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FOUNDING HEAVY STRUCTURES ALONG THE SLOPE OF SCHIST FORMATION

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ABSTRACT: Placing foundation at different or variable levels below ground can easily be dealt with using renowned structural analysis programs which can work out moments and reaction loads. However, these software codes may not be equipped with constitutive models that realistically represent the behavior of specific subsurface formation and geological settings. This work presents a case study for a major education institute with many facilities constructed along the slope line of a Schist formation. Inspection of excavations prior to the placement of foundations was carried out. Driving forces and moments were found to pose a significant risk in some parts of the project site and extra safe conditions at other parts and locations. The geological survey and mapping can be a good tool for verifying the support conditions in rock containing laminations and extra thin layers. Physical and chemical properties provide a guide for better design and construction. Precautions and procedure measures to avoid potential slope failures are addressed and outlined.

Keywords: Schist, Slope, Foundation, Failure

1. INTRODUCTION

The region of Aseer in Saudi Arabia is mountainous with moderate to very rough topography. Basic and metamorphic rocks are seen as outcropping and forming many elevated and extended ranges. The government decided to build a major training education institute at a site in an area known as Alhobail to the west of Abha and South of Rijal Alma town. (Northing 18° 05´ 50´´ Easting 42° 13´ 34´´).

A low-level land is adjacent to the site towards the west of the proposed construction. The project included three-story building with floor area of 1431 m2 for each level and two-story workshop building with floor area of 1661 m2 in addition to a mosque and other single story buildings and facilities. Site investigation works were carried out at two stages. The first stage was prior to the design and the second stage was prior to construction. Twenty-one (21) boreholes were advanced to 6m and 10 m depth below ground level. All borings encountered the hard Schist formation except for two borings where a backfill material was found extending beyond the depth explorations. Standard penetration tests were not enabled due to the presence of rock, boulders, and gravel. The authorities decided to shift the site location within the same terrain and close vicinity of the first selection. A second study was conducted which included twenty-five boreholes advanced to 6 meters and 10 meters below grade level in addition to five test pits excavated using hydraulic excavators to the rock level or a maximum depth of eight meters. Standard penetration tests conducted indicated low to medium dense formation for locations where deep fill material was encountered.

Figure 1 shows a satellite map and Fig. 2 shows the site works prior to excavations.

Fig.1. Satellite view of the project site.

The geotechnical firm recommended removing all top soils and placing the foundations 50cm into the rock formation. Allowable bearing capacity of 250 kN/m2 was recommended. The firm also recommended a safe slope of 1:1 for the soil formation and 1:2 for Schist or fragmented rocks. A typical fill can be seen in a plate shown in Figure 3.

The Schist formation is laminated and rich of mica, weak and disintegrated at some locations. The quality of rock is improving with depth.

Shear zones strike northeast, steeply dipping were indicated in plates shown in Figure 4.

Fig. 2. General site location before excavation works.

2. MATERIALS & SCHIST DESCRIPTION

Schist is a foliated metamorphic rock consisting of platy thin laminations made up of muscovite mica, biotite mica, and chlorite. Feldspar and quartz are also common within Schist. When a rock is subjected to a specific level of pressure and heat, the platy nature can appear. The rock is generally fine to medium coarse grained with a hardness in the range of 3.5 to 4, highly porous, with a shiny luster. Schist is different from Gneiss as the latter is a metamorphic form of volcanic rock while the Schist is from clays and mud. Sheet-like planner structure and alternating beds of light and dark colors can be used to differentiate between the two types.

Anisotropic properties of rock are associated with platy nature and foliated formation. This was found to affect the stability of many excavations and civil engineering projects.

Reference [1] stated that the quartzite schist exhibits maximum strength due to the higher content of quartz and low porosity providing better interlocking while biotite Schist provides loose interlocking leading to lower strength. Reference [2] studied engineering geological and geotechnical responses of schistose rocks for a project in India.

3. FOUNDING ALONG SLOPING GROUND IN CODES OF PRACTICE

International building code IBC 2015 [3] called for additional studies to be made as necessary to evaluate slope stability, soil strength, position and adequacy of load-bearing soils, the effect of moisture variation on soil-bearing capacity, compressibility, liquefaction, and expansiveness.

Fig. 3. Non-stable fill material within the vertical cut

Fig. 4. Shear zones and bedding orientation.

There is no specific recommendation for the possible anisotropy conditions or foliated type of rocks or cemented soils. The Saudi building Code SBC 303 [4] followed the IBC 2015 notification. Although calling for classification to be based on observations and tests, such as borings or test pits but there was no mention of geologic mapping or assessment of dip and strike or rock inclination. Major mass failure can occur if the geotechnical engineer or building official ignored the geological settings of the site. Section 1808.7 of IBC 2015 regulates the placement of foundations adjacent to slopes that are greater than one unit vertical to three units horizontal. Erosion characteristics of slope material are highlighted. Slope stability is well addressed in codes of practice but may not be of sufficient cover of rock anisotropy. IBC 2015 required that foundation clearance from slopes to be as shown in Figure 5. Setback distances were not based on the adverse geological condition of foliated rock material like schist, shale, slate, and gneiss.

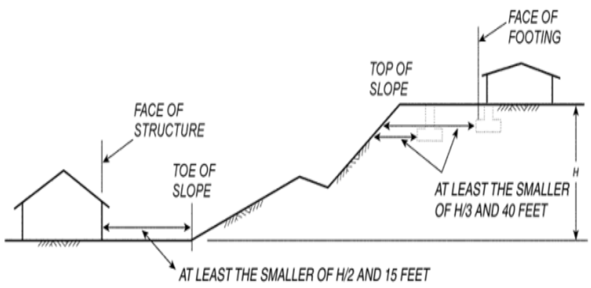

Fig. 5. IBC distance required from sloping ground.

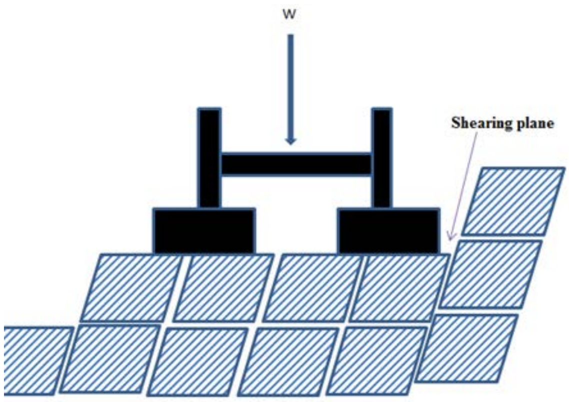

Fig. 6. Failure along shearing plane for footings placed on steps along the slope.

4. TYPICAL BOREHOLE AND TEST PIT LOGS

For this particular site, the geotechnical investigation resulted in boreholes described as two main layers. The top overburden soil is disintegrated silt or decomposed Shiest material followed by a hard medium to coarse-grained Schist. No information provided with regard to rock orientation, bedding, and weathering condition.

A site visit was conducted to inspect the excavated level for footings to be placed on the sloping ground. From the site visit conducted by the authors, footings were found set out in rows. Excavation of horizontal steps was noted regardless of a rock orientation. The orientation of shear planes in some cases in favor of better stability in some areas and non-stable in other areas. Moving the foundations away from the top of the slope for each step and extra excavation was recommended. Fig 6. Presents a diagram in which the subsurface ground is presented as oriented blocks where failure can occur due to shearing along predetermined planes. In such case over excavation and deep placement of foundations will not help in providing a stable ground.

The subsurface strata as obtained from boreholes and test pits is idealized and presented in Figure 7.

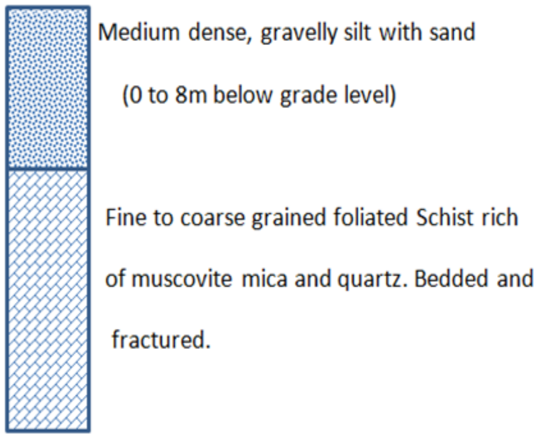

Fig. 7. Typical subsurface strata of the site.

5. STABILITY ANALYSIS

Foliated rock subjected to pressure and temperature stresses over an extended period of time is expected to result in anisotropic nature where physical and mechanical rock properties vary with direction. Reference [5] provides a study on the fracture properties of anisotropic rocks.

Reference [6] stated that the effect of strength anisotropy on the stability of slopes has commonly been investigated using the mass procedure utilizing either the conventional limit equilibrium procedure or the upper bound technique of limit plasticity. Unlike what is mentioned by reference [6] the geometry of the slip surface is totally controlled by the orientation and cleavage of rock. Pre-defined planes parallel to the direction of bedding planes are to be assumed as failure planes. The weight of the wedge and the superstructure constitute the main driving forces along failure planes. In the absence of specific orientation, Schist is assumed to have a slip surface angle of 68 degrees. This is the angle where slopes are expected to be stable [7]. Anisotropy must be considered for all geotechnical properties and these values can be obtained by performing tests in different directions. The interlocking nature can be figured out by direct observation or geological mapping. References [8], [9] and [10] provide a good highlight on the engineering properties of schist formation which will be very useful for the design engineer. Figure 8 indicates a predefined failure surface of Schist sloping ground.

The angle of repose or the angle where loose disintegrated Schist stockpiles stand without support is estimated at 45 degrees. The 1:1 vertical to horizontal slope recommendation is based on this. Figure 8 shows a natural slope at the edge of the site with 1:1 slope approximately.

Fig.8. Stockpile showing the slope of loose disintegrated Schist.

Figure 9 presents a wedge failure diagram for a 10m height slope. Figure 10 presents excavations as made for isolated footings.

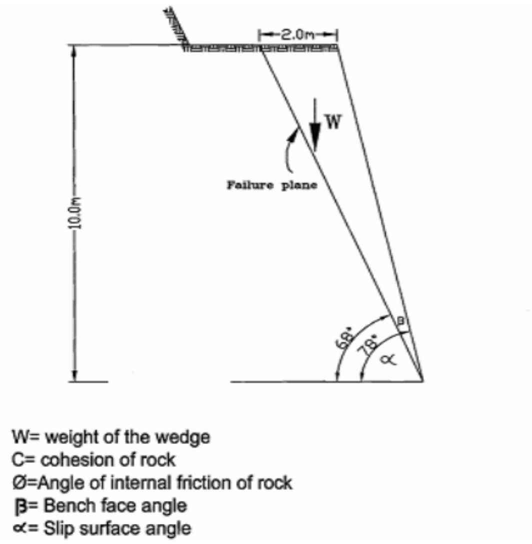

Fig. 9. Wedge failure diagram for a 10m height slope.

Fig.10. Excavations for isolated footings along the slopes of Schist.

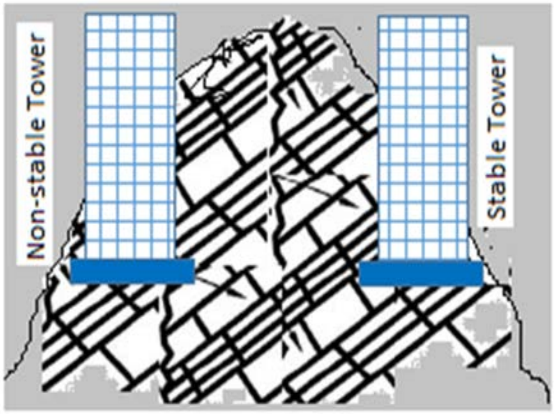

Fig.11. Stable and non-stable sides of the mountain

The investigation team for this site pinpointed areas likely to be of trouble.

Figure 11 provides a diagram of two towers placed on two sides of a mountain. One tower is nonstable because the driving forces are acting along weak bedded formation where shear failure can easily take place while the other tower is stable and the driving forces are not assisted by the rock orientation. .In case a non-stable condition is likely to occur it is better to relocate the structure and avoid the risk of schist shear failure.

The engineering and phyisco-mechanical properties of foliated rock need to be carefully investigated. The anisotropy of this type of rock can result in variable strength and shear resistance in multidirectional planes, [11], [12] and [13]. Some researcher introduced the concept of the anisotropy ratio [14]. This is defined as the ratio of any property measured at an angle parallel to the foliation compared to perpendicular or any other directions. The geological maps for areas where construction is intended provide useful details on the dip and strike of the formation as well as the direction of faults if any is expected. The southern province of Saudi Arabia involves vast areas covered with schist, gneiss and other types of metamorphic rocks. The foundations supporting different structures including buildings and bridges, slopes to the sides of roads and highways must be designed considering the isotropic properties of the underlying ground.

The case study presented in this paper highlights a very important feature which can be generalized for all rocks of similar nature. Reference [5] presented a comparison between four types of rocks including phyllite, schist, gneiss, and marble.

6. CONCLUSIONS

Like all other foliated rocks, the schist formation can be of serious stability problems and can endanger construction if not investigated for its orientation and physical properties. The geotechnical properties required for stability analysis shall be based on test results or measurements obtained from the site. The direction of joints and nature of the rock as reported on site must be carefully mapped and reflected in engineering drawings.

The national and international building codes of practice shall clearly indicate the importance of geologic mapping when foliated or non-homogeneous weak rock formation is encountered.

The presented case study is very useful for design and construction engineers and can be of help when structures need to be supported on an anisotropic and foliated rock. The slope stability needs to be carefully investigated.

Relocation of the structure is one choice when the proposed building is placed on a non-stable side of schist formation.

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