Geotechnical investigation to assess the use of calcareous mudstone as fills materials

Propriétés géotechniques de Marne calcaire pour leur utilization en remblais compactés

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ABSTRACT: For economic and construction schedule reasons, it was of interest to use calcareous mudstone and clayey limestone originating from required plant grading excavations for the construction of a fill platform supporting structures of a mining project in Peru. However, these materials are friable, break down upon handling, and exhibit swelling properties. Nevertheless, because of the high costs of hauling more favourable borrow materials from other sources, it was decided to construct a test fill, and to perform field and laboratory testing, to evaluate the technical requirements for achieving a satisfactory compacted fill using these materials. The field tests consisted of large-scale in situ density and plate loading tests, while the laboratory tests included soil classification, modified Proctor, triaxial (CID), and large size oedometer test. This paper describes the work performed and the most significant findings. As a result of this investigation, the fill was successfully constructed, with very significant savings in cost and schedule. Geotechnical properties of the material compacted to different densities are provided, including hyperbolic stress-strain parameters unique in technical literature for this type of material

RÉSUMÉ: Des raisons économiques et de délais ont conduit à considérer l'utilisation de marnes calcaires et de grès argileux, provenant des travaux de terrassements, pour construire les remblais d'appui de structures dans un projet minier au Pérou. Or, ces matériaux sont friables, présentent du gonflement et d'importantes ruptures de particules lors de leur manipulation. La construction d'un remblais expérimental, appuyé par des essais in-situ et de laboratoire, a été entreprise pour déterminer les contraintes téchniques nécessaires à considérer pour construire des remblais satisfaisants, étant donné les importants frais liés au transport de matériaux de meilleure qualité provenant d'autres sources d'aggrégats. Des mesures de densité à grande échelle et des essais de plaque ont été pratiqués in-situ, tandis que des essais de classification, de compactage, des triaxiaux drainés ainsi qu'un oedomètre de grandes dimensions ont été éffectués au laboratoire. Cet article décrit les travaux entrepris et présente les plus importants résultats obtenus. Cette recherche a permis de construire les remblais compactés d'une manière tout à fait satisfaisante avec d'importantes réductions de frais et de délais. Les propiétés géotechniques du matériau compacté à differentes densités sont présentées ainsi que les paramètres contraintes-déformations du modèle hyperbolique, uniques dans la littérature technique concernant ce type de matériau.

1 INTRODUCTION

The mining project is located in the "Cordillera Blanca" (White Mountains) of Peru at an approximate elevation at 4300m a.s.l. The concentrator plant is located on a platform constructed partially in cut and partially on a compacted fill up to 30m high. The main cuts were excavated in rock, which geologically corresponds to the calcareous mudstones and clayey limestone of the Celendin Formation of Upper Cretaceous age. Immediately after being excavated, these materials appear relatively competent, dense and moderately to lightly fractured. Exposed to cycles of saturation and drying or changes in climatic conditions, these rocks showed a friable behavior, a swelling potential, while a very significant breakdown of particles during handling was observed. The high cost associated with the use of borrow materials from other sources made it necessary to undertake an investigation to evaluate the suitability of the excavated rock for it use as a compacted fill material.

2 DESCRIPTION OF FIELD AND LABORATORY TESTING

To investigate the possibility and to optimize the use of the soft rock in the construction of the plant platform, a test fill was constructed to provide basis for the preparation of technical specification for the fill and in conjunction with laboratory testing, to provide geotechnical design parameters. The test fill was constructed in 5m wide strips with a length of 30m to 45m. In one of the strips, the fill was placed in four layers of 0.6m thickness, and in the second in two layers of 0.9m thickness. Each layer was divided into three sectors, subjected to 4, 6 and 8 roller passes respectively. Compaction was performed using a 10t vibratory roller, travelling at 2 to 4 km/h, with a vibration frequency of 2200 r.p.m. After every two passes, settlement of fill surface was measured by means of topographic surveying. The density was measured to a depth of 0.3m using a nuclear densometer for specific purpose of determining the relationship between density and settlement at the same point. The nuclear densometer measurements were calibrated by sand replacement method using a 0.3m diameter sand cone. A density measurement was also performed by the water replacement method (USBR 7221). Plate loading tests using 0.30m and 0.45m diameter plates were performed on the compacted fill surface, including one test done after wetting of the material.

Samples were collected before and after compaction of each layer, and laboratory testing was performed consisting of soil classification tests, Proctor compaction, consolidated-drained triaxial and a large-diameter oedometer tests. The triaxial and oedometer tests were performed on samples recompacted at the dry density and water content which, based on the test fill results, was expected to be specified for fill compaction.

3 RESULTS OF FIELD AND LABORATORY TESTING

The settlement of the fill surface induced by roller compaction increased with the number of roller passes up to about 6 passes. For 8 passes, there was no significant further increase of the layer settlement. The mean settlement corresponded to approximately 10% of the layer thickness for 0.6m thick layer, and 8% to 9% for 0.9m thick layer, as shown on Figure 1.

The dry density obtained using the sand cone test (0.3m diameter) differs significantly from the results provided by the nuclear densometer. Also, an important decrease of the density was detected in the bottom third of a 0.9m layer, compared to the upper two-thirds of the layer. The compaction of the material at that depth was very low and indicated that most of the compaction energy was absorbed in the first 0.6 m of the layer depth, see Figure 2.

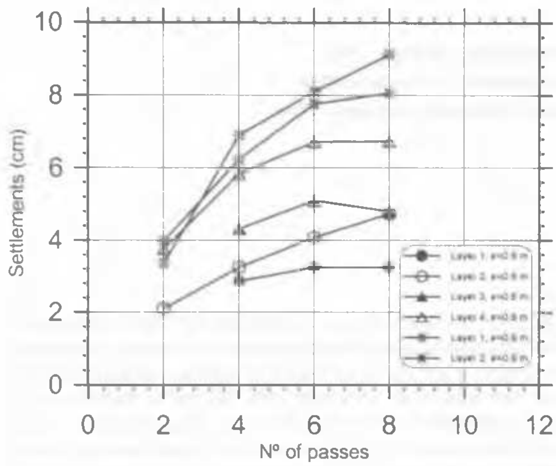

Figure 1. Settlement v/s number of passes.

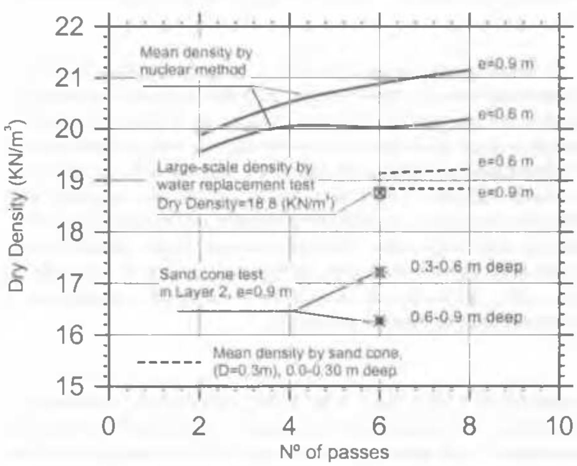

Figure 2. Dry density v/s number of passes.

Figure 3 shows typical grain size distribution curves obtained from samples after in situ compaction. Comparison with the results on samples taken from the stockpile indicated that roller compaction produced little changes in the particle size distribution. However, a series of Modified Proctor compaction tests showed that there was a large amount of particle breakdown during the execution of the tests. For this reason, it was necessary to treat the Modified Proctor test results with great caution when used as a mean of controlling compaction in the field.

Additionally, Los Angeles abrasion tests showed a very significant particle breakdown (45%) and magnesium sulfate immersion tests indicated loss up to 75% for coarse particles and 45% for fine particles.

With the objective to evaluate the deformation modulus of the compacted material, four plate load tests were carried out on the completed surface of the test fill in accordance with ASTM D-1194. Three of the tests were on the surface of the compacted material, while in the fourth test partial saturation was attempted by excavating a shallow indentation in the surface of the fill and filling it with water. The results are plotted on Figure 4 as vertical stress v/s average deformation, measured by three displacement gauges set on the plate. It can be seen that the results of the different tests are consistent, including for the test on the wetted material, even though the curve for the latter has a different shape due to a tilting of the plate during the progress of the test. A rock fragment below the fill surface under the plate caused the tilting.

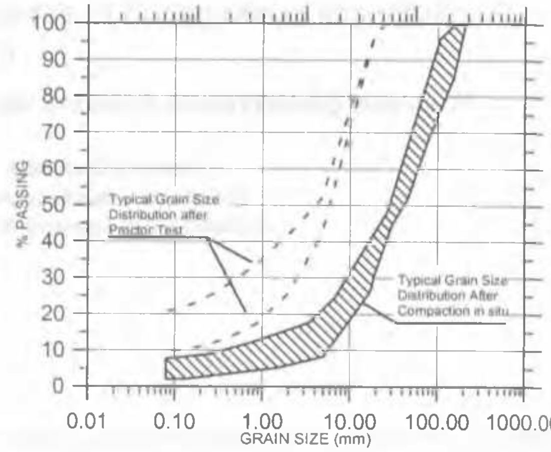

Figure 3. Grain Size Distribution.

In the unsaturated tests, the plots show a non-reversible displacement of 4 to 5 mm upon unloading. This behavior corresponds to an inelastic material. However, a very small reversible deformation, indicating a quasi-elastic modulus, is observed during the unloading-reloading cycles with amplitude of about 0.2 MPa. See Figure 4.

In order to optimize the use of the soft rock materials and to minimize the use of special procedures required to produce a compacted fill of satisfactory quality, based on the results of the test fill, the material was divided into two types, according to location in the fill. These were: "Class B rockfill", of lower density (nominally $\gamma_d = 18.8$ kN/m^3), placed in 0.6m lifts in plant fill areas outside of major structures influence areas and where its settlement would not affect structures; and "Class B select fill", of higher density (nominally $\gamma_d = 19.6$ kN/m^3), placed in 0.3m lifts in more settlement-sensitive areas. Class A rockfill and Class A select fill were imported, composed of durable materials and placed in selected most sensitive areas. Geotechnical design parameters were determined for both types of Class B materials, based on the testing outlined below.

Two sets of 0.15m diameter consolidated-drained triaxial tests were performed, on specimens compacted to the two above stated dry densities. The results are presented on Figure 5. The results showed that, at all confining pressures, the material presents a contractive behavior with a high volumetric strain denoting a very compressible material, despite the relatively high densities reached after isotropic consolidation. An unloading-reloading cycle performed on a specimen tested at a confining pressure of 0.59 MPa showed a very small recovery of axial

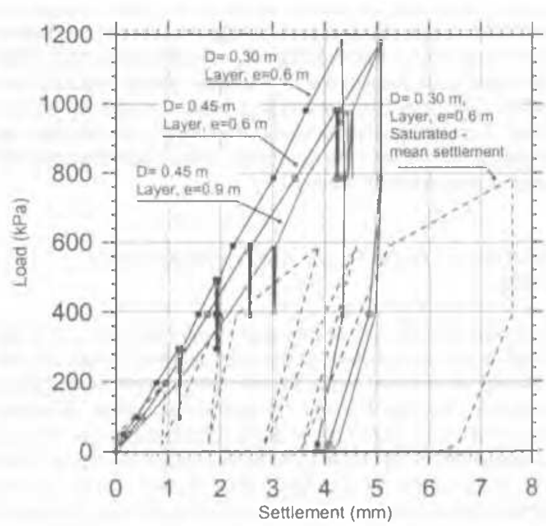

Figure 4: Plate load test results.

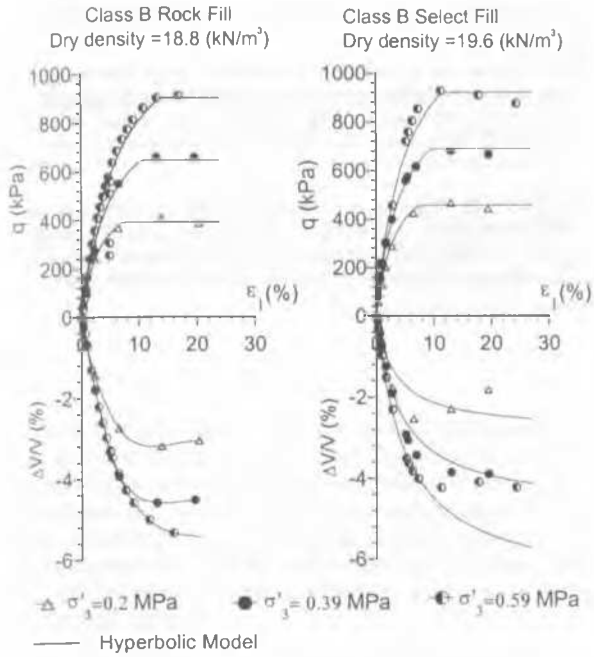

Figure 5. Consolidated-drained triaxial test results. Comparison between test data and hyperbolic model.

The results of the consolidated-drained triaxial tests produced the following hyperbolic parameters:

Parameters	Symbol	Class B Rock Fill	Class B Select Fill
Modulus number	K	308	338
Modulus exponent	n	0.17	0.24
Failure ratio	R_f	0.69	0.69
Bulk modulus number	K_b	93	168
Bulk modulus exponent	m	0.08	-0.15
Unloading - reloading modulus number	K_{ur}	2900	-
Effective cohesion, kPa	c'	30	40
Effective friction angle	ϕ'	30	31
Initial tangent modulus:			
Normalized Confining pressure (σ'_3/Pa)=1.94	Ei/Pa	370	381

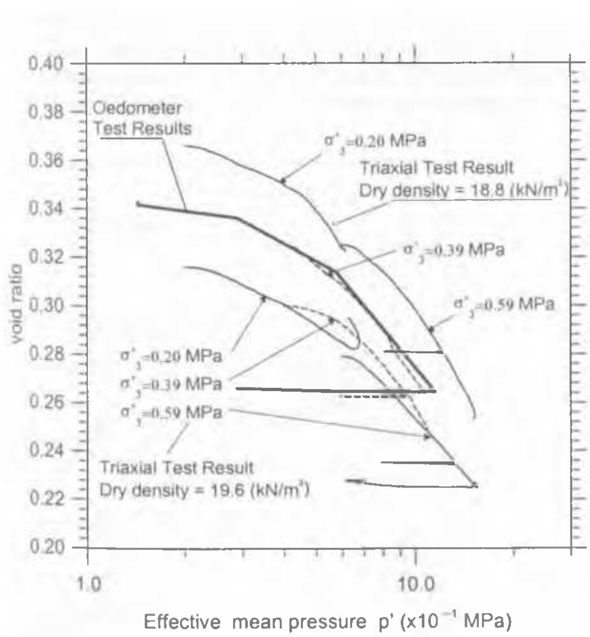

Figure 6. Large scale Oedometer test results compared with Triaxial tests results.

deformation. As described above, similar behavior was observed in the plate load tests performed in situ.

One consolidation test was performed, using a large oedometer cell (0.15m diameter and 0.1m high). The test results are indicated in Figure 6. In the loading stages below 0.39 MPa, the material behaves as overconsolidated. For loading greater than 0.39 MPa, the material displays a normal consolidated behavior and the compressibility increases considerably. This is most likely due to the particle breakdown occurring at higher pressures, causing large volumetric deformations.

The increase of deformations observed during the saturation phase imposed under a constant stress level shows the influence of water on the material compressibility. Also, the material continued to deform under a constant stress, although the deformation rate decreased with time. This phenomenon, similar to the creep in fine soils, can be explained by particle breakdown. Comparison of the e-log p' curves from the oedometer and the triaxial tests, presented in Figure 6 showed that the results of the two types of tests were very consistent.

4 CONCLUSIONS

The test fill, and the field and laboratory testing, resulted in an understanding of the behavior of the soft rock originating from the required excavations, permitting an optimization of its use in the construction of the fill platform supporting a part of the concentrator plant. This resulted in very significant cost and construction schedule savings. The test program also established the characteristics of the soft rock summarized below. The different stages of handling (excavation, transport to the stockpile, homogenization at the stockpile, transport to the site and spreading) produce a very significant particle breakdown, which was earlier indicated by Los Angeles abrasion test. Because greater breakdown of the larger particles results in a higher compacted density, in the earthwork specification a requirement was provided to include a combination of passes of a sheepsfoot roller and a vibratory roller. However, particle breakdown will lower the permeability of the fill, which could result in softening of the particles and increased compressibility. In addition, a magnesium sulfate immersion test indicated a very low resistance to freezing and thawing cycles, while CBR test results reflected the negative influence of water saturation on the behavior of the material. In view of these characteristics, to minimize the possibility of additional settlements, it was recommended to provide under-drains under the fill, consisting of non-degradable imported fill.

It was found that, in order to achieve a dry density on the order of 19.6 kN/m^3 and hence lower compressibility, the material had to be placed in 0.3m layers. This method was applied in areas where it was desirable to minimize the settlements. In areas where a higher compressibility was tolerable, the material was placed in 0.6m lifts, achieving a density of about 18.8 kN/m^3. In both cases 6 roller passes were applied, using a combination of sheepsfoot and vibratory roller.

The modulus obtained from plate load tests ranged from 60 to 92 MPa, for material at the water content existing after placement and compaction. An average modulus value of 33MPa was estimated for wetted material. Triaxial tests carried out under saturated conditions showed a large particle breakdown and highlighted the very compressible behavior. As could be expected, the deformation modulus values obtained in triaxial testing under saturated conditions were lower than those obtained from plate load test performed on under partially saturated conditions.

The results of triaxial tests indicated that the confining pressure had little influence on the modulus of the material, due to the large amount of particle breakdown. The deformation modulus obtained from the hyperbolic model gives an initial tangent modulus of 37 MPa for a confining pressure of 0.2 MPa. Similar results were obtained in tests on material compacted at the lower as well as at the higher density; in fact, only a small increase in deformation modulus was measured for the samples compacted at the higher density.

The e-log p' plots (Figure 6) for samples tested at both densities indicated a significant increase in compressibility at pressures higher than 0.39 MPa. This behavior was observed in both the triaxial and the oedometer test results. For this reason, in order to minimize settlement of foundations, the applied foundation pressure should not exceed 0.39 MPa.

5 PHOTOGRAPHS

Figure 7. Particle size distribution test in test fill

Figure 8. Water replacement test.

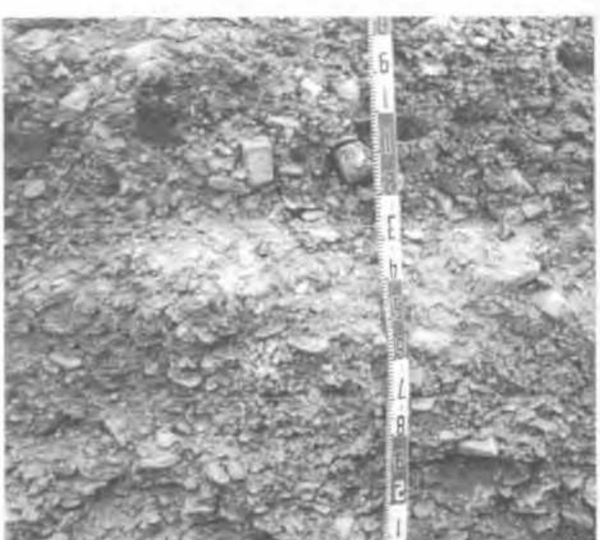

Figure 9. Wall of trench in Class B rockfill in test fill

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