JOINT TRANSPORTATION RESEARCH PROGRAM

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Engineering Properties of Marls

Introduction

The term marl is used to designate soft, carbonate-rich, low-organic, gray-colored, fine-grained soils typically deposited under lakes or swamps, which are commonly encountered in the midwestern region of the United States. Such layers are typically characterized by low dry density, very high water content, and low shear strength, and they pose concerns related to excessive settlement, slope instability, and increased downdrag on deep foundations. Despite the prevalence of marls in Indiana and the concerns associated with their behavior, very limited work has been done to study the engineering properties of these soils. This was the motivation for this research project, which involved two primary activities: (1) the creation of a map and database of existing information on marl deposits in Indiana; and (2) the in-depth characterization of the properties of a marl deposit in Daviess County, Indiana, which was considered representative of similar deposits encountered throughout the state.

The database used for mapping marl deposits in Indiana was generated from information available at the Indiana Department of Transportation (INDOT) and involved mining data from over 5,000 boreholes. Through this effort, 325 borelogs were identified as containing marl. The data from these borelogs were compiled using ArcGIS 10.0. The resulting map preserves information on location, project DES number and description, borehole number and coordinates, marl layer thickness and depth, and percentage of CaCO_3 , and marl classification. It is easily accessible and can be expanded as more data becomes available.

The second part of the project involved field tests and laboratory experiments. The field testing program included (1) seismic cone penetration tests with pore pressure measurements (SCPTu); (2) standard penetration tests (SPTs) for soil profiling and collection of disturbed samples; (3) field vane shear tests; and (4) the installation of an open pipe piezometer. High-quality Shelby tubes samples were obtained for laboratory tests using mud rotary drilling and a fixed piston sampler. The laboratory testing program involved (1) assessment of the index properties (Atterberg limits, natural water content, LOI, CaCO_3 content, pH, salinity, specific gravity, and particle size distribution analysis) over the entire thickness of the deposit; (2) characterization of the stress history profile and measurement of the consolidation and creep properties of the soil through incremental and constant rate of strain consolidation tests; and (3) investigation of the undrained shear behavior, including derivation of the SHANSEP parameters through K_0 -consolidated undrained triaxial tests. Additionally, the mineralogy and the microstructure of the soil were studied in detail using state-of-the-art techniques, including

X-ray diffraction (XRD), thermogravimetric analysis (TGA), and scanning electron microscopy (SEM) equipped with energy dispersive X-ray spectroscopy (EDX).

Findings

Examination in the laboratory of the soil samples revealed that the deposit is not homogenous as was initially anticipated, but is formed by two types of soils that repeat in horizontal thin layers. This stratification was not detected by the field tests. These two soils, referred to as “soil M” and “soil C,” are both characterized by very high calcium carbonate contents (over 50%, and close to 40%), but show distinct index properties (PL = 34.6 and 21.6; LL = 67.5 and 47.5; % clay = 20.2% and 36.9%; $G_s = 2.71$ and 2.79, for soils M and C, respectively). A characteristic specific to soil M, which is more prominent throughout the deposit, is the presence of shells. Additionally, this soil is characterized by a higher percentage of smectite minerals. Overall, the presence of these two soil types provided the opportunity to essentially study two types of marls and explore, in particular, the effect of shells, mineral composition, and carbonate content on both index and engineering properties.

The consolidation tests showed that the deposit has an OCR less than 2, approximately constant with depth. The presence of the shells and/or the higher calcium carbonate content translated into a slightly higher preconsolidation stress in soil M versus soil C. Both soils exhibit S-shaped compression curves, with compressibility parameters markedly dependent on stress level. Soil C is characterized by a higher compression index relative to soil M, although for both soils the data fall within the range typical of soft clays. K_0 -consolidated tests performed varying the pre-shear effective stress showed that both soils exhibit normalized behavior with the relationship between undrained shear strength, OCR and effective stress being well described by the SHANSEP equation: $S_u/\sigma'_{vc} = S(\text{OCR})^m$. However, there was a significant difference in the SHANSEP parameters measured on the two soils ($S = 0.28$ and 0.34 , and $m = 0.72$ and 0.85 , for soils C and M, respectively). Consistent with this observation, the maximum obliquity friction angle for soil M ($\phi'_{mo} = 39^\circ$ [likely affected by the presence of shells]) exceeded that measured on soil C ($\phi'_{mo} = 30^\circ$), and the value of the normally consolidated K_0 was greater for soil C ($K_0 = 0.56$) relative to soil M ($K_0 = 0.49$). For both soils the cohesion intercept was found to be negligible.

Comparison of the field data and laboratory results provides the means to validate existing correlations for interpretation of the geotechnical properties of marls from field results. For the site examined it was found that, of the 13 relationships examined,

only the one developed by Andrus, Monahan, Piratheepan, Ellis, and Holzer (2007) for soils with a Pleistocene geologic age provides a prediction of V_s from the CPT data consistent with the in situ seismic measurements. The preconsolidation stress of the deposit is best estimated from the CPT data using the correlation provided by Mayne (1995). The undrained shear strength, S_u , is best estimated from the CPT tip resistance data using the equation $S_u = (q_t - \sigma_{v0})/N_{kt}$, although for the same shear mode (triaxial compression) N_{kt} varies from 10 to 17 for soil M and soil C, respectively.

While the specific geotechnical data gathered for soils M and C are strictly applicable only to the site investigated, the work performed provides insights that have direct significance for construction on other marl deposits. In particular:

- While both the index and engineering properties of marls fell within the range typical of many other soft clays previously documented in the literature, the distinct properties exhibited by soils C and M identified in this project indicate that there is no "typical" marl, and that lessons from one deposit may not directly be extrapolated to others without consideration of index properties and mineralogical data. The data obtained as part of this project may be used as a guideline during the preliminary design stages, but any subsequent design stage will require the derivation of site-specific properties.
- The behavior of marls cannot be described solely by the CaCO_3 content, as the presence of shells as well as the mineralogy of the clay fraction play a critical role. For example, this research showed that the apparent inconsistency between Atterberg limits, carbonate content and clay content between soil M and soil C was explained by the higher smectite content of soil M.
- The fact that the soils examined exhibited normalized behavior indicates that the SHANSEP method can be effectively used for designing on marl deposits. This has significant practical value, as this method allows estimation of the undrained shear strength profile as the vertical effective stress and stress history profiles of the site change, which is critical to the design of staged construction/preloading procedures commonly employed in marl deposits. The SHANSEP parameters derived in this project may be used for obtaining undrained strength profiles during the preliminary design stage on other marl deposits once anisotropy effects are accounted for. A SHANSEP laboratory testing program should be conducted for any subsequent stages of design.
- The field vane test was not successful in characterizing the strength profile of the marl deposit examined in this work. This is consistent with previous experiences in deposits characterized by the presence of shells and/or sand lenses documented in the literature. While it should be discouraged in these cases, its use continues to be recommended for measuring the undrained strength of soft homogeneous deposits with no

shells or sand lenses, and thus it should be applicable to homogeneous marl deposits.

- This work has identified the correlations that provide the best estimates of shear wave velocity and preconsolidation stress, and these are recommended for preliminary design. The former should be used when seismic measurements of V_s are not available. Laboratory measurements of σ'_p are required in latter stages of the design.
- For predicting the undrained strength from CPT results, the significant (70%) difference in the values of N_{kt} found to best match the data for soil M versus soil C demonstrates that no single value of N_{kt} can be recommended for marl deposits. The values derived for soil M and soil C may serve as guidelines during preliminary design, but a site-specific calibration should be conducted for accurate predictions of the undrained strength profile. Once this is done, the CPT can be used very effectively to examine spatial variability effects.
- The sampling and specimen preparation techniques used in this study (drilling using a mud rotary, sampling using a fixed piston sampler, extrusion using a piano wire, trimming using a wire saw) were found to generate samples of high-quality and reliable laboratory test data. Their use is advocated for sampling and testing in all marl deposits.

References

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