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16. ABSTRACT

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The need for sieve analyses and grading studies is rather self-evident and the procedures involved are familiar to most engineers. However, it may be of interest to outline briefly some of the factors which lead to a study of aggregate gradations in California and to comment on some of the trends and relationships which came to light.

Mixtures of bitumen and mineral aggregate have been used since ancient times and bituminous pavements are by no means new. However, from time to time the same old combinations of asphalt and mineral aggregate have a rebirth under a new name usually with a real or implied modification in some element or proportion. When the first oil mix road in California was built in 1926 it was generally regarded as something new distinctly different from earlier types of bituminous pavements and attracted considerable attention because it appeared at a time when the need for low cost road surfacing was becoming acute. Today this type of surface covers many miles of rural highways.

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Gradation of Mineral Aggregates in Dense Graded Bituminous Mixtures

A Discussion

by

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Gradation of Mineral Aggregates in Dense Graded Bituminous Mixtures

By F. N. HVEEM*

THE use of mineral aggregates and soils in engineering works presents many problems due to variations in these materials. While physical and chemical differences are important, and have been much investigated, this paper will be confined to a discussion of particle size distribution or the granulometric composition and its effect on the design of mixtures.

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MANY DETAILED STUDIES

Wide-spread use of the oil mix type of surfacing has not been free from trouble and our present knowledge of the process has resulted from a great deal of study and research on the part of numerous highway departments. In common with other States, California is more or less continually investigating and attempting to improve design methods and testing procedures in order to assure satisfactory construction.

Since the first report by McKesson and Frickstad in 1927, detailed studies have been under way including among other things, an investigation of the possible influence of aggregate gradation. In 1929 there were a number of oil mix sections already in use ranging from good to poor. The main idea at that time was to find out why certain sections were behaving well and why others were showing considerable distress despite the fact that they had been constructed under the same specifications and apparently under the same conditions. We were well equipped for the study with a full quota of preconceived opinions and ingrained notions among which was the belief that the principles of aggregate gradation had been well expounded, and we were more or less prepared to find that many of the troubles on oil mix roads could be accounted for by improper grading of the aggregate. However, when a series of samples taken from good and bad sections were analyzed, it was a little disturbing to discover that some of the most unconventional and irregular grading curves were identified with the most successful roads, while in several failures, the gradings complied very nicely with orthodox ideas as represented by Fuller's curve.

DISCOVERY UPSETS THEORIES

This discovery was something of a shock and tended to destroy faith in "well known principles." We could not escape the conclusion that a satisfactory bituminous surface could be constructed almost without regard to aggregate gradations if the bitumen content was adjusted for the particular aggregate and gradation. It was evident that this optimum bitumen content had no consistent relationship to the void volume except that it was always less than the amount required to fill the voids. Against this conclusion was the fact that virtually all construction men are concerned with "good grading" and with "poor grading" and even though it was evident that the "principles of grading" must be quite elastic, the possibility still existed that there might be an "ideal grading." Therefore, the first step was to compare gradings of various mixtures for the purpose of discovering any common properties or similarities which might exist.

In order to cover as broad a field as possible, portland cement concrete gradings were included in the study as well as gradings of bituminous mixtures. As these gradings covered a wide range of sizes, it was necessary to prepare grading charts which would permit comparison on a relative scale. This brought up the question as to the type of chart and the scales to be used.

FULLER'S CURVE

Figure No. 1 shows a simple linear scale on which Fuller's curve has been drawn. Fuller's curve as you know, has the form of an ellipse on the finer portion of the curve and has been projected either as a curve or straight line from the vertical axis of the ellipse to the upper right hand corner of the chart. The linear scale for the sieve sizes is not very satisfactory because the lines in the sand sizes are too crowded for definition. A better type of chart is the semilogarithmic type shown on Figure No. 2. The abscissa value of the screen sizes on the logarithmic chart give good definition throughout the entire range. Fuller's curve is shown transferred to the semilogarithmic chart.

The following figures, No. 3 to 9, will show the results obtained by platting the grading curves of previously existing construction which, for the most part, represents gradings that resulted from long study or experimentation on the part of several individuals responsible.

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Fig. 1

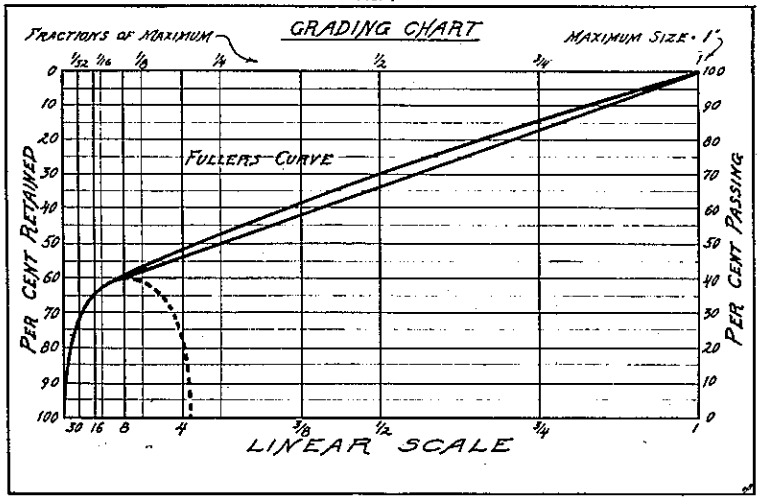


Fig. 2

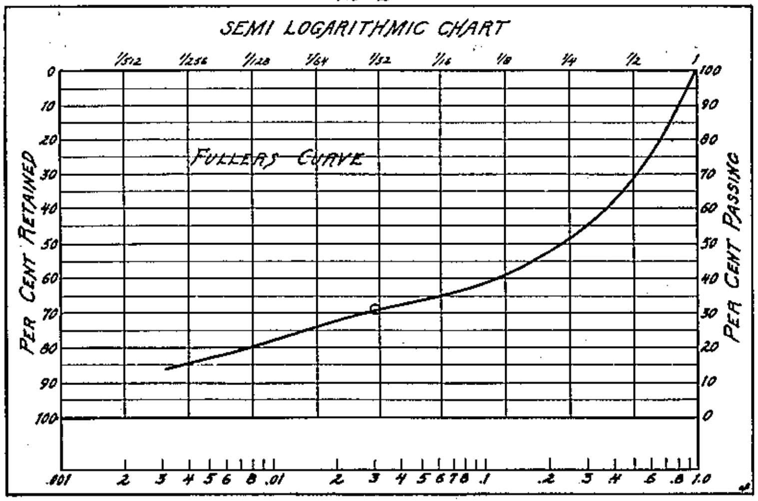


Fig. 3

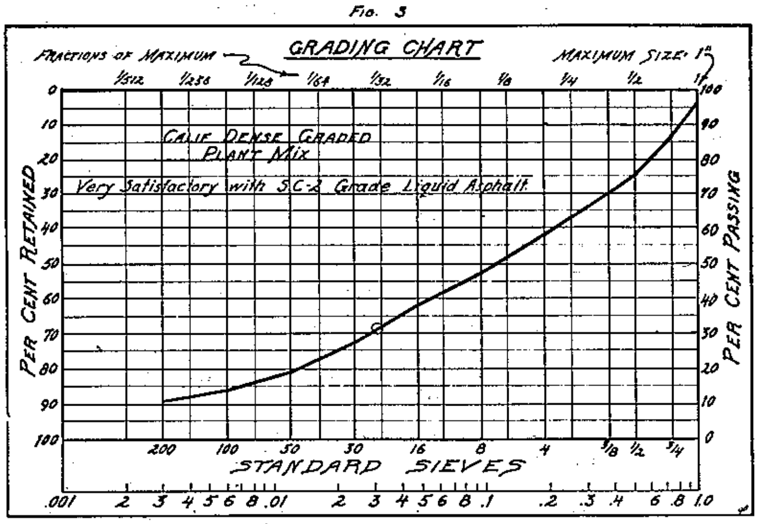


Fig. 4

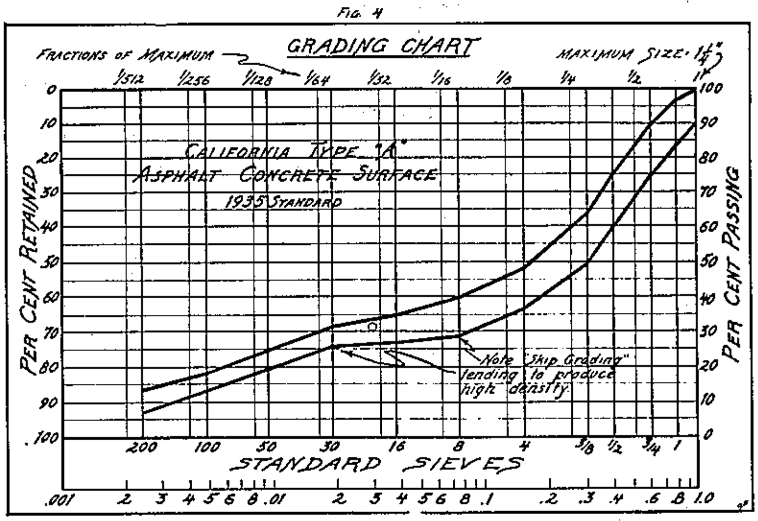


Fig. 5

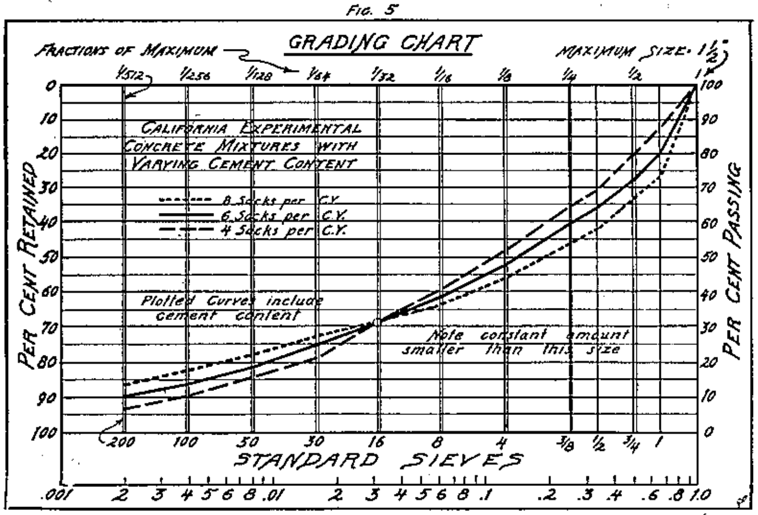


Fig. 6

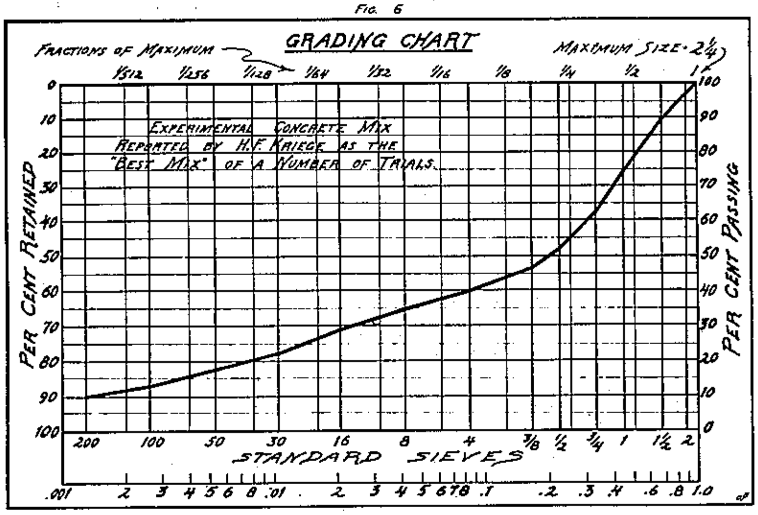


Figure No. 3 shows the grading of a plant mix surfacing in California from one of the most satisfactory jobs constructed prior to 1930. All material is smaller than 1 inch.

Figure No. 4 is Type "A" Asphaltic Concrete surface used in California for a number of years past. Material passes 1¼ inches.

Figure No. 5 is a series of three gradations of portland cement concrete using aggregate below 1½ inches, with three percentages of cement. The three mixes were part of a laboratory experiment aimed at securing similar workability and water cement ratios with the varying cement contents. It should be noted that for comparison portland cement concrete mixtures are platted with the cement content included with the aggregate. You will note that the three gradations developed experimentally tend to intersect at a point represented by 31 per cent of the vertical scale and at a size equal to .031 on the abscissa scale. This point will be referred to later.

Figure No. 6 represents a grading of portland cement concrete developed by Professor H. F. Kriege and reported in Rock Products. All aggregate was smaller than 2¼ inches maximum.

Figure No. 7 is the "best grading" developed in our own laboratory for Portland cement concrete with a certain type of crushed rock at 2½ inches maximum.

Figure No. 8 is paving concrete with 3½ inches maximum stone and Figure No. 9 is paving concrete using 4 inches maximum stone.

DIFFERENT EXPERIMENTS

I would again like to repeat that all of these gradations were developed by different individuals working independently and separated by considerable distance and time, and each one represents the most ideal combination which was developed after a great many trials and consideration of other combinations. These figures by no means represent all of the material studied. Each is somewhat typical of the particular size group. **In passing I might call attention to the fact that regardless of individual variations in coarse and fine aggregate all of these most satisfactory gradings tend to pass close to the point represented by the co-ordinates, 31 per cent of the material passing a size equal to .031 of the particular maximum size of the gradation.** This prevailing common type or pattern of grading seems to be too consistent to be accidental and has been used to establish grading charts which have been made the basis for the design of bituminous paving mixtures. These charts shown herewith, indicate tolerance limits which are, in effect, a rationalization of data similar to that just shown.

Figure No. 10 is a so-called general grading chart showing the slope of the curve from maximum to minimum with the abscissa values drawn as relative sizes only.

Figure No. 11 is the same type of curve on which the abscissa values represent actual sieves as they would appear for a grading ranging from 1 inch to dust. Having thus arrived at smooth attractive looking curves, through the simple expedient of ignoring those cases which did not conform, it may be well to offer some explanation which would help to show why this uniform type of grading will often be more satisfactory than other curves.

MAXIMUM DENSITY

Figure No. 12 is a collection of aggregate gradings which have been proposed, tried, or, in some cases, used with considerable success. I would like to point out the heavy shaded line which, from Professor Kriege's report may be taken as the ultimate in maximum density. Professor Kriege stated that if 50 per cent of the coarsest size was combined with 50 per cent of the finest material, the **resulting density would be greater than that of any other combination of sizes within the maximum and minimum limits.** It appears then, that any virtue in the type of grading shown on Figure No. 11, is due to the avoidance of certain difficulties more or less inherent in other patterns of gradation. These liabilities or hazards are set forth on the figure in the form of brief notes indicating possible or probable results should the grading curve go beyond the tolerance limits in the area of the chart covered by the notation. However, these notations are an over simplification. For example, on Figure No. 13 the hypothetical grading shown is deficient in fine sand. A grading of this type will ordinarily be porous and may or may not be undesirable depending on local conditions.

Figure No. 14 shows a distinctly different type of grading which is caused by an excessive amount of sand between the 30 and 100 mesh size. This type of curve is typical of a mixture containing wind blown sand. Our experience has shown that such mixtures are usually low in stability and are often permeable as well.

IDEAL GRADING

As a result of this study it was possible to assign a few reasons why a grading curve should have some particular or peculiar characteristics. It appears that there are a number of factors which may be affected by the gradation and also several **which are not.** It is necessary for the designer to distinguish and isolate the separate individual items and properties which are needed to accomplish the purposes of a particular project. It is also **necessary to know which of the essential properties depend on and are affected by the aggregate gradation.** With this information and knowledge, it is possible to develop an ideal grading for a specific purpose and from that to determine how nearly the ideal grading can be achieved with the aggregate available. Thus, the basic requirements and conditions can be stated rather briefly but it is not always a simple matter to arrive at a practical solution because in practice, the best grading that can be secured is usually a compromise.

As the word "compromise" implies recognition and allowance for the demands of several diverse elements, it is now necessary to describe some of the factors which may affect the choice of gradings. One of the first and desirable properties of mixtures are the qualities of plasticity and mobility which are usually grouped under the heading of workability. Hydraulic concrete, bituminous mixtures, and stabilized soils all must be workable; the degree required **depends on the conditions of use and type of equipment.**

WORKABILITY IMPORTANT

Workability is usually of greater importance in portland cement concrete than in bituminous mixtures, nevertheless, it is one common requirement which is affected by gradation.

Another property influenced by grading is permeability. The importance of this property depends almost entirely on the type of structure. (A distinction should be made between

Fig. 7

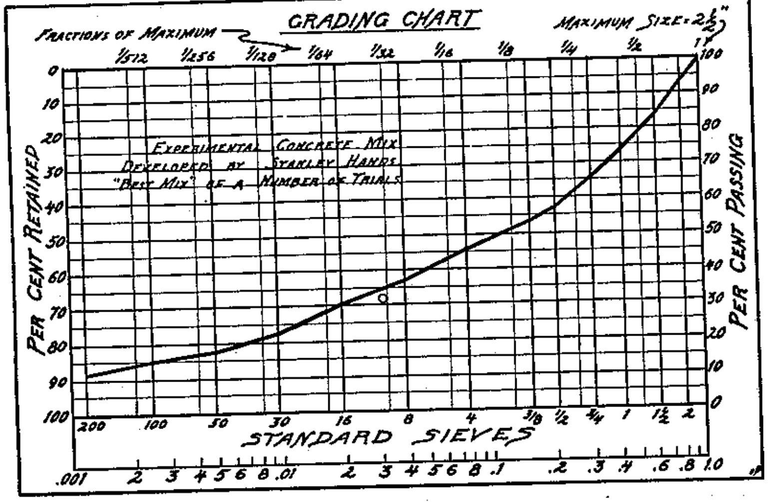


Fig. 8

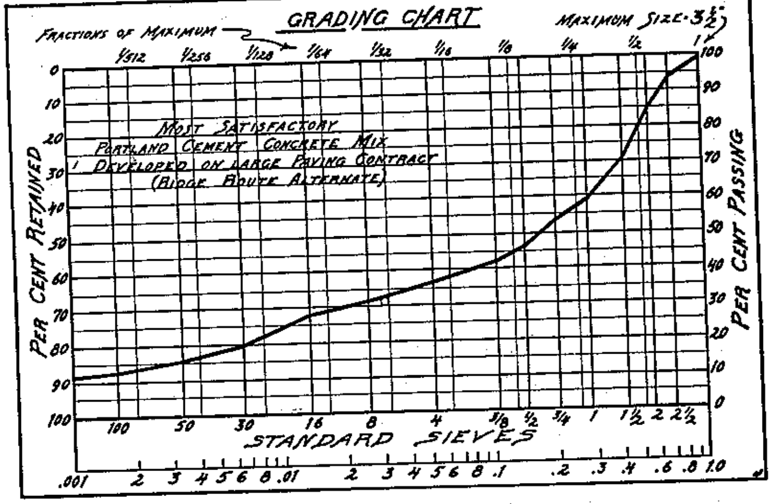


Fig. 9

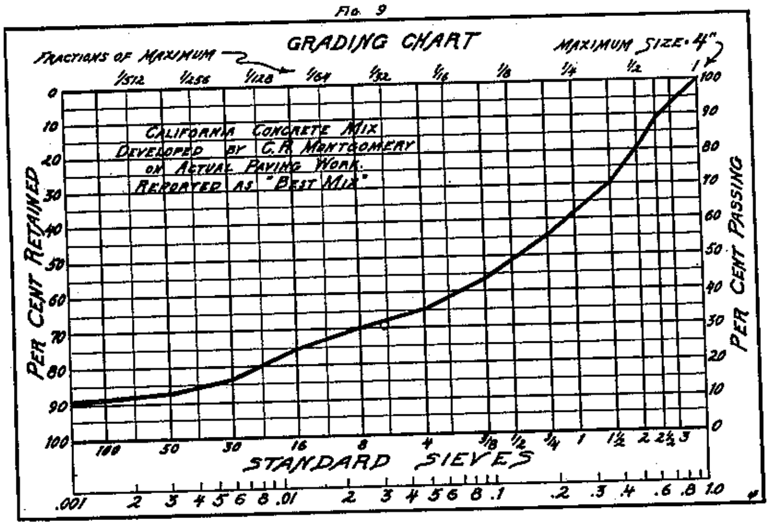


Fig. 10

STATE OF CALIFORNIA DIVISION OF HIGHWAYS MATERIALS & RESEARCH DEPT.

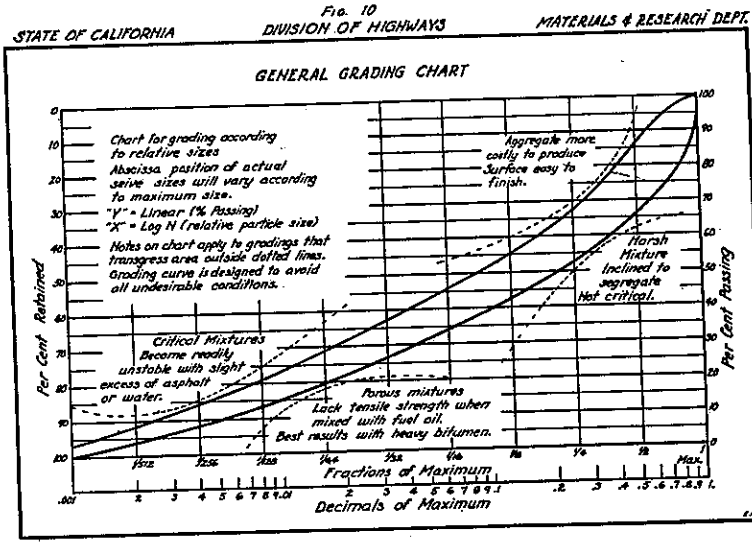


Fig. 11

STATE OF CALIFORNIA DIVISION OF HIGHWAYS MATERIALS & RESEARCH DEPT.

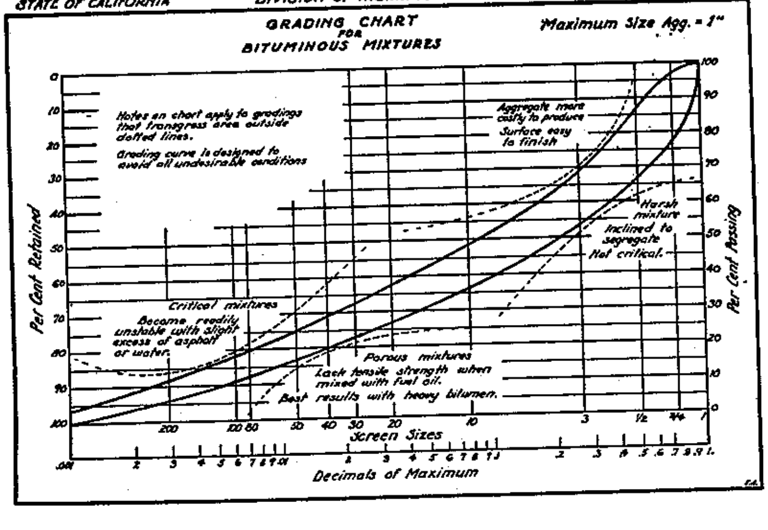


Fig. 12

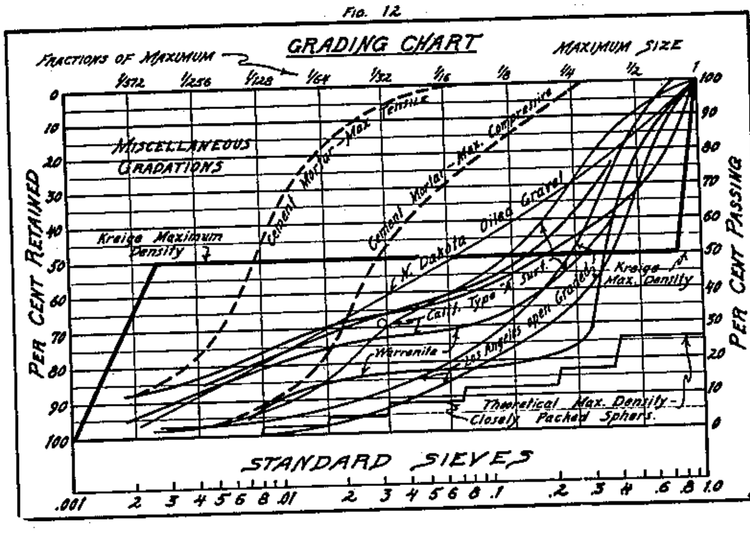


Fig. 13

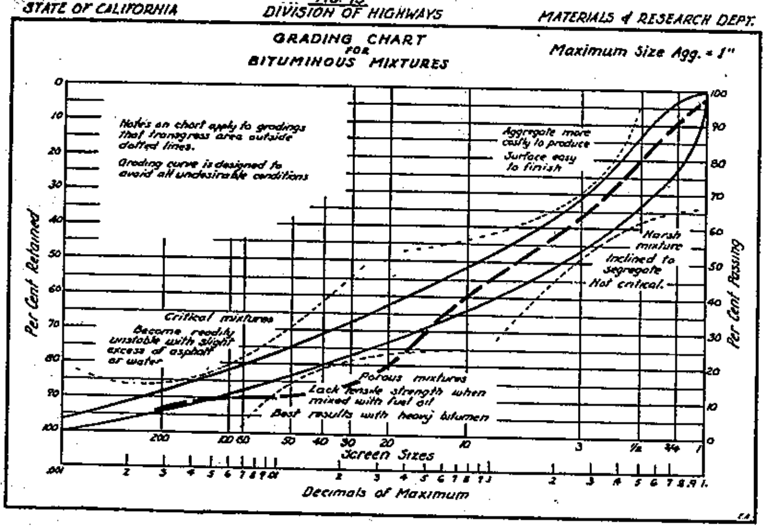


Fig. 14

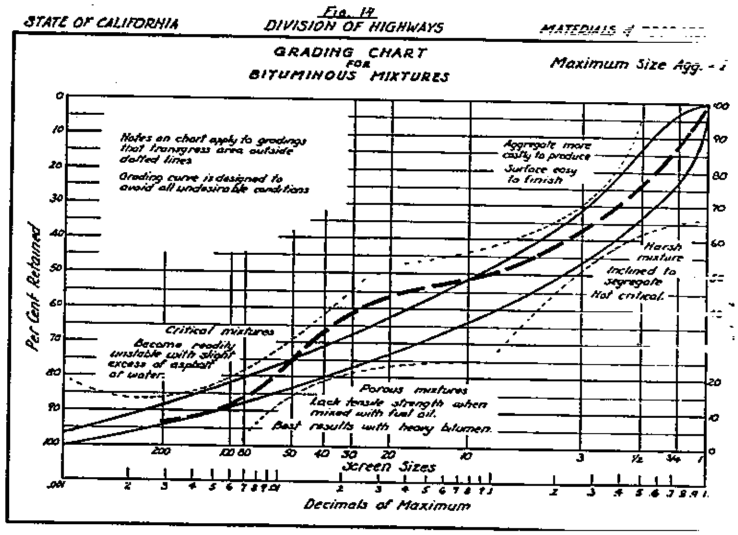


Fig. 15

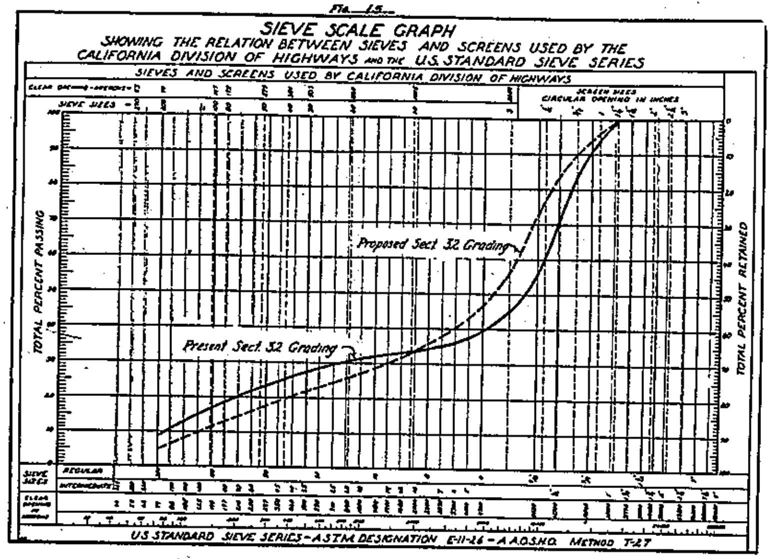
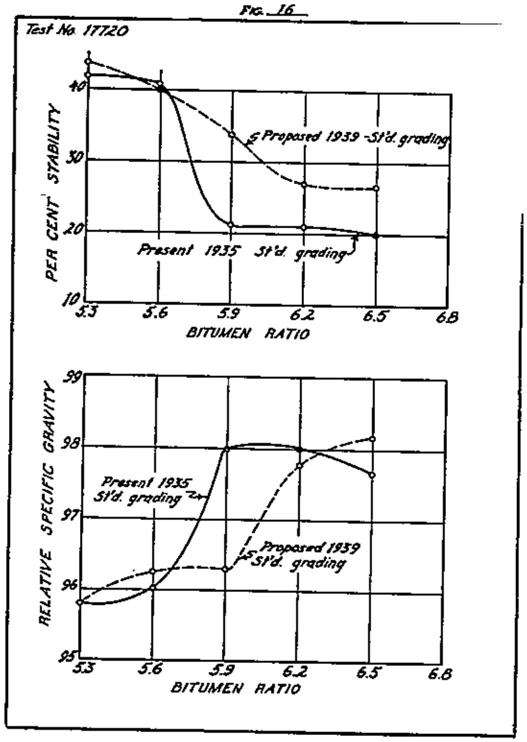


Fig. 16



permeability and density. The terms are not synonymous.) In paving mixtures it may be important that they be tight and relatively impermeable under conditions where it is necessary that a vulnerable subgrade be protected from the entrance of surface water through the pavement. It is often true, however, that the greatest danger of subgrade saturation comes from capillary moisture and a tight paving surface which restricts evaporation will frequently promote failure through an accumulation of moisture in a plastic subgrade. It has been demonstrated that a surface mixture with the proper degree of porosity will permit the subgrade to maintain a stable equilibrium by allowing moisture to evaporate rapidly enough to prevent excessive concentration. So far as is known, the design of paving mixtures has not often been deliberately adjusted to provide the necessary permeability. It is hereby suggested that it is a possibility well worth consideration.

Economy is a factor which may at times influence the choice of gradings but its importance varies with the particular conditions. Durability is important for virtually all structures but is not usually affected by the gradation of aggregate. Surface texture is a property peculiarly important to pavement construction and the present widespread interest in traffic safety makes skidding resistance an essential property, and the texture is inevitably influenced by the grading of the aggregate. Important properties which are only slightly or indirectly effected by aggregate gradation are the **compressive strength** of portland cement concrete and the **stability** of bituminous mixtures.

A great deal of discussion has appeared in technical literature concerning the significance of the voids ratio. So far as the writer has been able to determine, there is little evidence to show that the voids ratio can be dependably utilized in the design of mixtures. Neither the amount of binder required nor the important properties can be confidently predicted from a knowledge of the void volume alone. As stated by someone, while a packing box full of baseballs and one filled with peas will have virtually the same void volume, the number of points of contact and the superficial area will vary inversely with the particle diameters.

DESIGN OF ALL MIXTURES

In conclusion it may be pointed out, that mineral aggregates are possessed of one inherent property which affects the design of all mixtures regardless of the type of binder used. This property is described as internal friction of the granular mass implying that all solid particles offer resistance to sliding depending on their surface texture and pressure with which they are held in contact.

The equilibrium characteristics of the mass depend on the conditions which pertain at the points of contact between the discrete particles. A void has little if any character and particles do not transmit their influence across void spaces—only at points of contact. The stability of bituminous mixtures is largely dependent on maintaining a high value of internal friction, while on the other hand, the strength of portland cement concrete depends on the water cement ratio. This ratio can be maintained at its lowest value when the internal friction of the aggregate is inherently low, therefore the design of portland cement concrete tends to encourage the use of finer sands and smooth particles which in combination with water, promote mobility. In bituminous mixtures, the tendency should be towards the use of rough stone and a reduction of fine mobile material to the lowest amount possible in order to maintain high internal friction. However, as the stability of bituminous mixtures is also influenced by the cohesion any reduction in the amount of fines tends to reduce the cohesion values as well as to increase the permeability, thus we are around the circle and back to the need for compromise.

BEST GRADING

The best grading for any particular mixture can only be that which utilizes the available aggregates to give as many of the desired properties as may be possible. For this reason standardization of aggregate gradings can easily be carried too far and as utilization of aggregates is primarily a local problem due care should be exercised in the adoption of national standards for materials which are strictly speaking, not manufactured and which vary throughout the country. Commercial aggregates are not often shipped long distances and there seems to be no good reason for requiring that crushed stone, sand, or gravel, in one region should meet gradations found satisfactory for materials at some distant point.

As an example of the manner in which gradings can be slightly modified to secure less critical mixtures, figure No. 15 shows for comparison the asphaltic concrete grading used in California for a number of years past and the dotted line shows the modification which will be used in the future. The two gradings have virtually the same amount of sand finer than 10-mesh, however, the gradation of both fine and coarse material has been altered. This change in grading tends to reduce the density of the combination and will provide a mixture which is less critical.

STABILOMETER VALUES

Figure No. 16 shows comparative stabilometer values of the old and new type of grading. You will note that with a bitumen content of 5.6 stabilometer values are virtually identical. However, with a slight increase in asphalt, the older more dense mixture tends to lose stability rapidly whereas the modified gradation will show satisfactory stability up to about 6 per cent of asphalt and in no case falls as low as the older type.

The lower chart shows variations in density with the two types. With 5.9 per cent of asphalt, the new gradation has nearly 2 per cent greater void volume and in this connection a large number of studies have indicated that when the relative specific gravity is higher than 97 per cent, virtually all asphaltic mixtures tend to lose stability. Sufficient void space must be provided for the necessary amount of asphalt and the new type of grading has been found to be more accommodating and less critical than the older type.

In conclusion, it can be repeated that the best gradation is that which best suits the particular purpose and material available and, to borrow a phrase from Mr. T. C. Powers, **"A wide variety of gradings can be used but we can not tolerate much variation."**

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