ASSESSMENT OF EARTHWORKS BY GEOTECHNICAL ENGINEERING PERSPECTIVE

TOPRAK İŞLERİNİN GEOTEKNİK MÜHENDİSLİĞİ AÇISINDAN DEĞERLENDİRİLMESİ

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ABSTRACT

Earthwork operations are considered as a significant cost item in civil engineering projects. The primary roles of geotechnical engineering in the earthwork operations is to optimize excavation-fill costs by assessing the suitability of excavation material for re-using in filling purposes. The selection of the most appropriate method for excavation based on the mechanical and physical properties of issued lithological units also falls within the expertise of geotechnical engineers. The aim of this study is to address the efficient management of earthworks by geotechnical engineering perspective. As a first step, acquisition of the engineering parameters for relevant lithological units based on the geotechnical and geophysical site investigations are described. Correlations considered in parameter acquisition are expressed in detail. For the purpose of evaluating excavatability, methods based on basic soil & rock mechanics principles are compared with the innovative methods using the geophysical survey dataset to determine the method of excavation as equipment-based. In conclusion, the main steps to follow for establishing the re-usability of excavation materials in filling operations, utilizing data from both excavation and fill assessments are presented as a flowchart.
Keywords: Excavatability, filling, earthworks

ÖZET

Toprak işleri, mühendislik projelerinde önemli bir maliyet kalemi olarak değerlendirilmektedir. Toprak işlerinin yönetiminde geoteknik mühendisliğinin başlıca rolleri, projede ortaya çıkacak kazı malzemesinin dolgu imalatında kullanımının uygunluğunun değerlendirilmesi, litolojik birimlerin mekanik ve fiziksel özelliklerinin değerlendirilerek kazı operasyonlarının verimliliğinin arttırılmasıdır. Bu çalışma kapsamında toprak işlerinin verimli yönetimi noktasında geoteknik mühendisliğinin rolü ve problemlerin çözümlenmesinde takip edilebilecek hususların belirlenmesi amaçlanmaktadır. Değerlendirmeye tabi litolojik birimlere ait mühendislik parametrelerinin belirlenmesine

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yönelik adımlar, bu minvalde kullanılabilecek, literatürde kabul görmüş korelasyonlar çalışma kapsamında tariflenmiştir. Kazılabilirlik değerlendirmesinde geleneksel zemin-kaya mekaniği prensiplerine dayalı yaklaşımlar ve jeofizik araştırmalar sonucu elde edilen parametreleri esas alan yöntemler karşılaştırmalı olarak ele alınmıştır. Sonuç olarak, kazı ve dolgu değerlendirmesi sonucuna bağlı olarak, litolojik birimler bazında kazılabilirlik sınıflaması, bu sınıflamaya esas uygun ekipman seçimine yönelik yöntemler sunulmuştur. Kazıdan elde olunan malzemelerin dolgu işlerinde kullanılabilirliği noktasında takip edilebilecek başlıca adımlar bir akış şeması formunda sunulmuştur.

Anahtar Kelimeler: Kazılabilirlik, dolgu, toprak işleri

1. INTRODUCTION

Geotechnical assessment of earthworks is one of the most the challenging subjects for geotechnical engineering practice. This task may be defined as the interaction area of soil & rock mechanics, engineering geology, material & testing (Look, 2023) (See Figure 1). The scope includes many uncertainties due to the heterogenic nature of the soil and rock units respect to depth and region.

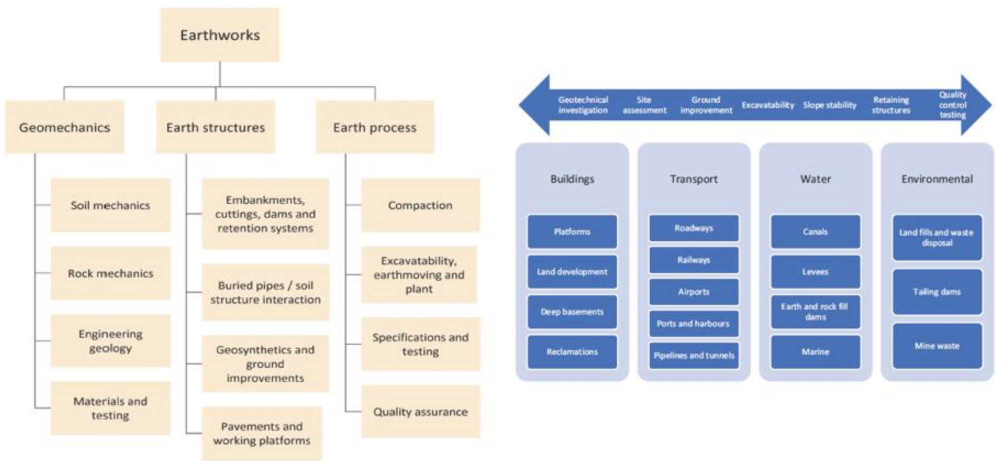


Figure 1. Earthwork elements and applications (Look, 2023)

Geotechnical assessment of earthworks has crucial mission for evaluating re-using options of excavated soil in filling, determining the volume of import material if necessary. These steps are very important for construction sequence. Importing significant amount of fill for construction may cause remarkable costs for the projects requiring enormous volume of earthworks such as dams, roads, railways, airports etc. The contractors would prefer to evaluate the possibility of re-using the excavated material as much as they can before considering the import option.

For the project dealing with big volume of excavations, excavatability of issued soil / rock layers shall be evaluated. Selection of equipment type is strictly based on the rock formation: Degree of weathering, strength properties, geologic origin, discontinuity etc. The proper method for cutting (digging, ripping or blasting) is based on the rock nature and available method for excavation. These are the critical decisions to be clarified due to project schedule and cost analysis.

Engineering geologists, geotechnical engineers and building material experts have important missions to propose an efficient method for earthwork constructions. However, there is no specified method for earthwork considerations: It is not a simple engineering approach like designing a load bearing pile or calculating a consolidation settlement for a conventional structure.

2. MAIN STEPS TO FOLLOW

General steps for earthwork assessment would follow the stages summarized as follows:

- Definition of geological-geotechnical conditions: Determination of soil strata, depth of layers, groundwater state, soil-rock properties based on geotechnical / geophysical surveys,
- Review of project specifications: Definitions for material types stated in earthwork specification of the project.
- Filling material definition: Listing the type and requirements of filling required in project for specific purposes: Base, subbase, structural fill, concrete aggregate etc.
- Site grading: Review of site grading drawings showing the regions require filling or cutting.
- Filling & cutting methodology: Definition of cutting & filling areas per geometrical condition of site, assessment of materials per mechanical and physical properties.
- In-Situ material availability evaluation: Comparing the in-situ material properties with the project requirements for filling works.

3. GEOTECHNICAL ASSESSMENT FOR FILLING WORKS

The project specifications for earthworks usually define all type of filling materials regarding to ease of use. Generally, project specifications refer to the international standards for physical and mechanical properties of project fills.

The main physical and mechanical characteristics of fill materials to be evaluated can be summarized as grain size distribution, Atterberg limits, linear shrinkage, California Bearing Ratio (CBR) and compaction characteristics. After the determination of these properties of existing materials, the conditions of the material shall be compared with the project requirements addressed in project specifications or referenced international standards. As a result, material re-usability can be expressed in the terms of material properties and project requirements. Investigation for reusability of in-situ material is based on two main steps:

- Determination of physical and mechanical properties of in-situ material

a) Grain size distribution
b) Atterberg limits
c) Linear Shrinkage, CBR
d) Result of compaction tests

- Comparison of the in-situ material properties with requirements of fill types.

At this stage, all type of properties may not be defined in site exploration studies. Therefore, well-known correlations for obtaining required properties shall be used.

3.1. Correlations for Filling Studies

Main correlations for filling material assessment are given as following:

- Atterberg Limits & Shrinkage, Swelling potential
- Soil index properties and soil classes & CBR
- Soil Class & CBR
- Modulus of subgrade reaction (k) & CBR
- Deformation Modulus (E_S) & CBR

Atterberg Limits & Degree of Expansion Shrinkage Correlation

Casagrande method may be used to define the shrinkage limit and potential of expansion based on shrinkage limits.
Casagrande (1932) suggested that the initial moisture content for shrinkage limit (SL) tests should be slightly above the plastic limit, but it is difficult to prepare specimens to such low moisture contents without entrapping air bubbles. It has been found that for soils prepared in this way and that plot near the A-line of a plasticity chart (Figure 2), the shrinkage limit is about 20.
If the soil plots an amount Δp vertically above or below the A-line, the shrinkage limit (SL) for soils that plot above the A-line;

$$SL = 20 - \Delta p \quad (1)$$

for soils that plot below the A-line;

$$SL = 20 + \Delta p \quad (2)$$

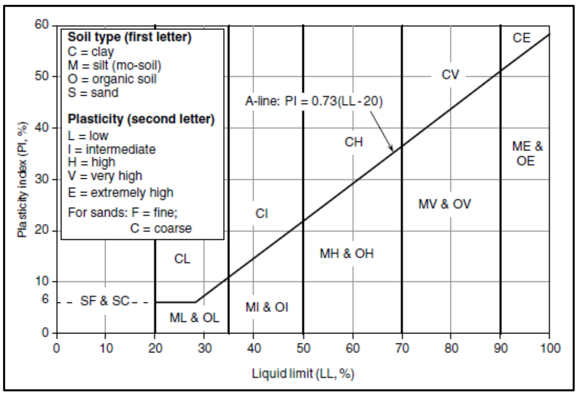


Figure 2. Atterberg plasticity chart (USCS)

Suggested guide to the determination of potential for expansion using shrinkage limit and linear shrinkage by Altmeyer (1955) is presented in Table 1.

Table 1. Expansion potential based on shrinkage limit and linear shrinkage (Altmeyer,1955)

Potential for expansion	Shrinkage limit (%)	Linear shrinkage (%)
Critical	<10	>8
Marginal	10-12	5-8
Non-critical	>12	<5

The expansion potential of fine-grained soils may be determined by following percent of fine content, Atterberg limits and SPT-N value adapted from Chen (1988) (Table 2).

Table 2. Gradation, SPT-N, Expansion Potential Relationship (Chen, 1988)

Laboratory and field data			Probable expansion (% total volume)	Swelling pressure (kPa)	Degree of expansion
Percentage passing 75 μm sieve (%)	Liquid limit (%)	SPT-N Value			
>35	>60	>30	>10	>1000	Very high
60-95	40-60	20-30	3-10	250-1000	High
30-60	30-40	10-20	1-5	150-250	Medium
<30	<30	<10	<1	<50	Low

Soil Index Properties and Soil Classes & CBR

California Bearing Ratio (CBR) is the main parameter for judging in-situ material is suitable for subgrade or not. However, adequate number of CBR testing may not be available during the material suitability assessment stage. It may be correlated from various soil properties such as gradation, soil class, strength characteristics etc.
Relationship with sieve size analysis and CBR is well-defined in NCHRP (2001) both for coarse and fine-grained soils (See Figure 3).

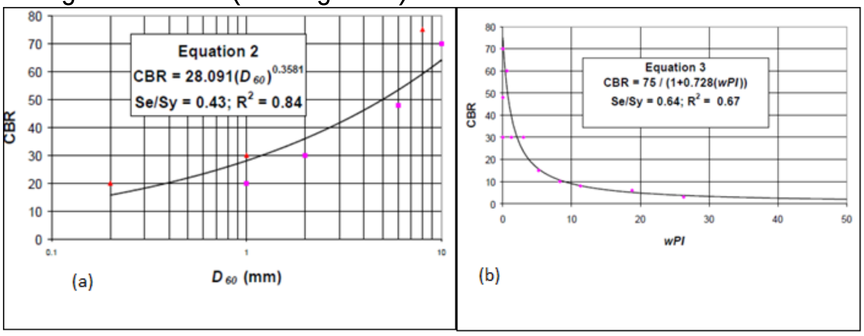


Figure 3. CBR & Soil Index Properties Relationship (Adapted from NCHRP (2001))

- wPI: P200*PI
- PI: Plasticity Index (Percentage)
- P200: Percentage passing #200sieve (Fine content) (Decimal unit)

This correlation is valid for soils classified as GM, SM, SC, ML, MH, CL, CH containing clay+silt material more than %12 in weight.

Modulus of Subgrade Reaction & CBR

Obtaining modulus of subgrade reaction (k) value is important for pavement design of airports (FAA). It is mostly used as acceptance criteria of rigid pavements (ie Runways). For flexible pavements, CBR is the control parameter. Therefore, using relationship between CBR and k is important to produce from existing parameter to another one. The relationship between CBR and k expressed by Tuleubekov & Brill (2014) is given as follows:

$$k = 28.6926 CBR^{0.7788} \ (k \ in \ pci) \quad (1)$$

Deformation Modulus (E_S) & CBR

Deformation modulus (Es) CBR relationship has been expressed by NAASRA (1979) as shown in Figure 4.

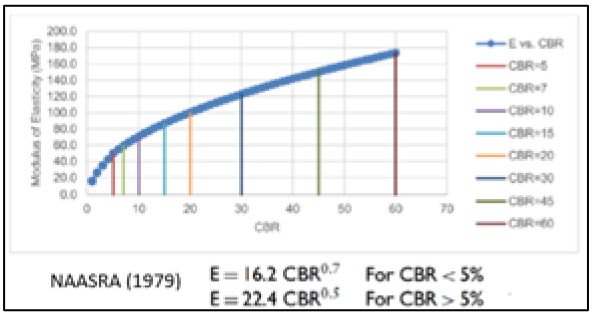


Figure 4. Deformation modulus (Es) & CBR relationship (NAASRA, 1979)

4. GEOTECHNICAL ASSESSMENT FOR EXCAVATIONS

For the projects requiring big volumes of cutting, the excavation procedure has an important role for the accurate estimate of project schedule. Excavation process shall be detailed by evaluating the grading plan of the site, lithology definition based on site investigations. The determination of excavation method for cutting area is critical. While soil excavations can be performed with simple type of excavators, rock excavation requires an extensive evaluation considering equipment type and mechanical nature of rock.
Common approaches used in the classification of rock excavations are listed as follows:

- Conventional Approaches: Focuses on mechanical rock properties: Pettifer and Fookes (1994), Rock Mass Rating (RMR), Geological Strength Index (GSI) etc.
- Geophysical approaches: Excavation assessment based on wave velocities obtained by geophysical investigations

4.1. Conventional Approaches

Pettifer & Fookes Excavation Assessment

In this method, the excavation class is determined by considering the rock quality designation (RQD) value for the relevant excavation depth. Regarding to RQD values, uniaxial compressive strength (UCS) - point load index (I_{s50}) values are determined for related sections.
Listed parameters are determined by following the related formulas:
Volumetric Joint Count (J_v) and discontinuity spacing index (I_f) are calculated as following

$$RQD = 115 - 3.3 * J_v \quad (2)$$

$$I_f = 3/J_v \quad (3)$$

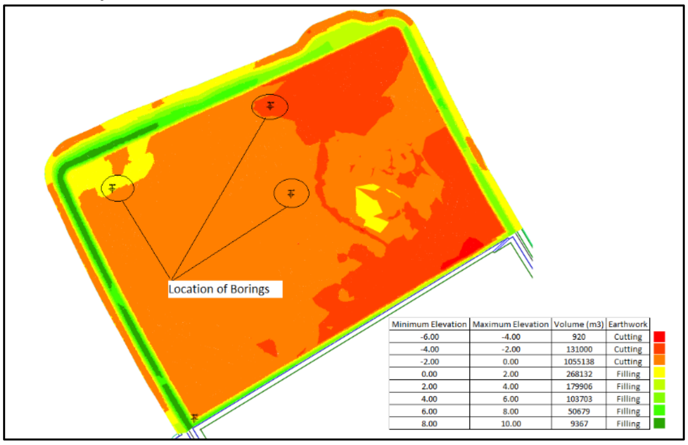
Pettifer & Fookes (1994) approach uses UCS≈20*I_{S50} equation to derive point load values. Even if there are many reported correlations published between UCS and I_{S50}, developing site-specific equation is strongly adviced to evaluate excavatability characteristics of rock layers.
The necessary steps to identify the excavatability state based on Pettifer & Fookes approach are given as follows. The example outputs reflecting grading plan and excavation classes are presented in Figure 5 and Figure 6, respectively

- Detection the existing borings performed in cutting sections,
- Determination the rock properties (RQD, UCS etc) from issued boreholes respect to cutting depths from site investigation locations,
- Determination the excavatability class of issued layers from Pettifer & Fookes chart,
- Calculation of total volumes for cutting respect to excavation depth from grading plan,
- Definition of the excavatability state and amount of material for the same area and depth.

Rock Mass Rating (RMR) & Excavation Assessment

Excavatability may be predicted by assessing Rock Mass Rating (RMR) values calculated from related borehole data. Abdullatif & Cruden (1983) proposed an estimation of excavatability related to RMR values. Regarding to excavation class based on RMR as following, example assessment output for tunnel excavation study is given in Figure 8.

- Digging (RMR<30)
- Ripping (31<RMR<60)
- Blasting (61<RMR<100)



Minimum Elevation	Maximum Elevation	Volume (m3)	Earthwork
-6.00	-4.00	920	Cutting
-4.00	-2.00	131000	Cutting
-2.00	0.00	1055138	Cutting
0.00	2.00	268132	Filling
2.00	4.00	179906	Filling
4.00	6.00	103703	Filling
6.00	8.00	50679	Filling
8.00	10.00	9367	Filling

Figure 5. Example grading plan (Tekfen Engineering, 2021)

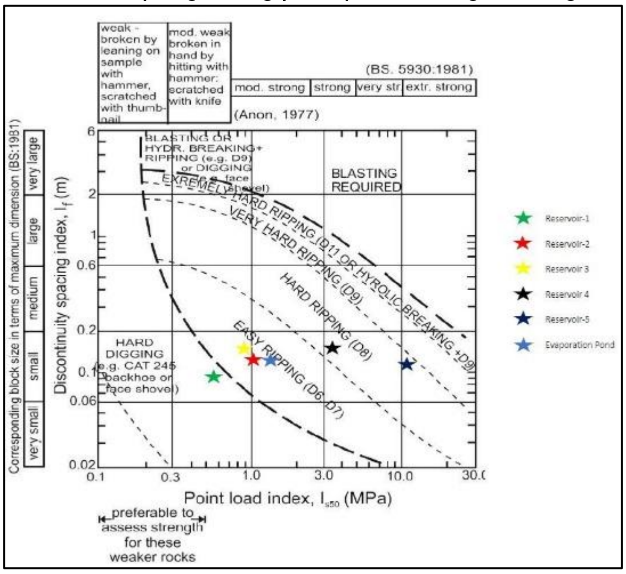


Figure 6. Excavatability assessment per Pettifer & Fookes (1994) approach (Tekfen Engineering, 2021)

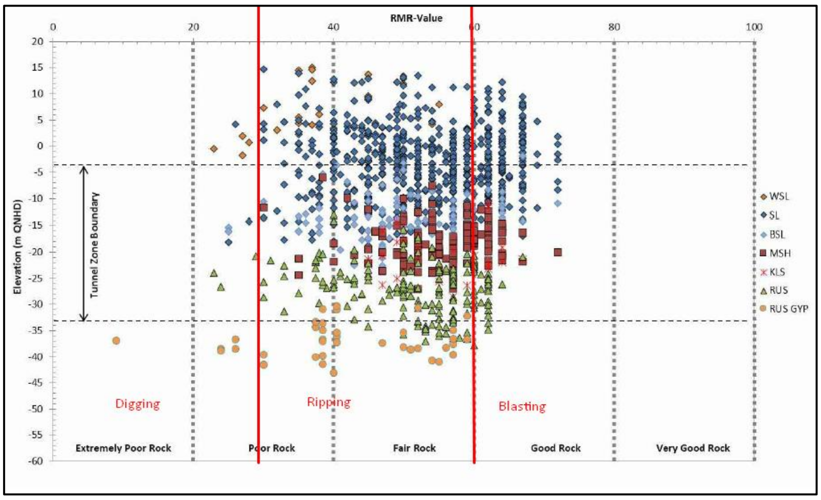


Figure 7. RMR & excavatability example (Tekfen Engineering, 2021)

4.2. Geophysical Approaches

Caterpillar Performance Handbook (2023) presents the excavatability states of different type of rocks based on the wave velocity measurements of layers. The individual charts are presented for each type of digging / ripping equipment produced by company. Seismic refraction survey results and geological description of rock layers to be excavated are used to identify proper digging & ripping equipment. Compared to the conventional methods as discussed in Chapter 4.1. Geophysical survey-based excavation assessment gives more reliable results due to the continous dataset obtained at site. Combining geophysical survey results with topographical data such as digital elevation model (DEM) may provide very accurate results to predict excavatability for the project sites such as ponds, solar photovoltaic plant fields etc (See Figure 8, Figure 9). Classification of excavation provides valuable data to contractors for earthwork operation planning in selection of adequate equipment.

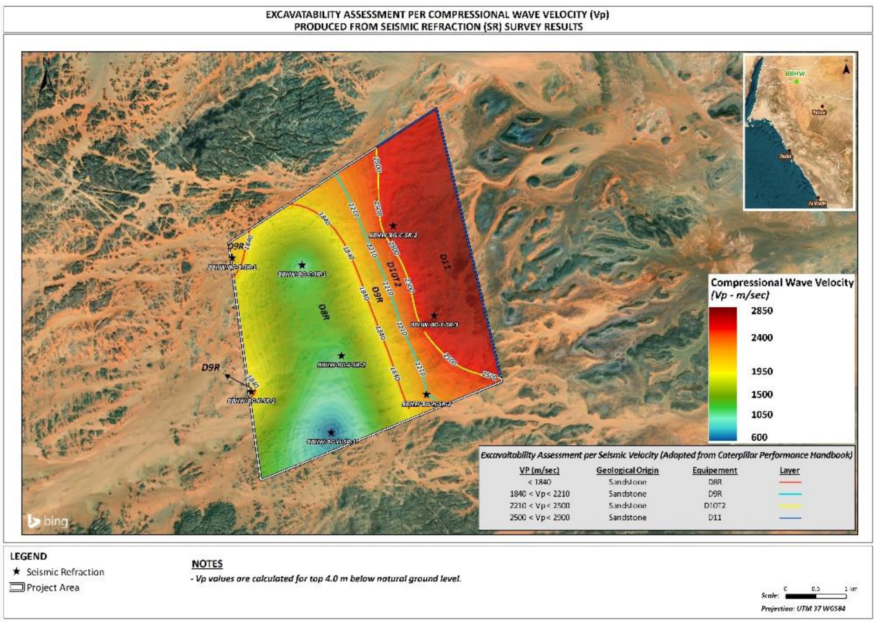


Figure 8. Geophysical survey-based excavatability Assessment (Assystem, 2024)

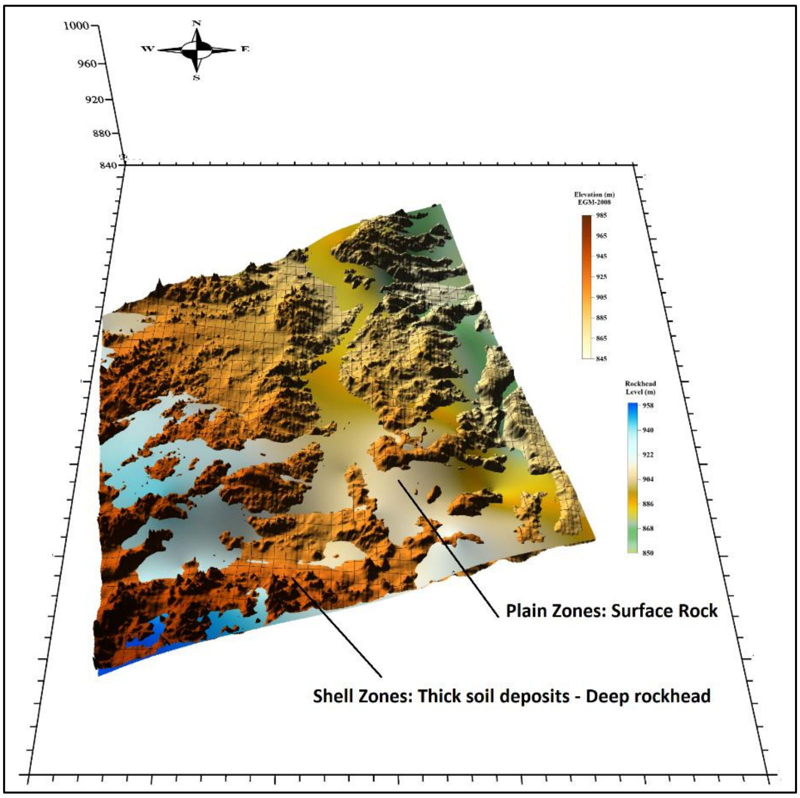


Figure 9. Comparison of Site Elevations & Rockhead Level for Excavation Zoning (Assystem, 2024)

5. RESULTS

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This study aims to highlight the role of geotechnical engineering in earthwork optimization studies. Geotechnical earthwork assessment has been divided to two main groups as filling and excavation evaluations. Optimization of filling works by assessing the filling material per geotechnical properties is addressed. Relevant approaches to identify physical and mechanical properties of fill materials are summarized. Filling assessment is finalized by checking the complience with the determined parameters and project specifications.

It is recommended that, development of site-specific correlations respect to physical properties of soils are rocks would provide very detailed dataset for the projects.

Geotechnical assessment for excavation is summarized by addressing excavation assessment methods both for conventional and geophysical-based. In order to perform a high-accuracy study, combining the results coming from conventional and geophysical methods are very important. The role of geographic information systems (GIS) is becoming more important in recent years by its advantage to address the critical regions of the project sites for excavation and filling aspects.

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