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Geological and geotechnical characterization of the Guadalupe Tuff Formation for the proposed Metro Manila Subway

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ABSTRACT

The Philippines will soon have its first ever underground rapid transit line. In order to proceed with a safe and cost-effective design, the complicated geologic and geotechnical conditions along the subway alignment must be well-understood. The subsurface condition of the proposed subway alignment is generally characterized by the Pleistocene Guadalupe Formation, known as the Guadalupe Tuff Formation. This paper discusses in detail this formation in terms of its geologic and geotechnical properties. Results of a reasonably comprehensive preliminary investigation and testing consisting of borehole drilling, permeability testing, borehole scanning, seismic velocity logging and ultrasonic pulse velocity testing, as well as compression tests on intact rock cores are discussed.

Keywords: Guadalupe Tuff Formation

1 INTRODUCTION

The Philippines is currently experiencing a stable economic growth, coupled with steady increase in population. Even as several transport infrastructures such as light rail transit system, national roads, and expressways are currently being developed, they remain insufficient in addressing traffic congestion in Metro Manila, the Philippines National Capital Region. In this context, the first ever underground rapid transit line in the Philippines, known as the Metro Manila Subway, was approved by the Philippine government for study and design, and subsequent construction.

The ~28 km subway will run in the heart of Metro Manila, traversing five (5) major cities namely: Quezon City, Pasig City, Makati City, Taguig City, and Pasay City. There are 13 proposed stations.

2 GEOLOGY AND SEISMICITY

2.1 Regional geology

The subsurface condition of the proposed subway alignment is generally characterized by the Pleistocene Guadalupe Formation, known as the Guadalupe Tuff Formation. This consists of the lower member Alat Conglomerate and upper member Diliman Tuff. The Alat Conglomerate is a group of massive poorly sorted round pebbles and small boulders conglomerate and sandstone with medium to thin bedded mudstone or shale, while the Diliman Tuff is a volcanic ejecta with some amount of tuffaceous sandstone, tuffaceous siltstone, and shale.

This formation, locally referred to as “adobe”, stretches from Quezon City in the north and extends to the Province of Cavite in the south.

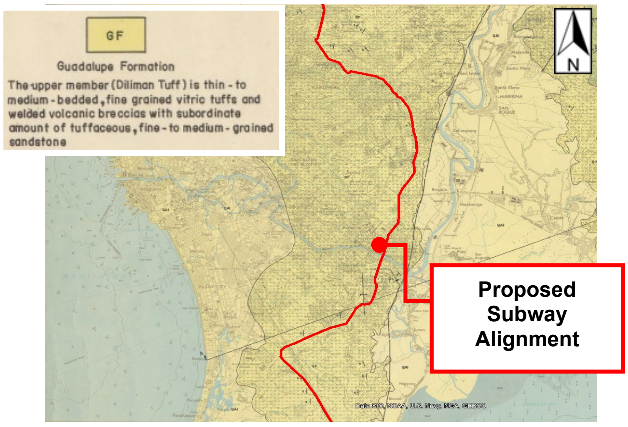

Fig. 1. Extract from the geological map of Manila and Quezon City quadrangle (Mines and Geosciences Bureau)

2.2 Tectonic setting

The Philippine Mobile Belt corresponds to the complex boundary between the Eurasian Plate and the Philippine Sea Plate. The Philippine Mobile Belt refers to the portion of the Philippine archipelago bounded to the west by the Manila-Negros-Cotabato-Sulu Trenches and to the east by the East Luzon Trough-Philippine Trench. The active 1200 km long Philippine Fault, as well as many other active seismic sources found within the Philippines, is a physical manifestation of the surrounding tectonic plates’ opposing movements.

The West Valley Fault System (WVF) is the nearest active fault to the subway alignment. It extends from the southern Sierra Madre to Tagaytay over a distance of 110 kilometers. It is a Type A fault that is capable of producing a magnitude 7.2 earthquake.

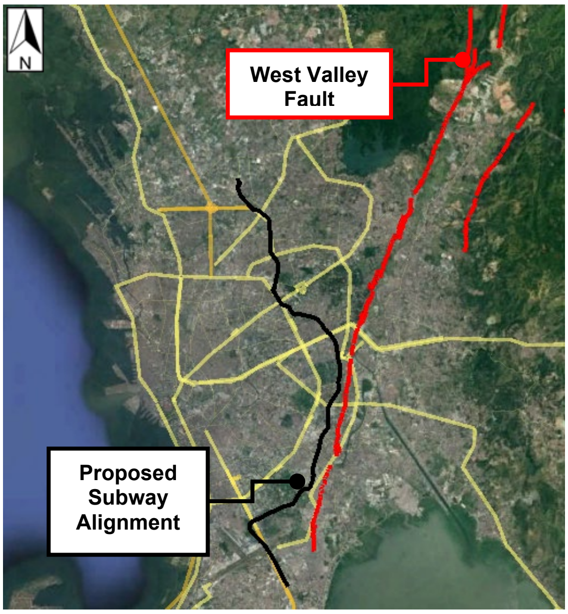

Fig. 2. West Valley Fault

3 GEOTECHNICAL INVESTIGATION PROGRAM

3.1 Drilling procedure (Field)

Wash boring procedures and standard penetration test are employed in order to advance the drill hole and to obtain the penetration resistance profile of the underlying soil.

3.2 Permeability testing (Field)

Permeability testing gives information regarding the aquifer properties surrounding a borehole, as well as the influence of overlying strata. Three methods have been recognized to be feasible in conducting single borehole permeability tests – a) Recovery Method (Bailer Test) which is used when the groundwater table in a borehole is shallow; b) Injection Method which is used when the groundwater table in a borehole is relatively deep compared to the test section; and c) Packer Test (Lugeon Test) which is performed to determine the effective transmissivity of the zone.

3.3 Borehole scanning (Field)

In designing underground tunnels, it is necessary to grasp the hardness of the surrounding rock and the distribution tendency of cracks. Borehole Scanning is carried out using either Optical Borehole Televiewer (OTV) or Acoustic Borehole Televiewer (ATV). These methods are selected to clarify the surrounding geotechnical structure and the distribution of open cracks, as well as the tendency of the cracks to propagate.

3.4 Downhole seismic survey (Field)

Downhole Seismic Survey is the most common method for obtaining in-situ compression wave (P-wave) and shear wave (S-wave) velocities (V_P and V_S, respectively). P-waves and S-waves are seismic body waves that travel at different speeds depending on the media they are propagating through. P-waves are able to propagate through solids and fluids, while S-waves can only propagate through solids.

3.5 Unconfined compression test (Laboratory)

The in-situ properties of rock core samples are largely affected by joints, faults, inhomogeneity, weakness planes, and other factors. In order to make a more accurate representation of these in-situ properties, it is important to conduct unconfined compression test on intact rock core specimens.

3.6 Ultrasonic pulse velocity test (Laboratory)

In order to obtain a better understanding of the hardness and strength of the surrounding rock, it is necessary to determine the Natural Ground Strength Ratio (S) of rock, which is the ratio of the seismic velocity of the rock mass to the sonic velocity of the intact rock core samples. For this reason, Ultrasonic Pulse Velocity (UPV) tests are conducted on rock core samples. With this parameter, designers can evaluate how the rock mass will behave as a whole while only relying on core samples.

4 RESULTS OF FIELD AND LABORATORY TESTING

4.1 Unconfined compression test results

The UCT results for most of the samples fall within the range of 1 MPa to 13 MPa. Outliers were also observed, such as those with very low UCS (<1 MPa), indicating the presence of semi-fractured or soil-like rock samples, and those with above-average UCS (>13 MPa) which may suggest scattered hard rock deposits. Based on the UCT results, it can be concluded that rock mass surrounding the proposed tunnel can be classified as soft rock. As such, it is expected that a number of intact rock core samples might exhibit some form of elastic-plastic behavior. This behavior is characterized by gentle-to-horizontal slope outside of the linear elastic region, like as shown in the right image of Figure 3.

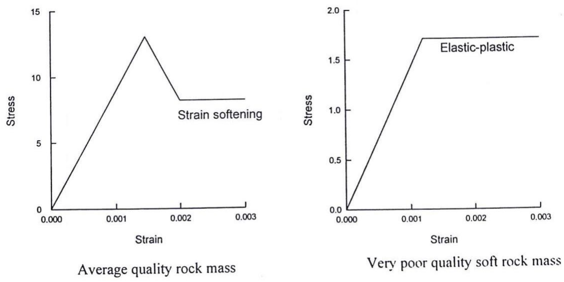

Fig. 3. Sample stress-strain curves of rocks (Hoek, E., 2007)

The trend of the UCS versus the static modulus of elasticity (E_S) generally follows the expected behavior of rocks, that is, as the UCS increases, so does the static modulus of elasticity, as shown in Figure 4.

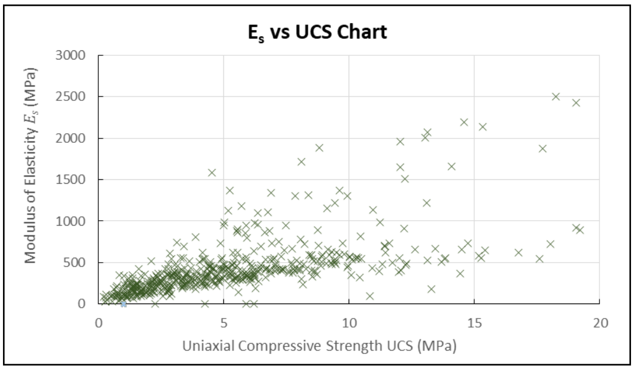

Fig. 4. Static modulus of elasticity vs UCS chart

4.2 Permeability test results

In accordance with Japan Geotechnical Society (JGS) 1314, the straight line method was used to determine the hydraulic conductivity of the test sections. The differential, s = |h0 – h|, between the equilibrium water level (h_0) and the water level in the measurement pipe (h) is plotted on the logarithmic scale (vertical axis) of a semi-log graph, versus the time (t) on the arithmetic scale (horizontal axis). A sample plot is shown in the following figure.

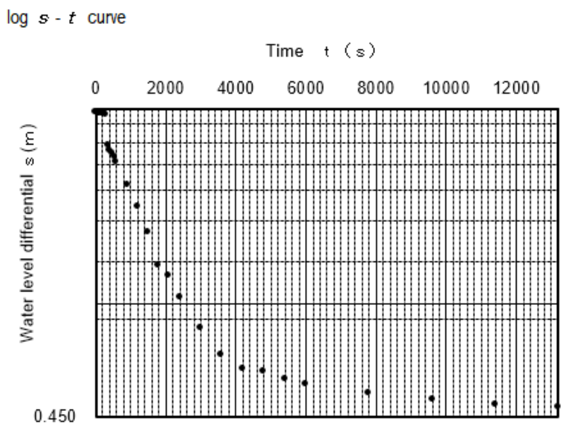

Fig. 5. Sample log s-t curve

Based on the results, the computed hydraulic conductivity values range from 2.45E-09 to 3.62E-05 m/s. These values are consistent with the range of permeability values for tuff, shale, and sandstone presented by D.J Allen et.al. in his paper "The physical properties of major aquifers in England and Wales" in 1997.

- Sandstone - 5 x 10^{-5} to 2 x 10^{1}
- Shale - 5 x 10^{-8} to 10^{-4}

4.3 Borehole scanning results

Based on the scanning results, the most prominent discontinuity set is the bedding. In rock masses, it is the geometry of these discontinuity sets, as defined by the strike and dip, that control the modes of failure in a tunnel – the most common modes of failure being wedge failure, planar failure, and toppling failure.

4.4 Ultrasonic pulse velocity test results

A total of 385 core samples, were tested for UPV with values of V_P ranging from 1045 to 4221 m/s (with an average value of 2275 m/s). Statistically speaking, the mean plus-or-minus the standard deviation (bandwidth) is 2275 ± 565 m/s, with the majority falling within the range 2245 to 2545 m/s. Out of the 385 tested samples, 64 of them fall below the lower limit of the said bandwidth and 24 of them fall above the upper limit. These values are indicative of rocks that can be classified as mainly sandstone or shales, which characterize the very composition of the tuff formation. Samples with slow propagation velocities (< 1500 m/s) are indicative of high shale composition, high porosity, high water content, unexposed change in material (layer of non-homogeneity), or some combination of these characteristics. Samples with faster propagation velocities are indicative of sandstone. Velocities that exceed 3000 m/s are generally intact, homogenous samples.

4.5 Downhole seismic survey results

From the results of the geophysical tests, in-situ V_P range from 338 to 2299 m/s while the average V_{S30} of all boreholes tested are along the borderline between S_C and S_B soil types of the National Structural Code of the Philippines (NSCP 2015). This is also consistent with the generalized Metro Manila V_{S30} site model, as published by Philippine Institute of Volcanology and Seismology (PHIVOLCS). Furthermore, the overall average V_{S30} for the project area is around 784 m/s, which just barely falls under soil profile type S_B (rock). This suggests that the project area is generally underlain by soft rock, which is also consistent with the UCT results.

Table 1. Soil profile classification (NSCP 2015)

Soil Profile Type	Soil Profile Name / Generic Description	Average Soil Properties for Top 30 m of Soil Profile		
		V_{S30} (m/s)	SPT, N-Value	Su (kPa)
SA	Hard Rock	> 1500		
SB	Rock	760 to 1500		
SC	Very Dense Soil / Soft Rock	360 to 760	> 50	> 100
SD	Stiff Soil Profile	180 to 360	15 to 50	50 to 100
SE	Soft Soil Profile	< 180	< 15	< 50
SF	Soil Requiring Site-Specific Evaluation			

Table 2. Average shear wave velocity for top 30 m of subsurface

Borehole No.	V_{S30} (m/s)	Soil Profile Type
IS-06	769	*SB*
IS-10	754	*SC*

IS-36	794	*SB*
IS-37	819	*SB*
Overall	784	S_B

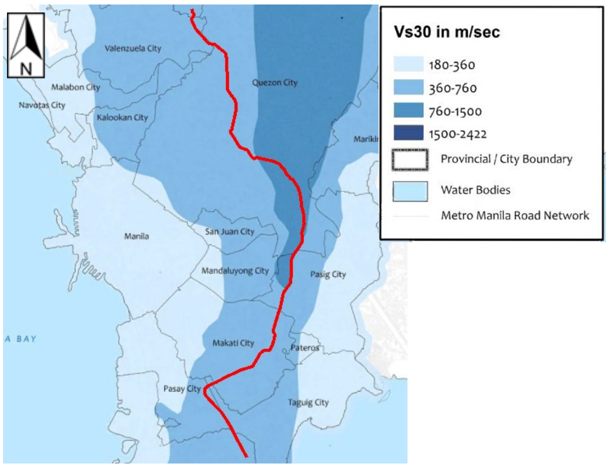

Fig. 6. Metro Manila V_{S30} site model (PHIVOLCS PEM 2017)

5 GEOTECHNICAL DESIGN CONSIDERATION

5.1 Foundation type

A foundation system composed of a thickened slab which serves as a mat foundation may be used for the subway stations. Figure 7 presents the allowable bearing capacities for Guadalupe Tuff considering varying widths and depths of mat foundation. These values may be increased by one-third (1/3) for analysis considering transient loads such as wind or earthquake.

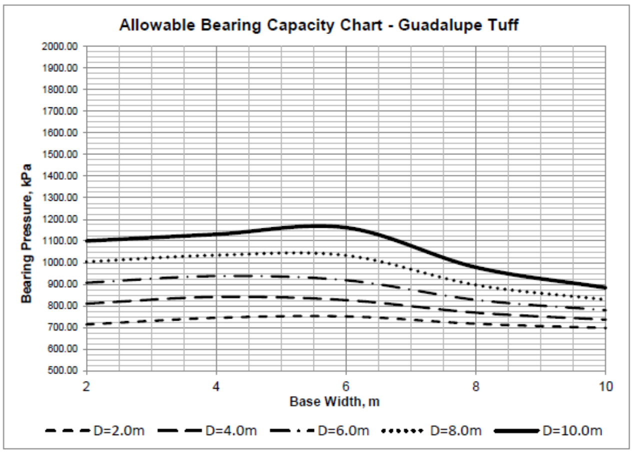

Fig. 7. Allowable bearing capacity of Guadalupe Tuff

5.2 Settlement

Guadalupe Tuff is generally well-consolidated and well-cemented. Considering the results of the unconfined compression test, it can be seen that the strength of the rock samples is within 1 MPa to 13 MPa, therefore settlement is significantly diminished.

5.3 Liquefaction

Except for a small portion in Taguig City, the site subsoil predominantly consists of medium dense to dense sand and medium stiff to very stiff clay underlain by Guadalupe Tuff Formation, which is known to be not liquefiable. Considering the subsurface conditions and the relatively deep groundwater level, the survey area is deemed not susceptible to liquefaction.

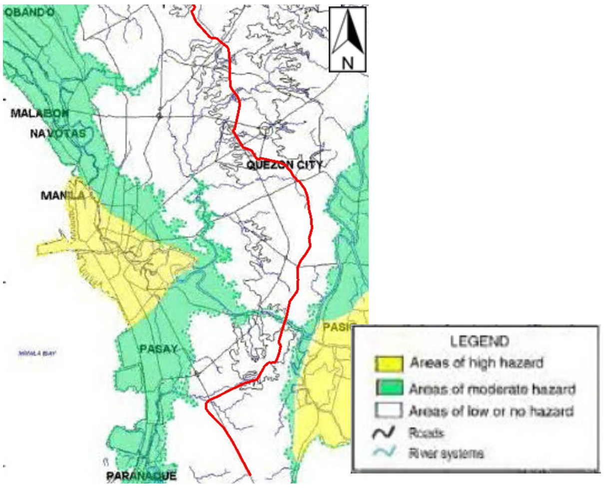

Fig. 8. Liquefaction hazard map of Metro Manila

5.4 Excavation Stabilization and Protection

It is recommended that the station excavations be monitored for the possible presence of fracture sets that are parallel or highly oblique to the excavation faces (based on borehole scanning results). These can lead to toppling failure. If present, this can be addressed by soil nailing and shotcrete. Otherwise, Guadalupe Tuff can be excavated vertically.

6 CONCLUSION

The complicated geologic and geotechnical conditions of the underlying formation along the subway alignment must be well-understood to be able to come up with a safe and cost-effective design of the subway. The results of the preliminary geotechnical investigation reveal that Guadalupe Tuff Formation is considered a suitable bedrock foundation for the subway project. A major consideration during the detailed engineering and construction is the proximity to the West Valley Fault.

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