THE BALTIC JOURNAL
OF ROAD AND BRIDGE ENGINEERING

2012
7(3): 204–211

MIX DESIGN WITH LOW BEARING CAPACITY MATERIALS

Gianluca Dell'Acqua[1], Mario De Luca[2], Francesca Russo[3]✉, Renato Lamberti[4]

Dept of Transportation Engineering "Luigi Tocchetti" University of Naples "Federico II"
Via Claudio 21, I-80125 Naples, Italy
E-mails: [1]gianluca.dellacqua@unina.it; [2]mario.deluca@unina.it;
[3]francesca.russo2@unina.it; [4]renato.lamberti@unina.it

Abstract. The roadway construction requirements for soils are generally fixed by standards. The most common constraints involving materials are Optimum Moisture Content (OMC), Max Dry Density (MDD) and bearing capacity predictable by using Proctor test and CBR test. These traditional tests are combined with other simple field tests to gain the max density. However, the use of low bearing materials such as clay and silt, and local resources is an important means of simplifying and economizing the road building still further. The main purpose of this experimental analysis is a procedure to characterize some road materials by its bearing capacity (CBR and MDD) from two simple standard tests (sieve analysis and Atterberg limits), and then a method to employ silt and/or clay in road mixture. The planned method suggests the minimal volume of high quality material in the roadway mixture added to silt and clay that must be available in the analyzed location, obtaining an ideal bearing capacity. Different soil types from various quarries and digs located in Southern Italy were used. The classic laboratory tests to assess the soil properties of all amassed study soils were carried out, i.e., the Atterberg limits and Grain Size Distribution (GSD). Correlations based on linear regression were then performed to determine the optimal combination of the properties measured with dependent CBR variables and Max Dry Density (MDD) to be predicted for low-volume roads. These equations were then validated by using four material types from outside the calibration sample.

Keywords: Atterberg limits, low bearing capacity material, mixture, CBR and MDD index.

1. Introduction

Rural roads, as presented in this paper, are a vital part of the infrastructure of societies: they allow a flow of goods and services throughout rural areas, support rural development, supply access to local markets, help attract teachers to rural schools and encourage rural technical support from government agencies, as well as providing a variety of other uses and benefits. About this, for example, safety performance of existing rural roads should be increased by targeting investments to the highest accident concentration sections and to the road sections with the highest accident reduction potential (Jasiūnienė *et al.* 2012). At the same time, however, road construction makes a significant adverse environmental impact (Skrinskas, Domatas 2006), modifying natural terrain, disturbing large areas, and leading to major cultural and land use changes. Thus, roads need to be well planned, well designed, well-constructed, and properly maintained for minimal adverse impact and to be cost effective in the long term with acceptable maintenance and repair costs. *The Low-Volume Roads Engineering Best Management Practices Field Guide* (BMPs) written by the USDA Forest Service and the U.S. Agency for International Development (USAID) is applied worldwide and helps to achieve these goals (Molenaar 2007).

Until fairly recently, there has been an inevitable tendency to rigidly apply imported specifications as "best practice" simply because there was little alternative other than taking unquantified risk in using untried materials and methods. However, with the wealth of research and development work undertaken over the past 28 years, new, "localized" standards and specifications have emerged in a number of innovative ways on the basis of quantitative evidence. There is thus a need to find solutions and instruments that will maximize maintenance and, in particular, make it more cost-effective from this point of view (Dell'Acqua *et al.* 2011). The value of the research and development work undertaken in Botswana in the roads sector over the last 3 decades has been substantial (Pinard *et al.* 1999). Much of this work has enabled best use to be made of the existing local natural resources that otherwise would have been excluded from consideration in road construction because of their nonstandard properties. It has also made it possible to find adequate solutions to locally prevalent engineering problems that occur because of road construction challenges posed by the physical

ISSN 1822-427X print / ISSN 1822-4288 online
doi:10.3846/bjrbe.2012.28
http://www.bjrbe.vgtu.lt

environment, as a result of which substantial cost savings have been made. Therefore the use of "low bearing capacity" as silt and clay materials represents a remarkable advantage in the low-cost simplified protocols concerning the roadway sector.

Berney IV and Wahl (2007), for example, have introduced a rapid soils classification kit with compact and easily transported instruments to provide an immediate reading for soil moisture, grain size distribution, and plastic limit. The ability to determine the construction requirements for soil without having to conduct laboratory testing is essential for creating an expedient field design process. The authors point out how in a military context a rapid soil assessment process requires the correlation of the Proctor and CBR responses with material properties which can be measured using field data within the allowable time frame.

The authors produced a software program which incorporated the numerical data generated from the soils kit, classified the soil and performed multiple regression routines based on a statistical analysis of a large database of soil properties to predict optimum water content and max dry density for the soil of interest. Built-in, higher-order regression equations allow the user to visualize complete moisture–density curves for varying compaction energies as well as soaked and unsoaked CBR as functions of water content for the constructed condition of the soil. The moisture–density curve and CBR strength represent the critical data necessary to enable contingency design and the construction of highways and airfields.

Bloser (2007) performed a comparative analysis experiment to provide a better understanding of wearing course aggregates. Three different road aggregates were compared in this study. The *first* is 2A: this aggregate has a max size of 2 in. (51 mm) and has relatively little fine material (0–10% passing through a sieve ASTM 200 – 2 mm). The *second* is DSA: it is designed to achieve max compaction density and is meant to be used as a wearing course for unpaved roads. DSA has a max size of 1.5 in. (38 mm) and a larger percentage of fine material (10–20% passing through a sieve ASTM 200 – 2 mm). Another important consideration of the DSA specification is the strict limitations on clay or soil content. No silt or clay may be added. The *last* material is DSA variation: it is similar in gradation to DSA, but has an additional 5% due to the weight of fine clays added to the material. These aggregates commonly used in Pennsylvania were compared using two different placement methods for each type of aggregate as part of a 3-year study to compare their long-term durability and cost-effectiveness. The two methods tested were the "dump and spread" method, known as tailgating, and the application of aggregate by a motor paver. No significant difference in performance was found between aggregate sections laid using a paver and the same aggregate laid by tailgating. The driving surface aggregate was the only aggregate of the three tested that did not show a statistically significant change in road elevation during the 3-year course of study. Results illustrate the importance of selecting a properly graded aggregate containing minimal clay and soil material for use as a surface aggregate on low-volume roads.

Molenaar (2007) described work done at the *Road and Railway Research Laboratory of Delft University of Technology* on the characterization of some tropical soils. The research work comprised classifying swelling clays, laterites, volcanic materials such as cinder, and locally available aggregates, as well as locally produced bituminous binders. All materials were sieved, and the plasticity parameters were determined. Then moisture–density relationships were determined using Proctor tests, and the CBR of the material was determined. Some materials were subjected to monotonic triaxial tests to determine the cohesion and angle of internal friction. Repeated load triaxial tests were performed on some materials to obtain information on resilient and permanent deformation characteristics. The conclusion of this research was that these soils are effectively categorized by means of CBR. Nevertheless, the use of triaxial tests was highly recommended. Furthermore, some materials originally rated as marginally suited or not suited for use in base and sub-base courses can be upgraded, effectively avoiding the high costs of producing and hauling high-quality materials.

Siddiki *et al.* (2004) have consolidated many results of research on geotechnical applications of coal combustion by-products, foundry sand, tire shreds, and crushed glass. These geotechnical applications suggest that significant cost savings are attained, in addition to a positive environmental impact by using these materials.

Ahmed and Khalid (2009) studied the use of waste and recycled materials in pavement foundations; their analysis focused especially on incinerator bottom ash (IBA) waste mixed with limestone at different levels, i.e., 0%, 30%, 50%, and 80%, to produce blends for use as pavement foundation layers. The study focused on evaluating the resistance to the permanent deformation of IBA-limestone blends, which is vital to prevent or minimize pavement rutting. To find out whether IBA was suitable for use as a pavement foundation layer, they studied its resistance using a cyclic (Amšiejus *et al*. 2009) triaxial test (CTT). An experimental program was designed to investigate the influence of plant-based enzyme treatment on the behaviour of these blends. Enzyme addition improved permanent deformation resistance for the control limestone blend; however, it had no noticeable effect on the IBA blends.

Since 2003, the *Dept of Transportation Engineering at the University of Naples* has been conducting a large-scale research program based on drivers behaviour on low-volume roads in Southern Italy and on its safety (Dell'Acqua 2011; Discetti *et al.* 2011) and operating management (Dell'Acqua, Russo 2011a; Dell'Acqua, Russo 2011b). The goal of this research study is to emphasize the significance of the recycled materials' use in the roadway mixture employing simplified low-cost standard.

This paper intends to illustrate an easy procedure to assess the bearing capacity of the soils employed in roadway construction by CBR index and max dry density obtained from simple standard tests, i.e., Atterberg limits and grain-size distribution (GSD).The proposed procedure also makes it possible to determine the max percentage of material with low bearing capacity (silt and/or clay) that are added to the material with high bearing capacity in the roadway blend to reach a good performance, once the desired strength of the soils to be utilized is known.

2. Data collection

The research presented here aims to illustrate a systematic and rapid procedure to create an optimal mixture for roadway use employing low bearing capacity and high-quality materials. Different soil types from various quarries and digs located in southern Italy were employed to construct the embankments, and to make up the sub-base and surface courses of the pavement. Table 1 shows the place from which the soil types come and the number of samples for each location. The initial phase of laboratory testing focused on the analysis of particle size distribution, and the designed procedure was developed starting from some standard ASTM procedures to obtain the soil properties as shown in Table 1. It was referred to ASTM 10, ASTM 40 and ASTM 200 sieves to classify materials according to Highway Research Board classification.

All materials were extracted about 1.00 m below ground level and their observed moisture content was approximately equal to 10–12%. Fig. 1 shows an example of some of the sites where the materials used for the experiment were located.

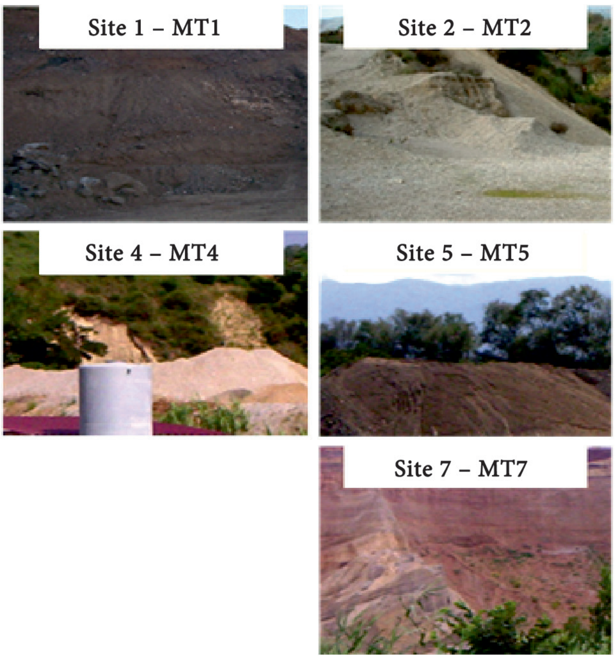

Fig. 1. Sites where the employed materials were located

Table 1. Soil types analysed and results of standard ASTM laboratory test

Material type	Site	Number of soil types analysed	Passing 10*ASTM* (2.00 mm), %	Passing 40*ASTM* (0.420 mm), %	Passing 200*ASTM* (0.074 mm), %	LL, %	PI, %	Proctor, g/cm^3	OMC, %	CBR, %	HRB classification
MT1	quarry	5	33.3	21.0	14.0	–	N.P.	2,30	4.90	100	A_{1a}
MT2	quarry	5	43.0	21.0	12.0	–	N.P.	2.32	5.04	100	A_{1a}
MT3	dig	6	97.7	96.2	91.8	34.4	6.7	1.94	8.00	14.0	A_5
MT4	quarry	4	21.7	12.6	8.4	18.6	2.0	2.40	6.00	83.0	A_{1a}
MT5	quarry	6	20.0	18.0	8.3	22.7	1.0	2.20	4.20	93.1	A_{1a}
MT6	dig	7	90.5	82.0	61.7	34.1	5.1	2.00	11.9	5.1	A_5
MT7	quarry	5	20.0	18.0	8.3	22.7	1.0	2.23	5.19	93.0	A_{1a}

Note: *CBR is at the MDD moisture condition (OMC).

The geological features of soil types are specified as follows:

- MT1 and MT4 materials are highly permeable and were taken from sandy alluvium and fluvial sediment;
- MT2 material derives from alluvium with inert stony matter and sand and grit, which reflects the intense washing away that has occurred in the site;
- MT3 material is a silt-clay soil taken from a road works site;
- MT5 material was collected from alluvium with stony and sandy inert matter;
- MT6 material is silt-clay soil with small amounts of sand, taken from a road works site;
- MT7 material is from alluvium with sand, gravel, and small amounts of medium and small silt and pebbles.

Table 1 shows the Liquid Limit (LL) and Plastic Index (PI) values for the soil samples according to the ASTM standard requirements. Moreover, the CBR (California Bearing Ratio) design criteria was assessed for each soil type for optimum moisture content (OMC) as determined using a modified AASHTO test. The soil types shown in Table 1 were employed to make different mixtures, varying their percentages. Table 2 shows the mixture produced and the results of standard laboratory testing for each blend as explained above; in particular, OMC was determined using a Proctor test for max dry density (MDD).

3. Data analysis

The classification of the designed mixtures was performed using a quality index for the mixture I_q based on the soil classification of the Highway Research Board that involves the particle size distribution and the susceptibility of materials to water. The I_q index is expressed as follows:

$$I_q = (1 - I_q^{10ASTM}) + (1 - I_q^{40ASTM}) + (1 - I_q^{200ASTM}) + (1 - I_q^{PI}), \quad (1)$$

where I_q^{10ASTM} – the percentage of mixture passing through the 10 ASTM sieve; I_q^{40ASTM} – the percentage of mixture passing through the 40 ASTM sieve; $I_q^{200ASTM}$ – the percentage of mixture passing through the 200 ASTM sieve; I_q^{PI} – the Plastic Index (PI) representing the difference between the Liquid Limit (LL) and the Plastic Limit (PL).

All indices shown in the Eq (1) were normalized according to the following expressions:

$$I_q^i = \frac{I_{qi} - I_{q\min}}{I_{q\max} - I_{q\min}}, \quad (2)$$

where I_{qi} – the index to be normalized with i associated with the 10 ASTM sieve, the 40 ASTM sieve or the 200 ASTM sieve, and i associated with PI; $I_{q\max}$ – the max value of the index to normalize; $I_{q\min}$ – the min value of the index to normalize.

Table 3 shows the normalized values of the indices for the experimental designed mixtures.

It is clear that I_q values close to zero are characteristic of poor mixtures while the index values close to four indicate a high-quality mixture even using "low bearing capacity".

4. Calibration procedure of the CBR and MDD prediction models

Once the quality index for each mixture was assessed, a series of linear regressions were performed to provide the users with two predictive equations to determine the

Table 2. Results of the standard laboratory test for designed mixtures

Mixture	Passing 10*ASTM* (2.00 mm), %	Passing 40*ASTM* (0.420 mm), %	Passing 200*ASTM* (0.074 mm), %	LL, %	PI, %	MDD, g/cm	OMC, %	CBR,* %	HRB classification
50%MT3 +25%MT2+ 25%MT1	65.5	50.9	34.8	23.1	5.5	2.11	5.2	69.0	A_4
55%MT3+ 25%MT2+ 20%MT1	69.1	54.0	39.0	22.9	5.5	2.09	5.5	52.0	A_4
60%MT3+ 20%MT2+ 20%MT1	73.8	66.1	60.2	27.2	5.8	2.06	5.9	17.7	A_4
80%MT1+ 20%MT2	86.7	81.0	75.0	28.2	6.0	2.01	6.1	43.0	A_4
85%MT3+ 15MT2	89.4	84.0	79.0	29.0	6.3	2.02	6.3	30.0	A_4
90%MT3+ 10%MT2	92.2	88.6	83.2	31.3	6.4	2.01	6.6	17.3	A_4
55%MT4+35%MT5+ 10 %MT7	22.0	14.0	8.00	17.0	2.0	2.40	5.2	76.1	A_{1a}
45%MT4+45%MT5+ 10%MT7	20.3	12.4	6.60	16.1	1.1	2.40	5.4	95.0	A_{1a}
35%MT4+35%MT5+30%MT7	20.0	10.0	7.00	17.7	2.5	2.30	5.4	88.0	A_{1a}
42%MT4+ 42%MT5+165MT7	33.4	23.6	10.2	22.5	4.3	2.30	6.0	50.0	A_{1a}

Note: *CBR is at the MDD moisture condition (OMC).

structural condition of the blends: the first refers to the forecast CBR value and the second refers to the MDD value.

The models were created using the statistics software *STATISTICA 7*. All parameters included in the models are significant to a 95% confidence level.

The best specification of the Ordinary-Least-Square model (OLS) of the CBR, where one independent variable appears, has the following Eq form:

$$CBR = 21.01 I_q + 13.27. \quad (3)$$

The adjusted coefficient of determination (r^2) of the model is 93.4%.

The best specification of the Ordinary-Least-Square model (OLS) of MDD, where one independent variable appears, has the following Eq form:

$$MDD = 0.101 I_q + 1.950. \quad (4)$$

The adjusted coefficient of determination (r^2) of the model is equal to 87.7%.

The statistical analysis of the coefficients in a CBR and MDD prediction models is shown in Table 4.

Table 5 shows the observed CBR and MDD values for each mixture obtained from laboratory testing, together with their predicted values obtained by using the regression Eqs (3) and (4), respectively.

5. CBR and MDD prediction model assessment procedure

The CBR prediction model and the MDD prediction models were then tested.

Two regression equations were applied to four soil types that were not included in the database used to calibrate prediction models.

The materials used for the assessment procedure were located in quarries in Southern Italy. These materials reflect the features of those adopted in the calibration phase as shown in Table 6.

Table 7 shows the observed values of CBR and MDD for each mixture employed during the validation procedure by means of laboratory testing and their predictive values calculated using the regression Eqs (3) and (4), respectively.

The procedure here presented is suitable for an I_q index falling within the range shown in Table 8, and for soils classified by HRB as follows:

- A1 – soils characterized by fragments of stone and sand;
- A3 – soils characterized by fine sand;
- A2 – sandy soils with silt and clay limited to subgroups A2-4 and A2-5;
- A4 – silty soils with LL < 40;
- A5 – silty soils with LL > 40.

Table 3. I_q index of designed mixtures to assess soil mechanical quality

Mixture	I_q^{10ASTM}	I_q^{40ASTM}	$I_q^{200ASTM}$	I_q^{PI}	I_q
100%MT1	0.171	0.128	0.087	0.000	3.61
100%MT2	0.296	0.128	0.063	0.000	3.51
100%MT3	1.000	1.000	1.000	1.000	0.00
50%MT3 +25%MT2+ 25%MT1	0.586	0.474	0.331	0.815	1.79
55%MT3+ 25%MT2+ 20%MT1	0.632	0.510	0.380	0.827	1.65
60%MT3+ 20%MT2+ 20%MT1	0.692	0.651	0.629	0.860	1.17
80%MT1+ 20%MT2	0.858	0.824	0.803	0.894	0.62
85MT3+ 15MT2	0.893	0.858	0.850	0.939	0.46
90%MT3+ 10%MT2	0.929	0.912	0.899	0.951	0.31
100%MT4	0.022	0.030	0.021	0.298	3.63
100%MT5	0.000	0.093	0.020	0.149	3.74
100%MT6	0.907	0.835	0.647	0.894	0.72
100%MT7	0.000	0.093	0.020	0.149	3.74
55%MT4+35%MT5+ 10%MT7	0.026	0.046	0.016	0.298	3.61
45%MT4+45%MT5+ 10%MT7	0.004	0.028	0.000	0.164	3.80
35%MT4+35%MT5+30%MT7	0.000	0.000	0.005	0.373	3.62
42%MT4+ 42%MT5+165MT7	0.172	0.158	0.042	0.641	2.99

Table 4. The statistical value of the coefficients in the prediction CBR and MDD model

Prediction model	Symbol	Coefficient	Standard deviation	*t*-student	Significance
CBR	Constant	13.27	3.907	3.399	0.0396
	I_q	21.01	1.443	14.556	< 0.01
MDD	Constant	1.950	0.027	73.499	< 0.01
	I_q	0.101	0.010	10.333	< 0.01

Table 5. Experimental and laboratory measurements for the CBR and MDD values

Mixture	Predicted CBR values	Laboratory measurement of CBR value	Predicted MDD value	Laboratory measurement of MDD value
100%MT1	89.2	100.0	2.32	2.30
100%MT2	87.1	100.0	2.30	2.32
100%MT3	13.3	14.0	1.95	1.94
50%MT3+25%MT2+25%MT1	51.0	60.0	2.13	2.11
55%MT3+25%MT2+20%MT1	47.9	52.0	2.12	2.09
60%MT3+20%MT2+20%MT1	37.8	23.0	2.07	2.06
80%MT1+20%MT2	26.3	35.0	2.01	2.01
85MT3+15MT2	22.9	28.0	2.00	2.02
90%MT3+10%MT2	19.8	17.3	1.98	2.01
100%MT4	89.5	83.0	2.32	2.40
100%MT5	91.8	93.1	2.33	2.20
100%MT6	28.3	22.0	2.02	2.00
100%MT7	91.8	93.0	2.33	2.23
55%MT4+35%MT5+10%MT7	89.2	76.1	2.31	2.40
45%MT4+45%MT5+10%MT7	93.2	95.0	2.33	2.40
35%MT4+35%MT5+30%MT7	89.4	88.0	2.32	2.30
42%MT4+42%MT5+165MT7	76.0	65.0	2.25	2.30

Table 6. Features of materials adopted in the assessment procedure

Mixture	Passing througwh 10*ASTM* sieve (2.00 mm), %	Passing through 40*ASTM* sieve (0.420 mm), %	Passing through 200*ASTM* sieve (0.074 mm), %	IP, %	CBR, %	MC, %	MDD, g/cm^3
MTA	28.0	18.2	12.2	NP	90.5	5.2	2.28
MTB	44.0	24.1	15.9	NP	96.7	5.1	2.32
MTC	90.0	87.0	85.0	5.2	16.0	6.9	1.95
MTD	60.1	48.0	32.2	4.4	55.0	4.9	2.11

Table 7. Experimental measures of CBR and MDD values for the validation mixtures

Mixture	Predicted CBR measurement	Experimental measurement of CBR value	Predicted MDD value	Experimental measurement of MDD value
MTA	97.3	90.5	2.35	2.28
MTB	88.9	96.7	2.31	2.32
MTC	13.3	16.0	1.95	1.95
MTD	53.8	55.0	2.14	2.11

Table 8. Range of I_q according to normalization procedure

Symbol	Max value	Min value
I_q^{10ASTM}	97.7	20.0
I_q^{40ASTM}	96.2	10.0
$I_q^{200ASTM}$	91.8	6.6
I_q^{PI}	6.71	0.0

In the case of a single mixture (or number of mixtures less than 4), for the correct application of Eqs (1) and (2) the normalization procedure has to refer to the range of I_q values shown in Table 8. A simple preliminary abacus was produced in the Fig. 2.

The Fig. 2 shows how the bearing capacity of the mixture by CBR index is quickly deduced from I_q index. Mixtures with a high CBR present an MDD value closer to the max value observed in Table 6 (e.g. MDD =

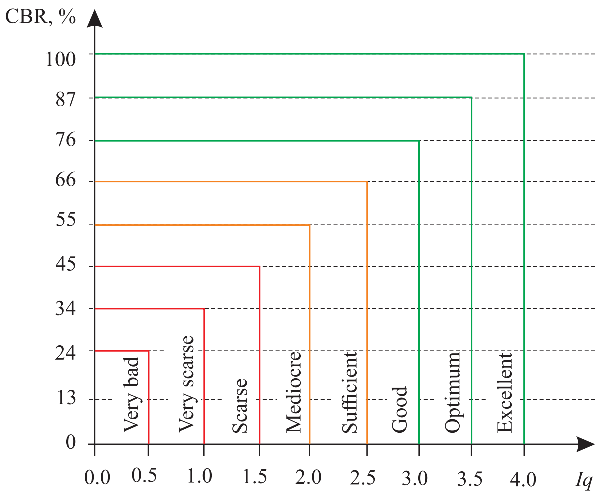

Fig. 2. Overall assessment of CBR index for road mixtures with "low bearing capacity" percentage

2.32 g/cm^3), while mixtures with a low CBR represent an MDD value close to the min value observed in Table 6 (e.g. MDD = 1.94 g/cm^3).

6. Results and conclusions

The experiment was carried out using a number of soil types from quarries and digs in Southern Italy. The study was divided into two phases: the first was concerned with data collection, the creation of mixtures using a percentage of "low bearing capacity" materials, and traditional laboratory tests of designed blends, while the second concerned the calibration and assessment of predictor CBR and MDD models using the index quality parameter I_q. This is an artificial parameter that reflects the Atterberg limits and grain size distribution of the mixture. The procedure presented here shows a strong linear correlation between the CBR and I_q, and MDD and I_q; these regression equations agree to fast assess the value of CBR index for a road mixture cutting the work time, the costs and the efforts of the designers.

The procedure also makes it possible to quantify the percentage of silt-clay materials that cannot generally be used in the road sector, to be included in the road mixture so as to reach an acceptable bearing capacity.

The two prediction models have an adjusted coefficient of determination (ρ^2) greater than 85% and they show the CBR value and MDD value per mixture without laboratory testing.

The two models were then validated by comparing the predicted values with the observed values not included in the calibration phase. This procedure confirmed the correctness of the regression equations.

In conclusion, the practical usefulness of the procedure here presented is the use of "low bearing capacity" materials, coming, for example, from trench digging, in mixtures used in road construction. During the experimental analysis presented here, it was seen how the CBR value for silt-clay material increases from 14 to 60 when this material is added in the right quantities to alluvium and fluvial sediment or else A1 and A3 type materials.

Therefore, the method is also particularly useful when there is a tight budget, which is often the case in the construction of low-volume roads. The procedure will improve as the database increases, with the assessment of additional geotechnical parameters using more tests, not necessarily to be carried out in the laboratory, and adjusting the quality index I_q to calculate the CBR indirectly, optimizing financial/material resources and decreasing the time needed.

Acknowledgements

The authors are grateful to Michael T. Long (Chair of TRB Low-Volume Roads Committee, Oregon D.O.T.) for his invaluable contribution to discussion and for his constructive suggestions and comments on the treatment data.

References

Ahmed, A.; Khalid, H. 2009. Deformation Properties of Untreated and Enzyme-Treated Bottom Ash Waste for Use in Foundations, *Transportation Research Record* 2104: 97–104. http://dx.doi.org/10.3141/2014-11

Amšiejus, J.; Dirgėlienė, N.; Norkus, A.; Žilionienė, D. 2009. Evaluation of Soil Shear Strength Parameters via Triaxial Testing by Height Versus Diameter Ratio of Sample, *The Baltic Journal of Road and Bridge Engineering* 4(2): 55–60. http://dx.doi.org/10.3846/1822-427X.2009.4.54-60

Berney IV, E. S.; Wahl, R. E. 2007. Rapid Soils Analysis Kit for Low-Volume Roads and Contingency Airfields, *Transportation Research Record* 1989: 71–78. http://dx.doi.org/10.3141/1989-50

Bloser, S. M. 2007. Commonly Used Aggregate Materials and Placement Methods: Comparative Analysis for a Wearing Course on Low-Volume Roads in Pennsylvania, *Transportation Research Record* 1989: 178–185. http://dx.doi.org/10.3141/1989-62

Dell'Acqua, G. 2011. Reducing Traffic Injuries Resulting from Excess Speed: Low-Cost Gateway Treatments in Italy, *Transportation Research Record* 2203: 94–99. http://dx.doi.org/10.3141/2203-12

Dell'Acqua, G.; Russo, F. 2011a. Road Performance Evaluation Using Geometric Consistency and Pavement Distress Data, *Transportation Research Record* 2203: 194–202. http://dx.doi.org/10.3141/2203-24

Dell'Acqua, G.; Russo, F. 2011b. Safety Performance Functions for Low-Volume Roads, *The Baltic Journal of Road and Bridge Engineering* 6(4): 225–234. http://dx.doi.org/10.3846/bjrbe.2011.29

Dell'Acqua, G.; De Luca, M.; Lamberti, R. 2011. Indirect Skid Resistance Measurement for Porous Asphalt Pavement Management, *Transportation Research Record* 2205: 147–154. http://dx.doi.org/10.3141/2205-19

Discetti, P.; Dell'Acqua, G.; Lamberti, R. 2011. Models of Operating Speeds for Low-Volume Roads, *Transportation Research Record* 2203: 219–225. http://dx.doi.org/10.3141/2203-27

Jasiūnienė, V.; Čygas, D.; Ratkevičiūtė, K.; Peltola, H. 2012. Safety Ranking of the Lithuanian Road Network of National Significance, *The Baltic Journal of Road and Bridge Engineering* 7(2): 129–136. http://dx.doi.org/10.3846/bjrbe.2012.18

Molenaar, A. 2007. Characterization of Some Tropical Soils for Road Pavements, *Transportation Research Record* 1989: 186–193.
http://dx.doi.org/10.3141/1989-63
Pinard, M. I.; Obika, B.; Motswagole, K. J. 1999. Developments in Innovative Low-Volume Road Technology in Botswana, *Transportation Research Record* 1652: 68–75.
http://dx.doi.org/10.3141/1652-09
Skrinskas, S.; Domatas, A. 2006. Analysis of Lithuanian Gravel Roads Paving Programme Implementation in 1998–2005, *The Baltic Journal of Road and Bridge Engineering* 1(4): 157–166.
Siddiki, N. Z.; Kim, D.; Salgado, R. 2004. Use of Recycled and Waste Materials in Indiana, *Transportation Research Record* 1874: 78-85. http://dx.doi.org/10.3141/1874-09

Received 11 March 2011; accepted 23 May 2011