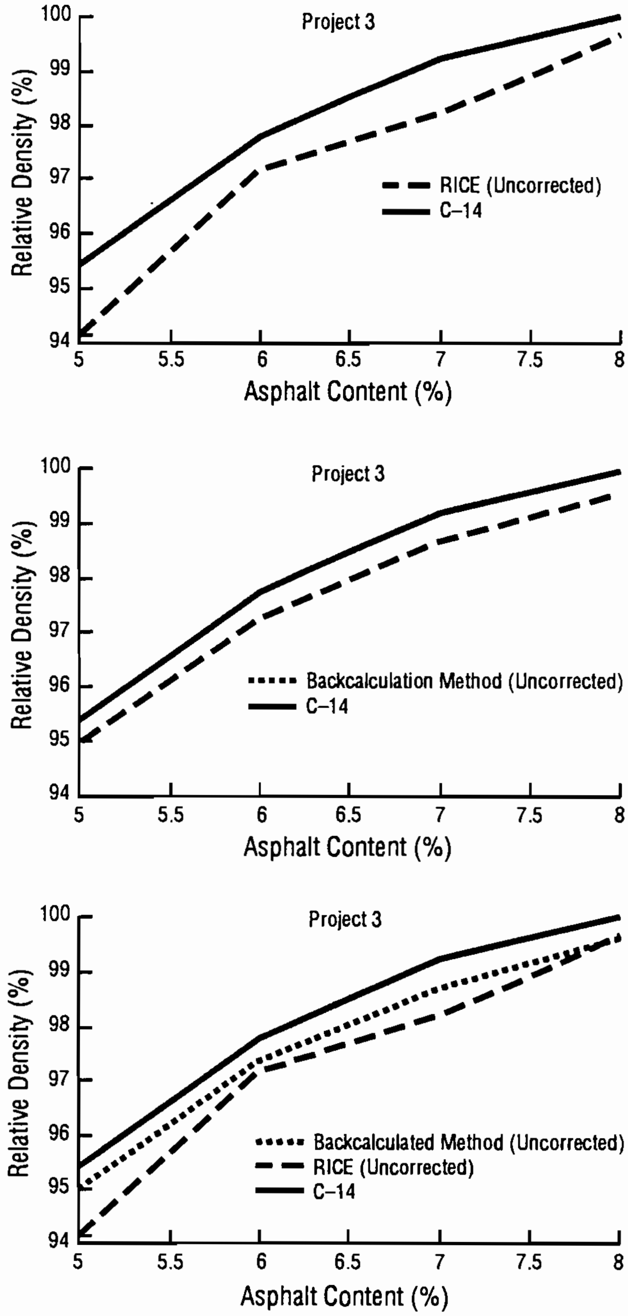



**Fig A-9. Relative densities based on different methods for Project 3.**

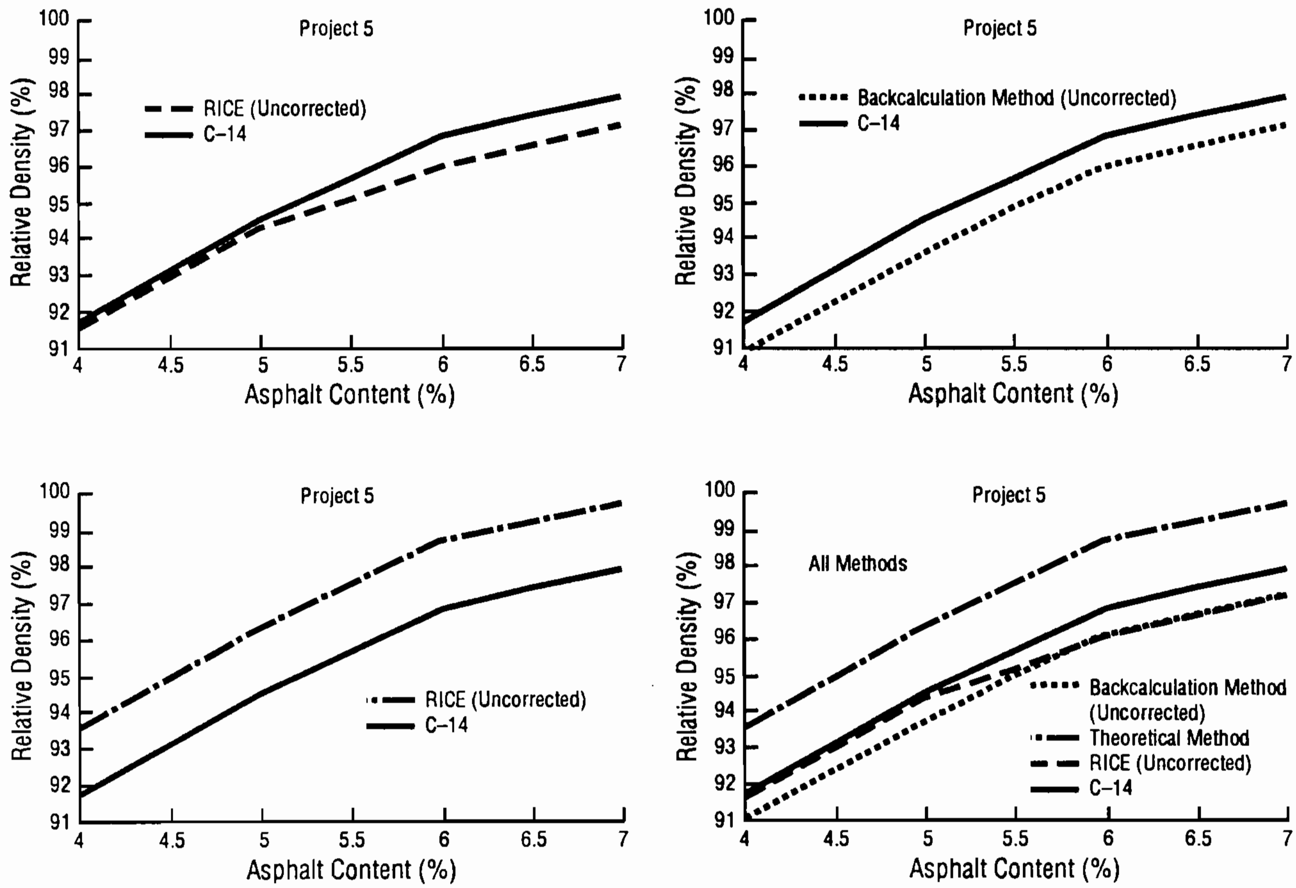



**Fig A-10. Relative densities based on different methods for Project 5.**

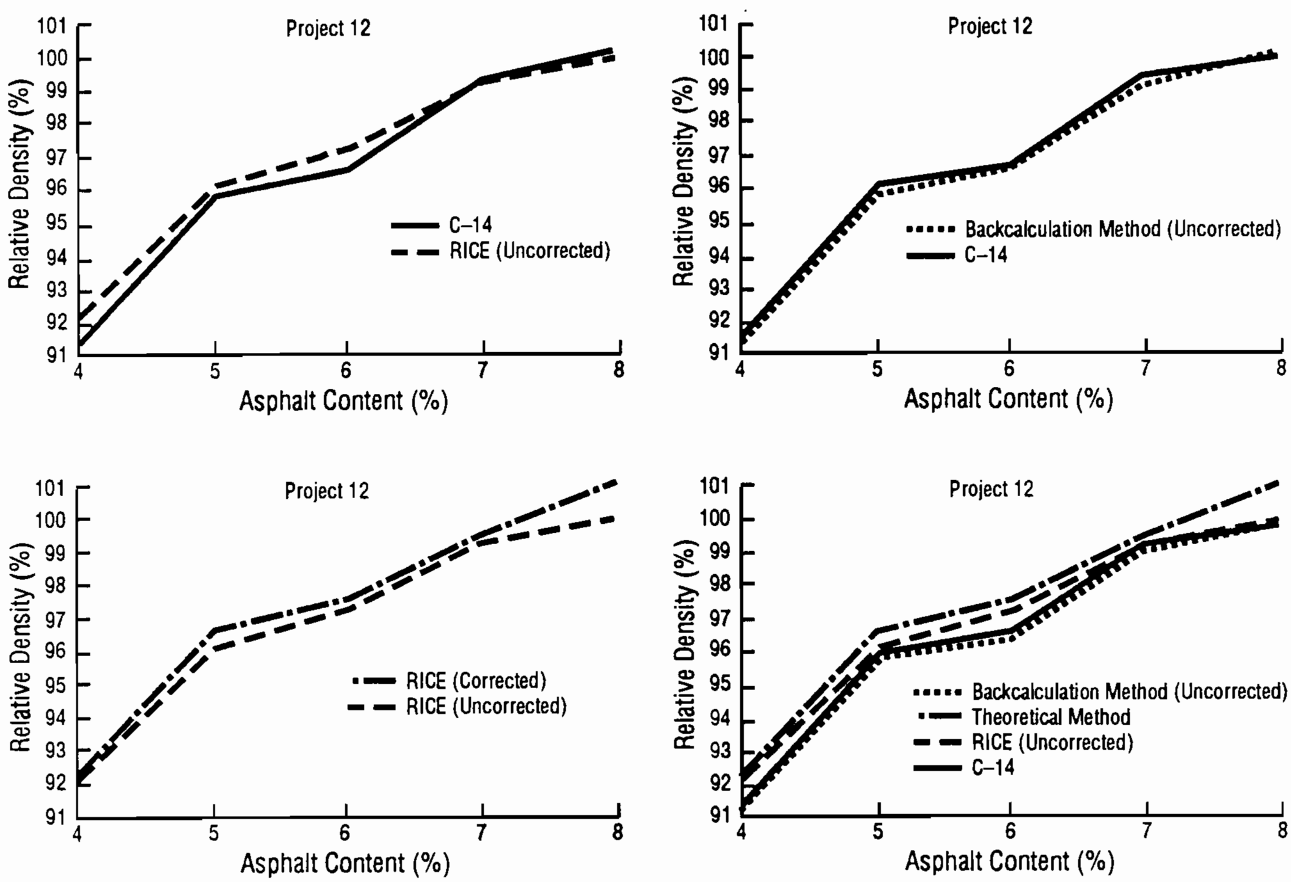



**Fig A-11. Relative densities based on different methods for Project 12.**

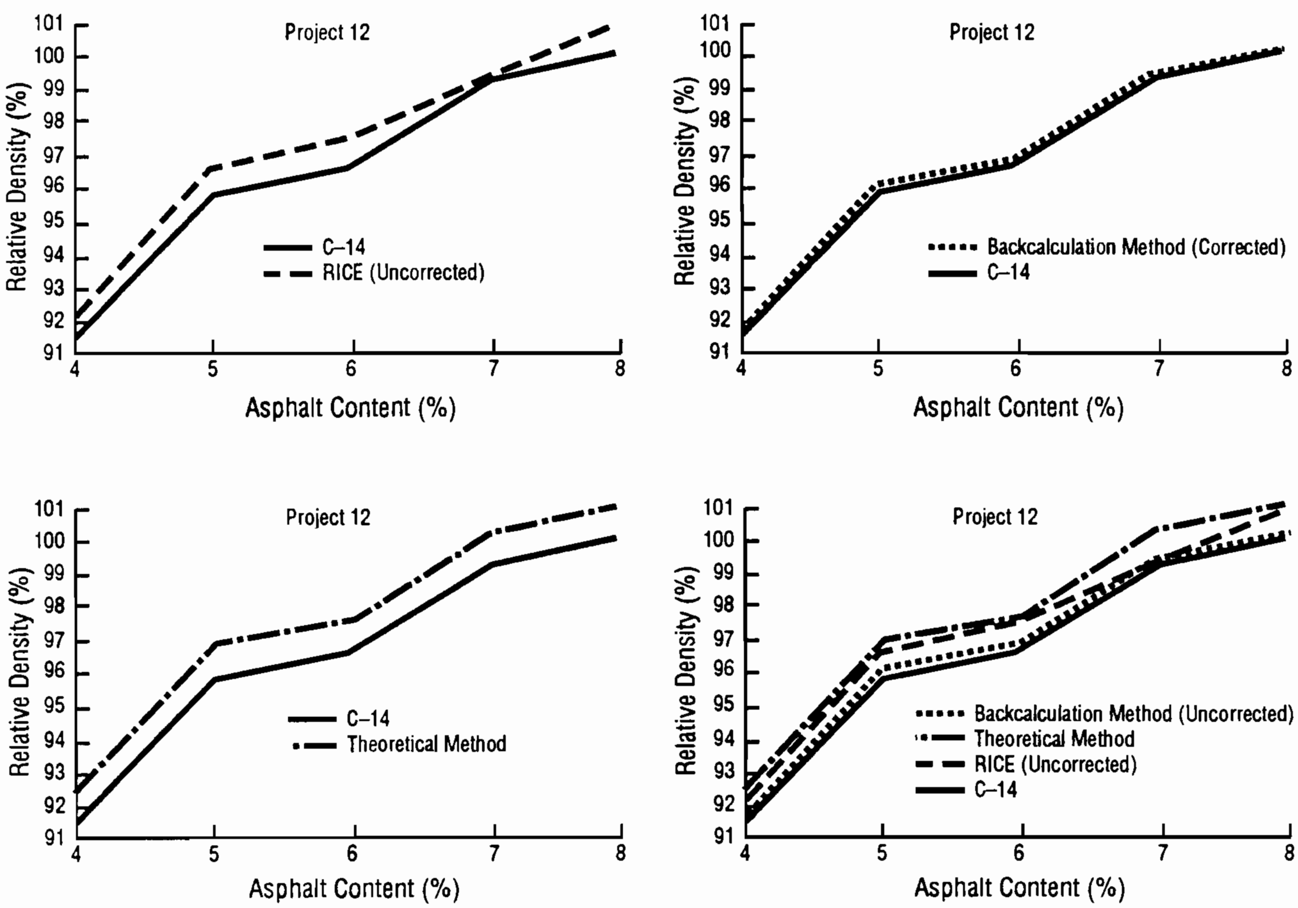



**Fig A-11 (continued). Relative densities based on different methods for Project 12.**

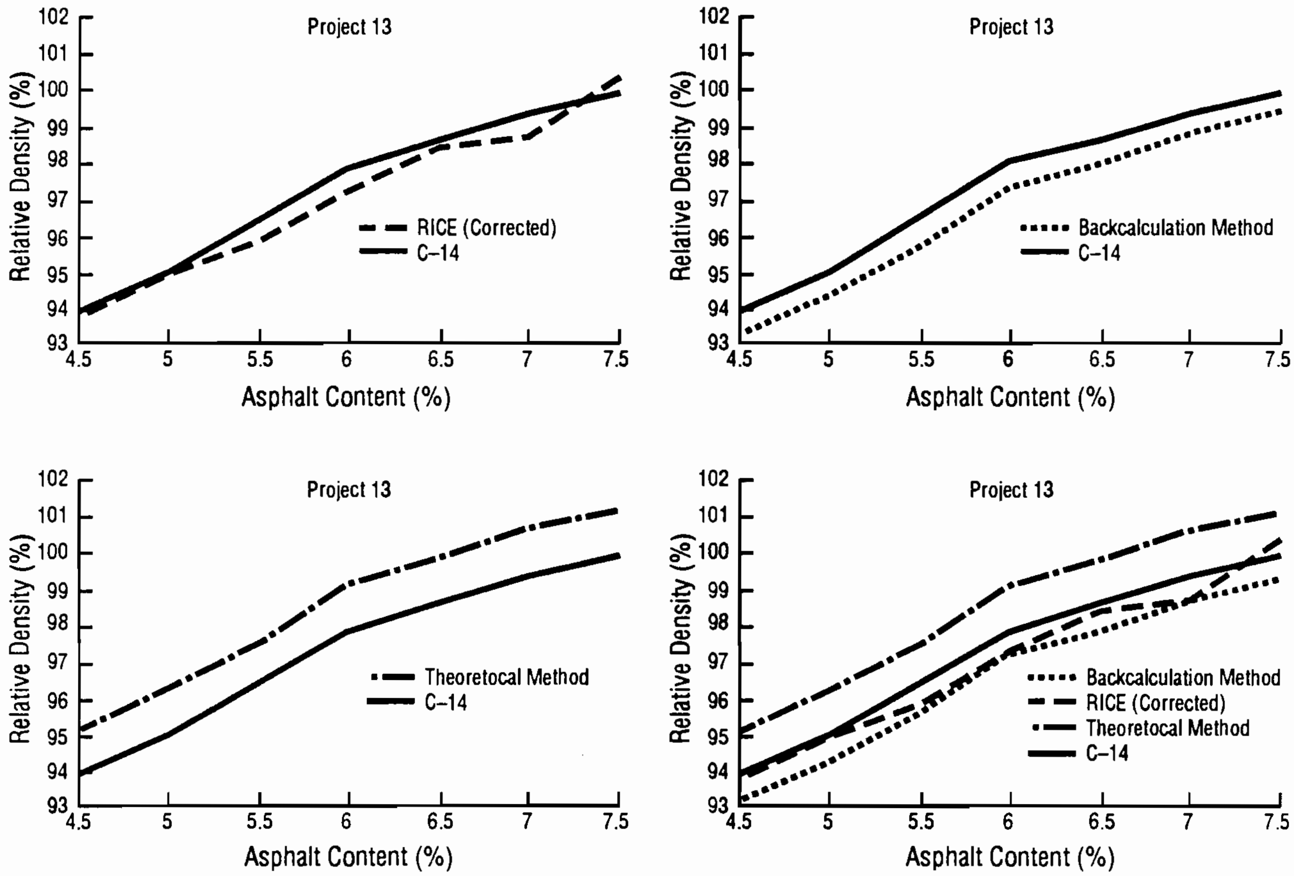
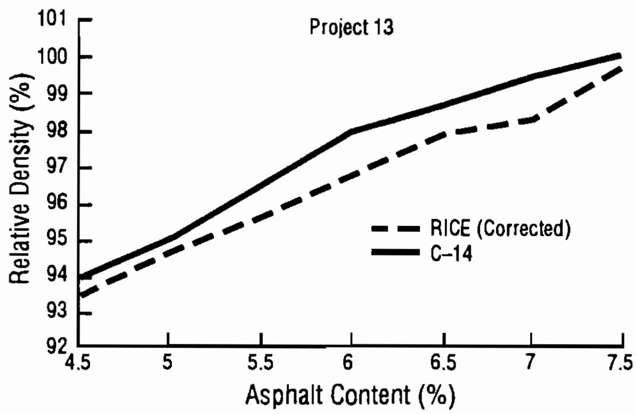
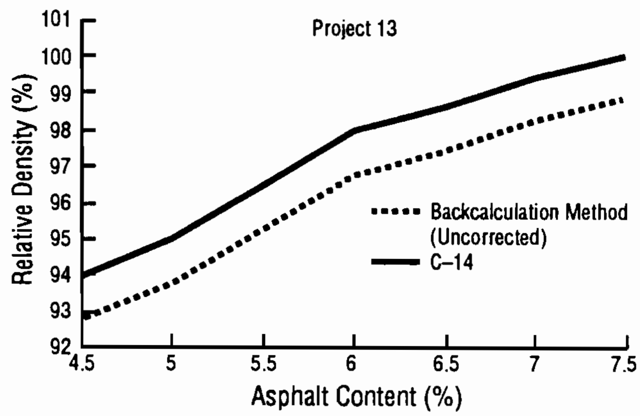
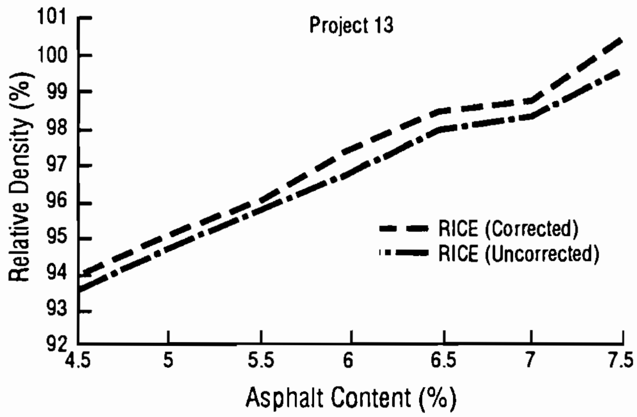



**Fig A-12. Relative densities based on different methods for Project 13.**



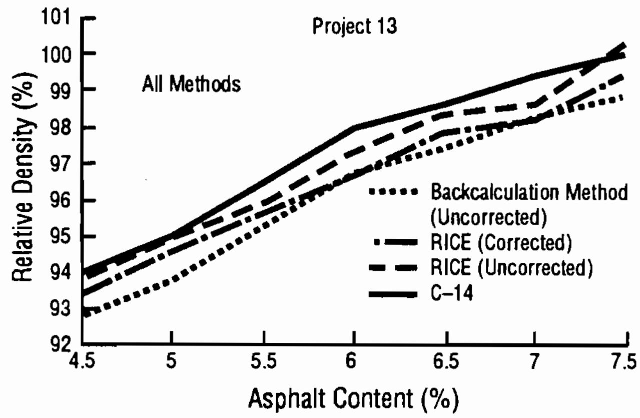




**Fig A-12 (continued). Relative densities based on different methods for Project 13.**

TABLE A-1. PROJECTS USED IN THE PRESENT STUDY

| Project | District | County | Aggregate Source | Aggregate Type | Mix Type | Asphalt Type | Asphalt Source | Asphalt S.G. | Aggregate Bulk S.G. | Design A.C. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | Lamar | B.H., F.P. | Limestone | D | AC-20 | Ardmore | 0.992 | 2.542 | 5.8 |
| 2 | 1 | Hunt | B.H., T.F. | Limestone | D | AC-20 | Texaco | 1.029 | 2.529 | 5.6 |
| 3 | 13 | Jackson | R.W., S.F. | Limestone | D | AC-20 | Gulf St | 1.024 | N/A | 4.5 |
| 4 | 6 | Midland | T.P. | Rhyolite | D | AC-20 | Fina | 1.029 | 2.501 | 6.2 |
| 5 | 13 | Calhoun | B.I., R.D., W.F. | GRVL/L.S.* | D | AC-20 | TFA | 1.022 | 2.578 | 5.0 |
| 6 | | | B.H., T.X. | Limestone | D | AC-10 | TFA | 1.021 | 2.500 | 5.3 |
| 7 | 14 | Travis | C.M. | Limestone | D | AC-20 | TFA | 1.022 | 2.534 | 6.0 |
| 8 | 16 | San Pat. | R.W., P.B., H.F. | Limestone | D | AC-10 | TFA | 1.020 | 2.584 | 4.2 |
| 9 | 16 | San Pat. | R.F., P.B. | Limestone | B | AC-10 | TFA | 1.020 | 2.571 | |
| 10 | 17 | Robertson | G.H., D.F. | Silicious | D | AC-20 | TX Gulf | 1.027 | 2.597 | 4.9 |
| 11 | 16 | San Pat. | G.H., O.P. | Limestone | D | AC-20 | Gulf St | 1.024 | 2.573 | 4.3 |
| 12 | 19 | Panola | G.H., S.P. | Silicious | C | AC-20 | Lion | 1.022 | 2.587 | 5.3 |
| 13 | 21 | Hidalgo | FD., BG., M.C. | | D | AC-20 | TFA | 1.022 | 2.542 | 5.2 |

* Crushed Gravel and Limestone

BG. = Ballenger
B.H. = Boorhem Fields
B.I. = Bay Incorporation
C.M. = Colorado Materials
D.F. = Downing Field Sands
FD. = Fordyce
F.P. = Farris Pit Field Sand
G.H. = Gifford Hill
H.F. = Hinze Field
M.C. = Monte Cristo Filed Sand
O.P. = Owens Prop. Filed Sand
P.B. = Parker Brothers
R.F. = Rodriguez Filed Sand
R.W. = Redland Worth
S.F. = Scholemen Field Sand
S.P. = Simms Pit Field Sand
T.F. = Tyne Pit Field Sand
T.P. = Transpeco
T.X. = TXI Field Sand
W.F. = Wedemier Field Sand

**TABLE A-2. EFFECTIVE SPECIFIC GRAVITY OF THE COMBINED AGGREGATES AT VARIOUS ASPHALT CONTENTS FOR DIFFERENT PROJECTS**

| Project | Asphalt Content (%) | $G_e$ From RICE (Uncorrected) | $G_e$ From RICE (Corrected) | $G_e$ From Backcalculation (Uncorrected) | $G_e$ From Backcalculation (Corrected) | $G_e$ From C-14 | High AC Used For Backcalculation |
|---|---|---|---|---|---|---|---|
| 1 | 4.0 | 2.617 | N/A | 2.581 | N/A | 2.567 | 8.0 |
| | 5.0 | 2.596 | N/A | | | | |
| | 5.5 | 2.597 | N/A | | | | |
| | 5.8 | 2.576 | N/A | | | | |
| | 6.0 | 2.603 | N/A | | | | |
| | 7.0 | 2.589 | N/A | | | | |
| | 8.0 | 2.581 | N/A | | | | |
| 2 | 4.0 | 2.602 | N/A | 2.547 | N/A | 2.536 | 8.0 |
| | 5.0 | 2.577 | N/A | | | | |
| | 6.0 | 2.562 | N/A | | | | |
| | 7.0 | 2.549 | N/A | | | | |
| | 8.0 | 2.547 | N/A | | | | |
| 3 | 5.0 | 2.645 | N/A | 2.618 | N/A | 2.604 | 8.0 |
| | 6.0 | 2.621 | | | | | |
| | 7.0 | 2.634 | | | | | |
| | 8.0 | 2.618 | | | | | |
| 4 | 6.2 | 2.545 | 2.534 | 2.562 | 2.551 | 2.540 | 9.0 |
| | 9.0 | 2.562 | 2.551 | | | | |
| 5 | 4.0 | 2.640 | | | | | |
| | 5.0 | 2.641 | N/A | 2.659 | N/A | 2.636 | 7.0 |
| | 6.0 | 2.662 | | | | | |
| | 7.0 | 2.659 | | | | | |
| 6 | 5.3 | 2.583 | 2.563 | 2.580 | 2.561 | 2.554 | 9.0 |
| 7 | 6.0 | N/A | 2.595 | N/A | N/A | 2.613 | N/A |
| 8 | 6.0 | 2.603 | 2.598 | N/A | N/A | 2.594 | N/A |
| 9 | 6.0 | 2.640 | 2.619 | N/A | N/A | 2.606 | N/A |
| 10 | 4.9 | 2.624 | 2.609 | 2.611 | N/A | 2.616 | 6.5 |
| 11 | 4.3 | 2.618 | 2.593 | N/A | N/A | 2.603 | N/A |
| 12 | 4.0 | 2.599 | 2.596 | 2.625 | 2.611 | 2.619 | 7.0 |
| | 5.0 | 2.611 | 2.596 | | | | |
| | 5.3 | 2.605 | 2.595 | | | | |
| | 6.0 | 2.599 | 2.590 | | | | |
| | 7.0 | 2.625 | 2.611 | | | | |
| | 8.0 | 2.642 | 2.589 | | | | |
| 13 | 4.5 | 2.595 | 2.583 | 2.614 | 2.598 | 2.578 | 7.0 |
| | 5.0 | 2.588 | 2.577 | | | | |
| | 5.2 | 2.605 | 2.599 | | | | |
| | 5.5 | 2.601 | 2.593 | | | | |
| | 6.0 | 2.615 | 2.597 | | | | |
| | 6.5 | 2.601 | 2.585 | | | | |
| | 7.0 | 2.614 | 2.598 | | | | |
| | 7.5 | 2.592 | 2.566 | | | | |

**TABLE A-3. STATISTICAL DATA ON DIFFERENCES BETWEEN EFFECTIVE SPECIFIC GRAVITY OF AGGREGATES FROM DIFFERENT METHODS**

| | When Algebraic Values Are Used: | | | | When Absolute Values Are Used: | | |
|---|---|---|---|---|---|---|---|
| | (Uncorrected) RICE C–14 | (Corrected) RICE C–14 | (Uncorrected) RICE B.C.* | | (Uncorrected) RICE C–14 | (Corrected) RICE C–14 | (Uncorrected) RICE B.C.* |
| Count | 12 | 9 | 9 | Count | 12 | 9 | 9 |
| Standard Dev | 0.025 | 0.013 | 0.030 | Standard Dev | 0.020 | 0.007 | 0.016 |
| Average | 0.021 | – 0.004 | 0.006 | Average | 0.025 | 0.011 | 0.024 |
| Minimum | – 0.020 | – 0.023 | – 0.025 | Minimum | 0.004 | 0.004 | 0.003 |
| Maximum | 0.066 | 0.013 | 0.055 | Maximum | 0.066 | 0.023 | 0.055 |

* B.C. : The Backcalculation Method

TABLE A-4. THEORETICAL MAXIMUM SPECIFIC GRAVITIES THROUGH DIFFERENT METHODS AT VARIOUS ASPHALT CONTENTS

| Project | Asphalt Content (%) | RICE (Uncorrected) | RICE (Corrected) | C-14 | $G_t$ Theory (Uncorrected) | Back-calculation (Uncorrected) | Back-calculation (Corrected) | High AC Used for Backcalculation |
|---|---|---|---|---|---|---|---|---|
| 1 | 4.0 | 2.456 | N/A | 2.414 | 2.392 | 2.426 | N/A | 8.0 |
| | 5.0 | 2.402 | N/A | 2.378 | 2.358 | 2.390 | N/A | |
| | 5.5 | 2.385 | N/A | 2.361 | 2.341 | 2.372 | N/A | |
| | 6.0 | 2.372 | N/A | 2.344 | 2.324 | 2.355 | N/A | |
| | 7.0 | 2.327 | N/A | 2.310 | 2.291 | 2.321 | N/A | |
| | 8.0 | 2.288 | N/A | 2.278 | 2.260 | 2.288 | N/A | |
| 2 | 4.0 | 2.452 | N/A | 2.396 | 2.390 | 2.405 | N/A | 8.0 |
| | 5.0 | 2.397 | N/A | 2.363 | 2.357 | 2.372 | N/A | |
| | 6.0 | 2.352 | N/A | 2.331 | 2.326 | 2.340 | N/A | |
| | 7.0 | 2.310 | N/A | 2.300 | 2.295 | 2.308 | N/A | |
| | 8.0 | 2.278 | N/A | 2.270 | 2.265 | 2.278 | N/A | |
| 3 | 5.0 | 2.451 | N/A | 2.417 | N/A | 2.429 | N/A | 8.0 |
| | 6.0 | 2.397 | N/A | 2.383 | N/A | 2.394 | N/A | |
| | 7.0 | 2.373 | N/A | 2.350 | N/A | 2.361 | N/A | |
| | 8.0 | 2.328 | N/A | 2.318 | N/A | 2.328 | N/A | |
| 4 | 6.2 | 2.332 | 2.323 | 2.328 | 2.297 | 2.345 | 2.336 | 9.0 |
| | 9.0 | 2.259 | 2.251 | 2.244 | 2.216 | 2.259 | 2.251 | |
| 5 | 4.0 | 2.483 | N/A | 2.479 | 2.430 | 2.499 | N/A | |
| | 5.0 | 2.447 | N/A | 2.443 | 2.396 | 2.462 | N/A | 7.0 |
| | 6.0 | 2.428 | N/A | 2.408 | 2.362 | 2.426 | N/A | |
| | 7.0 | 2.391 | N/A | 2.374 | 2.330 | 2.391 | N/A | |
| 6 | 5.3 | 2.389 | 2.373 | 2.366 | 2.322 | 2.387 | 2.372 | 9.0 |
| 7 | 6.0 | N/A | 2.376 | 2.390 | 2.327 | N/A | N/A | N/A |
| 8 | 6.0 | 2.381 | 2.377 | 2.374 | 2.366 | N/A | N/A | N/A |
| 9 | 6.0 | 2.410 | 2.394 | 2.384 | 2.356 | N/A | N/A | N/A |
| 10 | 4.9 | 2.438 | 2.426 | 2.432 | 2.416 | 2.427 | N/A | 6.5 |
| 11 | 4.3 | 2.450 | 2.429 | 2.438 | 2.412 | N/A | N/A | N/A |
| 12 | 4.0 | 2.448 | 2.445 | 2.465 | 2.438 | 2.470 | 2.458 | 7.0 |
| | 5.0 | 2.423 | 2.410 | 2.429 | 2.403 | 2.434 | 2.423 | |
| | 5.3 | 2.407 | 2.399 | 2.419 | 2.393 | 2.423 | 2.413 | |
| | 6.0 | 2.379 | 2.372 | 2.394 | 2.369 | 2.399 | 2.388 | |
| | 7.0 | 2.365 | 2.355 | 2.361 | 2.337 | 2.365 | 2.355 | |
| | 8.0 | 2.345 | 2.306 | 2.328 | 2.305 | 2.332 | 2.322 | |
| 13 | 4.5 | 2.427 | 2.417 | 2.413 | 2.383 | 2.443 | 2.430 | 7.0 |
| | 5.0 | 2.404 | 2.395 | 2.396 | 2.366 | 2.425 | 2.412 | |
| | 5.2 | 2.411 | 2.406 | 2.389 | 2.360 | 2.418 | 2.405 | 7.0 |
| | 5.5 | 2.397 | 2.391 | 2.379 | 2.350 | 2.408 | 2.395 | |
| | 6.0 | 2.391 | 2.377 | 2.362 | 2.334 | 2.391 | 2.378 | |
| | 6.5 | 2.364 | 2.351 | 2.346 | 2.318 | 2.374 | 2.361 | |
| | 7.0 | 2.357 | 2.345 | 2.330 | 2.302 | 2.357 | 2.345 | |
| | 7.5 | 2.324 | 2.305 | 2.314 | 2.287 | 2.341 | 2.329 | 9.0 |

**TABLE A-5. STATISTICAL DATA ON DIFFERENCES BETWEEN THEORETICAL MAXIMUM SPECIFIC GRAVITIES FROM DIFFERENT METHODS**

**When Algebraic Values Are Used:**

| | (Uncorrected) RICE – C–14 | (Corrected) RICE – C–14 | (Uncorrected) RICE – $G_t$* | (Corrected) RICE – $G_t$* | (Uncorrected) RICE – B.C.** | (Corrected) RICE – B.C.** | C–14 – $G_t$* | (Uncorrected) RICE – (Corrected) RICE |
|---|---|---|---|---|---|---|---|---|
| Count | 40 | 22 | 36 | 21 | 30 | 13 | 37 | 21 |
| Stand. Dev | 0.015 | 0.013 | 0.017 | 0.017 | 0.018 | 0.008 | 0.013 | 0.008 |
| Average | 0.015 | –0.003 | 0.040 | 0.026 | 0.001 | –0.011 | 0.026 | 0.012 |
| Minimum | –0.017 | –0.022 | 0.010 | 0.001 | –0.022 | –0.024 | 0.005 | 0.003 |
| Maximum | 0.056 | 0.017 | 0.067 | 0.051 | 0.047 | 0.001 | 0.062 | 0.039 |

**When Absolute Values Are Used:**

| | (Uncorrected) RICE – C–14 | (Corrected) RICE – C–14 | (Uncorrected) RICE – $G_t$* | (Corrected) RICE – $G_t$* | (Uncorrected) RICE – B.C.** | (Corrected) RICE – B.C.** | C–14 – $G_t$* | (Uncorrected) RICE – (Corrected) RICE |
|---|---|---|---|---|---|---|---|---|
| Count | 40 | 22 | 36 | 21 | 30 | 13 | 37 | 21 |
| Stand. Dev | 0.011 | 0.007 | 0.017 | 0.017 | 0.010 | 0.007 | 0.013 | 0.008 |
| Average | 0.018 | 0.011 | 0.040 | 0.026 | 0.014 | 0.011 | 0.026 | 0.012 |
| Minimum | 0.004 | 0.001 | 0.010 | 0.001 | 0.000 | 0.001 | 0.005 | 0.003 |
| Maximum | 0.056 | 0.056 | 0.067 | 2.451 | 2.451 | 0.051 | 0.062 | 0.062 |

* $G_t$: Theoretical maximum specific gravity from the theoretical approach based on the bulk specific gravity of the combined aggregates

**B.C.: Backcalculation maximum specific gravity from a RICE test performed at a high asphalt content

**TABLE A-6. THEORETICAL MAXIMUM SPECIFIC GRAVITIES FOR DIFFERENT PROJECTS AT DESIGN ASPAHLT CONTENT OR AT AN ASPHALT CONTENT CLOSE TO THE DESIGN VALUE**

| Project | (Uncorrected) RICE | (Corrected) RICE | (Uncorrected) Backcalculation | C-14 | $G_t$ Theory |
|---|---|---|---|---|---|
| 1 | 2.372 | – | 2.355 | 2.344 | 2.324 |
| 2 | 2.352 | – | 2.340 | 2.331 | 2.326 |
| 3 | 2.397 | – | 2.394 | 2.383 | – |
| 4 | 2.332 | 2.323 | 2.345 | 2.328 | 2.247 |
| 5 | 2.447 | – | 2.462 | 2.443 | 2.396 |
| 6 | 2.389 | 2.373 | 2.387 | 2.366 | 2.322 |
| 7 | – | 2.376 | – | 2.390 | 2.327 |
| 8 | 2.381 | 2.377 | – | 2.374 | 2.366 |
| 9 | 2.410 | 2.394 | – | 2.384 | 2.356 |
| 10 | 2.438 | 2.426 | 2.427 | 2.432 | 2.416 |
| 11 | 2.450 | 2.429 | – | 2.438 | 2.412 |
| 12 | 2.407 | 2.399 | 2.423 | 2.419 | 2.393 |
| 13 | 2.411 | 2.406 | 2.418 | 2.389 | 2.360 |

**TABLE A-7. DIFFERENCES BETWEEN THEORETICAL MAXIMUM SPECIFIC GRAVITIES AT DESIGN ASPHALT OR AT AN ASPHALT CONTENT CLOSE TO THE DESIGN VALUE**

| Project | (Uncorrected) RICE – C–14 | (Corrected) RICE – C–14 | (Uncorrected) RICE – $G_t$* | (Corrected) RICE – $G_t$* | (Uncorrected) RICE – B.C.** | C–14 – $G_t$* | (Uncorrected) RICE – (Corrected) RICE |
|---|---|---|---|---|---|---|---|
| 1 | 0.028 | – | 0.048 | – | – | 0.020 | – |
| 2 | 0.021 | – | 0.026 | – | – | 0.005 | – |
| 3 | 0.014 | – | – | – | – | – | – |
| 4 | 0.004 | –0.005 | 0.085 | 0.076 | –0.022 | 0.081 | 0.009 |
| 5 | 0.004 | – | 0.051 | – | – | 0.047 | – |
| 6 | 0.023 | 0.007 | 0.067 | 0.051 | –0.014 | 0.044 | 0.016 |
| 7 | – | –0.014 | – | 0.049 | – | 0.063 | – |
| 8 | 0.007 | 0.003 | 0.015 | 0.011 | – | 0.008 | 0.004 |
| 9 | 0.026 | 0.010 | 0.054 | 0.038 | – | 0.028 | 0.016 |
| 10 | 0.006 | –0.006 | 0.022 | 0.010 | –0.001 | 0.016 | 0.012 |
| 11 | 0.012 | –0.009 | 0.038 | 0.017 | – | 0.026 | 0.021 |
| 12 | –0.012 | –0.020 | 0.014 | 0.006 | –0.024 | 0.026 | 0.008 |
| 13 | 0.022 | 0.017 | 0.051 | 0.046 | –0.012 | 0.029 | 0.005 |
| Count | 12 | 9 | 11 | 10 | 5 | 12 | 8 |
| Stand. Dev | 0.012 | 0.013 | 0.023 | 0.026 | 0.010 | 0.023 | 0.006 |
| Average | 0.013 | –0.002 | 0.043 | 0.030 | –0.015 | 0.033 | 0.011 |
| Minimun | –0.012 | –0.02 | 0.014 | 0.006 | –0.024 | 0.005 | 0.004 |
| Maxinum | 0.028 | 0.017 | 0.085 | 0.076 | –0.001 | 0.081 | 0.021 |

* $G_t$: Theoretical maximum specific gravity from the theoretical approach based on the bulk specific gravity of the combined aggregates

**B.C.: Backcalculation maximum specific gravity from a RICE test performed at a high asphalt content

**TABLE A-8. RELATIVE DENSITIES THROUGH DIFFERENT METHODS FOR PROJECTS FOR WHICH RICE TESTS AT DIFFERENT ASPHALT CONTENTS ARE AVAILABLE**

| Project | Asphalt Content (%) | Relative Density (%) Based On | | | | | |
|---|---|---|---|---|---|---|---|
| | | (Uncorrected) RICE | (Corrected) RICE | (Uncorrected) B.C.* | (Corrected) B.C.* | C-14 | $G_t$** |
| 1 | 4.0 | 89.5 | – | 90.6 | – | 91.1 | 91.9 |
| | 5.0 | 93.0 | – | 93.5 | – | 93.9 | 94.7 |
| | 5.5 | 94.0 | – | 94.5 | – | 95.0 | 95.8 |
| | 6.0 | 95.3 | – | 96.0 | – | 96.4 | 97.3 |
| | 7.0 | 98.3 | – | 98.6 | – | 99.0 | 99.8 |
| | 8.0 | 99.6 | – | 99.6 | – | 100.1 | 100.9 |
| 2 | 4.0 | 91.6 | – | 93.4 | – | 93.8 | 94.0 |
| | 5.0 | 94.8 | – | 95.8 | – | 96.2 | 96.4 |
| | 6.0 | 98.3 | – | 98.8 | – | 99.2 | 99.4 |
| | 7.0 | 99.6 | – | 99.7 | – | 100.0 | 100.3 |
| | 8.0 | 100.4 | – | 100.4 | – | 100.8 | 101.0 |
| 3 | 5.0 | 94.1 | – | 95.0 | – | 95.4 | – |
| | 6.0 | 97.2 | – | 97.3 | – | 97.8 | – |
| | 7.0 | 98.2 | – | 98.7 | – | 99.2 | – |
| | 8.0 | 99.6 | – | 99.6 | – | 100.0 | – |
| 5 | 4.0 | 91.6 | – | 91.0 | – | 91.7 | 93.6 |
| | 5.0 | 94.3 | – | 93.7 | – | 94.5 | 96.3 |
| | 6.0 | 96.0 | – | 96.1 | – | 96.8 | 98.7 |
| | 7.0 | 97.2 | – | 97.2 | – | 97.9 | 99.8 |
| 12 | 4.0 | 92.1 | 92.2 | 91.3 | 91.7 | 91.5 | 92.5 |
| | 5.0 | 96.1 | 96.6 | 95.7 | 96.1 | 95.8 | 96.9 |
| | 6.0 | 97.2 | 97.5 | 96.4 | 96.8 | 96.6 | 97.6 |
| | 7.0 | 99.0 | 99.4 | 99.0 | 99.4 | 99.2 | 100.2 |
| | 8.0 | 99.3 | 101.0 | 99.8 | 100.2 | 100.0 | 101.0 |
| 13 | 4.5 | 93.4 | 93.8 | 92.8 | 93.3 | 93.9 | 95.1 |
| | 5.0 | 94.6 | 95.0 | 93.8 | 94.3 | 95.0 | 96.2 |
| | 5.5 | 95.6 | 95.9 | 95.2 | 95.7 | 96.4 | 97.5 |
| | 6.0 | 96.7 | 97.3 | 96.7 | 97.2 | 97.9 | 99.1 |
| | 6.5 | 97.8 | 98.4 | 97.4 | 97.9 | 98.6 | 99.8 |
| | 7.0 | 98.2 | 98.7 | 98.2 | 98.7 | 99.4 | 100.6 |
| | 7.5 | 99.5 | 100.3 | 98.8 | 99.3 | 100.0 | 101.1 |

* $G_t$: Theoretical maximum specific gravity from the theoretical approach based on the bulk specific gravity of the combined aggregates

**B.C.: Backcalculation maximum specific gravity from a RICE test performed at a high asphalt content

**TABLE A-9. DIFFERENCES IN RELATIVE DENSITIES THROUGH DIFFERENT METHODS**

| Project | C–14 – (Uncorrected) RICE | C–14 – (Corrected) RICE | Corrected RICE – (Uncorrected) RICE | $G_t$ – (Uncorrected) RICE | $G_t$ – (Corrected) RICE |
|---|---|---|---|---|---|
| 1 | 1.6 | – | – | 2.4 | – |
| | 0.9 | – | – | 1.7 | – |
| | 1.0 | – | – | 1.8 | – |
| | 1.1 | – | – | 2.0 | – |
| | 0.7 | – | – | 1.5 | – |
| | 0.5 | – | – | 1.3 | – |
| 2 | 2.2 | – | – | 2.4 | – |
| | 1.4 | – | – | 1.6 | – |
| | 0.9 | – | – | 1.1 | – |
| | 0.4 | – | – | 0.7 | – |
| | 0.4 | – | – | 0.6 | – |
| 3 | 1.3 | – | – | – | – |
| | 1.0 | – | – | – | – |
| | 0.6 | – | – | – | – |
| | 0.4 | – | – | – | – |
| 5 | 0.1 | – | – | 2.0 | – |
| | 0.2 | – | – | 2.0 | – |
| | 0.8 | – | – | 2.7 | – |
| | 0.7 | – | – | 2.6 | – |
| 12 | –0.6 | –0.7 | 0.1 | 0.4 | 0.3 |
| | –0.2 | –0.8 | 0.5 | 0.8 | 0.3 |
| | –0.6 | –0.9 | 0.3 | 0.4 | 0.1 |
| | 0.2 | –0.2 | 0.4 | 1.2 | 0.8 |
| | 0.7 | –1.0 | 1.7 | 1.7 | 0.1 |
| 13 | 0.6 | 0.2 | 0.4 | 1.7 | 1.4 |
| | 0.3 | –0.0 | 0.4 | 1.5 | 1.2 |
| | 0.7 | 0.5 | 0.2 | 1.9 | 1.7 |
| | 1.2 | 0.6 | 1.6 | 2.4 | 1.8 |
| | 0.8 | 0.2 | 0.5 | 1.9 | 1.4 |
| | 1.2 | 0.6 | 1.5 | 2.3 | 1.8 |
| | 0.4 | –0.4 | 0.8 | 1.6 | 0.8 |