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TRANSPORTATION LABORATORY

RESEARCH REPORT

CTB STUDY - ROUTE 91

FINAL REPORT

CA-DOT-TL-3149-1-76-21

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF STRUCTURES & ENGINEERING SERVICES
OFFICE OF TRANSPORTATION LABORATORY

February 1976

TL No. 643149

Mr. C. E. Forbes
Chief Engineer

Dear Sir:

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

CTB STUDY - ROUTE 91

Study made by	Roadbed & Pavement Branch
Under the Supervision of	John B. Skog
Principal Investigator	Robert N. Doty
Co-Investigator	Max L. Alexander
Report Prepared by	Max L. Alexander and William C. Meeker

Very truly yours,

George A Hill

GEORGE A. HILL
Chief, Office of Transportation Laboratory

Attachment

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ACKNOWLEDGEMENT

This report contains the findings of the state-financed research project titled "CTB Study - Route 91" E/A No. 643149. The contents reflect 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. This report does not constitute a standard, specification, or regulation.

The authors wish to express their appreciation to the District 07 Laboratory and Construction Department personnel, under the direction of John Solovieff, Marv Malkson, Don Woodard, and Dale Neumen, respectively, who cooperated in conducting this study and assisted in the preparation of the test specimens.

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INTRODUCTION

Since 1960, the California Standard Specifications (1) have required that aggregate for use in a Class A cement treated base (CTB) be of such quality that it will provide a minimum unconfined compressive strength of 750 psi in seven days when mixed with not more than 5% cement under laboratory conditions. The Standard Specifications do not include a strength requirement for the CTB placed on the roadway, but it is implied in other manuals and generally assumed among construction personnel that a compressive strength of 750 psi is intended in the roadway as well. Test Method No. Calif. 312-E (2), for example, indicates that field fabricated control specimens shall attain "desired compressive strengths" and, until recently, the Highway Design Manual stated that Class A CTB was expected to have a minimum compressive strength of 750 psi in seven days. As a result of these actual and implied requirements, many engineers have attempted to design CTB mixes having compressive strengths of at least 750 psi in the field.

Actually obtaining a CTB mixture which would provide these strengths has proven to be a very difficult proposition. This is due primarily to unavoidable differences in fabricating laboratory specimens as compared to placing the material on the roadway. Laboratory test specimens are prepared and tested under ideal conditions. Aggregate, cement and water are combined in exact proportions, compaction and testing are accomplished with precision equipment, and the test specimens are cured in a controlled atmosphere. Materials mixed and placed in the roadway, however, are subject to many potential variables. The Standard Specifications allow the cement content of CTB placed in the road to be as much as 0.6% less than the amount specified, and the moisture content can vary by ± 1% from optimum. The relative density of the CTB compacted on the

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road can be as low as 92% of the density achieved when the material is compacted by laboratory procedures. Also, field curing conditions are somewhat dependent upon the weather. Each of these variables can significantly affect the compressive strength of the CTB. To allow these variations and still achieve minimum 7-day compressive strengths of 750 psi, some engineers have found it necessary to specify cement contents of 6% or more and 7-day laboratory strengths of 1300 psi or more.

There are other engineers who believe that the 750 psi strength was originally intended as a means of evaluating the aggregates and that strengths significantly different than this could be tolerated in the field without decreasing the effectiveness of the CTB layer. Munday's evaluation of CTB performance (3), however, revealed that the maintenance-free service life of a road was directly related to the strength of the CTB layer. Although Munday's report, along with other miscellaneous data on file at the Transportation Laboratory, provided some insight into the ultimate strengths being achieved in CTB materials placed in the road, there was very little information available regarding relative progressive strength gains of in-situ CTB as compared to laboratory predictions.

The primary objective of this study was to develop a better understanding of the relative properties of CTB compacted and cured in the laboratory as compared to the same material compacted and cured in-place on the road. Because of an increasing interest in the use of lean concrete base (LCB), this data was also intended for use when evaluating and comparing the relative strength of LCB with CTB.

A new construction project on Route 91 near the City of Compton in Los Angeles County was selected for this study. Both LCB and Class A CTB were planned for use as base on adjacent portions of this road. The aggregates for both type of base were processed from the same material and a central batch plant located on the jobsite was used for all mixing.

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CONCLUSIONS, RECOMMENDATIONS AND IMPLEMENTATION

After three months, the CTB placed on this project had achieved approximately 70% of the 7-day strength of the same material when compacted in the laboratory. It is estimated that at seven days the in-situ strength may have been no greater than 50-60% of the laboratory 7-day strengths.

The lower "field" strengths are the result of a combination of allowable and unavoidable factors. Compacted density was probably the largest single contributing factor on this project, but the rate of moisture evaporation may have also had a significent effect.

Based on the findings of this study of one job and Munday's (3) findings, which were based upon a study of 35 separate projects, it is recommended that the in-situ strength of CTB be assumed as 70% of the 7-day strength of the same mixture when compacted by laboratory procedures. Since Munday's evaluations also indicated that it is desirable to attain an in-situ CTB strength of 750 psi, it is recommended that the CTB be designed for a strength of 1100 psi when compacted, cured, and tested under laboratory conditions.

To provide for unavoidable variations in cement distribution and other construction variables, it is recommended that the practice of increasing the design cement by .5 to 1 percent above the amount required to achieve the laboratory design strength be continued. Thus, Test Method No. Calif. 312 will be revised to require that cement treated base mixtures be designed to achieve 7-day laboratory strengths of 1100 psi.

No conclusions could be drawn from the results of the surface abrasion tests because of the minimal data and the lack of any standard for comparison. The amount of abrasion loss appears quite small, however, and the accumulated data may be of some future value for comparison with other materials.

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DISCUSSION AND DATA PRESENTATION

To gain a better understanding of the relative properties of field and laboratory compacted CTB, a plan was adopted to determine the compressive strength and abrasion resistance of each for a period of 3 months.

A then-current construction project near Compton, California (07-LA-91-R6.9/R9.6) was selected for this study. The aggregates for use in the CTB on this project were reprocessed construction materials including large percentages of portland cement concrete and asphalt concrete. Preliminary testing showed that this material met all of the requirements for CTB aggregate.

Concurrently with this study, the Concrete Branch of the Transportation Laboratory was conducting a study of lean concrete base on this same section of road. Since the same reprocessed aggregates were being used for both the CTB and LCB, the Concrete Branch was able to take advantage of the opportunity to compare the two products. The findings of that comparison were published in a separate report (4).

Four test sites were arbitrarily selected from the section of road constructed with CTB. The selection of these sites was, however, limited to the inside lanes, primarily because of the thinner PCC pavement to be placed in the #1 and #2 lanes. This decreased the coring costs.

At each test site, a sample of the prepared CTB material was taken from the windrow immediately after it was deposited on the roadway. The exact location of the sample was adjusted to the approximate center of the material delivered by one truck or trailer to assure that future cores taken within ± 20 feet of the same station would still be from the same

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batch. These samples were then transported to the district laboratory where multiple test specimens were compacted in tin liners in accordance with Test Method No. Calif. 312-E.

Nine test specimens each were fabricated from material sampled at test sites 1 and 4 and six specimens were prepared from material sampled at each of the other two test sites. After intervals of 7 and 28 days, three specimens were randomly selected from each group for unconfined compressive strength tests. Three specimens were also tested at 91 days for each of the two sites for which additional specimens were available. Prior to testing for compressive strength, the test specimens were stored in the sealed liners in the laboratory as per Test Method No. Calif. 312. On the day of testing, the liners were removed and the specimens immersed in water for six hours before capping and testing.

Meanwhile, on the roadway the windrowed CTB mix was spread and compacted to specified tolerances. The Standard Specifications require that the completed CTB layer be covered with a bituminous curing seal. Use of this curing seal, however, often results in a strong bond between the CTB and the PCC pavement (PCCP) which makes it difficult, if not impossible, to separate the two layers after coring without significantly damaging the core at the base/PCCP interface. To eliminate this bond, it was decided to place a 12 ft. x 12 ft. sheet of plastic over the CTB at each test site. It was intended that the plastic sheet would serve the purpose of holding the moisture in the CTB, but at the same time prevent bonding of the CTB to the PCCP. Elimination of the bond would, in turn, reduce the disturbance of the surface of the CTB when separating the CTB from the PCCP.

Unfortunately, however, this method did not work out satisfactorily. The combination of wind, neighborhood children, and the Contractor's

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operations succeeded in removing, or at least damaging, the plastic sheets at each test site. As a result, a portion of the test area was left without adequate protection from excessive drying. Because of this, it was necessary to take all of the core samples from adjacent areas which were protected by the conventional curing seal.

Three 5-inch diameter cores and three 4-inch diameter cores were cut at each of the four test sites twenty days after placement and again eighty days after placement. The cores were sealed in plastic bags and delivered to the Transportation Laboratory where they were held in the fog room until a total of 28 and 91 days had elapsed since placement. Then, following a 6-hour immersion in water, the 5-inch diameter cores were capped and tested for unconfined compressive strength.

The compressive strengths of both the laboratory compacted test specimens and the field cores are summarized in Table 1. The average values for each group of tests are also shown in graphical form in Figure 1. These data reveal a rapid gain in compressive strength of the laboratory compacted specimens from the time of compaction until they were tested at 7 days. Although not quite as rapid as the initial achievement of strength, there is also a significant, continuing increase in strength through the end of the study period of 91 days. The data fails, however, to show a corresponding strength gain for the same material when compacted on the road. There is, in fact, a strong indication that the material placed in the road had gained its ultimate strength by the time it had been in place 28 days as cores from only one test site showed a significant increase in strength after 28 days. No attempt was made to core the roadway material at 7 days because past experience has shown that the chances of success are negligible.

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TABLE 1

SUMMARY OF COMPRESSIVE STRENGTHS (psi)

Test Site		7-Day Cure		28-Day Cure		91-Day Cure	
		Lab	Field	Lab	Field	Lab	Field
		909	-	1106	870	1608	615
1		956	-	1210	700	1464	790
		1052	-	1019	748	1337	705
	Avg.	972	-	1112	773	1470	703
		1132	-	1281	647	-	615
2		916	-	995	504	-	555
		1059	-	1074	509	-	560
	Avg.	1035	-	1117	553	-	577
		963	-	1082	509	-	465
3		732	-	931	530	-	475
		740	-	1011	512	-	555
	Avg.	812	-	1008	517	-	498
		990	-	1074	594	1329	685
4		1000	-	1170	570	1289	815
		920	-	1106	647	1424	985
	Avg.	970	-	1117	604	1347	828
Overall Average		947	-	1088	612	1409	652 765*
% of 7-day lab standard		100	-	116	65	150	69

*Test results from sites 1 and 4 only.

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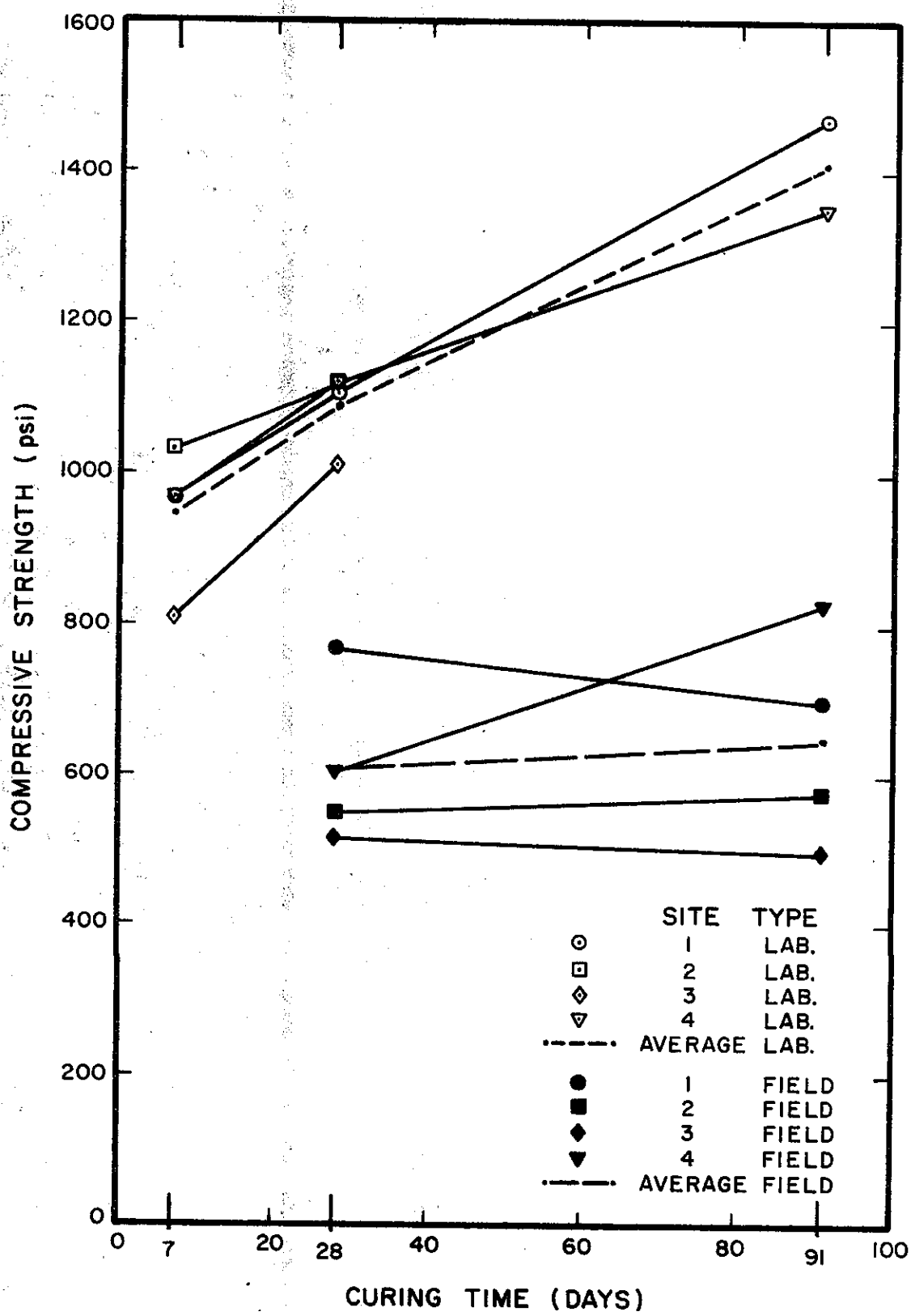
FIGURE 1

COMPRESSIVE STRENGTH vs CURING TIME
(LABORATORY AND FIELD COMPACTED SPECIMENS)



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The average compressive strengths for laboratory and field compacted materials after the different curing times are also included in Table 1 along with the relative strength of each group when compared to the 7-day strengths of the laboratory compacted specimens. Based on these data, the unconfined compressive strength of the laboratory compacted plant-mixed CTB is well above the 750 psi strength specified for design purposes. After continued curing periods of 28 and 91 days, the strength of the laboratory compacted briquettes increased by 16% and 50%, respectively, above the corresponding 7-day "laboratory" strengths.

In contrast, these same materials achieved much lower strengths after being compacted in-place in the road. When tested at 28 and 91 days after placement, the cores taken from the road had only 65 and 69 percent of the strength obtained in 7 days when the same material was compacted and cured in the laboratory. Since the observed increase in strength from 28 to 91 days for the cores was relatively small, it is assumed that the ultimate strength of the material in place on the road would probably not exceed 70 percent of the 7-day strength of the laboratory compacted CTB. On this basis, a 7-day laboratory strength of approximately 1100 psi would be required to assure an ultimate 750 psi strength for the same material compacted in-place in the road.

These findings are supported by Munday's (3) observations that only about 50% of the in-situ CTB had actually achieved a compressive strength equal to respective construction control 7-day compressive strengths and that about 1/3 of the in-situ CTB did not reach 75% of the construction control strength. Munday also found that maintenance-free service life of a road is a function of the compressive strength of the CTB. Only about 10% of the roads which had in-situ CTB strengths greater

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than 750 psi required major repairs before they had been in service 10 years. Approximately 50% of the roads with in-situ CTB strengths of less than 750 psi required major repairs in less than 10 years. To compensate for these differences between laboratory and in-situ strengths and to provide some assurance that the desired strengths are being achieved in the roadway, Munday suggested that laboratory design strengths be set 25 to 30 percent higher than the strengths actually desired on the road.

It must be stressed at this point that the differences between field and laboratory tests on the Route 91 project were observed even though normal variations in aggregates and the amount of cement and water were virtually eliminated because all the sampling at each site was from the same truck load of CTB. There were, however, opportunities for differences in densities of the compacted materials, differences in environmental influences, and differences in the degree to which the compacted material was protected from disturbance.

Determinations made at the time the laboratory specimens were compacted indicated that the moisture content of each sample was right at optimum. As a result, the maximum density for the mix should have been achieved. The construction control records revealed, however, that the relative densities of the materials compacted on the road averaged 96% but relative densities as low as 92% were recorded at individual locations.

In-place densities were determined by construction personnel using a nuclear gage. They did not, however, make density determinations within the limits of any of the test sites. To provide a direct comparison of the in-place densities and the laboratory densities of the same material, bulk specific gravities were determined on the cores and the laboratory-fabricated specimens using the procedures of Method "C" in

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Test Method No. Calif. 308-C (2). These specific gravities, which are summarized in Table 2, indicate that the relative densities of the material placed on the road at the test sites were approximately 93% of that attained in the laboratory.

A review of the individual test data and calculations revealed an apparent increase in the dry densities of the laboratory compacted test specimens between the time of compaction and after several weeks of curing. This increase is attributed to an increase in the sample weight as a result of the chemical combination of the mixing water with the cement. The average increase in dry density of five test specimens was 3.3 lbs/cu ft.

On the other hand, there does not appear to be a comparable increase in the dry densities of the material in-place on the road. The average density of the core samples taken from the road was estimated to be comparable to the densities determined shortly after compaction. Although strictly speculative at this time, it appears that confining the laboratory specimens in sealed containers during the curing period may improve the chemical reaction of the cement and water by holding all of the water in the mix.

Environmental conditions and manipulation of the CTB also differed significantly between the laboratory compacted test specimens and the material placed on the road. The CTB material used to prepare the laboratory specimens was taken from the fresh mix immediately after it was deposited on the roadbed. The samples of loose material were placed in the tin containers and covered with snug fitting lids for transportation to the laboratory. Upon arrival at the laboratory, a crew of several technicians worked together to process and compact the test specimens within the 1 hour ± 15 minute time limit specified in Test Method No. Calif. 312-E. Immediately after compacting the test specimens

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TABLE 2

SUMMARY OF DENSITIES (bulk specific gravity)

Test Site	Laboratory Specimen	Field Core
1	138.5	129
	134.2	131
		130
		129
2		131
		130
		128
3		129
		130
		129
4	141.0	132
	146.6	131
		131
		132
Overall Average	140	130 (93% relative density)

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into the required tin liners, snug fitting tin caps were placed on the ends and the edges wrapped with tape to seal in the moisture. After a few days in storage at the project office, the test specimens were transported to the Transportation Laboratory where they remained in the sealed containers until the day they were to be tested. During the first few days of storage and while being transported to the Transportation Lab, the specimens may have been subject to some temperature variations. Once delivered to the Transportation Laboratory, the temperature remained constant at about 70°F for the remainder of the curing time.

On the roadway, the material was subject to much broader variations in temperature, moisture content, and handling. After being deposited on the roadbed in windrows, the mixed material was spread with a CMI machine. This was followed by initial compaction and then a trimming pass with the CMI. Additional compaction, final trimming, and final compaction extended the manipulation of the material to approximately the 2-1/2 hour limit permitted by the Standard Specifications. The mixed material was, of course, being exposed to moisture evaporation conditions all through this period of time, especially during the time that it was in a loose condition and as it was being spread and trimmed with the CMI. After initial compaction and perhaps even before final compaction, water was periodically sprayed on the surface of the CTB in an effort to prevent excessive drying. At the end of the day, when compaction was completed, an asphalt curing seal was sprayed on the surface. With the curing seal as its only protection, the CTB remained exposed until the PCC pavement was placed. During a portion of this period preceding paving, the CTB was also subjected to some construction traffic.

It cannot be determined how each of these factors may have actually affected the strength of the in-place CTB but anything

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which would delay final compaction, disturb material that had already been compacted, or affect the moisture content could certainly have a detrimental affect. Combinations of any of these factors would compound the effect on strength. The construction operations on this job were, however, considered "typical" construction operations.

Tests were also performed on 28 and 91 day core samples in an effort to evaluate their relative resistance to surface abrasion. The procedure used for this portion of the study (see Appendix A) required bouncing rubber balls, at a high rate of speed, on the surface of the test specimen which had been confined in a testing apparatus and flooded with water. The amount of material, measured in grams, abraded from the surface of each test specimen is recorded in Table 3.

No standards have been adopted for this test but the amount of abrasion appears to be quite low. The abrasion losses from the cores taken after 91 days at site 4 are higher than the losses from the cores taken earlier from the same site; however, the losses still appear small. Examination of the test specimens prior to testing revealed that the surface of the 91 day cores from site 4 were noticeably more irregular than the 28 day cores. This was probably the result of surface tearing at some locations during the construction trimming operation.

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TABLE 3

SUMMARY OF ABRASION LOSS (grams)

Test Site		28-Day Field Cure	91-Day Field Cure
		1.3	2.3
1		2.3	1.0
		3.9	1.2
	Avg.	2.5	1.5
		5.4	-
2		1.7	-
	Avg.	3.6	-
		1.7	-
3		1.2	-
		2.1	-
	Avg.	1.7	-
		1.1	6.3
4		1.5	6.5
		-	2.0
	Avg.	1.3	4.9
Overall Average		2.2	3.2

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APPENDIX A

TENTATIVE METHOD OF TEST FOR DETERMINING THE SURFACE ABRASION OF CEMENT TREATED BASE IN THE PRESENCE OF WATER

Scope:

The surface abrasion test measures the ability of a compacted cement treated base to resist surface abrasion or raveling in the presence of water.

Procedure:

A. Apparatus

1. 1-Mechanical shaker * for shaking mold containing sample, water and rubber balls in a vertical direction at 1200 ± 10 cycles per minute with a 1" stroke.

2. 1-230°F oven.

3. 4-Rubber balls 1 1/8" diameter and weighing 15.5 grams ± 0.7 grams each. (Manufactured by Atlantic India Rubber Co., Chicago, Illinois, that are listed under mold number 1542 with a Shore Durometer hardness between 60 and 70.)
   The Sacramento Rubber Co., in Sacramento is presently stocking this item.

4. 1-250 Ml graduated cyclinder.

*Drawings No. D0469 (6 sheets) available from the Transportation Laboratory.

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5. 1-Polyethylene wash bottle.

6. Steel Pan 6" in diameter 1-1/2" deep.

7. Aluminum Pan 7-1/2" in diameter 2-1/2" deep.

8. 1-Balance having capacity 4,500 gm and sensitive to 0.1 gm.

9. 1 - steel test mold, 4 inches ID by 5 inches high, fitted with a watertight base and cover. A 1/8" steel ring, triangular in cross-section and inserted to form a lip, encircles the mold interior 2 inches above the bottom and combines with the base to hold the sample in place and protect the vulnerable edges of the specimen. (Drawings No. 696 [2 sheets])

B. Mixing and Fabrication

Fabricate at least three 2-inch thick 4-inch diameter specimens as per Test Method No. Calif. 312.

C. Test Procedure

1. Measure 250 ml of the water in a graduated cylinder and pour onto the surface of the specimen.

2. Place the four rubber balls into the mold; lock mold into place on mechanical shaker with wing nuts.

3. Shake sample at 1200 $\pm$ 10 C.P.M. for 4 minutes and remove from mechanical shaker.

4. Remove rubber balls and pour contents from mold into the preweighed pan. Wash all fines from the surface of the sample into the pan with the wash bottle.

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5. Let pan stand for one hour and decant as much of the clear water off as possible.

6. Heat pan and contents in 230°F oven until all water has been evaporated.

7. Weigh pan containing abraded material and record its weight. The difference between this weight and the original weight of the pan is the amount of abrasion loss in grams.

Reporting Results:

Report the average amount of abrasion loss, in grams, of material abraded for at least <u>three</u> replicate test specimens.

Precautions:

1. The rubber balls shall be free of soil prior to testing.

2. The rubber balls must be periodically checked for weight and they should be discarded when weight is not within specified tolerance.

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