

A SIMPLIFIED APPROACH FOR MIX DESIGN BASED ON SHAPE FACTORS OF COARSE AGGREGATES

CHOIX DE LA FORMULATION DES ENROBES FONDE SUR LA FORME DES GRAVILLONS

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Abstract

The stability of granular materials and bituminous mixes increases with increase in dry density or decrease in voids in the mix. Therefore the proportions of materials in the mix are designed to obtain a desired gradation which yields maximum density. An investigation was carried out on gradation requirements of the mixes to obtain maximum density and stability values, using coarse aggregates with different shape factors. It is found that there is an optimum value of gradation index n of the gradation equation : $p\% = 100 \frac{d}{D}^n$, for an aggregate with a given value of angularity number. N . A correlation between values of N and n has been obtained which can be used advantageously in mix design.

Résumé

La stabilité des matériaux granulaires et des mélanges bitumineux augmente avec la compacité ou avec la diminution des vides dans le mélange. C'est pourquoi la granularité du mélange est déterminée pour obtenir la densité maximale. Une recherche a été faite sur l'optimisation de la granularité des mélanges pour obtenir des valeurs maximales de densité et de stabilité en utilisant des gravillons avec différents facteurs de forme. Il se trouve qu'il existe une valeur optimale de l'indice "n" donné par l'équation de la granularité $p\% = 100 \frac{d}{D}^n$, pour un granulats ayant une angularité N donnée. Une relation entre N et n est obtenue et peut être utilisée pour déterminer la granularité du mélange.

1. Introduction

1.1. Density and Stability

The stability of granular pavement materials and bituminous mixes increases with an increase in the density or a decrease in the voids in the mix. Therefore it is a common practice to choose the grain size distribution of the coarse and fine aggregates in the mix so as to yield the maximum dry density value. In the case of bituminous mixes, it is also essential to ascertain the other requirements such as flexibility and durability.

1.2. Gradation and Density

The gradation to be aimed at or the "desired gradation" for different pavement works may be obtained from one of the following three approaches :

(i) Gradation tables standardised/recommended by different organisations [1, 2, 4, 7] (ii) Ideal gradation concept [5, 6] using the general equation, $P\% = 100 \frac{d}{D}^n$ where P is to percentage of materials finer than grain size d , D is the maximum size of the aggregate and n is the gradation index (iii) Experimental results based on the aggregate - binder concept [8, 9] giving the optimum proportion of fines corresponding to maximum density or stability.

The gradation tables have specified the limits or particle size distribution for granular base and surfacings of pavements and for bituminous concrete mixes. Corresponding to each grain size, the middle point of the range of percentage fines given in the table is considered as the desired gradation and the different aggregates are proportioned so as to obtain this gradation.

1.3. Shape and Gradation Index

Fuller and Thompson [5] assumed that all particles are spherical in shape and first, the largest particles are arranged in the densest state and the next smaller size of particles

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are chosen to just fit in the voids between the largest particles and this process is continued ; they theoretically determined the value of gradation index $n = 0.50$ in the ideal gradation concept. In the case of soil-aggregate mixes the particle shape is seldom spherical and for such materials. Talbot and Richort [10] suggested the value of gradation index $n = 0.333$ based on their test results.

The aggregate-binder concept was proposed by Miller and Sowers [9] by experimentally studying the effect of soil binder or fines in soil-aggregate mixes.

1.4. Shape Factor and Stability

Investigators like Herrin and Goetz [6] and Campen and Smith [3] have studied the effect of aggregate shape on the stability of bituminous mixes. Aggregates ranging from rounded to angular shape were found to have significant effects on the stability of bituminous mixes. But the shape factors of the aggregates were expressed only in qualitative terms and therefore definite conclusions shape factors of coarse aggregates quantitatively in terms of the angularity number N , flakiness index FI and elongation index EI .

2. Scope of the study

2.1. Various Shape Factors

The shape factors of aggregates used in pavement materials depend on the source, properties of the rock and the type and condition of the crushers. In India jaw crushers are commonly used at the site of the stone quarry. As the jaws of the crusher become worn, there is generally an increase in the values of N and EI .

2.2. Shape Factor and Grain Size Distribution

Four typical shape factors of aggregates viz., rounded, semi-rounded, angular and flaky are shown in Fig. 1. The rounded aggregates have least void content and the lowest N -value, when compared with angular and flaky particles. Therefore in coarse aggregates with higher values of N , the proportion of finer particles required to produce denser mix are also higher. If the gradation index n of the ideal gradation equation is decreased from 0.5 to a smaller value, the proportion of finer materials in the mix increases, as seen in Table 2. Therefore a correlation between the angularity number N and the gradation index n is likely to exist ; as the value of N increases, that of n should decrease. In this case it is assumed that the angularity number N of the coarse particles as well as other size ranges remain the same. But in actual practice the N values of materials of various size ranges are likely to slightly differ from each other ; in such cases, the weighted average value of N in the mix should be determined.

It may also be desirable to consider the effects of other shape factors like the FI and EI .

2.3. Objects

The standard gradation tables do not consider the variation in grain size distribution with change in any of the shape factors of the coarse aggregates, except proposing a range of values. For widely varying shape factors of aggregates available from different sources or batches, it is necessary to alter the grain size distribution suitably so as to obtain the maximum density or stability. The authors have often found that the middle point of the ranges suggested in the standard tables give too low values of density/stability of bituminous mixes in some cases, necessitating several trials by varying

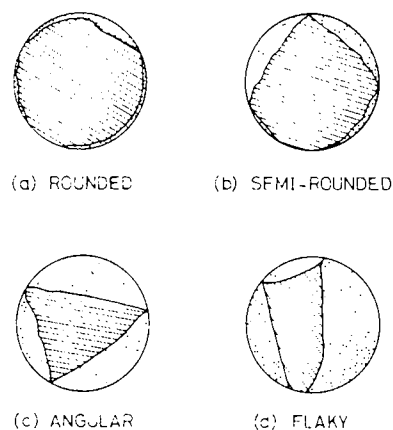


Fig. 1 : Typical shape factors of aggregates.

the grain size distribution within the given ranges till the required stability is achieved. In order to minimise the above trials, laboratory investigations were planned so as to establish a correlation between the weighted average angularity number N and the gradation index n of the ideal gradation equation, so that by finding the N values of the coarse fractions of the aggregate in the mix, it is possible to arrive at the desired gradation for maximum density/stability. By a suitable proportioning method, it is possible to obtain a gradation in the field which is closest to the desired gradation.

3. Laboratory experiments

3.1. Materials

Aggregates with different shape factors were collected from various parts of the country and they were sorted out in eleven different groups of aggregates mixes A, B, C, ... K, based on the N values of different size ranges. The values of shape factor of these aggregates are presented in Table 1.

Tab. 1 : Shape factors of materials used

Material	Specific Gravity	Weighted Average Values of		
		Angularity Number	Elongation Index	Flakiness Index
A	2.68	2.23	0	0
B	2.69	5.06	0	3.66
C	2.69	5.21	22.52	1.83
D	2.69	5.26	50	3.0
E	2.68	7.31	0	0
F	2.64	7.82	37.77	0
G	2.64	8.03	0	0
H	2.72	8.87	0	0
I	2.72	9.18	19.38	2.08
J	2.72	12.35	55.97	15.10
K	2.66	13.17	71.65	12.13

3.2. Variation in Grain Size Distribution

By adopting different values of the gradation index n in the gradation equation, the grain size distributions of each material in the mixes were altered. Six values of n were

considered between 0.2 and 0.5 and the gradations adopted in this investigation with each of the eleven materials are given in Table 2.

Tab. 2 : Gradation chart for various values of gradation index. n

Size, m ($\times 10^{-3}$)	Percentage passing for 'n'					
	0.20	0.25	0.30	0.33	0.40	0.50
20	100	100	100	100	100	100
16	95.6	94.57	93.5	92.9	91.5	89.4
12.5	91.0	88.91	86.8	85.6	82.9	79.1
10	87.1	84.10	81.2	79.6	75.8	70.7
6.3	79.4	74.92	70.7	68.3	62.9	56.1
4.75	75.0	69.85	64.9	62.2	56.3	48.7
2.36	65.2	58.61	52.7	49.4	42.5	34.4
1.18	56.8	49.21	42.8	39.5	32.2	24.3
0.60	49.6	41.62	34.9	31.4	24.6	17.3
0.30	43.2	35.0	28.4	25.0	18.6	12.2
0.15	37.6	29.43	23.0	19.9	14.1	8.7
0.075	32.7	24.75	18.7	15.8	10.7	6.1

3.3. Density Studies

Detailed investigation were carried out on the density values of dry mixes as per Table 2 and subjected to compaction on a standard vibrating table (50 cycles per second) for a period of 60 seconds. The tests were repeated till at least three consistent density values were obtained with each mix and the average density was then determined in each case. Thus with eleven different materials, the average density values of sixty-six mixes were determined. Also density tests were carried out on mixes obtained from the middle points of the ranges given in the standard gradation table on all the materials, for comparison.

3.4. Tests on Bituminous Mexes

The gradation of each mix which gave the highest density was chosen for preparing bituminous mixes for further tests. Marshall stability tests were carried out on each of those mixes. In order to compare the results with the conventional approach, bituminous mixes were prepared with gradation obtained from the middle points of the standard table and were tested.

4. Analysis of data and discussions

4.1. Relation between gradation index and density

The density values of the mixes obtained by varying the gradation index n were plotted for each material. It is interesting to note that there is an optimum value of n which gives maximum density of the mix for each material. These are shown in Fig. 2. It is also observed that as the angularity number N increases, the optimum value of gradation index n decreases.

4.2. Correlation between N and n

The weighted average of N of each mix corresponding to the optimum value of n producing maximum density was plotted against the optimum n value (Fig. 3). A linear relation is observed with regression equation :

$$n = 0.378 - 0.0098 N,$$

with coefficient of correlation $r = -0.9293$; ($r^2 = 0.8636$, number of points = 11, $F = 56.96$ significant at one per cent level of significance).

This shows that there is a good correlation between the angularity number and gradation index.

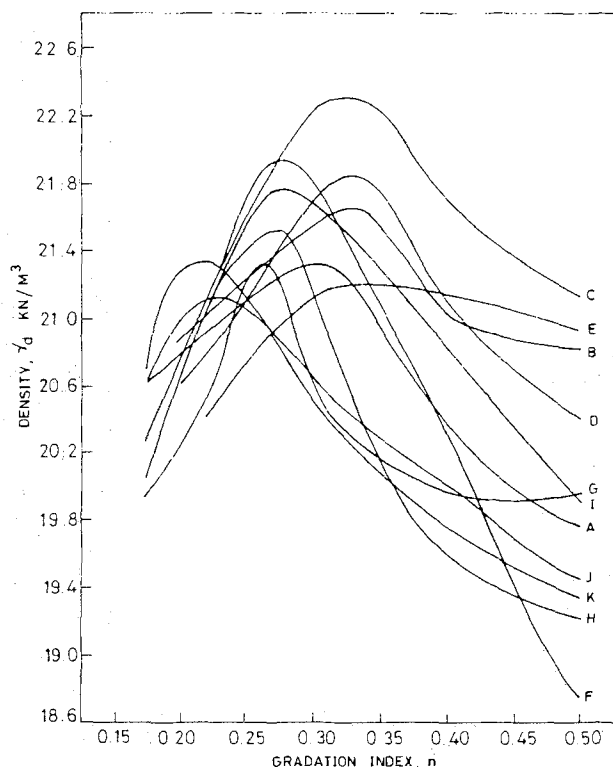


Fig. 2 : Relation between gradation index and density.

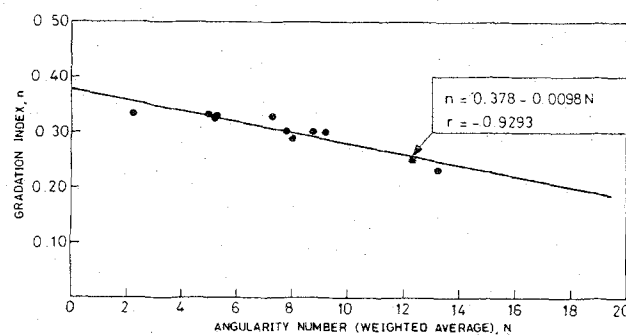


Fig. 3 : Correlation between angularity number and gradation index.

4.3. Comparison of Density Values

The density values obtained by the present approach corresponding to optimum gradation index were compared with those obtained from the middle point of the standard table. It was found that the density values by the present approach

were higher than the conventional approach in all the cases and the percentage increase in density by this approach varied from 4.23 to 13.28 percent and the average increase in the density for all the eleven materials was 9.77 per cent.

4.4. Comparison of Stability Values of Bituminous Mixes

The maximum values of Marshall Stability obtained for the mixes by the present approach at optimum n value were consistently higher than those obtained by the conventional method, the increase in maximum stability values being up to 90 per cent. The values of optimum bitumen content and flow are found to be slightly different by the two approaches due to variation in grain size distribution.

5. Conclusions

The present approach to decide the gradation based on the angularity number of coarse aggregates in the mix gives a grain size distribution corresponding to high values of dry density and stability. There is considerable saving in time and effort in order to obtain the maximum density by the present approach as the number of trials using different gradations within the ranges of standard tables could be avoided. First the angularity number of the coarse fraction of aggregates are determined and using the regression equation the optimum value of gradation index is found. Subsequently corrections are made for the weighted average value of N in the mix. An example of present approach is worked out and given in Appendix.

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APPENDIX

Typical Example for Deciding Gradation Based on Angularity Number

Step (i) : Maximum size of aggregate (100 % passing),
 $D = 20 \times 10^{-3} \text{ m}$

Size range in m ($\times 10^{-3}$)	Angularity Number (N)
20 -16	10.07
16 -12.5	8.49
12.5-10	9.35
10.0- 6.3	8.97

Mean $\bar{N} = 9.22$

Step (ii) : Determination of trial gradation :

From regression line or equation of n vs N , for mean $\bar{N} = 9.22$, $n = 0.2876 \approx 0.288$. Gradation obtained from equation $P/\% = 100 \frac{d}{D}^n$ with $n = 0.288$ is given below :

Size, n ($\times 10^{-3}$)	Percent passing
20	100
16	93.78
12.5	87.34
10.0	81.90
6.3	71.70

Step (iii) : Determination of Weighted Averages N :

Size range, n ($\times 10^{-3}$)	Percent, p	$p \times N$
20 -16	6.22	62.64
16 -12.5	6.44	54.68
12.5-10	5.44	50.86
10.0- 6.3	10.20	91.49
	28.30	259.67

$$\text{Weighted Average Value of } N = \frac{\sum pN}{\sum p} = \frac{259.67}{28.30} = 9.18$$

Step (iv) : Corrected Gradation :

Corrected gradation index n (from regression line/equation) = 0.288.

As the n -value obtained from mean N -value does not significantly differ from that obtained from the weighted average value of N , the gradation obtained in step (ii) may be used.

Note : If the revised value of n is different for the weighted average value of N , a new gradation table should be prepared with the revised value of n .