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Development of a Methodological Approach for Mapping Granular Soils for Pavement Layers

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Abstract

Civil engineering works require the selection of soil-type materials and the assessment of their geomechanical characteristics. However, the lack of relevant geotechnical mapping to facilitate the prediction of granular material zones for civil engineering works in Benin means that very costly and sometimes inconclusive prospecting has to be undertaken for each project. The aim of this study is to contribute to the availability of geotechnical mapping in Benin. For this purpose, and in order to capitalize on the data, the proposed methodological approach is based on the systematic and controlled recording of data produced by laboratories during geotechnical and geological surveys for road construction projects. To this end, a web platform called ROAD MAT has been designed for data recording. This platform has been tested using data from test results from sixteen boreholes drilled in the Mono department. These results show a predominance of soil class G2 and CBR class P2. The database is steadily expanding, and its use by stakeholders will make it possible to collect and centralize vital data to define benchmarks for greater control of geotechnical risks. This work therefore constitutes a blueprint for the development of geotechnical mapping in Benin.

Keywords

Geotechnical Mapping, Granular Materials, CEBTP Classification, Database, Methodological Approach

1. Introduction

Growing populations are creating a need for connections to link growing towns, ports and villages. The response to this need is infrastructure development, in particular road links, for which construction and maintenance require large quantities of materials to be extracted from the ground. As the road industry seeks out and exploits areas where materials can be extracted, these areas become increasingly scarce, alongside the need for agricultural land and urbanization. Materials used in the construction of road pavements have specific geomechanical qualities. For their exploitation, geotechnical surveys are carried out beforehand to identify the zones. This work takes place during the feasibility phase of each project. It can take from 6 to 13 months, depending on the scale of the project. Geotechnical maps are therefore recommended to facilitate access to the basic data needed to decide on the feasibility of projects.

A geotechnical map is a cartography that provides a generalized representation of all the components of a geological environment that are important for land development and for the design, construction and maintenance of civil engineering works and mines [1]. As an art form for representing spatial phenomena, cartography is subject to a process of abstraction involving selection, classification, simplification and symbolization. It is established by collecting data, processing the data to be mapped and producing the map. The development of Geographic Information System (GIS) software has made it easier to produce maps, saving time and money.

However, as far as the geotechnical map is concerned, data collection depends largely on the data collection and processing methodology. The southern part of Benin, which is already facing a booming urban dynamic [2], is facing a gradual disappearance of areas where road construction materials are collected, and a search for new areas in more remote parts. To prevent this situation in the country, the development of geotechnical maps could be a solution [3]. There are several approaches to acquiring geotechnical data for mapping: systematic inventory of materials [3], superimpositions of existing data (existing maps) and new data [4] [5]. In the case of Benin, which has no geotechnical map, this study aims to develop a methodological approach that collects the geotechnical data collected during geotechnical missions by means of an information platform.

2. Study Area

This study focuses on southern Benin, which largely overlaps with the coastal sedimentary basin and extends across the continental shelf [6] from the Atlantic Ocean up to latitude 7˚30'N. The entire region is subject to a subequatorial climate. The geomorphology is characterized by seven plateaus separated by large rivers and the Lama depression. To the north of these plateaus, the landscape consists of a vast peneplain interspersed with inselbergs, plateaus, and narrow valleys. The plateaus are composed of sediments deposited on the crystalline basement, which dates from the Quaternary, Tertiary, and Cretaceous periods. The crystalline basement of southern Benin can be considered a portion of continental crust, made up of meta-sedimentary series (quartzites, marbles, and parts of gneiss from various units) associated with granites of different ages (See **Figure 1**).

Figure 1. Localization bay of Benin (Litho library).

3. Materials and Methods

The methodological approach is in 3 phases as follows:

- Comparative analysis of four methods from the literature review.
- Presentation of the data recording platform.
- Implementation of the data extraction and granular soil mapping approach.

3.1. Comparative Analysis of Four Methods

A comparative summary of four methods from the literature review was carried out. It covers:

- The study for the establishment of geotechnical maps in Quebec [7], the study to produce a geotechnical map of the town of Ain Témouchent in Algeria [1].
- The study to produce a geotechnical map of the city of Lubumbashi [3].
- The study for the 2D and 3D stratigraphic modeling of the subsoil of the Brussels-Capital Region [4].

This review covers several regions of the world: North America, North Africa, Central Africa and Europe. No similarly studied sites were found in West Africa. The comparison covers data collection methods, data processing and the production of thematic maps.

- **Collecting data**

Based on their nature, the data originate from 4 sources:

- Base maps [1] [4].

- Aerial images [7].

- Geotechnical, geological and environmental study reports [1] [4] [7].

- Databases [3] [4].

Recourse to any one of these data sources depends on its availability in the country's historical archives. These data are generally available in developed countries: Quebec [7], Algeria [1] and Belgium [4]. However, this basic data is lacking in developing countries such as Congo [3].

- **Processing data**

Data processing leads to the determination of the parameters to be mapped: in the four cases studied, [1] and [3] carried out the geotechnical classification of soils according to several international systems (LCPC, GTR or AASHTO). In 2006, [4]. Digitized and modeled soil stratigraphy using borehole data. [7] also determined soil stratigraphy.

In other words, there are two key parameters for understanding soil: soil class and stratigraphy.

- **Techniques for creating maps**

Except for [7], who drew up a manual map, all three authors drew up the map using ArcGIS GIS and cartography software.

This comparative study shows that there is convergence in the methods used to collect, process and establish the maps. The use of particular data depends on the data sources and the means made available for data collection. Once the data has been collected, two parameters can be used to identify the soil. These are soil class and stratigraphy. These parameters, together with the geodetic coordinates, are used to draw up the maps.

3.2. Methodological Approach for Developing a Map in Benin

In Benin, there is no geotechnical mapping that could be updated, and the existing geological map has not been updated. On the other hand, geotechnical prospecting data is available from a number of players: geotechnical laboratories, contractors and project owners. This data is acquired repeatedly for each infrastructure construction project. The methodological approach is therefore as follows:

- Design of an open platform to feed the database. Each operator is approved and provides data to the database in a predefined format.
- The zoning unit is within the boundaries of the department. Benin has twelve
- The processing incorporated into the database enables soil classes and stratigraphy to be determined. The classification system is adapted to granular soils, in particular laterite, which is most commonly used in road layers in Benin.
- The maps are produced on ArcGIS 10.8 using data from the database.

3.3. Materials

The materials are:

- Data source: 6 road geotechnical study reports.
- Database design software: MySQL Workbench.
- Web development software and API: WINDEV & Node.js.
- Software and mapping: ArcGIS 10.8.
- Storage hardware: VPS cloud model server 3-PRODUCT CONFIGURATION: 8v CPU CORES 24 GB RAM STORAGE: 300 GB NVMe, 2 Snapshots, 1.2 TB SSD-32TB OUT + Unlimited In.

4. Results & Discussion

4.1. Design of a Data Recording Platform

The selection of a platform is guided by the need for it to be open and accessible to any operator approved by the national geotechnical authority to access and record their borehole data in real time. The platform design consists of a database deployed on a secure cloud server and processing and mapping applications.

- Database

Table 1 below describes the entities in the conceptual data model.

Table 1. Description of the entities in the conceptual data model.

Data type	Entity	Description
Metadata	Operator/ Laboratory	Data provider (laboratory or firm that carried out the tests). The data provider enters its address and certification. They receive autorisation to record the data and autorisation to access all the other data in the database
	File	References of the document that reports on the tests: project title—report (paper or digital format); archive location—validation level (preliminary design, detailed design, provisional or final)—legal ownership (project owner)—report production date
	Site	Type of site (laterite quarry, rock quarry, sand quarry, roadbed, etc.) Site information (description, name and location)
	Borehole	Description of the geospatial location of the survey point (zone code, GPS coordinates, etc.);
	Sample parameters	Type of sample (intact or reworked—location in coordinates (x, y and z)—results of tests carried out on the sample (AG, LA, Proctor, CBR, etc.)
Geotechnical data	Lithological section	Position of cut—depth—thickness, geotechnical name, color, natural water content—image of cut
	Granulometric analysis data	Sieves (record standard diameters) Percentage passing the sieve of diameter D
	Proctor	Percentage of optimum Proctor records the different percentages of optimum (100%; 95%; 90%) Proctor detail records the dry density (Dsopt) at the Proctor optimum modified according to the Proctor percentage
	Optimum water content	Optimum water content Proctor
	ICBR Index	CBR corresponding to Proctor's percentage
	Soil classes	Classification: different classification systems (HRB, GTR, LCPC, etc.) Soil class: class of soil (e.g. class A1a for HRB, the common name) Classification details: values for each parameter that classifies the soil

The diagram of the conceptual model of the database is shown in the following figures (see Figure 2).

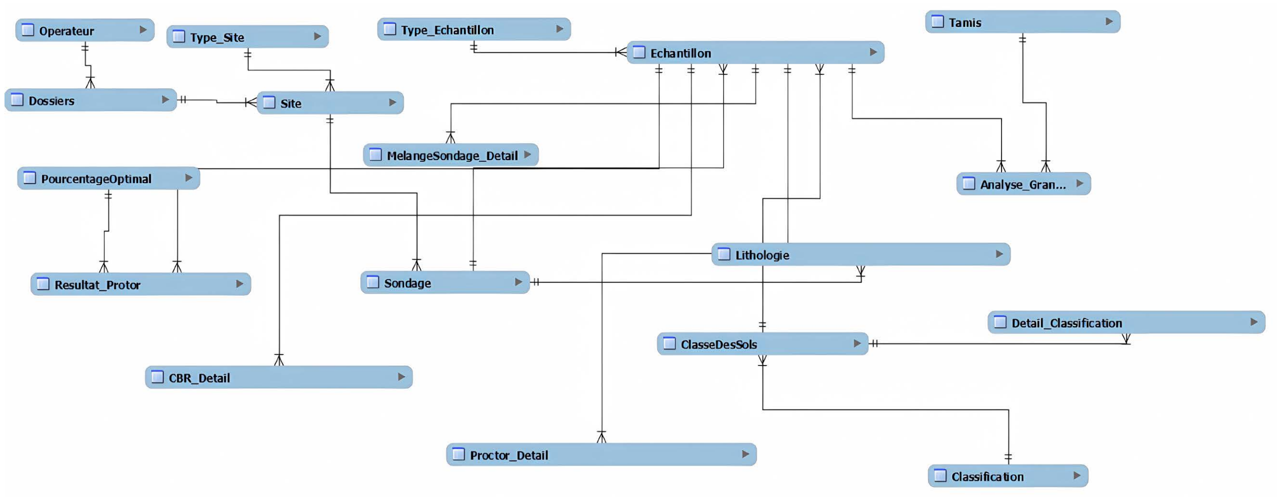

Figure 2. Schema of the conceptual database model.

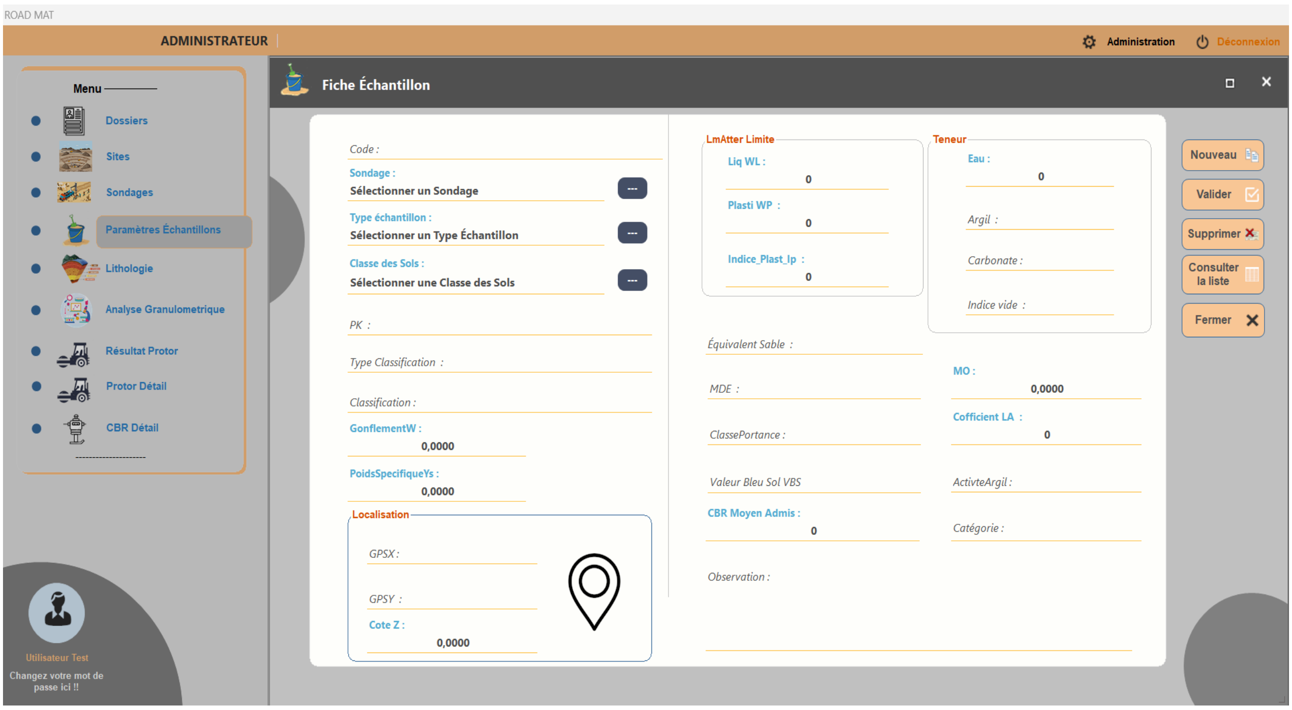

Figure 3. ROAD MAT home screen capture.

- *ROAD MAT platform*

The ROAD MAT platform is a user-friendly application for recording data in the database. It has an authentication interface, a welcome interface and interfaces for recording detailed data. Figure 3 shows a model interface for the ROAD MAT platform. It can be used to sort data and export results to different file formats (Word, Excel, KMZ, Shapefile).

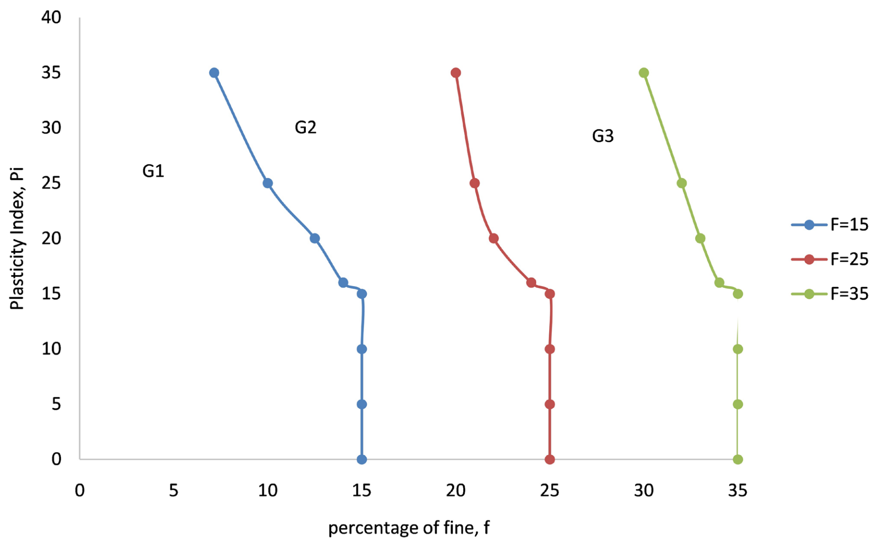

Figure 4. CEBTP classification curve [8].

- *Data processing*

To process the data, the geotechnical classes and the California Bearing Ratio (CBR) of the materials taken from the soil quarries were determined. Soil classification and bearing capacity are used to assess the geomechanical quality of granular materials that can be used for pavement layers. The classification method used is that of the Centre Expérimental de Recherches et d'Etudes des Bâtiments et des Travaux Publics (CEBTP) [8]. This classification was used to classify laterites from Côte d'Ivoire and the Democratic Republic of Congo [9]. It has the advantage of dividing laterites into three classes according to their decreasing geomechanical qualities (G1, G2, G3). The materials sampled in the borehole are assigned to each class as follows:

Considering:

The percentage passing the 0.08 mm sieve obtained by particle size analysis tests (standard NF P 94-056), noted (f);

- The plasticity index obtained by the Atterberg limit test in accordance with standard NF P 94-051, noted IP.

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- The plasticity index obtained by the Atterberg limit test in accordance with standard NF P 94-051, noted IP.

The class of the material: G1 - G2 - G3 (see **Figure 4**); a material is of class

o G1 if $f \leq 15\%$ for $IP < 16$ and $f*IP < 250$ when $IP > 16$

o G2 if $15\% < f < 25\%$, and $250 < f*IP < 600$ and $f*IP < 250$ when $IP > 16$

o G3 if $25\% < f < 35\%$, and $600 < f*IP < 1000$ when $IP > 28$

Type G1 is the best laterite gravel with a CBR of over 30, an OPM dry density of over 2.1 and a water content of between 5 and 8; Group G2 is made up of lower quality laterites with a CBR of between 15 and 30, an OPM dry density of between 2 and 2.1 and an optimum compaction water content of between 7 and 10, while

Group G3 is made up of laterites with a CBR of less than 15, an OPM dry density of between 1.9 and 2.2 and an optimum compaction water content of between 8 and 12 (see Figure 5).

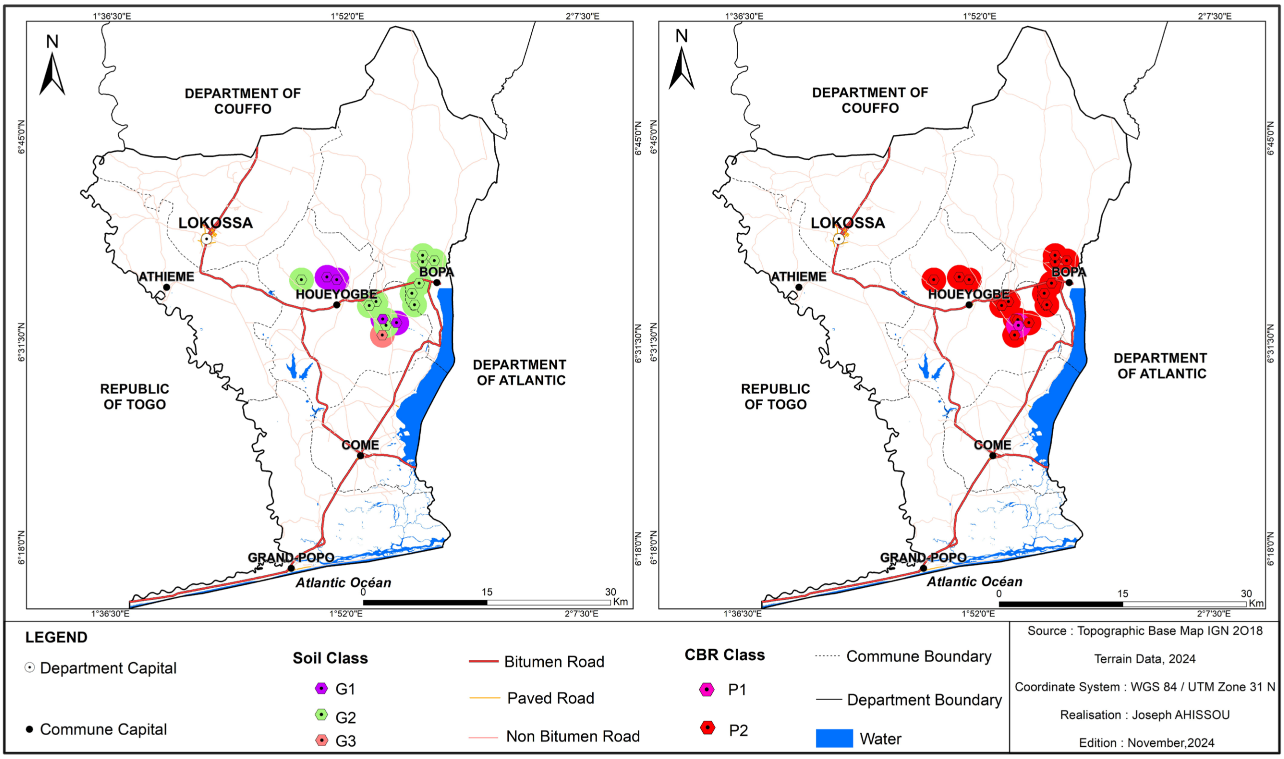

Figure 5. Class and CBR maps for Mono department.

In addition, three classes of CBR were defined by test in accordance with standard NF P 94-093 as follows:

- 5 < CBR < 30, materials accepted as subgrade; noted P1.
- 30 < CBR > 80, materials accepted as sub-base layer; noted P2.
- CBR > 80 materials accepted as base course, noted P3.

4.2. Test Results of the Methodological Approach

In order to validate the methodology, the data recorded relates to a selection of 714 km of linear roads in six departments, surveyed between 2014 and 2023 by the three main laboratories. However, Table 2 of results for the Mono department is presented below. It covers 16 holes drilled in laterite quarries.

From the table it can be seen that of the 16 boreholes, 4 belong to the G1 class, 11 to the G2 class and 1 to the G3 class, while 15 belong to the CBR P2 class and 1 to the CBR P1 class. We can deduce that the materials in this area of the country are of average geomechanical quality G2 and also of average CBR P2. This result provides geotechnical reference data for pavement design.

- **Drawing up the maps**

It used the ArcGIS 10.8 software to design and produce the granular soil class and CBR class maps. An extract of the results is shown in Figure 5.

Table 2. Soil class and CBR data for the Mono department.

N° Sounding	sieve 0.08 mmm (f)	IP	f*IP	Class of soil	CBR	Class of CBR	Longitude E	Latitude N
SEG1	15	10	150	G1	46	P2	1.8558333333333	6.5939167
SEG2	14	9	126	G1	39	P2	1.8449833333333	6.59685
SEG3	14	8	112	G1	52	P2	1.9214166666666	6.5469333
SEG4	15	9	135	G1	40	P2	1.9063833333333	6.55095
SEG5	22	15	330	G2	45	P2	1.9093333333333	6.5502
SEG6	26	17	442	G3	35	P2	1.9057666666666	6.5333333
SEG7	21	13	273	G2	79	P2	1.8988999999999	6.5699667
SEG8	23	15	345	G2	36	P2	1.9461666666666	6.5904
SEG9	23	16	368	G2	43	P2	1.95	6.6137667
SEG10	17	12	204	G2	58	P2	1.96265	6,61505
SEG11	18,5	10	185	G2	40	P2	1.95	6.62085
SEG12	21	11	231	G2	34	P2	1.9382000000000	6.57915
SEG13	18	13	234	G2	39	P2	1.9410500000000	6.5666667
SEG17	21	15	315	G2	28	P1	1.9099	6.5440833
SEG18	17	12	204	G2	50	P2	1.8914666666666	6.5657333
SEG19	21,5	13	279.5	G2	40	P2	1.8170000000000	6.5938333

Analysis of the maps gives an idea of the geographical dispersion of the boreholes associated with their geomechanical quality. Class G2 and P2 are dominant on both maps. It should also be noted that the geotechnical surveys were carried out in the same area (in this case, the commune of Houeyogbe). Surveys should be carried out in areas not covered by a materials inventory campaign to supplement the data provided by the surveys carried out for the roadworks.

5. Conclusion

This study's methodological approach highlights the systematic and controlled recording, for enhancement purposes, of data produced by laboratories and construction companies during geotechnical and geological surveys for road construction projects. To this end, a web platform for recording the data has been developed. An example of its application in the Mono department was presented, with data from 16 boreholes recorded. The results showed that the G2 soil class dominated (69%), while the CBR P2 class dominated (94%). The ROAD MAT platform and database are constantly being improved with the use of new BIG DATA possibilities. Its use by stakeholders will make it possible to collect and centralize vital data to define geotechnical parameter references for greater control of geotechnical risks. The adoption of the platform will also enable the development of geotechnical mapping, which until now has been non-existent in Benin.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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