Crushed Stone Behaviour as Related to Grading

L'Importance de la Granulométrie des Agrégats

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SYNOPSIS.

Crushed stone grading has been traditionally considered a factor controlling shear strength and compressibility. This fact is reflected in most specifications for these materials all over the world. In this paper, results from an investigation, using a Triaxial Texas Cell and specimens of sound crushed basalt with various grain size distributions, are presented. From the results obtained it is concluded that there is an "ideal" grading corresponding to high shear strength and low compressibility, but also that such desirable characteristics are lost -- even for a small deviations from the "ideal" grading, falling to values which become much more independent from the particle size distribution. Being this the case and knowing that in a real job it is almost impossible to obtain such an "ideal" grading, it seems that an extreme rigidity in the grading requirements is perhaps unrealistic.

1. INTRODUCTION.

Construction specifications for roads and airfields in most countries pay much attention to the grading - of the crushed stones to be used as bases of flexible pavements. In spite of that, there is a lack of information about the real influence of grading. There is also little knowledge about how the foundamental me-- chanical properties vary with grading.

This paper describes an investigation carried out at the Laboratory of the Geotechnical Department, Ministry of Public Works, Mexico, D.F. The research was aimed to define the influence of grading in the shear strength and stress-strain behaviour of crushed stone for pavement bases.

2. TESTING PROCEDURE.

All specimens tested were built-up with a sound -- crushed basalt of high quality (Table I). The original material was divided in ten portions of different - - sizes by sieving. Using different quantities of each portion, several gradings were prepared.

TABLE I

CRUSHED BASALT CHARACTERISTICS

Los Angeles Rattler Test (Type A)	8 %
Liquid Limit	25 %
Plastic Limit	16 %
Plasticity Index	9 %

Figure 1 shows the nine grading curves investi-- - gated. Of those curves, the ones named with numbers - (from 1 to 5) correspond to the first part of the investigation, and those named with letters (from A to E) correspond to the final part. In the same figure - are shown the border lines of three grading zones (I, II and III) which the Ministry of Public Works of Mexico uses to characterize these materials. It estab-- lishes that base materials should fall within zone I or II (preferably I).

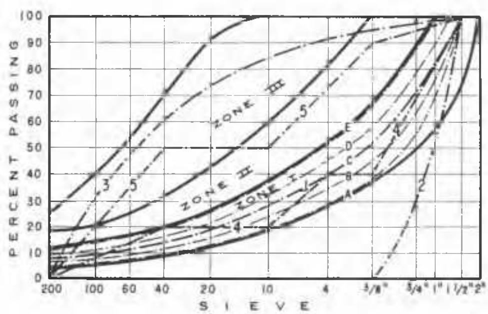

FIG. I GRADING CURVES INVESTIGATED.

All specimens were tested using the Triaxial Texas Cell (Tex. 113 E Test Catalogue 1970). Only results - obtained with two confining pressures (σ_3=0.703 and - σ_3=1.406 Kg/cm^2) are reported. Shear strength response is interpreted as the deviator stress corresponding - to three strains (δ=1.25%, δ=2.5%, δ=5%).

In the first part, five gradings were used to cover a wide range of materials so to bring out the major - tendencies of stress behaviour. Seven specimens of n° 1, n° 2 and n° 3 gradings were tested under each confining pressure, using the same material in each one of all seven specimens. It was intended to determine the consistency of the test results and also the - -

structural degradation if any. Only one specimen of nº 4 and nº 5 gradings was tested for each confining pressure. All specimens were compacted within the -- triaxial cell, by means of a vibratory table, - - - operated at 3600 c.p.m., (cicles per minute) with vibration amplitude of 0.63 mm, surcharge of 0.142 Kg/cm² over the specimen and for a period of 8 minutes. Water content was 15% in all cases. The unit weigths obtained varied widely, growing smaller, as expected, as the material was finer or uniform. The maximum - - grain size used was 38.1 mm (1 ½").

On the basis of the obtained results, it was de--- cided to run a detailed investigation around nº 1 - - grading. Accordingly, materials from A to E were tested. In fact, C material corresponds to nº 1 material. Six specimens of each of these materials were tested under each confining pressure. The laboratory work included 145 specimens tested.

3. TESTING RESULTS.

3.1 First Part.

Figure 2 shows results as to shear strength for - the three deformation levels and for σ_3=1.406 and -- 0.703 Kg/cm² confining pressures. (Similar curves — were obtained for the other confining pressure). - -- Grading is characterized by the Santos Constant, de-- fined as:

$$S = \frac{\sum_{i=1}^{n} Y_i}{100\, n} \quad \ldots\ldots\ldots \quad 1$$

Where:

Y_i= Ordinate of grading curve corresponding to - - - i-sieve.

n= Number of sieves used.

Roughly Santos Constant represents the area under the grading curve, corresponding a large value to a fine soil.

As seen, for all deformation levels, shear - - - - strength varies sharply with grading, corresponding a large resistance to nº 1 grading. Gradings nº 2 and 3 lead to minimum resistances. It should be noticed - - that material nº 2 corresponds to a uniform gravel -- and material nº 3 to a uniform sand, Materials nº 4 - and 5 have steppy grading curves, one being coarse -- and the other fine.

Figure 3 shows typical stress-strain relationships under a confining pressure of 1.406 Kg/cm². It should be noticed the great qualitative difference in mechanical behaviour as grading varies. This extraordinary sensibility leads to think on the importance of size distribution, but also on the imposibility to over--- come the practical difficulties in a real job as to - come out with an ideal grading. Perhaps, the statistical variations in the field are big enough to deter-- mine that a resistance, less than the optimum, is always obtained. If such is the case, an extreme concern about an "ideal" grading is illusory, and designing - with the maximum resistance will be dangerous. It - - seems that a more realistic attitude is to design and ask for a size distribution within a certain range, - according to the job possibilities.

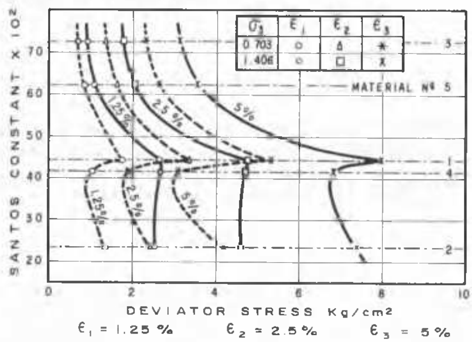

FIG. 2 STRESS-GRADING RELATIONSHIPS

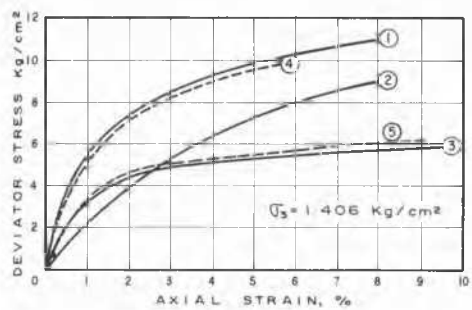

FIG. 3 STRESS STRAIN RELATIONSHIPS

3.2 Second Part.

Figure 4 shows the variations of the deviator - -- stress, drawn against the Santos Constant. Again it - is reported for the same two confining pressures and for the three deformation levels as before. It can be seen how, even for gradings within such a narrow - - limits, there is a significant quantitative differen- ce between finer and coarser materials. This fact - - points out the need for a review of the grading - - - acceptance criteria based on grading zones. In fact, Figure 4 shows that the resistance of a certain mate- rial inside zone I can be as high as the double, or - even more, than that of a material in the upper - - - border. In the same figure, border limits between - - zones are plotted through their Santos Constant. - - Values corresponding to the first part of the research are also plotted as means of correlation.

Figure 5 shows the stress-strain relationghips of materials from A to E. Again, remarkable differences are present. Resistance response exhibited by mate--- rials so similar may be as high as 50%.

4. STATISTICAL ANALYSIS OF LABORATORY DATA.

As established before, six or seven tests were run

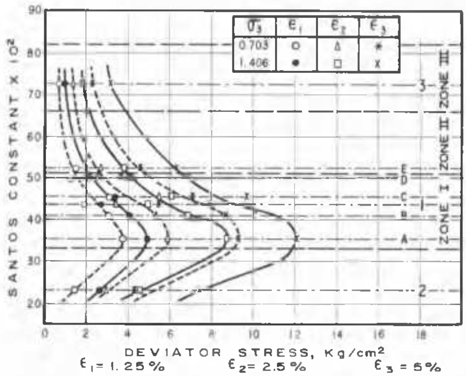

FIG. 4 STRESS - GRADING RELATIONSHIPS

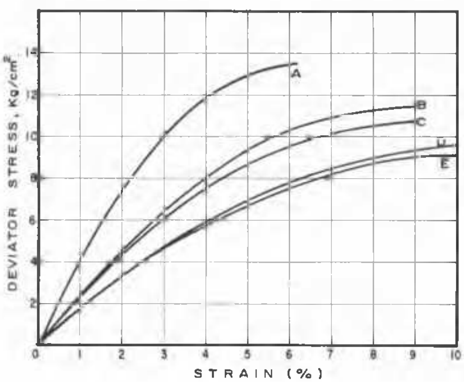

FIG. 5.— STRESS-STRAIN RELATIONSHIPS

for each same material. This large volume of data and the obvious dispersion of the values for the same conditions made it desirable to analize it statistically. A simple mean value did not seem to be adecuate and it was decided to give certain weigth to the number of specimens built with the same material and previously tested, as to take into account material variations. Accordingly, values for the deviator stress were plotted against the ordinal number of the test repetition. The resulting points in a bidimensional space were correlated by means of linear regression. The ordinate of this regression curve, corresponding to the mean value of the number of repetitions, was taken as the mean value of the deviator stress (σ_m) in the fashion shown in figure 6. The figure also shows two typical regression curves, corresponding to the general tendencies observed. Large dispersion of the triaxial test values is notorious, implying that the test consistency is doubtful. The effect of reusing the material, can also be seen. It can be explained in terms of particle breakage because, in spite of the dispersion, a general tendency to lower values with repeating loading is clear.

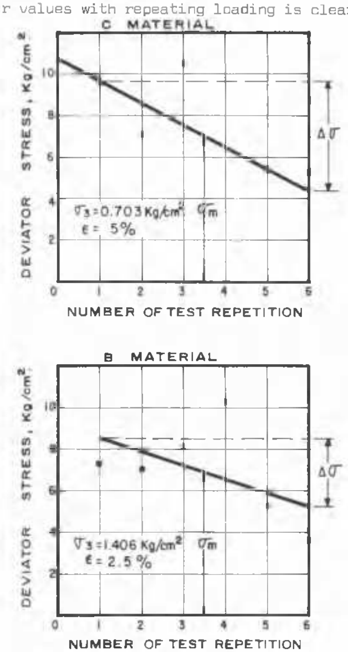

FIG. 6 - CORRELATION CURVES TO ESTIMATE THE MEAN VALUE

5. CONCLUSIONS.

- Resistant response of the crushed material used, probably representative of many of those commonly used as base materials, largely depends on the grain size distribution. Large differences as high as 100%, can be registered even for materials with grading curves that engineering practice might consider as similar.
- For each crushed material there seems to be an "ideal" grading curve, corresponding to a high resistant response. However, this response is so easily lowered even for small changes in grading, that high optimum values can not be considered as a field possibility. Design should then be based on resistance corresponding to a range of gradings accordingly to field conditions in each job.
- Specifying grading characteristics by relatively wide zones must be reconsidered, or at least zones must be established taking clearly into account the intended use of the material.
- Consistency of the triaxial test used seems to be low. Within the frame of flexible pavement technology it is commonly discussed the consistency of C.B.R. and plate tests, but usually the triaxial tests are less questioned. This fact can not be easily sustained.
- Particle breakage is very important.