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**16. ABSTRACT**

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It is recommended that changes be made in construction methods to eliminate the trimming operation from all forms of CTB construction.

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RESEARCH REPORT

# Evaluation Of Compaction Of Cement Treated Base

FINAL REPORT

CA-DOT-TL-3382-1-75-12

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Prepared in Cooperation with the U.S. Department of Transportation, Federal Highway Administration

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DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION AND RESEARCH
TRANSPORTATION LABORATORY

May 1975

FHWA D-2-16
TL No. 633382

Mr. R. J. Datel
Chief Engineer

Dear Sir:

I have approved and now submit for your information this final research project report titled:

EVALUATION OF COMPACTION
OF CEMENT TREATED BASES

Study made by . . . . . . . . . . . . . . . . Pavement Branch

Under the Supervision of . . . . . . . . . . . John B. Skog

Principal Investigator . . . . . . . . . . . . Robert N. Doty

Co-Investigator . . . . . . . . . . . . . . . . Brian D. Murray

Report Prepared by . . . . . . . . . . . . . . Brian D. Murray

Very truly yours,

George A Hill

GEORGE A. HILL
Chief, Office of Transportation Laboratory

Attachment

## ACKNOWLEDGMENTS

This study titled "Evaluation of Compaction of Cement Treated Bases" was conducted by the Transportation Laboratory of the Division of Construction and Research of the California Department of Transportation. Credit should be shared with the personnel involved with the data collection and testing. This included Donald L. Durr, Joseph B. Hannon, James A. Matthews, Robert D. Hamilton, Duane H. Andersen, and John Vail. The initial phase of the work was completed under the general supervision of Ernest Zube and then George B. Sherman.

The author also wishes to express his appreciation to the Construction Departments of Districts 01, 03, 06, 07 and 10 and the Resident Engineers for their cooperation on the six projects involved.

The research work reported herein was accomplished under Highway Planning and Research Project D-2-16 in cooperation with the U. S. Department of Transportation, Federal Highway Administration.
The opinions, findings and conclusions expressed are the views of the Transportation Laboratory which is responsible for the facts and the accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

## TABLE OF CONTENTS

## LIST OF TABLES



## LIST OF FIGURES

# INTRODUCTION

During the last twenty-eight years, California has placed thousands of miles of portland cement concrete (PCC) highway pavement over cement treated bases (CTB). Most of these pavements have given adequate performance; however, there is a persistent small percentage of PCC pavements which developed a faulting problem. This faulting results in a decrease in riding qualities and, in the extreme case, structural failure. Thus, elimination of pavement faulting will extend the service life of PCC pavements.

It has been reported (1) that a faulting condition develops as moisture and differential temperatures within the concrete produce a curling of the pavement slabs, resulting in a rocking movement on the CTB with the passage of heavy traffic. It has been theorized that this movement of the slab abrades the CTB surface and in so doing, generates a supply of fine material that is subsequently deposited, through water action, beneath the end of the approach slab adjacent to the joint in the pavement, thus creating a step-off. Since it appeared that a more abrasion-resistant CTB would retard this generation and subsequent accumulation of material at the pavement joints, a study of the construction procedures being used for CTB placement which might affect its surface integrity was conducted. Early in the investigation, it became apparent that the trimming operation was highly suspect as a factor contributing to a loss of surface integrity. The research was then directed towards a study of "no-trim" methods for placement of CTB. Surface profile, density, strength, and erodibility were investigated for CTB which was placed using both "trim" and "no-trim" methods.

## CONCLUSIONS

1. A wire-controlled automatic grading machine, vibratory screed, and steel drum roller can be used to place CTB with minimal surface grade variation and no need for trimming.

2. The nuclear density tests indicated that the surface integrity of cement treated base placed using no-trim methods was superior to that of CTB which had been trimmed.

3. The no-trim method of CTB placement contributes to a shorter operation time for placement.

4. The initial consolidation of the CTB by the vibratory screed permitted final compaction by the roller without excessive deformation and displacement as normally occurs during conventional placement.

5. Trimmed material placed and compacted in low areas does not bond to the underlying layer.

6. If cement treated base is placed using conventional construction methods, trimming reduces the standard deviation of the CTB surface grade variation by about 50%.

## RECOMMENDATIONS

This report indicates the advantages of not trimming cement treated base, and field studies indicated that a wire-controlled automatic grading machine, vibratory screed and steel drum roller can be used to place CTB with minimal surface grade variation and no need for trimming. Further, if such a system is used, the elapsed time from addition of water to cement and aggregate to completion of compaction does not have to exceed two hours.

Therefore, it is recommended that the construction industry be informed of these methods and at the earliest date a no-trim specification be written for use on a trial basis followed by complete elimination of the trimming operation from all CTB construction.

In the interval it is strongly recommended that a wire-controlled automatic grading machine or its equivalent be used in lieu of a motor grader for trimming operations. Further, any areas of low grade should not be filled with debris from the trimming operation but with surfacing material. We consider this recommendation of great importance to prevent pumping under PCC and preventing serious premature failures of asphalt concrete surfaces from pumping fines into the pavement.

## DISCUSSION

### Background

During the years 1944 to 1946 Hveem (1) conducted an investigation into the causes of faulting and pumping of joints in California's portland cement concrete (PCC) pavements. All PCC pavement at that time was placed on untreated aggregate base in California. He concluded that "the basic cause and origin of all joint troubles, including mud pumping and faulting, is the volume change of concrete arising from variations in moisture and temperature". This volume change caused curling or warping of the pavement slabs, thereby allowing alteration of the base due to passing wheel loads, especially when free water was present. His recommendation was that if slab movement cannot be prevented, the base material must be treated so as to "withstand the beating". In 1946, a four inch thick cement treated aggregate base covered by a heavy application of penetrating cut-back asphalt was used under a PCC pavement. Due to its success, this practice became common in California. Since 1950, all California Department of Transportation PCC pavements have been constructed on treated aggregate bases. These "treated" aggregate bases generally contained 3-5% cement and were compacted in place; however, a few have been treated with bituminous materials.

Problems can occur with many construction materials and practices; cement treated bases are no exception. Although California has used cement treated bases for about thirty years with generally good results, there is a persistent number of PCC pavements which have shown distress. In January 1970, the California Division of Highways published an interim report titled "California Pavement Faulting Study" (2). It contained the results of a limited statewide survey of rural PCC pavements constructed since 1960. Faulting was apparent in half of the randomly selected pavements aged three to eight years. Generally, only the truck lane joints were faulted, with the greater magnitude at the outer edge and only a minor amount at the inner edge. There were a few exceptions where more than just the truck lane was faulted, especially near urban areas where there were three or more lanes in each direction and a heavy concentration of truck traffic in more than one lane. This faulting condition prompted this investigation of CTB surface integrity as affected by construction placement procedures.

In order to effectively discuss construction equipment and procedures, it is first necessary to present a brief overview of the commonly used CTB placement procedures in California. The five general operations are: Depositing, Mixing, Spreading, Compacting, and Trimming.

Depositing and Mixing - These two operations are interrelated. The aggregate is deposited in windrows along the grade in either an untreated or treated (mixed in a central plant) condition. If placed in the untreated condition, cement is uniformly distributed along the top of the windrow, followed by a traveling road mixing machine (Figure 1) which simultaneously mixes the aggregate and cement and adds the necessary moisture.

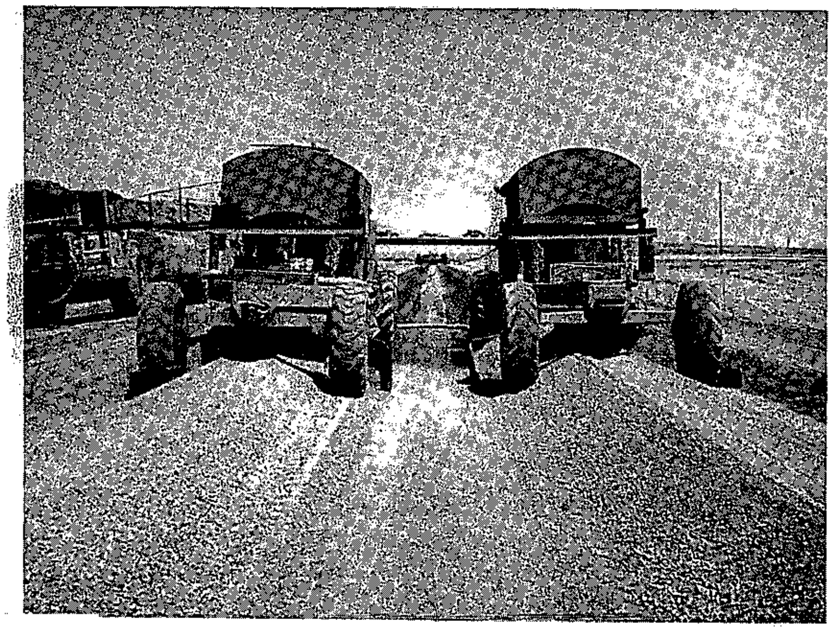

Figure 1 Typical Road Mixing Machines

Spreading - The windrowed treated aggregate is spread over the width of the roadway using either road graders or a wire controlled automatic grading machine (Figure 2).

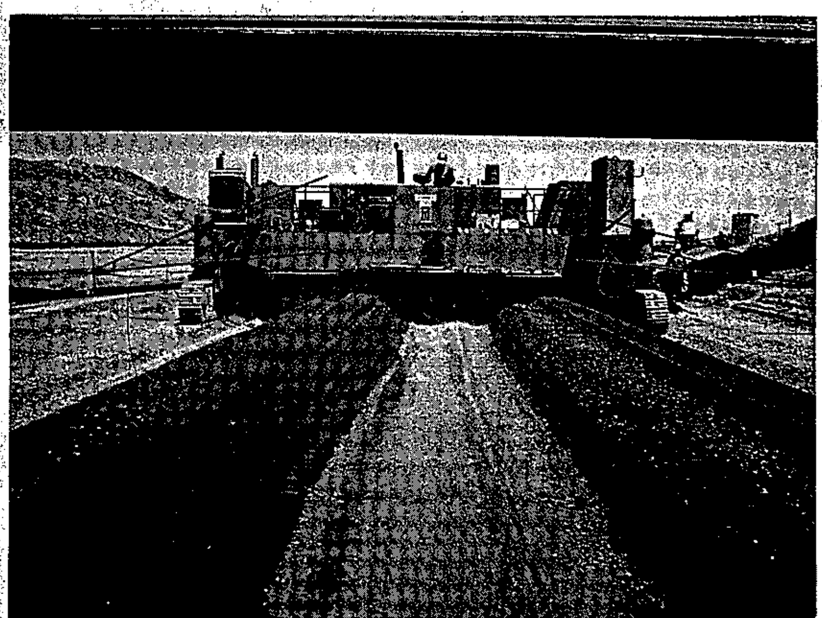

Figure 2 Wire-Controlled Automatic Grading Machine

Compacting - This is commonly performed by making sufficient passes with both steel-wheeled and rubber tired rollers to attain the specified compaction.

Trimming - This is the removal of "high" areas of CTB - that is, those that are above a specified grade elevation. The trimming is normally performed by one of two methods: 1) making a second pass with the laydown machine after lowering the screed or 2) using a blade or grader.

Initially, two CTB construction projects were selected as typical and the placement procedures used on those jobs were examined. During the initial investigation of these projects it appeared that the trimming operations created several negative factors which could contribute to faulting. These were as follows:

1. Trimming increased the elapsed time between the addition of water to the cement and aggregate and the completion of compaction and thereby provided a larger period for the CTB to dry out prior to the application of the curing seal.

2. Trimming disrupted the surface, damaging the initial bond between the cement and the aggregate and thereby weakening the upper surface (Figure 3).

3. Trimming deposited a thin layer of disturbed material in low spots which did not readily bond to the underlying CTB.

Recognition of these factors led to research to determine if modified CTB placing and compaction procedures might produce an acceptable cement treated base which would not require trimming.

Figure 3 Trimmed CTB Surface

A further investigation of the initial two CTB construction projects and an investigation of four additional CTB construction projects were conducted. These investigations consisted of both field and laboratory phases. The field phase consisted of selecting one or more test sections approximately 500 feet long on the main line, preferably without curves or cross slope, and monitoring both the surface grade variations and nuclear densities at various stages of placement as well as upon completion of placement. At a later time (to allow for strength development), four inch diameter CTB cores were taken from within the test sections. The laboratory phase consisted of determining core densities, compressive strengths, and abrasion resistance values as permitted by the physical condition of the cores obtained.

## Field Investigations

### Surface Variation vs. Placement Method:

Surface variations were obtained by taking string-line grade measurements at two foot intervals transversely and fifty foot intervals longitudinally, using the contractor's wire grade control as a reference. These measurements were analyzed using two methods. The first, a surface planar analysis, consisted of computing the "estimated standard deviation" for all grade points within a test section about the mean of the surface plane. The second method, a transverse cross section analysis, was performed on each test section by averaging the "estimate of the standard deviation" for each transverse profile. The values obtained by these two methods of statistical analysis were used in two ways. First, a comparison was made between the surface grade variations which occurred within individual test sections before and after the trimming operation. Secondly, the test sections were grouped by similarity of placement methods and the surface grade variations then averaged. This permitted a further comparison of placement methods vs. surface variation.

This information is presented in tabular form. The placement operations were performed in the order listed from left to right in Table 1. The X's indicate the equipment used to perform the placement operation. The numbers listed in the equipment columns are the surface variation values in feet following that phase of the placement procedure. The numbers in parenthesis are the values obtained by surface planar analysis and the other numbers are those values obtained by the transverse cross section analysis. Although the physical measurements were taken to the nearest hundredth of a foot, the calculated values are reported to the nearest thousandth because the sections with average values less than 0.01 foot did, in fact, contain several locations with deviations greater than 0.01 foot.

A review of the data in Table 1 indicates that trimming does reduce the magnitude of surface variation; however, test section 14 was placed without trimming and showed the lowest final surface variation. This indicates that a no-trim placement operation, which consists of accurately placing CTB to specified final grade without trimming, is certainly feasible.

As shown in Table 1, the test strips were constructed by a variety of procedures. Despite this variation in construction methods, the test sections were grouped into the following three classifications:

1. Prior to trimming.
2. After the final CTB surface was trimmed.
3. After the no-trim procedure was completed.

TABLE 1 - Placement Method and Surface Variations

| Test Section | Subgrade | Spread | | Compact | | | | Trim | | Compact | | | Trim | Compact | Final Surface Variation "S" |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *MG | MG | AG | VS | SS | SW | RT | MG | AG | VS | SW | RT | AG | RT | |
| 1 | | X | | | X | X | | | X | | | X | X | X | .011' (.016') |
| 2 | | X | | | X | X | | | X | | | .022' (.032') | X | X | - |
| 3 | | X | | | X | X | | | X | | | X | | | .013' (.017') |
| 4 | | X | | | X | | | | X | | | X | | | .010' (.013') |
| 5 | | X | | | X | | | | X | | X | X | | | .014' (.017') |
| 6 | | X | | | X | | | | X | | X | X | | | .015' (.019') |
| 7 | | X | | | X | X | | | X | | | | | | .009' (.018') |
| 8 | | X | | | X | .014' (.020') | | | X | X | | | | | .010' (.014') |
| 9 | | X | | | X | X | | | X | X | | | | | .012' (.019') |
| 10 | X | | X | | X | | | | X | | | X | | | .013' (.022') |
| 11 | X | | X | X | | X | | | | | | | | | .022' (.026') |
| 12 | X | | X | X | | X | | | | | | | | | .023' (.027') |
| 13 | X | | X | X | | .020' (.025') | | | X | X | | X | | | .012' (.016') |
| 14 | .014' (.018') | | X | .008' (.009') | | X | | | | | | | | | .008' (.010') |
| 15 | .014' (.015') | | X | .014' (.014') | | | X | | | | | | | | .013' (.013') |
| 16 | .016' (.017') | | .017' (.038') | | X | | X | | .032' (.057') | | | X | | | .019' (.048') |
| 17 | .016' (.022') | | X | | X | | .020' (.050') | | .021' (.024') | | | X | | | .011' (.012') |
| 18 | .026' (.028') | | .020' (.035') | | X | | .039' (.043') | | | | | X | | | .039' (.053') |
| 19 | .022' (.023') | | X | .022' (.026') | | X | X | X | | | | X | | | .017' (.026') |
| 20 | X | | X | X | | X | .018' (.021') | X | | | | | | | - |
| 21 | .020' (.035') | | X | | | X | .020' (.026') | X | | | | X | | | - |

***Abbreviations are as follows:**

**MG = Motor Grader**
**AG = Automatic Wire Control Grading Machine**
**VS = Vibratory Screed**
**SS = Segmented Steel Wheel Roller**
**SW = Steel Wheeled Vibratory Roller**
**RT = Rubber Tired Roller**

The average surface grade variation values for all the test sections, when grouped into these classifications, are presented in Table 2.

TABLE 2 - Average Surface Variations

| Classification | Test Sections | Planar Avg. "S" | Transv. Avg. "S" |
|---|---|---|---|
| 1 | 7 | .031' | .022' |
| 2 | 14 | .020' | .013' |
| 3 | 4 | .019' | .016' |

The information presented in Table 2 once again confirms that trimming reduces the magnitude of surface variation; however, the vertical control for those test sections placed using the no-trim procedure is certainly comparable with that for the trimmed test sections.

Nuclear Densities vs. Placement Method:

The following nuclear density work was performed to determine if trimming actually aggravated the surface integrity as it appeared to do during the initial investigations. From the generally accepted principles that compressive strength increases as density increases and compressive strength is directly related to other strength characteristics, the inference was made that surface strength is related to surface density. A nuclear gage operated in the backscatter mode was selected as the most appropriate means for determining the density of the top few inches of the CTB. Locations were randomly selected within each test section and nuclear densities obtained before and after the trimming operation. Because density is highly dependent on aggregate shape and grading, both of which varied for the projects reviewed, the densities were converted to percent relative compaction. Test Method No. Calif. 312, "Design and Testing of Classes "A" and "B" Cement Treated Bases", was chosen to determine the appropriate densities for computing relative compaction. The relative compaction results, grouped by project rather than by test section, are presented in Table 3.

TABLE 3 - Nuclear Density Results

| Project | Relative Compaction Before Trim | | | Relative Compaction After Trim & Rolling | | |
|---|---|---|---|---|---|---|
| | X | S | n | X | S | n |
| 1 | 94.4% | 1.76% | 9 | 91.5% | 3.01% | 9 |
| 2 | 93.3% | 2.62% | 5 | 92.7% | 1.37% | 5 |
| 3 | 89.9% | 2.53% | 6 | 86.3% | 2.87% | 6 |
| 4 | 89.9% | 1.58% | 6 | 90.4% | 0.79% | 6 |
| 5 | 96.0% | 1.80% | 8 | Not Trimmed | | |
| 6 | 97.5% | 0.50% | 2 | 95.0% | 2.00% | 2 |

These data indicated that the surface densities were reduced by the trimming operation which therefore infers a loss in surface strength. The relative compaction of the no-trim project is presented to illustrate that it possessed the highest final relative compaction.

Field Sampling:

In addition to the field investigations during construction, four inch diameter specimens of the CTB were later taken by coring through the pavement layer in all the test sections. The coring operation on each CTB project was delayed for a period from four to six months until just prior to opening of the roadway to traffic. This permitted increased strength gain and thereby facilitated removal of the cores intact. In spite of this, the coring operation frequently resulted in many of the fines being washed away and/or cracking of the CTB specimens. This necessitated additional coring to obtain sufficient samples for laboratory testing.

Laboratory Investigation

During this phase of the project, the physical properties of the CTB cores taken from the test sections were determined. The condition of the CTB specimens obtained varied from clumps of CTB to highly intact cores with the pavement layer still bonded to them. Although many of the specimens were broken during coring, thus requiring additional coring in the same area, all the specimens were evaluated as much as possible to provide a maximization of available data. All the specimens were subjected to the following testing if the specimen condition permitted.

1. Density Test
2. Abrasion Resistance Test
3. Unconfined Compressive Test

The results of these tests were grouped into trim and no-trim classifications to reflect placement procedure effects.

Density Tests:

The density test was performed on the CTB specimens prior to either the unconfined compressive strength test or the abrasion resistance test. Before the density test could be performed, it was necessary to separate those CTB cores still bonded to the pavement layer. To facilitate separation, these cores were placed in a 140°F oven for twenty-four hours to soften the curing seal. The separation generally occurred along the curing seal plane; however, some separations occurred either through the CTB on a plane nearly parallel to the curing seal or through both the CTB and along the curing seal plane.

Densities were determined for all the CTB specimens greater than approximately twenty-five cubic inches in volume. Each specimen was dried at 140°F to a constant weight which was recorded. A twenty-four hour water soaking followed, after which the specimen was weighed submerged in water and then again in air while still saturated. The dry density was calculated from these results using the following formula:

$$D_D = \frac{W_D}{W_A - W_W} \times 62.4$$

$D_D$ = Dry density in pounds per cubic feet.
$W_D$ = Weight of dry core in grams.
$W_A$ = Weight in air of saturated core in grams.
$W_W$ = Weight in water of saturated core in grams.

The dry density determined for each specimen was an average for the entire core. The dry densities of the individual cores did not indicate an advantage of one placement method over another as the differences became lost when averaged over the entire core. Therefore, the density results were treated as samplings and grouped into trim and no-trim classifications for each project. The averages and estimates of the standard deviation for the groups were calculated and are given in Table 4.

TABLE 4 - Core Dry Densities

| | Trim | | | No-Trim | | |
|---|---|---|---|---|---|---|
| Project | $\bar{X}$ | S | n | $\bar{X}$ | S | n |
| 1 | 135.3 | 2.3 | 46 | 132.3 | 2.1 | 6 |
| 2 | 138.8 | 3.0 | 5 | - | - | - |
| 3 | 140.1 | 2.0 | 5 | - | - | - |
| 4 | 134.1 | 2.0 | 5 | 130.2 | 3.0 | 6 |
| 5 | 139.0 | 3.1 | 6 | 138.5 | 2.7 | 6 |
| 6 | 137.0 | 0 | 4 | 137.0 | 2.0 | 10 |

The results indicate that the densities of those cores removed from the trimmed test sections are generally greater than those from the untrimmed areas. This might be expected as the trimmed sections received additional compactive effort following the trimming operation. Also, the higher surface densities of the untrimmed sections, as indicated by field nuclear testing, are masked when determining the density of the entire core. Although the higher density for the trimmed sections is apparent, the variation within each project group was too large to indicate a distinct advantage of one placement method over another.

Abrasion Resistance Tests:

To investigate the relative resistance to abrasion, CTB cores that separated along the curing seal plane (see Figure 4, Core No. 2) and those that separated partially in the curing seal and just below the curing seal in the CTB (see Figure 4, Core No. 11) were tested. The cores with their top surface exposed were placed in a closed cylindrical mold. Two hundred and fifty milliliters of water and four 1.33" diameter rubber balls were added. The mold was then subjected to a vertical oscillation of 1" at a speed of 20 cycles per second for four minutes at room temperature. This action caused the top of the specimens to be abraded by the water and rubber balls. The abraded material was then washed from both the mold and the core and collected in a pan for drying and weighing. The amount of abraded material indicated the relative capability of the core to withstand abrasion.

Cores which separated from the PCC through the curing seal were highly resistance to surface abrasion, and those that separated partially in the curing seal and just below the curing seal in the CTB showed only slight abrasion loss. The abrasion loss results indicate a well-cemented material just below the curing seal together with a well-bonded membrane. This is confirmed by the continued low abrasion loss even when some of the specimens parted just below the curing seal in some areas of the surface.

A number of separations occurred entirely within the upper portion of the CTB core on a plane nearly parallel to the curing seal. This material was friable and was not well-cemented together. The shear strength of this part of the core must be very low since it sheared before a heated asphalt layer, and one may assume that a high abrasion loss would have resulted if it had been possible to perform the abrasion test on this type of specimen.

An attempt was made to relate the type of separation to the trim or no-trim methods. No relation was found. This tends to indicate that there are random zones of weakness in the area just below the curing seal for both forms of construction. The extent of these zones and their importance in the faulting problem is unknown.

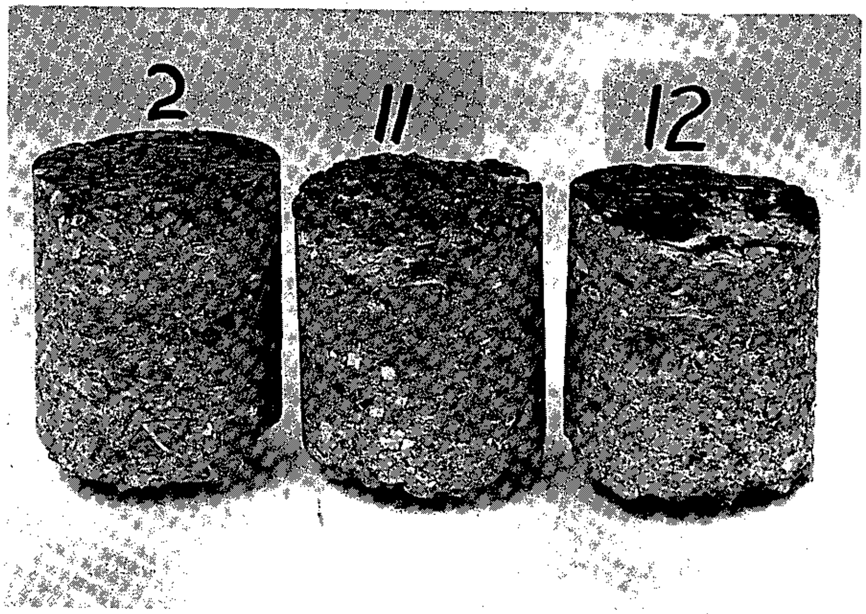


Figure 4 Typical CTB Cores

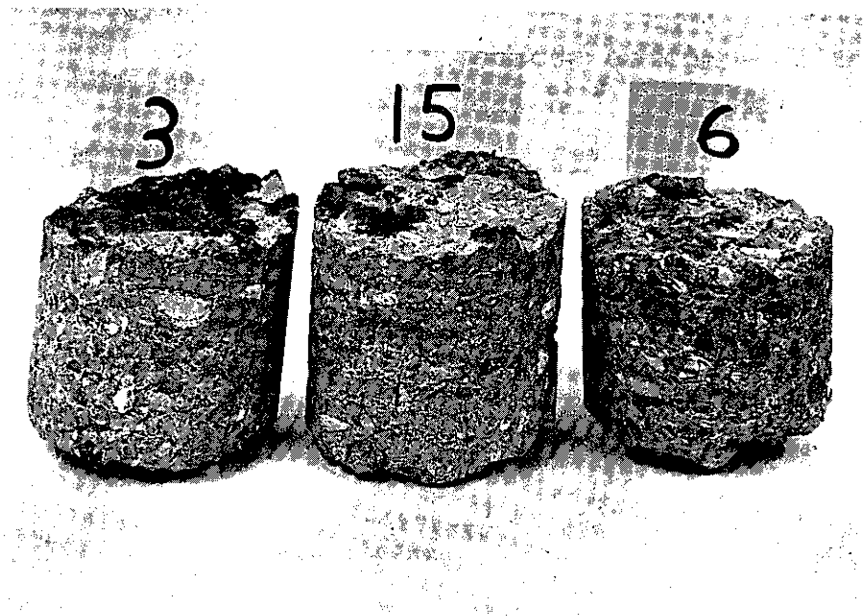


Figure 5 Typical CTB Cores

Unconfined Compressive Strength Tests:

The final test performed on the CTB cores was the unconfined compressive strength test. Those cores with a length of 2.5" or greater for their full diameter were selected for this testing and the following procedure was used. A diamond saw was used to trim those cores with extremely uneven ends the minimum amount necessary to permit capping. The cores were capped to provide flat, parallel surfaces and then soaked in water for 40+ hours. This was followed by loading the cores in compression at a rate of 0.05" per minute until failure. The total load at failure was recorded. This was converted to unconfined compressive strength by dividing by the average cross-sectional area of the core and multiplying by a length compensation factor, which is a factor developed over twenty-five years ago to convert the strength value of samples with a length to diameter ratio not equal to one to an equivalent compressive strength for a sample with a ratio of one. Only the strength results for those cores 3.4" or greater in length were selected for analysis. This was done because those cores shorter than 3.4" exhibited extreme variations in strength even when taken from the same test sections. The results from each project were separated into the trim and no-trim placement classifications, averaged, and an estimate of their standard deviation computed. The values representing compressive strength at an age of approximately six months are presented in Table 5.

TABLE 5 - Unconfined Compressive Strength of Cores

| | Trim | | | No-Trim | | |
|---|---|---|---|---|---|---|
| Project | $\bar{X}$ | S | n | $\bar{X}$ | S | n |
| 1 | 471.5 | 127.4 | 22 | 450.5 | 109.1 | 6 |
| 2 | 875 | 283 | 3 | - | - | - |
| 3 | 1550 | 76 | 3 | - | - | - |
| 4 | 1059 | 301 | 4 | 663 | 174 | 5 |
| 5 | 1098 | 304 | 4 | 967 | 120 | 2 |
| 6 | 517.5 | 51 | 4 | 560 | 98 | 8 |

These data indicate that higher compressive strengths occurred within the cores taken from the trimmed area. This most likely occurred because generally the average core densities of the trimmed areas were greater, as previously noted, and often the weaker top surface of the core was lost during coring or during separation from the pavement layer.

## SUMMARY

One can conclude from this work that while trimming disturbs the CTB top surface, the additional rolling performed after trimming densifies that CTB below the trimmed surface and results in a stronger material. Application of the curing seal apparently binds together that material disturbed during trimming. For these two reasons, a decisive advantage between trim and no-trim placement procedures could not be proved. However, a no-trim method capable of placing CTB to grade tolerances could specify additional rolling to yield higher densities.

No definite conclusions can be made pending a follow-up of the development, or lack thereof, of faulting on the projects studied.

## REFERENCES


1. Hveem, F. N., " A Report of an Investigation to Determine Causes for Displacement and Faulting at the Joints in Portland Cement Concrete Pavements on California Highways", State of California, Division of Highways, Materials and Research Department, May 1949.

2. Spellman, D. L., " California Pavement Faulting Study," State of California, Division of Highways, Materials and Research Department, January 1970.