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Foundation and Basement Construction of SG-Lotte

PF2107 - Construction Technology

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Tutorial 4 Group 2

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EXECUTIVE SUMMARY

As PFM Pte Ltd ("PFM"), we are one of the subcontractors engaged by Singsong Construction Pte Ltd, the main contractor of the SG-Lotte Project, which has been successfully won by SingLand Development Limited ("SDL"). Being within the first reserve of the railway protection zone, extra emphasis should be placed on the building's foundation and deep basement comprising of 4 levels. With our 2 decades of experience in the industry and our specialization in the construction the substructure, we have been contracted to focus on the foundation and basement of the building project to ensure that design plans are carried out according in an efficient and accurate while upholding high standards of safety management procedures during the project.

Through this report, we aim to provide a method statement detailing the construction of foundation system and basement of the SG-Lotte Building. In addition, we seek to address the difficulties that arise with constructing the foundation and basement systems in the Kallang Formation while taking the external environmental factors such as site, time, and existing infrastructure constraints into consideration. The key risks are identified first prior to start of foundation and basement designs. This ensures that the design and construction of foundation and basement meets and seeks to exceed the criteria that is required to be fulfilled in the guidelines set out under the various regulations such as WSH (Construction). Afterwards, an in-depth review is carried out to determine the foundation and basement design chosen and the method statement demonstrating how the construction of the two systems will proceed. Type of support used for excavation, technique of excavation, method of controlling groundwater and soil movement monitoring will be subsequently detailed. In latter sections, supporting arguments and justifications will be made with regards to the choices made. Relevant safety measures that must be observed throughout the construction process and the relevant legislation that our company should adhere to will be elaborated with reference to the current laws and regulations found in Singapore. Extra attention will be placed on the care that is required since the building project is situated near the underground MRT tunnel and on the associated details that need to be adhered. Lastly, we conclude with focusing on the technologies used during the construction and new innovative technologies that could be adopted to improve safety, time, cost and manpower efficiency.

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1.0 INTRODUCTION

1.1 BACKGROUND

SingLand Development Limited ("SDL"), a local developer, has won a land tender in Singapore for the development of a mixed-use building, namely "SG-Lotte", comprising a residential and commercial space. SDL and Land Transport Authority (LTA) have jointly engaged a main contractor, Singsong Construction Pte Ltd ("Singsong"), for the project construction and a new underground mass rapid transit (MRT) station. An underground MRT tunnel has already been built beneath the site. As seen in the figure below, site constraints are present due to the space and surrounding buildings. In addition, the project is time critical because of the requirements from developer and LTA.

SG-Lotte, a rectangular-shaped building, will be 250m in height with 35 floors and a 20m deep 4-level basement. The proposed design of the building comprises a retail space occupying the first 5 levels and all 4 levels of basement, while the rest of the floors above would comprise 500 residential units.



Figure 1.1: Site of SG-Lotte Building

Project Name: SG-Lotte Building

Location: Downtown Core, plot of land beside Marina One

Developer: SinLand Development Limited ("SDL")

Main Contractor: Singsong Construction Pte Ltd ("Singsong")

Project Start Date: January 2020

Projected date of completion: January 2025

Soil Formation: Kallang Formation

Singsong is highly regarded as one of the leading players in the construction industry due to the advanced construction technologies they had used and high safety standards, evidently from their excellent track record of having zero incidents in the past 10 years.

PFM Pte Ltd ("PFM") is one of the subcontractors engaged by Singsong and responsible for the construction of the substructure. For the substructure, PFM will be undertaking the construction of the foundation system and basement construction. In addition, during the Desk study stage, Singsong is particularly concerned about the excavation process. This is due to the past number of incidents which had happened in Singapore and around the world. Hence, PFM was engaged for its good reputation.

PFM Pte Ltd, established in year 1999, is a construction firm in Singapore with over 2 decades of experience in the industry. We offer a wide range of construction services, led by a team of highly experienced professionals. Our company strives to be the preferred Geotechnical specialist subcontractor bringing innovative and efficient solutions to the Singapore market. Therefore, we were engaged to construct the substructure and uphold high standards of safety management procedures during the project.

1.2 The Significance of Foundation system & Basement Construction

Foundation systems and basement constructions are the fundamentals of every building structure. To begin with the foundation system, it is important to consider the various factors such as soil conditions, load transfer patterns, shape and size of the building, site constraints and underground tunnel, during the selection of foundation systems for your building. In any case where the designed foundation system is inaccurate, it would result in devasting consequences affecting stakeholders or structural collapse, being the most extreme.

The provision of a basement will allow the building to have more usable space. However, basement construction can be challenging as the depth will go over 4.5 meters beneath ground level. Thus, it is important for sufficient considerations when doing excavation as it will affect soil movement which could result in ground subsidence, landslide, and toppling.

Safety is of utmost importance when it comes to construction and the understanding of challenges faced during foundation and basement construction are our priority. Our moral obligations are towards all stakeholders, and we aim to identify and prevent potential safety challenges during the excavation phase. By upholding high safety standards, we can prevent any direct costs such as unforeseen damages to neighbouring infrastructure, workers' accidents and hospitalisation. In addition, to prevent any indirect costs due to loss of reputation, negative publicity, and delay in work progression.

1.3 Key Objectives

This report aims to develop an innovative and efficient construction method to tackle the challenges faced, taking into consideration key factors affecting the construction of the foundation system and

basement. In addition, safety challenges, faced during the abovementioned construction phase, will be analysed, and assessed. This includes the construction during:

- Foundation Systems: Caissons
- Basement Construction
- Underground MRT tunnels

Once the challenges have been identified, current measures will be evaluated and recommendations will be made, in consideration of any potential long-term or short-term cost.

1.4 METHODOLOGY

This report will examine the data from site investigations and propose the most suitable construction method and technology for both foundation system and basement construction. Additionally, this report will study governing statutes and safety requirements during this construction phase, to ensure that safety standards will be met.

1.5 POTENTIAL DELIVERABLES

This report will serve as a method statement detailing the construction of foundation system and basement construction for SG-Lotte Building, which includes a list of safety guidelines, technologies used and risk assessment.

2.0 KEY LEARNING POINTS FROM PAST EXPERIENCES

2.1 UNDERSTANDING KEY RISKS FOR PFM PTE LTD

No.	Key Risks	Description & Mitigation Measures
1	**Design Risk**	**Factor of Safety (FOS) & Limit State Design (LSD)** Work closely with project's architect and structural engineer on adopting a Failsafe Design for the foundation and basement retaining walls. One approach is to implement FOS into the design, $FOS = \frac{load\ to\ cause\ failure}{actual\ load\ on\ structure}$. The other approach is to use LSD as defined in Eurocode to determine the ultimate load that will cause the structure to fail and design a structural system by factoring in the safety factors of material strength, permanent and variable loads (Goh, 2020). **Design for safety (Dfs)** Under the Workplace Safety & Health (WSH) Dfs regulations published in 2015, PFM Pte Ltd should work closely with main contractor and design team to identify and mitigate any safety and health risk of the project during the design stage in the conceptual and planning phase (design review process). Certain risks that cannot be mitigated should be communicated to the stakeholders of the project. Risks identified and design mitigation measures would then have to be properly documented in the Dfs register and also to keep it updated and communicate it (Chew, 2018; WSH, 2016).

No.	Key Risks	Description & Mitigation Measures
2	**Construction Risk**	**Thoroughness of site investigation** To reduce the risk of completion delay and cost overruns, a thorough site investigation using deep boreholes and laboratory testing of soils is a basic requirement for this project. Insufficiency of site investigate would have a detrimental effect on the construction of foundation, basement retaining walls and most importantly, during excavation (Chew, 2018). It is also important to consider the adjacent buildings and ensure that proper study and control is in place to take into account the potential ground movement during excavation. **Understanding of Soil Characteristics** Apart from a thorough site investigation, it is essential to have an in-depth understanding of soil characteristics in order to choose the most appropriate foundation system. Foundation system is the key to a building's structural integrity where various structural loads are transfer from the building into the foundation system and into the ground, thus it has to be strong enough to resist these loads (Chew, 2018). **Workmanship Risks** Some workmanship risk that could be faced by PFM Pte Ltd are poor concrete compaction, incorrect water to cement ratio and incorrect process of concrete works. These would result in cracks forming on foundation system or diaphragm walls and steel reinforcements within may become corroded (CCL, 2020). By working with reputable subcontractors and conducting regular inspections, this issue can be mitigated.

No.	Key Risks	Description & Mitigation Measures
3	**Workers Risk**	**Language Barriers and Training Issues** According to Trajkovski and Loosemore (2006), language barrier of non-English speaking migrant workers exposes them to higher risk of health and safety incidents. This is very similar to Singapore's context where 78% of workforce in the construction are migrant workers (Phua & Chew, 2020), where majority of them are from Bangladesh, India and Myanmar (Hirschmann, 2020). It is also important to note that Safety and Equipment trainings should be conducted in the migrant worker's home language and not in English as the use of English language proves to be less effective (Trajkovski & Loosemore, 2006). **Manpower Limitations** With Singapore's foreign labour policies in the limelight, the construction industry which relies heavily on foreign workers should aim to adopt more manpower reducing technologies to reduce the risk of any project delays due to manpower crunch (Phua & Chew, 2020). Project delays due to incompletion of substructural works will likely result in liquidated damages being claimed from PFM Pte Ltd and its reputation would be damaged as well.

No.	Key Risks	Description & Mitigation Measures
4	**Completion Risk**	Apart from factors previously mentioned above, the subsequent risks discussed below affect the project/ substructure completion.

Understanding environmental factors

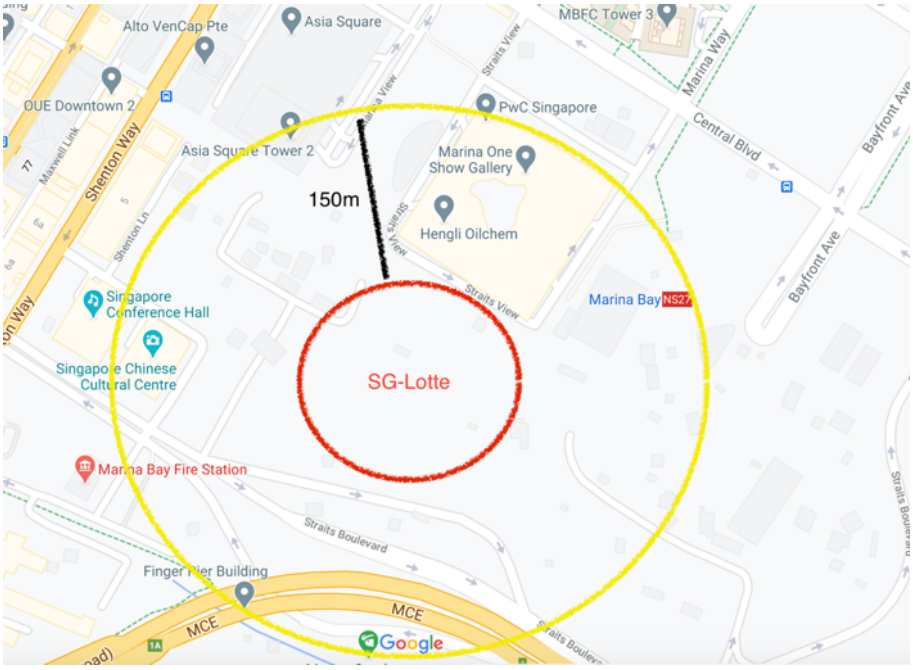


Figure 1.1a: Site map of SG-Lotte Building

Figure 2.1a above, shows existing high-rise office and residential buildings in the downtown of Singapore. This makes the construction of substructure even more challenging as noise pollution and site management have to be taken into consideration. The National Environmental Agency (NEA) regulates Construction Noise Pollution. According to NEA (2020), the maximum permissible noise level for residential buildings (less than 150m from construction site) and other buildings on Monday to Saturday, ranges from 75-90 dBA (7am to 7pm) to 55 dBA (10pm to 7am). From 2017 onwards, construction works are not allowed from Saturday 10pm to till the following Monday 7am, inclusive of Public holidays. However, works that are quieter may be performed with the approval of NEA.

Tasks/ Machinery	Average Noise (dBA)
Operating Bulldozer	100.2
Drill Motor	97.7

Table 2.1b: Examples of construction tasks and machinery.
Source: Birkner (2010)

Based on the figures above, noise pollution generated by construction tasks and machinery can easily exceed the maximum permissible noise level. Therefore, proper project schedule, site management and noise monitoring should be adopted to reduce the risks of any complaints resulting in project delay.

Design Error and Variation Order

Design errors is one of the leading factors in project delays and risk of cost overruns. When the building is improperly design, this may lead to serious issue such as where the structural strength of the building may not be sufficient, resulting in demolition of the original works or additions of structural reinforcements. It is also known as a variation order. When variation order is issue by the developer, this will naturally result in delay of project completion (Buys, 2015). However, if the design error is of no fault of PFM Pte Ltd and the variation order is issued from either the developer or main contractor, PFM Pte Ltd would not have to be liable for any liquidated damages that may arise from this delay. Nevertheless, the resources belonging to PFM Pte Ltd used for the project will stay for a longer time and would not be able to be allocated to another project.

Force Majeure

Although Singapore is one of few countries with the lowest risks of natural disaster (Black, 2011). Given the current COVID-19 situation globally, several construction companies in Singapore had been plagued by COVID-19 measures which does not enable them to complete their schedule work on time as their workers infected which resulted in manpower crunch. These companies then turned to invoking force majeure clauses in their contracts

No.	Key Risks	Description & Mitigation Measures
		to get extension of time. This is largely similar to the previously mentioned manpower limitation where newer manpower reducing technologies should be used to mitigate this risk.

No.	Key Risks	Description & Mitigation Measures
5	**Cost Risk**	Apart from the previously mentioned design error and variation order factor under completion risk, these are some keys contributing factors of Cost Risk. **Poorly defined scope and insufficiency of details** The scope of works should be clearly defined by the main contractor during the tendering process and details provided should be sufficient when preparing the Bill of Quantities (BQ) document. Since the tender has been awarded to PFM Pte Ltd, there is a risk that the scope and details are inaccurate and lack important details that might render the quantities and costs in the BQ document to be wrong. Leading to potential costs overrun. **Size and complexity of project** Given the complexity of the project, SG-Lotte Building, being above the first reserve of the railway protection zone and being surrounded by tall residential and office buildings, the construction of substructural systems will be costly and challenging. Costs will be higher due to the need for more technologically advanced construction equipment and monitoring systems to constantly monitor noise pollution, ground movements and vibrations. Costs will also be higher due to the need for more experienced team of personnel on site to manage the construction site.

No.	Key Risks	Description & Mitigation Measures
6	**Safety Risk**	Safety risk is one of the most common risk, with construction industry having one the highest incident rates (Chew, 2018). The following are the most applicable safety risks that is related to the construction of substructure elements. More details on basic safety requirements will be covered in subsequent section. **Electrocution Risk** Some common electrocution hazards that can be found at construction sites are overhead power lines, improperly maintained or unapproved extension cords and defective equipment (PLLC, 2016). Workers may come into contact with overhead power line when they are carrying ladders or other conductive materials. Improperly maintained or unapproved extension cords would be hazardous to workers around the area while defective equipment poses a fire risk too. A mitigation measure to address these risks would be for PFM Pte Ltd to comply with the legislation on *WSH (Construction) Part V Electrical Safety* and SS 650-1: 2019, Code of practice for temporary electrical installations - Part 1: Construction and building sites (Chew, 2018; SSO, 2007; SS, 2019). **Fire Safety Risk** Due to the nature of works undertaken by PFM Pte Ltd, there will be requirements for oxygen and flammable sources such as fuel and gas for the use of foundation construction and excavation. As such, WSH (General Provision) section (s) 37 mandates that reasonable practical steps should be taken in the workplace to ensure prevention of fire such as the separation of fuels sources and ignition, and there should be provision for means for fire extinguishing, led by a competent personnel, tests and drills should also be conducted (SSO, 2007). WSH (General Provision) s 38 also mandates safety provision in case of fire by having functioning effective warning devices and means of escape such as ingress and egress points (SSO, 2007). **Vehicular Incidents** Due to the nature of works that PFM Pte Ltd, would be involved in, earthmoving machinery such as Dumpers, Loaders, Backhoe, will likely be frequently used. These machineries are large and required proper training.

Due to the size of these machineries, there is also a higher risk of them hitting an object or other workers if safety measures are not properly adopted. Another common hazard involving these machineries could also be workers falling of them when entering or exiting (PLLC, 2014). WSH (Construction) s 28, vehicular hazards mandates that any machinery used in the worksite should be in good condition, operator is certified for the machinery and is instructed by supervisor to operate (SSO, 2007). In addition, supervisor should ensure that risk assessment is completed and communicated to the relevant stakeholders prior to operation of any machinery.

Lifting Operations

During the construction of foundation system and diaphragm walls, lifting operations will be present, thus it is important to address potential risk that may arise. WSH (General Provision) s 21, lifting appliances and lifting machines, and WSH (Construction) sections (ss) 134 and 135 regulates machineries used in lifting operations (SSO, 2007). Firstly, the lifting machinery has to be tested and certified at specific time intervals. Secondly, the safe working load of lifting machinery and their respective control panel and warning systems should be accurate and well-functioning. The safe working loads of lifting machinery shall not be exceeded at all times and it is the responsibility of the supervisor to enforce. In addition, operators of lifting machineries should be adequately trained and certified as specified in WSH (General Provision) s 21.

Excavation

This section is particularly important for PFM Pte Ltd as the company is responsible for the construction of foundation system and basement and excavation is the main requirement as part of the process. This section is heavily regulated by WSH (Construction) Part XI Excavation and Tunnelling Works. As a basic requirement, a professional engineer (PE) from PFM Pte Ltd is required to design adequate shoring to prevent the collapse of the excavation and the same PE or another appointed PE would have to certify that the shoring is properly constructed and is safe for usage. In addition, there should also be provisions for the following (not limited to) proper ventilation, illumination, communications, means of ingress and

No.	Key Risks	Description & Mitigation Measures
		egress, and rescue teams. This risk should be addressed during the design stage to prevent any mishaps from occurring.

2.2 NEAR MISSES & INCIDENTS

No.	Case Studies	Learning Outcomes
1.	**Temporary Earth Retaining Structure/ Excavation Failure**  *Figure 2.2a: Collapsed of adjacent road. Source: BCA (n.d. (a))* A 6-storey building with basement was proposed to be constructed and strutting for excavation works were supposed to be done in stages. However, strutting was only done for 3 sides while the 4th side had no strutting and was excavated to the depth of 4m. This process of excavation was different from what was proposed and resulted in the collapse of adjacent road pavement that also had construction materials placed on them (BCA, n.d. (a)).	The relevant legislation governing this mishap is WSH (Construction) Part XI Excavation and Tunnelling Works. 1. The method statement of the excavation works must be closely followed and any deviations from them must be checked and approved by the Professional Engineer (PE) that had designed it. The relevant legislation is WSH (Construction) Part XI (BCA, n.d. (a)). 2. Any additional loading such as machinery, materials etc should be adequately designed, or else they should not be placed near the excavation site (BCA, n.d. (a)). 3. Site Supervisor and Qualified Person should be proactive in looking out for any deviations and non-compliance with the method statement, and BCA should be notified if such a failure is to occur (BCA, n.d. (a)).

No.	Case Studies	Learning Outcomes
2.	**Improper use of Bored Pile Foundation for a 10-storey Building**  *Figure 2.2b: Insufficient length of bored piles. Source: BCA (n.d. (b))* The foundation designed for 2 blocks of 10-storey residential building with basement and soil investigation results from 3 boreholes showed that the bored piles foundation needed to have a penetration depth of 9 to 10 meters. An investigation into the foundation system took placed and revealed that the actual bored piles were of insufficient depth and the shorter piles were of poor concrete quality. It was also reviewed that the presence of granite was not taken into consideration in the foundation design (BCA, n.d. (b)).	1. A thorough soil investigation should be carried out and if necessary, use more boreholes to obtain more accurate data. The data obtained should also be closely studied so that the most appropriate design can be chosen (BCA, n.d. (b)). 2. Short piles should be socketed firmly into shallow hard stratum and particularly for inclined hard stratum (BCA, n.d. (b)).

3. **Case study of Extension to the current St. John's St. Margaret's Church located at Dover Crescent (Project Spring-Winter)**

The soil investigation comprised 4 boreholes and the soil were classified as Jurong Formation. In this case study, deep foundation was required, and bored piles were chosen as the foundation system.

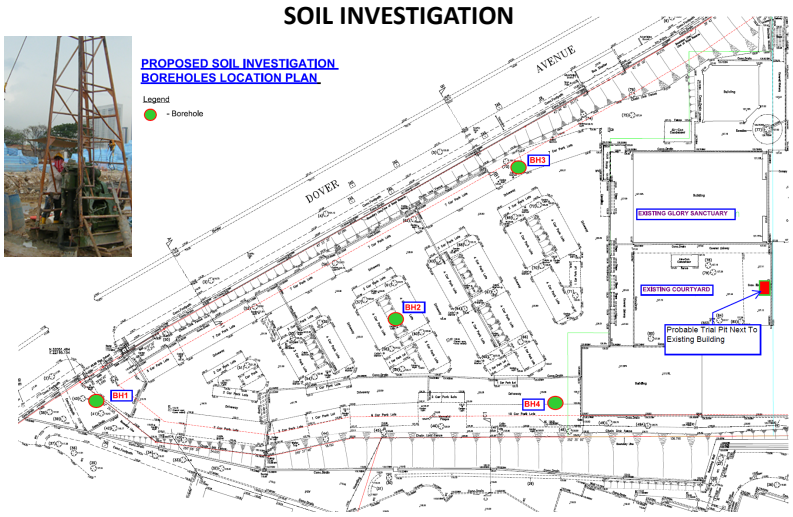


Figure 2.2c: Soil Investigation with 4 boreholes. Source: Wong (2020)

There were provision of ground monitoring equipment used in this project and they were Ground Settlement Markers, Building Settlement Markers, Tiltmeter, Vibration Meters, Inclinometers, Water Standpipe and Piezometer.

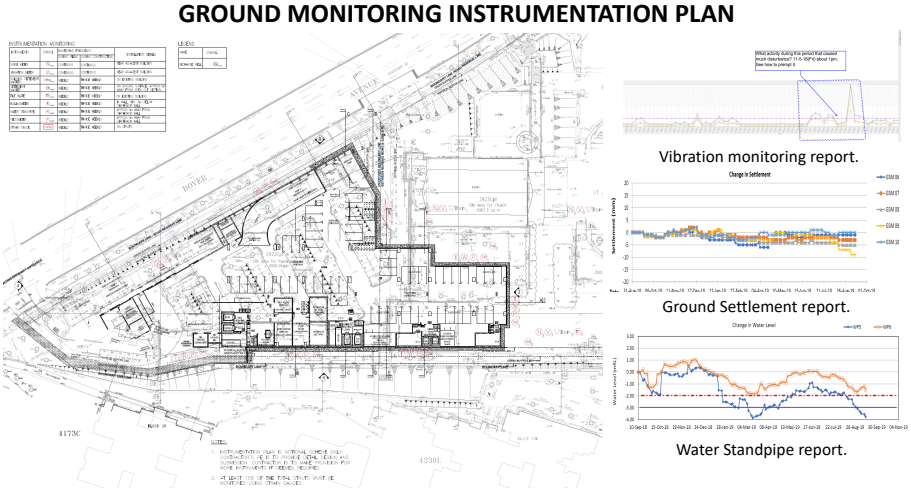


Figure 2.2d: Various monitoring reports generated for Ground Movement. Source:

A top-down method of construction of adopted for this project and it is detailed in figure 2.2e below.

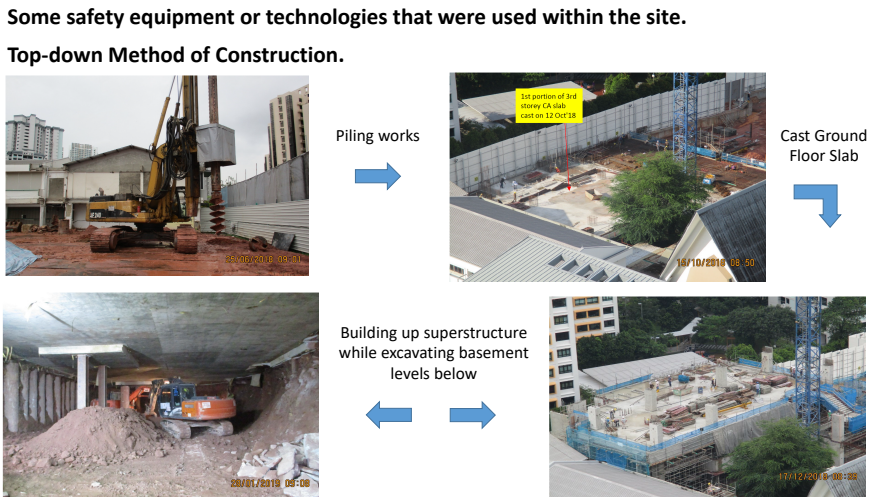


Figure 2.2e: Use of top-down method of construction. Source: Wong (2020)

Wong (2020), suggests the possibility of replacing concrete blocks used in pile static load test with steel plates. This is because using concrete blocks requires more preparation and groundwork while steel plates is 3 times smaller in volume. However, the downside of using steel plates is that the cost is higher or required loaning it from a source while concrete blocks are easily available at zero cost.



Figure 2.2f: Comparison of concrete blocks and steel plates for pile static load testing. Source: Wong (2020)

3.0 FOUNDATION SYSTEMS

The function of a foundation system is to primarily transfer the structural loads such as dead, superimposed and wind loads from a building safely into the ground. To ensure we attain a suitable foundation system for the building, there are several factors to be considered.

3.1 SELECTION CRITERIA OF FOUNDATIONS

Prior to the selection of foundation system, there are certain criteria to be considered and discussed. The following points would elaborate the factors that are to be considered in relation to project *SG-Lotte*.

3.1.1 SOIL INVESTIGATION

Other than the foundation design, the stability of the building relies upon the behaviour and characteristics of the soil under the loads. There are different types of soils with different properties sorted by the size of the particles. In Singapore, there are as many as 10 soil formations. For the purpose of this report, we will be focusing on the Kallang Formation, as required by the scope of the project.

3.1.1.1 Kallang Formation

The Kallang Formation comprises of marine clay, fluvial clay and estuarine with thickness up to 8m. The cohesive strength of the marine clay is low, and the in-situ moisture content is very close to the water limit, with moisture content estimated around 80%-100% depending on the depth (Chew, 2018). More often than not, it is combined with a mean shear strength of $10kN/mm^2$ and $40kN/mm^2$ for the upper and lower marine member respectively (Chew, 2018).

	SOIL PROFILE	N-VALUE	MOISTURE (%)
	Clayey fill	10-20	20-30
	Soft to firm marine clay (upper member)	<3	60-80
	Stiff clay	20-30	
	Firm marine clay (lower member)	<5	40-60
	Medium to dense cemented clayey sand	>100	20-30

Figure 2.1a: Soil Profile of the Kallang Formation (Chew, 2018)

There are many issues that may arise with such soil.

(i) Ground heave: The upward movement of the ground due to the expansion of the clay soils as its moisture level increases (Geobear, 2020)

(ii) Adjacent ground surface settlement: The uneven settlement may be caused by the shrinking and swelling of the clay soil.

(iii) Long term settlement and low bearing capacity: Due to the expansive nature of the clay soil, it reduces the bearing support and damage foundation.

(iv) Negative skin friction: The deformation of clay soil may cause friction between the foundation and the soil, as the soil drags downwards.

With its high compressibility and has low shear strength, it is no doubt that deep foundation is necessary.

3.1.2 Load Transfer Patterns

There are several types of loads to be considered before deciding the foundation type to be utilised. As we are aware of the function as well as the location of the *SG-Lotte* building, we would be focusing on three types of loads — dead load, live load and environmental load.

(I) Dead loads

Dead loads come from permanent parts of the structure and are static loads such as columns and beams, these loads are transferred to the structure throughout its lifespan.

(II) Live loads

Live loads are temporary loads, these loads are movable and can change from time to time. This type of load includes occupants and furniture. The live loads to be determined is done by the project's design team with regards to the intent of the building, which in this case is a mix-use building.

(III) Environmental loads

Environmental loads include snow load, earthquake load and wind load. Snow loads should only be considered in places with snowfall, which is not applicable to project *SG-Lotte* as Singapore is a tropical island.

As the island of Singapore is not located within the earthquake zone, it is not prone to earthquakes (Koh & Prasad, 2014). However, we should have a structure that is strong enough to withstand tremors such as the periodic tremors caused by Sumatra, Indonesia to avoid the downfall of any buildings. Structural integrity must be remained, even with low-level tremors.

Forces imposed on the building from earthquake are both vertical and horizontal forces, but focus should be remained on the horizontal forces of the building as tremors can cause the buildings to sway back and forth.

Wind load should be highly considered as it is applicable to any buildings in Singapore, especially tall buildings such as *SG-Lotte*. It is primarily a horizontal load that arises due to the movement of air relative to earth. The calculation of wind loads is dependent on the velocity of the wind as well as the size of the building. It is necessary for the design team to include wind loads in the structural design.

All in all, these loads mainly depend on the structure, in other words, an increasing number of floors would indicate an increasing number of dead loads. The choice of construction materials would also affect the number of loads exerted onto the foundation. For instance, the usage of reinforced concrete (RC) for the structure would have a higher impact on the foundation as compared to the usage of steel due to their weight (Natsoulis, 2020).

3.1.3 Structural Factors

Structural factors refer to the shape and size of the building. With reference to Point 3.1.2, the structure of the building will directly affect the type of foundation. As stated, the *SG-Lotte building* would be 250m high with a 20m deep 4-level basement. Moreover, due to the limited site constraint and tall height, the building would assume a slender body.

3.1.4 Site constraints

The site is located in Downtown Core, where the space would be limited. The confined site would then require for sufficient layout planning such as the movement of materials, storage of equipment, materials and temporary accommodations. There are buildings within close proximity as this area is known to be a Central Business District (CBD), hence there must be considerations with regards to the neighbouring buildings.

3.1.5 Site Investigation - Underground Tunnels and/or Services

As the project would be taking place close to the new underground MRT Line, within Zone 1, we must ensure that the construction of the building does not affect existing structures in place. A typical soil investigation would involve several aspects as shown in Figure 3.1b below.

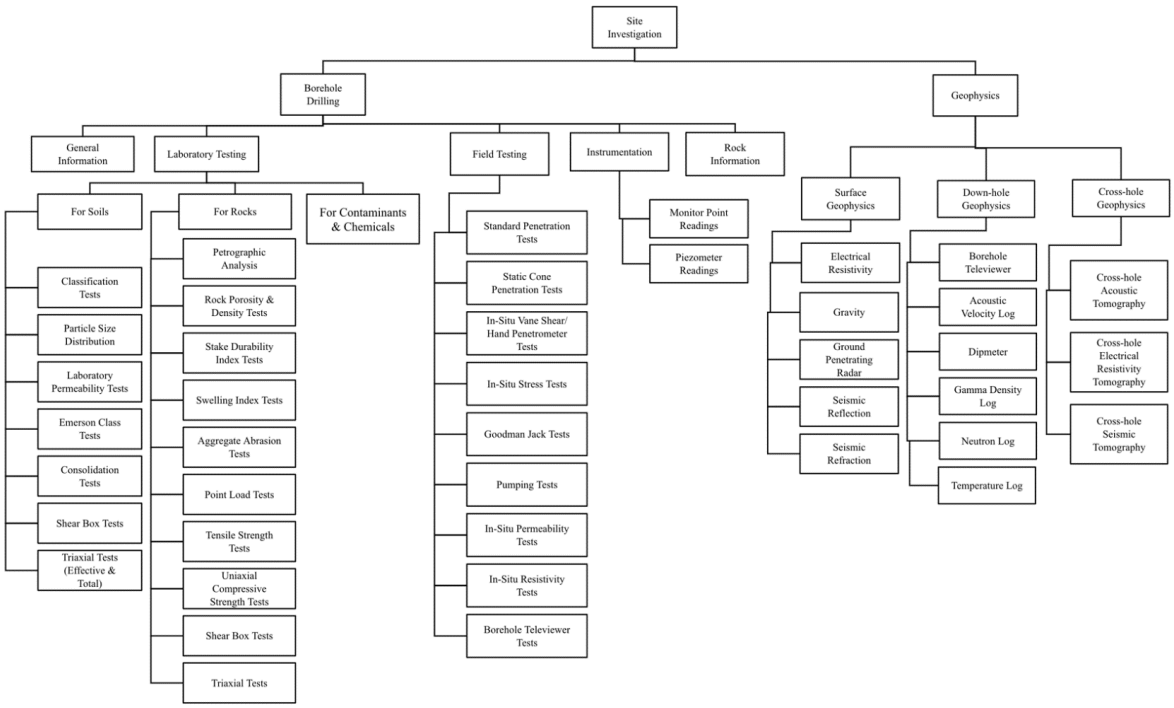


Figure 3.1b: Relationship Diagram during Site Investigation (BCA, n.d)

In general, the information that has to be retrieved from the investigation includes the general topography of the site, location of any underground structures, the general geology of the area and the history of the site. There should be an awareness of any particular feature that the site holds, such as the susceptibility to floods or soil erosion. There are also laboratory tests of soils and rocks that are to be conducted.

3.1.6 ENVIRONMENTAL ISSUES

There are many requirements to be aware of before the start of any construction project. As *SG-Lotte* would be constructed close to the new underground MRT Line, within Zone 1, we must be aware of the Rapid Transit System (RTS) viaduct on site. Excavation works might incur risks such as the damage or collision of RTS tunnels. It is important for the project team to seek approval from Land Transport Authority (LTA) prior to construction and follow guidelines (LTA, 2003). Moreover, signages and notices may be put up to prevent a series of unfortunate events.

As for the deep excavation taking place, we must be aware of the risk that works might potentially damage pipes and cables. To prevent such issues from arising, compliance with standard operating procedures (SOP) is necessary such as the Public Utilities Act and the Telecoms Act. Advisories should be taken seriously by qualified contractors (PUB, 2019; IMDA 2019), and failure to observe precautions may lead to penalties such as fines or imprisonment.

3.2 DEEP FOUNDATION

Together with the foundation design, the nature and strength of the materials to be utilised for the foundations should be taken note of. Based on the soil profile, there is insufficient soil capacity that is near the surface, hence loads are required to be transferred to firm layers substantially below the ground surface. This is thus important as to ensure structural continuity of the *SG-Lotte Building*.

	Displacement	**Replacement**	
	Pile	**Pile**	**Caisson**
Surrounding	Medium	High	Low
Vibration and Sound	High	Low	Low
Cost	High	Medium	Medium
Soil Condition	Hard	Medium	Soft

Table 3.2a: Comparison of deep foundation systems

Taking into consideration the deep foundation that this project requires, we have done a comparison between the various foundation systems (Table 3.2a). It does not require much space and as the *SG-Lotte Building* is to be located in a limited space in a CBD area, it would be more beneficial to use caissons. Moreover, as works are done in shafts, the vibrations, noise and dust are kept at a minimum. In general, caissons are more economical as their large diameters allow for lesser number of caissons as compared to multiple piles. As caissons are adaptable to a variety of soil types, and while the mix-used building is to be constructed on the Kallang Formation, the usage of caissons would be optimal.

3.3 CAISSONS

After doing up the necessary comparisons, we have decided to utilise caissons. Caissons have a box-like structure and has many comparable qualities with other foundation systems. It is similar to a cast-in-place pile (See Appendix A1) in terms of structure upon filled with concrete. It is also similar to a column footing (See Appendix A2) in terms of load transfer to the soil, however, differs in a sense that it is able to get through the unsatisfactory soil layers under the substructure of the building to reach a satisfactory bearing stratum (Figure 3.3a).

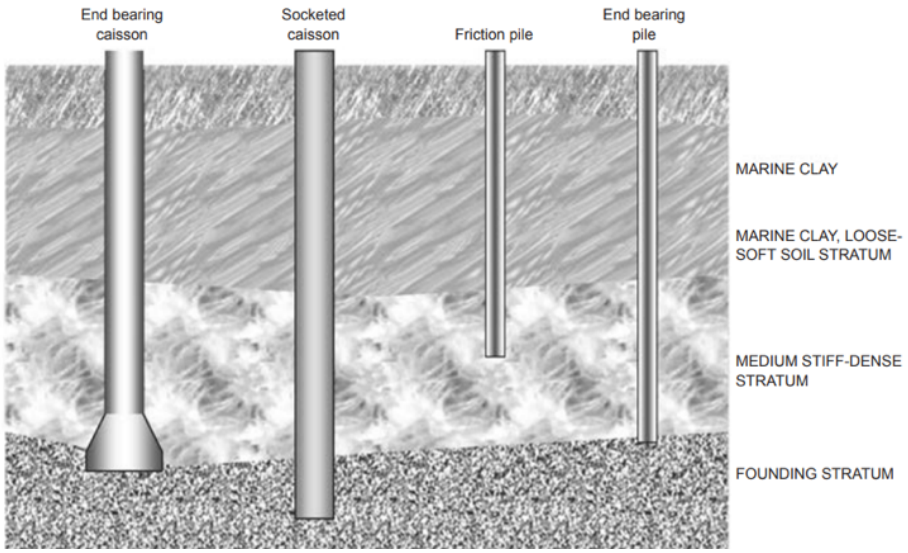


Figure 3.3a: Deep foundation systems (Chew, 2018)

There are several types of caissons with different designs and installations (Figure 3.3b). The following points would discuss the different types of caissons available *(Chew, 2018)*.

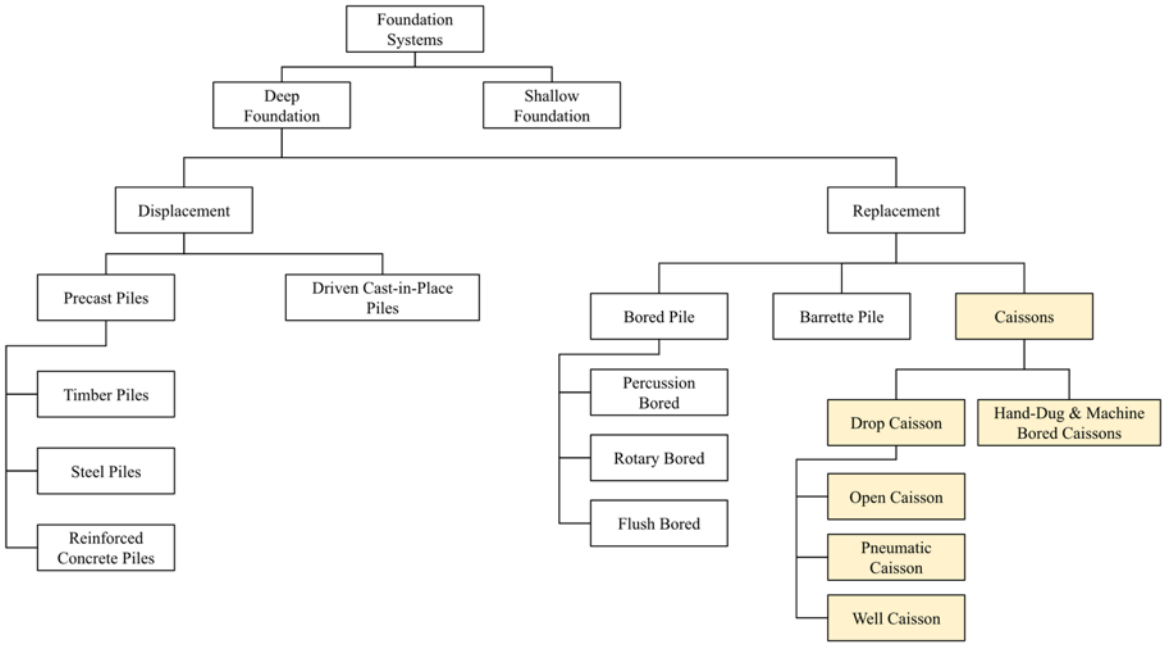


Figure 3.3b

3.3.1 BORED CAISSON

Commonly used in Singapore, bored caissons are caissons or cylindrical casings set into holes that were bored to depth by either a bucket drill, a mini excavator or hand digging. With diameters commonly ranging from 600mm to 6m, these are essentially pier holes filled with concrete in order to support columns. Excavation processes are located in the caisson shafts so as to minimise noise pollution, maintain air quality and minimise space, unlike the conventional bored pile methods (See Appendix

A3). After each stage of excavation has taken place, a concrete lining would be casted to resist the surrounding soil and water penetration.

3.3.2 GOW CAISSON

Gow caissons is a series of steel cylinders that is utilised during deep excavation to ensure the safety of workers as well as equipment. To facilitate deep excavation, each consecutive cylinder is smaller than the previous cylinder and each successive cylinder is driven deeper into the surrounding clay or slit. Depending on the soil conditions, a bell would then be excavated and filled with concrete. Upon completion of the excavation and construction, the steel cylinders are withdrawn. Essentially, the steel cylinders help prevent the collapse of soil upon venturing deeper.

3.3.3 SOCKETED CAISSON

The socketed caisson is similar to the gow caisson in Point 3.3.2, however, instead of belled, it is drilled into the bedrock. Using an auger, a steel pipe would be driven in the cylinder and when it touches the bedrock, a socket that is smaller than the caisson shell would then be churn drilled into the bedrock. Thereafter, the unit would be reinforced by concrete. In addition to its end bearing, the frictional forces between sides of the caissons and the rock contributes to its bearing capacity.

3.3.4 BOX CAISSON

Opening at the top, box caissons are structures that can be made out of timber or reinforced concrete (RC). These caissons are constructed onshore, floated to the designated location and are sunk into place with crushed rocks or sand reinforcing the weight, this secures the rigidity of the foundation. In cases where there is erosion occurs and weaken foundations, these caissons would be inappropriate. These caissons would be more fit for founding on a compact non-erodible gravel or rock which can be cut by dredging. In cases where the soft material is too deep for dredging, they are able to be found on a piled raft for additional support.

3.3.5 *Pneumatic Caisson*

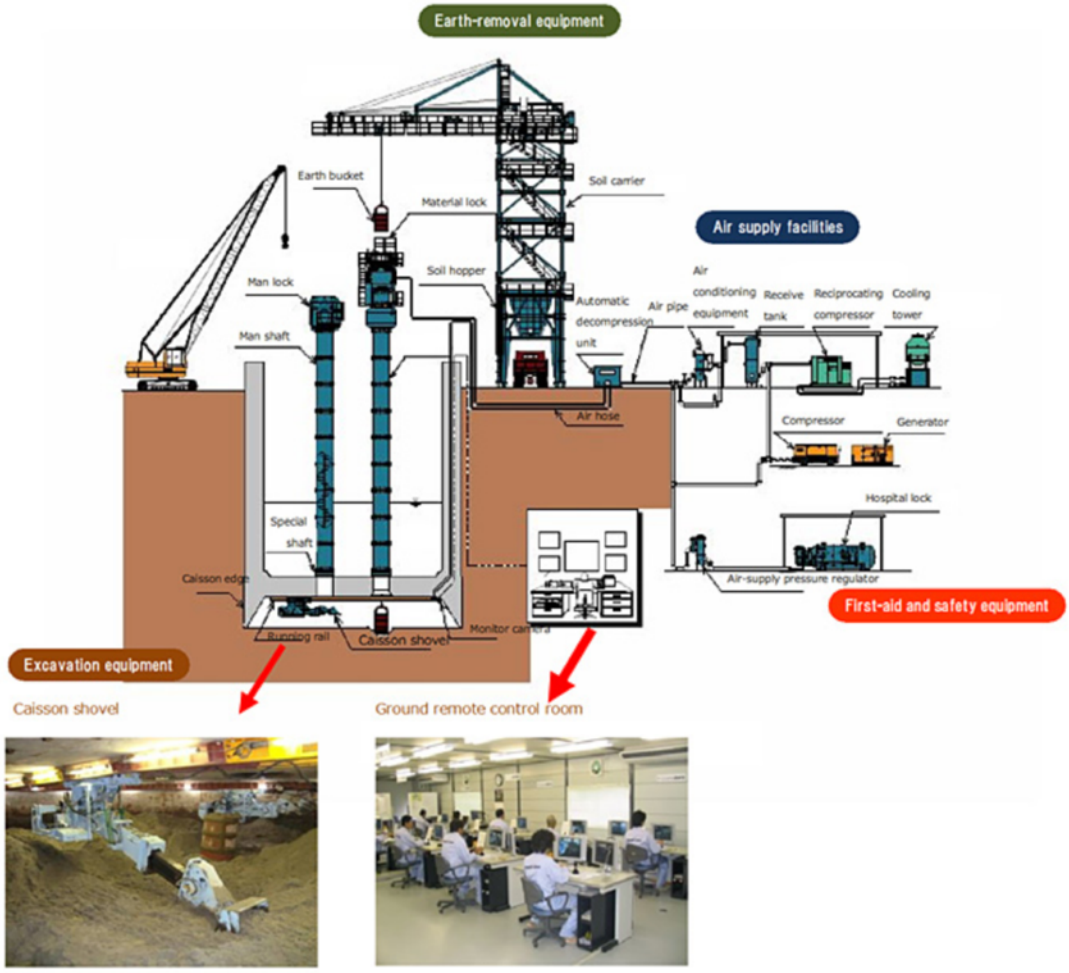


Figure 3.3c: Pneumatic caisson facilities (OSC, n.d.)

These are concrete boxes that are constructed on land with a compressed air chamber at the bottom of the box that balances with the groundwater in order to keep the interiors dry. This allows excavations to be carried out in dry condition. There are airtight steel shafts that are linked to the airtight working chamber for workers and excavation machinery to go and out. These shafts are secured with air locks in order to regulate the discrepancy between atmospheric pressure arising from the ground and chamber pressure. As the excavation progresses, the box would slowly sink into the ground until it reaches its designated depth. After which, the soil bearing capacity would be tested to ensure it is sufficient and the working chamber would then be filled with concrete to mark the completion of works. Figure 3.3c shows the outlay of the pneumatic caisson.

3.4 Chosen Caisson – Bored Caissons

As the excavation of the project takes place in a CBD area, it is recommended to use bored caissons with the use of hand excavation and mini excavator as this would allow minimal noise and vibrations in addition to the working shafts.

3.4.1 CONSTRUCTION SEQUENCE

The excavation and handling of materials as we dig deeper into the ground are done by technologies such as mini excavators and gantry cranes that would be further elaborated in Point 7.1. Works are done with adequate lighting and ventilation. The following steps describe the working sequence of bored caissons *(Chew, 2018)*.

1. Establishment of the level and position of the caissons.
2. With the use of mini excavators, the ground should be excavated with a depth of 1.5m. Thereafter, workers would manually hand dig the areas that are difficult for the excavator to reach.
3. A circular reinforcement mesh would be laid out as re-bars in the excavated ground for the caisson lining (Figure 3.4a), this is followed by the assembly of a steel ring wall formwork that would act as the caisson lining (Figure 3.4b). The formwork has three segments that are connected with a bolt, nut and locking pin.

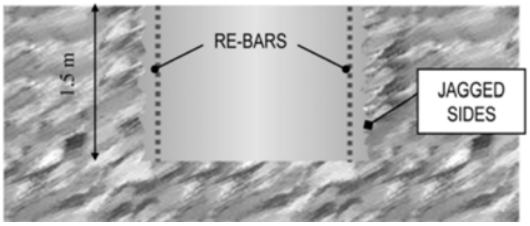


Figure 3.4a: Cross section of the circular reinforcement mesh

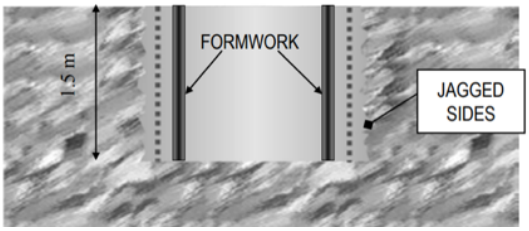


Figure 3.4b: Cross section of the steel ring wall formwork

4. Concrete would then be casted round the ring wall, the area around the formwork, as seen in Figure 3.4c.

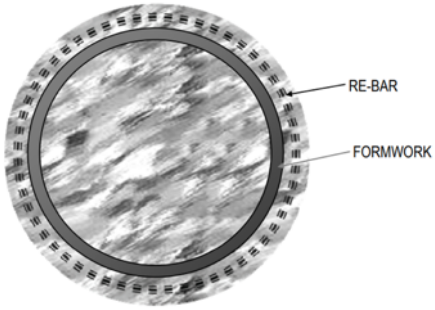


Figure 3.4c: Plan (Top) view of the Caisson

5. Step 2 is repeated; however, the formwork would be detached from the cast concrete in Step 4 by removing the locking pin together with the usage of a chain lock. Thereafter, using a gantry crane and a chain lock, the formwork would be lowered down, aligned and positioned to the newly excavated area.

6. To enhance and further secure the concrete placement, place the formwork slightly outwards as shown in Figure 3.4d. Upon casting the concrete, a gap should be left between the subsequent caisson rings to allow for grouting.

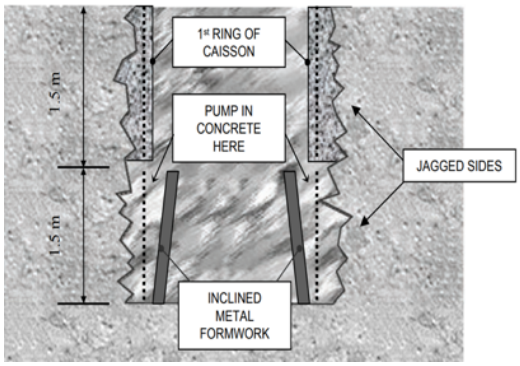


Figure 3.4d: Cross section of the subsequent rings

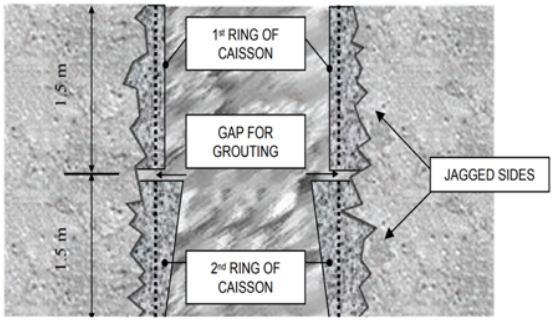


Figure 3.4e: Cross section of the gap between the subsequent rings

7. The caisson linings should be done up till the founding level.
8. The jack-in-test is then conducted within the gaps between the caisson rings (Figure 3.4e). We start by inserting hydraulic jacks into the gaps until the jacking has reached its target load capacity. This would allow us to assess the skin frictional resistance and ensure that the friction between the caisson lining and soil is strong enough to transfer loads. The placement of jacks is shown in Figure 3.4f below. Pressure and movement of the soil is then monitored using pressure gauges, level meters and dial gauges.

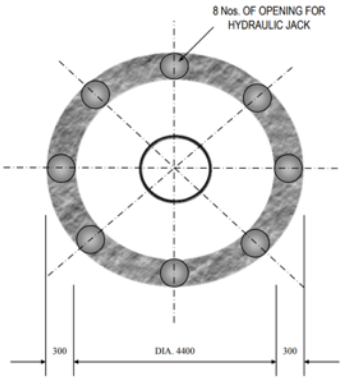


Figure 3.4f: Placement of hydraulic jacks

9. The dewatering system, whose importance is highlighted in Point 4.2, is to be monitored and the groundwater pressure surrounding the caissons should be controlled. Pore pressure changes and ground settlement should also be monitored. If need be, recharge wells can be provided.

10. The reinforcement of the caisson is then conducted by casting the caissons through tremie pipes. A concreting platform is to be present (Figure 3.4g). Sufficient vibration should be provided to ensure that the concrete is compact as well as a constant check on temperature to prevent micro-cracking due to high temperatures of hydration. The concrete should be casted to the desired height.

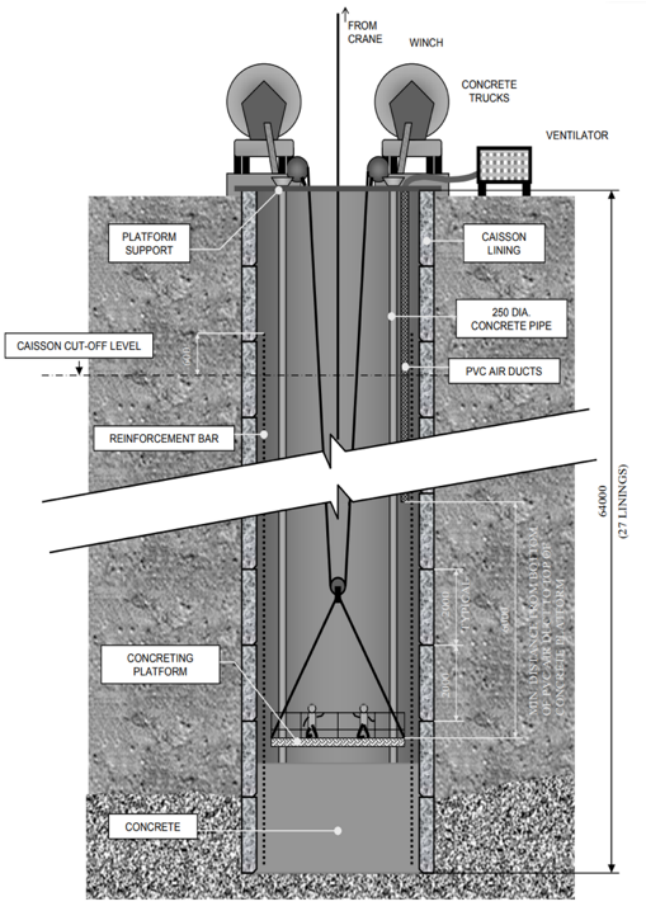


Figure 3.4g: Concreting process in a Caisson

3.5 Reference from Case Studies

3.5.1 Development Bank of Singapore (DBS) Building



Figure 3.5a: DBS Building (1974), (Singapore Memory, n.d)

Being the first of its kind to utilise large diameter caissons of 6.8m, the 50-storey building was once the tallest building in Singapore back in the mid 70s (Moh, 1994). It was constructed on reclaimed land and had to consider the soil characteristics, which were highly similar to project *SG-Lotte*.

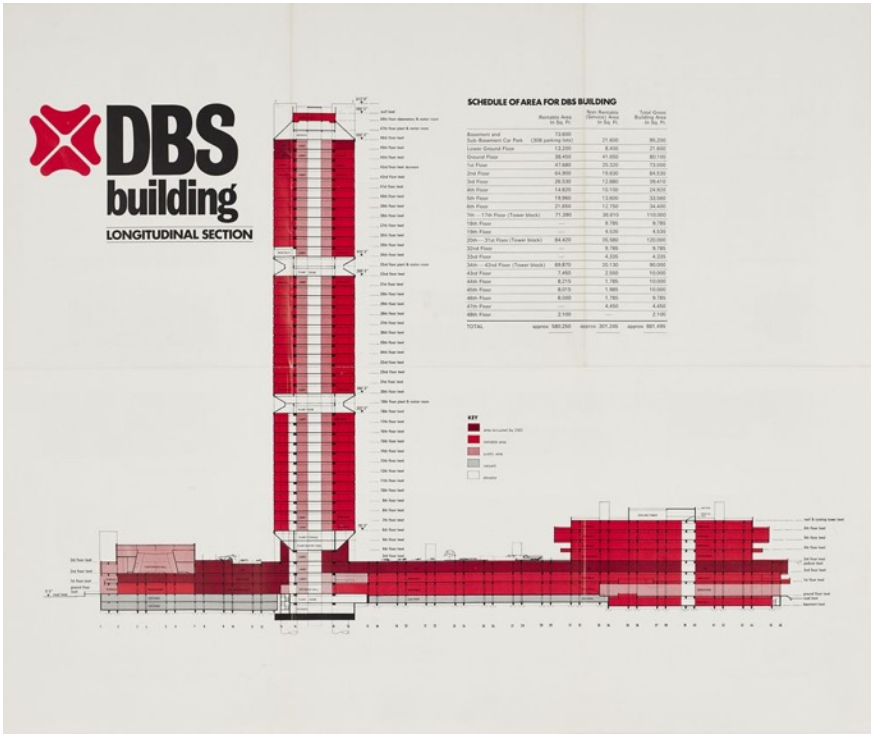


Figure 3.5b: Longitudinal section, floor plans, and a schedule of area for the DBS Building (M+, n.d)

Completed in 1974, this 201m tall structure is supported by 4 caissons, each with a load of 183MN, which ultimately inspired the bank's logo (M+, n.d). The soil consisted of soft marine clay, medium to dense sand and stiff clay followed by the mudstone and bedrock. Due to the heavy nature of the tower, as well as soil conditions, caissons were chosen for the foundation type. The type of foundation system utilised is deemed efficient as after decades, the settlement of the building was only recorded at estimated 20mm.

3.5.2 REPUBLIC PLAZA



Figure 3.5b: Republic Plaza (2004), (Janberg, 2004)

Similar to *SG-Lotte*, located within the CBD of Singapore and located near Raffles Place MRT Interchange, Republic Plaza is a 66-storey tall building with a height of 280m supported by 14 caissons. The caissons were designed to withstand loads of 181.5MN, 171.9MN and 117.8MN. The soil investigation concluded that the soil consisted of 2.3m to 3.4m. of fill, 1.1m to 4.2m of loose sad, soft marine clay and bouldery clay. The Jurong Formation lies under the bouldery clay, which consists of various layers of different soil types as stated in Figure 3.5c.

	SOIL PROFILE	N-VALUE	MOISTURE (%)
	Medium Stiff Sandy Silty Clay	10-20	20-40
	Soft Sandy Silty Clay	10-20	20-40
	Very Stiff Sandy Silty Clay	20-40	20-40
	Hard Silty Clay	60-80	20-40
	Very Dense Clayey Silt	>100	20-40
	Silty Clay with Shale	>100	20-40

Figure 3.5c: Soil Profile of the Jurong Formation (Chew, 2018)

Standard Penetration Tests (SPT) were conducted in the boreholes to estimate the compressibility and the shear strength of the soil condition. It was observed that the deeper the depth, the higher the penetration resistance (Broms & Lai, 1995).

During the design stage of the caissons, many factors were considered such as the factors considered in Point 3.2. Thereafter, the construction of caissons takes place. Load tests using hydraulic jacks were conducted to determine the shaft resistance of the caisson linings that were supporting the caissons in the bouldery clay. It is evident that the expected shaft resistance was lower than the actual shaft resistance, hence the length of the caissons was reduced which in turn reduced the costs and shortened construction time (Broms & Lai, 1995). Micropiles were also utilised to supplement the foundation as the it prevents the load transfer towards Raffles MRT tunnel.

4.0 BASEMENTS

The main purpose for the construction of the basement is to provide additional space as mentioned, additionally it also acts as a form of buoyancy raft or can be used to reduce net bearing pressure by the removal of soil.

4.1 SUPPORTING WALLS

When excavation is carried out, support is needed to prevent soil movement and to regulate groundwater level. The following are four of the common ways to provide support which can be used in isolation or combination:

1) Sheet Pile Wall

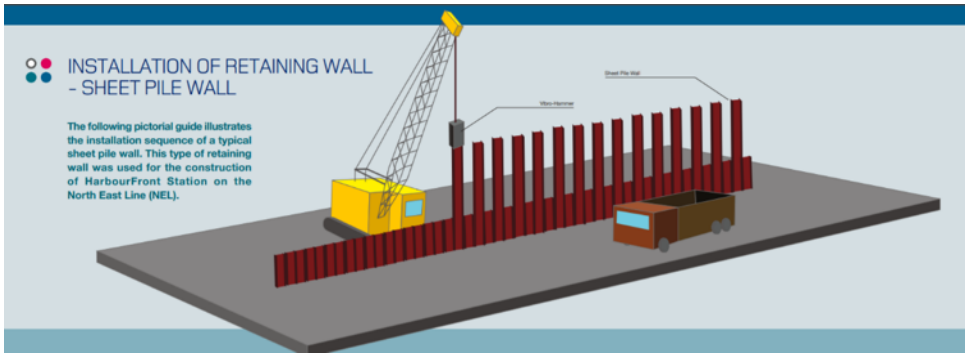


Figure 4.1a: Installation of Sheet Pile Wall (LTA, n.d. (a))

2) Diaphragm Wall

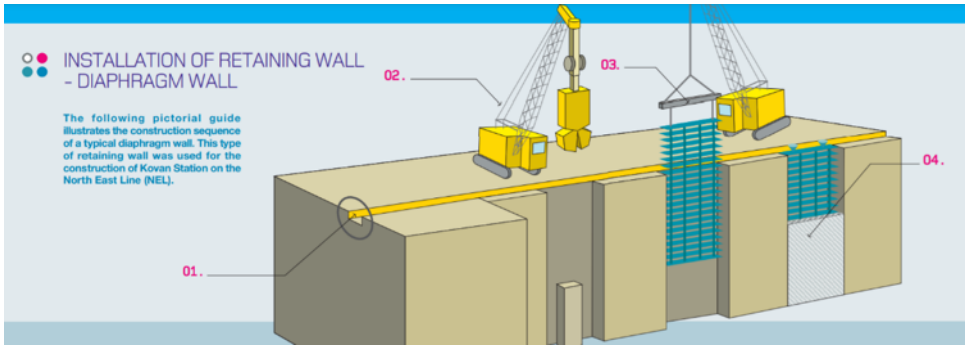


Figure 4.1b: Installation of Diaphragm Wall (LTA, n.d. (b))

3) Contiguous Bored Pile Wall

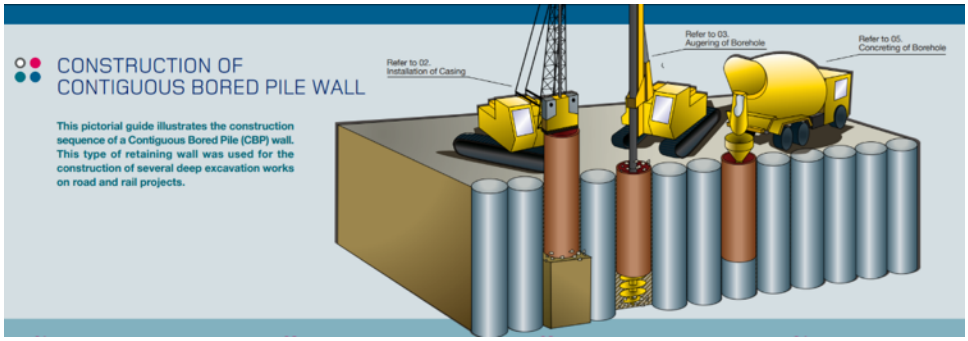


Figure 4.1c: Installation of Contiguous Pile Wall (LTA, n.d. (c))

4) Secant Pile Wall

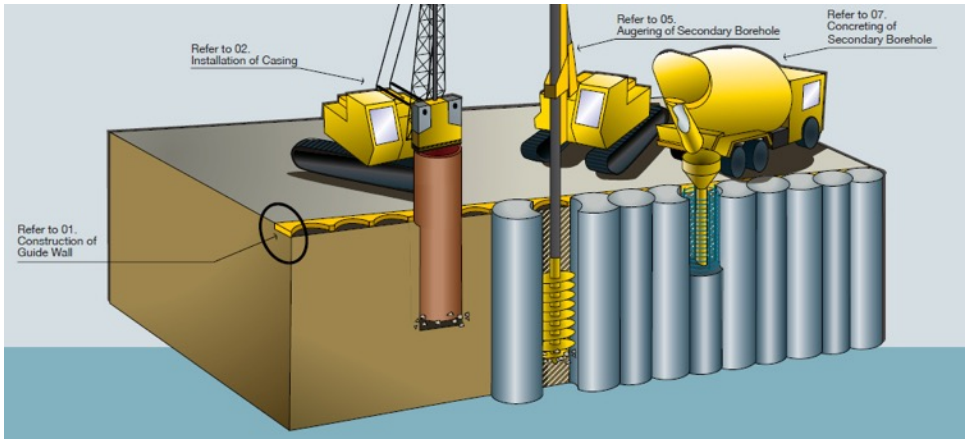


Figure 4.1d: Installation of Secant Pile Wall (RailSystem.net, 2015)

4.1.1 Diaphragm Walls

For *SG-Lotte Building,* Diaphragm walls have been chosen as the supporting walls. At the site of where the mixed-use building is to be constructed; the soil condition is made up of Kallang Formation as mentioned above. Depending on the depth, the natural moisture content found here is high at about 80% to 100%. Therefore, total waterproofing is needed due to the high moisture content found in the soil. With many surrounding properties and a MRT line in close proximity, noise and vibrations are to be minimized to avoid ground heave and disturbances of the soil. Additionally, Singapore's limited land space creates a very congested site for construction projects. Hence, due to the limitations and restrictions mentioned, diaphragm walls have been chosen as the supporting wall for the *SG-Lotte Building* Project.

The high cost for Diaphragm Walls could make this choice very uneconomical. Fortunately, by integrating them into the retaining structure, cost can be reduced (Designing Buildings Wiki, 2020). By casting cast-in-situ reinforced concrete and forming a complete continuous support structure around the area of excavation, support and watertightness can also be achieved.

The construction of the diaphragm walls is to be carried out prior to the caisson to minimize vibrations which might affect the MRT lines. Excavation is carried out within the bentonite slurry immersion and depending on the site investigation results, a clamshell grab, a trench cutter (hydro-fraise) and/or a drop chisel and a reverse circulation rig may be used until a trench with the necessary depth is created. After which, the first panel will be cast with the stop-end joint at one end. After the cast has dried, the adjacent panels will then be excavated and cast. The process repeats itself until all diaphragm walls have been cast. The stop-tube joint is embedded into the concrete and prevents water seepage by increasing the water seepage distance and preventing the passage of water in correspondence to concrete castings connecting points. Since it is a key waterproofing feature of the diaphragm wall, attention should be placed to ensure that it is installed properly. Lastly, given the restrictions of the project, since construction takes place within the first reserve, the diaphragm wall excavation must have an installation panel not exceeding 3 m in width (Chew, 2018 & LTA, 2015).

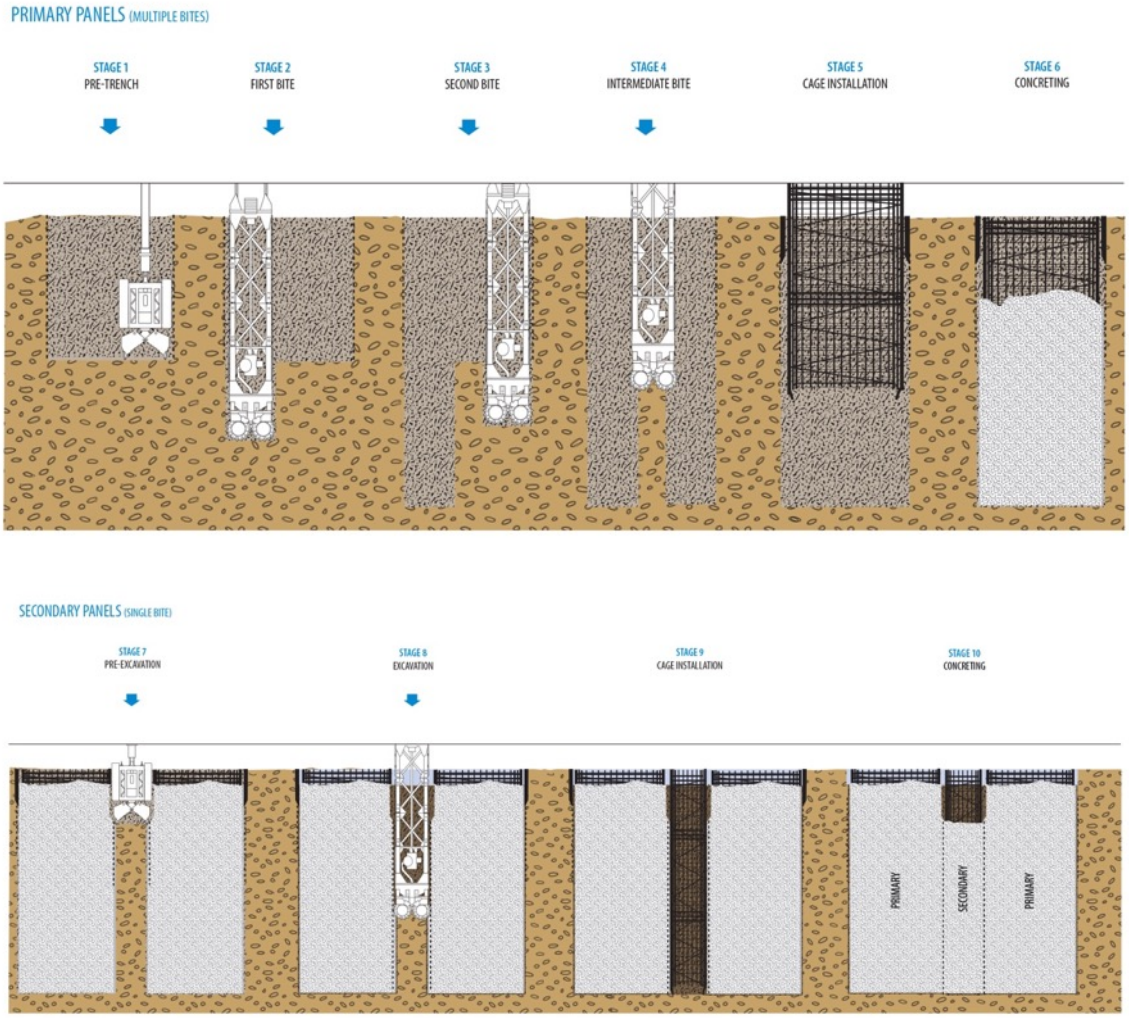


Figure 4.1e: Construction Process of Diaphragm Wall (TREVI, n.d.)

4.2 CONTROL OF GROUNDWATER VIA DEWATERING

Excavation which takes place below water table will encounter groundwater which affects the function and design of the facility (Powers, 1991). Groundwater causes problems to the excavation and buried structures. Problems include seepages that reduce the efficiency of construction operations, major inflows which results in instability, flooding and the collapse of excavation site (Calin et al., 2017).

Therefore, for excavation to proceed smoothly, groundwater has to be removed through use of dewatering. The methods of dewatering include:

1. Open pumping
    - Water flows into the excavation site and is collected in ditches and sumps before being pumped away
2. Predrainage
    - Groundwater table is lowered before excavation commences through the use of pumped wells, wellpoints, ejectors and drains
3. Cutoff
    - The use of steel sheet piling, diaphragm walls, contiguous bored pile and secant pile walls, tremie seals or grout to cut off water from entering the site
4. Exclusion
    - Water is excluded by utilizing compressed air, a slurry shield, an earth pressure shield jet grouting and ground freezing

(Chew, 2018)

Great care must be administered when choosing the method to adopt as the following complications could potentially if unsuitable groundwater control is selected.

a. The excavation may experience flooding as groundwater flows from water-bearing layers of soils or rocks into the site.
b. High pore water pressures in batter slopes at the excavation sides may cause instability or seepage erosion
c. Groundwater uplift pressures beneath the floor off an excavation may cause base heave or piping failure at the base of excavation.
d. Groundwater pressures may lead to excessive hydrostatic loads on excavation retaining structures
e. Damage may be caused to the environment or to adjacent properties, resulting in third party litigation or other legal issues (Powers, 1991 & Zheng & Li, 2012)

With reference to the Bucharest case study, the *SG-Lotte Building* project site has similar soil conditions and also consists of high underground water tables consisting in confined aquifers since Kallang Formation is generally consists of marine clay, fluvial clay and estuarine. In the Bucharest case study, 14 dewatering wells were positioned on the exterior of the diaphragm wall enclosure as seen from the diagram below. The dewatering deep wells protected the base soil against hydraulic cracks and uplift effects during the excavation process by reducing the pressure of the confined aquifer. As such, the loss of stability was avoided, and the project was able to reach its required excavation depth (Calin et al., 2017).

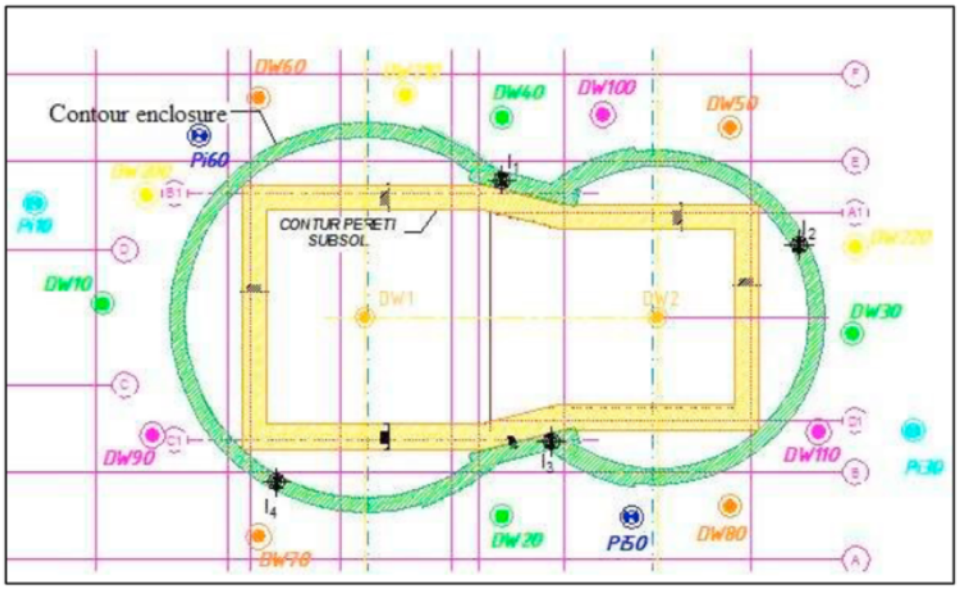


Figure 4.2a: Plan with the positioning of the dewatering wells for Bucharest (Calin et al., 2017)

Learning from this case study, we have also decided to adopt the method of deep wells as the dewatering process. Since there is high water content in the soil, the pre-drainage method, aside from the cutoff method already implemented, is ideal to lower the groundwater table before excavation. With the large volumes of groundwater to be pumped from the soil, deep wells are able to effectively pump out the high volumes of groundwater and are useful in preventing rapid recharging of the aquifer. Furthermore, with the deep depth of the excavation required, other dewatering methods are not as useful or economical (Griffin, 2020).

Several dewatering deep wells will be placed along the external perimeter of the diaphragm walls. This ensures that water seepage is intercepted before reaching the excavation site and to lower the water table to below the formation level as shown.



Figure 4.2b: Deep Wells Dewatering System (Back to Basic, 2020) & (WJ Canada, 2019)

However, deep wells can be less effective in low permeability soils (e.g., silts or silt sands) which make up a component of the Kallang Foundation soil. Therefore, according to the site results, the dewatering choice should be changed accordingly. In the case where deep wells are not suitable due to the low yields from the soil, an educator well system can be considered as an alternative method with its low flow rates which could produce higher yields (GWE, 2015). Educators are usually used to stabilized soil in the excavation site. High-pressured water is fed to the nozzle and venturi located at the base of the well by the supply pumps located at the ground level. The flow of the water then generates a vacuum in the well which draws in the groundwater (Back to Basic, 2020).

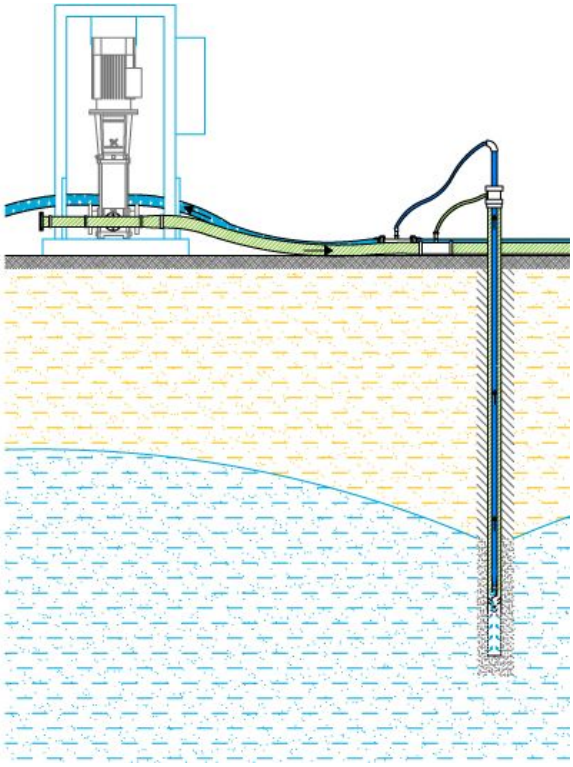


Figure 4.2c: Educator Well System (Back to Basic, 2020)

4.3 EXCAVATION OF BASEMENT

After the type of supporting wall and dewatering system is chosen, the excavation technique for the construction of the basement should be selected.

There are three main methods for excavation:

1. Open Cut Technique:
    - The ground is excavated to required depth and sides of the excavation are sloped to provide stability. Upon which, the basement is constructed afterwards from bottom upwards.

2. Cut and Cover Technique
    - The ground is excavated until the deepest basement level with sides of the excavation cut vertically downwards. Without the sloped side to provide stability, retaining walls and bracing are required. Afterwards, the basement is constructed in the conventional way from bottom upwards where temporary struts are slowly removed as the construction progresses.

3. Top-Down Technique
    - This technique constructs the basement in an inverse manner, beginning with the construction of the ground floor and excavating downwards to build the basement while constructing the superstructure above ground at the same time.

4.3.1 TOP-DOWN TECHNIQUE

After considering the three different methods, the top-down technique is proposed. With the limited space presented and tight time constraints as mentioned above, the top-down method is ideal since the superstructure and the basement can be constructed concurrently. Furthermore, since the permanent structure is constructed as excavation occurs, no strutting or additional temporary support is required to hold the excavated open pit nor is there any concerns about soil movement and water retention. It also allows early enclosure of the excavation which allows work to proceed even in adverse weather conditions.

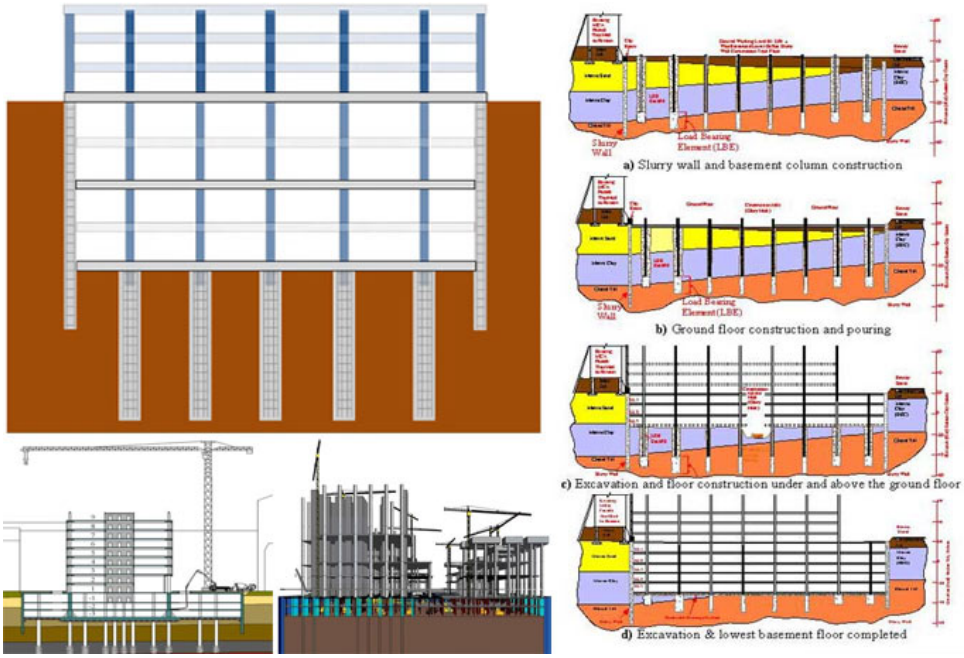


Figure 4.3a: Top-down Construction Technique (Construction Cost, n.d.)

However, there are also disadvantages to adopting this technique. To access each level below the ground slab, a temporary opening in the floor slab is used. Since the excavation and construction of basement level occurs after the floor above is built, there is limited headroom for excavation and restricted access for material handling. The small enclosed area also gives rise to dust, noise and visibility issues where mechanical ventilation and artificial lighting are required to overcome these problems. This method also prevents external waterproofing and there is the potential problem of water leakage at joints. In cases where prefounded columns are to be altered, great caution is needed to ensure effective load transfer. Overall, the excavation works, and substructure construction may be slower and more expensive if improper planning is not carried out.

These disadvantages should be noted, and meticulous planning should be carried out to mitigate the potential issues mentioned. For example, a detailed schedule could be planned to manage when and where materials should be delivered and stored as the construction progresses. With the schedule, materials are only delivered when needed, reducing the need for storage and thereby the congestion of the work site. Mini excavators also need to be employed to fit within the height restrictions. After soil analysis and site conditions are derived, the conditions should be rechecked to ensure that the top-down technique is ideal for the project. If the top-down method is deemed to be unsuitable because of unexpected major complications such waterproofing issues, the other two methods should be considered. Despite the potential problems, assuming that no significant obstacles are met, the top-down

method is chosen to be adopted for *SG-Lotte Building* due to the many benefits mentioned (Geotech, 2020; Quantity-takeoff.com, 2016 & Chew, 2018).



Figure 4.3b: Mini Excavators used in Basement Top-down Construction (MNH, 2017, 03:15–05:21)

4.3.2 TOP-DOWN CONSTRUCTION SEQUENCE

The following is the construction sequence that we will be observing for the *SG-Lotte Building* Project.

a. Construct the permanent diaphragm perimeter walls.
b. Form caissons the foundation to the required depth. Pour concrete to slightly over than the lowest basement slab level.
c. Before the concrete for the caissons set, insert steel stanchions/H sections (prefounded columns) into the upper part of the caissons.
d. Cast ground floor slab, with temporary opening at designated locations to provide access for excavation of the basements.
e. Excavate downward towards Basement Slab 1 through access holes. No horizontal strutting is required to support the excavation as the slabs act as the permanent horizontal supports
f. Case Basement Slab 1, with access holes at designated locations.
g. Excavate downward towards Basement Slab 2 through access holes.
h. Expose boreholes, construct pile caps and waterproofing for Basement Slab 2
i. Cast Basement Slab 2
j. Enlarge the exposed prefounded columns as required to form the columns of the basements

(Chew, 2018)

4.4 Soil Movement Monitoring

With many adjacent existing buildings and an underground MRT line, field conditions should be routinely measured to monitor soil movement. The following are instruments that should be installed at the *SG-Lotte Building*.

4.4.1 Inclinometers

This instrument monitors the lateral displacements in the ground and in the structures that lie below the ground level, deflections of retaining walls and piles, and deformation of the excavation walls, tunnels, and shafts (Chew, 2018 &Geotechnical Observations, n.d.). (A more detailed explanation ***7.2 Basement Construction (Diaphragm Walls and Excavation)***)

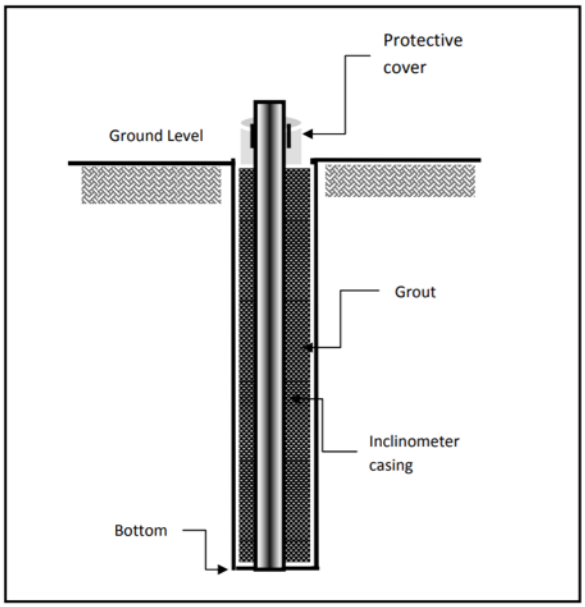


Figure 4.4a: Schematic diagram of inclinometer casing (GEOSMART, n.d.)

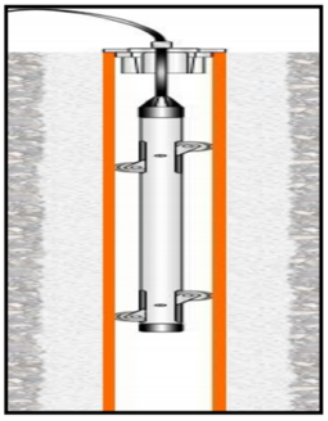


Figure 4.4b: Cross section view of inclinometer probe inside casing during monitoring works (GEOSMART, n.d.)



Figure 4.4c: Inclinometer Installation (Geotechnical Observations, n.d.)

4.4.2 WATER STANDPIPES

It is used to monitor groundwater level, control rate of dewatering in excavation work, monitor seepages and very models of flow (Chew, 2018). (A more detailed explanation ***7.2 Basement Construction (Diaphragm Walls and Excavation)***)

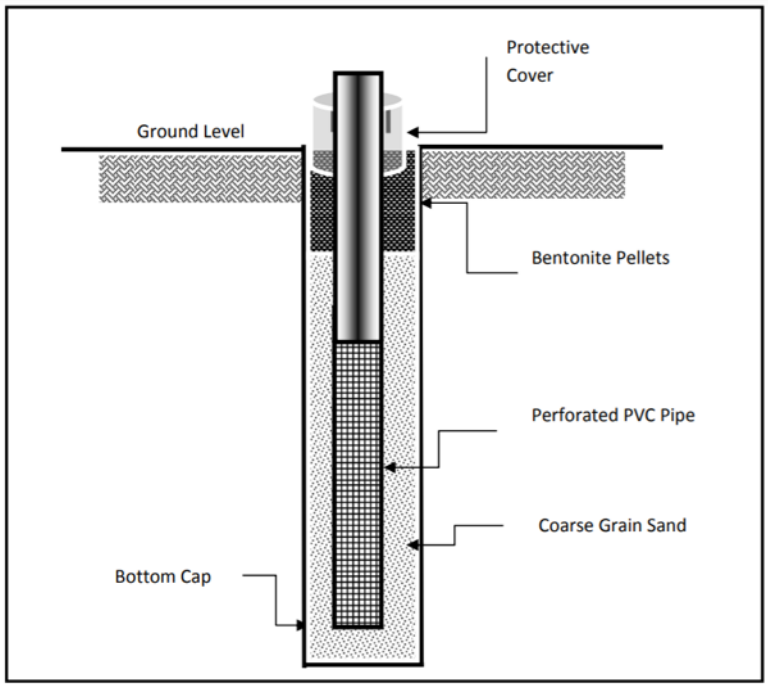


Figure 4.4d: Schematic diagram of ground Water Standpipe (GEOSMART, n.d.)

4.4.3 PNEUMATIC PIEZOMETERS

The instrument determines the stability of slopes, embankments and ground movement by monitoring pore water pressure. It can be used to monitor dewatering schemes for excavations and underground openings, seepage and groundwater movement, water drawdown during pumping tests and to determine the safe rates of fill or excavation, slope stability, the effects of dewatering systems used for excavations etc. (Chew, 2018; DGSI, 2019 & Soil Instruments, n.d.). (A more detailed explanation ***7.2 Basement Construction (Diaphragm Walls and Excavation)***)

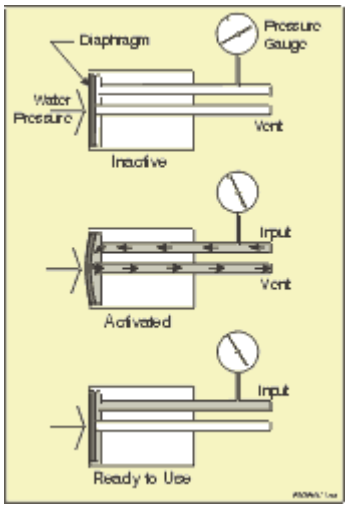


Figure 4.4e: Operating Principle of Pneumatic Piezometers (DGSI, 2019)

4.4.3 TILTMETER SYSTEM

It is a sensitive inclinometer designed to monitor small changes in the inclination and to provide an accurate history of the structure's movement. They use a force-balanced servo-accelerometer to measure inclination and give early warnings of potential structural damage allowing for early intervention (Chew, 2018 & QSafe, 2020). (A more detailed explanation ***7.2 Basement Construction (Diaphragm Walls and Excavation)***)



Figure 4.4f: Worker taking tile meter readings (Kimaro, 2017)

4.4.4 Settlement Markets

It monitors vertical ground settlement when measured against a known fixed datum. When displacement of a retaining wall or structure exceeds the allowable values, site work will be stopped immediately. Ground treatments and strengthening can be used to rectify the issues (Chew, 2018). (A more detailed explanation ***7.2 Basement Construction (Diaphragm Walls and Excavation)***)

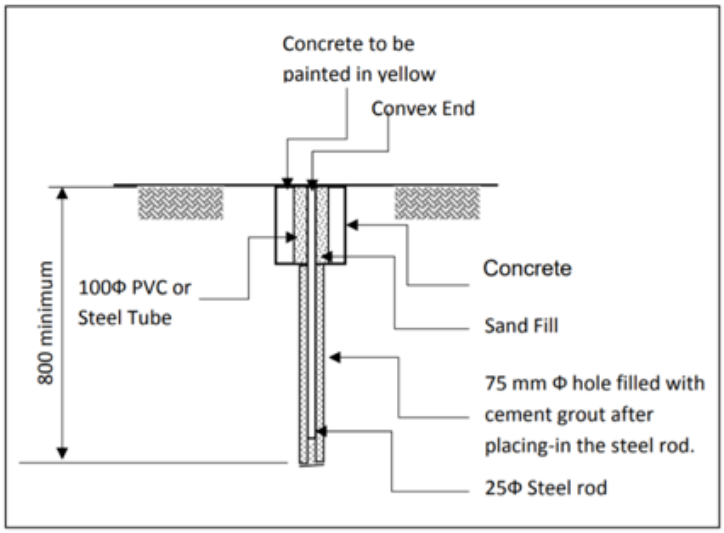


Figure 4.4g: Schematic diagram of installed settlement marker in soil (GEOSMART, n.d.)



Figure 4.4h: Settlement Marker in Ground (GEOSMART, n.d.)

5.0 BASIC SAFETY REQUIREMENTS

The Project requires numerous complex processes that must pass requirements and regulations set out by the Singapore Government in relation to safety. In order to ensure zero incidences and that a high standard of safety is kept, several sources of regulations and codes to be referred to are listed below with brief descriptions on relevant sections. These will be delved into deeper during the Project in order to ensure total compliance and zero incidences.

5.1 EXCAVATION SAFETY REQUIREMENTS

Excavation is one of the most dangerous construction operations because it deals with Earth removal to make space for construction projects.

Some big risks include having a cave-in which can result in workers injuring themselves or death, fall loads and incidents involving mobile equipment. One cubic yard of soil can weigh as much as a car. Asphyxiation due to lack of oxygen in a confined space and inhalation of toxic fumes and drowning. With fatality rates in excavation being 112% higher than general construction, Government regulations surrounding excavation exist as the basic safety requirements in excavation.

Stated below are the basic excavation safety requirements.

Workers are required to:

1. Keep heavy equipment away from trench edges.
2. Keep surcharge loads at least 2 feet (0.6 meters) from trench edges.
3. Know where underground utilities are located.
4. Not work under raised loads.

Trench Inspection:

A “competent person” must check the trenches every day before workers enter to eliminate excavation hazards. A competent person is an individual who can identify existing and predictable hazards or working conditions that are hazardous, unsanitary, or dangerous to employees and who is authorized to take prompt corrective measures to eliminate or control these hazards and conditions. It is required that trenches are inspected before each shift starts and after a rainstorm or any other hazard-increasing occurrence to ensure its safety for the workers. If an unsafe condition is discovered, the site project manager must be informed immediately. The project manager may order a stop to all works within the excavation and revoke permits for such work.

Ventilation:

The site must be tested, and preventative measures must be taken for unfavourable air quality conditions including low oxygen, and the presence of toxic gases or flammable gases and vapours.

- The air in the tunnel must contain:
  - At least 19.5% oxygen by volume; and
  - Not more than 23.5% oxygen by volume
- Appropriate ventilation systems must be installed for the supply of fresh air into free air tunnels. The use of air that has passed through underground oil or fuel storage areas are not permitted for use as ventilation for these tunnels.

Illumination Level:

- All tunnel work areas must have sufficient illuminance
- Emergency back-up generators are mandatory in the event of a power supply failure.

Ensuring Tunnel Stability:

All reasonably practicable measures must be taken in order to fortify tunnel stability, and to prevent the risk of anyone being trapped during the event of a tunnel collapse or being injured by anything that falls into the tunnel. In order to mitigate the risk of collapse of the shaft or the earth surrounding it, as well as flooding, all the tunnels and shafts in the worksite must be designed and constructed as adequately as possible. Before the start of and during tunnelling works, the roof, face and walls of the tunnel work areas must be inspected and tested regularly to ensure its safety. Within the tunnels itself, there must be a provision and maintenance of adequate clearances or refuge areas to reduce the risk of worker injury as a result of vehicles, equipment or fixtures.

Railings and Signs:

1. Notices/Signboards to be placed in noticeable and appropriate locations to warn workers of excavation works.
2. Guardrails must be placed on every open side of an excavation area where the depth exceeds 2 metres, as well as on every open side of a cantilevered or material platforms with a fall height exceeding 2 metres.
3. Toe-boards may be used instead of Guardrails for cantilevered or material platforms with fall heights above 2 metres.

Access and Egress:

1. The occupier of the worksite must ensure there is the presence of an adequate number of safe accesses to and egresses from the excavation worksites installed in appropriate locations that can be readily accessible by workers.

Fire:

1. Fire-fighting facilities must be adequately provided. This includes fire alarms connected to the ground level.
2. At least 1 joint exercise with the SCDF in the course of tunnelling works has to be conducted.
3. Fire drills must be held once every 3 months in the worksite.

Protective Systems:

Workers are prohibited from entering an unprotected trench without a protective system.

Protective Systems are hard to design as there are many factors to consider; Soil Classification, depth of cut, water content of soil, changes due to weather or climate, surcharge loads and other operations in the vicinity. Some examples of protective systems include:

- Sloping: Trench wall slopes away from excavation
- Shoring: Installing aluminium hydraulics or other supports to prevent soil movement/cave-ins
- Shielding: Trench boxes/other supports to prevent soil cave-ins

(Workplace Safety and Health (Construction) Regulations, 2007)

5.2 Concrete Works

A significant amount of concrete will be utilised, especially for caissons. Hence, Government regulations pertaining to concrete works have also been included in this report.

In the case of formworks:

1. Concrete placement is not to done in a way that would affect any formwork structure stability within the worksite.
2. Concrete placement cannot start before the design or any alterations to the formwork structure has been thoroughly inspected and certified by the professional engineer that designed the abovementioned formwork structure.
3. For the formwork structure where concrete placement is in progress, persons not necessary for the works should not be allowed within the vicinity.
4. Formwork structure inspections must be regularly conducted during concrete placement to check for the formwork structure's (a) stability, and (b) soundness.

5. Point 4 is to be done by the formwork supervisor, who has the duty to ensure that reasonably practicable measures are taken so that inspections are done properly and thoroughly.

(Workplace Safety and Health (Construction) Regulations, 2007)

5.3 Lifting Operations

The use of cranes and similar equipment to move loads will be employed during the Project, as such, the following will be adhered to:

1. Good strength and stability to be ensured for all lifts and material handling machinery within the worksite.
2. Certified capacity charts by an authorised examiner must be provided and made clearly visible in all cranes stipulating the safe loads of different lengths of jib at various radial distances and angles.
3. Any lift or material handling machine to start operation for the first time must thoroughly examined and inspected by a competent person, with cranes and lifts to be examined by an authorised examiner.
4. Measures are to be taken so that suspended loads are not moved over any person, and that loads are controlled with tag-lines in order to prevent these loads from swinging or turning freely.
5. Prohibition of any person from riding on any loads, buckets, skips, cars, slings or hooks of machinery.
6. No suspended loads when a crane or material handling machinery is in use is allowed.
7. In the case of employee lifts, these lifts must be operated by a designated car attendant who must practice due diligence in the operation of these lifts.

(Workplace Safety and Health (Construction) Regulations, 2007)

5.4 Guidebook for Structural Design against Seismic Actions

Singapore is not prone to Earthquakes; however, tremors do still occur when Earthquakes hit nearby Sumatra, Indonesia. In 2013, it was measured that there is a probability of distant earthquake exceedance of 10% in 50 years. This leads us to consider the protection against seismic activity for the long term. As such, the Guidebook for Design of Buildings in Singapore to Requirements in SS EN 1998-1, created by the Building and Construction Authority of Singapore (BCA) for buildings above 20m in height, is referred to. (BCA, 2013)

5.5 CODE OF PRACTICE FOR RAILWAY PROTECTION

The Handbook on Development & Building Works in Railway Protection Zone was created by the Development and Building Control Department, Land Transport Authority in Singapore. The code is of relevance to works done within the railway protection zone, as this project is. This includes the requirements needed in order to obtain approval for project works, with reference to several Government Regulations. Following this code will allow for a streamlined submission and approval process, on top of guiding project works in terms of design and planning.

Objectives to be met:

1. Structural Safety

   Works are to not cause physical damage to or affect the integrity and durability of the Rapid Transit System's (RTS) structures. It is advisable that the RTS structures' design and condition is examined to understand the potential effects on it from the project works.

2. Operational Safety

   It is imperative that the project works do not exceed the design limits and raise the possibility of causing deformation/changes or misalignment to the RTS tunnels and tracks. This could result in trains being unable to move at optimum speeds, or derailing.

3. Fire Safety

   The Project Works are to not obstruct or affect any means of fire escape from the RTS. There must be adequate provision of fire safety measures and protection systems.

4. Flood Protection

   The Project Works are to not introduce any risk of flooding to the RTS. Possible sources of flood risk include underground links and service connections.

5. Inspection and Maintenance

   The Project Works must not obstruct or affect RTS inspection and maintenance works.

(Land Transport Authority, 2005)

6.0 GOVERNING BODY/ STATUTE (LEGAL ASPECTS)

6.1 REQUIREMENTS ON DOCUMENTS TO BE SUBMITTED

Section 4 Building Control Regulations 2003 - Application for approval of plans of building works

(1) For the purposes of section 5(1) of the Act, an application for approval of the plans of building works shall be accompanied by the following documents:

(a) the following plans of the building works prepared in accordance with these Regulations and such other requirements as the Commissioner of Building Control may, from time to time, specify:

(i) building plans;

(ii) detailed structural plans and design calculations;

(iii) site formation plans and pile layout plans;

(iv) where applicable, civil defence shelter plans;

(v) where applicable, geotechnical building works plans; and

(vi) where applicable, demolition works plans;

(b) a notification signed by the developer of those building works or the builder of the building works of the appointment of the qualified person who prepared the plans of the building works;

(c) where the written permission of the competent authority is required under the Planning Act (Cap. 232) in respect of any development of land involving the proposed building works, a copy of the notice of grant of written permission issued by the competent authority or a copy of the lodgment receipt in lieu of written permission issued by the competent authority;

(d) where an application has been made under section 6A(1) of the Act for a waiver or modification of any requirement of these Regulations, a copy of the application;

(e) where alternative solutions are to be utilised in respect of the building works, a list of the alternative solutions together with the certification of one or more specialists in the alternative solutions referred to in section 9(2)(b)(ii) of the Act, where such certification has been obtained; and

(f) such other document as the Commissioner of Building Control may require.

(2) The application for approval of plans and the documents referred to in paragraph (1)(b), (e) and (f) shall be —

(a) in such form as may be required by the Commissioner of Building Control; and

(b) accompanied by the appropriate fee specified in the Second Schedule.

Section 4 of The Building Control Regulations 2003 (Chapter 29) states the requirements for the submission of documents to be approved. The documents would have to include: Building plans, detailed structural and design calculation, site formation plans and pile layout plans. Where applicable, it would also have to include: Civil defence shelter plans, geotechnical building works plans, and demolition works plan. All the above-mentioned plans are to be prepared by a qualified person, who is a professional engineer in the appropriate discipline.

Given the nature of the excavation and construction, pursuant to section 4 of the Building Control Regulations 2003 (Chapter 29), building plans, detailed structural and design calculation, site formation plans and pile layout plans are to be submitted and approved by the relevant authority before construction can commence.

6.2 REQUIREMENTS DURING EXCAVATION WORKS

Section 77 Workplace Safety and Health Act (Construction) - General requirements on excavation work

(1) It shall be the duty of the occupier of a worksite where excavation works are carried out to comply with paragraphs (2) to (11).

(2) Subject to paragraph (3), where the depth of any excavation in a worksite exceeds 1.5 metres or where the banks are undercut, adequate shoring by underpinning, sheet piling, bracing or other means of shoring shall be provided to prevent collapse of the excavation, or any structures adjoining or over areas to be excavated.

(3) No shoring shall be required under paragraph (2) if the excavation in the worksite has been examined and certified by a professional engineer to be safe without any shoring.

(4) Where the depth of any excavation in a worksite exceeds 4 metres, adequate shoring by underpinning, sheet piling, bracing or other means of shoring shall be made or erected in accordance

with the design of a professional engineer to prevent collapse of the excavation, or any structures adjoining or over areas to be excavated.

(5) Where the depth of any excavation in a worksite exceeds 4 metres, no work (other than excavation or shoring operations) shall be carried out inside the excavation until after a certificate under regulation 78(2)(ii) has been issued in respect of the underpinning, sheet piling, bracing or other means of shoring for that excavation.

(6) During any excavation work in a worksite, all reasonably practicable measures shall be taken —

(a) to prevent any person being trapped by the collapse of the excavation;

(b) to prevent any person being struck by an object, such as an excavating machine or by any material dislodged by the machine;

(c) to prevent any person falling into the excavation; and

(d) to prevent any person inhaling, or otherwise being exposed to, carbon monoxide or another impurity of the air in the excavation.

(7) Excavated material or other superimposed loads shall be so placed away from the edge of the excavation in a worksite to prevent the materials or other loads from falling into the excavation, or cause the banks to slip or cause the upheaval of the excavation bed.

(8) The open side of any excavation in a worksite which exceeds 2 metres in depth shall be provided with adequate guard-rails to prevent persons from falling into the excavation.

(9) Notices shall be put up at appropriate and conspicuous positions to warn persons about the excavation in a worksite.

(10) The excavation in a worksite and its vicinity shall be inspected by a designated person after every rain storm or other hazard-increasing occurrence.

(11) Where any inspection made under paragraph (10) reveals that the excavation in the worksite is not safe for entry, the designated person shall immediately inform the project manager of the worksite of the unsafe condition.

(12) Upon being informed, the project manager of the worksite may order that all works within the excavation cease immediately and revoke any permit-to-work issued for such work.

(13) It shall be the duty of the designated person to take, so far as is reasonably practicable, such measures as are necessary to ensure that any inspection carried out under paragraph (10) is conducted properly.

(14) Any designated person who contravenes paragraph (13) shall be guilty of an offence and shall be liable on conviction to a fine not exceeding $2,000 and, in the case of a second or subsequent conviction, to a fine not exceeding $5,000.

Section 77 of the Workplace Safety and Health Act (Construction) states the general requirements to be followed on excavation work. These requirements are to be followed during any excavation works such as the excavation of basement.

6.3 LIFTING OPERATIONS AND USE OF MACHINERIES ON SITE

Section 21 Workplace Safety and Health Act (General Provisions) - Lifting appliances and lifting machines

(1) No lifting appliance or lifting machine shall be used unless an authorised examiner has —

(a) tested and examined the lifting appliance or lifting machine; and

(b) issued and signed a certificate of test and examination, specifying the safe working load of the lifting appliance or lifting machine.

(2) The certificate of test and examination referred to in paragraph (1)(b) shall be kept available for inspection.

(3) Every lifting appliance and lifting machine shall be thoroughly examined by an authorised examiner at least once every year or at such other intervals as the Commissioner may determine.

(4) Every crane, crab and winch shall be provided with a readily accessible and efficient brake or other safety device —

(a) which will prevent the fall of the load when suspended; and

(b) by which the load can be effectively controlled while being lowered.

(5) Every hand winch shall be fitted with an efficient pawl capable of sustaining the safe working load.

(6) Every lifting appliance and lifting machine —

(a) shall be conspicuously marked with its safe working load or loads and a distinctive number or other means of identification; and

(b) in the case of a jib crane so constructed that the safe working load may be varied by the raising or lowering of the jib, shall have an accurate indicator, which must be placed so as to be clearly visible to the driver of the jib crane, that shows the radius of the jib at any time and the safe working load corresponding to that radius.

(7) No lifting appliance or lifting machine shall be loaded beyond its safe working load except by an authorised examiner or an inspector for the purpose of testing such lifting appliance or lifting machine.

(8) Every lifting appliance and lifting machine shall be adequately and securely supported and —

(a) every rope, chain or wire;

(b) every part of a stage, framework or other structure; and

(c) every mast, beam, pole or other article of plant supporting any part of the lifting appliance or lifting machine,

shall be of good construction, sound material and adequate strength, having regard to the nature of the lifting appliance, its lifting and reaching capacity and the circumstances of its use.

(9) All rails on which a travelling crane moves, and every track on which the carriage of a transporter or runway moves shall —

(a) be of proper size and adequate strength;

(b) have an even running surface;

(c) be properly laid, adequately supported or suspended; and

(d) be properly maintained.

(10) If any person at work at any place in a workplace is on or near the wheel tracks of an overhead travelling crane where he would be liable to be struck by the crane, effective measures shall be taken to ensure that the crane does not approach within 6 metres of that place.

(11) If any person at work in a workplace is not on or near the wheel tracks of an overhead travelling crane but is in a place above floor level where he would be liable to be struck by an overhead travelling crane, or by any load carried by the crane, effective measures shall be taken to warn him of the approach of the crane unless the work of the person is so connected with or dependent on the movements of the crane as to make the warning unnecessary.

(12) A lifting machine shall not be operated except by —

(a) a person trained and competent to operate that machine; or

(b) a person under training who is under the direct supervision of a qualified person.

(13) No person below the age of 18 years shall be at work —

(a) operating any lifting machine driven by mechanical power; or

(b) giving signals to the operator of any lifting machine.

(14) It shall be the duty of the occupier of a workplace in which any lifting appliance or lifting machine is used to comply with paragraphs (1) to (13).

(15) It shall be the duty of an authorised examiner to —

(a) issue and sign a certificate, in a form determined by the Commissioner, of the result of the examination referred to in paragraph (3);

(b) provide the certificate referred to in sub-paragraph (a) to the occupier of the workplace;

(c) inform the Commissioner —

(i) as soon as is reasonably practicable, if the examination shows that the lifting appliance or lifting machine cannot continue to be used safely unless repairs are made; or

(ii) in any other case, within 28 days of the completion of the examination, of the results of the examination in a manner acceptable to the Commissioner; and

(d) exercise all due diligence in making any certification or in conducting any test or examination of any lifting appliance or lifting machine under this regulation.

(16) It shall be the duty of the owner of a lifting appliance or lifting machine to ensure that it is —

(a) of good mechanical construction, sound material and adequate strength; and

(b) properly maintained.

(17) An inspector may at any time test any lifting appliance or lifting machine and may prohibit its further use if he is not satisfied that the lifting appliance or lifting machine is safe for the use to which it is put.

(18) Any person who contravenes any prohibition of an inspector under paragraph (17) shall be guilty of an offence and shall be liable on conviction to a fine not exceeding $20,000 or to imprisonment for a term not exceeding 2 years or to both.

Register of lifting gears, etc.

Section 134 Workplace Safety and Health Act (Construction) – Strength and Stability

(1) It shall be the duty of the owner of a crane, an employee's lift or a material handling machinery being used in a worksite to ensure that the crane, employee's lift or material handling machinery is —

(a) of good construction, sound material and adequate strength;

(b) free from patent defects; and

(c) properly maintained.

(2) It shall be the duty of the operator of a crane or material handling machinery being used in a worksite to ensure that the crane or machinery, as the case may be, is positioned and operated as to be stable.

Section 135 Workplace Safety and Health Act (Construction) – Capacity Chart

(1) It shall be the duty of the owner of any crane used in a worksite to comply with paragraphs (2), (3) and (4).

(2) Where the capacity of the crane used in a worksite is variable, a capacity chart shall be provided.

(3) The capacity chart shall —

(a) be posted and maintained in the crane which is clearly visible to the operator;

(b) set out the safe loads for various lengths of jib at various angles and radial distances; and

(c) be prepared and certified by an authorised examiner, unless it is furnished by the manufacturer or builder of the crane.

(4) Where outriggers are provided, the safe loads with and without the use of outriggers shall be specified.

Section 21 of the Workplace Safety and Health Act (General Provisions) and sections 134 and 135 of the Workplace Safety and Health Act (Construction) states the requirements for carrying out lifting operations on the worksite, in which the project would have to adhere to as cranes and other machineries are being used for lifting works.

6.4 USAGE OF CONSTRUCTION VEHICLES

Section 28 Workplace Safety and Health Act (Construction) - Vehicular hazards

(1) Where in a worksite, any work is performed over, on or in close proximity to a street, public road or any other place where public vehicular traffic may cause danger to any person who carries out the work, it shall be the duty of —

(a) the employer of any person who carries out the work in the worksite; or

(b) the principal under whose direction any person carries out the work in the worksite,

to ensure that —

(i) the worksite is barricaded;

(ii) suitable warning signs and warning lights are set up to direct traffic away from the worksite; and

(iii) where necessary, the traffic is specially controlled by designated persons.

(2) It shall be the duty of the owner of any vehicle used in a worksite to ensure that the vehicle is of good construction and roadworthy.

(3) No person shall drive a vehicle of any class or description in a worksite unless he has obtained the authorisation of the occupier of the worksite to do so.

(4) It shall be the duty of the occupier of a worksite to ensure that no person shall drive a vehicle of any class or description in the worksite, except a person who has obtained the authorisation to do so referred to in paragraph (3).

(5) It shall be the duty of —

(a) the employer of any person who drives any vehicle in a worksite; or

(b) the principal under whose direction any person drives any vehicle in a worksite,

to ensure that the person does not drive the vehicle unless the person —

(i) has been fully instructed as to the dangers likely to arise in connection therewith and the precautions to be observed; and

(ii) has received sufficient training to operate or drive the vehicle.

(6) Nothing in this regulation shall derogate from the effect of the Road Traffic Act (Cap. 276).

(7) Any person who contravenes paragraph (3) shall be guilty of an offence and shall be liable on conviction to a fine not exceeding $1,000 and, in the case of a second or subsequent conviction, to a fine not exceeding $2,000.

Section 28 of the Workplace Safety and Health Act (Construction) states the requirements for the use of vehicles on the worksite, which the project would have to adhere to as construction vehicles would be utilised on the worksite.

6.5 PREVENTIVE MEASURES AGAINST FIRE ON SITE

Section 21 Workplace Safety and Health Act (General Provisions) – Prevention of fire

(1) All reasonably practicable steps shall be taken in a workplace to keep sources of heat or ignition separate from —

(a) flammable materials in the workplace; or

(b) any process carried on at the workplace that gives rise to any flammable gas or vapour.

(2) There shall be provided and maintained in a workplace means of extinguishing fire which shall be —

(a) readily accessible;

(b) adequate and suitable having regard to the circumstances of each case; and

(c) tested by a competent person at such regular intervals as the Commissioner may determine.

(3) It shall be the duty of the occupier of a workplace to comply with paragraphs (1) and (2).

Section 21 Workplace Safety and Health Act (General Provisions) – Safety provisions in case of fire

(1) There shall be provided in a workplace such means of escape in case of fire for the persons at work in the workplace —

(a) as may be reasonably required in the circumstances of each case; and

(b) which shall be properly maintained and kept free from obstruction.

(2) The contents of any room in which persons are at work shall be so arranged or disposed that there is a free passageway for all persons at work in the room to a means of escape in case of fire.

(3) In every workplace, all doors affording any person at work in a workplace means of exit from —

(a) the workplace;

(b) any room in the workplace; or

(c) any building or enclosure in which the workplace is situated,

shall only be locked or fastened in such a manner that the doors can easily and immediately be opened from the inside.

(4) In every workplace, all doors affording means of exit from the workplace for the persons at work in the workplace shall, except in the case of sliding doors, be constructed to open outwards.

(5) Every exit affording means of escape in case of fire or giving access to such means of escape shall be conspicuously marked with an exit sign of an adequate size.

(6) In every workplace, effective steps shall be taken to ensure that all the persons at work in the workplace are familiar with —

(a) the means of escape in case of fire and their use; and

(b) the routine to be followed in case of fire.

(7) In every workplace, there shall be effective warning devices that —

(a) are capable of being operated without exposing any person to undue risk;

(b) are maintained and tested at least once every month;

(c) give warning in case of fire; and

(d) are clearly audible throughout the workplace.

(8) It shall be the duty of the occupier of a workplace to comply with paragraphs (1) to (7).

Section 37 and 38 of the Workplace Safety and Health Act (General Provisions) states the requirements for constructions to avoid the occurrence of fire on site and the emergency guidelines should a fire breakout on the construction site which the project would have to follow.

6.6 Rapid Transit Systems (Railway Protection, Restricted Activities) Regulations

Under the Rapid Transit Systems (Railway Protection, Restricted Activities) Regulations, restricted activities are only allowed to be carried out within the railway protection zones after permission is obtained from LTA. The list of restricted activities is defined as follows:

(a) the movement or operation of any crane, whether fixed or mobile, hoist, ladder, drilling or piling equipment, excavator or any other mechanical equipment or vehicle;

(b) the installation of boreholes, wells, sheet-piles, pile foundations, ground anchors and horizontal tie backs;

(c) the storing or placing, or causing or allowing the storage or placement of, any equipment goods, material or thing or any solid, liquid or gaseous matter or substance; and

(d) the digging or excavation of trenches or pits, the carrying out of earthworks and backfilling, or the shifting or pushing of earth or soil from one area to another, whether or not such activities are carried out manually or by mechanical means;

(e) the dredging of sea beds or river beds and the anchoring of vessels with displacement (laden) weight of more than 20 tonnes;

(f) the erection of sheds, shelters, tents, scaffolding, maintenance towers, ladders, hoardings and other similar temporary structures for the purpose of trade fairs, fun fairs, exhibitions, entertainment, night markets, religious functions or ceremonies;

(g) the planting of trees with a full grown height extending above the parapet or wing wall of the railway;

(h) the use of explosive material for the purpose of blasting, demolition or removal of rocks; and

(i) the construction of an underground passageway designed —

(i) for use as a street or railway;

(ii) to serve as a conduit for utilities; or

(iii) to provide access for people, vehicles or equipment to any underground working site.

Given that the project would be constructed above a new MRT station, the above regulation would apply as excavation works would have to be done in the railway protection zone. Thus, an approval by LTA would be required to carry out the excavation works required.

The nature of the excavation and piling works should also follow the Code of Practice for Railway Protection published by LTA:

Piling works:

		First Reserve	Outside First Reserve	
			Second Reserve	Third Reserve
Underground, Transition or Sub-aqueous	Clearance	Not allowed*	Allowed if piles are kept at least 6m clear on plan from the exterior edge of rapid transit system structures.	Allowed.
	Debonding	Not applicable.	Load bearing piles within the zone of influence of rapid transit system structures shall be debonded according to the requirements of Clause 9.3.3.	Not Required.
	Method of Installation	Not applicable.	(a) Piles shall generally be constructed by augering or reverse circulation drilling techniques. (b) Stability of the ground shall be ensured by the use of casings and/or drilling mud as appropriate. (c) Use of percussively driven concrete piles, steel H-piles, sheetpiles or tanalised timber piles is not acceptable. (d) Use of rock chopping chisels is prohibited. (e) Use of vibratory method of installing and extracting sheetpiles, H-piles or casings is prohibited.	Rock chiselling and percussive piling techniques is acceptable.
At grade	Clearance	Not allowed.	Allowed.	Allowed.
	Method of Installation	Not applicable.	(a) Use of percussively driven concrete piles, steel H-piles, sheetpiles or tanalised timber piles is not acceptable. (b) Use of drilling fluid in the drilling of piles shall be carefully controlled to prevent an increase in the piezometric head in the railway protection zone.	
Above ground	Clearance	Not allowed.	Allowed if piles are kept at least 3m clear on plan of the toe of the existing raker pile supporting the rapid transit system structures.	

Basement and Tunnel Construction:

(a) Where basements are more than 1m below the existing ground water table, they shall be made watertight. The base slab shall be designed for full hydrostatic pressures and pressure relief in the form of weep-holes or drainage blankets is not allowed.

(b) Where tunnel construction works are permitted, the temporary or permanent linings shall be made watertight to prevent any seepage of water into the proposed tunnels under both temporary and permanent conditions.

Excavation works:

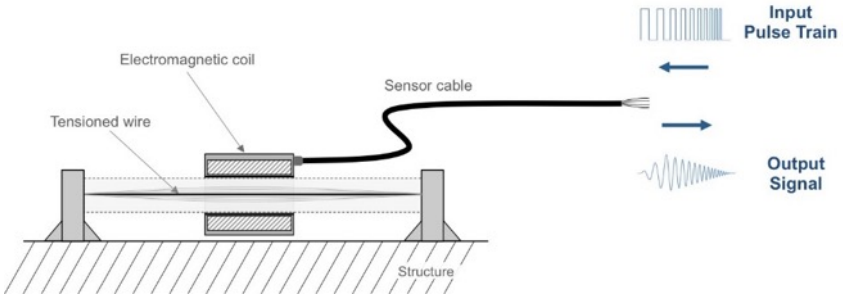
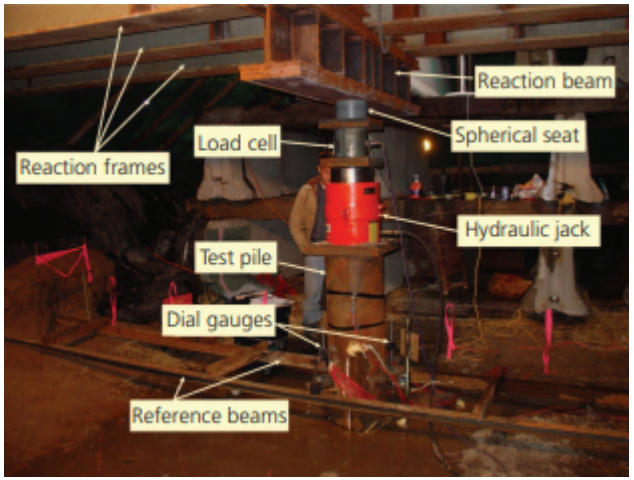
	First Reserve	Outside First Reserve
Underground / Transition	Not allowed*	Allowed subject to : (a) Piezometric Pressure in Compressible Soil The piezometric pressure in compressible soils within the first and second reserves shall not be reduced by more than 10kPa. Where the rapid transit system structures are supported on piles or other foundations extending below the compressible layer, this clause may be waived. The definition of compressible soils shall make reference to LTA Design Criteria for Road & Rail Transit Systems. (b) Cut-off Wall No trench, excavation, caisson, pile or well deeper than 1m below the existing ground water level shall be allowed unless suitable measures such as installation of cut-off wall, excavation under stabilising fluid or mud, etc. are taken to control the reduction of piezometric pressure. (c) The stability of the rapid transit system structures adjacent to/ below the excavation shall be checked against the effect of buoyancy, uplifting, etc. (d) The design of temporary works for the excavation shall ensure adequate factor of safety against basal heave, hydraulic uplift of the base, toe-stability of retaining walls, material failure, strut failure, etc.
At grade	Not allowed.	Same as above
Above ground	Not allowed.	Allowed subject to item (c) above if lowering of the ground water table is expected due to the excavations.

7.0 TECHNOLOGIES USED

7.1 CONSTRUCTION OF FOUNDATION SYSTEM

NO.	EQUIPMENT/ TECHNOLOGIES	BRIEF DESCRIPTION
1.	**Mobile Gantry Cranes**  *Mobile Gantry Crane transporting steel cylinders*	Gantry crane is a crane that is built atop a gantry, which can typically carry heavy loads by resisting the torque created by the load using its structure. Mobile Gantry Cranes on the other hand are typically smaller compared to Gantry Cranes and have tyres, usually rubber, to increase its mobility around the construction site. These Mobile Gantry Crane could be used to transport steel cylinders that are used for the construction of foundations to different spots on the worksite.

2.	**Mini Excavator**  *Mini Excavators used to dig around excavation site*	A mini excavator is a tracked or wheeled vehicle that is used for construction. Compared to conventional excavators, mini excavators are lighter and smaller, and thus offer reduced track marks and top ground damage. The smaller size of the mini excavator also provides an advantage when attempting to dig holes in smaller areas where it is harder to reach with a typical excavator. (Zitzman, 2017) Mini excavators could be utilised during the excavation works on site at any hard to reach areas on the project site.
3.	**Hydraulic Jacks**  *Hydraulic Jacks used as support*	A hydraulic jack is a mechanical device used to lift bulky objects, vehicles, equipment, or to apply huge force using a hydraulic fluid as the primary source of power. These are widely used in the automotive, industrial and construction industries. During construction, the high lifting power of these hydraulic jacks are being utilised to lift heavy load. The use of hydraulic jacks could help during the construction of caissons to ensure safety due to the high strength of these jacks.

4.	**Pressure Gauges, Level Meters, Strain and Dial Gauges etc.** (To test for negative skin friction)  *Vibrating-wire strain gauges*  *Set-up for pile testing*	Monitoring tools such as pressure gauge, level meter, strain and dial gauges are used for pile load testing. Vibrating-wire strain gauges are being utilised due to their long-term stability under static loading which is essential for pile set-up investigation (Bica et al, 2013). These monitoring tools would be useful when conducting soil investigations for the project in section 3.1.1.

NEW TECHNOLOGY THAT CAN BE INCORPORATED		
6.	**Unmanned Aerial Vehicle (UAV) equipped LiDAR**  *GreenValley International UAV LiDAR System*	An UAV equipped with LiDAR can help construction reach a new height. It can function as a secondary layer of checks by assisting engineers and site supervisors in conducting progress checks and conducting safety checks remotely (Microdrones, 2020).
7.	**Unmanned Mini Excavator**  *Remote Excavator, XE15R*	The XE15R is an unmanned excavator that has a height of 1.35m and a width of 1.08m. It also features a 100m wireless connectivity range with self-learning function where it can save its operating manoeuvres and replay them on demand. This can potentially be a manpower saving measure where such a machinery is small enough to manoeuvre tight spaces and is able to be automated when performing digging operations in a similar environment especially given that the Caisson dimension is fixed till the required depth. With remote sensors onboard, there may also be lesser risk as compared to a manned mini excavator when digging operations are performed concurrently with worker(s) in the area. One additional factor may also be the reduced requirements needed for working in confined space as lesser manpower is required.

7.2 Basement Construction (Diaphragm Walls and Excavation)

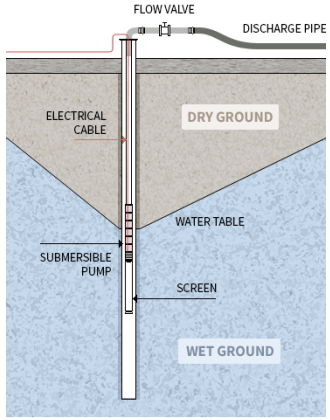
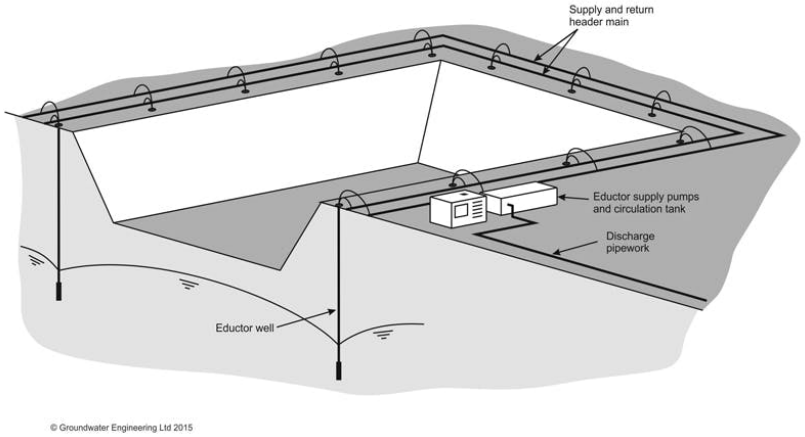
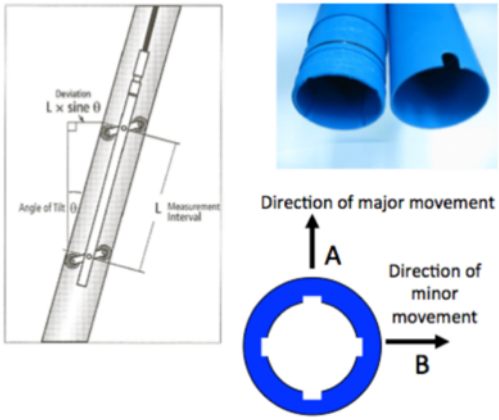
NO.	EQUIPMENT/ TECHNOLOGIES	BRIEF DESCRIPTION
1.	**Dewatering** • **Supporting Walls**  *Supporting Cutoff Walls* • **Deep Wells**  *Depiction of how Deep Well System operates*	As mentioned in Part 4.2, the soil condition at the site is Kallang Formation. Hence, the supporting walls and cut-off, dewatering technique, will be the diaphragm walls. Other dewatering techniques we will be using include: • Deep Wells Referring to the diagram, deep wells use the drilling and pumping techniques to draw water out from the ground (Ketek Group, n.d.; GroundWater Engineering, n.d.). This is where a number of wells are drilled in close proximity, along the perimeter of the area, and pumps are submerged into them to drain out the water. This technique is able to drain water out from a larger area efficiently. • Educator well system As Kallang Formation consists of low permeability soil, this system operates to draw water out from this poorly draining soil (GroundWater Engineering, n.d.). It acts like a vacuum and uses the suction to force the water out, which will be pumped out to the tank on ground level.

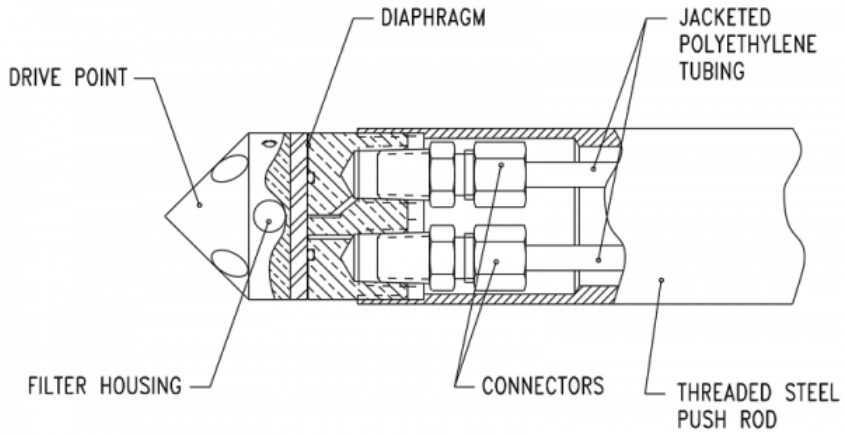
	 *Image of Deep Wells above ground* • **Educator well system**  *Depiction of how Educator Well System operates*	
2.	**Mini Excavator**	Please refer to Part 7.1

3.	**Inclinometer (GEOSMART, n.d.)**   *Casing top and metal protective box around inclinometer* **Inclinometer probe (GEOSMART, 2021)**  *Inclinometer Probe*	To carry out measurements of lateral displacements, the inclinometer plastic tube casing is installed into stable ground, near vertical boreholes that pass through suspected zones of movement. After the installation of inclinometer casing into the hole, the casing top is capped to prevent the entry of foreign particles. Metal protective boxes are used to prevent the instruments from being disturbed. Instrument identification is affixed on to the box. Next, the inclinometer probe which contains a gravity-actuated transducer fitted with wheels, is lowered into the casing and guided by internal grooves to survey the line of the inclinometer casing and keep it centralized in the casing as the survey takes place. An initial angle reading is taken to establish the profile of the casing at the beginning. Subsequently, as the construction progresses, the changes in the profile are recorded. The difference in angle readings represent the displacement occurred and further analysis will show the ground movements that have occurred. These data can be taken manually or automatically via the readout unit which is connected by a cable to the inclinometer. When using the inclinometer, the following are procedures and caution that should be implemented to improve the quality of the measurements taken.

	 *Workers carrying out measurements using the Inclinometer*  *Sprung Wheels to hold Inclinometer Probes in the centre*	o Sources of systematic errors (e.g. bias, changes in alignment of sensors, depth positioning) should be regularly examined and adjusted where required. Adjustments applied should be recorded for future references. o Use at least two independent inclinometer probes for multiple reference readings and compare readings between the probes. o Probes and cables should be examined for any wear and damage after each run to identify problems at an early stage (Chew, 2018 & Geotechnical Observations, n.d.)
4.	**Water Standpipes (GEOSMART, n.d.)**	A 50mm standpipe is lowered into a drilled 150mm at required depth. A cap and protective box are placed over the water standpipe tube opening to prevent disturbance. This is then backfilled with sand and the tubing is terminated at the surface and s protective cap is placed at the mouth of the tube. The water level indicator is lowered down the standpipe until it

	 Cap and protective box *placed over the Water Standpipe T*ube **Water level indicator**  *Water level Indicator*	comes into contact with water which is indicated by a light and buzzer sounds. The water level is represented by the depth markings on the cable. (Chew, 2018)

	 *Worker carrying out measurements using a Water Standpipe*	
5.	**Pneumatic piezometers**  *Pneumatic Piezometer*	The piezometer is usually sealed with a bentonite seal above the sand pocket to isolate the groundwater pressure at the tip. To prevent vertical water movement, the circular space around the riser pipe and the borehole is backfilled to the surface with a bentonite grout. The pneumatic tubes are connected to a terminal at the surface where readings can be obtained with a pneumatic indicator. The piezometer contains a flexible diaphragm with water and gas pressure each acting on one of the sides of the diaphragm. When pore water pressure is exerted on the diaphragm, the water level inside the standpipe rises. Reverse pressure is then applied until pressure equilibrium is reached and vice versa. The height of the water above the filter tip is equal to the pore-water pressure and the pneumatic indicator shows these readings on the pressure gauge where measurements can be collected. (Chew, 2018; DGSI, 2019 & Soil Instruments, n.d.)

	 *Cross Sectional Area of Pneumatic Piezometer*	
6.	**Tiltmeter System (QSafe, 2020)**  *Tiltmeter System Components*	A tiltmeter is simple to install and the various tilt plates can be easily monitored using a single tiltmeter. Being made from ceramic or bronze, the tilt plates also have excellent temperature stability, are durable and weather resistant. They can be mounted horizontally or vertically to be used on bottom surfaces and side surfaces, respectively. The tilt plates are usually bonded or screwed onto the structure in designated locations. To obtain tilt readings, the operator first connects the tiltmeter to the readout unit and positions it on the tilt plate. The displayed reading is recorded. Thereafter, the tiltmeter rotated 180° and the second reading is taken. The two readings are averaged to cancel any sensor offset. By

		comparing the current and the initial reading, changes in tilt are derived. (Chew, 2018 & QSafe, 2020)
7.	**Settlement Markers**  *Settlement Markers on C*oncrete	These markers are used to measure the vertical displacement of any surfaces and settlement. It is monitored through levelling survey and regular monitoring of readings (Chew, 2018).

NEW TECHNOLOGY THAT CAN BE INCORPORATED		
8.	**3D Laser Scanning and Digital Photogrammetry for Basement Construction Progress Tracking** • Light Detection and Ranging System (LiDAR) • Digital Photogrammetry  *LiDAR Sensor*  *3D Photogrammetry from Agisoft Metashape*	LiDAR equipment and 3D Photogrammetry software can be used together to develop accurate real time 3D images of Basement Construction Progress such as tracking of excavation (El-Omari & Moselhi, 2008). This allows the management to easily keep track of progress of excavation works without the need of being physically present in the worksite. More specifically, this reduces the number of times and number of personnel in the worksite of basement excavation which is also known as confined spaces where safety is of high concern. By having accurate real time 3D images of the progress site, project management can also be improved. Early detection of errors or flaws in Safety can also be identified and mitigated early.

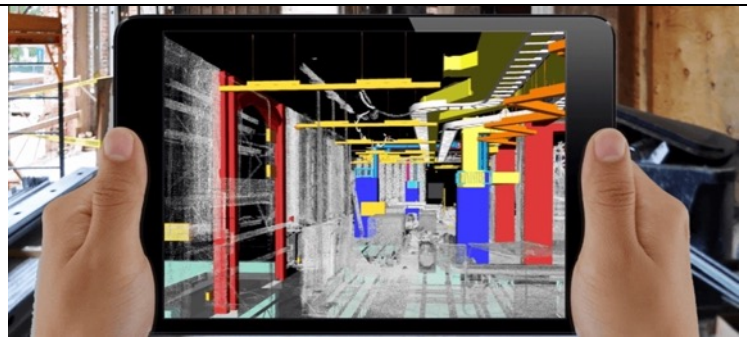
7.3 Construction Safety Technologies

In construction sites, safety is always the top challenge due to many factors, like the heavy machinery and equipment. Currently, traditional guidelines and practices on safety are still the norm in Singapore, with little use of technology. Hence, Singsong hopes to integrate some of the latest technologies into the safety aspect of project. Through the advancements in technology, responses towards workplace incidents and the general construction site safety have seen developments. Listed below are the technologies recommended to enhance workplace safety in the Singapore's construction industry.

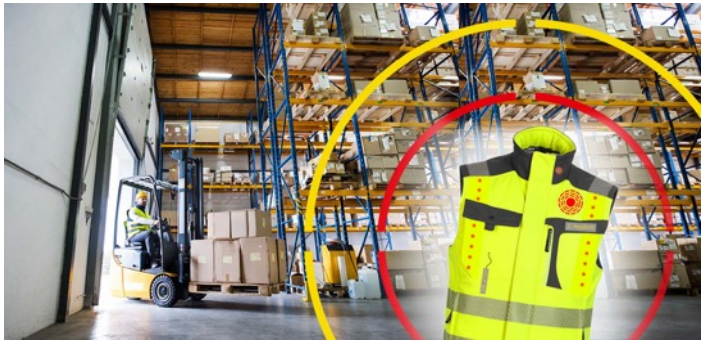
NO.	EQUIPMENT/ TECHNOLOGIES	BRIEF DESCRIPTION
1.	**Drones**  *Drones at the Construction Site*	Firstly, the usage of drones in the construction industry is becoming more popular. According to Raphaelson (2018), drones are unmanned flying agents, which can be used for a variety of functions in the industry. These include site surveying, identifying potential danger and conducting inspections on the site during construction. Drones can also be employed to supervise the safety of employees and provide updates on the changing work environment. It helps to keep a record of all activities during construction and all stakeholders will be kept informed as well (Chaturvedi, 2018). Overall, drones have helped to reduce costs and increase productivity for projects. Examples on how drones can be integrated with safety procedures: • Trench inspection – Instead of having to physically walk through the sites for inspections, the inspectors could utilise drones to do a site survey for those applicable. If there are any abnormalities, inspectors can then examine it physically.

		• Ensuring tunnel stability – When conducting inspections on the tunnel works, drones can be used to first examine the area. Another key benefit of the drone technology is the integration with construction software, like Building Information Modelling (BIM) (Chaturvedi, 2018). This is done through the ability of drones to capture high-resolution imagery of the project site. With this integration, BIM adoption would be more encouraged in the industry as it is simpler to create 3D models in the software. This helps to increase efficiency, productivity and provide a better understanding of the project.
2.	**Virtual Reality (VR)**  *Worker using VR for Training*	Secondly, virtual reality (VR) simulation can be used to train employees on equipment operations and safety training (Raphaelson, 2018). Accidents and even deaths have occurred before because of the lack of training. Training and practice are compulsory for workers to operate the heavy equipment, like cranes. However, it is very costly and dangerous to train the workers physically on site. Hence, with the use of VR, these training can be done using physical equipment but virtually, which is much safer and provides more experience (Strohanova, 2019). Mistakes could be made until workers master the equipment and they will not injure themselves nor damage the equipment. In addition, VR allows for remote virtual site visits by the clients and contractors (Strohanova, 2019). They would be able to monitor and supervise the construction progress. Virtual discussions and changes,

		which applies only during the planning stage, with the model in view could also be done. The software should be able to show updated construction progresses and help to generate any statistics report automatically. VR could also be used for ensuring tunnel stability. These helps to save costs, increase quality and allow for better time management.
3.	**Augmented Reality (AR)**  *Bricklayers Utilising AR*	Similarly, augmented reality (AR) helps in the coordinating of safety in the construction industry too. Firstly, AR provides a more accurate and precise design of the structure (Souza, 2019). For example, as seen in the picture on the left, workers are able to lay the bricks more precisely on the location of the brick wall through the AR glasses they are wearing. This implies that with the help of AR, there will be more precision on what will be built, which includes all levels of materials and installations. Contractors and architects are also able to have a virtual walkthrough of the structure, having a constructability review and looking at the mechanical and electrical installations in the walls (Yoders, 2018). In the constructability review, contractors will also be able to pinpoint the more challenging and dangerous works during construction and put more emphasis on these areas. In addition, the use of AR would be able to provide real-time information on any gas pipe or underground obstructions when doing underground construction (Morozova, 2019). This will be very advantageous as any

	 *Using AR to Virtualise Equipment in Site*	hinderance with these obstructions might be deadly. In our case, the use of AR will be very beneficial as the basement will be built above Zone 1 of the MRT tunnel. With regards to the above mentioned, AR primarily benefits in the safety aspects, more efficient project management and collaboration and reduction in number of times in rectifying the works. This helps in cost-savings and efficiency.
4.	**Mobile Applications** *Scribe Application*	Next, the use of a mobile application can enhance safety during construction. Mobile Applications should be used to track and monitor employees' activities and locations during work, post safety issues on the project, and keep records of past safety incidents (Raphaelson, 2018; JLG, 2018). Features should include: • GPS tracking – to monitor employees' movements and activity, especially if they are performing the duties alone. In any case where they are taking too long or inactive, supervisors could be alerted immediately to assess the situation. • Panic button – In the case where any accidents, this is to allow employees to send a panic alert immediately to request for immediate assistance.

	 *Fieldlens Application*  *StaySafe Application*	• On-the-go reporting system and record keeping – to allow any worker on site to report any safety issues once noticed. He will be able to provide real-time information and photographs or videos if needed. Appropriate action can then be taken immediately to resolve the issues. In addition, the application will help to record and document all safety issues that have occurred for reference. Some mobile applications with these features are already in the market, like the StaySafe, Scribe for OSHA and Fieldlens (Raphaelson, 2018; JLG, 2018). Hence, these applications would have to be integrated in Singapore and employees have to be IT trained for these applications to be effective.
5.	**Hard Hats That Detect Carbon Monoxide**	Safety of everyone on the worksite should be taken into account and basic safety gear should be available. Typically, hard hats are compulsory for every worker in the construction site for safety (Raphaelson, 2018). The hats are to protect against any impact to the head, like falling objects and falling down. Under the daily Trench

	 *Hard Hat with Carbon Monoxide Detectors*	Inspection, there should be a field to check if all employees are geared with the hard hats before starting work (OSHA, n.d.). In addition, these hard hats should be supplemented with carbon monoxide detectors (Raphaelson, 2018). This is to detect the presence of the deadly gas and alert workers immediately for evacuation. With the detectors on the hard hats, workers will be able ascertain if a project site is safe for construction and take necessary action for everyone's safety.
6.	**Smart safety wearables**  *Safety Vests*	Similar to the mobile application, Smart safety wearables can be used to effectively enhance safety in construction sites, including safety vests, boots, and hard hats (Raphaelson, 2018). These wearables have functions like the mobile application. Below are some additional functions: Safety vests – These vests are compulsory for anyone at construction sites and it would serve as an effective safety instrument. An example is the Smart safety vest by ELOshield (2019), which acts like a smart clothing. The vest, which is installed with a tracking and detection system, will be able to send signals to parties when danger approaches. For example, when a forklift is within range of a personnel, an alarm will go off from the vest to alert him. In addition, a message will be sent to the truck and



Safety Helmets



Safety Boots

it will automatically slow down to allow reaction time of the personnel. The system has a long-range detection system that is all rounded so as to prevent any accidents. These vests are also installed with a name badge, LED stripes for visibility, metal detector and gas detection sensory (ELOshield, 2019; Rajendran, Wahab & Yeap, 2020) .

Smart helmet – Safety helmets can be installed with in-built cameras with telecommunication services to provide real-time information and even videos (Lim, 2019). Similar to the mobile application, workers are able to report any information even if their hands are occupied. Since it is compulsory for all workers to wear the helmet, the wearable can act as an attendance taking device and notify supervisors if anyone on site is not following the rules.

Safety boots – These boots have similar features as the mobile application. An example is from Intellinium (2020) and one special feature is the Smart man-down. Other than detecting whether the worker is inactive, it has a feature to detect if the worker has fallen. In addition, if he does not respond to a signal, whether to request for help, alert will be automatically sent to supervisors.

With these technologies integrated in the essentials of all construction personnel, there is no need for them to carry any additional devices.

7.	**Site Sensors**  *Site Sensors for Monitoring Site Conditions*	Adding on to smart safety equipment, site sensors could be installed in construction sites for safety. These sensors could be used to survey different areas of the sites to provide essential information, like the noise levels, temperature, energy usage and volatile organic compounds (Raphaelson, 2018; RedTeam, n.d.). With these sensors installed around the sites, workers will be alerted immediately about the suitability of the site conditions Other than sensors for the surroundings, sensors can be integrated with the machinery for their maintenance, especially for critical ones like a backhoe (Nichols, 2020; RedTeam, n.d.). With these sensors, operators will be alerted if there is any need for cleaning, malfunction, part degradation or just a reboot. In addition, construction equipment can benefit from these sensors too. They will be able to monitor the supply, health, and lifespan of materials, like concrete (Ellis, 2020). Thus, the supply chain of materials can be maintained. Different materials react differently in different circumstances, like the temperature. Hence, with the sensors, planning can be done. Overall, with these functions, machine downtime, costs and the chance of any injury caused by the machines' malfunctioning are reduced.

CONCLUSION

In conclusion, this report provides a method statement on the construction of the foundation system and basement for SG-Lotte. Having identified the risks, it provides an overview of the risk assessment for PFM Pte Ltd. In addition, supporting construction technologies and key criteria in addressing the risks identified, which are vital to operations of PFM Pte Ltd, were stated and elaborated. Similar past case studies were also shared for stakeholders as additional key learning points. Hence, this method statement documents the procedures and guidelines for the safe operations of the foundation and basement works for the building.

REFERENCES

1. Agisoft. (n.d.). Intelligent Photogrammetry. Agisoft. https://www.agisoft.com/pdf/metashape_presentation.pdf
2. Back to Basic. (2020). Four Methods of Dewatering and How to Choose One. https://backtobasics.edu.au/2020/01/four-methods-of-dewatering-and-how-to-choose-one/
3. Ball, M. (2015, September 7). XCMG Launches Fully Remote-Controlled Intelligent Excavator. XCMG. https://www.unmannedsystemstechnology.com/2015/09/xcmg-launches-fully-remote-controlled-intelligent-excavator/
4. BCA. (n.d., (a)). Temporary Earth Retaining Structure/ Excavation Failure. BCA. https://www1.bca.gov.sg/docs/default-source/docs-corp-regulatory/building-control/lessons-learnt-from-structural-failures/temporary-earth-retaining-structures-or-excation-works-failures.pdf?sfvrsn=8b0badf3_2.
5. BCA. (n.d., (b)). Improper use of Bored Pile Foundation for a 10-storey Building. BCA. https://www1.bca.gov.sg/docs/default-source/docs-corp-regulatory/building-control/lessons-learnt-from-structural-failures/improper-use-of-bored-pile-foundation-for-10-storey-apartments.pdf?sfvrsn=903bcc20_2
6. Bica, A. V. D., Prezzi, M., Seo, H., Salgado, R., & Kim, D. (2014). Instrumentation and axial load testing of displacement piles. Proceedings of the Institution of Civil Engineers. Geotechnical Engineering, 167(3), 238-252. doi:10.1680/geng.12.00080
7. Birkner, J. (2010, July 1). Noise in Construction. EHS Today. https://www.ehstoday.com/ppe/article/21910176/noise-in-construction.
8. Black, S. (2011, March 17). The five countries with the lowest risk of disaster. Business Insider. https://www.businessinsider.com/5-countries-with-the-lowest-risk-of-disaster-2011-3.
9. Broms, B. B., & Lai, H. P. (1995, December). The Republic Plaza in Singapore – Foundation design. Proceedings In Bengt B. Broms Symposium in Geotechnical Engineering, Singapore, 13-15. World Scientific.
10. Building and Construction Authority (BCA). Geology & Site Investigation Works. Geology & Site Investigation Works | Building and Construction Authority (BCA). https://www1.bca.gov.sg/regulatory-info/building-control/geology-site-investigation-works.
11. Building and Construction Authority. (2013, April 25). Guidebook for Design of Buildings in Singapore to Requirements in SS EN 1998-1. Retrieved from https://www1.bca.gov.sg/docs/default-source/docs-corp-regulatory/building-control/bc3-2013.pdf.

12. Buys, F. (2015, September 6). Five Cause of project delay and cost overrun, and their mitigation measures. Linkedin. https://www.linkedin.com/pulse/five-causes-project-delay-cost-overrun-mitigation-measures-buys
13. Calin, N., Radu, C., & Bica, I. (2017, March). Dewatering system of a deep of excavation in urban area – Bucharest case study. Elsevier Ltd. https://doi.org/10.1016/j.proeng.2017.11.149
14. Chaturvedi, A. (2018, November 23). Drones to propel new innovations in the construction industry. Geospatial World. https://www.geospatialworld.net/blogs/drones-to-propel-new-technological-innovations-in-the-construction-industry/
15. Chew, M. Y. L. (2018). Construction Technology for Tall Buildings (5th ed.). World Scientific Publishing Co. Pte. Ltd. https://doi.org/10.1142/10465
16. Construction Cost. (n.d.). Details of top down construction method. http://constructioncost.co/details-of-top-down-construction-method.html
17. Cotney Construction Law [CCL]. (2020). Poor Workmanship Leads to Construction Defects. CCL. https://trentcotney.com/construction/poor-workmanship-leads-to-construction-defects/.
18. Designing Buildings Wiki. (2020, September 2). Diaphragm wall. https://www.designingbuildings.co.uk/wiki/Diaphragm_wall
19. DGSI. (2019). Pneumatic Piezometers. Durham Geo Slope Indicator. https://durhamgeo.com/product/pneumatic-piezometers/
20. Ellis, G. (2020, January 14). Sensing the Future of Building: The Role of Sensors in Construction. Autodesk Construction Cloud. https://constructionblog.autodesk.com/sensors-in-construction/
21. El-Omari, S., & Moselhi, O. (2008). Integrating 3D laser scanning and photogrammetry for progress measurement of construction work. Automation in Construction, 18(1), 1-9. doi:10.1016/j.autcon.2008.05.006
22. ELOshield. (2019, February 15). New: Smart safety vest for ELOshield. Elokon. https://www.elokon.com/en-EN/newsroom/details/smart-safety-vest-for-eloshield.html
23. Geobear. (2020, February 5). What is Heave? https://www.geobear.co.uk/what-is-heave/
24. GEOSMART. (n.d.). Geotechnical Instruments. http://geosmart.com.sg/technical/Geotechnical_Instruments.pdf
25. Geosmart. (n.d.). Settlement Markers. Geosmart. http://geosmart.com.sg/technical/Geotechnical_Instruments.pdf
26. Geotech. (2020). Retaining structures - Top-down construction method. https://www.geotech.hr/en/top-down-construction-method/
27. Geotechnical Observations. (n.d.). Inclinometers. http://www.geo-observations.com/inclinometers

28. Geotechnical Observations. (n.d.). Inclinometers. Geotechnical Observations. http://www.geo-observations.com/inclinometers
29. Goh, Y. M. (2020). Limit State Design. National University of Singapore.
30. GreenValley Technologies. (n.d.). LIAIR SERIES. GreenValley Technologies. https://greenvalleyintl.com/hardware/liair-series/
31. Griffin. (2020). Deep Well Systems. Griffin Dewatering Corporation. https://www.griffindewatering.com/construction-dewatering/deep-well-system/
32. GWE. (2015, February 15). Deep Well Dewatering. Groundwater Engineering Limited. https://www.groundwatereng.com/blog/2015/02/deep-well-dewatering
33. GWE. (n.d.). Construction Dewatering. GWE. https://www.groundwatereng.com/uploads/groundwater_engineering/files/TDS_-_Construction_Dewatering_V4.pdf
34. GWE. (n.d.). Eductors. GWE. https://www.groundwatereng.com/dewatering-techniques/eductors
35. Hirschmann, R. (2020, June 5). Number of foreign construction workers employed in Singapore from 2013 to 2019. Satista. https://www.statista.com/statistics/1054354/singapore-foreign-construction-workers-employed/
36. Infocomm Media Development Authority (IMDA). (2019, February). REQUIREMENTS TO BE COMPLIED WITH BY EARTHWORKS CONTRACTORS FOR THE PREVENTION OF DAMAGE TO TELECOMMUNICATION CABLES. https://www.imda.gov.sg/-/media/imda/files/regulation-licensing-and-consultations/licensing/licenses/earthworks-requirementsversion10.pdf?la=en.
37. Intellinium. (2020). Connected Safety Shoes, Smart PPE and Connected Worker. Intellinium. https://intellinium.io/smart-connected-safety-shoes/
38. Janberg, K. (2004, May 10). Republic Plaza, Singapore. Structurae. https://structurae.net/en/media/18195-republic-plaza-singapore
39. JLG. (2018, December). Construction Site Safety Technologies: Top 5 Mobile Apps for the Job. JLG. https://www.jlg.com/en/direct-access/2018/12/03/construction-site-safety-technologies
40. Ketek Group. (n.d.). Dewatering Techniques and Solutions. Ketek Group. https://ketek.ca/services/dewatering/
41. Kimaro. (2017). Tilt Meter. Kimaro Geotechnical Pte Ltd. https://kimaro.com.sg/tilt-meter/
42. Kimaro. (n.d.). Tilt Meter. Kimaro. https://kimaro.com.sg/tilt-meter/
43. Koh, J., & Prasad, V. J.-M. (2014, October 13). Earth tremors in Singapore. https://eresources.nlb.gov.sg/infopedia/articles/SIP_65_2005-02-02.html.
44. Land Transport Authority (LTA). (2005, January). Handbook on Development & Building Works in Railway Protection Zone.

https://www.lta.gov.sg/content/dam/ltagov/industry_innovations/industry_matters/development_construction_resources/Building_Works_Restricted_Activities_in_Railway_Protection_Zone/Codes_of_Practice_Standards_Specifications_Guides_Forms/Handbook_on_DevelopmentBuilding_Works_in_RPZ.pdf.

45. Lim, B. (2019, February 25). Innovation: Smart Helmet for Workers. New Straits Times. https://www.nst.com.my/lifestyle/bots/2019/02/463500/innovation-smart-helmet-workers
46. Lior, Z. (2017) When and where to Use a Mini Excavator. https://www.bigrentz.com/how-to-guides/use-mini-excavator#:~:text=A%20mini%20excavator%20is%20a,excavators%20at%2010%2C000%20lbs%2C%20though.
47. LTA. (n.d., (a)). INSTALLATION OF RETAINING WALL - SHEET PILE WALL. Land Transport Authority. https://www.lta.gov.sg/content/dam/ltagov/getting_around/public_transport/rail_network/pdf/spw_final_inside.pdf
48. LTA. (n.d., (b)). TOP-DOWN CONSTRUCTION. Land Transport Authority. https://www.lta.gov.sg/content/dam/ltagov/getting_around/public_transport/rail_network/pdf/topdown_final.pdf
49. LTA. (n.d., (c)). CONSTRUCTION OF CONTIGUOUS BORED PILE WALL. Land Transport Authority. https://www.lta.gov.sg/content/dam/ltagov/getting_around/public_transport/rail_network/pdf/cbp_final.pdf
50. LTA. (2009). Guide to Carrying out Restricted Activities within Railway Protected and Safety Zone. https://www.lta.gov.sg/content/dam/ltagov/industry_innovations/industry_matters/development_construction_resources/Building_Works_Restricted_Activities_in_Railway_Protection_Zone/Codes_of_Practice_Standards_Specifications_Guides_Forms/Guide_to_carrying_out_restricted_activities_within_railway_protection_and_safety_zones.pdf
51. M+. Section and floor plans, Development Bank of Singapore (DBS) headquarters building (1969–1975), Singapore. M+ Collections Beta. https://collections.mplus.org.hk/en/objects/section-and-floor-plans-development-bank-of-singapore-dbs-headquarters-building-19691975-singapore-ca29-2-3-13
52. Microdrones. (2020, August 28). Using Drones in Construction for Aerial Inspection, Photogrammetry or Lidar. GEO4 Construction. https://www.geo4construction.com/news/using-drones-in-construction-for-aerial-inspection-photogrammetry-or-lidar
53. MNH. (2017, August 17). Top Down Excavation Process at Concourse [Video]. YouTube. https://www.youtube.com/watch?v=9v-nlVtKEoM&ab_channel=MNH

54. Moh, Z.-C. (1994). Current deep foundation practice in Taiwan and Southeast Asia. MMA. http://www.maa.com.tw/common/publications/1991/1991-076.pdf
55. Morozova, A. (n.d.). How Augmented Reality Is Used in the Construction Industry to Save Money and Speed Up Projects. Jasoren. https://jasoren.com/augmented-reality-in-construction/
56. National Environmental Agency [NEA]. (2020, February 20). Construction Noise Pollution. NEA. https://www.nea.gov.sg/our-services/pollution-control/noise-pollution/construction-noise-control.
57. Natsoulis, N. (2020, June 19). Comparing Steel Construction and Concrete Construction. MEP Engineering & Design Consulting Firm. https://www.ny-engineers.com/blog/comparing-steel-construction-and-concrete-construction.
58. Nichols, M. R. (2020, January 9). Smart Sensors Are A Game Changer For The Construction Industry. Euro Scientist. https://www.euroscientist.com/smart-sensors-are-a-game-changer-for-the-construction-industry/
59. Oriental Shiraishi Corporation (OSC). Outline of Pneumatic Caisson Method. http://www.orsc.co.jp/english/tec/newm_v2/ncon02.html
60. OSHA. (n.d.). eTools. OSHA. https://www.osha.gov/SLTC/etools/construction/trenching/excavchec.html
61. Ouster. (2020). OSO. Ouster. https://ouster.com/products/os0-lidar-sensor/
62. Phua, R. & Chew, H. M. (2020, June 9). Can Singapore rely less on foreign workers? It's not just about dollars and cents, say observers. CNA. https://www.channelnewsasia.com/news/singapore/singapore-foreign-workers-reliance-challenges-12806970
63. PLLC. (2014, April 30). What are the causes of accident on construction site?. PLLC. https://www.perecman.com/blog/2014/april/what-are-the-causes-of-accident-on-construction-/.
64. Public Utilities Board (PUB). (2019, October). PUB (WRN) ADVISORY NOTE ON PREVENTION OF DAMAGE TO PUBLIC SEWERAGE SYSTEM. https://www.pub.gov.sg/Documents/WRN_AdvisoryNotes.pdf.
65. QSafe. (2020). Tilt Monitoring. QSafe. https://www.qsafe.com.sg/tilt-monitoring-system-singapore/
66. Quantity-takeoff.com. (2016). Advantages and Disadvantages of Top Down Construction. Construction Cost Estimating. http://www.quantity-takeoff.com/top-down-construction.htm
67. RailSystem.net. (2015). Secant Pile Wall Construction. Http://Www.Railsystem.Net/Secant-Pile-Walls/. http://www.railsystem.net/secant-pile-walls/

68. Rajendran, S. D., Wahab, S. N., & Yeap, S. P. (2020). Design of a smart safety vest incorporated with metal detector kits for enhanced personal protection. Safety and Health at Work, doi:10.1016/j.shaw.2020.06.007
69. Redteam. (n.d.). Site Sensors and Construction: Enhancing the Jobsite Ecosystem. Redteam. https://www.redteam.com/site-sensors-and-construction-enhancing-the-jobsite-ecosystem/#:~:text=Through%20the%20use%20of%20site,information%20during%20the%20construction%20process.
70. Reuters. (2020, February 19). Singapore Construction Firms seeking force majeure advice as coronavirus causes labour crunch. The Straits Times. https://str.sg/JGeA_The Perecman Firm [PLLC]. (2016, July 12). Electrocution Hazards on construction sites. PLLC. https://www.perecman.com/blog/2016/july/electrocution-hazards-on-construction-sites/.
71. RocTest. (n.d.). FPC-2 Pneumatic Piezometer. RocTest. https://roctest.com/en/product/fpc-2-pneumatic-piezometer/
72. Singapore Memory. DBS Milestone : DBS Building at Shenton Way. Singapore Memory. https://www.singaporememory.sg/contents/SMB-d118c2e6-43ce-49ff-885f-8302a038d95d.
73. Singapore Standards [SS]. (2019). SS 650-1: 2019 Code of practice for temporary electrical installations - Part 1: Construction and building sites. SS. https://www.singaporestandardseshop.sg/Product/SSPdtDetail/9b277ae1-6b87-4e67-b458-1b8a69c4968e.
74. Singapore Statues Online [SSO]. (2007). Workplace Safety and Health (General Provisions) Regulations. Workplace Safety and Health Act (Chapter 354A). https://sso.agc.gov.sg/SL/WSHA2006-RG1#legis.
75. Singapore Statues Online [SSO]. (2007). Workplace Safety and Health (Construction) Regulations. Workplace Safety and Health Act (Chapter 354A). https://sso.agc.gov.sg/SL/WSHA2006-S663-2007?DocDate=20140409&ProvIds=legis#legis
76. Singapore Statutes Online [SSO]. (2007). Workplace Safety and Health (Construction) Regulations (PART VII, s 47). Retrieved from https://sso.agc.gov.sg/SL/WSHA2006-S663-2007.
77. Singapore Statutes Online [SSO]. (2007). Workplace Safety and Health (Construction) Regulations (PART XI, s 77-90) Retrieved from https://sso.agc.gov.sg/SL/WSHA2006-S663-2007
78. Singapore Statutes Online [SSO]. (2007). Workplace Safety and Health (Construction) Regulations (PART XV, s 134-140) Retrieved from https://sso.agc.gov.sg/SL/WSHA2006-S663-2007.
79. Singapore Statutes Online [SSO]. (2007). Workplace Safety and Health (Construction) Regulations (PART IX, s 65) Retrieved from https://sso.agc.gov.sg/SL/WSHA2006-S663-2007

80. Shuttlelift. (n.d.). Why Shuttlelift. Shuttlelift. https://www.shuttlelift.com/
81. Soil Instruments. (n.d.). Pneumatic Piezometer. https://soilinstruments.com/products/water-monitors-piezometers-meters/pneumatic-piezometer/
82. Souza, E. (n.d.). 9 Augmented Reality Technologies for Architecture and Construction. Arch Daily. https://www.archdaily.com/914501/9-augmented-reality-technologies-for-architecture-and-construction.
83. SRI International. (2017, October 23). Augmented Reality Solutions for Construction Inspection [Video]. Youtube. https://www.youtube.com/watch?v=8lY4qaVvR8c
84. Strohanova, C. (n.d.). 4 Ways to Use Virtual Reality in Construction Industry. Jasoren. https://jasoren.com/virtual-reality-in-construction/
85. Trajkovski, S., & Loosemore, M. (2006). Safety implications of low-english proficiency among migrant construction site operatives. International Journal of Project Management, 24(5), 446-452. doi:10.1016/j.ijproman.2005.11.004.
86. TREVI. (n.d.). DIAPHRAGM WALLS - HYDROMILL. https://www.trevispa.com/en/Technologies/diaphragm-walls-hydromill
87. TreviFoundations. (n.d.). Diaphragm Walls. TreviFoundations. https://www.trevikuwait.com/viewdoc.asp?co_id=4341
88. WJ Canada. (2019). Deepwell Systems. https://wjcanada.com/our-services/deepwell-systems/
89. Workplace Safety & Health [WSH]. (2016). Workplace Safety and Health Guidelines (Design for Safety). WSH. https://www.wshc.sg/files/wshc/upload/cms/file/WSH_Guidelines_Design_for_Safety(1).pdf
90. Wong, M. S. K. (2020). Project Spring-Winter (PSW) [Slides].
91. Zheng, G., & Li, Z. (2012). Effect of staged dewatering and excavation on the heave of soil beneath deep excavation. Taylor & Francis Group. https://www.issmge.org/uploads/publications/6/13/2011_081.pdf

APPENDICES

Appendix A: Foundations

A1: Cast-in Piles

Cast-in piles are constructed by generally driving a steel casing into the ground and then filling it with concrete. The steel shells driven into expansive soils should be filled with concrete as soon as possible and withdrawn after driven in the ground to prevent the damage of the shell due to lateral soil pressure.

A2: Column Footing

Column footing is a type of shallow foundation system. It is a block of concrete that transfers the concentrated load coming from above across a sufficient large area of soil such that the allowable stress of the soil is not exceeded.

A3: Bored Pile Methods

Bored piles are formed by boring or removing a circular column of soil using an auger or boring bucket. Steel reinforcements are then inserted and filled with wet concrete through a tremie pipe. During boring, casings or bentonite may be utilised to prevent the collapse of soil.

