Engineer of Materials for the Kansas Highway Commission, initiated the project; to R. D. Finney, present Engineer of Materials of the Kansas Highway Commission, under whose supervision this work was completed; to C. H. Scholer, Professor of Applied Mechanics, Kansas State College, for his helpful suggestions and assistance rendered in tabulating much of this data; to E. E. Larson, Engineer in charge of obtaining this data; and to C. R. Fricke and D L. Lacey, Engineers, who assisted in this work.

PROGRESS REPORT ON CALIFORNIA EXPERIENCE WITH CEMENT TREATED BASES

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SYNOPSIS

The California Division of Highways has built 123 miles of pavement base by mixing cement with granular materials of many kinds and compacting on the subgrade by rolling or tamping Most of these bases have been for first class road improvements. The materials have included fine silty sands, streambed gravels, disintegrated granite, soft crushed sandstone, fairly clean sand and aggregates suitable for concrete, and many construction methods have been tried Twenty-eight projects ranging in length from one-half mile to 13.1 miles have been constructed.

Since in most cases the material for cement treated bases in California is brought from an approved pit or quarry it was found economical and otherwise desirable to use plant mixing rather than road mixing.

These cement treated bases are giving satisfactory service Attempts to use thin bituminous surfaces on the cement treated bases did not give satisfactory results and hence a 3-in layer of bituminous surfacing has been adopted as standard practice on California primary roads of moderate to heavy traffic.

The mixture design is based on compressive strength requirements of 850 lb per sq. in at 7 days and 1000 lb. per sq in. at 28 days.

California experience with cement treated base construction dates from 1937 although some minor investigations along this line were made as early as 1921

The work in 1937 and 1938 consisted of road mixing cement with the local materials in the subgrade and these early projects may be considered as patterned after the original soil cement stabilization idea which has been applied extensively in other sections of the United States where the tendency has been to confine operations of this nature to cement treatment, or stabilization as it has been called, of local fine grained soils.

Most of the cement treated base construction in California, however, has been in connection with first-class road improvement where the traffic includes medium to heavy industrial equipment and where a more substantial base was required than on lightly traveled secondary roads.

California has found it difficult economically to justify soil cement construction, even on a moderate scale for lightly traveled secondary roads as an alternate to bituminous surfacings on selected material or gravel bases.

On the more heavily traveled highways, however, there appears to be a very definite economic justification for this special type of construction, provided granular soils, streambed aggregates, or other materials of a suitable nature are at hand. Such materials have been

found readily available in many localities and it is under such conditions that projects involving approximately 120 miles of cement treated bases have been completed or are now under construction

Most engineers accept without question the assumption that high compressive strength in standard paving concrete is a "good thing" and, after years of painstaking care and inspection, are inclined to regard clean well-graded aggregates as essential and to feel a strong professional distaste for mixing good cement with ordinary soil, dirty sand, or pit run gravel Nevertheless, when funds are inadequate to build the mileage of high type roads that the public demands, the engineer is forced to consider less expensive alternates.

The process of hardening soil with portland cement is not new—sections were constructed in Pennsylvania and elsewhere prior to 1930 but were apparently little publicized and it was not until 1936 that the work in South Carolina was brought to the attention of highway engineers throughout the country. California first experimented with the process in 1937, constructing two sections of one mile each by State maintenance forces. The first was an attempt to salvage an asphaltic macadam road surface that had failed consistently for several years in spite of reworking This project, while relatively expensive, has been entirely successful.

Two additional road mix projects, each 3 miles long, were constructed by contract, one in 1938 and one in 1939 In each instance the base has given satisfactory service to date but certain inherent defects in road mixing operations were evident on each project Laboratory studies also revealed that it was impossible to secure the full benefit of the cement treatment by road mix methods using farm type equipment, largely because of the time required for mixing and shaping It was found that, as a rule, the shorter the time interval between the first mixing of cement, water, and soil and the compaction of the mixture, the greater the degree of compaction obtainable and the higher the ultimate strength

Considerable experience with the oil mix type of construction had proved that plant mixing methods were on the whole more dependable and in general produced results more uniform and satisfactory than road mixing without appreciably increasing costs. Therefore it seemed logical that there would be similar advantages in plant mixing cement treated mixtures.

In the majority of highway construction projects in California for which cement treatment can be economically considered, the base material is imported from an approved pit or quarry; hence, mixing at the pit in a central plant involves no extra haul and is otherwise more efficient Moreover, plant mixing eliminates most of the high moisture loss which occurs by evaporation during road mixing in hot, dry weather.

In consideration of the anticipated advantages, plans were prepared in 1939 to construct three projects of cement treated base ranging from 6 to 9 in. thick surfaced with plant mix. Since that time (with the exception of three contracts on which traveling mixers were employed) central mixing plants have been used on all cement treatment contracts let by the California Division of Highways.

About this time the designation, "cement treated base," was adopted, primarily to avoid the term "soil stabilization," which has been applied to so many diverse types of soil treatment that it has lost any definite meaning. Engineering terms such as subgrade, base, or pavement do not carry any subtle appeal or attempt to convey the idea that these elements have either high or low quality. So-called stabilized soil may mean almost any treatment and the soil may or may not have acquired permanent stability as a result of the treatment.

The term "cement treated base" implies no quality beyond stating that cement has been added to the soil or aggregate for whatever it may be worth It was not the intention to restrict the term to a type of aggregate or to a type of construction operation—it applies to any base in which the aggregate is treated with cement and compacted on the subgrade by rolling or tamping.

Another departure from previously established procedure is in the method of expressing the cement content. It has been general practice throughout the United States to express the cement content in terms of equivalent volume and this is undoubtedly the best basis for comparing results between separate projects However, this method is convenient only to laboratory or technical men and is of little value to the resident engineer, to the con-

tractor, or to the inspector who must check proportions daily. The largest number of individuals involved in the design and construction of highways are more interested in the weight relationships and it is distinctly less confusing in a large organization if all proportions are understood to be on the same basis; thus the percentage of water in a soil, the quantity of asphalt or road oil in the surfacing, and the percentage of cement are in California practice all expressed in terms of percentage by weight of the dry aggregate.

Under present procedure the cement content recommended for a given project is usually the amount required to develop a compressive strength of at least 1000 lb. per sq. in. after 28 days or 850 lb. within 7 days. Ordinarily this requires something more than 6 per cent of cement by weight and it is thought that less than this amount may cause difficulties in securing uniform distribution during mixing. It should be understood, however, that several of the earlier projects were constructed wherein the compressive strength is considerably less than 1000 lb. per sq. in. and many of these projects are still giving satisfactory service. It is appropriate therefore, to consider using some lower strength as a standard for deciding on the proportion of cement to use This would be true particularly for certain combinations of light traffic and favorable foundations.

CALIFORNIA CEMENT TREATED BASE PROJECTS

Five contracts for plant-mixed cement treated base, with an approximate combined length of 29 miles, had been let by the spring of 1940 and were completed late that year or early in 1941. Since that time, some 20 additional plant-mixed projects have been built, bringing the total mileage for this type of construction to 116 6 miles. These projects have involved a very wide variety of materials, ranging from fine silty sand to aggregates suitable for concrete and including streambed gravels, disintegrated granite, soft crushed sandstone and fairly clean sand In each instance the specifications for grading, etc , were written to conform to the locally available material and the limits of cement content were adjusted to provide a range which would produce the specified compressive strength, usually 850 lb per sq. in at 7 days or 1000 lb. at 28 days on a specimen 4 in. in diameter and 4 in. high.

The location, length, year of construction, kind of mixer, and general type of material, including the proportion passing a No. 4 sieve, are shown in Table 1. Further details, including grading, percentage of cement, unit weight, test results, etc , are shown in Table 2.

Except for modifications to provide for the introduction of cement and water, standard asphalt paving plants were used in all but three contracts and thus were available for both the cement treated base and the bituminous wearing surface.

All cement treated base projects are protected by a 3-in layer of dense grade bituminous mixture

Whenever the aggregate contains coarse material, the specifications provide for separation on a No. 4 or a ¼-in screen with a storage bin for each size Wide tolerances are commonly specified in the grading limits in order to cover the material in the approved source of supply which preliminary investigation and laboratory tests have shown to be suitable for use

The first plant mix contract to start construction was in Southern California between Beaumont and Banning, VIII—Riv-26-A, B. The raw material was an alluvial deposit of sand and gravel with about 10 per cent coarser than a No 4 sieve The contractor installed a Blystone rotating blade type of mixer, and, after changing the driving gears, etc., to accommodate the heavy load, fairly satisfactory results were secured The original weight per batch was approximately 4700 lb raw soil, 282 lb. cement, and 525 lb water. (6 per cent cement and 11 per cent of water by weight. Later the cement content was increased to 7 per cent)

Placing and compacting the treated material on the roadbed presented an entirely new set of problems compared to previous road mixed jobs or to previous experience with bituminous mixtures First, the quantity of treated material and the difference between the uncompacted and compacted volumes was much greater for the cement treated mixture; hence, the ordinary type of spreader box could not be used to advantage. A blade grader was found to be unsatisfactory for a number of reasons of which the more important were· the repeated trips of the grader built up hard

TABLE 1

SUMMARY OF CEMENT TREATED BASE PROJECTS BUILT BY CALIFORNIA DIVISION OF HIGHWAYS

Project (County, route section)	Located near the city of	Date base const	Length	Type of mixer	Type of spreader	Cem	Pass No 4	Type of aggregate
			Miles			%	%	
VIII—Riv-26-A,B	Beaumont	9/40	6 1	Revolv. blade	Bulldozer	6	90	Sand, some grav.
II—Teh-3-C	Red Bluff	9/40	6 0	Tilting drum	Spreader box	6	40	Sandy gravel
X—Mer-18-A	Merced	11/40	3 3	Pug mill	" "	7	53	" "
VIII—Riv-19-A	Riverside	11/40	3 0	Revolving blade	Bulldozer	7	79	Disin granite
VIII—Riv-26-C	Banning	2/41	11 0	Pug mill	"	6	59	Sandy gravel
III—Yol-7-Wd,B	Woodland	8/41	4 5	" "	"	6½	52	" "
V—SB-2-G	Santa Barbara	9/41	3 4	" "	"	7	82	Soft cr sandst
V—SB-2-F	" "	11/41	2 0	" "	"	7	79	" " "
VIII—Riv-78,19-D,C	Riverside	11/41	1 6	Gardner tr mix	Motor grader	8	85	Disin granite
VII—Ora-184-A	Santa Ana	11/41	6 3	Pug mill	Bulldozer	7	100	Fine silty sand
VI—Ker-58-L	Bakersfield	1/42	0 5	" "	Motor grader	7–8	86	Crusher waste
VI—Ker-142-Bkd A	"	2/42	0 8	Revolv drum	" "	8	43	Concrete aggr
VIII—SBd-26-Rld,B	Redlands	3/42	3 2	Pug mill	Barber-Greene	7½	53	Crush limest
VIII—Riv-78-D	Riverside	7/42	5 0	" "	" "	7	50	Gravel & D G
VIII—Riv-78,19-C,D	"	7/42	1 4	" "	" "	7	58	" & "
VII—Ora-171-B	Buena Park	7/42	2 0	" "	Bar -Gr & bla	8–10	80	F snd+slt &crr
V—Mon-Fdr (2)	King City	8/42	3 9	" "	Bulldozer	8–9	50	Sand & gravel
V—Mon-Fdr (1)	San Ardo	9/42	5 9	" "	"	7	58	" "
V—Mon-Fdr (3)	King City	9/42	13 1	" "	"	7–8	50	" "
V—Mon-Fdr (4)	" "	10/42	8 5	" "	" (25 Ft)	7	60	" "
V—Mon-Fdr (5)	" "	10/42	3 0	" "	"	8	50	" "
V—Mon-Fdr (6)	" "	10/42	6 0	" "	"	8	50	" "
VII—LA-169-A	Long Beach	9/42	2 1	Gardner tr mix	Motor grader	10	89	Clayey snd&gr
VII—LA-Fdr(Fl Str)	Los Angeles	12/42	1 3*	Bar-Gr contin	Bulldozer (25)	9½	100	Fine slty sand
VII—LA-Imp Hwy	" "	6/43	1 5	Pug mill	"	11	100	" " "
X—SJ-Fdr	Stockton	6/43	2 4	Bar-Gr travel	"	12	100	" " "
II—Sha-3-A	Redding	7/43	4 0	Pug mill	"	6	54	Sandy gravel
VI—Kin-10-B	Lemoore	11/43	10 8	" "	Barber-Greene	8	100	Fine, silty sand
Total Mileage			122 6					

An additional 8 4 miles was constructed 1937–39 by farm type road mix methods

* A flight strip 150 ft wide

TABLE 2

TYPICAL VALUES FOR GRADING, UNIT WEIGHT, AND TEST RESULTS ON CEMENT TREATED BASES CONSTRUCTED BY THE CALIFORNIA DIVISION OF HIGHWAYS

Project	Approx Aver Grading Per cent Passing				Base Thick In	Cem	Wt	Compressive Strength			
								Test Spec		Cores 30-90 Da	
	1½"	1"	No 4	No 200				7 Da	28 Da		
						%	*Cu Ft*				
VIII—Riv-26-A,B	100		90	10	6–9	6–7	125	720	875	710	
II—Teh-3-C		100	40	2	6	6	140	1700	2130	2420	
X—Mer-18-A		100	53	8	6	7	145	1155	1365	2190	
VIII—Riv-19-A	100		79	3	6	7	129	845	1110	970	
VIII—Riv-26-C	100		59	2	6	6	142	1150	1795	2155	
III—Yol-7-Wd,B		100	52	2	6	6 5	145	1330	1625		
V—SB-2-G		100	82	11	6	7	125	1210	1310		100% passing ½ inch
V—SB-2-F		100	79	10	6	7	125	1116	1220		100% passing ½ inch
VIII—Riv-78,19-D,C		100	85	6	6	8	122	1020	1100		
VII—Ora-184-A			100	2	8	7	117	565	800		80–90% passing no 16
VI—Ker-58-L	100		86	16	8	7	117	710	995	535	Cores-118 lb per cu ft
						8	117	1060	1380	410	Cores-112 lb per cu ft.
VI—Ker-142-Bkd A		100	43	0	6	8	137	1420	2010	2035	
VIII—SBd-26-Rld B	100	92	53	4	6	7 5	130	975	1475		
VIII—Riv-78-D	100	93	50	2	6	7	130	1335	1625		
VIII—Riv-78,19-D,C	100	97	58	3	6	7	133	1085	1340		
VII—Ora-171-B		100	80	6	6	8	126	1045	1470		
V—Mon-Fdr (2)		100	50	9	6	11	128	995	1365	1410	
V—Mon-Fdr (1)		100	58	6	6	7	122	960	1180	1060	
V—Mon-Fdr (3)		100	50	6	6	7	119	1030	1175		
							130	1140	1325	1190	
V—Mon-Fdr (4)		100	60	7	6	7	128	1085	1420		
V—Mon-Fdr (5)		100	50	7	7	7	123	1035	1225		
V—Mon-Fdr (6)		100	50	7	7	7	123	1090	1240		
VII—LA-169-A	100	98	89	38	6	10	119	945	1200		
VII—LA-Fdr(Lomita)			100	11	6	10	123	945	1240		100% pass no 16
VII—LA-Imp Hwy			100	13	7	11	120	1170	1880		
X—SJ-Fdr			100	15	6	12	116	990	1350		100% pass no 16
II—Sha-3-A		100	54	5	6	6	133	945	1175	1625	
VI—Kin-10-B			100	10	6	8 2	115	895	1090		99% pass no 16

ridges where the wheels compacted the loose material and the blade then filled the tracks; compaction planes were formed wherever loose material was bladed into smooth partially compacted surfaces; and the time required to spread the treated material on a roadbed of sufficient length to permit efficient operation of the blade, plus the time required to blade the section, caused an excessive lapse of time between mixing and compaction, with a resultant loss in final compaction.

When the contractor found his spreader box inadequate, he followed the suggestion of one of the engineers of the Division of Highways and adapted a bulldozer for use as a spreading device. An R.D. 8 tractor equipped with a 12-ft. blade was converted by welding heavy side wings, extending about 6 ft. to the front, to the ends of the blade. Truck wheels were mounted on each wing by means of an adjustable arm so that the weight of the blade could be carried by these wheels rolling on the subgrade thus dispensing with any support from the hoist cables. By supporting the spreader on the subgrade, the cutoff edge of the spreader could be maintained at a uniform height above the subgrade irrespective of the fluctuations in the load. The tractor traveled on the freshly spread material and moved ahead as each truck dumped its load in the box formed by the dozer blade and its side-wings.

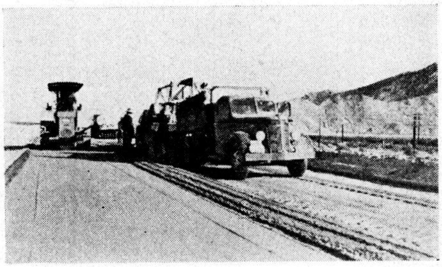

Figure 1. General layout of placing operation on two-lane construction. The truck standing on the subgrade is about to discharge into the hopper of the spreading device illustrated in Figure 2.

The device has proved to be a fairly satisfactory solution of the placing problem and similar arrangements, using either wheels or runners for front supports, have been used on most of the projects constructed to date.

At first an attempt was made to use a sheepsfoot tamper for initial compaction, as had been the practice on previous road mix construction. Its use, however, proved impractical since the direction could not be reversed with any degree of success and any attempt to turn on the narrow strip of material caused an excessive displacement of the treated soil. Moreover, the use of the sheepsfoot caused an unnecessary delay in final compaction; hence its use was abandoned and a 12-ton, three-wheeled roller was operated immediately behind the bulldozer spreader. It was found that the required degree of compaction could be obtained (provided the rolling began immediately after spreading) even though the compacted thickness of the base on this project varied from 6 to 9 in.

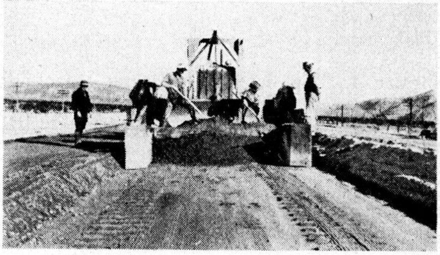

Figure 2. Typical spreading device constructed by adding side wings and depth control units to a bulldozer. Project east of Banning. Aggregate is pit run gravel.

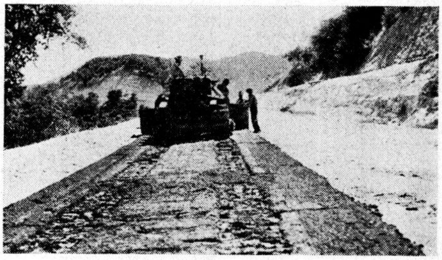

Figure 3. Typical appearance of freshly spread cement-treated base as it appears just behind the bulldozer spreader and before compaction has started.

In order to secure full width (25 ft.), in a substantially continuous operation, the treated material was spread one-half width for 5 or 6 loads, then the bulldozer moved ahead, off the freshly spread material, backed onto the opposite lane and the second half brought up even with the first section. The bulldozer then moved to the first lane and the process was repeated. In the meantime the roller had

compacted the first half to within a few feet of the center, moving on across the road as soon as the spread on the second half had been completed. At least 15 ft. at the end of each strip was left uncompacted to permit the bulldozer to resume its spread with its treads in their old tracks.

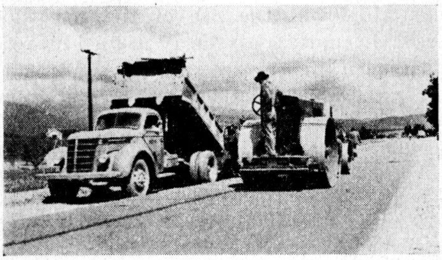

Figure 4. The first three stages of placing operations. Fresh mixture being dumped. Center lane spread but not compacted. Initial compaction on outer lane.

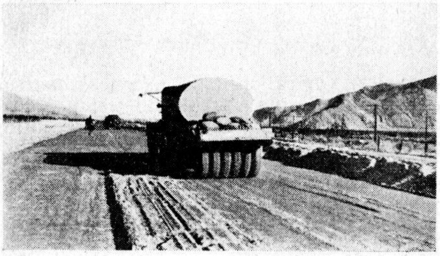

Figure 5. Final compaction with pneumatic-tired roller. Initial compaction is done with a three-wheeled, 12-ton roller.

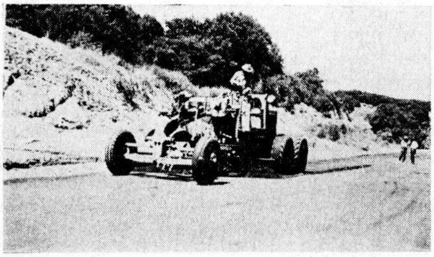

Figure 6. Illustrating trimming of compacted surface by a motor grader which is necessary when the intial spread is uneven. Trimmed material is wasted on the shoulders, and no attempt is made to fill low spots or depressions.

The use of this self-propelled type of spreading equipment has made it possible to spread the proper thickness of cement treated base in one operation without subsequent shaping or displacement. The tractor treads leave partially compacted tracks in the loose material but these tracks are not subsequently filled and thus do not interfere with uniformity of final compaction.

It was necessary to add a V-shaped device in front of the bulldozer blade to force part of the mix to the corners of the box. Plowpoints or similar devices were also added to some of the V's on subsequent projects to help eliminate the irregularities in spread caused by partial compaction when the bulk of the load was dumped from the trucks.

After rolling had been completed, the compacted base was trimmed by means of a blade grader in order to produce a true surface. All material cut off by the blade was wasted on the shoulders in order to avoid compaction planes or thin surface laminations.

Inasmuch as the aggregate on this project was largely sand, with but 10 per cent of gravel coarser than No. 4 mesh, special precautions were necessary to avoid laminations or compaction planes.

After trimming, the surface was further compacted by means of pneumatic rollers. Water was applied when necessary, not only during the final pneumatic rolling but also during the initial rolling.

After the pneumatic rolling, an asphaltic curing seal was applied by hand spraying. On this project RC-2 was used as a seal but on most of the projects constructed subsequent to 1940, emulsified asphalt has been used applied at a rate of 0.15 to 0.25 gal. per sq. yd.

Within a few days after the start of operations at Beaumont, placing of the cement treated base was begun on the Red Bluff job, II-Teh-3-C. There the aggregate was a fairly well graded streambed gravel with very little dust passing a 200-mesh sieve. The rock particles varied from extremely hard to fairly soft but when mixed with 6 per cent of cement by weight, developed crushing strength above 2000 lb. per sq. in.

The contractor had available a 2-yd. tilting drum type concrete mixer and constructed his plant around this unit for the cement treated base. As, in a cement treated base mixture, only enough water is used to secure maximum compaction, the mix is usually too dry for efficient mixing or discharge from a standard drum type mixer. In the Red Bluff case,

however, the aggregates contained no clay and very little fines, so that fairly successful results were obtained. It was necessary, however, to clean the mixer frequently and some erratic results in the finished base were attributed to failures to keep the drum and paddles clean enough for thorough mixing. The average mix contained 7800 lb. aggregate, 470 lb. cement, and 580 lb. water (6 per cent of cement and 7 per cent of water by weight of dry aggregate).

The contractor had provided a pair of large spreader boxes on long runners for placing the base material. It was found necessary to enlarge the discharge openings and to add some V-blades in the hopper after which the boxes worked fairly well.

Because of the large percentage of rock coarser than No. 4 and the small proportion of fines, there was almost no tendency for the formation of compaction planes on this project and it was found possible to use the blade in conjunction with the heavy rollers and unnecessary to waste the trimmings. Inasmuch as it was difficult to operate the spreader boxes so as to avoid the formation of a trough at the center line where the two spreads joined, this ability to cut and fill was a distinct advantage.

A maximum size of 1 in. was specified for the aggregate on this project and the elimination of oversize helped to avoid undue tearing up of the compacted base during finishing operations.

A unique feature of this job was the use of a wooden mat on which the wheeled tractor and pneumatic roller turned around to avoid abrading the finished surface.

Because of the difficulties experienced with the sheepsfoot roller at Beaumont, no attempt was made to use one for compaction at Red Bluff. Moreover, the aggregate was not of a soil type on which a sheepsfoot is effective.

On one end of this project it was necessary to carry traffic on the base within 2 hr. after its construction. The curing seal was protected by a thin earth blanket and no ill effects could be detected from the immediate use of the base. In fact, cores taken later indicated higher than average strength for this section.

The third plant mix project for cement treatment X—Mer-18-A, consisted of a 7-ft. widening strip on the edge of an existing concrete pavement near Merced in central California. The aggregates were obtained from a creek bed deposit of sandy gravel. The rock particles were very hard and high in specific gravity. A spreader box equipped with long runners, one of which was kept on the existing pavement provided a uniform spread of treated mix for the narrow width and per-

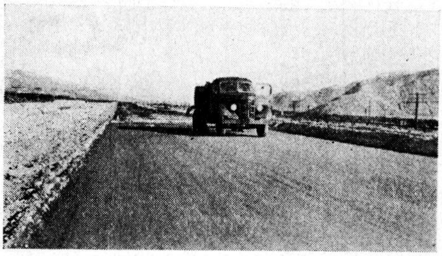

Figure 7. Emulsion tank and hand-operated outfit maintained on truck used for applying the emulsified asphalt curing seal. Application is made by hand-operated spray.

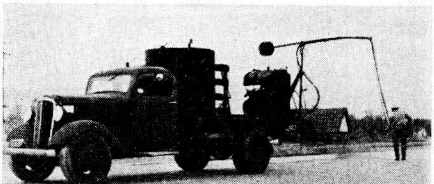

Figure 8. Another example of emulsion spray equipment

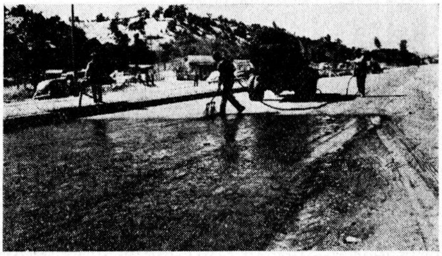

Figure 9. Close-up of emulsion spray being applied to the fresh surface to form a curing seal

mitted immediate compaction with a 13-ton, three-wheeled roller. No trimming was necessary after rolling. An average relative compaction of 100 per cent (145 lb. per cu. ft. dry weight) was obtained on this project.

The fourth plant mix job, Riverside to 3 miles west, involved the use of disintegrated

granite as an aggregate. This material pulverized as excavated to a fine granular product, very uniform in size and fairly easy to mix and place. The resulting base, while not especially high in compressive strength (970 lb. sq. in. average), was very uniform throughout the project and is apparently entirely adequate.

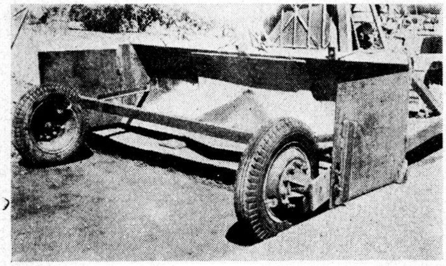

Figure 10. Small bulldozer conversion for spreading 10 ft. widening strip

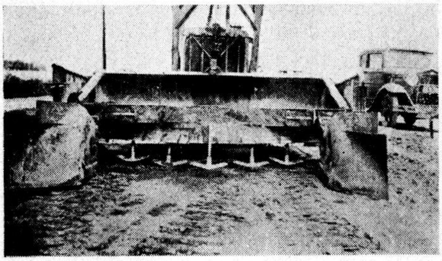

Figure 11. Spreader showing plows for loosening spread to secure uniform density

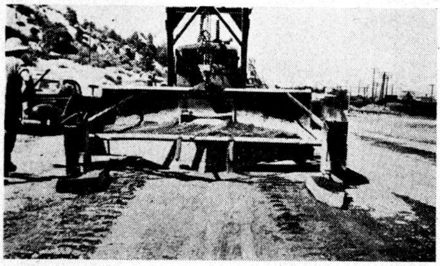

Figure 12. Latest version employing diagonal blade to distribute mixture uniformly. Project near Redding.

The fifth contract (Banning to Palm Springs Junction) on which construction began late in 1940, involved treatment of an exceptionally good aggregate (viewed from the perspective of concrete practice) taken from a clean, well graded streambed gravel deposit. The contractor installed a large pugmill (8000-lb. capacity) and was able to achieve a high daily rate of production.

A drag, pulled behind the bulldozer spreader, was here used for the first time. It was intended to produce a more uniform spread of treated material ahead of compaction, and because of the character of the mix and the comparatively cool humid weather prevailing during most of the construction period, this procedure proved of considerable advantage. Subsequent attempts on other projects to secure a smooth surface through the use of a drag have been less successful. The bulk of surface irregularities developed during compaction are due to variations in the density of the loosely spread material rather than to unevenness in the loose surface behind the spreading device.

Such variations in semi-loose density can only be corrected ahead of the cut-off blade of the spreader and are not affected by a drag. The use of the drag means a considerable delay in the start of compaction and usually results in a corresponding decrease in compaction and strength.

Twenty-eight cement treated base projects with an aggregate length of 122 miles (including a flight strip 1.5 mile long having a total area of 67,000 sq. yds.) have been constructed to date. (Table 1.) In general, except for three projects on which travelling mixers have been used, the construction practices have been similar to those described for the first five contracts. However, each job varied in some details from the others and special mention may be made of the following:

Santa Ana to Corona Del Mar. VII—Ora-184-A

This project involved the cement treatment of a fine sand containing 10 to 15 per cent of particles passing a 200-mesh sieve. The pit contained some large pockets of a poorly graded sand deficient in fines. Attempts by the contractor to utilize the latter material resulted in construction difficulties, poor compaction, and low strength. As soon as this defect was noted, special precautions were taken to use only the better graded sand and improved results were obtained. Special precautions were required during rolling to avoid the formation of shear planes near the surface and at the same time to obtain full compaction. In spite of these difficulties, however, an

average compacted dry weight per cubic foot of 117 lb., representing a relative compaction of 95 9 per cent, was obtained.

North of Santa Barbara. V—SB-2-F, F—SB-2-G.

North of Santa Barbara on the Coast Highway were two adjoining projects which required cement treatment of an aggregate obtained from a massive formation of soft sandstone. This rock was very soft and easily crushed, hence the specifications required that all the aggregate should pass a ½-in. screen and at least 95 per cent should pass a ⅜-in screen. The treated material handled very nicely on the road and produced an average compacted dry weight slightly above 125 lb per cu. ft. (equivalent to a relative compaction of 96 per cent+). The final trimming of the surface with a blade grader produced an especially smooth finish.

Adjacent to March Field near Riverside. VIII—Riv-78, 19-D,C, VIII—Riv-78-D.

These were two companion projects, which marked the first successful use of a self-propelled mechanical spreading machine (Barber-Greene) of the type developed for placing bituminous pavements The bulk of treated aggregate required for a 12 ft width of base, 6 in in compacted thickness, is so great as to tax these machines to the limit of their capacity. When properly operated, however, they produce a very uniform spread of treated base.

City of Bakersfield. VI—Ker-142-Bks.

This project utilized a manufactured aggregate with a rigidly controlled grading as follows

Passing	1 inch Screen, %	100
"	⅜ inch Screen, %	80
"	No 4 Sieve, %	43
"	No 8 Sieve, %	38
"	No 30 Sieve, %	15
"	No 200 Sieve, %	0

The mix was designed for a cement content of 3 sacks per cu. yd of compacted base (a little over 8 per cent, by weight). Mixing was done in a revolving drum mixer (Koering 27-E Paving Mixer) using 3370 lb , dry weight, of aggregate, 3 sacks of cement and sufficient water to give a moisture content of 6½ to 7 per cent. The base was constructed during February, 1942, and the cool, damp, weather combined with the use of clean crushed aggregate, entirely free from any tendency to form compaction planes, enabled the contractor to secure an excellent, thoroughly compacted job by rather unorthodox methods

The project was small, approximately ¾ mile in length, and of a varying cross-section. The treated material was placed in narrow deep strips by means of spreader boxes, bladed to the approximate section, thoroughly wheel rolled by means of a large dump truck, loaded by a water tank to a weight of over 6000 lb. for each of its four rear wheels. After rolling, the base was bladed again to the proper shape and section, then further rolled, first with a 13-ton tandem roller, then with the truck. Cores cut from the treated base after curing showed an average relative compaction of 101.7 per cent (138 3 lb. per cu ft dry weight) and a compressive strength of 2035 lb. per sq in at 28 days.

Cutting and filling with a blade, as described above, would have been unsuccessful with finer or more sandy aggregates and the long working period would have been very detrimental in warmer or drier weather.

Hunter Liggett Access Roads. Between Bradley and King City V—Mon-Fdr

Approximately 40 miles of cement treated base on access roads for the Hunter Liggett Military Reservation southwest of King City were constructed during the summer of 1942 under four State highway contracts and two State supervised W P A contracts On one project the raw material excavated from the pit was extremely wet and gave considerable trouble on the screens. At the start of the work the contractor ran this wet aggregate through the drier which had been set up for subsequent use in preparing the bituminous surfacing course and removed part of the water to facilitate screening As a result, the aggregate was still hot when it was mixed with cement and the treated material reached the street at a temperature of 130 to 140 F. Inasmuch as no provision had been made in the specifications for such a contingency, operations were permitted for a few days until test results could be obtained showing the detrimental effects of the excessive heat on compaction and on strength. As soon as proof

was available, however, the preliminary heating of aggregate was stopped.

On the second project, two bulldozer spreaders were used side by side for a time and usually good results for uniformity of spread were obtained. A breakdown of one spreader and a union ruling of an operator for each machine (although the machines were side by side and only one operated at a time) caused a reversion to the use of a single spreader. Careful control of the dumping and spreading produced excellent uniformity in density of the loose material and no trimming of the compacted surface was necessary.

On a third contract, a series of tests was carried out to determine the effect upon compaction of using a drag behind the spreader and of using the bulldozer spreader to obtain partial compaction ahead of the roller. It was found that each process caused a delay in final rolling and a definite lowering of the relative compaction of the finished base and that where the double delay due to tractor compaction and the use of the drag occurred, the reduction in relative density was very marked. Moreover, neither method, singly or in combination, produced a final surface as smooth as could be obtained by careful control of dumping and spreading.

On the fourth project, the contractor built a spreader box 25 ft. wide on the Blade of his R.D. 8 bulldozer thereby spreading the full width of the roadbed in one operation. The machine operated successfully and simplified the operation of the roller and eliminated the need for leaving a short section at the end of each half width spread uncompacted until the spreader returned to each side. Traffic was handled by detour.

The gravel comprising the aggregate used on all but 10 miles of the base at the eastern end of these projects contained a fairly high percentage of a very light, highly absorbent rock, known as Monterey shale, but no evidence is yet available to indicate the ultimate effect of the shale on the quality of the treated base.

Lincoln Avenue to Orangethorpe Avenue. VII—Ora-171-B.

This project, located near Buena Park, involved the use of a clean but fairly well graded sand combined with 20 per cent of No. 3 crushed rock from a commercial plant and 5 per cent of fine silt. The subgrade was constructed of the same sand without the rock or silt; and as it contained practically no binder or cementing material, considerable trouble was experienced in backing the trucks over the subgrade to the spreader. In order to overcome this difficulty, a small amount of cement was spread on the subgrade, mixed to a depth of 6 in., and the subgrade recompacted. This treatment enabled the trucks to operate without difficulty the next day.

For the first half of the job, a Barber-Greene mechanical spreader was used but after it broke down, a blade grader was used to complete the project. Inasmuch as the sandy aggregate was of the type especially susceptible to the formation of compaction planes the comparative behavior of the two portions of the project under service will prove of considerable interest.

Lomita Flight Strip. VII—L.A.

The Lomita Flight Strip offered two features of interest. A Barber-Greene travelling mixer was set up in the pit to act as a stationary plant mixing cement with the sand which was used as aggregate. The sand and cement were fed in steady streams through control gates to the continuous pugmill mixer where the water was added. About 45 sec. were required for passage through the pugmill and a very uniform mixture was obtained. From the mixer the treated material was conveyed by a belt to the loading hopper for the trucks. Spreading was accomplished in 25-ft. widths by means of the 25-ft bulldozer spreader previously described.

March Field Access. VIII—Riv-19, 78-C,D.

On this project, located near Riverside, the base material was hauled from its point of origin, spread on the roadbed, compacted and shaped, then scarified and bladed into three windrows. Cement in a volume equivalent to 8 per cent by weight of the dry aggregate was spread on each windrow and mixed with the aggregate by means of a Gardner travelling mixer. The mixer made three trips for each windrow, mixing the cement and soil dry the first time and adding the necessary moisture on the next two trips. The treated material was spread by a blade grader and then compacted.

Bellflower Boulevard. VII—L.A-169-A

This project, located near Long Beach, involved the reconstruction of a portion of the pavement on Bellflower Boulevard where a number of failures had occurred in a select material base. The work was performed by state maintenance forces and consisted of the removal of the bituminous surfacing, scarifying and mixing of the top 6 in of the subgrade, treating the material with cement, recompacting the base and replacing a bituminous wearing surface. The base material was treated in three 8-ft. widths. Cement, at a rate of 10 per cent by weight, was applied by an automatic spreading device attached to bulk delivery trucks and mixed with the soil by means of Gardner travelling mixers The resulting windrows of treated material were spread by two blade graders making one pass in tandem, the first blade throwing the mix to one side and a few inches above the required thickness and the second blade cutting it to the proper thickness and throwing to the opposite side. A spring tooth harrow followed the blades to loosen the compacted tracks. Two sheepsfoot tampers hooked together with their drawbars in opposite directions made three trips without turning, then the surface was reshaped by a blade and compaction completed by means of an 8-ton tandem roller. The resulting compaction averaged 92 5 per cent of that obtained on control specimens. No heavier roller was obtainable.

Access Road to Lathrop Storage Depot. X—S. J-Fdr.

On this project, a few miles outside of Stockton, the raw material, a fine silty micaceous sand, was hauled from the pit, dumped on the roadbed, and then mixed with cement and water by means of a Barber-Greene travelling mixer. A bulldozer spreader, of the type previously described, followed immediately behind the mixer, spreading in one pass the windrow of treated material left by the mixer. The roller followed the spreader and the time interval between mixing and compaction was the shortest of any project constructed to date.

GENERAL COMMENTS

The rate of production on the various projects varied over a wide range, from an average of 44.4 tons per hour for the 1500 lb. capacity pugmill used on X—Mer-18-A to 115 tons per hour at Red Bluff and over 200 tons per hour at Banning on VIII—Riv-26-C

The mixture of cement, water, and aggregate is much more bulky than an equivalent weight of a bituminous mixture and from 40 to 50 per cent greater than an equivalent weight of portland cement concrete. Consequently, the usual manufacturers rating of the capacity of the various pugmills was generally in excess of the quantity of cement treated material that could be thoroughly mixed. When overloaded, a part of the raw material tends to float on the top of the batch and receive no actual mixing Various methods of preventing these dead areas were tried but the best was to reduce the size of the batch to an amount that could be thoroughly mixed. Thorough cleaning of the mixers was also necessary several times each shift

Inasmuch as smoothness of riding surface is an important consideration, considerable attention has been given to spreading and rolling the treated material to produce the smoothest possible base without losing time in securing compaction. Experience has shown that careful attention to establishing absolutely uniform density in the spread of loose mix is especially important. Operation of rollers in such manner as to avoid displacement of base material is also necessary.

To date, except in a few instances, where settlement of the subgrade, etc, has caused trouble, all cement treated bases are giving satisfactory service As most of the work of this type has been on primary highways (i.e. from moderate to heavy traffic roads) attempts to use thin bituminous wearing surfaces, (less than 2 in.) resulted in early failures through cracking and slipping on the base. Consequently, a minimum 3-in. layer of bituminous surfacing has been adopted as standard practice for this class road and continued experience justifies this policy.

On all projects, the trucks hauling the treated mix from the plant to the point of spreading have been required to use tarpaulin, or similar covers, to prevent drying of the surface of the load. Likewise, the contractors have been required to keep sufficient sprinkling equipment on hand to maintain not only the required moisture content for compaction but to prevent the formation of a surface layer of dry

material. Once the treated material dries out, little or no hardening will take place.

Only in exceptional cases involving clean rocky mixes will a second layer of cement treated material bond to the smooth surface which has been compacted or partially compacted. The cleavage planes produced between two such layers may not be noticeable while the base is fresh and moist but will show up distinctly after hardening has occurred. Hence the emphasis which has been placed on the avoidance of any filling of low spots in the final trimming of compacted bases, etc.

Frequent references have been made to compaction of the cement treated mixture. It is thought that too much emphasis cannot be placed on this feature of base construction. Early studies showed that the strength of the hardened mixtures was more affected by variations in compaction than by equivalent variations in any other factor A decrease of 5 per cent in the compacted unit weight will usually cause a greater decrease in compressive strength than a decrease of 10 to 15 per cent in the quantity of cement used. Figure 18 shows typical examples of the effect of varying degrees of compaction Field experience has confirmed laboratory studies in all cases and has indicated that the portion of aggregate finer than No 4 mesh should be more than sufficient to fill all the voids between the coarse particles of rock in order that all the fine matrix around the rock particles shall receive the full compacting load

Field control of cement treated base construction involves the following procedures on the part of the resident engineer in addition to the usual construction supervision

1 Checking of the aggregate character and grading, the moisture and cement content of the finished mix
2 Preparation of test specimens from the treated material
3 Determination of the unit compacted dry weight of the completed base or, expressed as a percentage of the required unit weight, its "relative compaction"

The checking of aggregate character and grading, the cement and moisture additions, etc., correspond to similar practices for bituminous mixtures and portland cement concrete and offer no unusual problems.

As a rule at least four test specimens are prepared each day Two are molded from a sample of treated material obtained immediately after mixing and frequently two more from a sample taken from the mix after it has been spread on the road and immediately prior to compaction.

A cumulative average of the daily specimens taken at the plant indicates the compaction possible for the treated mixture and is usually used as the 100 per cent value for the determination of relative compaction. The samples taken from the street, or roadbed, indicate the loss, if any, of possible compaction which has occurred during hauling and spreading, and furnish typical examples of what should be obtained in the finished base.

Several determinations each day of the unit weight actually obtained in the compacted base show the degree to which the contractor is obtaining the desired results and, by comparison with the unit weights of test specimens, give some indication of the probable strength of the hardened base.

In general, California experience has indicated that satisfactory cement treated bases for use under a bituminous wearing course may be constructed from an extremely wide variety of mineral aggregates and with a broad range of cement contents. As a rule, the presence of coarse aggregate tends to produce greater strength for a given cement content due to the increased richness of mixture of fines and cement, but some instances have been noted where fine grained soils with a considerable percentage of clay produced exceptionally high compressive strengths with low cement contents

Moreover, a question exists as to whether the present standards of compressive strength (850 lb at 7 days or 1000 lb at 28 days) are necessary These values have been lowered on occasions to permit the use of materials which would not meet such requirements and so far those bases with lower strength are satisfactory Also, tests on cores cut from some of the finished projects show that certain bases which are giving satisfactory service under heavy traffic have compressive strengths around 400 to 500 lb. per sq in

It is hoped that further light may be shed on actual requirements, both as to quality of finished product and nature of test procedure, by studies now in progress or anticipated.

These projects have been constructed on highways ranging from intermediate to heavy

traffic classification and the attractive features are first, lower initial cost, compared to the older heavy pavements, with ability to carry considerable traffic; second, the possibility of treating otherwise poor aggregate or soil for the secondary or light traffic road, third, comparative freedom from warping and curling with fluctuations in temperature and moisture which means that the cement treated base enjoys the full support of the subgrade at all times.

LABORATORY TEST METHODS AND PROCEDURES

With the inauguration of cement treated base construction in California, the methods of testing recommended by the Portland Cement Association for soil-cement construction

Figure 13. Left, Initial Compaction with ¾-in. rod. Right, Second Stage of Compaction Using 2-in. Tamper. This operation is followed by a compressive load of 2000 lb. per sq. in.

were adopted and used on the first projects. However, in view of the type of coarse granular aggregate commonly treated, it has not appeared necessary to follow the detailed A.S.T M. methods developed primarily for the soil types Frequently the time allotted for testing is insufficient to complete the numerous cycles of the wetting and drying operation and this has encouraged the adoption of testing procedures that can furnish reliable indications in two weeks or less

Present procedure relies almost entirely on the compressive strength test, using the wetting and drying procedure only for the soil types and the freeze-thaw test when materials will be placed at high altitudes subject to low temperatures

Specimens are compacted by hand rodding in a mold 4 inches in diameter; see Figure 13 The mold designed for rapid operation consists of a solid cylinder 8½ in. long with a split innner sleeve recessed to hold a tin liner; see Figures 14 and 15. The 4 in. diameter specimen, 4 in long, is compacted in this tin liner in two equal layers using a small round tamping rod of ¾ in diameter. The tamping is continued until the rod tamps out of the material (Somewhat similar to the action of a

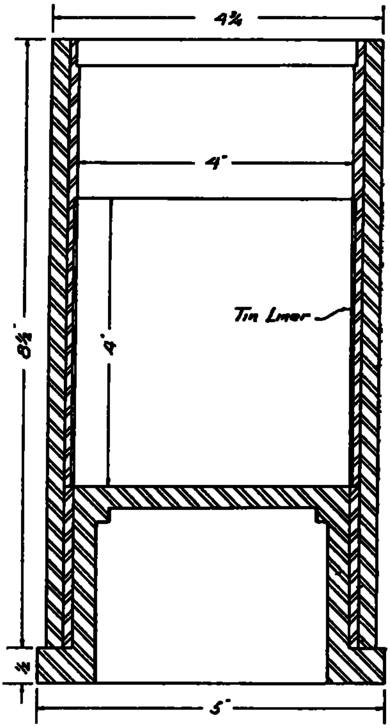

Figure 14. Cross Section of Split Mold

sheepsfoot roller). The surface of the specimen is then smoothed with the large 2-in. diameter tamper and the specimen compressed under 2000 lb. per sq. in between double acting plungers The entire mold, with the tin liner and contained specimen, is then placed in a special appliance (Figure 16) and the specimen removed by ejecting the split inner sleeve, see Figure 17. The specimen is then stored for curing in a moist closet.

On the date specimens are to be broken, the tin liner is removed by opening the soldered joint with a knife and the specimens are placed in water After a minimum of 4 hr in water

the compressive strength is determined in the usual manner. The values reported are for a height diameter ratio of one.

With the granular types of material we have not found any mixtures which failed to pass the wetting and drying test if the compressive strength at 28 days was over 1000 lb. per sq. in.

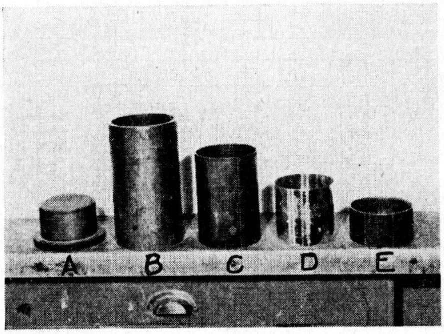

Figure 15. Parts of Mold Assembly. A, Base Plate. B, Outer Cylinder. C, Flexible Split Steel Liner, Recessed to Accommodate Tinned Jacket, D, $\frac{1}{4}$-in. Inside Diameter. E, Section of Split Ring Inserted After Jacket is in Place.

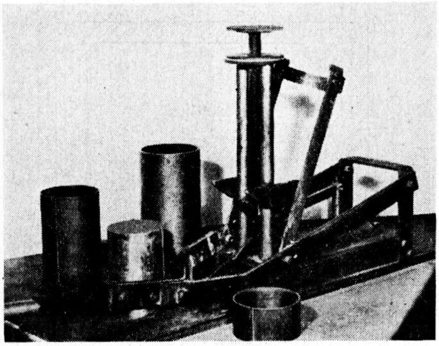

Figure 16. Leverage Apparatus for Stripping Mold

As a matter of interest we have been making compressive strength tests on the specimens after 12 cycles of wetting and drying. A limited number of such tests indicate that compressive strength is a satisfactory index to the effect of alternate wetting and drying and has the advantage of eliminating the personal equation bound to be present in hand brushing; see Figure 19.

An attempt was made further to reduce the time required for preliminary investigation by the use of stabilometer tests at 2 days. These stabilometer tests displayed a general correlation to the 28 days compressive strength but

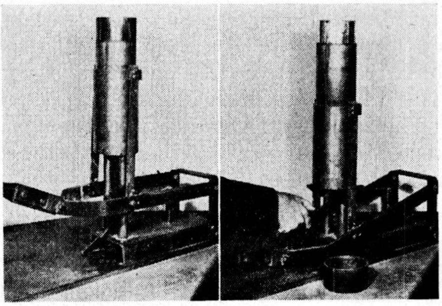

Figure 17. Left, Mold Assembly in Place Showing Outer Sleeve Being Stripped by Hand Lever. Right, Central Column or Pedestal Being Elevated to Lift Compacted Specimen with Tin Jacket Out of Split Mold.

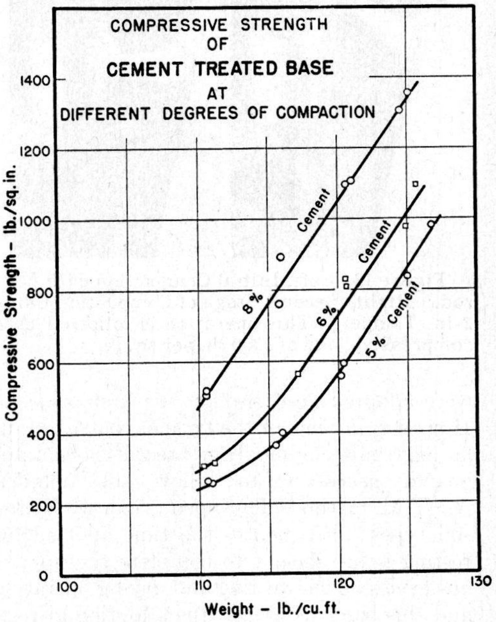

Figure 18. Variations in compressive strength caused by variations in degree of compaction. Samples were made from fine graded granular disintegrated granite. The absolute values shown are typical of this aggregate only and may be higher or lower with other materials.

the correlation was not close enough to warrant using the test for approving or rejecting materials. It is believed, however, that the

method might have value in combination with a development of the surface chemical factors as reported by Winterkorn and Fahrman to provide a rapid quality test.

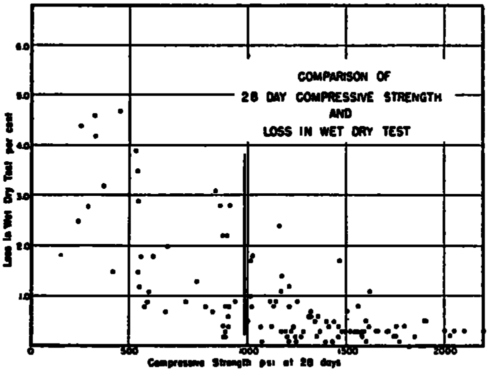

Figure 19. A chart showing comparison between loss by brushing after 12 cycles of alternate wetting and drying compared with the compressive strength at 28 days. It will be noted that wet and dry losses are very low when compressive strength is above 1000 pounds per square inch.

SPECIFICATION REQUIREMENTS

The success of cement-treated bases in California has been found to depend upon adherence to certain specified procedures developed from the extensive field and laboratory experience reported.

The following excerpts from the California specifications and explanatory notes cover the important features peculiar to this type of base.

Materials

Mineral aggregate shall be free from adobe, vegetable matter, and other deleterious substances.

The combined material shall be uniformly graded from coarse to fine and of such size that, when tested on laboratory sieves, the percentage composition by weight shall be as follows unless otherwise specified in the special provisions:

	%
Passing 1-in. sieve	100
Passing ¾-in. sieve	90–100
Passing No 4 sieve	40– 75
Passing No 30 sieve	15– 40
Passing No 200 sieve.	3– 15

The mineral aggregate shall be of such quality that when mixed with portland cement in the minimum amount specified in the special provisions and compacted with optimum moisture content, the compressive strength of the mixture shall be not less than 850 lb. per sq. in. at 7 days or not less than 1000 lb. per sq. in. at 28 days. If required in the special provisions, the cement treated specimens may be tested to determine resistance to alternate cycles of freezing and thawing or of wetting and drying or both

The aggregate gradation given is typical of satisfactory grading and tolerances; however, it is expected that this grading specification will be changed or modified to suit local material.

Proportioning

The mineral aggregate shall be separated into two sizes on the No. 4 sieve and stored in separate bins.

Mineral aggregate and cement shall be proportioned by weight except that when continuous mixers are used the proportioning may be by volume, provided the equipment regulating the rate of feed of the various materials is adjustable and is automatically controlled to furnish a uniform rate of flow of each material corresponding to the required proportions by weight. Cement delivered in sacks will be assumed to weigh 94 lb. per sack Cement shall be added to the base materials in a manner that will cause the cement to be distributed throughout the coarse or fine aggregates and shall not enter the pugmill as a distinct unit separated from the aggregates. Water may be proportioned by weight or volume. Variations in the proportion of any ingredient of more than 2 per cent from the quantity specified shall not be exceeded

The clause relating to procedure for adding cement is intended to require the contractor to arrange the proportioning equipment so that the cement will be discharged into the pugmill simultaneously with the aggregate in order to hasten the distribution of cement throughout the mixture

Mixing

The mineral aggregate, cement, and water shall be mixed in a central mixing plant of the pugmill or revolving spiral blade type, using either a batch or a continuous mixing process. The mixing shall be continued until the cement and water are thoroughly and evenly distrib-

uted throughout the mass and a uniform mixture of unchanging appearance is obtained The minimum mixing time for batch mixers shall be 45 sec. after all materials are in the mixer. For continuous mixers, at least 45 sec. shall elapse from the time material enters the mixer until it leaves

The quantity of water put into the mix shall be adjusted to permit maximum compaction of the treated material on the roadbed

Sufficient mixing capacity shall be provided to permit construction of the individual base strips at a rate of not less than 100 tons per hour.

The requirement relating to mixing capacity is definitely important as it has been found difficult to secure the best results unless construction proceeds at a fairly rapid pace It is necessary that an appreciable length of base be constructed each hour in order to permit effective operation of rolling and finishing equipment

Placing

The base mixture shall be placed by a spreading device in a manner to produce a layer of loose material of uniform density and of the proper thickness to provide a thoroughly compacted base conforming to the lines, grades, and dimensions shown on the plans The material shall not be dumped in piles on the roadbed. Material shall be spread for the full width of the roadbed or lane under construction Tracks or partially compacted areas produced behind the cut-off blade by spreading equipment which rides on the freshly spread material will not be considered objectionable provided no displacement of material or filling of the tracks occurs No equipment producing tracks which cannot be removed by subsequent compaction may be used for spreading

A blade grader shall not be used for spreading the treated base material except when specially authorized

The surface of the subgrade shall be thoroughly moistened immediately prior to placing base mixture thereon and shall be kept moist but not excessively wet until covered by the base material

Depositing and spreading the material on the roadbed shall commence at the point farthest from the point of loading and shall progress continuously without breaks, except as otherwise directed or permitted by the engineer

Whenever full width construction is possible, the treated base material shall be spread for the entire width Should permission be granted for the use of one piece of spreading equipment operating alternately on two lanes of the road, not more than 25 min shall elapse between time of placing on opposite sides of the roadway at any location.

If traffic or other local conditions make part width construction, including compaction and finishing, necessary, a windrow of shoulder material or soil shall be placed and compacted so as to form a choker for the inner edge of the portion under construction. The choker shall be completed in advance of placing the base material and its toe shall be not less than 3 in. outside the finished trimming line of the compacted section of base

Only in rare cases has it been found possible to blade cement treated mixtures after spreading without developing planes or laminations; therefore it is necessary to emphasize the need for making the initial spread smooth and of uniform density so as not to require subsequent shaping or blading prior to compaction.

Compacting

Immediately upon the completion of each portion of the spreading operations, the cement treated base shall be thoroughly compacted by means of a three-wheeled roller weighing not less than 12 tons or by other approved equipment which will produce the required degree of compaction throughout the full depth of the treated base Rollers with wheel diameters small enough to cause the formation of transverse cracks in the partially compacted base shall not be used The compacting equipment shall have sufficient capacity to produce the required degree of compaction within the time limits specified, and at least one roller shall be provided for the first 125 tons, or part thereof, and one additional roller for each 100 tons per hour in excess of 125 tons of treated base constructed per hour

Rolling shall commence on the shoulder, or on compacted material, with not more than 75 per cent of the width of one rear wheel on the uncompacted material and shall proceed without interruption across the area to be compacted until the required degree of compaction is attained Successive trips shall be so spaced that not more than 75 per cent of the width of one rear wheel is on uncompacted material at any time

The surface of uncompacted, partially compacted or completely compacted material shall be kept moist at all times, without moving equipment over uncompacted material

If the surface of the compacted material does not conform to specifications for smoothness, etc , it shall be trimmed by means of a self-propelled blade grader Trimming shall be

done in such manner as to cause the least possible loosening of the compacted base material and to leave no loose material on a compacted surface. No material cut away by the blade shall be recompacted as a part of the cement treated base.

Immediately after trimming, or after compacting, if no trimming is necessary, a pneumatic roller shall be used to complete the surface compaction. Pneumatic-tired rollers may be of either two-axle or one-axle type and the weight per tire shall not be less than 400 lb. Their construction shall be such as to permit loading to a total weight of 2,000 lb. per tire if required and to permit operation both forward and backward without turning on the roadbed. The roller or its towing equipment shall be provided with means for applying a fine spray of water to the base during rolling operations.

The surface of the fully compacted base shall not deviate more than ⅜ in. from any portion of a 10 ft straight edge laid in any direction on the surface.

The compacted dry weight per cubic foot of the treated material in the finished base shall not be less than 95 per cent of that determined as an average of maximum compaction for the materials in use

Heavy three-wheel rollers have proved to be the most satisfactory available equipment but rolling with pneumatic tires definitely improves the surface hardness and density It should be realized that a smooth polished finish on the base is not desirable as it tends to promote slipping of the bituminous wearing surface. The most desirable base finish is of pebbly texture.

Curing

After the base has been finished it shall be covered with a curing seal of asphaltic emulsion, penetration type, applied at the approximate rate of from 0 15 to 0 25 gal per sq yd or in quantities as directed to secure a continuous membrane of asphalt over the surface of the base

The curing seal shall be applied as soon as possible after the completion of finishing operations, and the base shall be kept moist until the seal is applied

No equipment or traffic with a loading per unit area greater than that used for compaction shall be permitted on the finished base during the first seven days of its curing period, nor shall any traffic be permitted thereon that may damage the seal of the asphaltic curing membrane. Where necessary to permit traffic to use the base before the end of the curing period, the seal shall be protected by sanding All such protective material shall be completely removed from the base before the bituminous surfacing is placed.

Several different asphaltic materials, whether cutback or emulsion type, will produce a satisfactory seal, however, emulsions have proved to be the most practicable as they are usually applied in uniform quantities and heating is not required. As the curing seal is applied a little at a time throughout the day, the problem of maintaining cutback asphalt at a suitable application temperature has been found to be troublesome.

There is no evidence of harmful result from opening the base to traffic immediately, provided the curing seal is protected by sand or some means to prevent picking up by tires.

Operation Time

Not more than 30 min shall elapse between the time the base materials are mixed and the time the mixture is spread on the subgrade, nor shall more than 30 min elapse between the time of depositing on the subgrade and the time of starting compaction Not more than one hour shall elapse between the time of starting compaction and the time of completion of finish rolling

Operation time requirements are important and should be rigidly enforced The limits established have been found adequate on many projects

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