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CALIFORNIA MIX DESIGN FOR CEMENT TREATED BASES

By

F. N. Hveem* and E. Zube**

SYNOPSIS

The California Division of Highways has constructed extensive mileage of cement treated bases since 1938. These bases have been used primarily under asphaltic concrete pavements carrying moderate to heavy traffic. Depending upon the traffic intensity, 2" to 5" of asphaltic concrete is placed as a wearing course over these treated bases. The increasing occurrence of pumping and step-offs in PCC pavements as a result of a large increase in truck traffic has led to the construction of so-called cement treated subgrades under all newly placed concrete pavements beginning about 1945. The materials used in the earlier jobs included fine sand, disintegrated granite, sandstones and streambed gravels. During the last few years, more emphasis has been placed on the use of granular materials which has resulted in a decrease in cement content and tends to minimize shrinkage cracks.

In the design of the pavement structure, a reduction in the overall thickness is obtained by virtue of the cohesion or tensile strength of the cement treated base.

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The mix design is based on a compressive strength requirement of 750 pounds per square inch (on a 4" x 4" cylinder) after a seven day curing period. A rapid cement control test for field use to determine the actual percentage of cement in the mixture has been developed.

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INTRODUCTION

Scanty records and hazy recollections do not warrant any definite statement about the time or place when portland cement was first mixed with soil to produce a hardened water resistant support base for highway pavements. Once the process had become established however, at least one engineer was heard to remark that he "could have discovered it years before." He had observed that truck drivers hauling cement over a dirt road would occasionally scatter a few sacks in some of the mud holes in order to get through. These crude mixtures of soil and cement were apparently effective, but he did not take the hint.

According to available information, a cement treated section was constructed in Pennsylvania prior to 1930. Apparently, this project was not publicized, and in fact, appears to have been carried out almost in an atmosphere of secrecy. However, regardless of accidental or scattered

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prior trials, South Carolina deserves the credit for first constructing and reporting successful soil-cement bases. The pioneer work in South Carolina was reported in 1936.

While California had tried mixing portland cement with heavy clay soils as far back as 1921, there was no immediate follow up or attempt to develop the process further. Following the reports from South Carolina, in 1937 California constructed two sections each approximately one mile long using State forces. Additional projects, each some three miles in length, were constructed under contract in 1938 and 1939.

Up to 1940, all work of this type in California employed the road mix method. However, it was often difficult to secure uniform construction both in depth of material treated and in thorough distribution of the cement. Furthermore, road mixing with farm equipment, such as disc and harrow, then generally used, required considerable time and it was common to have a delay of six or eight hours between the introduction of cement and water and final compaction which, of course, had a considerable adverse effect on the compressive strength.

Long experience in mixing asphaltic materials both by road mix and plant mix methods had indicated the superiority of plant mixing so far as speed and uniformity are concerned. It seemed logical that the process of mixing soil and cement

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would likewise be improved. Therefore, beginning in 1939 three projects were initiated requiring the mixing of cement with pit run gravels or granular materials in a central mixing plant.

In view of the fact that the materials we proposed to treat were generally granular and not of the type that an agriculturist would ordinarily class as "soil", it was decided that the term cement treated base was more appropriate. Also, the term "soil stabilization" was being widely appropriated by salesmen or advertising agencies and applied to a variety of treatments which have little or nothing in common. Since that time, all work of this sort in California has been called "Cement Treated Base" regardless of gradation of the soil, mineral aggregate or the method of mixing. Another change from eastern practice is in the method of expressing the cement content. Designating cement contents in terms of volume is sound from a theoretical standpoint, but it is less convenient in practical application. There are many more individuals engaged in construction control and inspection than there are in the laboratories; therefore, we elected to specify the cement content in terms of percentage by weight of the aggregate. By this step, we have a uniform practice for indicating the amount of water in a soil, the amount of asphalt or road oil used in bituminous mixtures and the percentage of cement in cement treated bases,

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all of which are now stated in terms of percentage by weight of the dry aggregate.

Some 30 miles of plant mixed cement treated base had been completed by 1941 and this mileage had increased to over 100 miles by the end of 1943.[1] During this period, laboratory work was under way to determine appropriate test procedures, methods of mixture design, specifications, et cetera. The establishment of test methods must, of course, require some knowledge of the essential properties, and it was taken for granted that cement treated base mixtures should develop some appreciable compressive strength in line with the usual concepts concerning the properties of portland cement concrete. The question of what strengths were appropriate was not so self-evident and was much debated. As in all new developments, ideas are prone to be influenced by the evolutionary steps involved or by the background of the individuals. Those engineers who had long experience or indoctrination in the design and construction of concrete were inclined to favor high strengths for cement treated bases. Therefore, these treated bases were regarded by some as a sort of inferior concrete while a few of us thought of them as an improved aggregate base. The "concrete boys" were inclined to think that anything developing less than 3000 psi must be of dubious quality. On the other hand, tests on specimens of the best crushed stone base aggregates "cemented"

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with natural fines gave only 75 psi, and as these crushed stone bases had proven to have the qualities necessary for supporting heavy loads, there seemed to be no reason for requiring extraordinarily high compressive strengths for cement treated bases.

It was decided to follow the practice established by the Portland Cement Association for the size of specimen (4-in. in diameter and 4-in. in height). However, in order to permit ready compaction in the field and shipping of the specimens to a central laboratory a procedure was developed involving the use of specimen molds in the form of thin metal shells or sleeves which are made to order from tinned sheet. (See attached Test Method No. Calif. 312). By the means adopted, it is possible to compact the test specimens, seal the containers, protect and hold the specimens without loss in moisture until time for testing. The tin sleeves are then opened along the soldered joint and the specimens soaked before testing to determine compressive strengths.

A curing period of seven days was adopted in order to shorten the time of testing. A compressive strength requirement of 850 lb per sq in. in 7 days, and 1000 lb per sq in. at 28 days, was agreed upon. In general, the compressive strength at age of 7 days is about 85% of that obtained at 28 days.

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The next step was to establish a suitable compaction procedure which would simulate the compaction to be expected on the road. It will be noted that the compressive strength increases very rapidly with increased compaction. Cores were taken from finished bases and comparisons were made with laboratory compacted specimens for density and strength. The compaction procedure finally adopted was aimed at reproducing the results found in the core specimens.

It became evident that a rather wide variety of aggregate types and gradations could be successfully treated with cement, and it has been the general practice to write grading specifications which would permit the use of local materials with a minimum of waste or importation of expensive aggregates. However, the gradation of the aggregate can have some effect on the compressive strength.

It became evident that with the granular materials being used, substantial compressive strength values could be developed even with nominal amounts of cement ranging from 4 per cent to 6 per cent of the aggregate. Therefore, as mentioned earlier, the mix design was initially based on a compressive strength requirement of 1000 psi at the age of 28 days. Work was governed by this concept for two or three years. However, a number of engineers began to complain of the transverse shrinkage cracks which appeared in the bituminous surfaces over these bases and a quick survey of all jobs constructed

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seemed to indicate that cracks were more evident and often opened wider over the high strength bases than over the sections where the strengths were low. This led to a revision in our ideas for strength requirements and, as a result, four types of cement treated bases were established as follows:(2)

Class	Compressive Strength at Seven Days	Typical Cement Content (by dry wt of agg)
A	750 psi	3-1/2 to 6%
B	400 psi	2-1/2 to 4-1/2%
C	R-Value = 80+	2 to 3%
D	(A reconstruction method where an existing asphalt treated surfacing is scarified and mixed with an equal amount of existing base or imported gravel. No strength requirement specified.)	4 to 6%

The Portland Cement Association had recommended a test procedure involving alternate cycles of wetting and drying, after which the surface of the specimen is abraded by means of a wire brush. It was judged that this operation was subject to considerable variation, depending upon the individual operator, and after some investigation it was concluded that the same evidence of deterioration could be produced by making compressive strength tests after a series of wet and dry cycles. (See attached Test Method No. Calif. 314). However, we have encountered only a few types of

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material in California where the wet and dry test procedure seemed to be warranted.

A freeze-thaw test, patterned after the wetting and drying method, has also been developed to determine the durability of cement treated base mixtures where intensive frost conditions are anticipated. (See attached Test Method No. Calif. 313.) This test has not had much application in "sunny" California, however, since only a limited mileage in the high mountain regions require consideration of severe winter conditions.

When the cement treated bases were first being considered in California, recommendations from the Portland Cement Association favored the use of only a thin bituminous surface in the form of a seal coat or surface treatment. However, we did not feel that such a surface would be adequate for heavy traffic, and there were reports from other states that failures had occurred because of the slipping or peeling off of the thin surfaces. Observations on one or two of our early projects where the bituminous surfacing was varied from 3/4 inch to 1-1/2 inch in thickness indicated that slippage failures were much more likely to occur with the thin bituminous surface layers. Therefore, about 1940 it was decided that cement treated materials should be regarded only as a base and should be protected by a substantial dense graded asphalt surface course not less

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than three inches in thickness. With a few exceptions, this policy has been maintained, and experience in this state seems to justify the practice of placing an adequate thickness of asphaltic surfacing over these treated bases.

With the completion of an intensive survey and an investigation of portland cement concrete pavements through the years 1944 to 1946, it was concluded that some means must be provided to prevent the loss of support caused by the pumping out of subgrade soil from beneath the concrete slabs. Several means were considered and undoubtedly several expedients would be effective but a cement treated layer 4" thick seemed to be the most economical and it appeared that such a base would resist erosion <u>if protected by a heavy penetration application of cutback asphalt</u>.(3)

The first cement treated subgrade to support a concrete pavement was constructed in 1946 and within the next year or so it became general practice throughout the state. Since 1950, all concrete pavements in California have been placed over treated bases. In a few cases where the underlying soil was a relatively clean cohesionless sand, asphalt treated subgrades were used in lieu of portland cement and for many years it appeared that the performance was about equal. However, it is becoming increasingly apparent that the asphalt treated subgrades are less permanent, but the cement treated subgrades (now called CTB Type B) can be

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considered as being successful in more than 95 per cent of all the projects built. Pumping has been eliminated and faulting at the joints is rarely perceptible as a result of this design, even though dowels or load transfer devices are not used. When used to prevent pumping and erosion of the subgrade support, cement treated bases were usually constructed after the side forms were in place, the mixing being done by traveling mixing machines.

This extended use of road mixing for the cement treated bases under concrete pavements led the construction forces to believe that road mixing would be more economical and equally satisfactory for the heavier bases required to support an asphalt pavement. With the passage of a few more years it became increasingly evident, however, that there were more failures and more evidence of generally poor results. An investigation led to the recommendation that the road mixing process be abandoned for all heavy duty main line highways and that its use should be confined to lightly traveled roads or to the relatively thin treatment employed beneath concrete pavements. It also became evident that there was more evidence of distress in the Class C bases using the very low cement contents. Furthermore, the thin bases ranging from 5-in. to 6-in. have not given a satisfactory performance in many cases, and today it is standard practice for heavy traffic roads to construct cement treated bases no less

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than 8-in. in thickness to be covered with at least 3-in. or 4-in. of dense graded asphaltic concrete.

In effect then, we have a composite pavement in which the general behavior and characteristics are very similar to the pavements constructed 50 to 60 years ago in which an asphalt wearing surface was supported by a lean concrete base. It may be pointed out, however, that for a given aggregate and cement content, a cement treated base is superior to and more efficient than plastic concrete. The water-cement ratio law is still in force and these relatively dry mixtures rolled and compacted with heavy equipment are stronger than if enough water were added to permit placing as conventional concrete.

CEMENT TREATED BASE MIX DESIGN METHOD

The design of Classes A and B cement treated base (CTB) mixtures largely involves determining, by laboratory tests, the amount of cement and water necessary to meet the minimum 7 day compressive strength requirements with a given source of aggregates. California specifications require that aggregate for cement treatment must have a sand equivalent of not less than 25 and conform to the following requirements unless special gradings are provided in the Special Provisions for the particular project.

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Sieve Size	Per Cent Passing
1"	100
3/4"	90-100
No. 4	35-55
No. 30	10-30
No. 200	3-9

The above grading is identical to our Class 2 Aggregate Base. It should be pointed out, however, that cement treated bases have been constructed in California using a wide variety of aggregate gradings, particularly when local deposits are utilized.

Optimum Moisture Determination. The first step in the laboratory testing involves the determination of the optimum moisture at which maximum density and consequently the highest compressive strength will occur. Briefly, the procedure consists of fabricating three 4" dia x 4" high test specimens containing different percentages of moisture but the same amount of cement, typically 3 or 4% (the exact amount of cement is not important to this phase of the test). The mixtures of cement, aggregate and water are hand rodded (mechanical kneading compaction can be used an an alternative) into molds containing tin sleeves and then loaded in a press (or hydraulic jack in frame), for a period of 2-1/2 minutes, to 25,000 lbs or about 2000 lb per sq in. During the process of static loading, notation is made of any moisture squeezed out of the specimen. The amount of such moisture loss is determined by weighing immediately before

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and after application of the static load. The amount of moisture added to the mixtures, during the fabrication process, is set high enough so that some moisture will be exuded from at least two of the three specimens. One of the specimens should be prepared at the point of saturation which is normally considered to be attained when 1 to 6 grams of water are squeezed from the specimen. The other two should be slightly above and below (this is usually plus and minus 1 or 2% moisture) saturation respectively. The optimum moisture and density are calculated from the saturated specimen which exuded the 1 to 6 grams of water. All three specimens are then cured and tested for 7 day compressive strength for supplemental information. While the optimum moisture determination is necessary to the second phase of the laboratory test, it is also reported for ultimate use in field construction control. In this case the moisture content is usually expressed as a range which extends from the point of saturation to approximately 1% below this point. The test data (including compressive strength) from the specimens fabricated above and below the saturation serve as a guide in establishing this range.

At this point it might be well to digress for a moment and discuss the background which forms the basis for our mode of optimum moisture control of CTB's. In the original field studies, it was found that the optimum moisture condition

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which produced the highest density and strength under normal construction compaction, occurred most frequently when a small excess of moisture was present in the mixture. On the basis of this observation we developed the compaction procedure for laboratory specimens which indicated a reasonable correlation of physical properties between field cores and specimens fabricated at the saturation point. It is often found in the laboratory that continued increases in the moisture at compaction, beyond the saturation point of the specimens, will result in further increases in density and resulting higher strength. Our experience indicates, however, that these higher laboratory values are usually excessive, in relation to the physical properties actually attained under normal field compaction, if "over-saturation" of the material occurs during construction.

This concept is illustrated in Figure 1, with test data from an actual project constructed in Santa Barbara county. During construction numerous "street" specimens were fabricated by laboratory methods using freshly mixed CTB sampled from the grade. It is noted from the charts that both the densities and compressive strengths of the laboratory compacted street specimens (shown as solid lines) continue to increase in magnitude, even when the moisture content of the material is so high that 40 or 50 grams of water are squeezed out during fabrication. About one year

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after construction, a number of 4-inch diameter CTB cores were cut from the road at specific locations where the moisture condition of the material at time of construction was known. The density and compressive strength data from the cores are plotted on the charts (in Figure 1) against the amount of moisture squeezed from street samples previously obtained at the same respective road locations where the cores were taken. While there is a scattering of core data, due to the influence of factors other than moisture (e.g., cement distribution, variations in construction compaction, etc.), it is still possible to define the trend by plotting an average of the values obtained (shown as dashed lines in Figure 1). It is noted that contrary to the laboratory tests, the highest density and strength is attained in the road when the moisture level is in the area where saturation of the compacted material just occurs (normally occurring when 1 to 6 grams of moisture are squeezed out of fabricated specimens) and that "over saturation" causes a corresponding reduction in these properties when the water cannot be "squeezed out".

An explanation of this paradox lies primarily in behavior of CTB materials under "static" load conditions in the laboratory process as compared to what usually happens in construction compaction. When a moisture content above saturation is encountered, the laboratory method causes

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the excess water to be permanently removed from the specimen. Any resulting higher density (as compared to a saturated condition) is presumably due to the added lubrication provided by the excess moisture and the fact that the volume of the void spaces in the specimen are reduced during the 2-1/2 minute static compaction period in proportion to the amount of the moisture squeezed out. However, in the case of construction compaction on the road, the surplus moisture generally remains in the material for two reasons. First the application and release of load, by the passage of a compactor wheel (or roller) at any given point on the CTB, is almost instantaneous and does not normally allow sufficient time for the movement of the water through the pore spaces and out of the material. Secondly, the compacted underlying subbase or basement soil, which is usually fairly impermeable, forms a highly resistant barrier to the complete escape of the excess moisture. The moisture retention in the CTB layer not only affects the density of the material but causes a higher water-cement ratio (and a corresponding lowering in strength) than if the water could escape as it does in test specimen fabrication. In the final analysis, the optimum moisture-density relationship, determined from the test at the point of saturation is most nearly related to the behavior of the same material when subjected to the proper

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construction compaction and does not necessarily relate to the absolute maximum compaction that is possible to attain in the laboratory test.

Compressive Strength Determination. The next step in the mix design concerns the fabrication of a test series for compressive strength determinations. Again, three or more specimens are prepared but in this case, the moisture content is held constant at the optimum moisture level determined from the previous test series. Each specimen is fabricated at a different cement content which is normally arranged in approximately 1 or 2% increments to cover the anticipated range for the class of cement treatment under consideration. The specimens are molded and compacted, in the same manner as previously described for the optimum moisture series, and then subjected to a curing period. This is accomplished by either storing in a moist cabinet or sealing the specimens by taping metal covers on the ends of the tin sleeves. After curing in this manner for 6 days, the sleeves are removed and the specimens are submerged in water for one more day. At the conclusion of the 7 day curing, the specimens are capped with plaster of Paris and tested for ultimate compressive strength in a testing machine. Interpolation of the compressive strength data thus obtained, is used to determine the amount of cement required to meet the specified strength under optimum moisture conditions. Recommendations of cement

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content for field application usually include an additional 1/2% cement in order to cover the normal variation of cement distribution in the mixture which is characteristic of field mixing operations. This provides some assurance that most of the mixture will contain at least the minimum amount of cement required by the design; if the construction operations are carried out properly.

Effect of Grading. As mentioned earlier satisfactory cement treated bases have been constructed using many types of gradings. Materials uniformly graded from coarse to fine require less cement; whereas, materials lacking either in coarse aggregate or fines require higher cement contents to meet equal specification requirements. Figures 2a & b and 3a & b show the relation between % passing the #4 sieve and compressive strength. Figures 3a & b show that there is a small increase in compressive strength if the aggregate is crushed.

Ratio of Per Cent Passing 200 Mesh Sieve to Per Cent Passing 30 Mesh Sieve. In order to obtain an indication of the compressive strength from sieve analysis only, of sands or sandy soils, work was performed some years ago by varying the relationship between the amount of materials passing the No. 30 and No. 200 mesh sieves and some interesting data was obtained.

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Recognizing that this class of material develops the most trouble in terms of compressive strength and field compaction, when relatively low cement contents are used, we conducted a series of tests using a fixed cement content of 3 per cent and varying the ratio of the passing No. 30 and No. 200 sieves on various sandy materials by means of adding a filler.

Figures 4 and 5 and Table A indicate that in order to obtain compressive strengths ranging from 200 to 400 psi on the normal sandy material using 3.0 per cent cement, the ratio of material passing the No. 200 to % passing No. 30 sieve should not be less than 15 per cent and possibly not more than 40 per cent. It will also be noted that the density or wt per cu ft of the compacted material should range from 120 to approximately 130 lb per cu ft.

These experimental combinations were tested to provide some indication of the compressive strength that could be assumed from an inspection of the sieve analysis. Due to the necessity of employing blending operations to obtain the proper ratio it may not, in many cases, be practicable in actual construction practice to vary or adjust the proportion of fine material. It appears, however, that these relationships may be useful to field engineers in trying to determine reasons for any sudden reduction in strength.

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Effect of Clay Balls. On one project encountered some years ago hardened clay balls were present among the coarse aggregate. To determine the effect on the compressive strength a series of tests were performed in which the percentage of hard balls of clayey material was varied. Figure 6 shows the results obtained. A 10% addition of clay balls to the sound aggregate reduced the strength about 25%.

Compaction and Curing. Figure 7 shows the effect of delay in compacting the materials on the road and the resulting reduction in compressive strength for two different materials. To guard against this our Standard Specifications specify that "not more than 2 hours shall elapse between the time water is added to the aggregate and cement, and the time of completion of final compaction after trimming". Figures 8a & b and 9 show the relationship between density of the specimens and the compressive strength. Figure 10 shows the effect of moisture on the density of cement treated specimens.

In connection with the USBPR Record Sampling Program, we have obtained field compaction densities on 261 cores from 19 different projects and compared the field densities to laboratory compacted specimens. Our specifications require that the CTB material shall be compacted to at least 95% of the laboratory compacted specimen. The Ogive curve, Fig. 11 indicates that 40% of the cores showed

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compaction between 95 and 100% of the laboratory compaction. 50% showed in excess of 100% laboratory compaction. 10% were compacted to less than 95%. However, only 1-1/2% were compacted to less than 90% and none to less than 86% of relative compaction.

Figure 12 indicates the gain in strength with increasing curing time (after compaction) for two different materials, a well graded (from coarse to fine) aggregate and a sandy material. As a rule clean sandy materials are not too well suited for cement treatment as they require a relatively high cement content to bind the individual sand grains together. A blend of a fine filler material to reduce the size of the voids will reduce the required cement content markedly.

Figures 13a, b & c and 14a & b show the increase in compressive strength with curing time for miscellaneous aggregates and soil types when treated with 3, 4, 5, 6 and 8% of cement. Well graded gravelly materials when treated with the higher cement content develop strengths comparable to weak concrete. All material show a gain in strength with adequate curing.

Figure 15 shows the effect of curing temperature for two different aggregates. The higher temperatures expedite the gain in strength as is well known from concrete experience. Therefore, it is well to note that a cement treated

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base constructed during the warm summer months will have no difficulty in obtaining the specification requirement in 7 days. However, with the same aggregate and amount of cement, but with construction in the late fall or at higher altitudes where air temperatures are low, strength will develop slowly and if subjected to heavy construction traffic, cracks may develop and thus greatly reduce the anticipated slab strength.

Effect of Additives. A few years ago a short research project was conducted for the purpose of determining the effect of some commercial additives upon the compressive strength of cement treated aggregates. Figure 16 shows the results obtained. The effect on the silty and sandy silt materials was not very pronounced. Some noteworthy variations, however, were apparent in the sand-gravel material.

Some years ago the addition of asphaltic emulsion to cement treated aggregates was proposed. One reason being that some of our Class D CTB in which an old asphaltic surface was pulverized and mixed with the untreated underlying base material and cement treated, had shown excellent service records. Figures 17a, b & c show the results obtained after various methods of curing. Although the addition of emulsion seems to be slightly beneficial on some materials subjected to special curing periods, the additional handling

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of another material and the more complicated construction operations are factors that increase cost and may add to construction difficulties. The benefits of admixture with asphalt are not necessarily reflected by strength tests.

Cement Treated Bases Subject to Sulfate Exposure. Up to the present time, the destructive action of sulfates on cement treated bases (CTB) has not been encountered frequently enough to be considered a serious problem in California highway construction. While there are some localized areas in our central valleys and interior desert regions which abound with "alkali soils" (primarily containing minerals in the form of sodium and magnesium sulfate), these localities are generally isolated geographically and are, for the most part, traversed by roads which carry only light to medium traffic. As a consequence only a few CTB projects have been constructed in areas where the base would be subjected to the most severe alkali attack.

However, some of these CTB projects have shown evidence of distress as a result of alkali attack. Thorough field investigations along with laboratory experiments have resulted in the determination of several important criteria which serve as "guidelines" for constructing more highly sulfate resistant CTB's in the future.

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First, it is most important to use a well graded coarse granular aggregate for cement treatment. Fine grained CTB's are fundamentally more susceptible to alkali attack. Secondly, Class A cement treated bases should be used and it is preferable to increase the cement content at least 1% above that required in normal mix design. Sulfate resistance increases rapidly with higher cement contents. Thirdly, a Type II or Type V cement if readily available, should be used. However, experience indicates that this measure is not nearly as effective in CTB as it is in portland cement concrete for minimizing sulfate attack. Finally, construction compaction should be undertaken to provide the densest mixture possible in order to minimize water permeability. Also, care must be exercised during construction not to create drainage conditions which would promote the leaching of alkalis from surrounding soils with the consequent concentration in the structural section.

Curing Seal of CTB. The present California Standard Specifications specify that the curing seal be applied as soon as possible, but not later than 8 hours after the completion of final rolling. The curing seal shall consist of MC-2 (now MC-250) and be applied at a rate between 0.15 and 0.25 gallon per sq yd of surface.

Our previous specifications permitted the use of asphaltic emulsion either penetration or mixing type. From

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the construction standpoint it appears that asphaltic emulsion is preferable as it can be applied cold and applied at frequent intervals whenever a certain stretch of road has been compacted. The MC-2 on the other hand, has to be heated for proper spray application and this can occasionally present a problem. The advantage of the MC-2, however, is that some penetration into the CTB occurs, without softening of the top crust. The emulsion as a rule, does not penetrate into the compacted CTB and more or less covers the surface as a sheet, Fig. 18. If traffic has to be carried through the job or construction equipment is permitted to travel on the cement treated base, very often the emulsion layer will stick to the rubber tires and peel off. This usually is not the case with an MC-2 curing seal. In case of the emulsion it may be necessary to apply a light sand cover to protect the curing seal. All loose sand, of course, should be removed before any surfacing is placed.

In the case of portland cement concrete pavements, any layer of asphalt placed on the cement treated subgrade and then covered with a concrete pavement has a strong tendency to adhere tenaciously to the underside of the superimposed concrete slabs. When this happens the asphalt film will be pulled upward and leave the cement-treated subgrade without protection when the concrete slabs curl upward at the ends as invariably occurs at some season of the year or at some time of the day.

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Laboratory trials indicated that cutbacks would penetrate the average cement-treated subgrade layer to depths ranging from 1/4 in. to 1/2 in. and, therefore, even though a superficial layer of asphalt adheres to the concrete, it is expected that there will be a sufficient amount of impregnation in the cement-treated subgrade to resist erosion when water is churned back and forth by the pumping action of the slab ends.

A RAPID CEMENT CONTROL TEST FOR CEMENT TREATED BASES

There has long been a need for a rapid field test which can be used to determine cement distribution in cement treated bases during the course of construction. The trend in California toward using higher quality aggregate thereby lowering the cement content, as well as the use of road mixing methods, made it imperative that such a test be developed. Such things as the uniformity of materials in the windrow, uniformity of cement spread in advance of mixing, poor mixing due to high speeds of the mixer, size of windrow in relation to the capacity of the mixer, as well as the mechanical condition of the mixer itself can all profoundly influence the uniformity of cement distribution and thereby the uniformity of strength in the cement treated base. While central mixing plants are not subject to as many variables as road mixing, serious variations in cement distribution of the

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final mixture can occur from malfunctioning or poorly equipped plants.

The California Division of Highways laboratory has in the past investigated several test methods, such as: Chemical Analysis, Compressive Strength and Electrical Conductivity measurements. For various reasons these test methods did not prove satisfactory for field control.(4) A method originally developed in England was, after considerable modifications and refinements, adopted. It is based on chemical titration methods, (see attached Test Method No. Calif. 338).

Two different titration procedures are available and the selection of the particular procedure, for use on a given project, is dependent on the nature of the aggregates encountered. The first procedure is called the "Acid-base Method" and is used where the aggregates do not react with hydrochloric acid. In cases where aggregates which react with this acid, are encountered, the second procedure called the "Constant Neutralization Method" is used.

Briefly, the Acid-base Method consists of placing a 300 gram sample of treated aggregates (which can contain up to 1-1/2" size coarse aggregates) in a plastic container and introducing a measured quantity of 3N hydrochloric acid. This is followed by a standardized stirring procedure, during which the acid neutralizes the cement, contained in the

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sample, and causes a proportional reduction in the acidity or Ph of the total solution. This reduction in acidity is determined by withdrawing a measured portion of the liquid from the plastic container, adding a few drops of phenolphthalein indicator solution to the withdrawn portion and titrating it with sodium hydroxide (NaOH). The amount of NaOH, in milliliters, required to neutralize the residual acid is inversely proportional to the cement content of the sample.

The acid-base test is comparatively simple and results can be obtained on groups of eight samples in about 45 minutes, excluding sampling and preparation time.

The constant neutralization method is used where the CTB aggregates contain significant amounts of such substances as limestone, calcite or dolomite and can be performed on a maximum number of four 300-gram test specimens at one time. The specimens are placed in a plastic container to which 250 milliliters of water and a small quantity of phenolphthalein solution are added. The solution will immediately turn pink due to the release of hydration products from the cement. Then using a burette containing 3N hydrochloric acid the operator continuously adds acid and stirs the mixture to maintain a colorless solution for one hour. The amount of hydrochloric acid used in this process is determined from volume measurements with a burette or by weight.

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Experience has shown that the amount of acid used is directly proportional to the cement content of the treated base sample.

This method is based on the principle that the rates of hydrolysis producing hydroxyl ion (OH^-) are greatly different for cement and limestone. The hydrolysis of limestone is very slow compared to that of cement. The aggregate size of the limestone as compared to the particle size of the cement also retards the observed rate of hydrolysis of limestone.

The application of either of these procedures, in the field during construction operations, is relatively simple. At the beginning of the testing operations on the project the operator must first establish a standard curve by testing specimens fabricated to known cement contents with the cement, aggregate and water to be used on the job. This standard curve then provides the reference for calculating the cement content from test data on field treated samples. Incidentally, the same test procedures can also be used without alteration, for determining the percentage of lime in bases which have been treated with commercial hydrated calcium lime.

The titration test has proven to be a very effective construction control "tool". California Standard Specifications now limit the variation from the planned cement content to a maximum of $\pm 0.6\%$ cement (by dry weight of aggregate) for road mixing and $\pm 0.4\%$ cement for plant mix

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operations. This in combination with the fact that up to 32 samples can be tested on the project in an 8 hour day, by one operator, provides the engineer with an enforceable "on the spot" means of finding and correcting deficiencies as they happen. The arrangement of the testing equipment in a convenient and compact kit form, as shown in Figure 19, further enhances the usefulness of the methods for field application.

There are many ways in which the titration may be utilized by the engineer to disclose sources of poor cement distribution during CTB operations. The use of various sampling techniques in combination with thorough and detailed knowledge of particular construction processes, often makes it possible to isolate and correct the offending element. The three actual CTB projects, briefly described below, demonstrate the typical role played by the titration test in the control of CTB production.

Figure 20 displays an example involving a batch type plant mix operation. When nonuniformity was encountered during sampling of successive batches, it was found that the cement weighing scale was out of calibration. After corrective measures a vast improvement in cement distribution was noted as shown by the curve labeled "after" in Fig. 20.

Figure 21 shows results from a continuous mix type plant operation in which samples taken at approximately

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30 second intervals indicated fluctuations in cement content from a high of about 5% to a low of 2.5% cement. After installation of a larger diameter screw in the conveyor this problem was solved.

A particular road mixing operation is illustrated in Fig. 22. While the planned cement content was 3.0% test results on samples taken transversely across the "spread out" material indicated a high of 6% and a low of 1.5%. Although the contractor was permitted to try several corrective measures, it soon became apparent that this particular piece of equipment was unsuitable. When another machine was subsequently used, the cement distribution became satisfactory as indicated by Curve Y. We feel that the use of the titration tests has helped enormously to secure cement treated bases of consistently uniform quality.

CALIFORNIA METHOD OF REDUCING THICKNESS OF UNTREATED BASE BY USING CEMENT TREATED BASE

In the California Method for determing the design thickness for flexible and composite type pavements, the cohesion or tensile strength of the various layers making up the structural section, is evaluated. The design values are established from a large number of cohesiometer tests, correlation with test track data and correlation with experience on our own highways.

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The following design cohesiometer values are presently used:

Asphaltic Concrete	400
CTB Class A	1500
CTB Class B	750
Road mixed surfacing	150
Soils, aggregate bases and Class C CTB	100

From original test track studies it was found that the thickness of cover is proportional to $\frac{1}{\sqrt[5]{coh}}$ or $\frac{1}{coh^{.2}}$

It is very often convenient to express the total thickness of cover required in terms of gravel equivalent. The gravel equivalent, as the name implies, is the thickness of gravel (sand, crushed stone or other granular material) required to protect the underlying material from a given load, and is based on an assumed cohesion value of 100 for the granular cover material.

Through our design relationships and cohesiometer values, the unit thickness of CTB[5] may be determined and expressed in terms of equivalent thickness of gravel (or other granular material).

Therefore, the equation for unit "gravel equivalent" may be derived as follows:

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Let Tg = Thickness of gravel

Cg = Cohesiometer value of gravel

Tx = Thickness of other material

Cx = Cohesiometer value of other material

Then

$$\frac{Tg}{Tx} = \frac{\sqrt[5]{Cg}^{\,1}}{\sqrt[5]{Cx}^{\,1}} = \frac{\sqrt[5]{Cx}}{\sqrt[5]{Cg}} = \sqrt[5]{\frac{Cx}{Cg}}$$

If Tx = 1" and Cg = 100 (Cohesiometer for untreated soils or gravel)

Then $Tg = \sqrt[5]{\frac{Cx}{100}}$

Application of this equation to cement treated base (CTB) and asphaltic concrete (AC) (for comparison), gives the following unit gravel equivalents:

(1) Class A CTB

$Tg = \sqrt[5]{\frac{1500}{100}} = 1.72$ inches of gravel per inch of CTB

(2) Class B CTB = 1.50 inches per inch

(3) Asphaltic concrete = 1.32 inches per inch

A reduction in base thickness, from that required for uncemented aggregate bases, is therefore, made when Class A or B CTB is used.

1. Class A CTB reduces the thickness of untreated base by 42%.
2. Class B CTB reduces the thickness of untreated base by 33%.

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subject to sulfate exposure, a rapid field test method for determining the percentage of cement in a mixture and the California method of utilizing the slab strength of cement treated bases, thereby reducing the total thickness of the structural thickness are also discussed.

The California Division of Highways has constructed, during the last 25 years, many thousands of miles of cement treated bases utilizing local inexpensive aggregates whenever possible. Some of these early roadways are still in good condition and carry traffic far in excess of what was expected of them. Distress has developed in some of the bases primarily from poor distribution of cement and inadequate compaction during construction. Nevertheless the overall excellent performance of the cement treated bases under bituminous pavements as well as under portland cement concrete pavements has materially minimized pavement failures and reduced maintenance costs of the California State Highway System.

ACKNOWLEDGMENT

The writers wish to acknowledge the assistance given by Mr. Daniel Howe and Mr. Masayuki Hatano in preparing this report and collecting the data presented.

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It should be pointed out, however, that if the reduction in thickness from an untreated base layer results in a CTB thickness of less than 6", it is advisable from the construction standpoint and due to variations encountered in the construction of any base, that the CTB layer be built at least 6" thick, and preferably not less than 8" when used under asphalt concrete surfacing. We found on our own test track that cement treated bases less than 5" in thickness over a saturated subgrade are subject to early breakup if exposed to even a comparatively small number of truck repetitions.

SUMMARY

The California design method for cement treated bases and the primary functions of these bases in the construction of both asphalt concrete and portland cement concrete pavements is presented. The method is based on the seven day compressive strength of laboratory fabricated specimens. Some historical background dealing with this type of construction is included. Various factors which influence the desired strength such as grading, optimum moisture content, compaction, density and curing of the compacted base are discussed and illustrated with charts. In addition, related subjects such as effect of curing temperatures, clay balls in the mixture, effect of additives, cement treated bases

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TABLE A

Effect on the Compressive Strength, Density and % Voids of Compacted Cement Treated Material When the Ratio of the % Passing the 200 Mesh Sieve to the % Passing the No. 30 Sieve is Increased by the Addition of Fine Blending Material.

Sample No.	Type Material Tested	% Blending Material Used	% Passing No. 30 Sieve	% Passing No. 200 Sieve	Ratio No. 200 to No. 30	Compr Str Lbs/sq in 3% cement	Lbs/cu ft Compacted	% Voids	Curing Period
CT 2288	Sandy Gravel	None	38	1	3	65	116.5	29.5	7 day
	from Gravel Bar	5	41	6	15	150	120.2	27.3	"
	Feather River	10	44	11	25	220	124.0	24.9	"
	Dist. III	16	48	16	34	325	129.3	21.7	"
CT 2508	Sandy Soil	None	46	3	6	145	116.2	30.9	"
	from SD Co.	5	49	8	16	240	120.7	28.3	"
	Dist. XI	10	51	12	24	325	124.1	26.2	"
		17	55	19	35	475	129.8	22.9	"
CT 2525	Sandy Soil	None	80	4	5	235	115.5	32.9	"
	from SD Co.	8	82	12	14	315	120.1	30.0	"
	Dist. XI	18	84	21	25	340	122.7	28.5	"
		28	86	30	35	385	124.7	27.3	"
CT 2733	Sandy Soil	None	97	9	9	95	112.3	35.2	"
	Borrow Pit	6	97	14	14	165	115.4	33.4	"
	Austin Rd. and	17	97	24	25	230	119.2	30.7	"
	Rt. 66 Dist. X	29	98	34	35	270	121.3	29.2	"
CT 2757	Sand	None	44	2	5	55	115.7	30.2	"
	Reliance Pit	5	47	7	15	185	122.5	26.1	"
	Dist. XI	11	50	12.5	25	270	126.9	23.5	"
		18	54	19	35	380	130.7	21.5	"
CT 3176	Sandy Soil	None	92	9	10	175	115.8	30.9	"
	United Pipe	6	92	13.5	15	225	118.7	29.2	"
	Pit No. 2	16	93	23	25	295	121.8	27.4	"
	Dist. X	27	94	33	35	380	125.0	25.5	"
CT 3297	Sandy Soil	None	42	3	7	110	114.8	31.5	"
	Jenkins Pit	4	45	7	15	190	118.1	29.6	"
	Dist. VI	10	48	13	27	295	123.7	26.2	"
		16	51	18	35	400	127.2	24.1	"

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2. Standard Specifications, State of California, January, 1960

3. F. N. Hveem "Construction Practices on Cement-Treated Subgrades for Concrete Pavements". Bulletin 265 (1960) Highway Research Board, Washington, D.C.

4. Daniel R. Howe. "A Rapid Cement Control Test for Cement Treated Bases". Presented at Third Annual Highway Conference, College of Pacific, Stockton, California, March 1-3, 1960.

5. "Soil Stabilization with Portland Cement". Highway Research Board Bulletin 292.

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FIGURE 1

COMPARISON OF FABRICATED STREET CTB SPECIMENS WITH CORES TAKEN FROM THE ROAD ON THE BASIS OF THE DEGREE OF SATURATION OF CTB MATERIAL DURING CONSTRUCTION

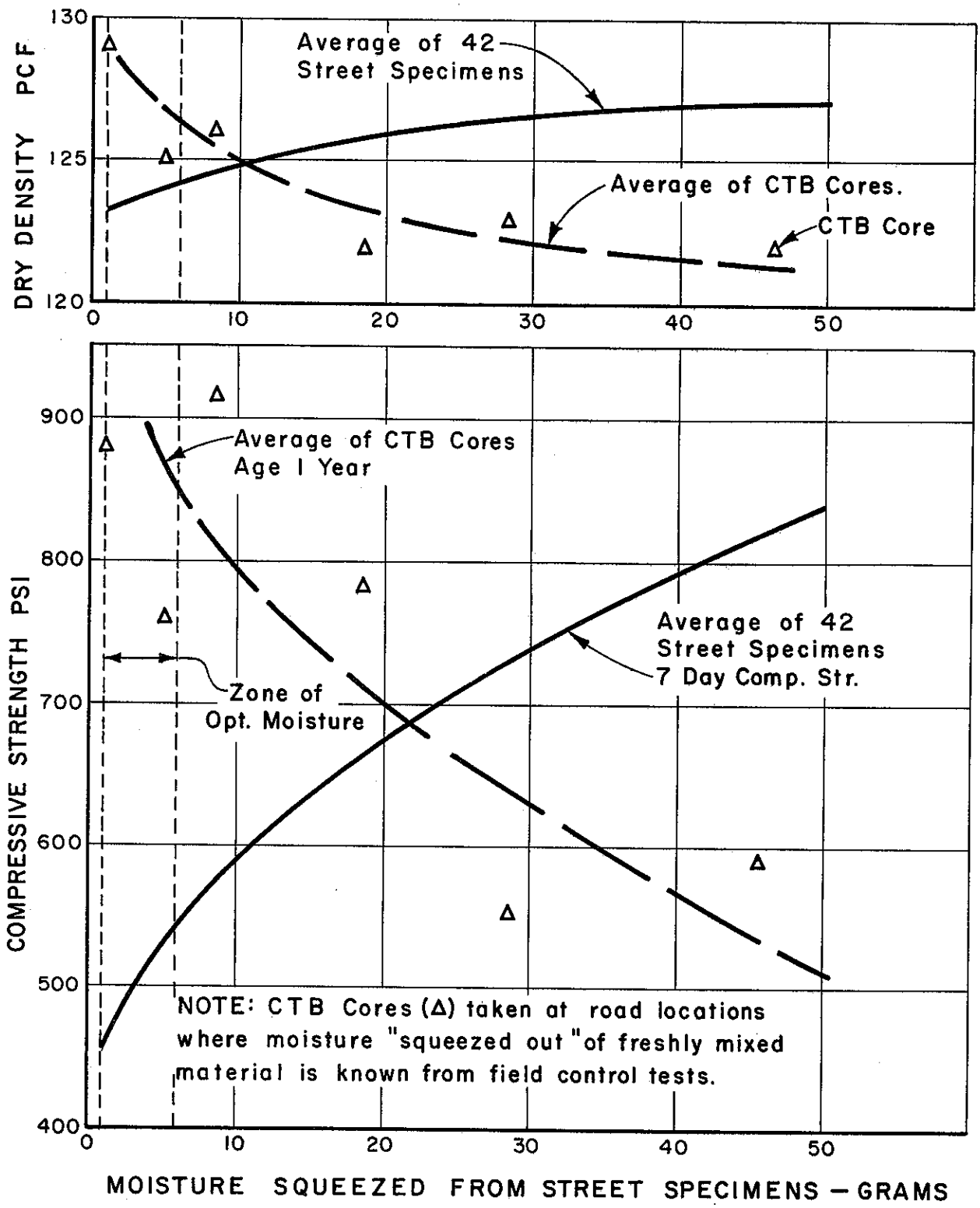

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FIGURE 2

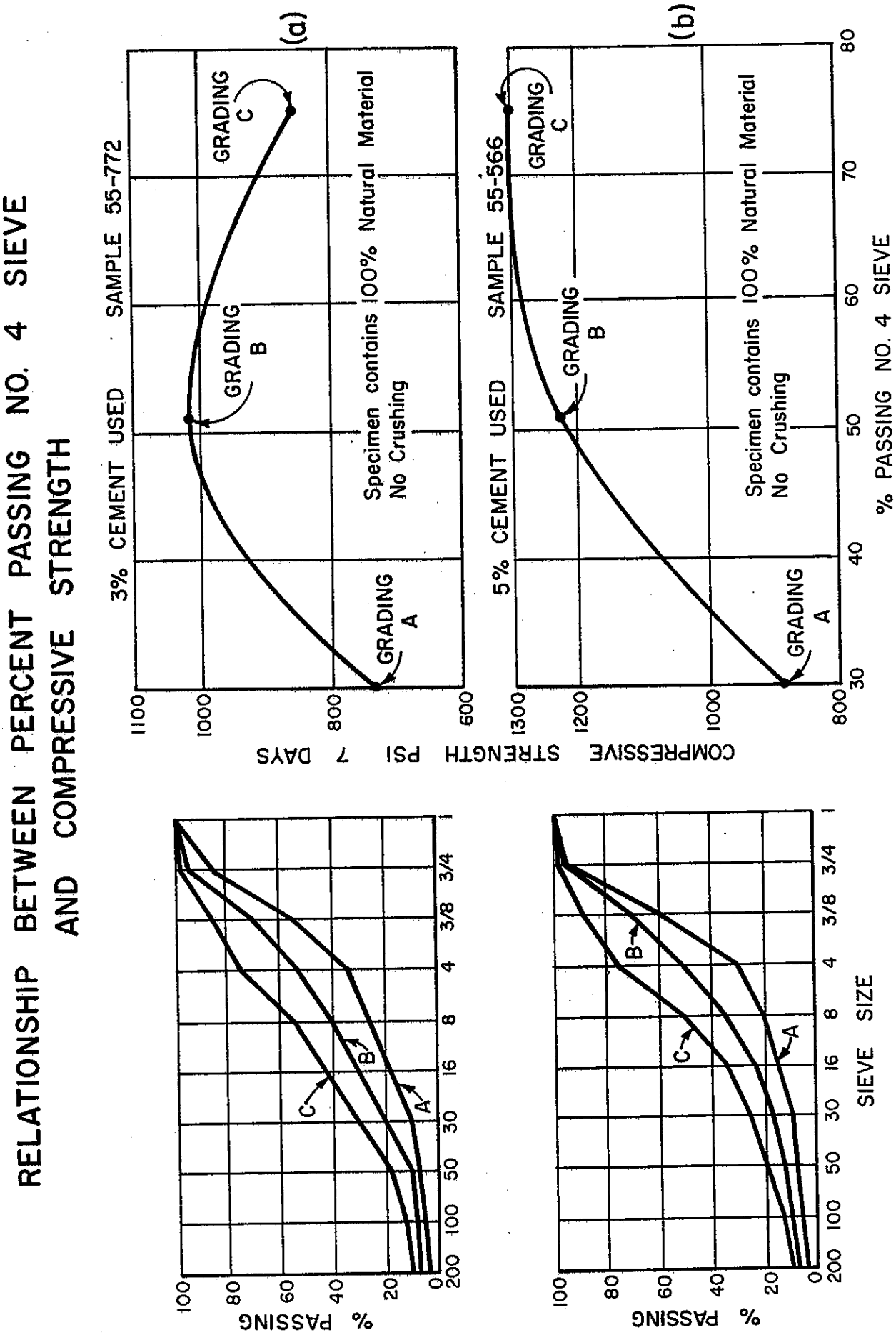

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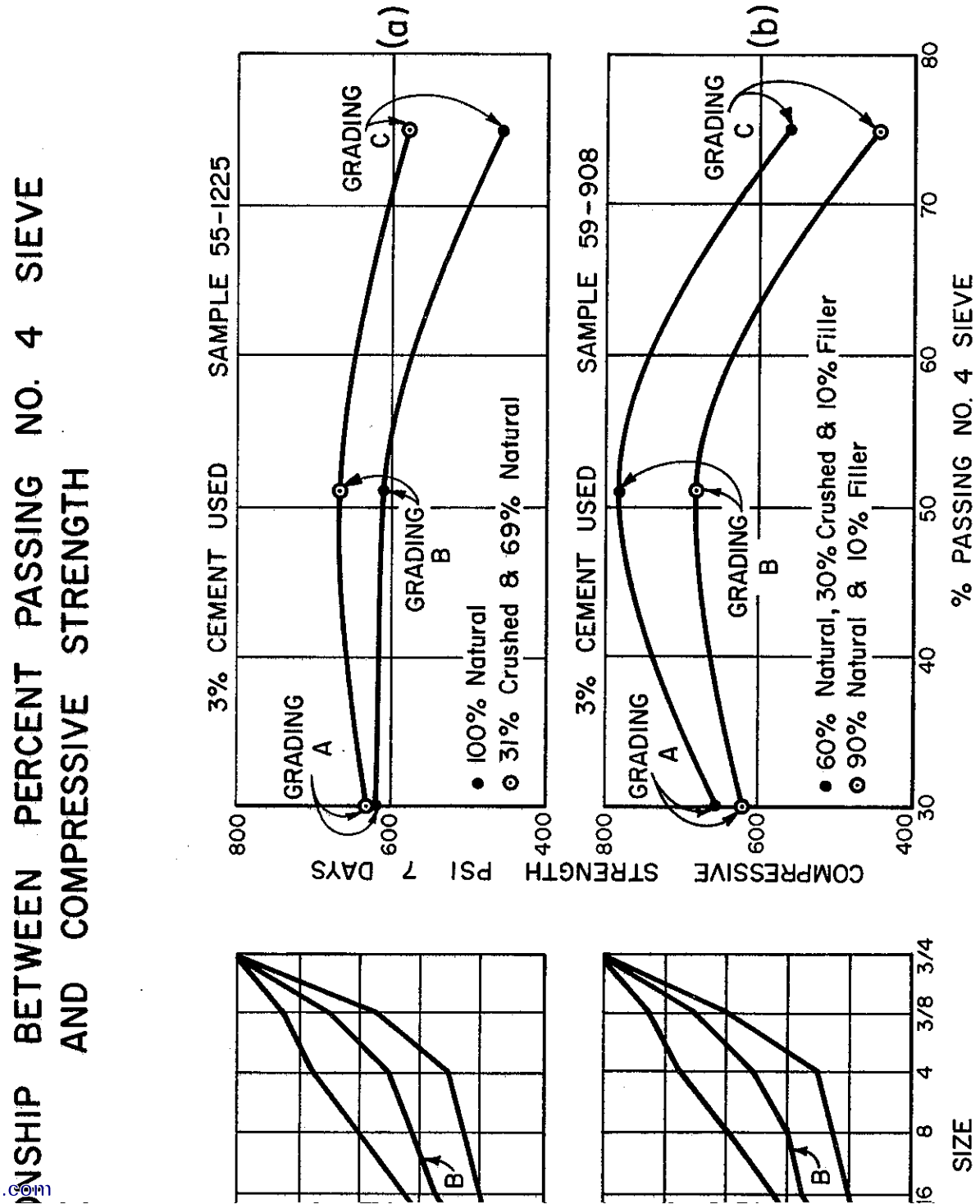
FIGURE 3



RELATIONSHIP BETWEEN PERCENT PASSING NO. 4 SIEVE AND COMPRESSIVE STRENGTH

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FIGURE 4

RELATIONSHIP BETWEEN COMPRESSIVE STRENGTH AND RATIO OF PERCENT PASSING NO 200 TO PERCENT PASSING NO 30 SIEVE

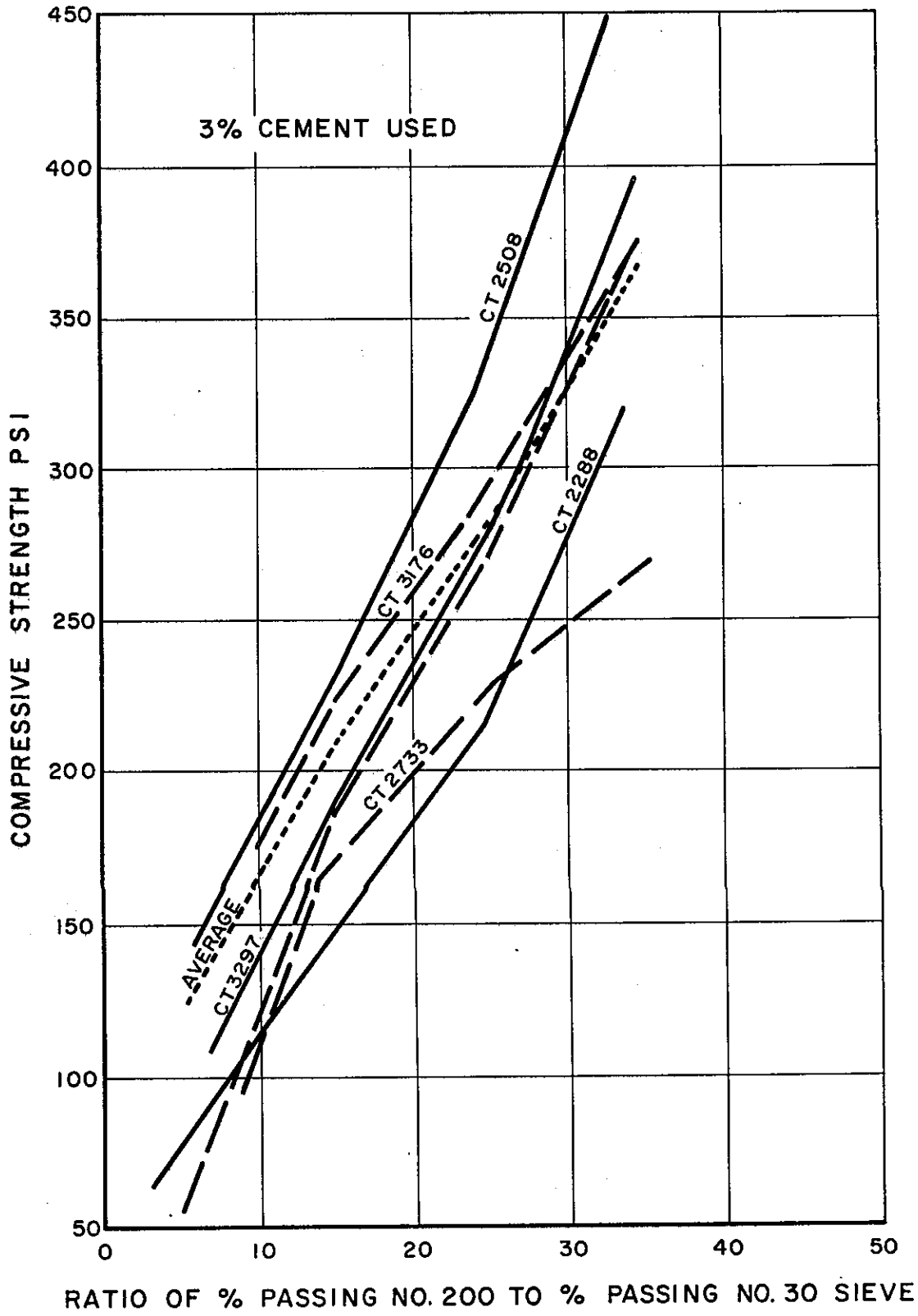

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FIGURE 5

RELATIONSHIP BETWEEN COMPRESSIVE STRENGTH AND DENSITY

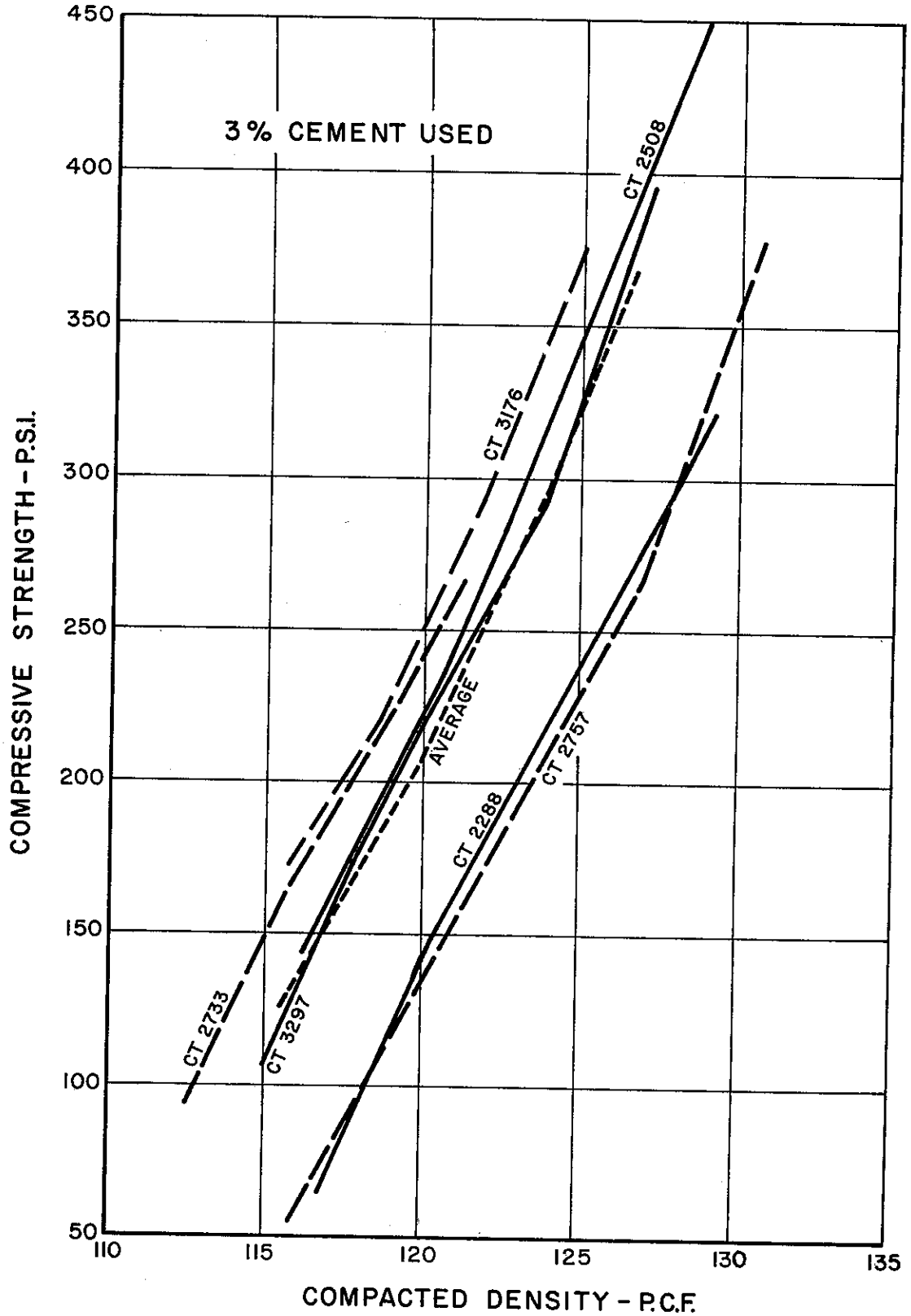

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FIGURE 6

EFFECT OF ADDING VARYING PERCENTAGES OF HARD BALLS OF CLAYEY MATERIALS TO A WELL GRADED MATERIAL

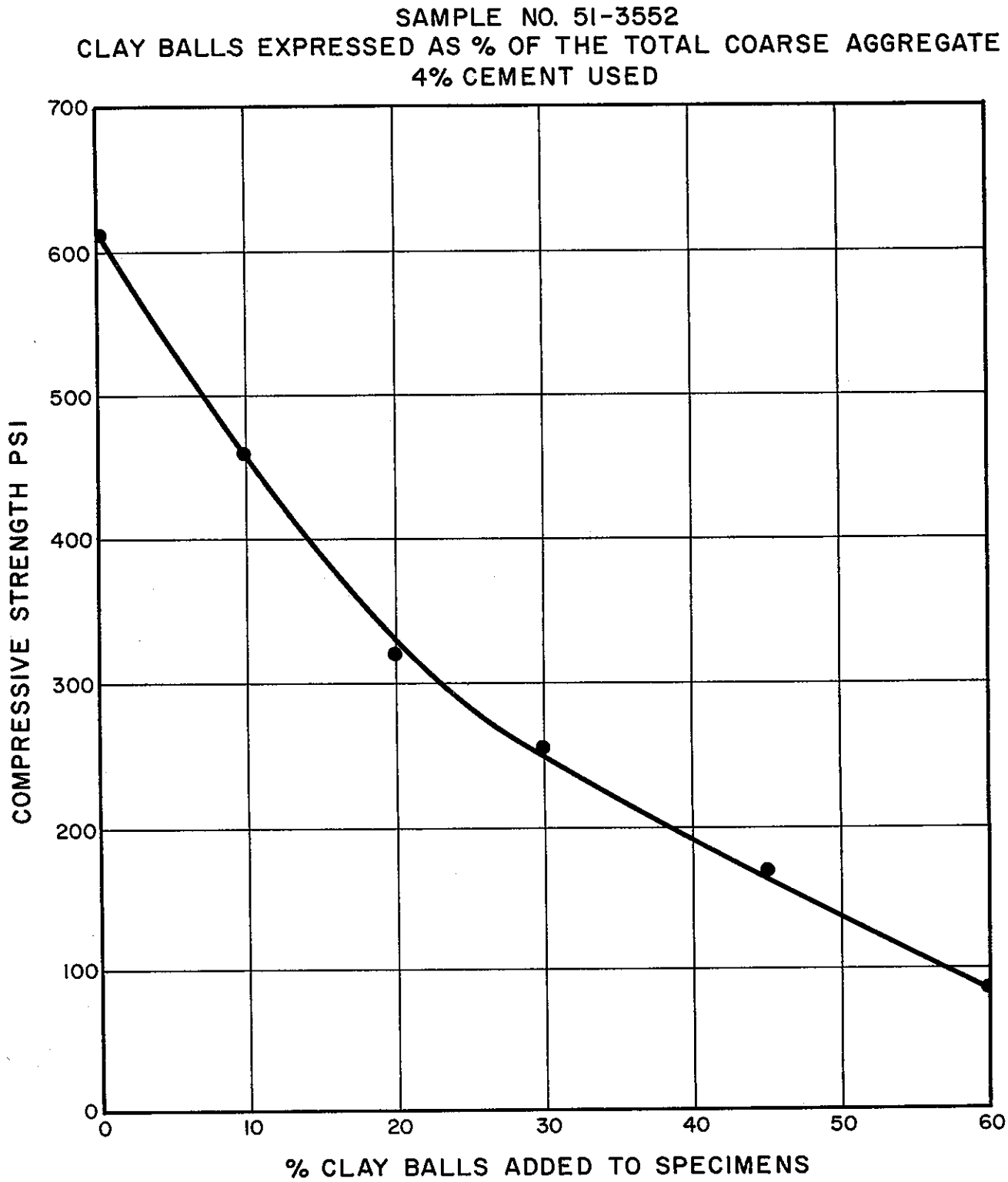

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FIGURE 7

RELATIVE COMPRESSIVE STRENGTHS OF CEMENT TREATED SPECIMENS WHEN MIXTURES WERE ALLOWED TO STAND FOR DIFFERENT INTERVALS BEFORE COMPACTING

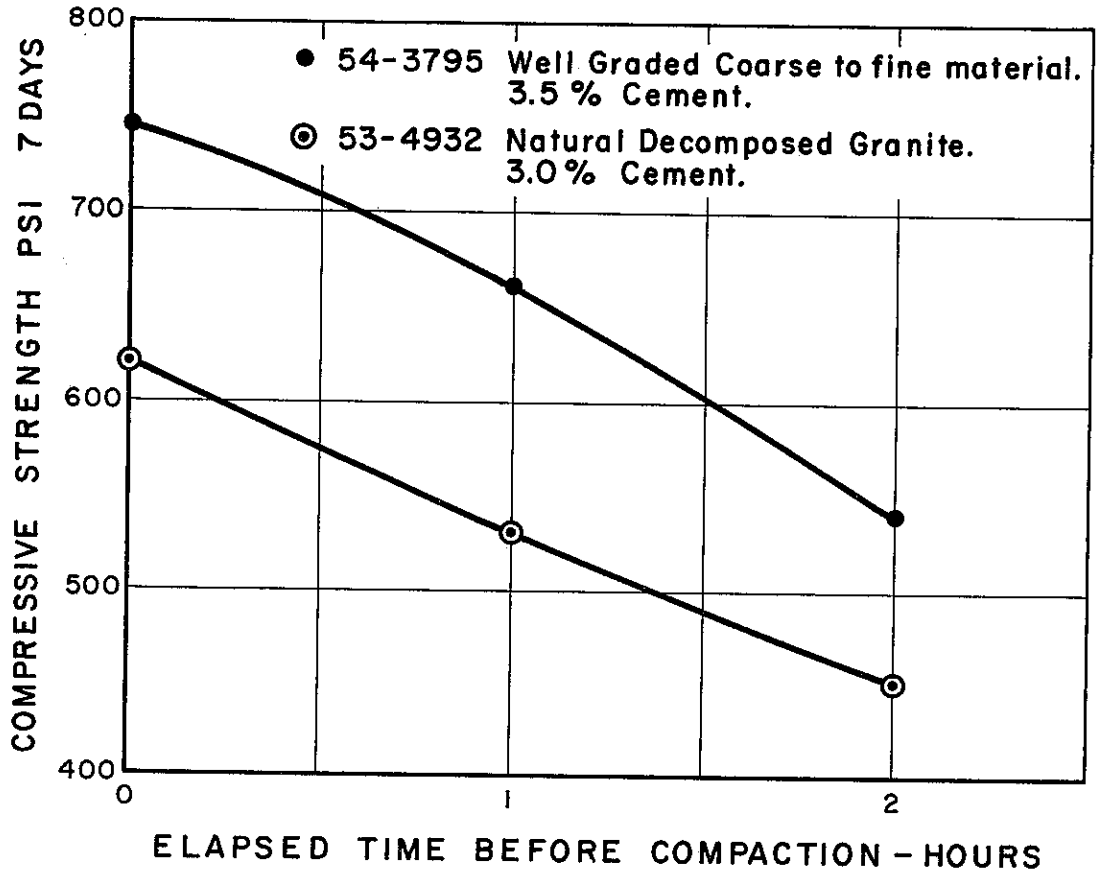

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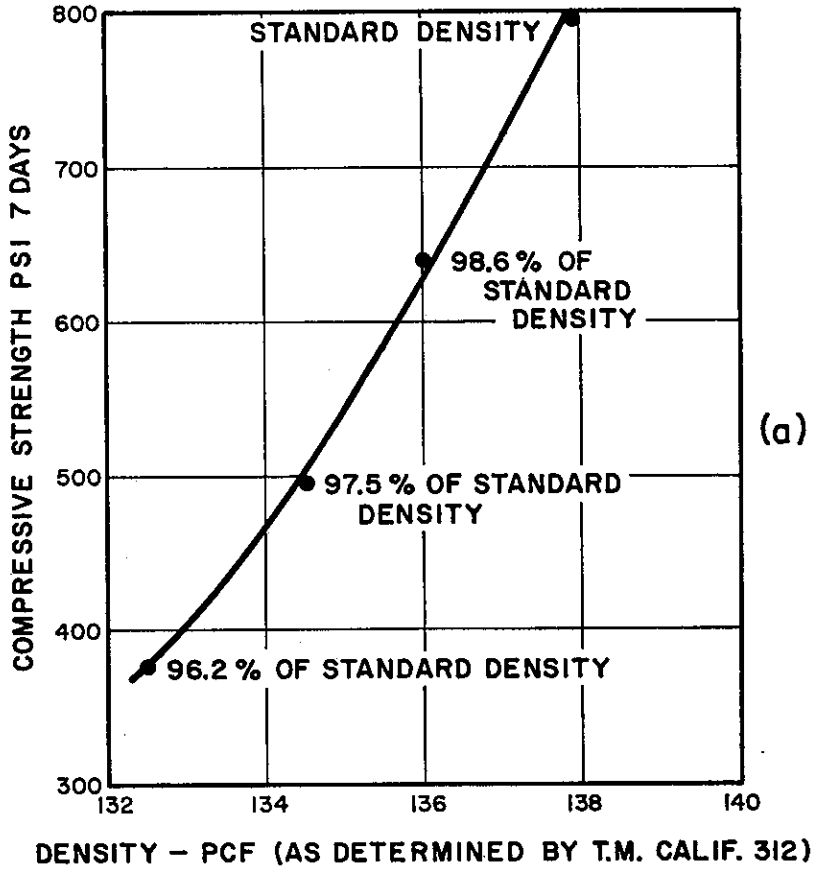
FIGURE 8

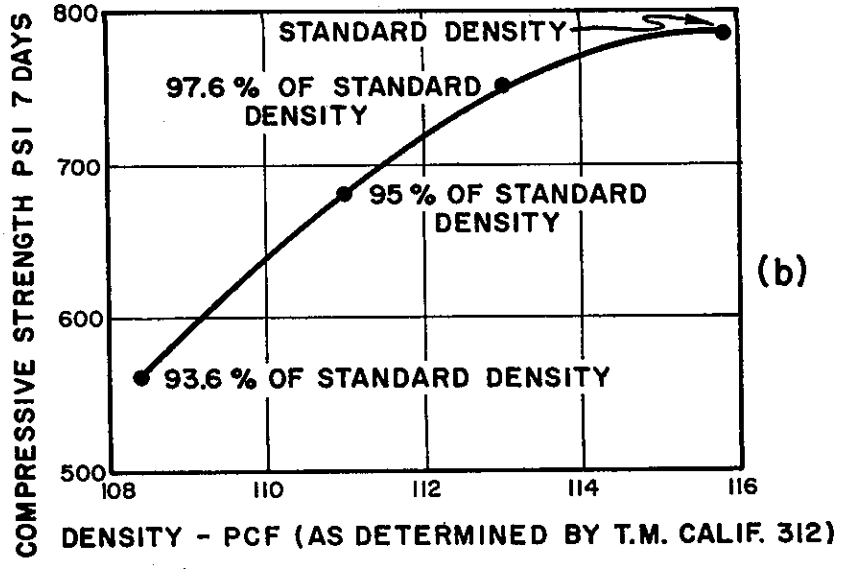
RELATIONSHIP BETWEEN COMPRESSIVE STRENGTH AND DENSITIES OF CTB TEST SPECIMENS

SAMPLE NO. 58-2143 WELL GRADED COARSE TO FINE MATERIAL
3.5 % CEMENT & 7.2 % MOISTURE
DENSITIES VARIED BY USING DIFFERENT STATIC LOADS



(a)

SAMPLE NO. 59-1362 SILTY SAND
6% CEMENT & 15.0% MOISTURE USED
DENSITIES VARIED BY USING DIFFERENT STATIC LOADS



(b)

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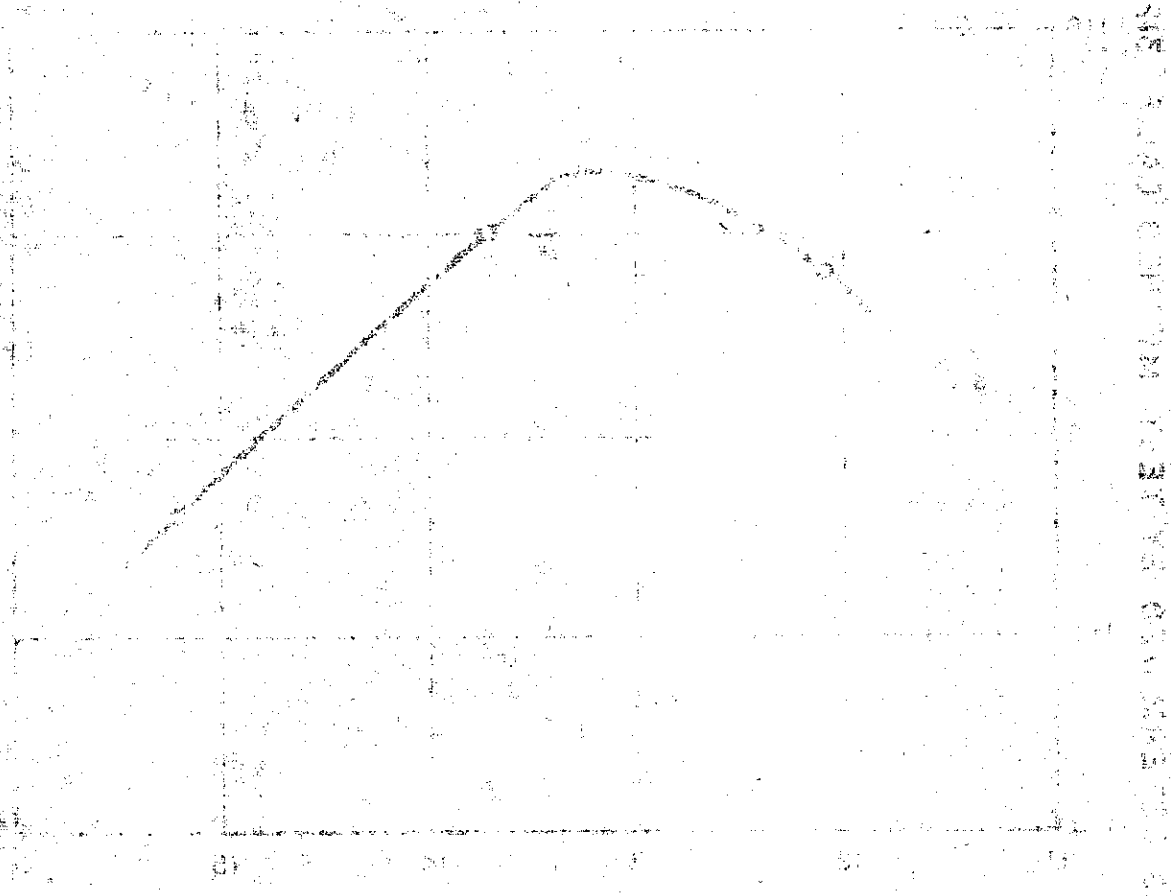

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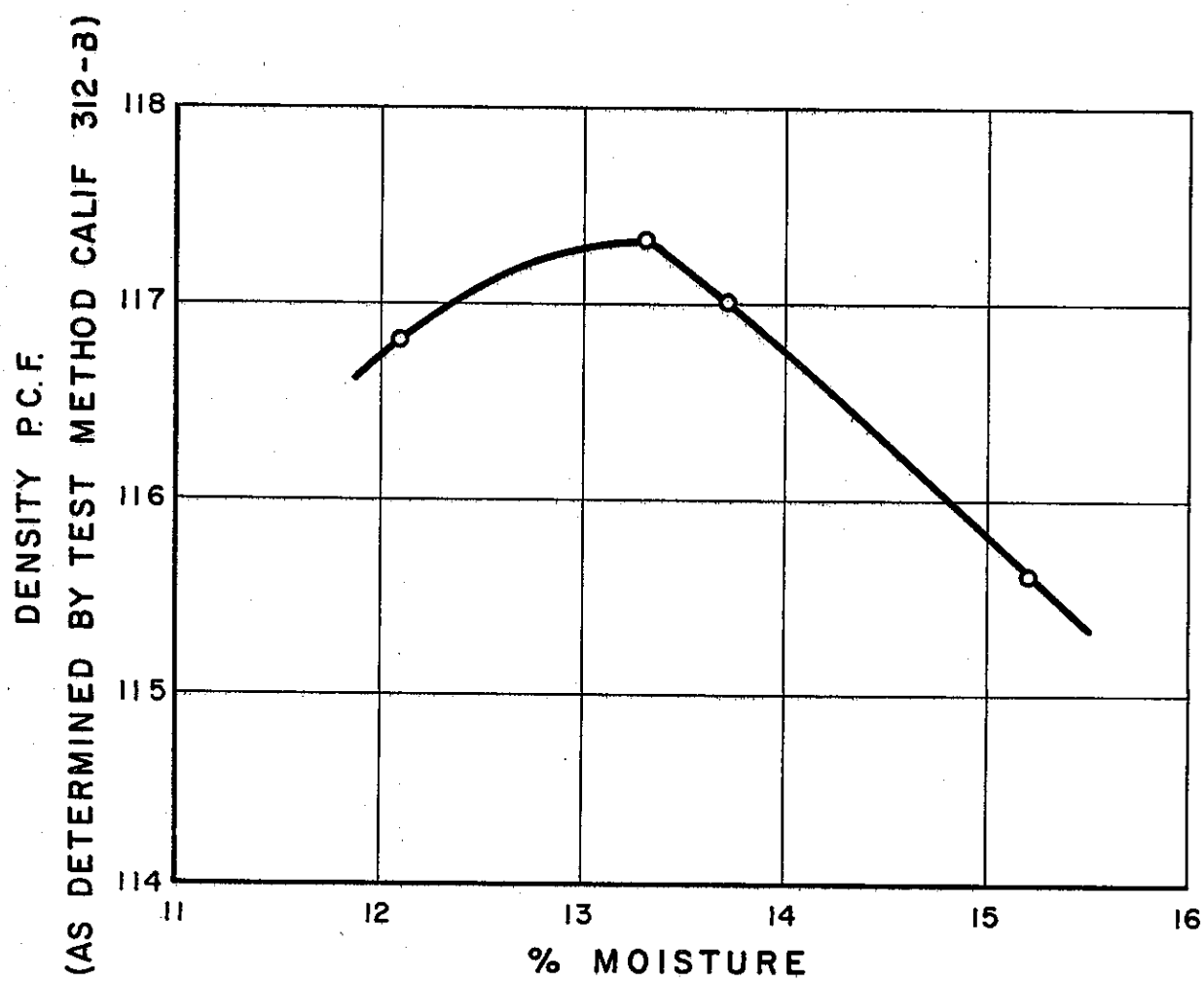
FIGURE 10

MOISTURE DENSITY CURVE

SAMPLE NO. 59-1362
SILTY SAND
IV-CC-75, 107-SUSP.



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RELATIONSHIP BETWEEN DENSITY AND COMPRESSIVE STRENGTH OF CTB SPECIMENS

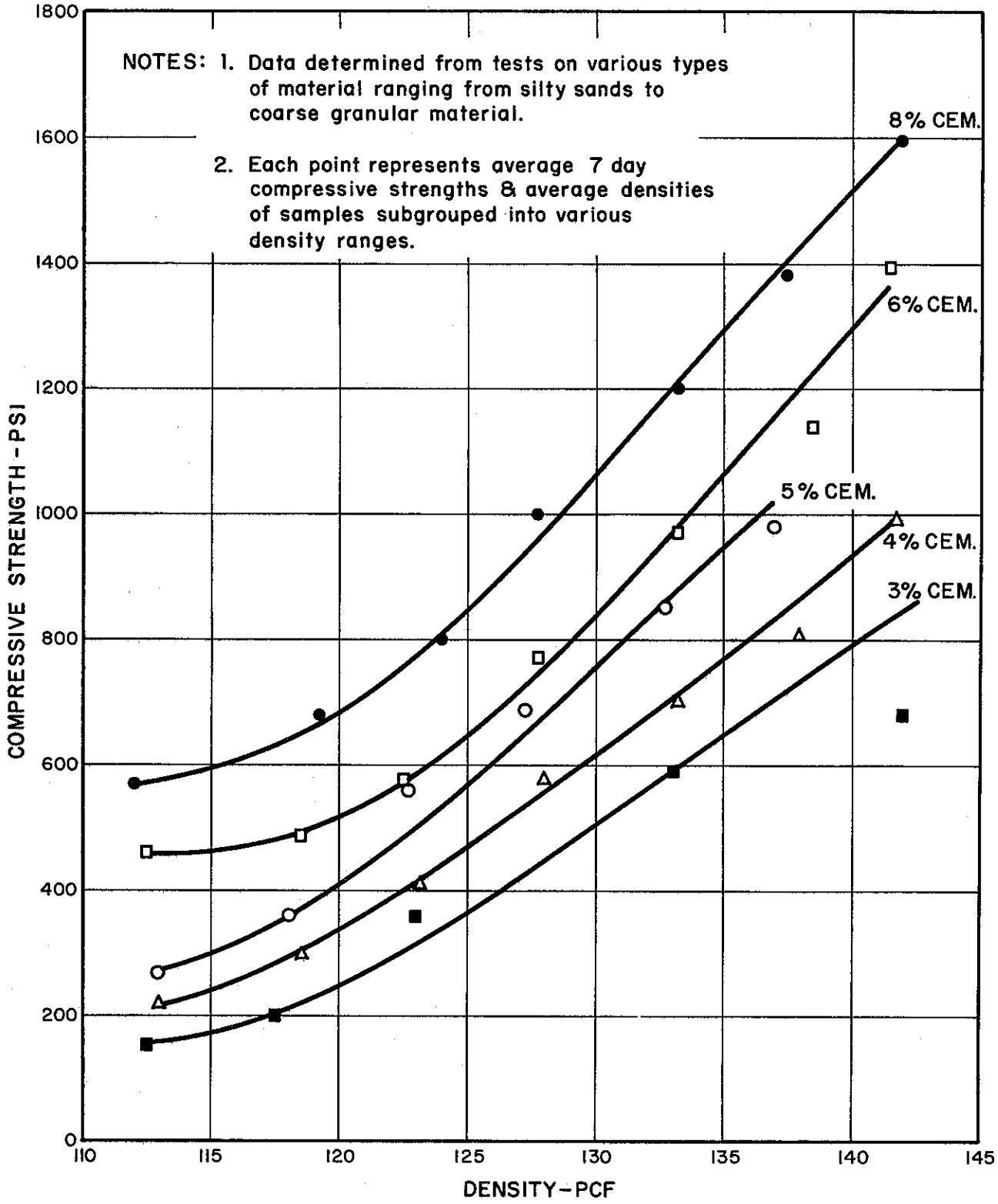

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FIGURE 11

COMPARISON OF CONSTRUCTION AUDIT CEMENT TREATED BASE CORES WITH LABORATORY SPECIMENS

Ogive curve shows % relative compaction of 261 field cores from 19 projects as compared to average densities by laboratory compaction.

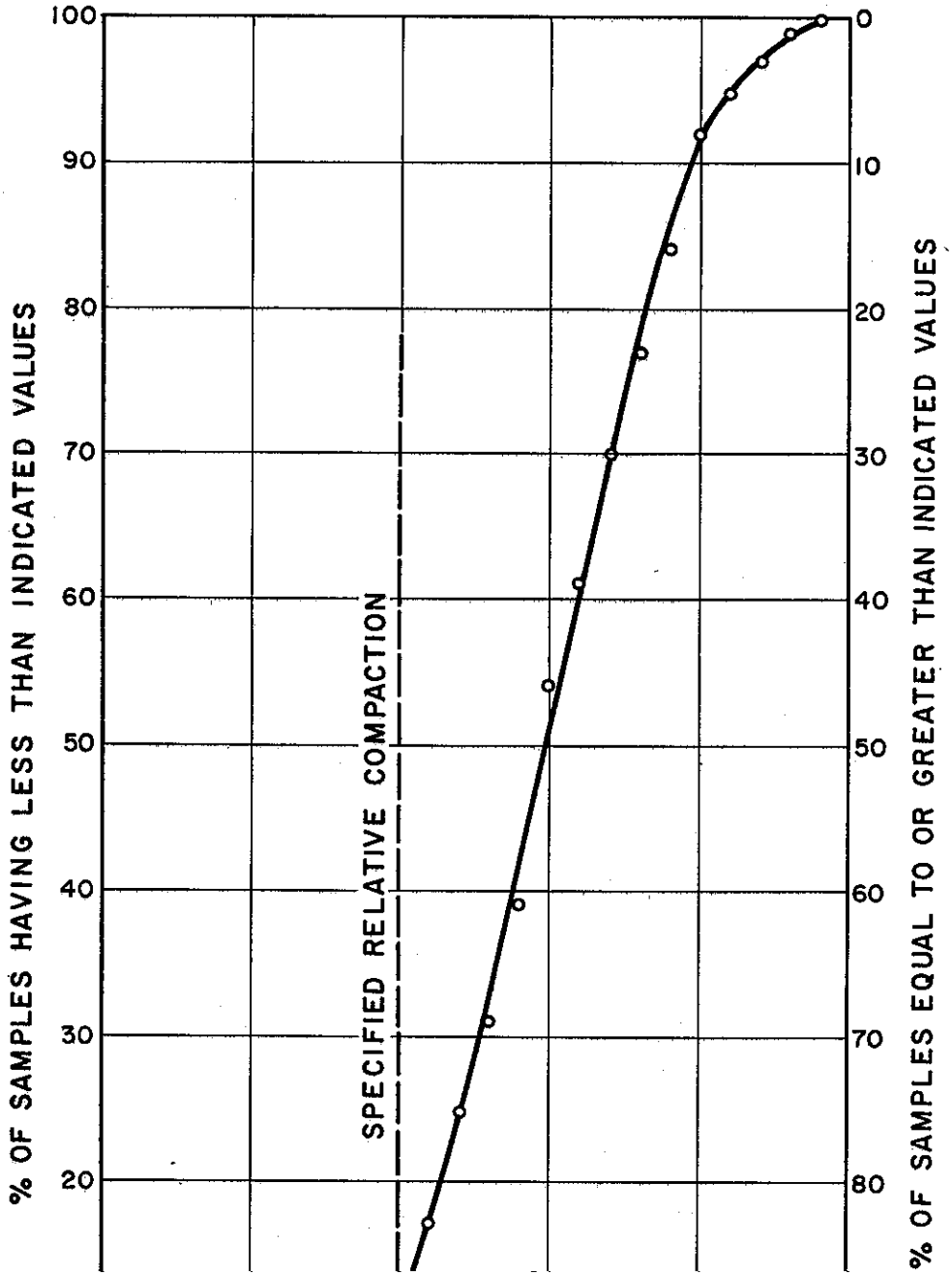

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FIGURE 12

RELATIONSHIP BETWEEN CURING TIME AND COMPRESSIVE STRENGTH OF CTB SPECIMEN

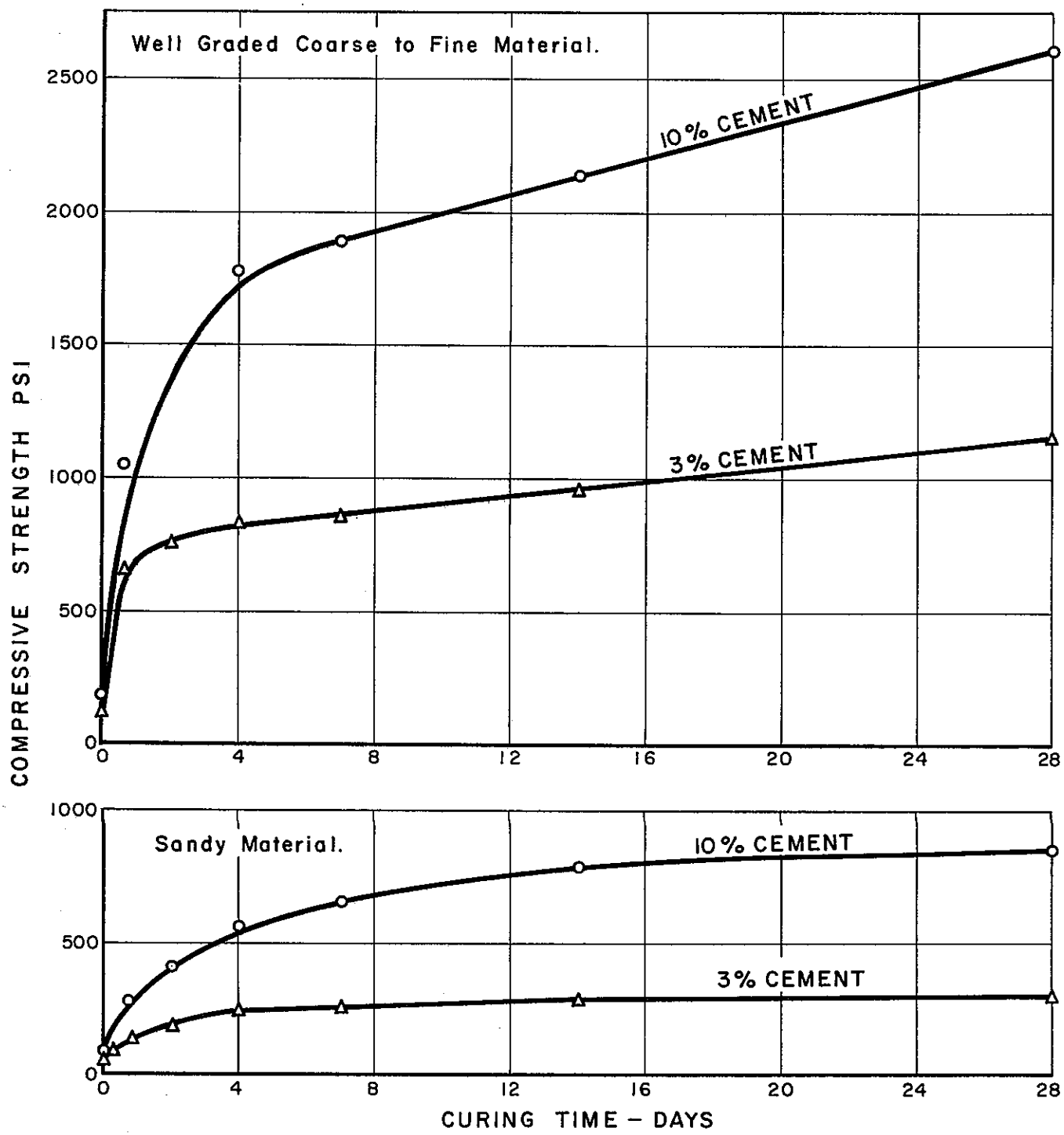

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FIGURE 13

RELATIONSHIP BETWEEN CURING TIME AND COMPRESSIVE STRENGTH OF CTB SPECIMENS

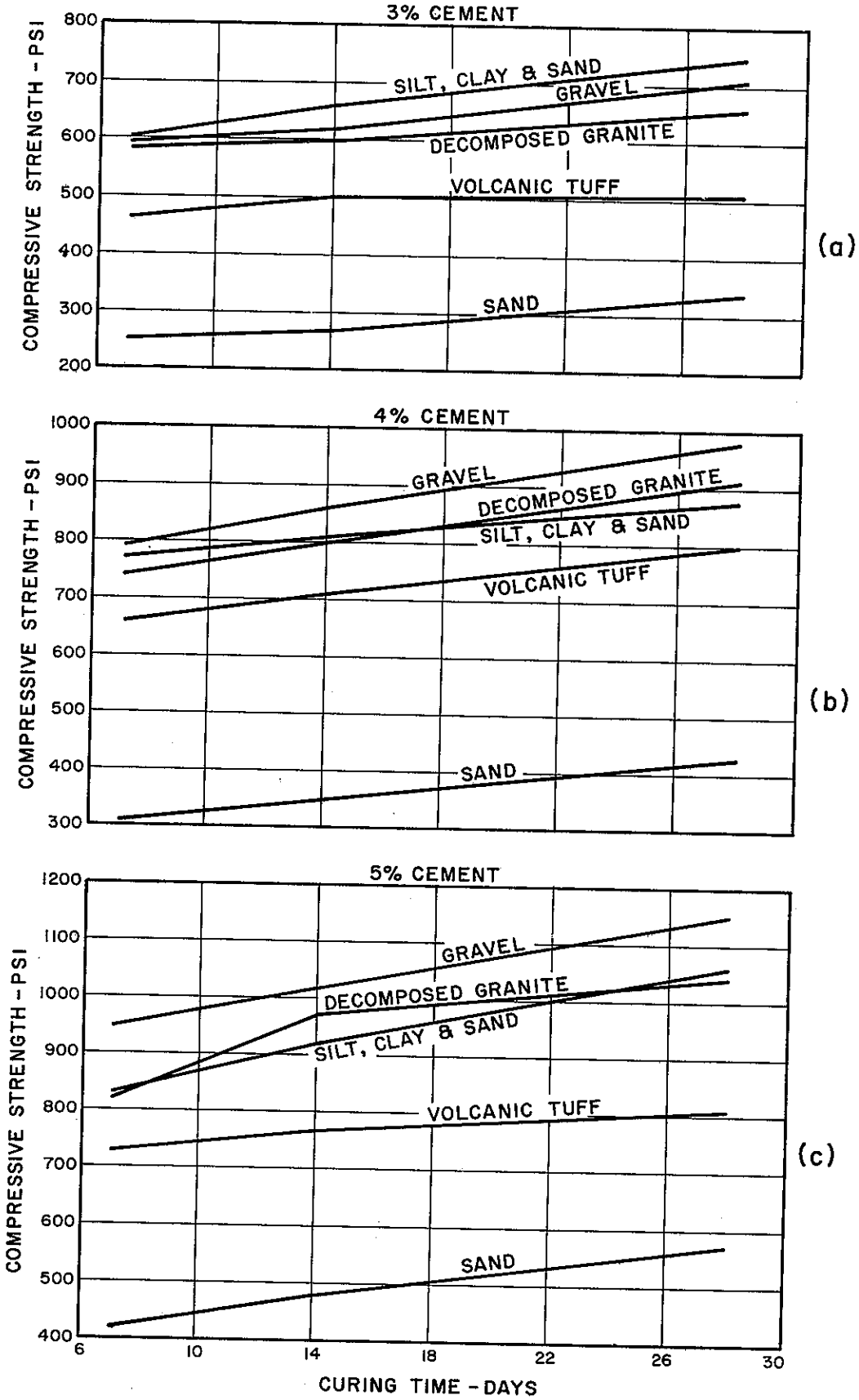

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FIGURE 14

RELATIONSHIP BETWEEN CURING TIME AND COMPRESSIVE STRENGTH OF CTB SPECIMENS

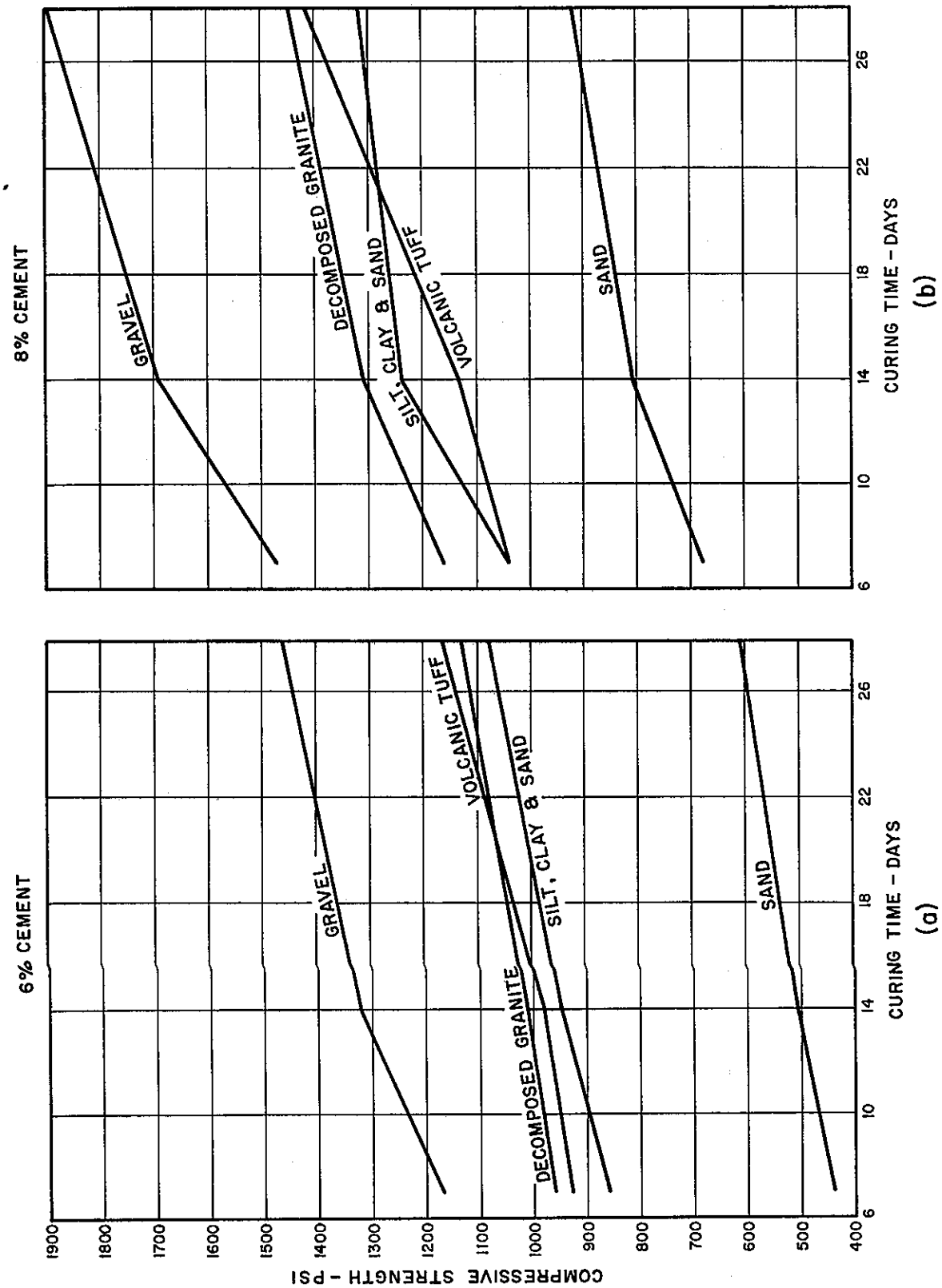

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FIGURE 15

COMPARISON OF COMPRESSIVE STRENGTHS OF CTB SPECIMENS CURED FOR 3, 7 AND 28 DAYS AT 50 75 AND 100 DEGREES

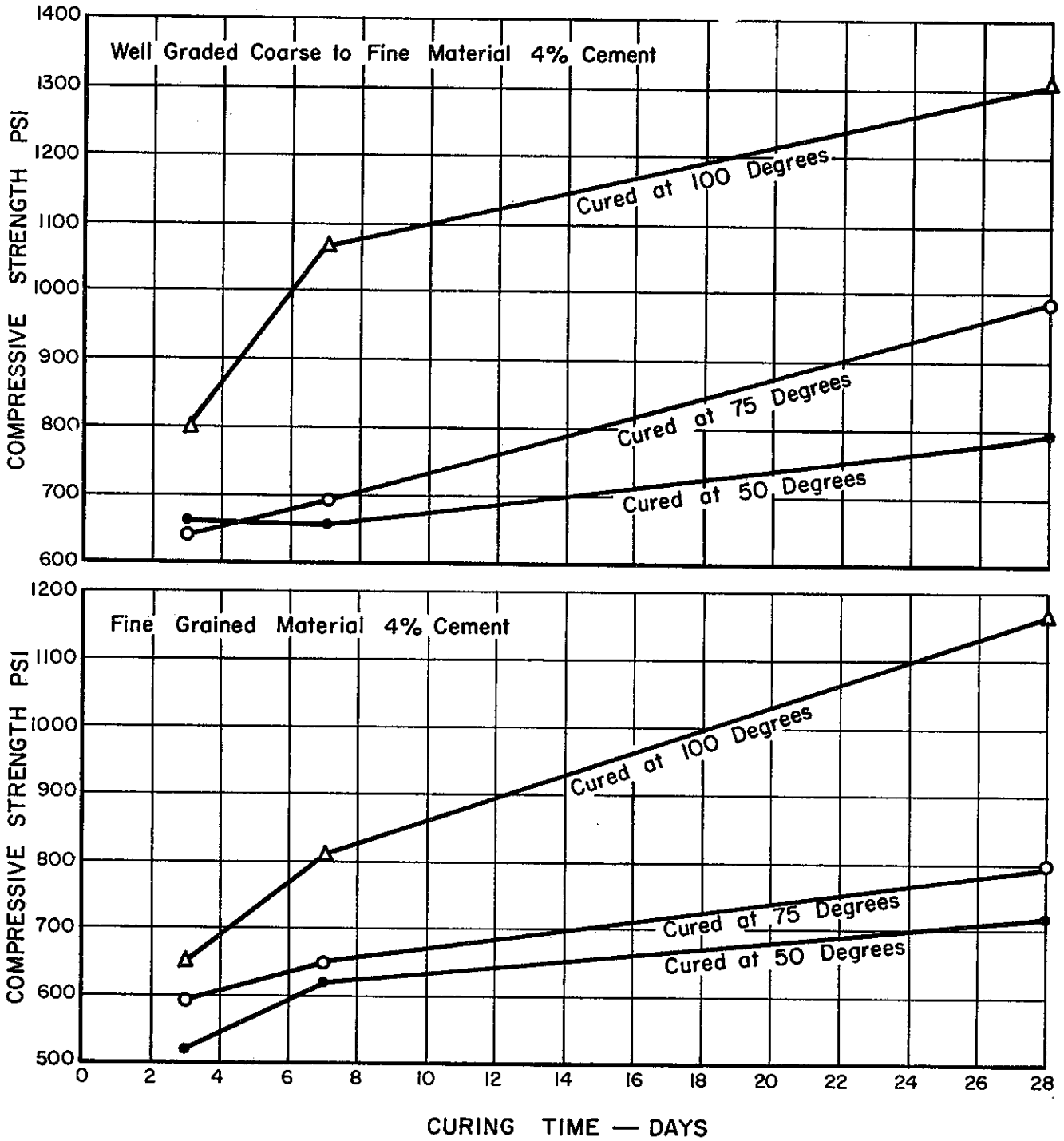

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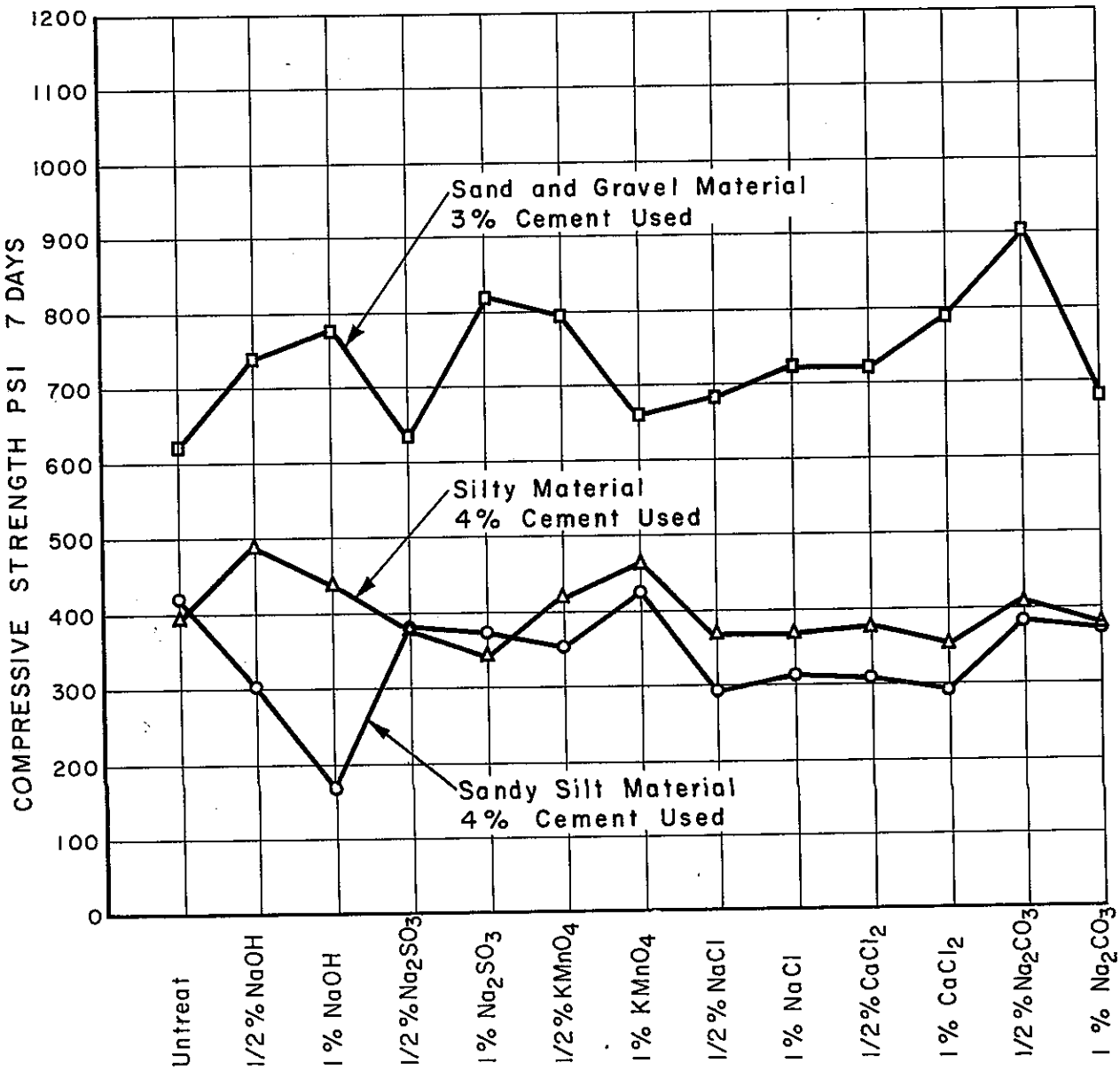
FIGURE 16

COMPRESSIVE STRENGTH ON SPECIMENS FABRICATED WITH CHEMICAL ADDITIVES



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EFFECT ON COMPRESSIVE STRENGTH OF TEST SPECIMENS

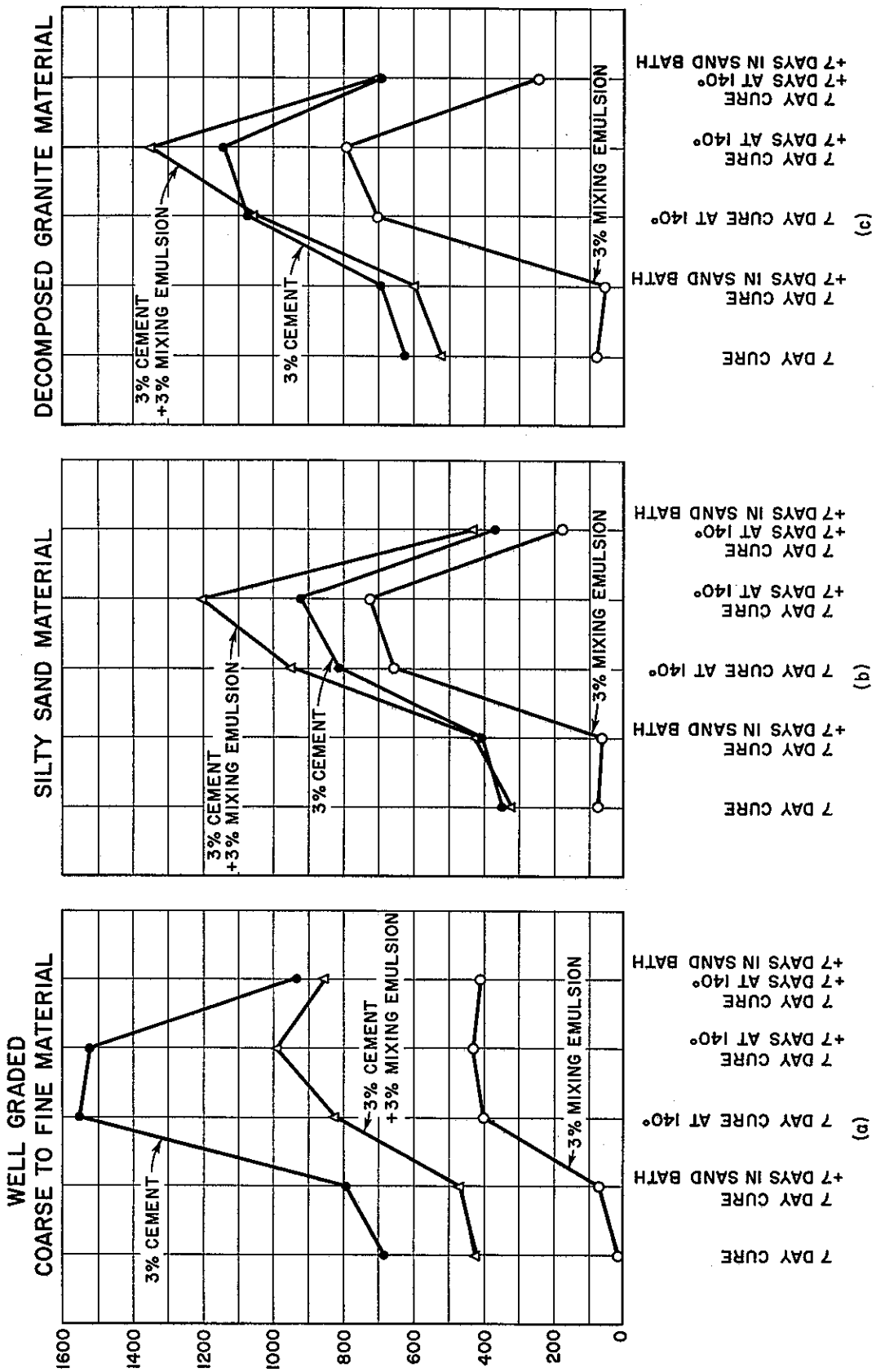

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FIGURE 18

fig 16

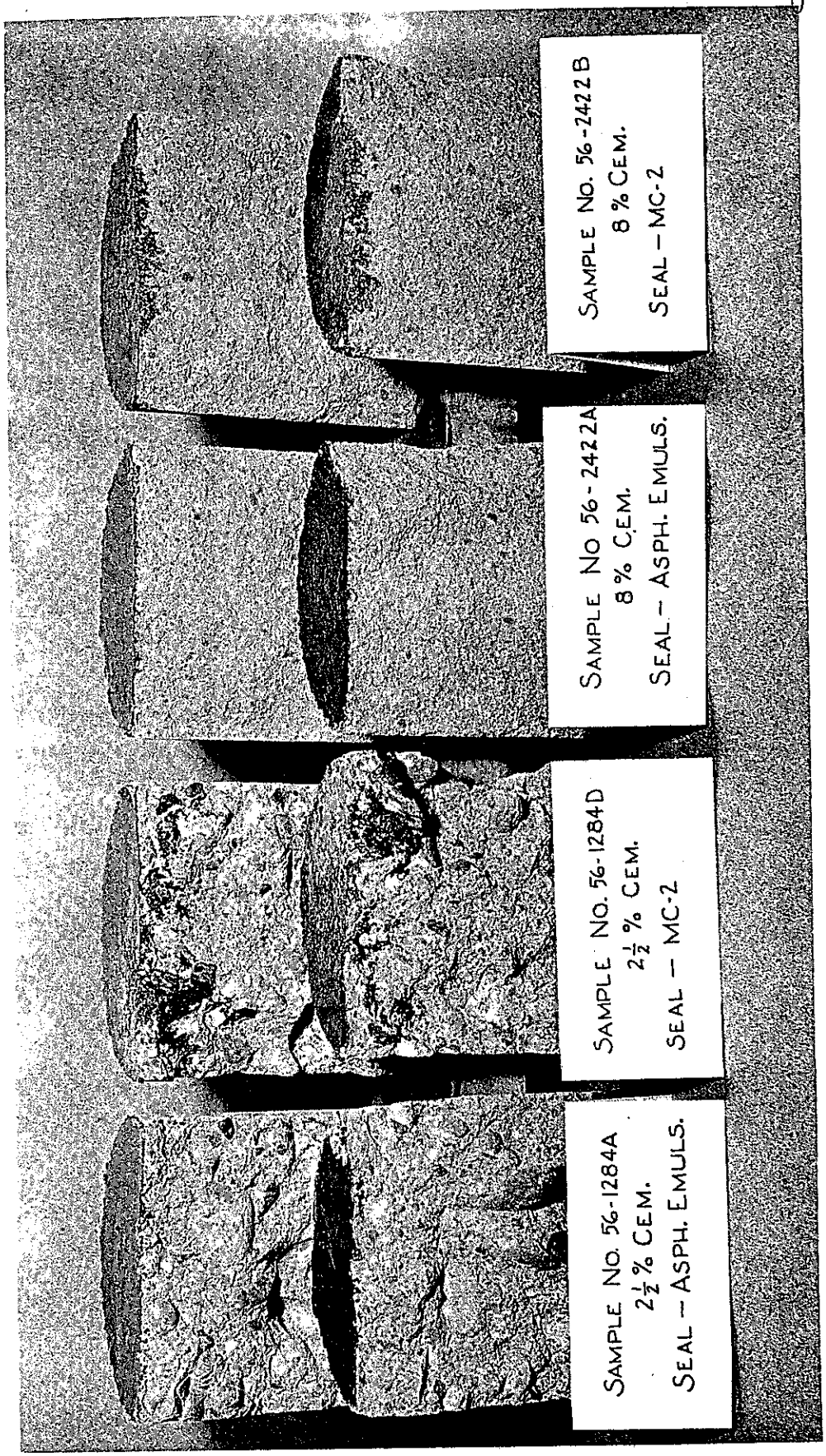

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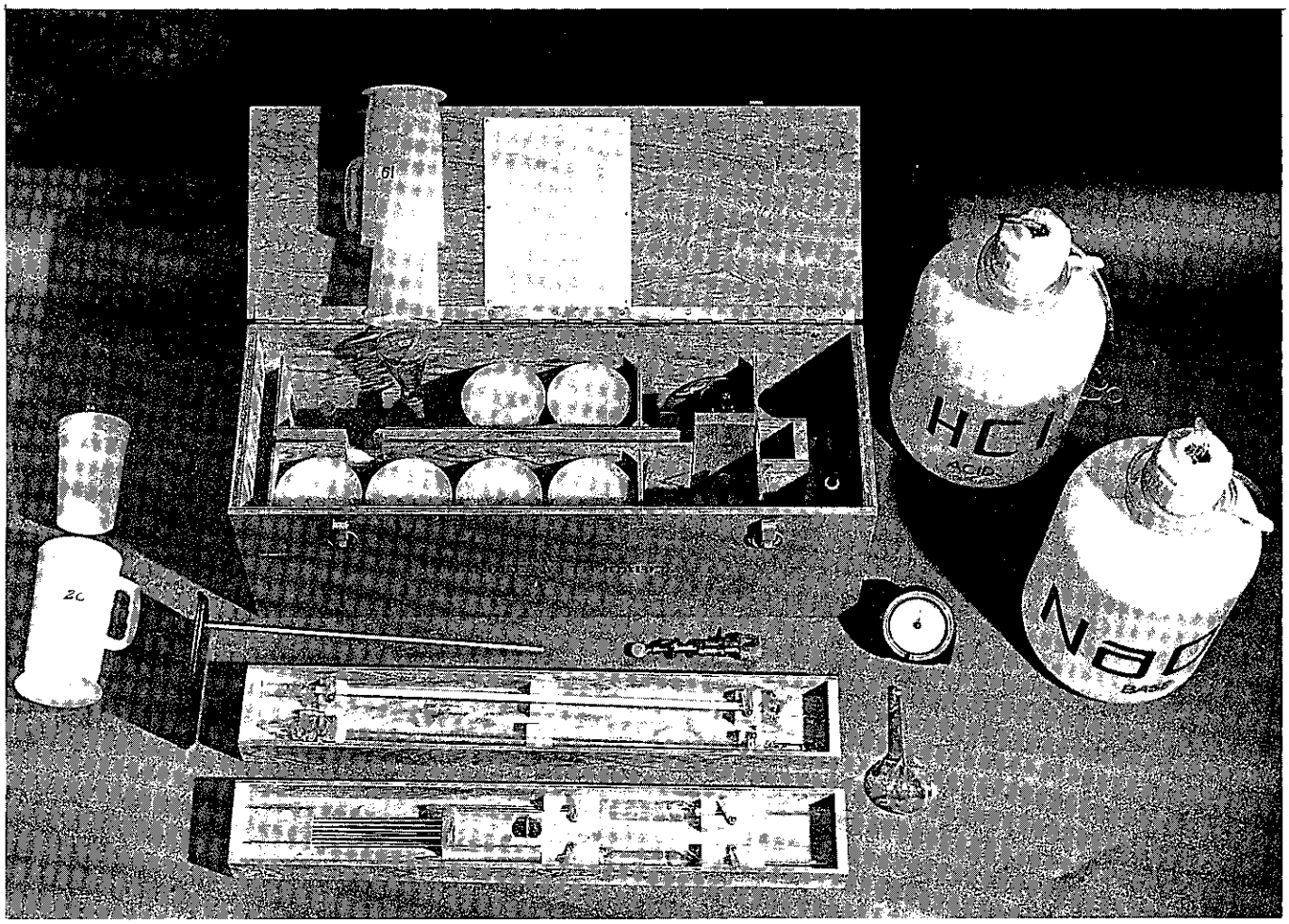
fig 17



The field kit for the titration test.

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FIGURE 20

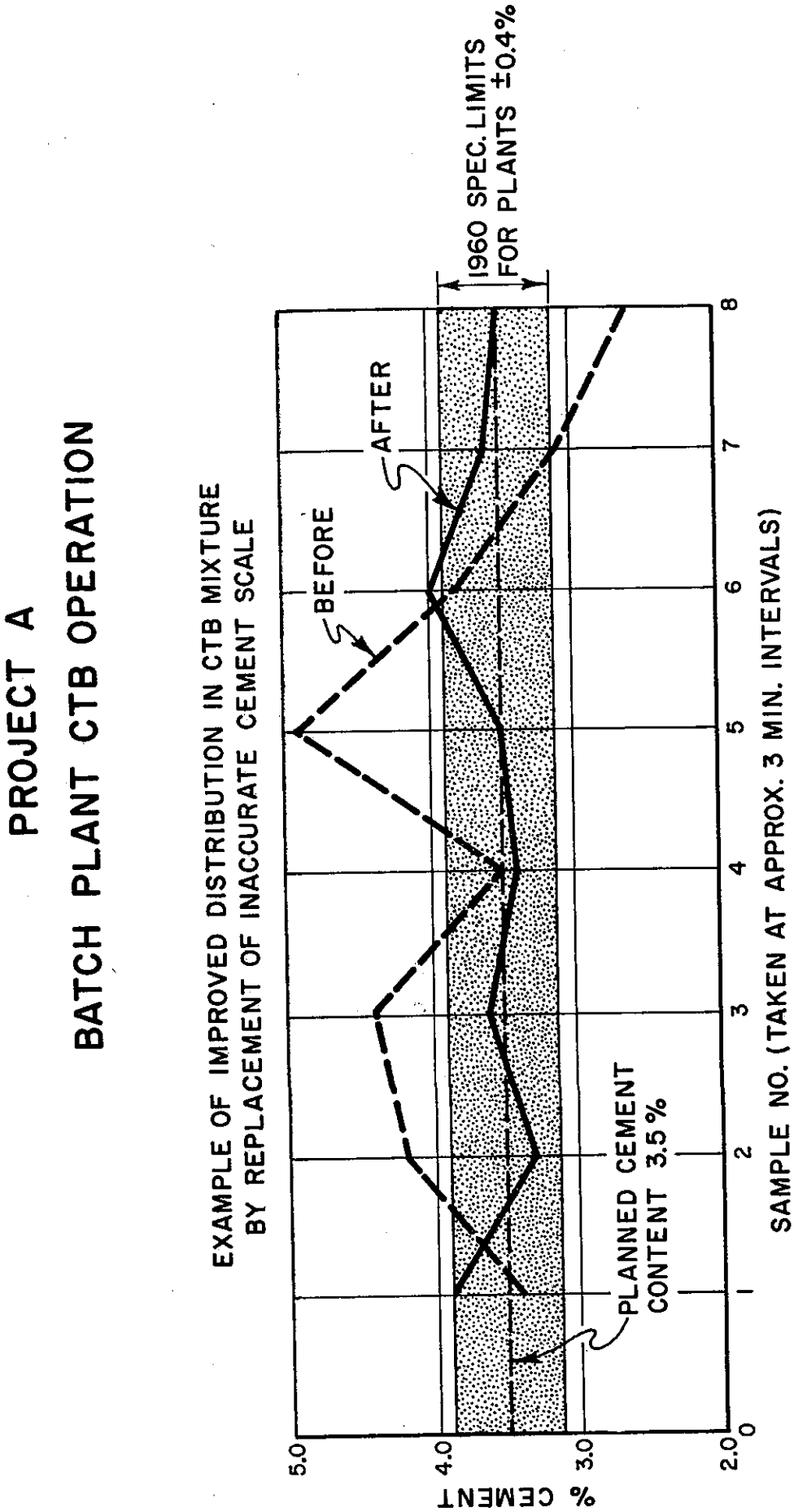

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FIGURE 21

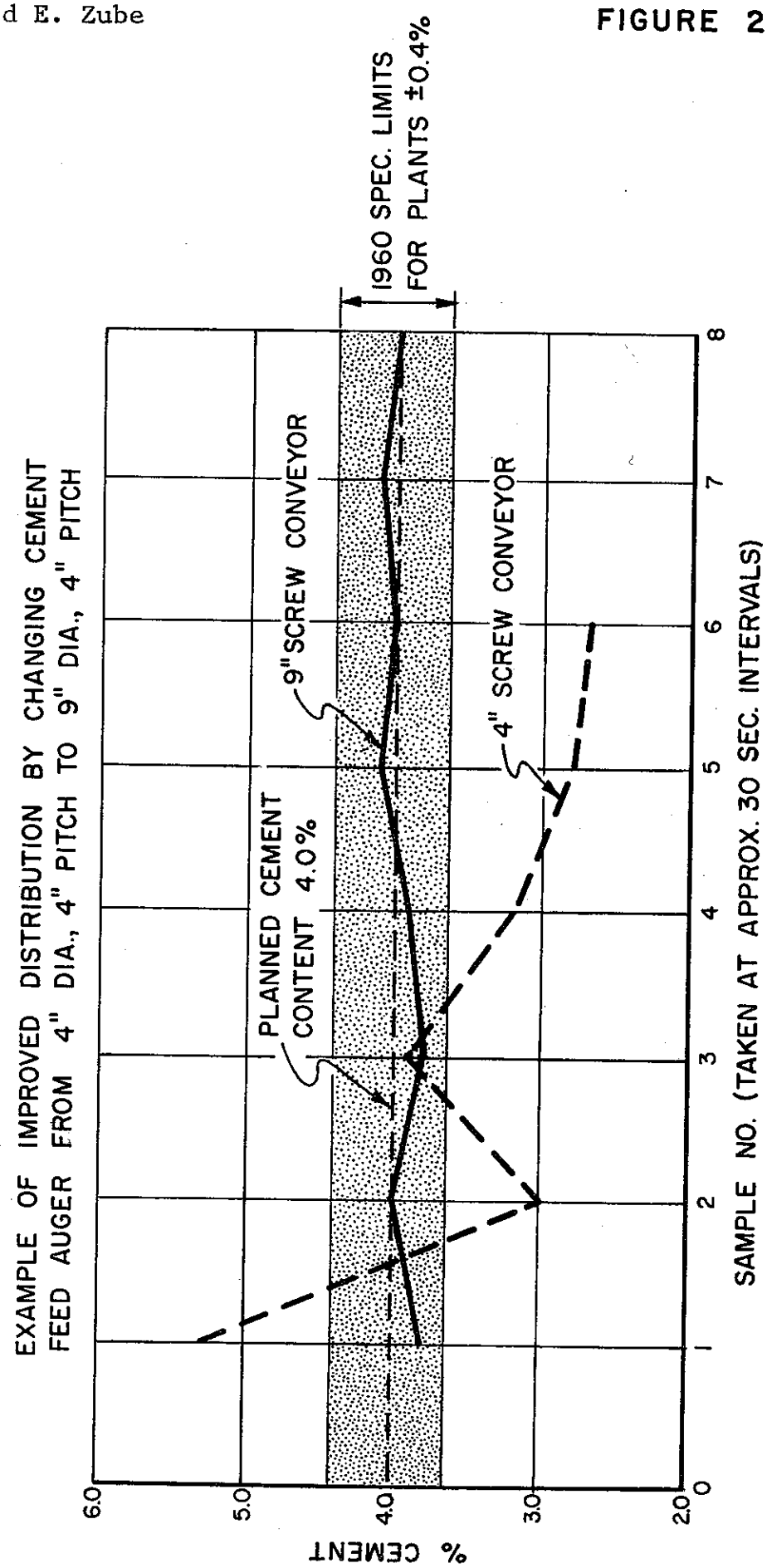

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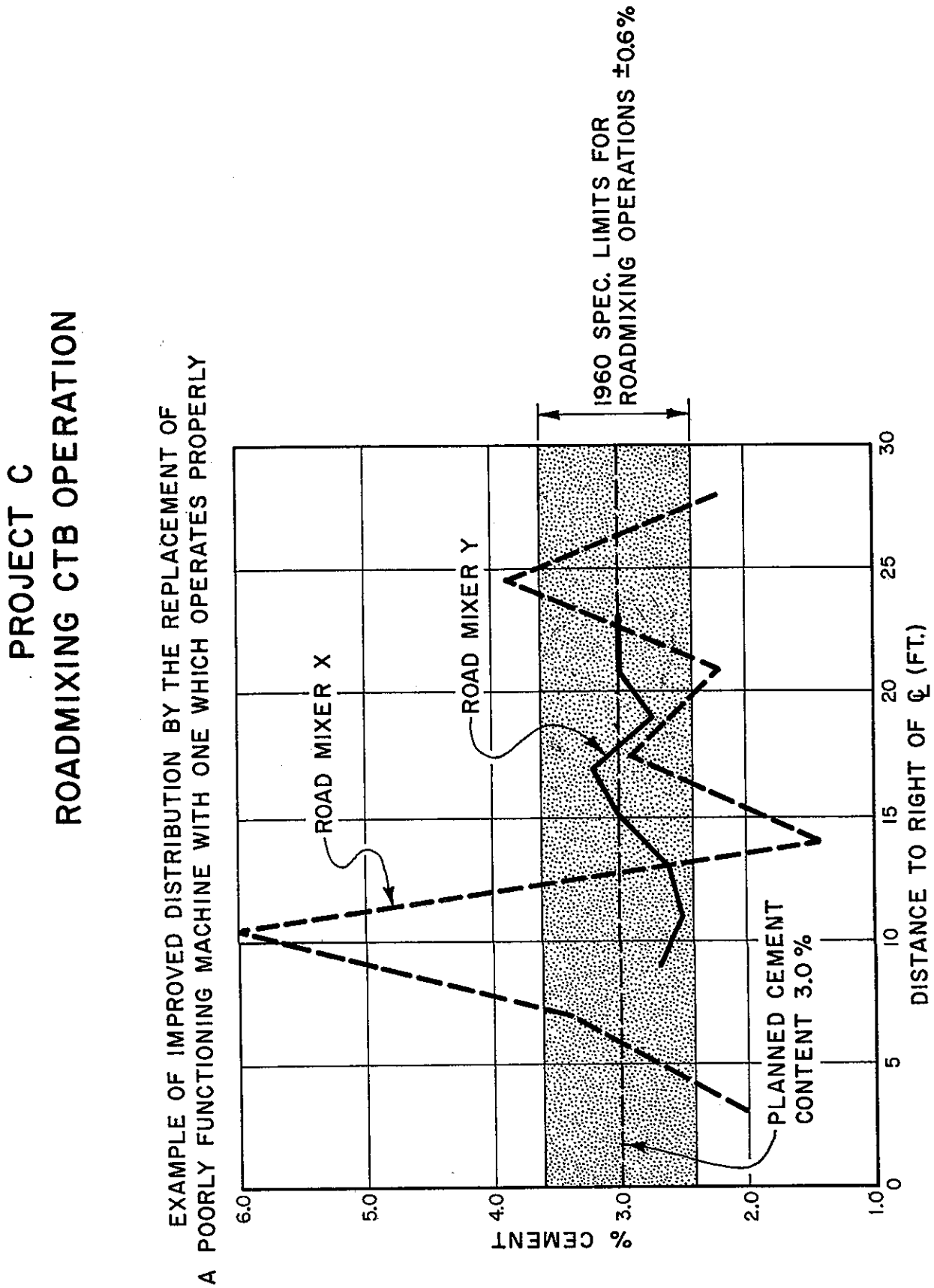
FIGURE 22



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Test Method No. Calif. 312-B
January 3, 1956
(10 pages)

State of California
Department of Public Works
Division of Highways

MATERIALS AND RESEARCH DEPARTMENT

METHOD FOR DETERMINATION OF COMPRESSIVE STRENGTH OF CEMENT TREATED BASES, CLASSES "A" AND "B," AND CEMENT TREATED SUBGRADE

Scope

This method describes the procedure for determining compressive strength as an index of the effectiveness of cement treatment in imparting desirable properties to base and subgrade materials.

PART I. LABORATORY METHOD

Procedure

A. Apparatus

1. Drying and preheating oven thermostatically controlled to 230 ± 10 F.
2. Drying and preheating oven thermostatically controlled to 140 ± 5 F.
3. Water tank, 6 in. deep for use in submerging test specimens.
4. Balance with capacity of 5,000 g., accurate to 1 g.
5. Balance with capacity of 500 g., accurate to 0.1 g.
6. Sample splitter, riffle type, ¾-in. openings.
7. Sieves, U. S. Standard sizes, 1-in., ¾-in., ½-in., ⅜-in., No. 4, square openings.
8. Pans, 10 in. diam. x 2 in. deep.
9. Pans, 6 in. diam. x 1½ in. deep.
10. Metal scoop, No. 3.
11. Funnel weigh scoop and tare weight.
12. Testing machine, 50,000-lb. capacity.
13. Water spray metering device with turntable, Figure I.
14. Mechanical mixing machine.
15. Mixing bowl and concrete cylinder cans.
16. Large mixing spoon.
17. Mechanical compactor, kneading type (optional). See Method No. Calif. 901 for details.
18. Compaction accessories, hand method, Figure II.
19. Compaction accessories, mechanical method, Figure V.
    (The accessories for the hand compaction method can also be used for the mechanical compaction method.)
20. Mechanical device for pushing samples from mold, Figure III.
21. Measuring gauge and stand, Figure IV.

B. Test Record Form

Use work card "Laboratory Record of Cement Treatment," Form T-342, for recording test data.

C. Preparation of Sample

1. Both proper preparation and accurate quartering of test samples, in addition to use of proper testing procedure, are necessary in order to obtain accurate test results and good test reproducibility. See Test Method No. Calif. 201 for description of proper methods to use for initial sample preparation and quartering.
2. Samples submitted for cement treatment tests are divided into the following five categories:
   a. Bin samples or windrow samples.
   b. Stockpile samples.
   c. Pit or quarry samples.

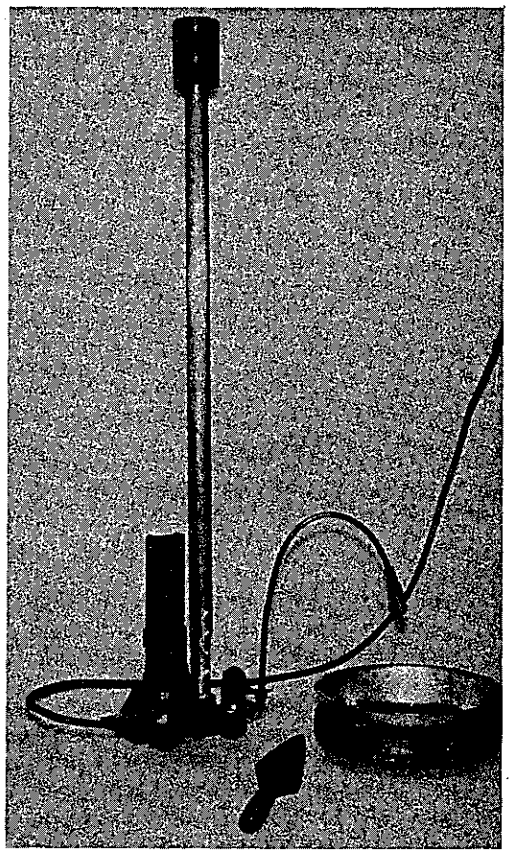

FIGURE I

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gregates and percentage of fine aggregates as follows:

Sieve size	Percent passing	Percent retained
1 in.	100	0
¾ in.	96	4
⅜ in.	80	20
No. 4	60	40

Cumulative weights of aggregates, cement and moisture for one 4 in. × 4 in. compacted specimen are as follows:

	Cumulative dry weights in grams	Cumulative moisture correction	Cumulative corrected weights in grams
Ret. ¾ in.	.04 × 1,634 = 65	.008 × 65 = 1	66
Ret. ⅜ in.	.20 × 1,634 = 327	.008 × 327 = 3	330
Ret. No. 4	.40 × 1,634 = 654	.008 × 654 = 5	659
Pass. No. 4	1.00 × 1,634 = 1,634	5 + .012 (1,634 − 654) = 17	1,651
Cement	1.05 × 1,634 = 1,716	17	1,733
Water		1,716 + 17 + 80	1,813

$$\text{Total moisture in sample} = \frac{17 + 80}{1,716} = .057 \text{ or } 5.7 \text{ percent}$$

D. Determining Optimum Moisture

1. When combinations of various sized particles of mineral aggregate and a constant weight proportion of cement are mixed with different quantities of water and then compacted by identical methods, the use of one certain moisture content will usually result in a greater density (as indicated by the compacted dry weight of material for a given volume) than will be the case using any other moisture content for the particular material under consideration. The amount of water thus required for maximum compaction, expressed as percent of the dry weight of the material, is commonly referred to as the "optimum moisture content" for that combination of aggregates and cement.

2. If no previous data on the soil or aggregates in question is available, a trial initial moisture content may be estimated from the appearance of the soil or from its sieve analysis. Usually, tests are started with a moisture content below the expected optimum. As a rule, an initial moisture of 3 percent to 7 percent, depending upon the type of material, will give a good starting point.

3. An estimation is made of the weight of dry material required to fabricate the 4 in. x 4 in. test specimen. This estimate is based upon the type of material to be used for the test. For simplicity, the several different types of materials may be classified according to their densities or compacted dry weights per cubic foot, which normally ranges as follows:

Volcanic tuff	70 to 100 lb. per cu. ft.
Fine sand	110 to 120 lb. per cu. ft.
Silty sand or sandy soil	120 to 128 lb. per cu. ft.
Clayey silt or fine grained soil	125 to 135 lb. per cu. ft.
Decomposed granite	128 to 132 lb. per cu. ft.
Coarse to fine or well graded material	130 to 145 lb. per cu. ft.

This classification is given merely as a guide for the operator in selecting proper weights to begin the tests. However, some materials may produce densities higher or lower than those shown.

4. The following formula may be used for determining the total combined weights of aggregate and cement that are required for the fabrication of 4 in. x 4 in. test specimens of various weights per cubic foot:

$$W_g = \frac{W_f H}{.303}$$

Where:

W_g = Dry weight in grams of 4 in. × 4 in. compacted test specimen.
W_f = Dry weight in lbs. per cu. ft. of compacted test specimen.
H = Height of test specimen in inches.
.303 = Constant used to convert weight in grams to weight in lbs. per cu. ft. for a 4-in. diam. specimen having a height H.

Example:

Assume a weight of 107 lb. per cu. ft. for a trial density and a cement content of 2 percent. Substituting in above formula,

$$W_g = \frac{107 \times 4}{.303} = 1412 \text{ g. of cement and aggregate}$$

$$\frac{1412}{100 + 2} \times 100 = 1384 \text{ g. of aggregate}$$

$$1412 - 1384 = 28 \text{ g. of cement}$$

5. In order to simplify the procedure for calculating the amount of aggregate and cement to be used in fabricating one 4 in. x 4 in. test specimen, a table is furnished (Figure VI), for reference. This table gives dry weights of materials in grams required to produce one 4 in. x 4 in. test specimen with cement content varying from 2 percent to 8 percent by weight, and densities varying from 107 to 150 lb. per cu. ft. If quantities of material are needed to make specimens with a density lower than 107 or higher than 150 lb. per cu. ft. the above formula must be used.

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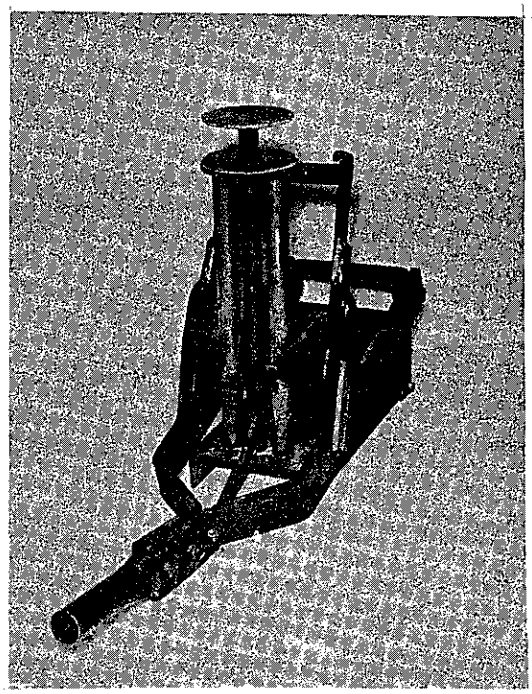
No. 4, and insert bottom plunger No. 5 and extension sleeve No. 6. Insert the U-shaped spacer No. 7 between bottom of mold and bottom plunger. A set of these spacers should be available with thicknesses of $\frac{1}{16}$ in., $\frac{1}{8}$ in. and $\frac{3}{16}$ in. Use the thinner spacers when compacting granular materials, and use the thickest one when compacting plastic materials. Remove the spacer on completion of the hand compaction, and the space provided by its use results in a double plunger effect under the static load. Place the assembled mold on a solid foundation during compaction.

b. Pour approximately one-half of the prepared sample in the mold. If the material contains rock particles larger than $\frac{1}{4}$-in., rod 20 to 30 times with a $\frac{3}{8}$-in. bullet shaped rod (part No. 9 in Figure II), while pouring in mold to prevent rock pockets forming at the bottom or sides of the specimen. Tamp the first layer of material with 50 blows using the small end of the 6-lb. hand tamper (part No. 10 in Figure II). Physical exertion in tamping should be only sufficient to move the tamper up and down in approximately a 4-in. travel. Guide the tamper over the entire surface of the specimen. The actual compactive effort should be provided only by the combined weights of the tamper and the operator's hand. At the end of the 50 blows the tamper should be penetrating into the specimen about $\frac{1}{2}$ in. Avoid having a smoothly compacted surface at this stage because it will result in a compaction plane in the specimen when the next layer is tamped, and this would prevent the two layers from being bonded together.

c. Place the remaining portion of the sample in the mold (rodded, if sample contains coarse aggregate), and tamp, using 100 blows with the small end of the hand tamper. Level off the top of the compacted specimen by tamping lightly with the large end of the tamper in order to provide a smooth surface on an even plane at right angles to the axis of the mold. Remove the extension sleeve and the spacer, insert the follower (part No. 8 in Figure II), and place the assembly in the compression machine. Gradually apply a total load of 25,000 lb., using 1 min. to attain the first 20,000 lb. and one-half min. for the next 5,000 lb. Hold the total load of 25,000 lb. for 1 min. before releasing.

d. Push the compacted specimen, in its tin jacket, from the mold by means of a suitable device. A mechanical device for this purpose is shown in Figure III. Immediately weigh the specimen and tin jacket.



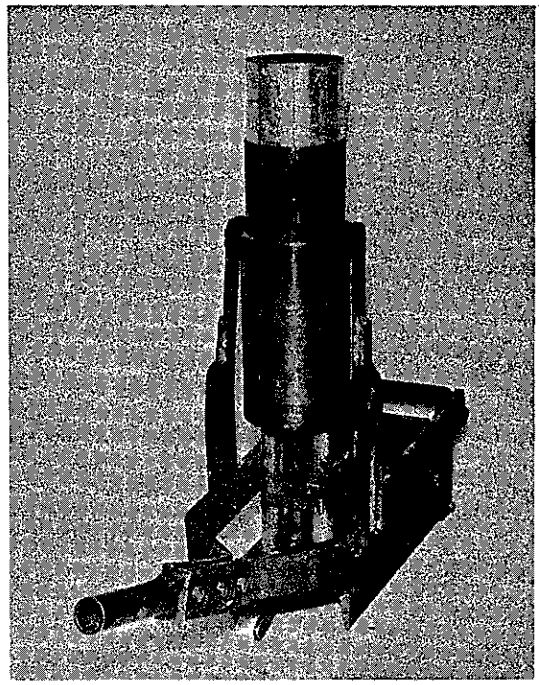


FIGURE III

Measure the height with the measuring gauge, Figure IV, by taking several readings half way between

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the center and edge of the specimen and computing the average of these measured lengths.

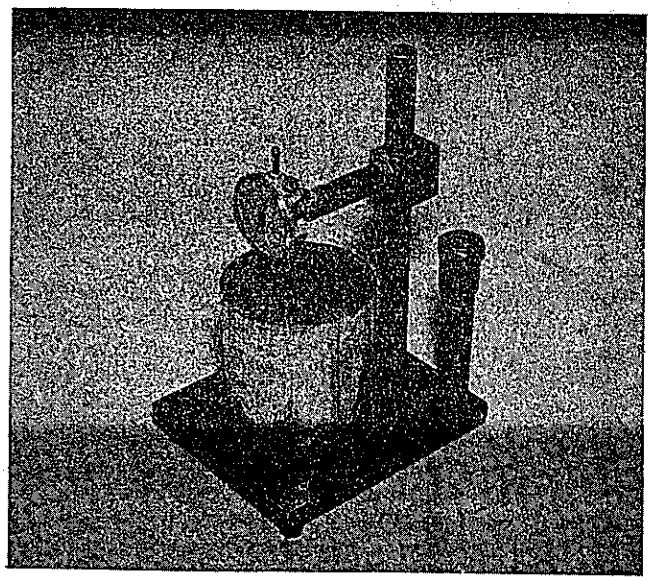

FIGURE IV

e. From the determined amount of moisture in the specimen, calculate the dry weight of the specimen. Knowing the dry weight and the measured height of the specimen, the equivalent compacted dry weight in lb. per cubic foot can be obtained from the table, Figure VI. (If the height is less than 3.988 in. or more than 4.012 in., the formula shown in Section D, Paragraph 4, must be used instead of the table.)

f. Properly mark the test specimen for identification purposes, and the specimen is ready for curing prior to testing.

g. If the specimen is to be tested for compressive strength only, the identification number can be marked on the side of the specimen with a grease pencil. However, if the specimen is to be tested for "wetting and drying" or "freezing and thawing" there is danger of losing such identification due to sloughing; therefore, it is advisable to attach a small numbered brass or copper washer to the top of the specimen by means of a brass screw.

2. Method "B"—mechanical compaction

a. Refer to Method No. Calif. 901 for method of operation and calibration of the mechanical compactor.

b. Assemble the component parts of the compaction mold, Figure V. Insert the long expansion liner, marked (B) in steel mold (A) so that ends are flush. Insert the tin liner (C) from opposite end of mold until it butts against expansion liner (B). Follow tin liner (C) with the short expansion liner (D) and insert bottom plunger (E).

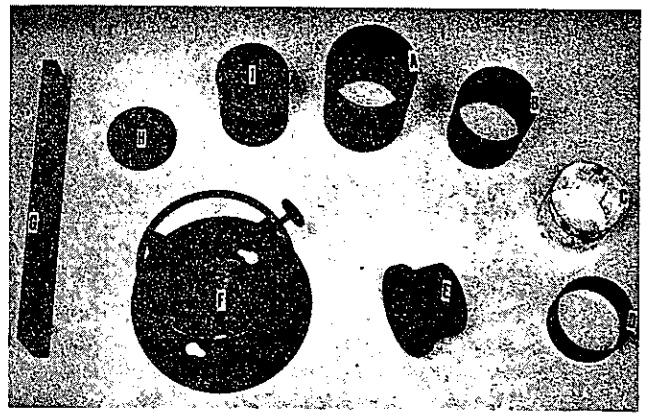

FIGURE V

c. Place the assembled mold in mold holder (F), and adjust mold vertically to provide approximately $\frac{1}{8}$ in. clearance between lower edge of mold and the base plate of the mold holder. Clamp mold in place, position the assembly on compactor turntable, and lock it on the studs provided.

d. Place the wood shim (G) under metal feeder trough to provide the additional height necessitated by the longer compaction mold.

e. Place mixed sample in the feeder trough, and distribute the loose material uniformly along the full length of the trough.

f. Start compactor and adjust the air pressure to 15 psi gauge reading.

g. Use a spatula, formed to fit the inside of the feeder trough, and push the lower 3 in. of material from the trough into the mold. With the compactor still in motion, push the remainder of the sample into the mold in 30 equal parts; push one part into the mold with each blow of the compactor foot. After all the material is in the mold, add 10 additional blows to level and seat the material.

h. Increase air pressure to a previously determined gauge reading that will provide a compactor foot pressure of 350 psi, and place the rubber disk (H) on top of the partially compacted specimen.

i. Apply 100 tamps to the specimen.

j. Immediately upon completion of the 100 tamps, remove the rubber disk and insert the follower (I) into the mold.

k. Place the mold holder containing the mold and test specimen in the testing machine and slowly apply a static load of 1,000 psi (12,500 lbs. total load) to the specimen at a rate requiring $1\frac{1}{2}$ min. to reach the maximum. Hold the load for 1 min. before releasing.

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l. The test specimen is now ready to be pushed out of the mold and cured for the compressive strength test.

F. Curing Test Specimens

1. Store or seal all test specimens in such a manner after compaction that no moisture is lost from the specimens during the curing period. This can be accomplished by curing specimens in a moist cabinet, by covering specimens with wet burlap, or by placing lids on each end of the tin sleeve and sealing with adhesive tape.
2. Cure all test specimens for six days. Then remove the tin sleeves and use a wax pencil to write proper identification on the side of the specimens.
3. Next, submerge the specimens in water for one day. This concludes the seven-day curing period, and the specimens are ready to be tested for compressive strength.

G. Testing for Compressive Strength

1. Remove test specimens from the soaking tank and dry the surfaces of the specimen with a cloth.
2. For each specimen, grease two 6 in. x 6 in. glass plates on one side using ordinary lubricating oil. Arrange the glass plates in a double row on a table and place the surface dried test specimens in a row between the two rows of greased plates.
3. Mix enough plaster of Paris with water to form a thick paste sufficient in quantity to cap approximately six specimens, top and bottom.
4. Place an amount of the paste equivalent to a large tablespoonful on top of each of the test specimens and on each of the glass plates in the row nearest the operator.
5. Place the outer row of glass plates that have no paste on them on the top surface of the specimens containing the plaster paste. Force the plates down until the paste covers the entire surface of the specimens. Then, place the specimens with top plates in place on the row of plates that have paste on them, and press the specimens down until the paste covers the entire area of the bottom of the specimens. Adjust the specimens while plaster is still soft so that top and bottom plates are as nearly as possible at right angles to the vertical axis of test specimen.
6. Allow specimens to stand for a period of 30 to 40 minutes to permit hardening of the plaster. Remove the glass plates by tapping the edges lightly with a piece of soft wood. If difficulty is experienced in removing the plates, apply warm water and continue tapping lightly.
7. The specimens are now ready to be placed in the testing machine for compressive strength tests.
   a. If mechanical testing machine is used, the travel of the head shall be at the rate of 0.05 in. per min.
   b. If hydraulic testing machine is used, apply the load at the rate of between 20 and 50 lb. per square inch per second. Ideal rate of loading on a 4-in. diameter specimen for the hydraulic testing machine is 2,200 lb. total load in 5 seconds.
8. Apply the load until ultimate fracture of the test cylinder occurs. An initial fracture will usually occur at approximately 80 percent of the load required for ultimate fracture.

FIGURE VI

TABLE OF WEIGHTS FOR USE IN FABRICATING 4-IN. DIAM. X 4-IN. HIGH TEST SPECIMENS OF VARIOUS WEIGHTS PER CU. FT.

Wt. lbs. cu. ft.	Total grams cement + agg.	Grams cement						
		2 percent	3 percent	4 percent	5 percent	6 percent	7 percent	8 percent
107	1,412	28	41	54	67	80	92	105
108	1,426	28	42	55	68	81	93	106
109	1,439	28	42	55	69	82	94	107
110	1,452	29	42	56	69	82	95	108
111	1,465	29	43	56	70	83	96	109
112	1,478	29	43	57	70	84	97	109
113	1,492	29	44	57	71	85	98	110
114	1,505	30	44	58	72	85	99	111
115	1,518	30	44	58	72	86	99	112
116	1,531	30	45	59	73	87	100	113
117	1,544	30	45	59	74	87	101	114
118	1,558	31	45	60	74	88	102	115
119	1,571	31	46	60	75	89	103	116
120	1,584	31	46	61	75	90	104	117
121	1,597	31	47	61	76	90	105	118
122	1,610	32	47	62	77	91	105	119
123	1,623	32	47	62	77	92	106	120
124	1,637	32	48	63	78	93	107	121
125	1,650	32	48	64	79	93	108	122
126	1,663	33	49	64	79	94	109	123
127	1,676	33	49	65	80	95	110	124
128	1,690	33	49	65	81	96	111	125
129	1,703	33	50	66	81	96	111	126
130	1,716	34	50	66	82	97	112	127
131	1,729	34	50	67	82	98	113	128
132	1,742	34	51	67	83	99	114	129
133	1,756	35	51	68	84	99	115	130
134	1,769	35	52	68	84	100	116	131
135	1,782	35	52	69	85	101	117	132
136	1,795	35	52	69	86	102	118	133
137	1,808	36	53	70	86	102	118	134
138	1,822	36	53	70	87	103	119	135
139	1,835	36	53	71	87	104	120	136
140	1,848	36	54	71	88	105	121	137
141	1,861	37	54	72	89	105	122	138
142	1,874	37	55	72	89	106	123	139
143	1,888	37	55	73	90	107	124	140
144	1,901	37	55	73	91	108	124	141
145	1,914	38	56	74	91	108	125	142
146	1,927	38	56	74	92	109	126	143
147	1,940	38	57	75	92	110	127	144
148	1,954	38	57	75	93	111	128	145
149	1,967	39	57	76	94	111	129	146
150	1,980	39	58	76	94	112	130	147

To obtain weight of aggregate subtract weight of cement from total weight of cement and aggregate.

9. Report the test results as compressive strength in pounds per square inch which equals the total compression load divided by the end area of the test cylinder.

   In the standard 4-in. test cylinder the end area is 12.57 sq. in. An optional method is to multiply the total compression load by .080, in lieu of dividing total load by 12.57.

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Reporting of Results

Report the test results on Test Report Form T-346. Include grading used, compressive strength, and recommended moisture and cement contents.

PART II. FIELD METHOD

A. Apparatus

1. Balance with capacity of 5,000 g., accurate to 1 g.
2. Split compaction mold, 4-in. diam. x 11.5 in. as shown in Figure VII.

HYDRAULIC COMPACTION APPARATUS

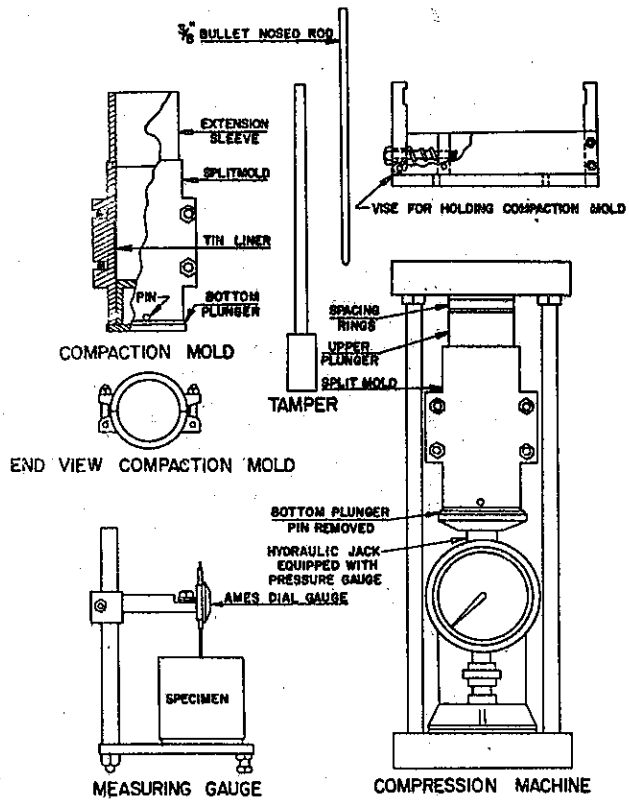

FIGURE VII

3. One compression machine consisting of a 12-20-ton capacity hydraulic jack fitted with a spherically seated head and mounted in a 30-in. frame.
4. Tamper, rod, tin liners and bottom and upper plunger as shown in Figure II (Nos. 1, 5, 8, 9 and 10).
5. Measuring gauge and stand as shown in Figures IV and VII.
6. Special bench vise for holding compaction mold as shown in Figure VII.
7. 6 in. x 12 in. concrete cylinder cans with lids.
8. Two 6 in. x 6 in. glass plates for each specimen.
9. Miscellaneous items such as spoons, spatulas, scoops, scotch tape, etc.

B. Materials

1. A supply of gypsum casting plaster.
2. Cartons for shipping test specimens.
3. Supply of ½-in. adhesive tape.

C. Procedure for the Fabrication of Test Specimens

1. Obtain representative samples of the freshly mixed materials daily. Normally two samples should be taken, one from the mixing plant and one from the street immediately ahead of rolling operations. To protect against the loss of moisture, place all samples in 6 in. x 12 in. concrete cylinder cans and immediately cover.
2. Transport the cans to the point of fabrication and fabricate samples with the least possible delay. Protect against loss of moisture at all times.
3. Immediately upon arrival at the point of fabrication, remix the sample and screen through a 1-in. sieve. Only the minus 1-in. material is used in making test specimens.
4. Quarter out the approximate amounts required for the moisture determination and test specimen. The amount of material for moisture samples should be approximately 1,000 g. The amount of material needed for fabricating a test specimen is shown in the attached Figure VI.

   It is of extreme importance that test specimens be fabricated as soon as possible after the mixing process. The hydration of the cement can cause a serious loss of compressive strength as well as a reduction in the density of the test specimen.
5. Weigh the material for both moisture samples and test specimens to the nearest gram, and weigh as rapidly as possible to avoid loss of moisture. Ordinary baking pans, approximately 9 in. x 5 in. x 4 in., make convenient weighing pans. Protect all material for test specimens against loss of moisture after weighing, and do not delay between weighing and fabricating.
6. Assemble the 4-in. mold with the tin liner in place and the plunger held one space from the bottom by means of the pin. (For some soils it may be necessary to hold the bottom plunger further from the end of the mold in order to prevent the rim of the mold from coming in contact with the shoulder of the plunger before compaction is completed. In such cases, insert the pin through successively higher holes until satisfactory results are secured.)
7. Place the extension sleeve on top of the mold and add approximately half of the weighed sample with a scoop or large spoon. If the material contains rock particles larger than ¼ in., rod 20 to 30 times with a ⅝-in. bullet-nosed rod

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during this operation in order to prevent the formation of rock pockets at the bottom or sides of the specimen. Tamp the first layer of material 50 blows with the *small end* of the 6-lb. hand tamper. Physical exertion in tamping should be only sufficient to move the tamper up and down in approximately a 4-in. travel. Guide the tamper over the entire surface of the specimen. The actual compactive effort should be provided only by the combined weights of the tamper and the operator's hand. Avoid a smoothly compacted surface because it will result in a compaction plane in the specimen when the next layer is tamped, and will prevent the two layers from bonding.

8. Place the remaining portion of the sample in the mold and rod if sample contains coarse aggregate. It is not necessary to rod fine material such as sand. Tamp the second layer using 100 blows with the *small end* of the hand tamper. Level off the top of the compacted specimen by tamping lightly with the *large end* of the tamper in order to provide a smooth surface on an even plane at right angles to the axis of the mold. After tamping is completed, remove the extension sleeve.
9. Place the top plunger in position, then place the entire assembly on the hydraulic jack in the compression frame. If necessary, place one or more of the spacing rings between the top plunger and the top of the frame to prevent excessive travel of the jack. *Remove the pin that holds the bottom plunger in place* and gradually apply a total load of 25,000 lb.; use 1 min. to attain the first 20,000 lb., ½ min. for the next 5,000 lb. and hold the 25,000-lb. load for 1 min. Then release the load, place the mold in the vise, take out the plungers, open the mold, remove the specimen with its tin jacket and weigh.
10. Determine the height with the measuring gauge by taking several readings half way between the center and edge of the specimen and computing the average of these measured lengths. The height measurement is illustrated in Figure VII.
11. If water is squeezed out of the specimen during compaction, a notation should be made of the amount as a guide in maintaining optimum moisture control in the field. This is done by taking the difference between the net weight of the specimen and the net weight of the sample used. Headquarters laboratory will normally make optimum moisture determinations on preliminary samples which may serve to compare with field results. However, in applying optimum moisture control in the field, consideration must be given to evaporation losses in mixing and handling and allowances made accordingly.
12. Determine the moisture content of the sample by weighing the material set aside for this purpose (approx. 1,000 g.) to the nearest one (1) gram and drying in a 230-F. oven to constant weight.

$$\text{Percent moisture} = \frac{\text{Wet weight} - \text{dry weight}}{\text{Dry weight}} \times 100$$

13. After determining the height and weight of the compacted specimen, print the proper identifying marks on the side of the tin liner with a wax pencil. Place tin caps on each end and seal with masking tape.
14. Cure the specimens for two days in a cool place and then ship the test specimens to the district laboratory for testing.

D. Procedure for the Determination of Compressive Strength in the Field

1. If it is necessary that compressive strengths be determined on the job, the test specimens should be cured for six days. The curing shall be accomplished by placing lids on each end of the tin sleeve, sealing with adhesive tape and then storing in a cool place such as the shady side of a building. However, during cold weather, the test specimens should be protected from freezing. At the end of the six-day curing period, remove the caps and liners and transfer the identifying marks to the side of the specimen with a wax pencil.
2. Immerse the specimens in water for one day in order to complete the seven-day curing period required for the compressive strength test.
3. Remove the specimens from the water bath, wipe the surfaces with a dry rag and cap both ends of each specimen with gypsum casting plaster as follows:
   a. Select two glass plates, approximately 6 in. x 6 in., for each specimen and lay them out on a table or bench.
   b. Oil the top of each glass with common motor lubricant.
   c. Measure out into a suitable container about a cup of gypsum casting plaster for each specimen to be capped.
   d. Add water and mix to a fairly thick paste.
   e. Place a tablespoonful of paste on top of each test specimen and immediately force one of the plates down on the paste on top of each specimen to form full caps.
   f. Place a tablespoonful of paste on each of the other glass plates and press each of the specimens firmly on a glass plate so as to form full caps.
   g. Allow the caps to harden for a minimum of 30 minutes and then remove the glass plates by tapping the edges lightly with a piece of soft wood. If difficulty is experienced in removing the plates, apply warm water and continue tapping lightly.

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4. The specimen may be tested for compressive strength as soon as the glass plates are removed. Center the specimen on the head of the hydraulic jack in the compression machine and apply the load at the rate of between 20 and 50 lb. per square inch per second. A convenient rate of loading when using the compression machine on a 4-in. diameter test specimen is 30,000 lb. per minute. This allows easy conversion in the field to desired load-time units (i.e. 500 lb. per second). Apply the load until ultimate fracture of the test cylinder occurs. An initial fracture will usually occur at approximately 80 percent of the load required for ultimate fracture.
5. Report the test results as compressive strength in pounds per square inch which equals the total compression load divided by the end area of the 4-in. diameter test specimen (12.57 sq. in.). Fig. VIII lists the unit compressive stress in increments of 500 lb. total load.

FIGURE VIII

TABLE OF UNIT COMPRESSIVE STRENGTH

4-in. Diameter Cement Treated Base Specimen

Total load (lbs.)	Compressive strength (psi)	Total load (lbs.)	Compressive strength (psi)	Total load (lbs.)	Compressive strength (psi)
500	40	10,500	840	20,500	1,640
1,000	80	11,000	880	21,000	1,680
1,500	120	11,500	920	21,500	1,720
2,000	160	12,000	960	22,000	1,760
2,500	200	12,500	1,000	22,500	1,800
3,000	240	13,000	1,040	23,000	1,840
3,500	280	13,500	1,080	23,500	1,880
4,000	320	14,000	1,120	24,000	1,920
4,500	360	14,500	1,160	24,500	1,960
5,000	400	15,000	1,200	25,000	2,000
5,500	440	15,500	1,240	25,500	2,040
6,000	480	16,000	1,280	26,000	2,080
6,500	520	16,500	1,320	26,500	2,120
7,000	560	17,000	1,360	27,000	2,160
7,500	600	17,500	1,400	27,500	2,200
8,000	640	18,000	1,440	28,000	2,240
8,500	680	18,500	1,480	28,500	2,280
9,000	720	19,000	1,520	29,000	2,320
9,500	760	19,500	1,560	29,500	2,360
10,000	800	20,000	1,600	30,000	2,400

Procedure for Determining the Density of Test Specimens

The density of the test specimen, based on the dry weight of material, is calculated from the data obtained in the "Procedure for the Fabrication of Test Specimens" using the following formula:

$$D = \frac{30.3W_w}{(100 + M)H}$$

Where:

D = Dry density of the test specimen in lb. per cu. ft.
W_w = Wet weight of the test specimen in grams.
M = Percent moisture of the sample.
H = Height of the test specimen in inches.
30.3 = Constant used to convert weight in grams to lb. per cu. ft. for a 4-in. diameter specimen having the height measured in inches.

REFERENCES

Test Method No. Calif. 201
Method No. Calif. 901
Method No. Calif. 905

End of Text on Calif. 312-B

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State of California
Department of Public Works
Division of Highways

MATERIALS AND RESEARCH DEPARTMENT

METHOD OF FREEZING AND THAWING TEST FOR COMPACTED TEST SPECIMENS OF CEMENT TREATED BASES, CLASSES "A" AND "B," AND CEMENT TREATED SUBGRADE

Scope

This method, which is a modification of A. A. S. H. O. Designation: T 136, is intended for determining visual physical condition, volume change (swell), and compressive strength after the compacted test specimens have been subjected to repeated cycles of alternate freezing and thawing.

Procedure

A. Apparatus

1. Freezer or refrigerator capable of maintaining a temperature of minus 10 F. or lower.
2. All of the apparatus specified for Test Method No. Calif. 312.

B. Test Record Form

Record the test data on work card, Form T-342.

C. Preparation of Test Specimen

Prepare and compact the specimen, using optimum moisture and desired amount of cement, in accordance with Test Method No. Calif. 312.

D. Curing Test Specimen

1. Store or seal test specimen in such a manner that no moisture is lost from the specimen during the curing period. This can be accomplished by curing specimen in a moist cabinet, by covering specimen with wet burlap, or by placing lids on each end of the tin sleeve and sealing with adhesive tape.
2. Cure test specimen for seven days. Remove the tin sleeves and make sure that the numbered identification disk is attached to the top of the specimen.

E. Freezing and Thawing Cycles

Place the specimen in a freezer or refrigerator having a constant temperature not warmer than minus 10 F. for 22 hr., then remove, surface dry, weigh (to detect any sloughing), and measure for height. Place in a moist cabinet and allow to thaw for 22 hr., remove, and again weigh and measure. This constitutes one cycle of freezing and thawing. Continue this freezing and thawing process until 12 cycles have been completed, provided, of course, that serious disintegration of the specimen does not occur sooner.

F. Test Calculations

1. If the specimen has increased in length after completion of the 12 cycles of alternate freezing and thawing, calculate the volume change as percent of original volume. If the specimen has decreased in length, consider the volume change zero.

   The formula for volume change is:

   $$\text{Percent volume change} = \frac{V_2 - V_1}{V_1} \times 100$$

   V_1 = Volume of specimen at beginning of cycle period
   V_2 = Volume of specimen at end of cycle period

   Example:

	Height of specimen	*Diameter of specimen*
Before cycle period	4.092 in.	4.000 in.
After cycle period	4.097 in.	4.005 in.

   $V_1 = (2)^2 \times 3.1416 \times 4.092 = 51.421$ cu. in.
   $V_2 = (2.0025)^2 \times 3.1416 \times 4.097$
   $= 51.614$ cu. in.

   $$\text{Volume change} = \frac{51.614 - 51.421}{51.421} \times 100$$
   $= 0.4$ percent

2. Examine the specimen visually for physical condition, and report as excellent, good, fair or poor.
3. Then submerge the specimen in water for one day and test for compressive strength as specified in Test Method No. Calif. 312.

Reporting of Results

Report the test results on Test Report, Form T-346.

REFERENCES

A. A. S. H. O. Designation: T 136
Test Method No. Calif. 312

End of Text on Calif. 313-B

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State of California
Department of Public Works
Division of Highways

MATERIALS AND RESEARCH DEPARTMENT

METHOD OF WETTING AND DRYING TEST FOR COMPACTED TEST SPECIMENS OF CEMENT TREATED BASES, CLASSES "A" AND "B," AND CEMENT TREATED SUBGRADE

Scope

This test, which is a modification of A. A. S. H. O. Designation: T 135, is intended for determining visual physical condition, volume change (swell), and compressive strength after the compacted test specimens have been subjected to repeated cycles of alternate wetting and drying.

Procedure

A. Apparatus

All of the apparatus specified for Test Method No. Calif. 312.

B. Test Record Form

Record the test data on work card, Form No. T-342.

C. Preparation of Test Specimen

Prepare and compact the specimen, using optimum moisture and desired amount of cement, in accordance with Test Method No. Calif. 312.

D. Curing Test Specimen

1. Store or seal test specimen in such a manner that no moisture is lost from the specimen during the curing period. This can be accomplished by curing specimen in a moist cabinet, by covering specimen with wet burlap, or by placing lids on each end of the tin sleeve and sealing with adhesive tape.
2. Cure test specimen for seven days. Remove the tin sleeves and make sure that the numbered identification disk is attached to the top of the specimen.

E. Wetting and Drying Cycles

1. Submerge the specimen in water for 5 hr., remove, surface dry, weigh (to detect any sloughing), and measure for height. Then place in a drying oven with temperature at 140 F. and leave for 42 hr., at which time remove and again measure and weigh.
   a. The above procedure constitutes one cycle of wetting and drying; and with the time used in transferring, weighing, and measuring adds up to a total time of approximately 48 hr.
   b. Continue this wetting and drying process until 12 cycles have been completed, provided of course that serious disintegration of the specimen does not occur sooner.

F. Test Calculations

1. If the specimen has increased in length after completion of the 12 cycles of alternate wetting and drying, calculate the volume change as percent of original volume. If the specimen has decreased in length consider the volume change zero.

   The formula for volume change is:

$$\text{Percent volume change} = \frac{V_2 - V_1}{V_1} \times 100$$

V_1 = Volume of specimen at beginning of cycle period

V_2 = Volume of specimen at end of cycle period

Example:

	Height of specimen	*Diameter of specimen*
Before cycle period	4.092 in.	4.000 in.
After cycle period	4.097 in.	4.005 in.

$V_1 = (2)^2 \times 3.1416 \times 4.092 = 51.421$ cu. in.

$V_2 = (2.0025)^2 \times 3.1416 \times 4.097$
$= 51.614$ cu. in.

$$\text{Volume change} = \frac{51.614 - 51.421}{51.421} \times 100$$

$= 0.4$ percent

2. Examine the specimen visually for physical condition, and report as excellent, good, fair or poor.
3. Then submerge the specimen in water over night and test for compressive strength as specified in Test Method No. Calif. 312.

Reporting of Results

Report the test results on Test Report, Form T-346.

REFERENCES

A. A. S. H. O. Designation: T 135.
Test Method No. Calif. 312.

End of Text on Calif. 314-B

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State of California
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Division of Highways

MATERIALS AND RESEARCH DEPARTMENT

DETERMINATION OF CEMENT CONTENT IN CEMENT TREATED AGGREGATE BY THE METHOD OF TITRATION

Scope

This method covers the procedures for determining the percentage of Portland cement in freshly mixed cement treated base on a project under construction. The determinations are based upon chemical titration methods which relate the cement concentration of field treated samples to known solution concentrations. Two different titration procedures are given; first, an acid-base titration method and second, a constant neutralization method. Normally the first method is used when the aggregates *do not* react to hydrochloric acid. This method is fast and experience indicates that it can be used for about 90% of the aggregates in California. However, when aggregates are encountered which react to hydrochloric acid, the second *method* must be used.

This test method is divided into the following parts:

General
- I. Method of Test by Acid-Base Titration
- II. Method of Test by Constant Neutralization
- III. Method of Field Sampling

This test method was designed for Portland cement treated aggregates, but the same procedure can also be used for determining the percentage of lime in aggregates which have been treated with commercial hydrated calcium lime.

GENERAL

The *first* thing that *must* be done when testing for cement content on a cement treated base project is to determine whether significant amounts of such substances as limestone, calcite, dolomite, etc., which are subject to attack by hydrochloric acid, exist in the aggregate. The following procedure accomplishes this and indicates whether Part I or Part II of this Test Method should be used for cement content determinations.

The Acid-Base test, Part I of this Test Method, is performed on duplicate aggregate blank (containing no cement) specimens using the procedures for test specimen preparation, acid digestion and titration given in section E-4 (Part I). This test is then repeated on duplicate test specimens composed of standard or graded Ottawa sand. Glass beads of the type normally used for highway centerline stripes may be substituted if Ottawa sand is not readily available.

The appropriate test procedure for use on a project is based upon the following determination:

If either of the titration tests using aggregate blanks require an amount of sodium hydroxide which is six (6) mililiters (mls.) or more lower than the average of the Ottawa sand blanks, the Constant Neutralization Method, Part II, shall be used. If the difference is less than 6 ml., the Acid-Base test, Part I, should be used (Part II may also be used in this case if desired).

It is *imperative* that the proper test method be selected *first* before proceeding with a determination of actual cement content.

PART I. METHOD OF TEST BY ACID-BASE TITRATION

Scope

This method describes a procedure for cement content determination based upon the neutralization of the cement with an excess of hydrochloric acid. The residual excess acid, as measured by back titration with an alkali, is inversely proportional to the cement content of the treated base sample. This test procedure cannot be used if acid active aggregates, as indicated at the start of this Test Method under "General", are used in the cement treated material.

Procedure

A. Apparatus

1. 1—100 ml. titrating burette
2. 1—100 ml. pipette
3. 1—Burette stand and burette clamp
4. 4—200 ml. volumetric flasks
5. 8—250 ml. Erlenmeyer flasks
6. 8—plastic beakers approximately 500 mls. min. capacity
7. Glass (or plastic) dropping bottle

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8. 8—2 quart wide-mouth polyethylene containers
9. 3—5 gal. plastic "carboys" equipped with siphons, neoprene or tygon tubing, hose clamps etc., for containing working solutions of acid, base and water (do not substitute glass containers for the plastic carboys).
10. 8—Stainless steel stirring rods
11. ⅜ inch sieve, 12" Dia.
12. 1½ inch sieve, 12" Dia.
13. Ohaus balance (or equal), 5 Kg. capacity, graduated to 1 gram
14. Torsion balance, 500 gm. capacity, graduated to 0.1 gram
15. Timer

B. Reagents and Materials

1. *Hydrochloric acid* (approx. 3N)
Pour the contents of two full standard 6 lb. bottles of concentrated hydrochloric acid C. P. (Service & Supply stock No. 69010.81) into one of the 5 gal. plastic carboys. Add tap water in approximately one gallon increments until 5 gal. of solution is obtained. After each addition of water shake the carboy vigorously for about one minute to obtain a homogeneous mixture.

2. *Sodium Hydroxide* (approx. 1N)
Use the following procedure for making 5 gallons of solution:

a. Using a second plastic carboy, dissolve 800 grams of sodium hydroxide pellets (Service and Supply stock No. 69010.83) in about one gallon of hot tap water at a temperature of approximately 110 F. (This can be judged as being about as hot as a person's hand can stand.)

b. Stopper and shake the carboy vigorously for about one minute.

c. Continue adding tap water in one gallon amounts and shake after each addition until 5 gallons of solution is attained. After the first gallon of water is added, successively reduce the temperature of each subsequent increment until the last gallon is added at the temperature of the cold tap.

d. Cool to room temperature, then examine the solution for suspended matter by looking down through the neck opening of the carboy while using a flashlight around the outside of the bottom for illumination. The solution *must* be clear for use. Experience indicates that when suspended matter in the form of a precipitate is present it is usually the result of either insufficient heat in the mixing water or insufficient agitation. Dissolving the objectionable precipitate requires reheating the 5 gallons of solution. Since this is normally impractical, it is better to discard it and mix a new solution.

NOTE: The operator(s) mixing the acid and base solutions are required, for safety, to wear chemical protective gloves, goggles, and aprons.
Do not use compressed air to agitate the solutions in the carboys.

3. *Phenolphthalein indicator solution* (1% solution)
Dissolve 5 grams of phenolphthalein powder U.S.P. in 250 mls. of ethanol. Dilute with 250 mls. of distilled water (Service & Supply stock No. 69010.85 for prepared 1% solution).

4. *Ottawa sand* (Standard or Graded).
Glass beads of the type normally used for highway centerline stripes may be substituted if Ottawa sand is not readily available.

C. Test Record Form

Use work card "Field-Laboratory Record of Titration Tests", Form T-3040, for recording project, calibration, and field test data (See Figure II). (Service & Supply Stock No. 12953.40)

D. Titration of Field Samples

1. Determine whether the aggregate reacts with acid, as described at the beginning of this Test Method under "General". If the aggregate does not react with acid, proceed with this method.

2. Secure from one to eight field samples of cement treated aggregate by means of the procedure specified in Part III. Each field sample should weigh at least three kilograms.

3. Prepare from one to eight 300 gram specimens as follows:

a. Determine total weight of each field sample to nearest 5 grams.

b. Remove and waste any aggregate retained on the 1½ inch sieve.

c. Separate sample on the ⅜ inch sieve and determine the proportion passing the ⅜ inch sieve on the basis of total sample weight including retained 1½ inch material.

d. Recombine the retained and passing ⅜ inch portions for the 300 gram test specimens in their "As received" proportions, place each specimen in a separate two quart plastic container, and line the containers up along the front of the work bench.

e. In field testing operations there is a lapse of time between the mixing of the cement treated base and the final preparation of the 300 gram test specimens. This is the time required to obtain a sample, transport it to the testing location and prepare the 300 gram test specimens. Since the cement is hydrating during this period some changes will occur

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in the test determinations depending on the length of the time lapse. Therefore, in order to correct for these changes, establish by trial the time lapse required for the particular project and use this as the "standing period" specified in section E-3-g of this Part I. The standing period used for subsequent samples should be within ± 15 minutes of this established period.

4. Measure accurately for each specimen 200 ml. 3N HCl, using the volumetric flask; pour into an Erlenmeyer flask and set one flask behind each specimen container.
5. Measure accurately for each specimen 400 ml. tap water; pour into a plastic beaker and set one beaker behind each Erlenmeyer flask of acid.
6. Start the timer, add the 200 mls. of acid to the first specimen and stir for 45 seconds. Add 200 mls. of acid to the second specimen and stir 45 seconds. Continue this procedure until 200 mls. of acid has been added to all specimens and they have each been stirred 45 seconds.
7. When timer reaches 6 minutes, start stirring of each specimen for 45 seconds, in sequence.
8. When timer reaches 12 minutes, again stir each specimen for 45 seconds, in sequence.
9. When timer reaches 18 minutes, add the 400 mls. of water from the plastic beaker to the first specimen and stir for 45 seconds. Add 400 mls. of water to the second specimen, stir 45 seconds, and continue procedure until 400 mls. of water has been added to all specimens and they have each been stirred for 45 seconds.
10. Rinse out the Erlenmeyer flasks.
11. Allow specimens to settle until timer reaches 30 minutes, then pipette a 100 ml. portion of the residual acid solution from the first specimen and deposit in one of the clean Erlenmeyer flasks. At 45 second intervals, pipette 100 mls. of solution from each of the other specimens in sequence and deposit in clean Erlenmeyer flasks.
12. Add two droppers full (approximately 40 drops) of phenolphthalein solution to the solution in each of the Erlenmeyer flasks.
13. Titrate the solution in each flask by adding 1 normal sodium hydroxide (NaOH) from the burette until a deep red color is formed which does not fade when the flask is shaken for one minute. If allowed to settle for a few minutes, the clear liquid should remain red. Record the burette readings to the nearest 0.2 ml. for the solution in each flask. (See the reverse side of work card, Form T-3040, as shown in Fig. II).
14. Using the resulting titration values, determine the percentages of cement in the specimens from the standard curve (see section E and Fig. II).

E. Determination of a Standard Curve

1. The standard curve establishes the relationship between the amount of sodium hydroxide used in titration and the percent cement in a test specimen for the particular aggregates, cement, and water used on the project.
2. Two points are needed to establish the standard curve; one point will be determined from duplicate tests on specimens containing 5% cement and the other from duplicate tests on aggregate blank specimens.
3. Use the following procedure to fabricate and test the calibration test specimens containing 5% cement.
   a. Determine a representative field moisture (%) for the cement treated material from road moisture samples obtained after mixing.
   b. Refer to Table No. 1 and select the weight of aggregate corresponding to the appropriate moisture content and 5% cement. This figure is the dry weight of untreated aggregate required to make a 5% calibration test specimen of 300 grams. If the samples of untreated aggregate initially contain moisture, then adjust the weight of aggregate plus water to conform to the tabular values.
   c. From the project records determine the average percentage of untreated aggregate passing the ⅜ inch sieve. This percentage passing the ⅜ inch sieve along with the portion retained on the ⅜ inch sieve will be the proportion used for the calibration specimens.
   d. Remove and waste any aggregate in the sample of untreated material retained on the 1½ inch sieve and then separate the sample on the ⅜ inch sieve. Recombine for duplicate calibration test specimens with the aggregate weight found in (b) above, and with the ⅜ inch sieve proportions found in (c) above.

TABLE NO. 1
QUANTITIES OF MATERIALS FOR CALIBRATION SPECIMENS CONTAINING 5% CEMENT

% Moisture	*Dry Wt. of Agg. in grams*	*Mls. of Water*	*Wt. of Cement in grams*
5	271	15	13.6
6	270	17	13.5
7	267	20	13.3
8	265	22	13.2
9	263	24	13.1
10	260	27	13.0
11	257	30	12.9
12	255	32	12.8
13	252	35	12.6
14	250	37	12.5
15	249	39	12.4
16	247	41	12.3
17	244	44	12.2
18	242	46	12.1
19	240	48	12.0
20	238	50	11.9

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e. Pour the weighed aggregates and cement (cement weighed to 0.1 gram) into the two quart plastic container and dry mix together thoroughly with a stainless steel stirring rod.

f. Add the mls. of water given in Table No. 1 and again mix thoroughly.

g. In order to correlate with the field testing operations, allow the mixture to stand in the covered plastic container for a period of time which corresponds to the time required to obtain a field treated sample, transport it to the testing location and prepare the 300 gram test specimens (see Section D-3-e). Normally the standing period should not be less than 30 minutes nor more than 90 minutes.

h. At the conclusion of the standing period, start the acid digestion and titration test procedure given in the preceding Section D.

4. Use the following procedure to fabricate and test the aggregate blank specimens:

a. Using the representative field moisture (%) as determined in Section E-3-a, refer to Table No. 2 for the proper quantities of dry aggregate and water to be used.

TABLE NO. 2
QUANTITIES OF MATERIAL FOR AGGREGATE BLANK SPECIMENS

% Moisture	*Dry Wt. of Agg. in grams*	*Mls. of Water*
5	286	14
6	283	17
7	280	20
8	277	23
9	275	25
10	273	27
11	270	30
12	268	32
13	266	34
14	263	37
15	261	39
16	259	41
17	256	44
18	254	46
19	252	48
20	250	50

b. Use these weights of dry aggregate to fabricate duplicate aggregate blank specimens in the manner described in Section E-3-d.

c. Pour the aggregates and water into the two quart plastic container, mix thoroughly, allow to stand for the standing period as specified in Section E-3-g, then test in accordance with preceding Section D.

5. Plot the burette milliliter readings (abscissa) against the percent cement (ordinate) for both the duplicate 5% cement specimens and the duplicate aggregate blank specimens (0% cement) on the graph provided on Form T-3040 as illustrated in Figure II. Draw a straight line between the averages of the paired tests. This is the standard curve for determining the cement content of field mixed cement treated specimens.

F. Precautions

1. This test should not be performed by persons subject to color "blindness".

2. Keep all reagent bottles closed when not in use to prevent evaporation and the consequent changes in concentration.

3. Rinse and drain all glassware and plasticware when the day's work is done.

Notes

A standard curve should be determined *at least once per day*. In event of any change in source of aggregate or cement or new working solutions of acid or hydroxide, another determination should be made.

Hazards

Extreme care should be exercised in handling the concentrated solutions of hydrochloric acid (HCl) and sodium hydroxide (NaOH). If either of these chemicals are spilled in the eyes, on the skin, or on the clothing, the affected areas should be flushed immediately with liberal quantities of water.

Care should also be exercised in the use of the dilute solutions of HCl and NaOH as these dilute solutions can also be harmful to the eyes, cuts, skin, or clothing.

The following safety recommendations regarding the use of this test method are by the State Division of Highways Safety Engineer:

1. Since the test is a chemical analysis requiring the handling of acids and bases, it is recommended that its use be limited to Materials & Research trained and controlled personnel.

2. Information on the test should include a requirement that when handling either acids or bases, personnel will be required to wear chemical protective gloves, goggles, and aprons.

3. Test instructions should contain a requirement that glass carboys are not to be substituted for plastic carboys described in the test apparatus and that all containers having either acids or bases, or solutions made from them, are to be clearly labeled.

4. It is suggested that there be some notation that while there is limited danger associated with getting a part of the final solution in the mouth after it has acted on the cement, extreme care should be taken not to permit any of the pure acid to get into the mouth.

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5. Personnel conducting experiments should know that Phenolpthalein has been known to cause allergic symptoms in humans and has a powerful laxative effect. It can be toxic. Exposed personnel who are sensitive to it should wear protective clothing, if necessary, to avoid bodily contact. Do not ingest.

PART II. METHOD OF TEST BY CONSTANT NEUTRALIZATION

Scope

This method is an alternate to the Acid-Base test procedure, Part I, and is used for determining cement content when the aggregate is found to react with acid. The determinations are based upon the continuous neutralization of an aqueous solution from the cement treated aggregate specimen for a specified time period. This is accomplished by adding sufficient acid to just neutralize the OH ion which is continuously being liberated during the hydration of the cement. The amount of acid used is directly proportional to the cement content of the treated base sample.

Procedure

A. Apparatus

1. 1—100 ml. titrating burette or other device permitting slow, easily controlled addition of acid.
2. 1—burette stand and burette clamp.
3. 4—2 quart wide mouth polyethylene containers.
4. 2—5 gal. plastic "carboys" equipped with siphons, neoprene or tygon tubing, hose clamps, etc., for containing acid working solution and water (do not substitute glass containers for the plastic carboys).
5. Glass dropping bottle.
6. 4—stainless steel stirring rods.
7. 3/8 inch sieve, 12 inch Dia.
8. 1½ inch sieve, 12 inch Dia.
9. Ohaus balance (or equal), 5 kg. capacity, graduated to 1 gram.
10. A balance having a minimum capacity of 1 kg. and graduated to 0.1 gram.

B. Reagents

1. *Hydrochloric acid* (approx. 3N)

   Pour the contents of two full standard 6 lb. bottles of concentrated hydrochloric acid C.P. (Service & Supply stock No. 69010.81) into one of the 5 gal. plastic carboys and dilute with tap water in the manner indicated in Part I, Section B-1, to make 5 gal. of solution.

   NOTE: The operator(s) mixing the acid solution are required, for safety, to wear chemical protective gloves, goggles, and aprons. *Do not* use compressed air to agitate the solution in the carboy.

2. *Phenolphthalein indicator solution* (1% solution)

   Dissolve 5 grams of phenolphthalein powder U.S.P. in 250 mls. of ethanol. Dilute with 250 mls. of distilled water. (Service & Supply stock No. 69010.85 for prepared 1% solution.)

C. Test Record Form

Use work card "Field-Laboratory Record of Titration Tests", Form T-3040 for recording project, calibration, and field test data (See Figure III). (Service & Supply stock No. 12953.40.)

D. Test Procedure for Field Samples

1. Secure one to four 3 kilogram field samples of the cement treated aggregate using the procedure specified in Part III. Prepare 300 gram test specimens as desscribed in Part I, Section D-3.
2. Place each specimen in a separate 2 quart plastic container.
3. Add 250 ml. of tap water to each specimen and start timer.
4. Add two droppers full (approximately 40 drops) of phenolphthalein solution to each container. The water solution will normally turn red due to the presence of cement.
5. Weigh each plastic container, including its contents, to the nearest 0.5 gram.
6. At 10 minutes after the addition of water, start adding the 3N hydrochloric acid with a titrating burette while *stirring continuously*.

   a. The initial amount of acid to be added is based upon the planned cement content of the mix and is determined from Figure I.

      Example: Suppose the planned cement content for a given project is 3½%. Enter the abscissa of the chart in Figure I at 3½% and find the intersection with the upper diagonal line. Reading from the ordinate to the nearest milliliter, it is noted that 15 mls. of HCL is required. Use the titrating burette to measure and add the 15 mls. of acid to the specimen in the plastic container. When the proper amount of acid is used, the red color in the solution will disappear.

   b. When the red color starts to reappear, after the initial introduction of acid, use the

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burette to make a second addition of acid in the amount (mls.) indicated by the lower diagonal line (at the planned cement content) of the chart in Figure I.

7. After the first two additions of acid, make subsequent additions at random as the red color reappears using only the minimum amounts necessary to cause the color to just disappear and maintain a neutral solution. This requires *constant* attention by the operator.
8. Besides the stirring accomplished during the actual introduction of the acid, additional light stirring (for about 3 seconds) should be performed every minute with every fifth minute being devoted to deep stirring (for about 6 seconds).
9. Continue this procedure of adding acid and stirring until one hour after the initial addition of water to the specimen (see 3 above). Then reweigh the plastic container and contents to the nearest 0.5 gram.
10. From the difference between the initial and final gross test specimen weights (see Fig. III), calculate and record the total weight of hydrochloric acid used to neutralize the solution.
11. Using the resulting weight of hydrochloric acid, determine the percentage of cement in the specimens from the standard curve (see Section E and Fig. III).

E. Determination of a Standard Curve

1. The standard curve establishes the relationship between the amount of hydrochloric acid used to neutralize the OH ion in the cement and the percent cement in the test specimen for the particular aggregates, cement, and water used on the project.
2. Normally only one point is needed to establish the standard curve and this point is determined from duplicate tests on specimens containing 5% cement. However, if a small sample of untreated aggregate in water shows a red color on adding a few drops of phenolphthalein solution, indicating the presence of water soluble alkalis, then duplicate aggregate blank specimens should also be tested.
3. Fabricate calibration test specimens using the applicable portions of Part I, Section E-3 & E-4.
4. Perform the Constant Neutralization test procedure in accordance with Section D of Part II with the exception that the first and second addition of acid shall be based upon 5% cement content using Figure I (which gives 21 and 8 mls. respectively).
5. Using the graph provided on Form T-3040, plot the grams of acid used against percent cement for both duplicate 5% cement specimens (also aggregate blank specimens if tested; see 2 above) as illustrated in Figure III. Draw a straight line from the origin of the chart (or the average of the duplicate blanks) to the average of the tests on the 5% specimens. This is the standard curve for determining the cement content of field mixed cement treated specimens.

F. Precautions

1. This test should not be performed by persons subject to "color blindness".
2. It is very important that the operator *vigilantly* maintain a neutral solution by repeatedly adding acid as soon as the pink color reappears. Neglect of this item will cause inaccuracies in the cement determinations.
3. After first two additions of acid, use only the amount necessary to just eliminate the red color. Excess acid may attack the aggregates, particularly in the later phases when the amount of hydration products from the cement remaining in the mixture may be low, resulting in erroneous cement determinations. It is also possible that the use of excessive acid in the final stages could cause the total quantity of acid to exceed that which would have normally been attained at the end of the one hour time period.
4. Keep all reagent bottles closed when not in use to prevent evaporation and the consequent changes in concentration.
5. Rinse and drain all glassware and plasticware when the day's work is done.

Notes

While the total amount of acid used for neutralization is determined by weight in this procedure, it may also be measured in volumetric units using titrating burettes. However, since it is customary to test more than one specimen at a time (four simultaneous tests are the maximum number for this procedure) and volume measurements would require a burette for each sample, it is more convenient to use the weight basis. A titrating burette is normally used in this procedure only as a convenient implement for introducing the acid and not as a measuring device (except when metering the 1st & 2nd additions of acid in accordance with Section D-6 of Part II).

The purpose of the chart in Figure I is to provide a sufficient time lapse, before the red color reappears in the solution, for the operator to adequately process four specimens in the early stages of the test. The indicated amounts are calculated to allow a slight excess of acid which under normal circumstances will usually retard the color return for 2 or more minutes. Studies indicate that the amounts of acid prescribed

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CONSTANT NEUTRALIZATION PROCEDURE

Hydrochloric Acid Starting Quantities

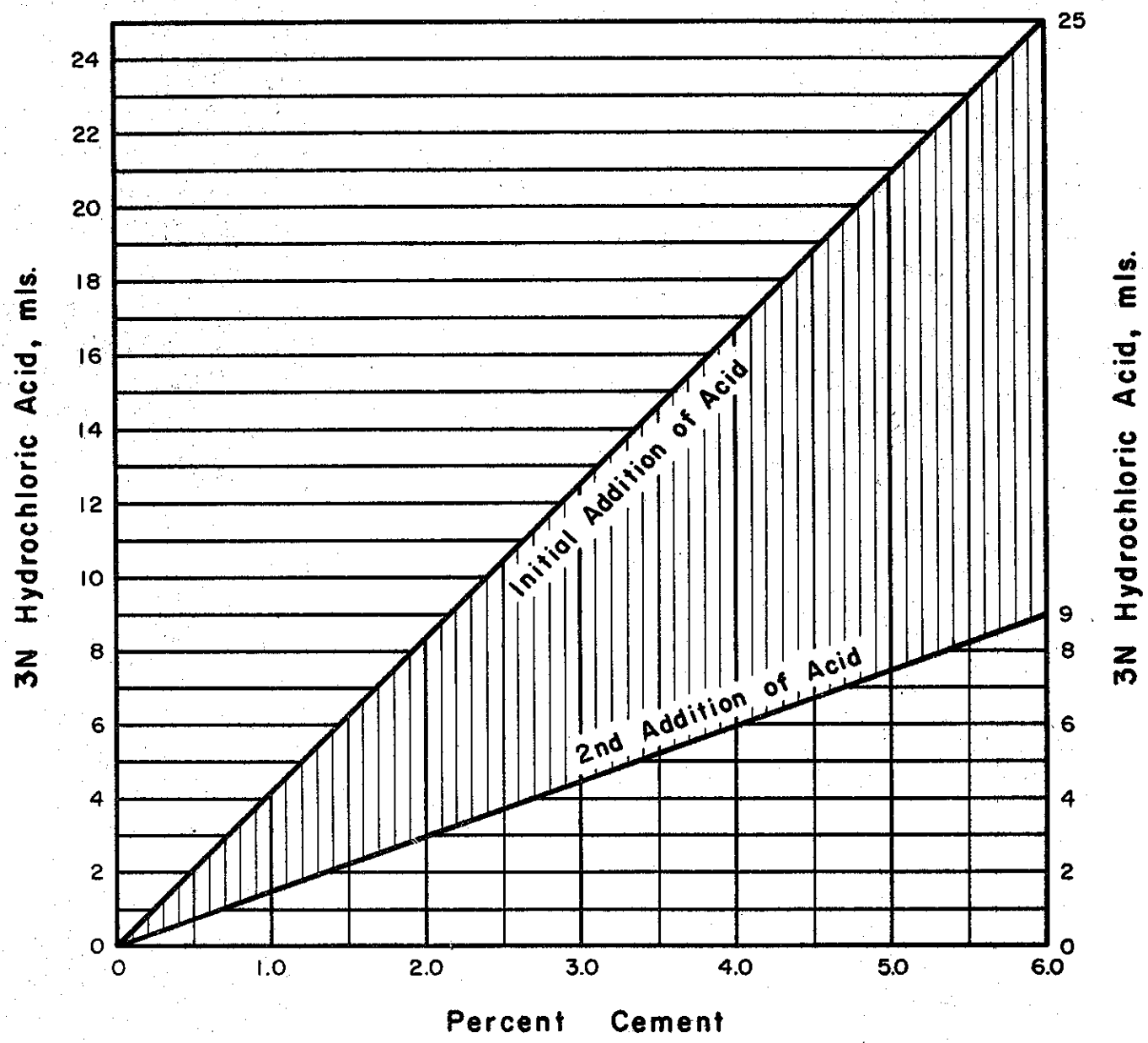

FIGURE 1

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in Figure I for the first two additions, will not affect the accuracy of the test, however care must be exercised, in performing the balance of the procedure, not to permit any further excess of acid.

A standard curve should be determined *at least once per day.* In the event of any change in source of aggregate or cement or a new working solution of acid, another determination should be made.

PART III. METHOD OF FIELD SAMPLING

Scope

This method describes the procedure for sampling cement treated bases to obtain representative portions for cement determinations.

All sampling should be performed for a definite purpose such as to determine the efficiency of the mixer, the relationship between the cement and aggregate feeds, or the general overall variations in cement content during the day.

Procedure

A. Equipment

1. Pick
2. Shovel
3. Hand Scoop
4. Covered containers of 3 Kg. min. capacity

B. Test Record Form

Keep all pertinent data regarding the project and individual samples on Form T-3040 "Field-Laboratory Record of Titration Tests". (See Figures II & III)

C. Size of Sample

Each sample should weigh approximately 3,000 grams.

D. Sampling for Determination of Efficiency of Mixers

1. *Central Batch Plant*

   The most desirable method of sampling a central batch plant is after the material has passed through the paving machine or spreader box. This sampling will check the combined efficiency of the mixer and paving machine. If too large a variation is found in the different samples, further sampling directly from the plant must be done in order to isolate the trouble.

2. *Continuous Mix Plant*

   A continuous mix plant generally feeds the mix onto a conveyor belt. Samples should be taken directly from the belt. Samples taken at five or ten minute intervals from the belt will give a good check on the efficiency of the plant, including the cement and aggregate feeds.

3. *Road Mixers*

   Sampling should be from the material just as it leaves the mixer. To check the efficiency of the mixer, several samples (generally four) should be taken transversely to the direction of spread. When sampling from a windrow, remove about four inches of the surface material, then take one sample near each toe and one near each edge of the top for a total of four samples. When sampling from spread out material, take the four samples equidistant from each other across the spread, starting about one foot inside each edge. Each sample should represent the full depth of spread.

E. Sampling to Check Overall Fluctuation in Cement Content

After the mixers and spreaders have been checked and it is determined that the equipment is in satisfactory adjustment, it is important to take occasional samples to make sure that the cement feed is remaining constant. Therefore, several samples should be taken in the direction of spread. Each sample should represent the average transverse section.

REFERENCES

A California Method.

End of Text on Calif. 338-A

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STATE OF CALIFORNIA—DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
Field-Laboratory Record of

TITRATION TESTS

For Cement Content Determination of CTB
FORM T-3040 (REV. 11-59)

Sheet 1 of 1 Sheets
Date NOVEMBER 6, 1957
Operator TROTTER

PROJECT DATA

Dist.	Co.	Rte.	Sec.	Contract
III	Pla.	37	B	57-3TC21-F

Limits: BETWEEN HEATHER GLEN & COLFAX

Source of Aggregate: BEAR RIVER
Cement Brand: IDEAL

Cement Mixer Make: MADSEN
Road Mix ☒ Plant { Batch ☐ Cont. ☐

Cement Spreader: HOPPER TRUCK

PLANNED	Thickness	Cement	Water
	8"	4.5 %	6.0 %

DETERMINATION OF METHOD OF TEST

Item	Specimen Type	Jar No.	NaOH Ml.	Control Values
A	Ottawa Sand	7	102.6	Av. Mls. 102.7
		8	102.9	
B	Aggregate Blank	9	100.0	Lowest Value 100.0
		10	101.5	
C	Av. of A—Lowest Value of B			2.7

If C<6 mls use Acid-Base Proc. (Part I) . . . . ☒ *
If C≧6 mls use Const. Neut. Proc. (Part II) . . . . ☐

CALIBRATION RECORD FOR STANDARD CURVE

Station of Agg. Sample	Curve No.	% Cement	Jar No.	NaOH Ml. ** ~~DSI-gr.~~
360+00	2	0	9	100.0
" "	2	0	10	101.5
360+00	2	5	9	53.4
" "	2	5	10	52.6

FIELD NOTES

MIXER SPEED 22'/min.

U.B. AGGS. 1½" max.

See Reverse Side for Tests on Field Samples

* Check appropriate item.
** Cancel words not applying

STANDARD CURVE

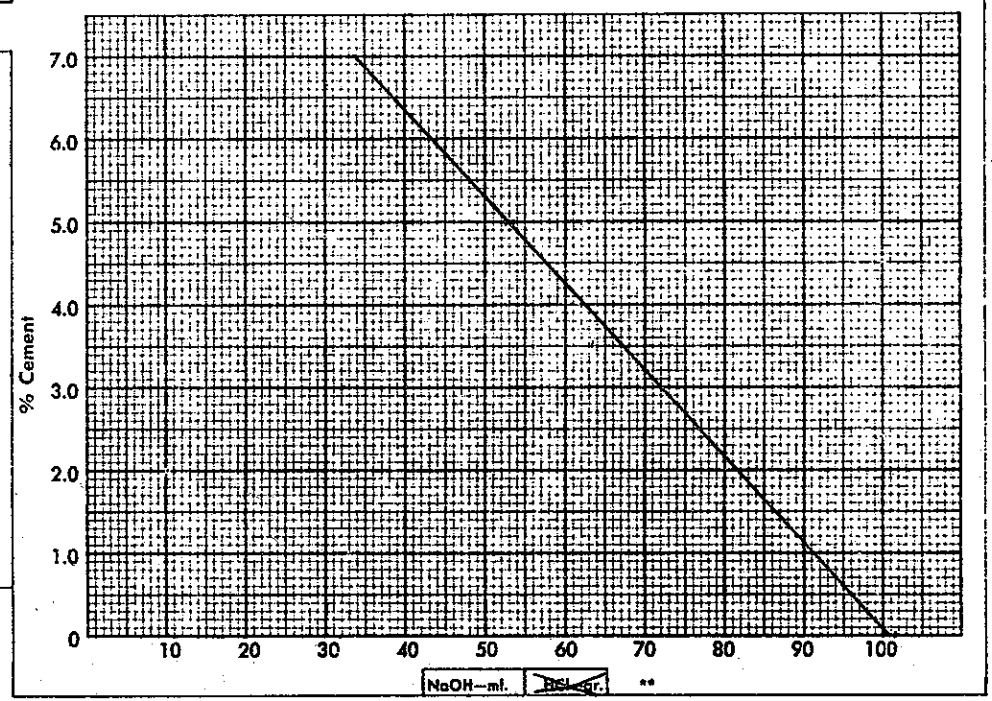

FIGURE II

Test Method No. Calif. 338-A
January 1, 1960

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TEST RECORD OF FIELD SAMPLES

Station	Position	Depth	Time Mixed	Sample Proportions: Sample Wt. Grams	Sample Proportions: Pass ⅜ Grams	Sample Proportions: % Pass ⅜	Jar No.	Gross Jar Wt. Grams †: Start	Gross Jar Wt. Grams †: Final	NaOH Ml. ** ~~HCl Gr.~~	% Cement	Remarks
349+50	12' Lt. ℄	0-8"	0830	4070	1470	36	1			67.4	3.5	AVERAGE = 3.9%
	14' Lt. ℄	"	"	4740	1700	36	2			64.0	3.9	
	16' Lt. ℄	"	"	4350	1840	42	3			61.4	4.1	
	18' Lt. ℄	"	"	4880	1840	38	4			61.6	4.1	
365+90	12' Lt. ℄	0-8"	0950	3890	1650	42	5			53.6	5.0	AVERAGE = 4.4%
	14' Lt. ℄	"	"	4995	2175	44	6			61.4	4.1	
	16' Lt. ℄	"	"	3435	1775	52	7			59.6	4.3	
	18' Lt. ℄	"	"	3960	1895	48	8			60.6	4.2	
374+00	20' Lt. ℄	0-8"	1030	3550	1100	31	1			58.6	4.4	AVERAGE = 5.0%
	22' Lt. ℄	"	"	3965	1825	46	2			49.0	5.5	
	24' Lt. ℄	"	"	3600	1690	47	3			51.8	5.2	
	26' Lt. ℄	"	"	3420	1410	41	4			55.0	4.8	
343+50	27' Lt. ℄	0-8"	1340	4075	1550	38	5			55.0	4.8	AVERAGE = 4.6%
	29' Lt. ℄	"		5280	2240	42	6			65.6	3.7	
	31' Lt. ℄	"		5600	2260	40	7			53.6	5.0	
	33' Lt. ℄	"		3235	1105	34	8			54.8	4.8	
342+00	24' Lt. ℄	0-8"	1340	4560	1970	43	1			58.8	4.4	
340+00	24' Lt. ℄	"	1350	4430	1810	41	2			55.6	4.7	
336+00	24' Lt. ℄	"	1415	6030	2810	47	3			51.0	5.3	

** Cancel words not applying
† Required only for the Constant Neutralization Procedure (Part II, Test Method No. Calif. 338)

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FIGURE II—Continued

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STATE OF CALIFORNIA—DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

Field-Laboratory Record of

TITRATION TESTS

For Cement Content Determination of CTB

FORM T-3040 (REV. 11-59)

Sheet	1	of	1	Sheets
Date	SEPT. 26, 1958			
Operator	TROTTER			

PROJECT DATA

Dist.	Co.	Rte.	Sec.	Contract
IV	CC	75-107	A, Wlc.	58-4TC17-FI

Limits

Source of Aggregate: SELECTED PIT - DIV. OF HIGHWAYS

Cement Brand: S.CLARA - TYPE II

Cement Mixer Make: MADSEN

* Road Mix ☐ Plant { Batch ☐ Cont. ☒

Cement Spreader: BELT

PLANNED	Thickness	Cement	Water
	6"	6.0 %	17.0 %

DETERMINATION OF METHOD OF TEST

Item	Specimen Type	Jar No.	NaOH Ml.	Control Values
A	Ottawa Sand	3	94.4	Av. Mls. 94.6
		4	94.8	
B	Aggregate Blank	1	58.2	Lowest Value 58.2
		2	61.6	
C	Av. of A—Lowest Value of B			36.4

If C<6 mls use Acid-Base Proc. (Part I) . . . . ☐ *

If C≧6 mls use Const. Neut. Proc. (Part II) . . . . ☒

CALIBRATION RECORD FOR STANDARD CURVE

Station of Agg. Sample	Curve No.	% Cement	Jar No.	~~NaOH Ml.~~ ** HCl Gr.
PIT SAMPLE	1	5	5	65.1
		5	6	64.4

FIELD NOTES

See Reverse Side for Tests on Field Samples

* Check appropriate item

** Cancel words not applying

STANDARD CURVE

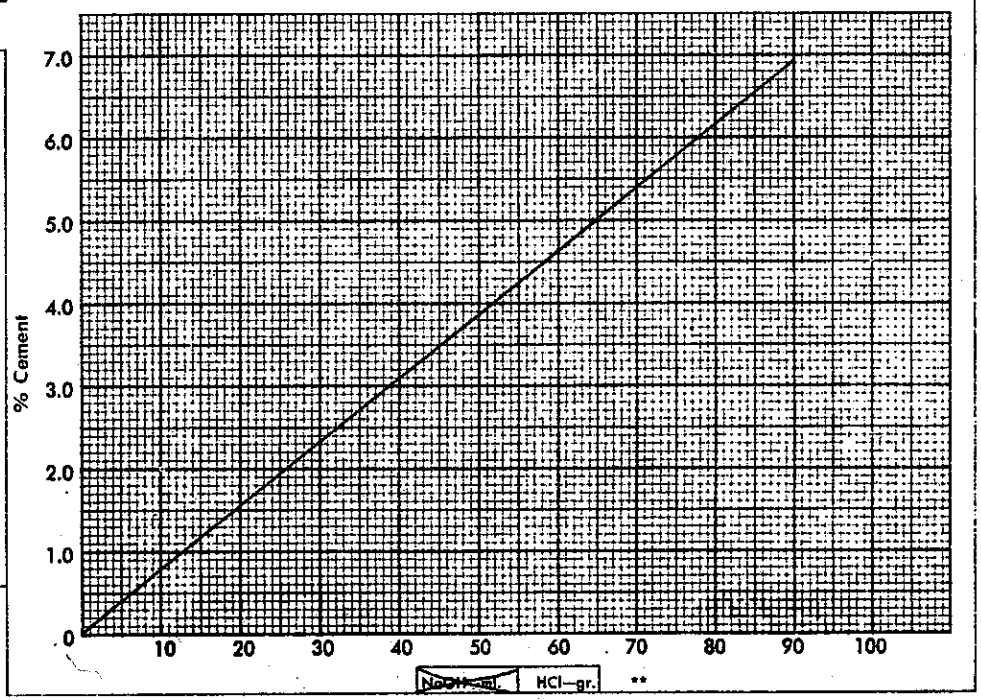

FIGURE III

Test Method No. Calif. 338-A

January 1, 1960

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TEST RECORD OF FIELD SAMPLES

Station	Position	Depth	Time Mixed	Sample Proportions: Sample Wt. Grams	Sample Proportions: Pass ¼ Grams	Sample Proportions: % Pass %	Jar No.	Gross Jar Wt. Grams †: Start	Gross Jar Wt. Grams †: Final	NaOH Ml. ** / HCl Gr.	% Cement	Remarks
SAMPLED	FROM BELT	@	0835	4280	3170	74	10	808.5	883.0	74.5	5.7	AVERAGE = 6.0%
30 SEC.	INTERVALS			4010	3050	76	11	813.5	892.5	79.0	6.1	
				3815	2990	78	12	806.5	891.5	85.0	6.5	
				4435	3295	74	13	816.0	890.5	74.5	5.7	
SAMPLED	FROM BELT	@	1100	3600	2880	80	10	830.5	901.0	70.5	5.4	AVERAGE = 5.7%
30 SEC.	INTERVALS			3775	3050	81	12	808.5	878.5	70.0	5.4	
				4140	3470	84	13	809.0	880.0	71.0	5.5	
				3700	3005	81	14	811.5	897.5	86.0	6.6	
SAMPLED	FROM BELT	@	1350	5110	3910	77	10	810.5	876.0	65.5	5.0	AVERAGE = 5.1%
30 SEC.	INTERVALS			4770	3690	77	12	812.5	884.0	71.5	5.5	
				4060	2920	72	13	808.0	871.0	63.0	4.9	
				4270	3380	79	14	808.0	873.5	65.5	5.1	

** Cancel words not applying
† Required only for the Constant Neutralization Procedure (Part II, Test Method No. Calif. 338)

FIGURE III—Continued

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