Relation between CBR and Modulus of Strength

Relation Expérimentale entre le CBR et le Module de Résistance

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Summary

This paper presents the results of tests carried out at the Laboratório Nacional de Engenharia Civil, in order to relate the CBR with the modulus of strength (product of the modulus of subgrade reaction K_s and the diameter of the loading plate, then independent of the diameter) the purpose being to apply these results to the design of rigid and flexible pavements.

CBR and load tests have been carried out (in the mould and with the CBR plunger) on three types of soils (silt, fluvial outwash and argillaceous sand) on crushed stone and on mixtures of basaltic and calcareous crushed stone with argillaceous sand.

The conclusion is drawn that the modulus of strength is 10 to 20 times the CBR for soft materials and 10 to 30 for hard materials, and that the modulus of subgrade reaction, K_s, is $\frac{1}{8}$ to $\frac{1}{4}$ CBR and $\frac{1}{8}$ to $\frac{1}{3}$ CBR for soft and hard materials respectively.

Sommaire

On présente dans cette communication les résultats d'essais effectués au Laboratório Nacional de Engenharia Civil afin de déceler une corrélation entre le CBR et le module de résistance (produit du module de réaction K_s par le diamètre de la plaque de chargement, donc indépendant du diamètre), le but étant d'en faire l'application au dimensionnement des revêtements rigides et flexibles.

On a fait des essais CBR et des essais de charge (dans le moule et avec le piston CBR) sur trois types de sols (silt, alluvion et sable argileux) sur des gravillons et sur des mélanges de gravillons basaltiques et calcaires avec du sable argileux.

On a conclu que le module de résistance varie de 10 à 20 fois le CBR pour les matériaux mous et de 10 à 30 fois pour les matériaux durs, et que le module de réaction, K_s, varie, respectivement de $\frac{1}{8}$ à $\frac{1}{4}$ CBR et de $\frac{1}{8}$ à $\frac{1}{3}$ CBR.

The most widely known methods of pavement design are those that make use of the CBR test for flexible pavements and a loading test on large plates for rigid pavements.

The CBR test is carried out according to a standard method (Road Research Laboratory, 1952). In the loading test a circular plate is used with a diameter d subject to a load Q; the settlement δ corresponding to Q is determined and then the modulus of strength E is computed. Its value is approximately

$$E = \frac{\sigma . d}{\delta} \qquad \dots . \ (1)$$

that can be written as

$$E = \frac{\sigma}{\epsilon} \qquad \dots . \ (2)$$

where

$$\epsilon = \frac{\delta}{d} \qquad \dots . \ (3)$$

The modulus of strength E is an intrinsic characteristic of the soil as is proved by Fig. 1, that was plotted from data gathered from researches carried out by McLeod (1947) and Nascimento (1953). It can be seen that tests carried out on the same soil with bearing plates whose diameters ranged from 30 cm to 1·00 m yielded the same curve connecting stresses with strains.

It is believed to be of great interest to determine the relationships between the parameters CBR and E with a view to establishing a general design method for rigid and flexible pavements. For that purpose, researches are under way at the Laboratório Nacional de Engenharia Civil and their present status is presented in this paper.

The materials made use of in these tests were a silt, a fluvial outwash, an argillaceous sand, a basaltic crushed stone, a mixture of basaltic crushed stone with argillaceous sand and a mixture of calcareous crushed stone with argillaceous sand. The particle-size distributions and the Atterberg limits of the materials used are shown in Figs. 2 and 3.

The CBR tests were performed according to the usual procedure, without soaking and on both ends of the sample. The load tests were carried out on the same samples that were afterwards subject to the CBR tests, and with the CBR plunger itself with loading steps of about 0·5 kg/cm^{-2} for the soils and of about 5 kg/cm^{-2} for the other materials; each value of the load was kept constant for 1 minute. The CBR plunger was used for the loading tests because the value of E, as stated above (Fig. 1), does not depend on the diameter of the bearing plate.

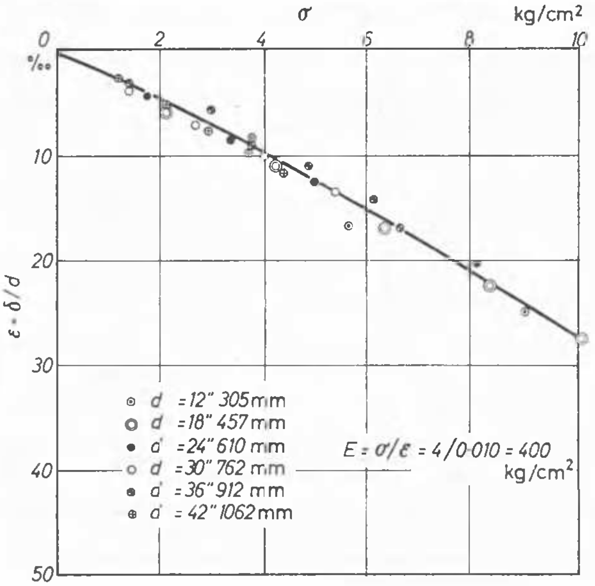

Fig. 1 Load curve obtained from loading tests on plates of different diameters. From data gathered in McLeod's papers

Courbe de charge obtenue au cours des essais de charge sur des plateaux de différents diamètres. Tracée à partir d'éléments des travaux de McLeod

Samples were prepared according to the CBR standards; but in the case of crushed stone and the mixtures of crushed stone with argillaceous sand a circular base 9·8 cm in diameter (area 75 cm²) was adapted to the compaction rammer for the ten first and the ten last blows on each layer.

The test results are shown in Tables 1 and 2 and in the diagrams of Figs. 4 and 5; the first of these has natural scale and the second a logarithmic diagram.

Table 1

Results of the tests on soils

Résultats des essais sur trois sols

Material	*Wet density* (g cm^{-3})	*Moisture content* (%)	CBR (%)	*E* (kg cm^{-2})	*Relative compaction* (%)
Silt *Maximum density:* $\gamma_0 = 1{\cdot}65$ g cm^{-3} *Optimum moisture content:* $W_0 = 17\%$	1·69	16·1	3·0	31	89
	1·73	17·0	2·2	59	90
	1·76	17·4	3·7	28	91
	1·76	17·4	9·2	55	91
	1·88	13·7	10·9	125	100
	1·90	14·0	9·1	140	101
	1·92	13·7	5·9	50	102
	1·97	16·5	3·7	25	103
	1·97	16·5	1·5	31	103
	1·99	15·0	12·7	44	105
Fluvial outwash $\gamma_0 = 1{\cdot}60$ g cm^{-3} $W_0 = 22\%$	2·01	22·4	11·8	156	103
	2·01	22·4	11·8	150	103
	1·95	22·0	11·0	133	100
	1·95	22·0	11·0	156	100
	1·91	23·0	9·2	115	98
	1·91	23·0	9·6	115	98
	1·92	22·0	10·3	137	98
	1·92	22·0	10·3	137	98
	1·77	23·0	8·9	119	90
	1·77	23·0	6·6	116	90
	1·77	23·0	7·7	100	90
	1·77	23·0	7·0	114	90
Argillaceous sand $\gamma_0 = 1{\cdot}98$ g cm^{-3} $W_0 = 11\%$	1·96	10·9	6·6	83	90
	1·96	10·9	5·9	72	90
	1·96	10·8	7·4	125	90
	1·96	10·8	5·2	90	90
	2·24	10·1	3·7	40	103
	2·16	9·6	12·9	167	100
	2·16	9·6	13·3	125	100
	2·19	8·9	16·4	190	102
	2·19	8·9	16·4	187	102
	2·20	10·4	11·2	78	100
	2·20	10·4	13·3	163	100
	2·06	10·8	9·6	104	94
	2·06	10·8	9·6	133	94
	1·95	9·8	10·0	133	90
	1·95	9·8	8·1	125	90

Table 2

Results of the tests on crushed stone and on crushed stone with argillaceous sand

Résultats des essais sur pierre concassée et sur pierre concassée et sable argileux

Material	*Proportions* (%)		CBR (%)	*E* (kg cm^{-2})
	Stone	*Sand*		
Basaltic crushed stone	—	—	52	560
Basaltic crushed stone with argillaceous sand	80	20	92	1670
	80	20	70	1670
	75	25	52	500
Calcareous crushed stone with argillaceous sand	75	25	103	3200
	75	25	100	2500
	75	25	111	3200
	75	25	92	3200
	70	30	148	1400
	70	30	136	1560
	70	30	136	2040
	80	20	74	2080
	80	20	148	2500

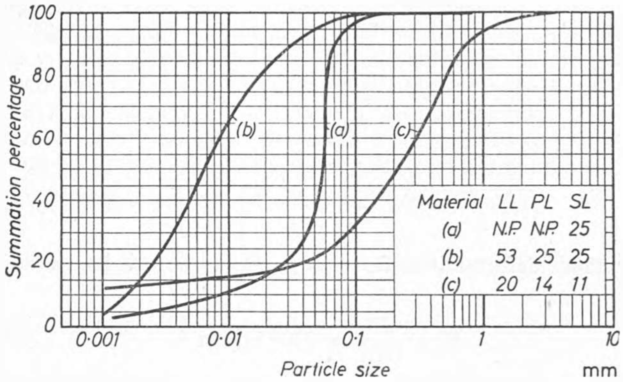

Fig. 2 Particle-size distribution curve and Atterberg limits of: (a) silt; (b) fluvial outwash; and (c) argillaceous sand

Courbe granulométrique et limites d'Atterberg: (a) du silt; (b) de l'alluvion; et (c) du sable argileux

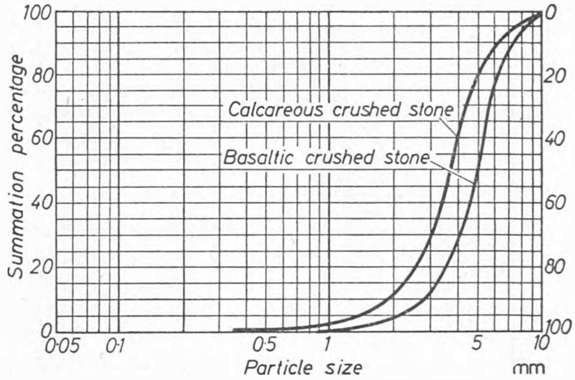

Fig. 3 Particle-size distribution curves of the basaltic crushed stone and of the calcareous crushed stone

Courbes granulométriques des gravillons basaltiques et calcaires

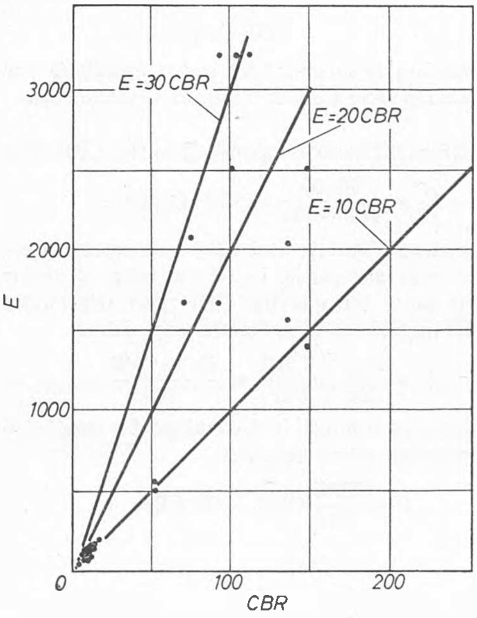

Fig. 4 Relationship between CBR and *E* natural scales

Relation entre CBR et *E* échelles 1:1

In order to interpret the results of these tests, a standard CBR test curve (CBR = 100) was traced in Fig. 6, stresses (σ) being plotted as a function of strain (ϵ) (NASCIMENTO *et al.*, 1955). To the normal CBR settlement $\delta = 0{\cdot}25$ cm a strain $\epsilon = 0{\cdot}05$ corresponds for diameter $d = 5$ cm; a load corresponding to CBR = 100 a stress $\sigma = 70$ kg/cm^{-2} corresponds.

The modulus of strength of the standard curve is given by

$$E_0 = \frac{\Delta\sigma_0}{\Delta\epsilon} \qquad \ldots\ (4)$$

for small deformations far enough from rupture its value is (Fig. 6)

$$E_0 = \frac{20}{0{\cdot}01} = 2000 \text{ kg/cm}^{-2} \qquad \ldots\ (5)$$

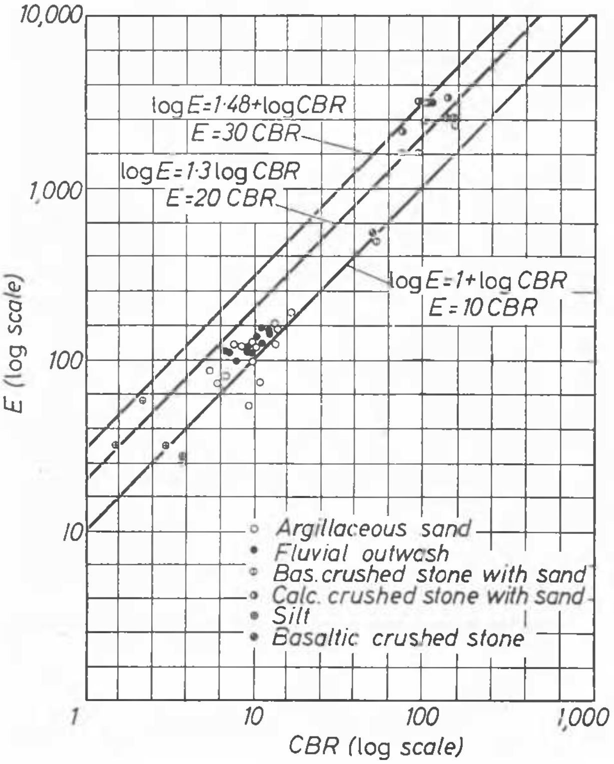

Fig. 5 Relationship between CBR and E logarithmic scales
Relation entre CBR et E échelles logarithmiques

and for the deformations corresponding to the CBR (Fig. 6)

$$E_0 = \frac{70\text{–}60}{0{\cdot}05\text{–}0{\cdot}04} = 1000 \text{ kg/cm}^{-2} \qquad \ldots\ (6)$$

If the load curve obtained in a CBR test on any material is similar to the standard curve, i.e. if the ratio of abscissae is constant, that same ratio is the CBR and the modulus of strength of the material is given by the expression

$$E = \frac{\Delta\sigma_0 \times \text{CBR}}{\Delta\epsilon \times 100} = \frac{E_0 \times \text{CBR}}{100} \qquad \ldots\ (7)$$

If the modulus of strength is determined for small deformations, the expression above becomes

$$E = \frac{2000}{100}\text{ CBR} = 20 \text{ CBR} \qquad \ldots\ (8)$$

and for large deformations, near to the CBR

$$E = \frac{1000}{100}\text{ CBR} = 10 \text{ CBR} \qquad \ldots\ (9)$$

In Figs. 4 and 5 the results corresponding to materials with a low CBR, comply with expression $E = 10$ to 20 CBR. The materials with a higher strength so far tested show a tendency to higher values of E, ranging from 10 to 30 CBR. The reason for this increase lies in the shape of the load curves for hard materials, which differ from those of soft materials. Rupture is more conspicuous in the former as can be seen schematically in Fig. 6, in which the curve similar to the standard CBR curve is represented by the dotted line and the actual curve by the full line. From here, although the modulus of strength of both curves is the same, the effective CBR is shown to be lower for the dotted curve, hence the ratio E/CBR is higher.

From equations 8 and 9 we can obtain the relationships between the modulus of subgrade reaction, K_s, and the CBR. As K_s is given by

$$K_s = \frac{\sigma}{\delta} \qquad \ldots\ (10)$$

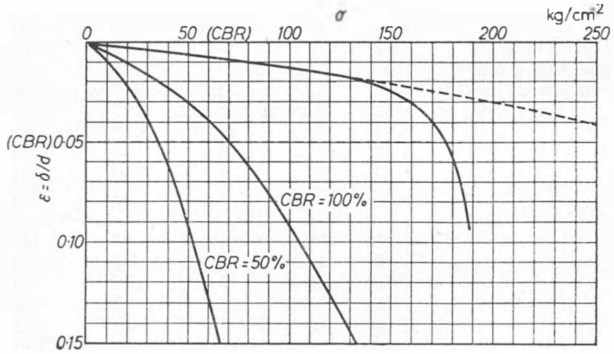

Fig. 6 Diagram presenting the standard loading curve for the CBR test, compared with two materials, one soft, the other hard
Diagramme où l'on présente la courbe-type de charge de l'essai CBR, comparée avec deux matériaux, l'un mou, l'autre dur

we can put (equation 1)

$$K_s = \frac{E}{d} \qquad \ldots\ (11)$$

for $d = 75$ cm (30 in.), is from equation 8

$$K_s = \frac{20 \text{ CBR}}{75} = \frac{\text{CBR}}{4}$$

and from equation 9

$$K_s = \frac{10 \text{ CBR}}{75} = \frac{\text{CBR}}{8}$$

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