ARTICLE

Finding the ‘golden ratio’: selecting the right retaining system for metro deep excavations

Metros have been an integral part of cities since 1863, helping to reduce commuting costs and create an eco-friendlier environment. Despite being mainly underground excavations (tunnels and caverns), these necessitate deep excavations for the stations and entrances and are rarely risk and problem-free.

“Non-structural support systems are always the most cost-effective retaining system since these require minimum support and time for implementation”

What are the key risks associated with metro construction?

The main risk associated with metro construction is related to settlements and lateral displacements during the excavation works (either during the open excavations or tunnelling), which can cause damage to buildings and utilities, whilst others are related to the underground water management[1].

To reduce the risk of settlements and displacements and avoid potential damages to the excavation and adjacent structures, the thorough investigation of the following is required for the designs to be developed:

— underlying geotechnical conditions

— the loading from the surrounding structures

— the type and depth of the adjacent building’s foundation

— the location of the adjacent structures from the excavation.

What are the types of retaining structures in deep excavations?

For deep excavations, either in urban or rural environments, the necessity of retaining structures is always considered to ensure safe environments during temporary (construction) and permanent (operation) conditions. The main differences between urban and rural excavations are the existence of adjacent buildings and the design life of the excavations (permanent or temporary). The first difference is linked to the loading conditions, whilst the second with the material to be used for the support of the excavations’ slopes, and eventually the design life of the excavation.

1 See https://www.fticonsulting-emea.com/insights/articles/water-inflows-deep-excavations-karstified-rock

The retaining structures can be classified as non-structural (open cuts with or without local support of rock bolts / soil nails and shotcrete) or structural (gravity walls, pile walls, diaphragm walls). The structural retaining systems can be sub-divided into contiguous (watertight) and non-contiguous (non-watertight).

Non-structural support systems are always the most cost-effective retaining system since these require minimum support and time for implementation, whilst structural support systems are expensive and time-consuming to administer.

Typical sections of support systems for deep excavations (structural and non-structural) are presented in Figure 1.

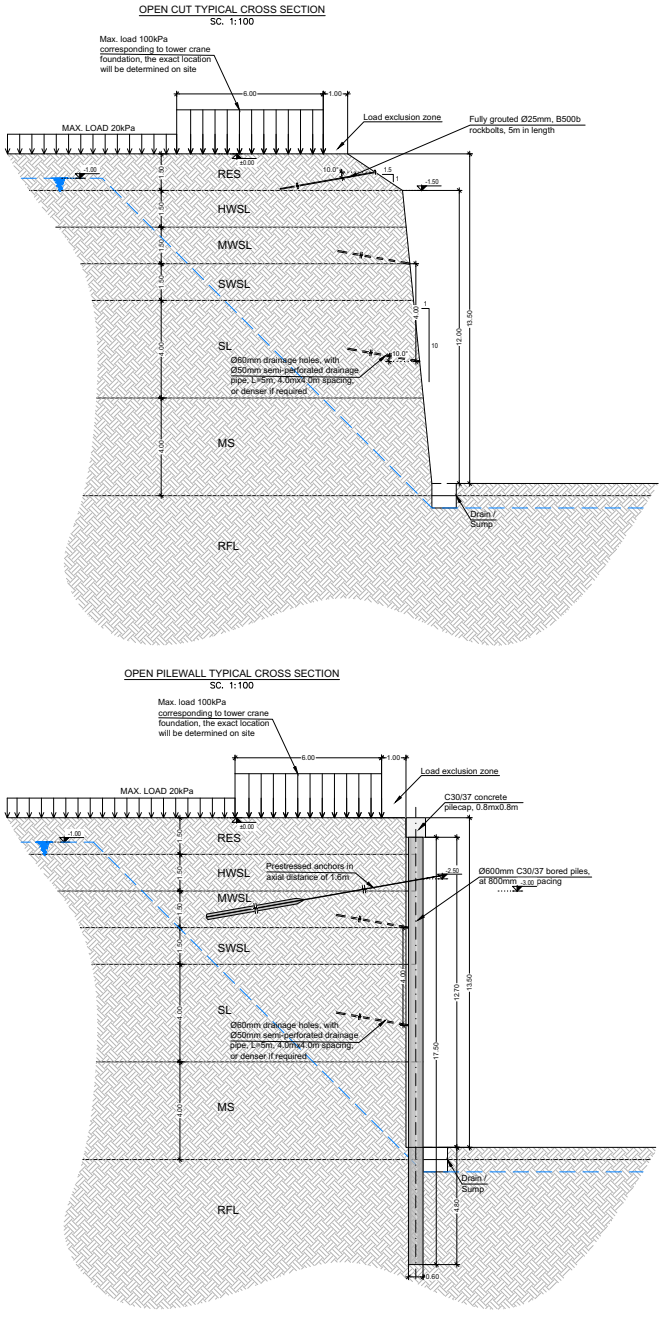

Figure 1. Typical sections of structural and non-structural support systems

How to select the appropriate type of retaining structure

Selecting the retaining structure is not a straight-forward decision and is related to many factors. For example, in an urban deep excavation in rock formation, the feasibility of the open cut (non-structural) is related not only to the strength of the rock but to the existence and location of surrounding buildings and the importance of them (for example, religious buildings, hospitals, antiquities). These factors can directly prohibit the applicability of an open cut and lead to a more robust structural retaining structure. On the contrary, under the same geotechnical conditions, a rural excavation is dependent only on the available land (expropriation boundaries) for the construction of an open cut.

The designers must always find the "golden ratio" between the type of retaining structure and the cost of the construction. In many cases, which eventually lead to arbitration and disputes, designers must mitigate their own risk of unexpected geotechnical conditions on-site and propose to the contractors a "no-risk", unnecessarily robust solution that is expensive and time-consuming to the construction.

"The designers must always find the "golden ratio" between the type of retaining structure and the cost of the construction."

A simplified tool to quickly select the type of retaining system can be seen in Figure 2. Here, the effect of the groundwater has been omitted.

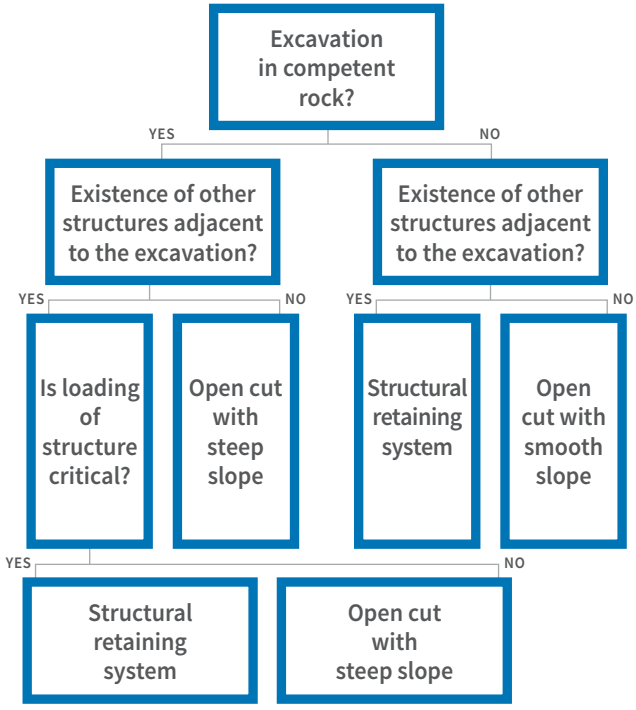

Figure 2. Simplified tool for the proper selection of the retaining system.

What are the consequences of selecting the wrong retaining system?

Whether in rural or urban environments, the selection of the retaining system plays a vital role for both the economy of the construction and the short and long-term safety. In the event of an unnecessarily robust retaining system, the contractor will be required to increase the cost and time of the construction, which essentially leads to money and time spent outside of the budget and program.

"Whether in rural or urban environments, the selection of the retaining system plays a vital role for both the economy of the construction and the short and long-term safety."

Although a more expensive construction leads to more money and time spent, a wrongly estimated solution may result in under-designing the requirements, and eventually may lead to damages, injuries or even deaths during construction or operation. The under-design of a retaining system is mainly due to the wrong assessment of the geotechnical parameters or due to underestimation of the adjacent structures' loading.

Incidents, as minor as a few centimetres of displacement or settlement with the formation of minor cracks, to the total collapse of the excavation with simultaneous damages to adjacent structures and injuries or deaths, have been recorded around the world, both in urban and rural projects. Such failures always result in disputes between the contractors and the designers. In brief, the results from the selection of the retaining system are presented in Table 1.

ISSUES ARISING FROM THE SELECTION OF THE RETAINING SYSTEM

Aspect	Under designed	Proper designed	Over designed
Cost	Lower than budget	As per budget	Over budget
Time	Shorter than planned	As per plan	Longer than planned
Potential Consequence	Risk of failure (for example, collapse)	None	Cost and time impact
Potential Result	**Dispute / Legal**	—	**Dispute**

Table 1. Results from the selection of the retaining system.

As is evident, the proper selection of the retaining system determines the outcome of the construction and the relationship between the involved parties. If a good relationship is established between the parties, the project can be developed smoothly; if it's not, time and money may be consumed by arbitrations and litigations, where the outcome eventually becomes public and can damage the reputation of those involved.

"The proper selection of the retaining system determines the outcome of the construction and the relationship between the involved parties"

EVANGELOS GEORGOPOULOS
Senior Consultant - Construction Solutions, Qatar
+974 4404 1694
Evangelos.Georgopoulos@fticonsulting.com