# PROPOSAL OF PERFORMANCE BASED SPECIFICATIONS FOR SELECTION AND PLACING OF NATURAL MATERIALS FOR ROAD EMBANKMENT CONSTRUCTION

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## ABSTRACT

Natural materials, called “soils” in the field of road constructions, are judged suitable or unsuitable according as they satisfy or not specifications. Since specifications for the selection of natural materials to be used in embankment construction change considerably according to the country and to the moment, the same soil can be judged suitable or unsuitable.

As for as soils are concerned, only very few concepts are widely accepted.

At a given compaction energy, for different water contents, a Proctor curve describes well the mass of volume of a soil, while a CBR curve (California Bearing Ratio) describes well its stability. The CBR is not a mechanical property, though for its determination, loads and deformations are measured.

The reference compaction energy changes from country to country, but until now on sites it was supposed that the higher the compaction energy of a soil, the higher would be its CBR. On the contrary on many sites it has been found that beyond a certain compaction energy the CBR decreases. Such behaviour was known since long ago: the CBR-curves of a soil traced for different energies intersect themselves. Beyond the water content marking the intersection point the higher CBR is found on the curve traced for the lower compaction energy. Therefore modified Proctor energy doesn’t always bring to better mechanical properties of soils than standard Proctor energy. Especially for fine-graded soils the best mechanical properties may be better achieved adopting standard Proctor energy.

Soils for the construction of road embankments are selected until now on the base of classification criteria, i.e. on the base of grain-size distribution (a geometric property) and plasticity (a property which defines the aptitude of a soil to be modelled in a wider or narrower range of water content). Grain size-distribution and plasticity have no relation with the mechanical properties of soils. Therefore the compliance of a soil with classification based criteria does not involve its performance for road construction.

Finally it is proposed to abandon soil classification and to select soils for road construction according to a CBR based procedure which chooses compaction energy and compaction water content range to achieve good mechanic and volume stability. This procedure should allow the use of almost every soil for embankment, avoid the necessity to take in consideration "materials not compliant with specifications", allow mechanical equivalence of natural and non-natural materials.

## KEY WORDS

SOILS CLASSIFICATION / COMPACTION ENERGY / PROCTOR CURVE / CBR CURVE/ SOILS SUITABILITY

## 1. CLASSIFICATION BASED SPECIFICATIONS FOR SELECTION OF SOILS FOR EMBANKMENT CONSTRUCTION ARE UNSATISFACTORY

At present selection and acceptance of natural materials, called “soils” for utilization in road constructions is based on the classification of soils which was fully discussed and precised on occasion of a symposium on the identification and classification of soils held in Atlanta, 1950. The special publication ASTM (ASTM, 1950) permits to appreciate to which extent the soils were a new subject for the engineers. As Burmister remarked engineers were “newcomers in the field of soil science and, consequently, have borrowed ideas, theories, techniques and procedures from old timers such as those engaged in agriculture, ceramics and geology”. Then engineers for soils did not use the concepts of strength of materials or the theory of elasticity. In 1950 a standard method of test was not yet issued for the determination of the moisture-density relation of soils, though the Tentative Method of Test ASTM D698-42T had been prepared since 1942. Nor a standard method was issued for the determination of CBR, though a Suggested Method of Test for California Bearing Test was submitted by the Corps of Engineers and published in 1950 (ASTM, 1950). This means that all the discussions which produced the soils classification could not take into account of the moisture-density relation, and of the CBR.

A soils classification involves that the suitability of a soil for road constructions does not depend nor on the procedure for its compaction, nor on its mineralogical nature, but only on its sieve analysis and plasticity. Apart from this principle, since then several soils classifications, more or less different, where adopted in the different administrations.

It is surprising how the concept of soils classification has been preserved in decades and has widespread all over the world. Some administrations have tried to characterize the soil classification with a special name or procedure, but we can eventually recognize that every soil classification is based only on sieve analysis, particularly on the percentage passing to a sieve with small openings, and on its plastic limits.

On the other side the two following instances push against the stability of the classification and induce variations:

-the need to use locally available soils

-the need to avoid further acceptance of a soil after it has been deemed as a possible cause of unsuccessful road construction.

Such variations occur from country to country or in the same country in the time. Though formally minor, they may produce relevant effects and change a soil from suitable to unsuitable for road constructions or vice versa. The suitability of a soil for road constructions is decided until now on the basis of such formal criteria without any regard to a rational analysis in terms of strength, fatigue or deformations of the road structure. This is most likely the reason why since more than a decade road engineers are discussing how to use marginal materials in road constructions, i.e. materials not compliant with specifications. The fact itself that this discussion has risen suggests that classification based specifications are not really reliable for the purpose to select and accept soils for road constructions.

## 2. CBR TESTS, E MODULI AND LOAD DURATION

It has been observed that the CBR index and the elastic E moduli provide very similar information and correlations between CBR index and E modulus are generally recognized. Indeed during a CBR test penetrations (displacements) are measured and the corresponding forces which produce the penetrations. Moreover the geometry of a CBR Test is the same as the geometry of a Load Bearing Test on a plate with infinite stiffness which, in the hypothesis of homogeneous and elastic soil, permits to determine the E modulus. In reality the well known relations E=10 CBR (E measured in MPa) or E=100

CBR (E measured in $Kg/cm^2$) can be deduced expressing the CBR and the E modulus of in terms of forces and deflections measured during the CBR test. On the other hand the E modulus of soils depends, more than E moduli of other construction materials, both on the procedure used for applying the load and on the procedure for the preparation of the specimen. The CBR Test, very practical and widespread all over the world, provides information on the soils mechanical performances though the standardized loading procedure is not deemed satisfactory in order to define an E modulus.
Indeed the load duration of tests to evaluate E moduli of road materials should represent the effects of the traffic and take into account both of the traffic speed and of the depth of the material in the road (Barksdale, 1971), (Comenale, 2000), (Bird, 2001), (Comenale, 2001). Theoretically the proper parameter to characterize and select soils is the E modulus, which is used in the road thickness design. After years of efforts research has provided procedures for the determination of the E modulus (LTTP, 1996).
The E modulus is more representative than CBR of the embankment conditions under the traffic loads because of the shorter load duration in its test procedure.
The present procedures (LTTP, 1996) for the determination of the E moduli require to compact specimens with the same moisture content and the same density of the in situ soil, or, in case such data are not available, at the optimum moisture content and 95% maximum dry density. Such procedure does not permit to detect three important aspects of the soils behaviour which can be known performing CBR tests for a range of moisture contents.

## 3. CBR TESTS SHOW THAT SOILS PERFORMANCES DEPEND ON COMPACTION ENERGY AND MOISTURE CONTENT

The CBR is determined for different energy levels at the optimum water content or for a range of water content (AASHTO, 1993) (ASTM, 1994).
The determination of the CBR for a range of water content permits to detect the three following aspects of a soil behaviour and to take into account of all of them both in the soils selection phase, and in the construction phase:

a) The mechanical performances of a soil in a road construction (the CBR index) do not depend so much on its present moisture content and dry density, as on its compaction procedure, i.e. on the compaction energy and moisture content.
b) It is not always true that an increase of the compaction energy improves the mechanical performance of a soil.
c) A soil swells because of moisture content variations. Also the swelling depends mostly on the compaction procedure, i.e. on the compaction energy and moisture content.

Unfortunately the CBR for design and construction of roads is almost always determined at the optimum water content in the assumption that the CBR index increases regularly with the dry density. On the contrary sometimes it happens that the increase of compaction induces no increase of CBR and sometimes it also happens that an increase of compaction induces a decrease of the CBR. This kind of data is sometimes wrongly attributed to test errors, while they are consistent with the information above mentioned in b). More than once apparently contradictory results of CBR tests at the optimum water content have been satisfactorily explained through the execution of CBR tests for a range of water content. Finally the determination of the CBR at the optimum water content provides partial information, is not satisfactory for repeatability and may lead to wrong interpretation of data.
Moreover only apparently the CBR for a range of water content requires more time than CBR at the optimum water content. Indeed the latter requires the prior determination of the optimum moisture content (an extra work and an extra possibility of errors), while the CBR

for a range of water content includes the determination of the dry density curve (on the same specimens prepared for penetration in the CBR loading machine).

3.1 The mechanical properties of a soil (its CBR) depend on the compaction energy and water content

The CBR test for a range of water content permits to plot a family of curves, as shown in figure 1.a.

FIG. 1a

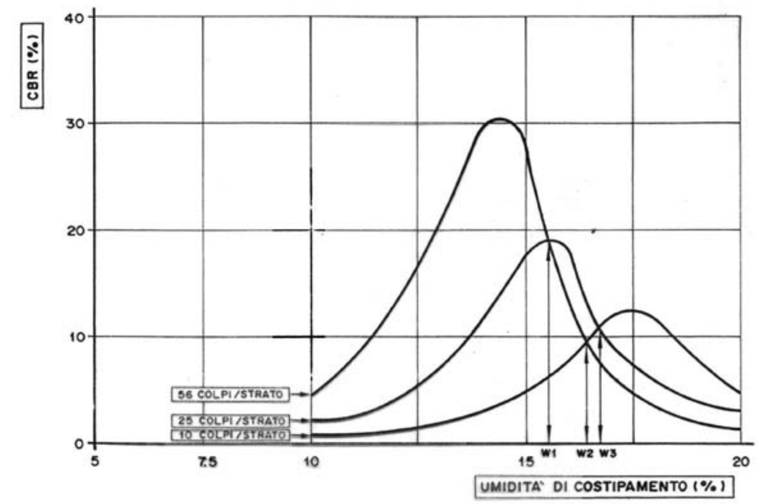


**Figure 1.a - Family of CBR curves for different compaction energies**

FIG. 1b

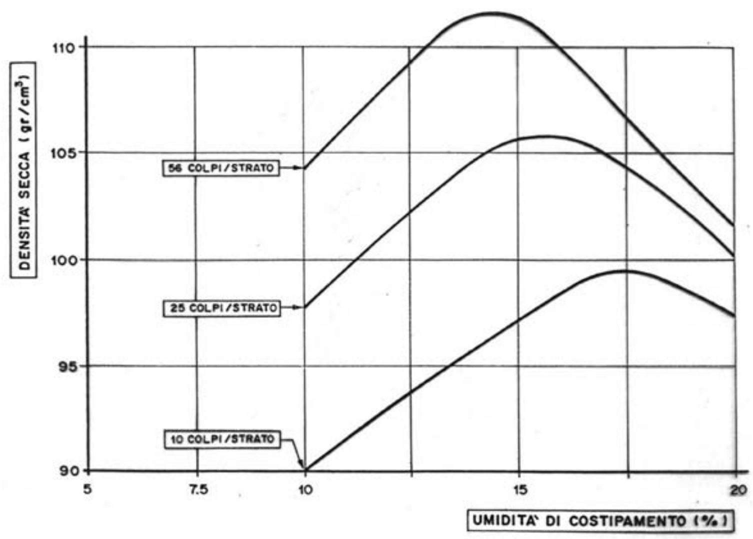


**Figure 1. b - Family of dry density curves for different compaction energies**

Every curve is relative to an energy level and provides the CBR index for every water content at compaction time. The curves show that the mechanic performance of a soil (its CBR index) depends on the compaction energy and on water content. At first sight the CBR curves (figure 1.a) are similar to the curves (figure 1.b) plotted with the dry densities determined on the same CBR specimens after compaction. Also the dry density of a soil depends on the compaction energy and on water content. Both CBR curves and compaction curves have a maximum value which is higher when the compaction energy is higher. The “wet” side of the CBR curves is often steep and small variations of the water content in the range near the optimum water content may bring high variations of the CBR.

For this reason the CBR for a range of water content is easily repeatable, while the CBR test at the optimum water content may be hardly repeatable.

3.2. It is not always true that an increase of the compaction energy improves the mechanical performance of a soil

The water content corresponding to the maximum dry density for a certain compaction energy is called “optimum moisture content”. The water content corresponding to the maximum CBR value and the water content corresponding to the maximum dry density (optimum moisture content) for the same compaction energy have nearly the same value, sometime the same value. Sometime the optimum moisture content is higher than the moisture content corresponding to the maximum CBR as in the case shown in figure 2. Such circumstance, not so rare, was detected (Demonio Aeronautico, 1954) in the Geotechnical Laboratory of the Italian Air Force where, since then, it has been considered useful to determine the CBR for a range of water content.
This circumstance is important for two reasons

a) Since the “wet” side of the CBR curve is often very steep, it may happen that the CBR value corresponding to the optimum water content, so far almost always used to evaluate the CBR, may be remarkably lower than the maximum CBR value.

b) CBR curves intersect as shown in figure 1.a while density curves do not intersect as shown in figure 1.b. This means that a soil with a certain moisture content, when progressively compacted, always increases its density, not always its CBR. In particular in fig. 1.a three CBR curves are plotted corresponding to the compaction energy of 10, 25 and 56 blows of the Proctor hammer. The two CBR curves corresponding to the compaction energy of 56 and 25 blows intersect in the point with abscissa $w_1$, higher than the water content corresponding to the maximum CBR. It can be seen that, for every water content inferior to $w_1$ the $CBR_{56}$ of the specimen compacted with 56 blows per layer is higher than the $CBR_{25}$ of the specimen compacted with 25 blows per layer and that this latter is higher than the $CBR_{10}$ of the specimen compacted with 10 blows per layer. For water contents higher than $w_1$ the $CBR_{56}$ of the specimen compacted with 56 blows per layer is lower than the $CBR_{25}$ of the specimen compacted with 25 blows per layer. By compacting a soil with higher water content than $w_1$ at a compaction energy corresponding to 56 blows of Proctor hammer, a higher dry density is obtained than the dry density obtained at a compaction level corresponding to 25 blows of Proctor hammer, but a lower $CBR_{56}$ than the $CBR_{25}$. Since the optimum water content may be higher than the water content corresponding to the maximum CBR value, it may happen that the optimum water content has the same value, or is also higher, than the water content $w_1$ corresponding to the intersection point. In such case the $CBR_{56}$ at the optimum water content may be the same as the $CBR_{25}$ or lower and the higher compaction energy produces the unwanted effect of the same CBR obtained with less energy or lower.

In general a soil with given water content, progressively compacted, above a certain compaction energy, has decreasing CBR values, i.e. decreasing mechanic performances, while its density is still increasing.

3.3. Also the swelling depends mostly on the compaction procedure, i.e. on the compaction energy and moisture content.

The soaked CBR test permits to plot the curve of swelling after 4 days soaking. Such swelling is a measure of the volumetric stability of the soil when its moisture content changes from the initial compaction water content with cycles of drying and soaking. The swelling values measured in CBR tests for a range of water content are plotted on a regular curve, are repeatable, easy to interpret in order to forecast the swelling in the road life. For a given compaction energy it is possible to evaluate the swelling range for a compaction water content range. The three swellings measured in a CBR test at the optimum water content may be very different values, not satisfactory for repeatability, nor easy to be interpreted for forecasting the swelling during the road life.

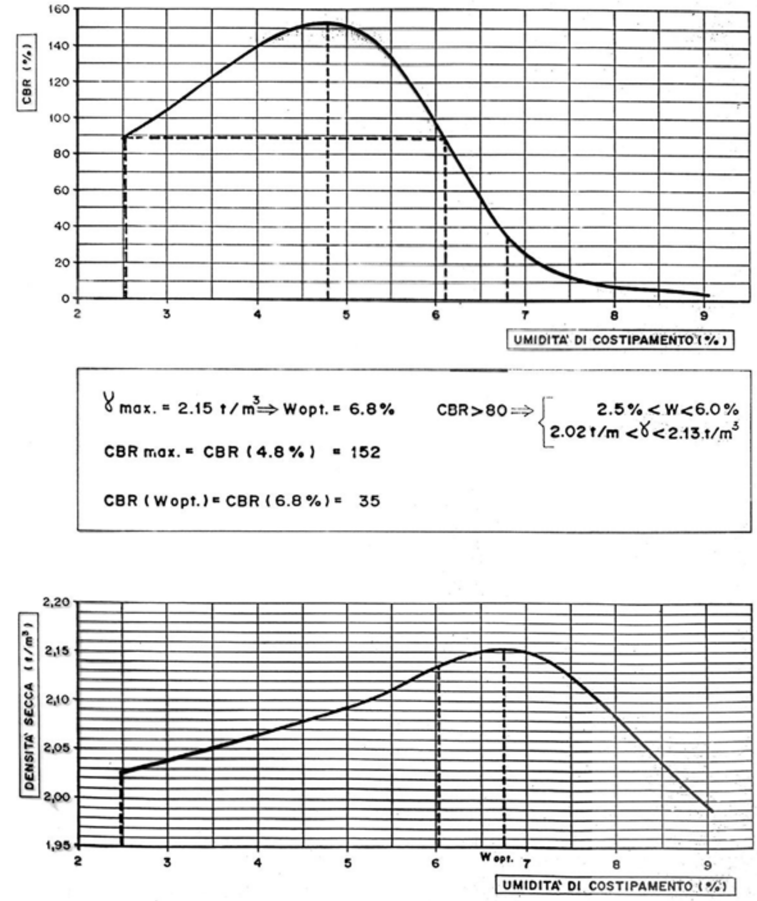


**Figure 2 - CBR curve and dry density curve plotted from the same specimens**

It has been already reported (Comenale, 1998) that the usual classification criteria are not valid for latherites, soils common in hot climates and successfully used for road constructions, despite their fine fraction and the plasticity of their fines. It has been also found that it is necessary to perform CBR tests for a range of water content in order to obtain a satisfactory knowledge of the latherites performances and to establish consequent specifications for compaction. It has been pointed out that satisfactory CBR values are to be targeted and not the optimum water content, nor very high dry densities.
All the above has been shown with a wide amount of data drawn from CBR tests for a range of water content.
In general a CBR test for a range of water content is suitable for obtaining an adequate knowledge of the soils performances, since it permits the simultaneous examination of the compaction curve and of the CBR curve in order to determine the range of water contents and the range of densities producing satisfactory CBR values and acceptable swelling values. These ranges of water content and dry density shall be targeted on site. In this way it is possible to find out for every soil the best compaction procedure (compaction energy and water content), to accept for road constructions a wider variety of soils, to have quarries at limited hauling distances. The definition of the compaction procedure involves that not only it is necessary to target in situ dry densities higher than a minimum value, but also to avoid over wetting and overcompacting which can lead to extremely low mechanical performances of the soils compared to the their targeted best performances.

## 4. CONCLUSIONS

It is proposed to abandon soils classification (sieve analysis and plasticity limits) for the selection of soils to be used in the road embankments construction and to replace it with the CBR test for a range of water content which permits to know and to forecast the performances of a soil in terms of mechanic and volumetric stability. On the basis of such knowledge it is possible to choose the best placing procedure (compaction energy and water content) in order to get the best performances of the available soils. Therefore it is proposed to judge a soil suitable for embankment construction if it is possible to determine compaction levels and water content intervals which conduct to targeted CBR intervals and to acceptable swelling intervals. Such performace based criteria will permit to avoid:

- of wrongly considering unsuitable a soil for embankment construction,
- wrong compaction procedures which can involve waste of compaction energy and low mechanic performances.

Adopting the CBR tests for a range of water content to select soils to be employed in the embankment construction brings the economic and ecological advantage to permit distributed exploitation of borrow pits instead of big concentrated borrow areas and savings of water in countries where water is precious.

It is also proposed to adopt procedures for the determination of the E modulus of a soil which permit to appreciate its variation with both the main parameters which affect the real mechanical performances of a soil, i.e. the compaction energy and moisture content.

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