Dynamic *CBR* as a method of embankment compaction assessment

Dynamique *CBR* comme une méthode d'évaluation de compactage du remblai

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ABSTRACT: In engineering practice, earth construction requires suitable soil compaction, usually relating to the Proctor methods. Materials of the built-in embankment and the subgrade have their own specifications, dependant on the kind of earth structure and soil plasticity characteristics. Care should be taken not to use compaction degree (% of maximum compaction) as the only parameter to assess soil compaction. This applies to both cohesive soil and to fly ash whose permeability and mechanical properties dependent on moisture content at compaction. Therefore, for these types of soils California Bearing Ratio could be used as a method of compaction assessment being an indicator of soil bearing capacity. The *CBR* research was done for both static (classic) and dynamic methods on fly ash samples without soaking them to replicate field conditions. A load of 2.44 kPa was applied to all the samples subjected to penetrations. The dynamic *CBR* tests were conducted by using Light Weight Deflectometer consisting of a falling weight to produce a defined load pulse of the *CBR* piston. The *CBR* test could be used for running compaction control during embankment erection, which specially refers to dynamic *CBR* test due to the speed of research execution.

RÉSUMÉ: Dans la pratique d'ingénierie, la construction en terre nécessite un compactage du sol adapté, concernant en général les méthodes Proctor. Les matériels encastrés du remblai et de la plate-forme ont leurs propres spécifications, dépendant du genre de la construction en terre et de caractéristiques de plasticité du sol. Il faut prendre soin de ne pas utiliser le degré de compactage (% de compactage maximum) comme le seul paramètre pour évaluer la compactage du sol. Cela s'applique aux sols cohésifs et à cendres volantes dont la perméabilité et des propriétés mécaniques dépendent de la teneur en humidité au compactage. Donc, pour ceux types de sol l'indice portant californien pourrait être utilisé comme une méthode d'évaluation du compactage étant un indicateur de la capacité portante. Les recherches *CBR* ont été effectuées pour les méthodes statiques (classiques) et dynamiques sur les échantillons de cendres voltantes sans les faire tremper à reproduire les conditions de terrain. Une charge de 2,44 kPa a été appliqué à toutes échantillons soumis à des pénétrations. Les tests de dynamique *CBR* ont été effectués a l'aide de déflectomètre constitué par la masse tombante pour produire une impulsion de charge définie du piston *CBR*. Le test *CBR* pourrait être utilisé pour exécuter le contrôle du compactange lors de l'érection de remblai, qui se réfère en particulier à l'essai dynamique de *CBR* en raison de la rapidité d'exécution de la recherche.

KEYWORDS: compaction, California Bearing Ratio (*CBR*), dynamic *CBR* (CBR_d), fly ash, compaction assessment.

1 INTRODUCTION

In engineering practice, earth construction requires suitable soil compaction, usually relating to the Standard and Modified Proctor methods. Materials of the built-in road embankment and the subgrade have their own specifications, dependant on the kind of earth structure and soil plasticity characteristics. Care should be taken not to use compaction degree (% of maximum compaction) as the only parameter to assess compaction of material in embankments. This applies to both cohesive soil and fly ash. The permeability and mechanical properties of compacted fly ash are dependent on moisture content present during compaction, as are properties of cohesive mineral soils (Turnbull and Foster 1956, Mitchell et al. 1965, Zabielska-Adamska 2006 and 2011). Consequently different values of geotechnical parameters are obtained for water content on either side of the optimum water content on the compaction curve, for the same dry densities. Thus for these types of soils California Bearing Ratio, *CBR*, may be used as a method of compaction assessment, since it is an indicator of ground bearing capacity broadly used in the design of civil engineering.

The laboratory *CBR* tests by means of both static (classic) and dynamic methods were carried out to establish relationship between bearing ratio and fly ash compaction. Samples, compacted by the Standard or Modified Proctor methods, were prepared without soaking them to replicate field conditions during earth structure erection. The dynamic *CBR*, CBR_d, tests were done by using impact generator and guide rod, which are the parts of Light Weight Deflectometer (LWD), and additional equipment in a *CBR* piston. A falling weight is to produce a defined load pulse of the *CBR* piston that can be used both in laboratory and field tests. The aim of this study was to prove that *CBR* tests could be used as the methods of road embankment or subgrade compaction assessment. This refers especially to CBR_d test which may be used for running compaction control during embankment erection due to the speed of research execution, as well as Light Weight Deflectometer (Sulewska 2012).

1 LITERATURE REVIEW

California Bearing Ratio, *CBR*, is expressed as the percentage ratio of unit load, p, which has to be applied so that a standardized circular piston may be pressed in a soil sample to a definite depth with a rate of 1.25 mm/min and standard load, corresponding to unit load, p_s, necessary to press the piston at the same rate into the same depth of a standard compacted crushed rock.

$$CBR = \frac{p}{p_s} \cdot 100\% \qquad (1)$$

CBR value is used for evaluation of the subgrade or subbase strength, and may be applied to assess the resistance to failure or indicate the load-carrying capacity. It should be noted here that *CBR* values in pavement design do not reflect the shear stresses that are generated due to repeated traffic loading. The shear stress depends on many factors; none of them is fully controlled or modelled in CBR test (Rico Rodriquez et al. 1988, Brown 1996).

In laboratory, *CBR* penetration test is performed on material compacted in a specified mould and placed in loading machine equipped with a movable base that rises at uniform rate used in forcing the penetration piston into the specimen. Tested specimens are penetrated directly after compaction or are to be previously soaked. *CBR* test *in-situ* is carried out with a mechanical screw jack for continuous increase of the applied load to the penetration piston. A reaction forcing the penetration piston into the soil is provided by a lorry equipped with a metal beam and attachments under its rear.

The dynamic *CBR*, CBR_d, test can be performed both in laboratory and *in situ*. The test can be conducted as an alternative to the static *CBR* test, especially due to the short period of time required. CBR_d advantage, compared with the classic *CBR*, is the elimination of a loading frame necessary in static loading. The CBR_d test is carried out with the use of Light Weight Deflectometer**,** where a falling weight is used to generate a defined load pulse on the *CBR* piston. CBR_d is calculated on the basis empirical formula (Zorn 2002) as:

$$CBR = \frac{87.3}{s^{0.59}}(\%) \tag{2}$$

where 87.3 is the number standing as a value of dynamic loading including empirical coefficient, and *s* is the settlement in millimetres. CBR_d is recommended to specify when it is greater or equalled 20% and is equalled or lower than 150%.

Turnbull and Foster (1956) carried out broad studies on *CBR* for compacted mineral soils. They determined penetration resistance of unsoaked samples of lean clay, compacted by means of four different energy values and at different moisture contents. It was proved that the *CBR* value for compacted clay is a function for both water content as well as dry density. Compacted samples reached higher *CBR* values when higher energy values were applied. Moisture increase of compacted samples decreased *CBR* value and in cases of compacted samples with moisture contents greater than optimum water content, penetration resistance was close to zero. Soaking of samples caused the decrease of *CBR* value, quite significant in compacted samples – dry of optimum, less significant at optimum water content. The smallest decrease was observed in samples compacted at wet of optimum. Rodriguez et al. (1988) described *CBR* dependence on compaction parameters– moisture contents and dry densities, as well as on conditions of compaction– energy and methodology of compaction. The authors point to the fact that the *CBR* value of the soil compacted with higher energy value may be lower than that resulting from the compaction with lower energy value. *CBR* dependence on moisture in the process of compaction was confirmed in the course of studies conducted by Faure and Viana Da Mata (1994). The authors straightforwardly claim that dry density resulting from the compaction of a sample does not have any impact on *CBR* value which, on the other hand is influenced by moisture present in the process of compaction. *CBR*'s relationship with moisture content was also observed in the case of compacted marl from Saudi Arabia (Aiban 1995), where marl was subjected to tests at moisture optimum and moisture on the dry and wet sides of optimum. Moisture–density curves and *CBR*(*w*) dependency curves were said to be similar; the highest *CBR* values were obtained at optimum moisture. The studies of the samples tested immediately after compaction and the soaked samples confirmed that the effect of soaking is decreased when the samples are compacted at moisture greater than optimum.

Zabielska-Adamska (2006 and 2011) concluded that the highest *CBR* values for unsoaked samples of fly ash (class F) appear in modified compaction – in case of moisture level below optimum, and in standard compaction – in case of moisture level within or slightly below optimum. In saturated samples, the highest values for bearing ratio *CBR* are present in moisture level equal optimum for both compaction energy levels. Once optimum moisture is exceeded, *CBR* value drops dramatically, regardless of the compaction energy and method of preparation of samples, soaked or unsoaked. High moisture results in the loss of contact among fly ash grains. Hence *CBR* value dependence on moisture level of fly ash is quite apparent. *CBR* of samples compacted by means of modified method for optimum moisture is almost twice as high than in the case of optimum compaction by standard method, which points to a significant influence of compaction energy and dry density. It is interesting how compaction energy influences *CBR* in samples of the same level of moisture, compacted, however, with the use of different energies. Ash samples with moisture value *w,* compacted by Proctor modified compaction, where $w > w_{opt1}$, show far lower *CBR* than samples of the same moisture level *w*, but compacted by standard method where $w < w_{opt2}$. The lowest *CBR* in the analysis of various samples of fly ash was obtained in case of fly ash of the finest graining which influences increase of optimum moisture and decrease of density of solid particles. Zabielska-Adamska and Sulewska (2009) studied relationships between *CBR* and analysed parameters of various samples of fly ash by means of Artificial Neural Networks (ANNs) and as a result concluded that the most relevant variables were ρ_d and relation w/w_{opt}, which confirms the fact that optimum water content and moisture content at compaction are the most significant parameters in *CBR*. Dry density, as another significant parameter, should be considered as dominant when comparing *CBR* values for different fly ash shipments compacted with the use of different energies.

The results of the dynamic *CBR* are extremely poorly represented in the literature, which is probably due to a low prevalence of this method in the world. The first study of CBR_d, done on the road mineral materials, were presented by Weingard et al. (1986). A good correlation between test results was obtained using static and dynamic method. A study conducted by Schmidt and Volm (2000) is the only one known to the authors of this paper which presents results of research with CBR_d carried out on cohesive soil with different compaction. The studies were conducted for silty clay with moisture content grade from 11 to 18%, and optimum water content established as 15.6%. As a result of laboratory studies, the researchers obtained two curves $CBR_d(w)$ and $CBR(w)$, shifted in relation to each other by approximately 5–7%. In case of moisture content greater than optimum, the difference between static values and dynamic values changed to approx. 9%. Higher bearing ratio was obtained in dynamic studies. CBR_d is recommended for control research in embankment erection with the use fine grained soils compacted at moisture contents lower than optimum.

2 LABORATORY TESTS

All the tests were conducted on the basis of fly ash from hard coal burning in Bialystok Thermal-Electric Power Plant, stored at a dry storage yard. The fly ash shipment corresponded in graining to sandy silt. Physical parameters are shown in Tab. 1.

The laboratory *CBR* tests were carried out to establish relationship between bearing ratio and fly ash compaction. The tested samples were compacted by two methods: the Standard Proctor and the Modified Proctor at moisture contents within the range of $w_{opt} \pm 5\%$ for each compaction method. The fly ash samples were saturated 24 hrs prior to the test so that their moisture content could increase by approx. 2.5%. After that, they were deposited in sealed containers. Each compaction curve point was designated on a separate sample. During the compaction tests, individual samples of fly ash were used only once, otherwise they could not be regarded as representative (Zabielska-Adamska 2006). The *CBR* tests were conducted on unsaturated samples. All the samples subjected to penetration, tested both methods – static and dynamic, and were loaded with ASTM 1883-73 recommended load of 2.44 kPa. The static (classic) *CBR* research was done on fly ash samples directly after compaction. Higher *CBR* value was accepted as a result

Table 1. Geotechnical parameters of tested fly ash shipment.

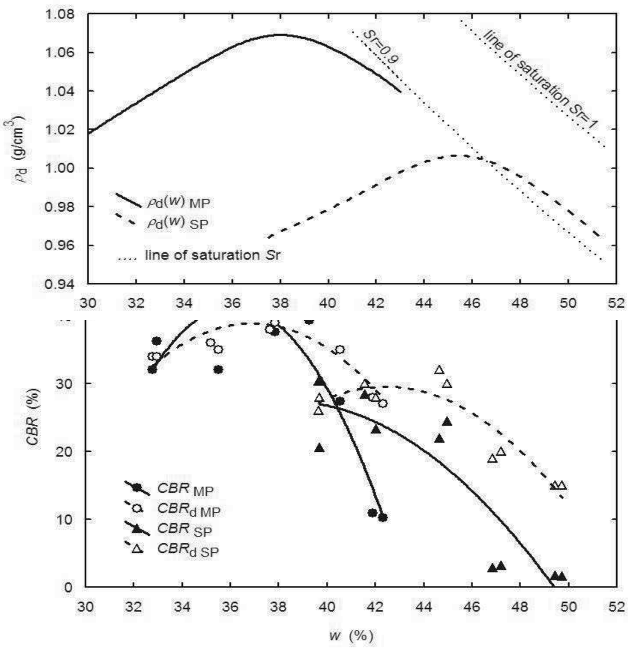
Tested fly ash parameters			
D_{50} (mm)	ρ_s (g/cm^3)	$C_U = D_{60}/D_{10}$	$C_C = D_{30}^2/D_{60} \cdot D_{10}$
0.055–0.065	2.11±0.01	3.89–4.25	0.94–1.03
Modified Proctor method		Standard Proctor method	
w_{opt1} (%)	$\rho_{d\,max1}$ (g/cm^3)	w_{opt2} (%)	$\rho_{d\,max2}$ (g/cm^3)
37.00	1.068	45.50	1.009



Figure 1. *CBR* research (from the left): static test; changed mould basis and prepared mould extension for dynamic *CBR*; specimen ready for dynamic test (photo by Zabielska-Adamska).

calculated on the basis of pressing piston resistance, represented in a given depth – 2.5 or 5.0 mm. Next, after levelling off the surface of the same specimen and replacement of basis of the mould, dynamic *CBR* was carried out. The CBR_d tests were conducted using Light Weight Deflectometer (LWD) consisting of a falling weight (7.07 kN) vertically movable along the guide rod to produce a defined load pulse (3.6 MN/m^2) of the *CBR* piston. Electronic measurement system gauged the depth of the piston's penetration in the tested soil after a single impact. *CBR* tests are shown in Figure 1.

Figure 2 represents the results of standard and dynamic *CBR* testing, depending on moisture content at compaction, in relation to compaction curves of fly ash, obtained by means of two Proctor methods. Static *CBR* results confirm earlier results obtained by the author. *CBR* of unsaturated samples of fly ash reaches the highest values in the case of samples compacted at the moisture content lower than optimum. The samples compacted above optimum water content have still lower *CBR* values simultaneously with an increase of moisture content. These relationships can be observed in both methods of compaction – standard method and modified method. However, samples compacted with the use of modified Proctor method, the curve $CBR(w)$ definitely reaches maximum. The shape of the curves $CBR_d(w)$ is similar to that obtained according to the standard method – $CBR(w)$. In the case of modified compaction, curves $CBR_d(w)$ and $CBR(w)$ are characterised by a similar scope of moisture content; from w_{opt1}–5% to optimum moisture content, w_{opt1} (difference in relation to *CBR* – up to about 2.5%). Once curve $CBR_d(w)$ exceeds $w_{opt1,}$ it also exceeds standard curve, passing *CBR* by 16% at w_{opt1}+5%. In the case of standard compaction, at moisture level w_{opt2}–5%, CBR_d value equals *CBR* value. After this, as the moisture content increases the difference also increases and when the moisture level is equal to w_{opt2}, the *CBR* difference is exceeded by 5%.



$CBR_{MP} = -1026.64 + 59.09w - 0.82w^2$ (R^2=0.8751)
$CBR_{d\,MP} = -467.44 + 27.46w - 0.37w^2$ (R^2=0.7768)
$CBR_{SP} = -297.17 + 16.96w - 0.22w^2$ (R^2=0.8047)
$CBR_{d\,SP} = -519.42 + 25.88w - 0.30w^2$ (R^2=0.8468)

Figure 2. *CBR* test results versus moisture content at compaction in comparison with compaction curves: MP – Modified Proctor method, SP – Standard Proctor method, *CBR* – static test results, CBR_d – dynamic test results.

With further increase of moisture content, the difference may be as high as 13%. Significant differences in the results of the studies carried out by means of static and dynamic methods, at moisture level exceeding w_{opt} originate from the differences in speed of loading and lack of possibility of pore pressure dissipation in the case of impact loading. Similar observations can be made during studies on the influence of penetration ratio on the resistance of saturated clayey soils in cone penetration tests (Kim et al. 2008).

Figure 3 presents dependence of static and dynamic *CBR* on dry density. It can be seen in Figure 3 that there are points standing out, with the coordinates (ρ_d, *CBR*) obtained in the case of standard method at moisture content higher than optimum by at least 2.5%, and in modified method higher by at least 5%. This is the result of dependence of mechanical parameters of fly ash on moisture content in the process of compaction. Once these points are excluded, statistically valid relationships - $CBR(\rho_d)$ can appear, especially in the case of CBR_d values, where for value $CBR_d(\rho_d)$ coefficient of determination R^2=0.8675 was obtained (Fig. 4). CBR_d dependence on *CBR* is also statistically valid. Equation $CBR_d=17.28+0.52CBR$ explains 84.9% of variance in the value of statistic *CBR*.

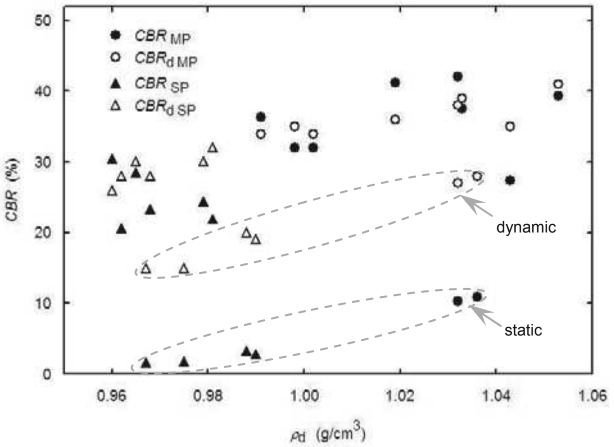


Figure 3. Relationship between *CBR* value and dry density with an indication the points obtained at moisture contents at compaction $w=w_{opt}$+(2.5–5%): MP – Modified Proctor method, SP – Standard Proctor method, *CBR* – static test results, CBR_d – dynamic test results.

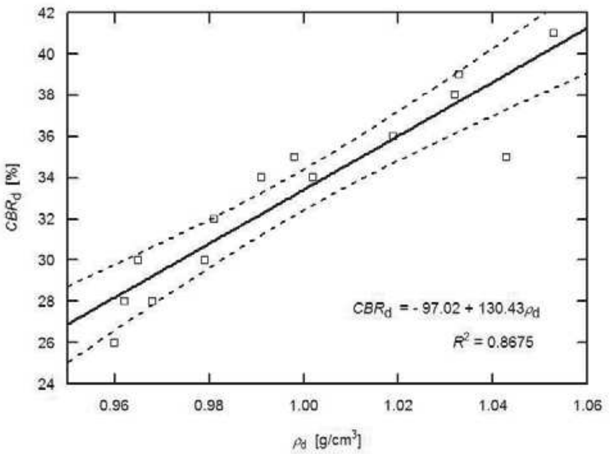


Figure 4. *CBR* value versus dry density excluding the points obtained at moisture contents at compaction $w=w_{opt}$+(2.5–5%), along with 95% confidence interval.

3 CONCLUSIONS

1. The dynamic *CBR* method, as well as static (classic) method can be used to assess compaction of fly ash and cohesive soils embedded in subgrade or layers of embankment. The results of studies of CBR_d, and *CBR*, are closely connected with the characteristics of compaction.
2. The current compaction quality control of fine grained anthropogenic ground conducted through CBR_d tests with the use of Light Weight Deflectometer producing a defined load pulse of the *CBR* piston is recommended in the cases of embedded material at moisture contents equal optimum or lower. CBR_d studies of anthropogenic ground compacted at moisture levels exceeding optimum water content may lead to overstating of the test results due to lack of pore pressure dissipation after impact ground loading.
3. Dynamic *CBR* test, using Light Weight Deflectometer, should be widely used due to its speed and ease of research as an alternative method to classic method of quality control in compaction process or assessment of subgrade bearing capacity.

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