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# Application of Excavation Management Theoretical Measures in Tunneling Works for MRT3 Project

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**Abstract**: Apart from maintaining the efficiency of the excavation process, the Excavation Management System should be considered to avoid over-excavation, which can lead to sinkholes or ground settling during the excavation process. There are several ways for calculating the amount of excavated material based on the measurements. These can be expressed as excavated volume, mass, or dry mass using various formulae. Measurement errors, mechanical, electrical, and hydraulic concerns, the influence of time, and changing geology are all examples of such influences. The findings in this research indicates that the used of theoretical methods in calculating outflow rates which is related resulting to over excavation laid on the behaviour of the different calculation methods, during situations such as a face collapse, calibration error of sensors, water inflows or compressed air interventions. Through this breakthrough, our country's excavation tunnelling EMS will develop in accordance with that of other industrialised countries. It also provides engineers with tools for detecting early indicators of over-excavation.

**Keywords**: EMS, Excavation Process, Volume, Mass, Over-excavation

## 1. Introduction

The infrastructure of a railway is a complex and multi-disciplinary engineering system comprising of earthworks, bridges, tunnels, steelwork, timber, and a track system that acts as the foundation of the railway. The track alignment must be within a millimetre of the design to give a smooth ride for a train. Tunnelling is one of the critical infrastructures that is frequently included in the package of a railway project in the railway sector [2]. For example, the ongoing Mass Rapid Transit Line 2 project (Putrajaya

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Line), originally the Sungai Buloh – Serdang – Putrajaya Line, is regarded to have a longer tunnel than the MRT Kajang Line, measuring 13.5 kilometres and including nine underground stations.

Aside from assuring the excavation process's effectiveness, the Excavation Management System should be considered to avoid over-excavation, which can result in sinkholes or ground settling throughout the excavation process. Furthermore, EMS employs STP in some measurements and the imposition of penalties to provide engineers with sufficient and relevant real-time data to identify potential over-excavation early and take the required steps to avoid the emergence of a sinkhole at the surface[1].

Our country's EMS for tunneling will develop in line with other developed countries if it is successful. It also provides facilities for engineers in terms of tools to identify early signs of over-excavation. In addition, this study also provides an understanding of the existence of limitations or assumptions in a system, and it leads to the existence of new methods that are more efficient.

## 2. Materials and Methods

Management System performs a comparison of measured data to the expected theoretical value. A result with a considerable deviation indicates either an error (due excavations to incorrect assumptions or instrumentation inaccuracy) or a probable over-excavation requiring immediate action. The volume accuracy is calculated by flow meters fitted along the slurry feed and discharge lines. According to previous studies and research [3], reconciliation with Excavation Volume is unsuitable since it frequently produces considerable deviations, particularly during slurry system blockage. It is always unwise to rely on a single computing method and a single set of sensors (flow-meters) for reconciliation considerations under EMS. Additionally, there are restrictions on the application of Excavated Volume for diagnosing over.

### 2.1 Fundamental Principles of Soil and Rock Composition

To comprehend the theory of Excavation management systems, one must first comprehend the fundamental soil structure, which is consisting of solid particles, water, and air [1]. The schematic phase diagram of the soil and rock composition by mass and volume is shown in Figure 1 below.

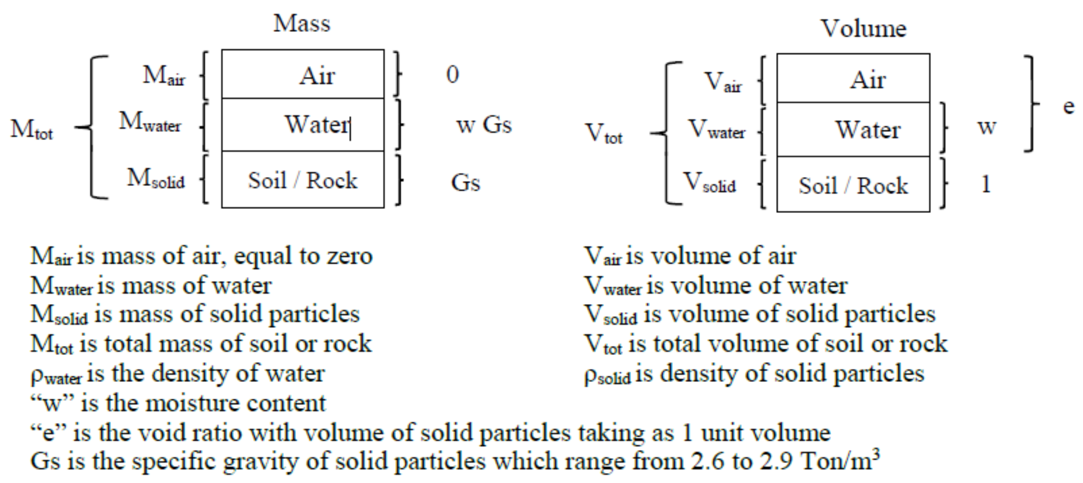


**Figure 1: Fundamental Principles of Soil and Rock Composition (Singapore Land Transport Authority, 2018)**

### 2.2 Equations

#### 2.2.1 Theoretical Dry Volume and Dry Mass

The dry mass formula is based on equivalency of masses:

$$M_{total} = M_{solid} + M_{water} \qquad Eq.\ 1$$

It also can be expressed as:

$$V_{tot}\rho_{in-situ} = V_{solid}\rho_{solid} + V_{water}\rho_{water} \qquad Eq.\ 2$$

Water's volume can be expressed as:

$$V_{water} = V_{tot} - V_{solid} - V_{air} \qquad Eq.\ 3$$

Since the volume of air in thoroughly saturated soil is equal to zero, the following is true:

$$V_{water} = V_{tot} - V_{solid} \qquad Eq.\ 4$$

Then substitute it into (Eq. 2)

$$V_{tot}\rho_{in-situ} = V_{solid}\rho_{solid} + V_{water}\rho_{water} \qquad Eq.\ 5$$

$$V_{tot}\rho_{in-situ} = V_{solid}\rho_{solid} + (V_{tot} - V_{solid})\rho_{water}$$

$$V_{tot}\rho_{in-situ} = V_{solid}\rho_{solid} + V_{tot}\rho_{water} - V_{solid}\rho_{water}$$

$$V_{tot}\rho_{in-situ} - V_{tot}\rho_{water} = V_{solid}\rho_{solid} - V_{solid}\rho_{water}$$

$$V_{tot}(\rho_{in-situ} - \rho_{water}) = V_{solid}(\rho_{solid} - \rho_{water}) \qquad Eq.\ 6$$

Because the volume of solids is equal to the dry volume, the formula can be stated as follows:

$$V_{dry} = V_{tot}\frac{\rho_{in-situ} - \rho_{water}}{\rho_{solid} - \rho_{water}} \qquad Eq.7$$

Using Eq. 8, the dry soil mass can be then calculated as:

$$M_{dry} = \left(V_{tot}\frac{\rho_{in-situ} - \rho_{water}}{\rho_{solid} - \rho_{water}}\right)\rho_{solid} \qquad Eq.\ 8$$

Using the Bulk Density from site inspection reports, which reflects actual conditions such as the existence of air spaces or unsaturated soil, the in-situ density in formulas (Equation 9) and (Equation 10) may result in approximations, as detailed further in this work [1]. To apply formulas (Equation 7) and (Equation 10), a "calculated" in-situ density is required, consistent with the assumption of totally saturated soil (Equation 10). The in-situ density can be computed using the formula:

$$V_{tot}\ (\rho_{insitu} - \rho_{water}) = V_{solid}\ (\ \rho_{solid} - \rho_{water}) \qquad Eq.\ 9$$

So basically, the formula stated above assumes of fully saturated soil, utilizing the bulk density ($\rho$bulk) acquired directly from soil study would result in an estimate of theoretical dry mass.

Formula for the determination of approximated value of Dry Mass:

$$M_{drysoil} = (V_{tot}\frac{\rho_{bulk} - \rho_{water}}{\rho_{solid} - \rho_{water}})\rho_{solid} \qquad Eq.\ 10$$

As a result, this equation should not be utilized with soils that contain a high amount of air, as this will significantly affect the result.

2.2.2 Calculation of Theoretical Dry Volume Using Dry Density

A simple way to calculate the theoretical dry soil mass is using the dry density with following formula the theoretical dry soil mass is straightforward when using the following formula:

$$M_{drysoil} = V_{tot}\rho_{dry} \qquad Eq.\ 11$$

The density can obtain from the SI data or calculated using the dry density with following expression:

$$\rho_{dry} = \frac{\rho_{bulk}}{1+w} \qquad Eq.\ 12$$

$$\text{Porosity (n)} = 1 - \frac{\rho_{dry}}{\rho_{solid}} \qquad Eq.\ 13$$

$$V_{dry} = V_{tot}(1-n) = V_{tot}\ \frac{(100-n)}{100} \qquad Eq.\ 14$$

## 3. Results and Discussion

### 3.1 Results

a. Method 1: Calculation of Theoretical Dry Mass for Fully Saturated Soil

An approximation of the Dry Mass can be determined:

$$M_{dry\ soil} = V_{tot}\frac{(\rho\text{bulk} - \rho\text{water})}{(\rho\text{solid} - \rho\text{water})}\ \rho_{solid}$$

From the Eq. 7, total volume can be calculated as:

$$V_{tot} = V_{water} + V_{solid}$$

For example, based on the Table 3.1 the highest volume of water ($V_{water}$) recorded is 16.646 L while the volume of solid excavated is 41.7857 T

$V_{tot}$ = 0.01635 +41.7857
= 41.802 T

By assuming the value of solid density between $2.65 g\ cm^{-3}$ and density of water compliance with standard and real-time data, the final bulk density from the SI data of borehole stated the value is 2.012 while the density of water injected for temperature not exceed 28 degrees is 0.99669 gram/cm$^3$.

$$M_{dry\ soil} = 41.802\ \frac{(2.012 - 0.9969)}{(2.65 - 0.9969)}(2.65)$$
= 68.0225 T

b. Method 2: Calculation of Theoretical Dry Volume Using Dry Density

A simple way to calculate the theoretical dry soil mass is using the dry density with equation:
$M_{dry\ soil} = V_{tot}\ \rho_{dry}$

The dry density can be obtained directly from SI data.

Total Volume can refer to Method 1.

$$M_{dry\ soil} = (41.802)(1.569)$$
$$= 65.587\ T$$

### 3.2 Discussions

The dry mass formulas utilizing in situ density are first shown to produce results that are too different from the theoretical target values and should therefore be disregarded. Our initial belief that the dry mass formulas employing fixed water density and generalized particle density are quite accurate is confirmed when comparing the theoretical dry mass with the remaining dry mass formulas. They deviate from the target line just enough to be feasibly applied without sacrificing accuracy. A precise solution is also obtained using the solids material volume formula [3]. However, it is practically challenging to quantify the solids volume of a sample of excavated material.

Based on the observation on between the two methods, both have its own use and helpful in calculating dry mass and dry volume to early detect the over-excavation that will occur in excavation works. Method 1 calculated based on assumption fully saturated soil and not taken from the Soil Investigation (SI) then Method 2 considering air void which use formula involving porosity [4].

In most circumstances, using dry mass or dry volume measures over volume- or mass-based measurements is preferable, but there are certain drawbacks, according to a comparison of the various methodologies now used. The best method for managing excavations is therefore thought to be a combination of volume and dry mass or volume and dry volume.

## 4. Conclusion

The purpose of this study was to demonstrate the theory behind the Excavation Management System (EMS) through a variety of methods. Few method lists employ dry mass, and the dry volume formula detects over-excavation or any imperfection in the system too early when only one technique of reconciliation is used in EMS. The dry volume formula is technically good but difficult to compare to a reference value, hence the simplified dry mass formula is often the most suggested calculation approach. This research also highlights the usage of different theoretical approaches to the Excavation Management System, which represents methods and formulas being used in another country indirectly will provide references for future tunneling in Malaysia Tunneling System. Nonetheless, it is essential to understand each system that influences engineering assumption and interpretation to come out with a different solution to each problem**.** The control of over-excavation is essential for the project's safety, and this systematic method to excavation management is a proactive and preventive strategy particularly suitable to tunneling in urban settings [5].

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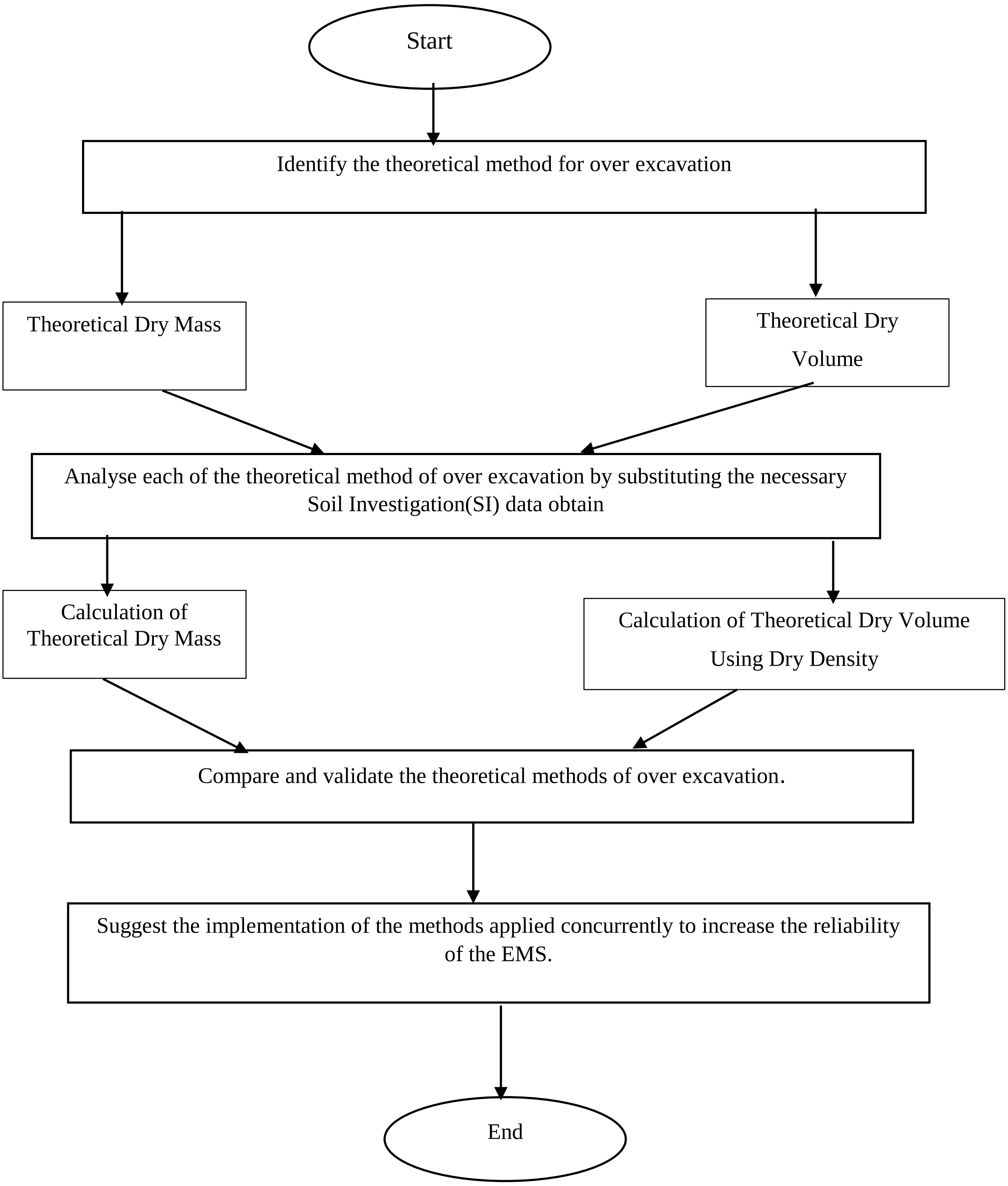
## Appendix A

### Flow Chart of Methodology



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