Abstract—Recent urbanisation of central parts of Greater Khartoum has necessitated the use of deep excavations for foundation of high rise buildings and infrastructure projects. The conditions of the subsoil, the safety of neighbouring structures, ground water regime, limitations of vibration and noise caused by construction must all be considered for choice of deep excavation support system. Economic factors and local availability of equipment and technical staff are also governing factors for the choice of an appropriate system.

Three case studies in which shoring was used are presented. Two are for high rise buildings and one for infrastructure project. Contiguous and secant bored concrete pile walls are presented as relevant solutions. Construction was completed and reported.

Keywords—Deep excavations, shoring, contiguous piles, secant piles.

I. INTRODUCTION

Urbanization is a trend that has been growing world wide since the middle of the last century. Large metropolitan cities in Europe, North America and the South East Asia region are evolved this trend.

Fast population growth, limited land resources, high rise buildings, sophisticated and complex infrastructure needs has caused extra pressures for the use of deep excavation underground construction.

Environmental and social constraints such as limitations on noise levels, vibration, and soil movement in nearby or neighbouring existing structures are been considered. [1, 2, 3, 4].

Khartoum city was developed as the capital of the Sudan since the establishment of the Anglo-Egyptian rule of the country at the turn of the twentieth century. A simplified master plan for Khartoum was introduced in 1898 by Lord Kitchener the Governor General of the new Sudanese Anglo-EGyptian colony. Another master plan was produced in 1908 by Macklin. The first well developed Khartoum structural plan was presented by Doxiades in 1958 after the independence of Sudan. That was followed by structural plans in 1976, 1992, and 2010. [5, 6].

Through these structural plans two trends were clear. Rural expansions of swath areas in the periphery and urbanisation of central area have emerged as two different and sometimes contradicting developments.

The rural expansion is associated with movement and displacement of population from the rural country side areas. It is associated with poverty and lack of infrastructure for an ever increasing number of people. The issues associated with this trend are not within the scope of this paper.

The centers of the three cities comprising Greater Khartoum i.e. Khartoum, Omdurman and Khartoum North experienced considerable rise in land prices, emergence of multi storey buildings as a norm with increasing number of floors from two and three stories to higher buildings exceeding twenty stories. Due to scarcity of land at these city centers use of deep excavation for underground construction of multiple basements are now normally considered. Shoring of such excavation may be used.

II. CONSTRAINTS ASSOCIATED WITH DEEP FOUNDATION CONSTRUCTION

As the construction project develops the need for excavation of foundation depths of 5 meters or more below existing grade requires more attention to be paid to subsoil site conditions. The reasons for this are:

1. Differing soil properties have to be considered. Generally sandy soil need lateral support while construction progresses. Clayey layers are less prone to problems specially if they are partially saturated as is the case in the semi-arid region of central Sudan.
2. Existence of ground water or perched ground water at shallow depths may cause problems that require expensive dewatering and/or shoring with waterproofing for basement construction.
3. Effects of excavation on neighbouring existing buildings, infrastructures such roads and water and waste water pipelines may cause problems and may lead to damage and legal actions.
4. Environmental factors such as noise, vibrations … etc.
5. Safety considerations for workers and equipment at deep excavations.

The effects of these factors increase dramatically with increase in excavation depth. For the case of a double or more basement of about 7 to 8 meters depth temporary or permanent shoring becomes a technical, and safety requirement.
All these conditions led to considering shoring activities to address such situations.

III. SUBSOIL CONDITIONS

Geological and geotechnical conditions in the Greater Khartoum Area is dominated by soil layers of clay, silt, sand and mixtures thereof underlain by Nubian sandstone, mudstone and chert. The soil layers extend in depth from 0 to about 20 to 30 m depth. The Nubian formation extends from few meters to tens of meters and is underlain by basement complex formation.

Clays in the Central Sudan are dominated by expansive soils called Black Cotton Soils. These are generally unsaturated stiff clays that exhibit volume change associated with changes in moisture content. Silt and silty clays are also frequently encountered. Silty and clayey sands as well as sand are also encountered. Fine to medium sands as well as coarse sand and gravel also exist. There are some sand layers that are loose depending on the deposition process.

The ground water depth varies widely in the area. Depths vary from few meters to more than 20 meters to non-existent. Perched ground water may be encountered if an impermeable layer exists at shallow depths. Infiltration of water from rain, existing infrastructure, or any other surface water used would collect and create what is referred to as perched ground water.

IV. EXCAVATION SUPPORT FOR DEEP FOUNDATIONS

Many types of excavation support may be considered[7]. These may include:

a- Retaining walls.
b- Diaphragm walls.
c- Sheet pile walls.
d- Soldier piles with timber lagging walls.
e- Pile walls (contiguous, tangent or secant).

The choice of support type is dependent on many factors such as soil conditions, ground water and/ or dewatering needs, excavation depth, space to nearest structures, dynamic effects of installation of driven piles, safety considerations as well as economic considerations. The availability of construction equipment, familiarity with their use, availability of materials and their cost are governing factors.

For urban areas distances between structures are usually small, hence retaining walls are generally excluded. Diaphragm walls are generally considered too expensive except for very deep excavations as may be needed for underground transport systems or tunnels.

Soldier piles with wooden lagging walls are one of the oldest construction systems. They cannot be used when water table is encountered unless dewatering is used. This system is generally used for narrow temporary excavation. The lagging may need struts and the whole system is generally not very stiff.

Sheet piles are of the driven pile types. Vibration and noise are main constraints associated with sheet pile construction. In many situations sheet piling may need lateral support. Existence of ground water is not a problem for use of sheet piles. Sheet pile material is generally imported from specialized manufacturers and may incur extra cost. Pile driving equipment availability is also another constraint.

Bored concrete pile wall is the last option. Construction material i.e. concrete and steel reinforcement as well as drilling rigs are available in most places together with experienced personnel. For cases of high ground water secant piles are chosen while contiguous piles can be used in other cases.

V. BORED PILE SHORING TYPES

A. Contiguous Piles

These are piles that are placed at some spacing between them so they do not touch each other. Spacing of one to two pile diameters are not unusual. The spacing depends on soil arching and is generally related to clayey nature of subsoil. For partially saturated clayey soils and when water table is not a factor contiguous piles is an option. For sandy soils the stability of the sand in between piles must be carefully evaluated. Silty soils must also be considered carefully. Fig. 1 depict the case of contiguous piles.

![Contiguous Pile Wall](image)

Fig. 1: Schematic Plan View of a Contiguous Pile Wall

B. Secant Piles

These piles are constructed in two phases. In the first stage female unreinforced concrete piles are constructed. Male reinforced concrete piles are then installed so that there is an overlap between the adjacent male and female piles. Fig. (2) shows the secant pile setup. Generally female piles are cast using a weaker concrete mix than male piles.
Secant piles are chosen in case high water table and/or dewatering are in consideration. If the subsoil consists of sandy layers then this type of pile may be considered.

**C. Tangent Piles**

Tangent piles are as the name indicates touching each other. They are used in cases that are considered transitional between contiguous and secant piles. All piles are however made of reinforced concrete. Fig. 3 shows tangent pile arrangement.

In this paper, we will concentrate on the contiguous and secant pile types, and their construction based on case studies for each type:

**VI. CASE STUDIES**

**A. ACOLID Tower at Ammarat District, Khartoum**

1) **Building Type:** A high rise tower of 10 floors is now already constructed in Khartoum. Initially it was designed with a raft foundation with a 3.00 m depth basement.

Design review led to a decision of having two basement with a total depth of 6.50 to 7.00 meters. Existing neighboring residential building is less than 2.00 m from the new tower building. Two roads are adjacent to this structure. Fig. 4 gives a plan of the existing and new construction.

2) **Subsoil Conditions:** Soil profile at this site is shown in Fig. 5 The subsoil conditions are made of alluvial deposits from existing ground level to about 26.00 m depth. This was followed by Nubian sandstone and mudstone formation which is a weak rock formation typical of Khartoum area. The alluvial deposits are comprised mainly of clayey to silty sand layer that is followed by clayey to sandy silt layer. The top 1.00 m is composed of a highly plastic clay layer [8].

The ground water level was reported at 12.00 m depth. Seasonal variations are expected with the flooding of the river Nile and its tributaries.
3) Support of Deep Excavation: The decision to excavate to a depth of about 7.00 m has led to close consideration of excavation support. Although the ground water level is not a significant factor, it is expected that some perched water or any seasonal variation in ground water level may lead to careful consideration of waterproofing of raft foundation and retaining walls.

The existence of used residential buildings adjacent to this tower, and the possibility of litigation if any damage is highly expected. The infrastructure of roads neighbouring the plot is another constraint with the municipal authorities supervising the situation.

The type of support chosen was bored contiguous piles. Pile diameter is 0.50 m and pile spacing was 1.0 m center to center. Pile length designed at 12.00 m. Table 1 shows the details of pile design while Fig. 6 shows the actual construction of the pile wall.

<table>
<thead>
<tr>
<th>Excavation Depth (m)</th>
<th>Pile Diameter (m)</th>
<th>Piles Spacing (m)</th>
<th>Pile Length (m)</th>
<th>Pile Reinforcement</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.0</td>
<td>0.5</td>
<td>1.0</td>
<td>12.0</td>
<td>8 Ø 16</td>
</tr>
</tbody>
</table>

**Table 1: Contiguous Pile Design for ACOLID Tower**

**Fig. 6 ACOLID Tower Contiguous Piles**

B. Al-Tadamon Islamic Bank (TIB) Tower at Mugran District, Khartoum

1) Building Type: TIB tower was designed as a multi-storey building of 15 floors and a double basement substructure with a maximum depth of about 7.00 m. The building is adjacent to three roads and a neighbouring office building made of three storeys. The space between the existing office building and expected excavation for TIB tower is about 2.00 m. Fig. 7 gives the location of the new tower.

**Fig. 7 Map of TIB Tower**
2) Subsoil Conditions: Fig. 8 shows the soil profile. Two stages of Site Investigation (SI) were conducted. The first SI was conducted prior to design while the second SI was carried out at a later stage after excavation began. The owner and consultant worried about the existing office building which began to show some distress. Shoring was then seriously considered at this stage.

The boreholes showed similar soil stratification with slight variation in few layers. One borehole indicated very stiff to hard silty clay layer while the other two boreholes the clay layer in the top 7.5 m followed by silt layer in the following 3.00 m [9].

Ground water level was observed in this site at 7.50 m depth. As the second stage SI was carried out in the river flood season this is generally the highest level of GWT.

Table 2 shows the design of the piles constructed in the TIB site. Fig. 9 shows the pile types constructed.

3) Support of Deep Foundations: The excavation for two basement necessitated the consideration of deep excavation. The apparent distress to adjacent office building confirmed this. Although the ground water table existed just below excavation, it is expected that dewatering may be needed. Above the bottom of excavation the soil layers are generally stable clayey layers and hence contiguous pile foundation is proposed. Three pile configurations were proposed based on soil layers encountered.

Table 2 shows the design of the piles constructed in the TIB site. Fig. 9 shows the pile types constructed.

C. Sewage System in Khartoum North. Phase 1. (SSKN1)

1) Building Type: This project consists of a sewage pumping station for collecting municipal sewage from different housing, municipal and industrial blocks. Large concrete tanks are constructed underground and then pumped to the next stage until they reach the final treatment plant.

Geotechnical Site Investigation was carried out before construction. After construction started, ground water table was struck at 6.00 m depth. Fine sand layers were also encountered and it was difficult to proceed with excavation. Owner, consultant and contractor all were looking for shoring solution of this project [10].
A complementary SI was carried out to determine design parameters for shoring of deep excavation. The foundation for the concrete tanks are to be at a depth of 9.00 m depth. Fig. 10 shows the map of the SSKN1. The plot is surrounded by roads on two sides while the other two sides are covered by institutional municipal buildings.

2) Subsoil Conditions: The different boreholes showed similar stratification. The top 3.0 m is high plastic silty clay (CL to CH). This is followed by 3.0 m of low to high clayey silt (MH to ML). A layer of silty sand (SM) extends to 15 m, followed by poorly graded sand (SP). The ground water level is encountered at 6.0 m depth. Fig. 11 shows the soil profile SSKN1 site.

3) Support of Deep Excavation: Location of site is typical of urban conditions. Two sides of the plot are roads while the other two sides are neighbouring municipal building. The ground water level is high and ground water lowering will be required. Layers of silt and sand exist within the excavation depth. All these conditions led to a choice of secant piles as deep excavation support.
Table 3 gives the design details for this project while Fig. 12 shows the construction at the site.

### Table 3: Design of Secant Piles for SSKN1

<table>
<thead>
<tr>
<th>Pile Type</th>
<th>Excavation Depth (m)</th>
<th>Pile Dia. (m)</th>
<th>Overlap (m)</th>
<th>Pile Length (m)</th>
<th>Pile Reinforcement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary</td>
<td>5.5</td>
<td>0.6</td>
<td>0.10</td>
<td>14.0</td>
<td>16 φ 20</td>
</tr>
<tr>
<td>Primary</td>
<td>5.5</td>
<td>0.6</td>
<td>0.10</td>
<td>8.0</td>
<td>No Reinforcement</td>
</tr>
</tbody>
</table>

Three case studies were given and the choice of support system was presented. Cast in-situ concrete pile walls are used. Contiguous and secant piles were used depending on subsoil conditions and ground water situation.

### REFERENCES


### VII. CONCLUSIONS

Urbanisation is a worldwide trend in all countries. The need for deep excavation is a result of such urbanisation trend. An overview of different deep excavation support types is given for various scenarios of loading, subsoil conditions, adjacent structures, environmental constraints and equipment and technical expertise availability.