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Importance of Deep Excavation Support and Its Influence on Adjacent Buildings

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Abstract: This paper aims to investigate the important role of deep excavation support and its effect on nearby existing buildings, especially those founded on shallow foundations. Excavation of basement or foundations induces movements as a consequence of stress-release from earthwork and an increase in overburden pressure in the retained ground. Ground movements throughout excavation result in damage to existing structure located nearby. An intensive literature of previous experiences on supporting deep excavation and their impact on neighboring structures reviewed. This paper presents three case histories and two local current cases of excavations, which caused damages either on their own projects or on adjacent buildings. The results revealed that there are numerous sources of risk associated with performing deep excavations in urban areas, they must be considered in the design and execution of the excavation works for a minimum cost. General conclusions have been drawn from the study findings.

Keywords: Adjacent buildings; deep excavation; foundations; influence; risk.

1. INTRODUCTION

Construction work requires ground excavation with vertical or near vertical cuts. The faces of the cuts need to be protected by temporary bracing systems to minimize the excavation area, to keep the sides of deep excavations stable, and to ensure that movements will not cause damage to neighboring structures or to utilities in the surrounding ground. Furthermore, excavation support is an issue of extreme importance to construction safety due to the serious threat to life posed by a potential earth collapse, in addition to their fundamental influence on profitability, speed, and quality of construction projects. Despite the great importance of excavation support systems, most designers and contractors have limited knowledge about their design and construction, and they rely heavily on experience.

Damage to buildings adjacent to excavations can be a major design consideration when constructing facilities in congested urban areas. As new buildings are constructed, the excavations required for basements affect nearby existing buildings, especially those founded on shallow foundations. Thus, excavation support system design must prevent any damage to adjacent structures or balance the cost of a stiffer support system with the cost of repairing damage to the affected structures.

This study aims to emphasize on the influence of deep excavations and their effects on projects and adjacent existing buildings. To achieve this, intensive literature of relevant international historical cases were reviewed. Furthermore, two current cases in Khartoum State were investigated and discussed.

2. LITERATURE REVIEW

It is important to reduce the effect of constructing project on constructed projects and vice versa, [1]. Deep excavations in urban areas require special considerations due to the buildings and other engineering constructions existing nearby. Deep excavations for construction can significantly influence the existing buildings in the neighborhood, [2]. The proper design and construction of shoring systems are critical to the safety of the personnel that work within excavations, and also to the surrounding environment, [3]. Analysis of deep excavation is required, usually before the start of the design process. This is a typical problem of soil-structure interaction. Earth is a nonlinear material, inelastic and anisotropic behavior is strongly influenced by the presence of pore water. Some types of soils present properties of consolidation and creep. Theoretical analysis of deep excavations involving simulations of elasto-plastic behavior of the earth, behavior interface between land and retaining system as well as the process of excavation, [4].

2.1 Deep Excavations Hazards

The danger of deep excavations is an often-overlooked issue in construction. There are numerous sources of risk or hazard associated with performing deep excavations in urban areas. Risk relates to exposure to the danger and is defined as "the probability of any injury or loss occurring from the hazard". A hazard is a source of danger which can be defined as "a condition or situation that exists in the work environment that could result in physical harm, injury and/or damage", [3]. The assessment of risk sources for disposal may occur additional measures and expenditure in the design and implementation enclosure excavated, that investor is forced to bear. The shape and dimensions in plan and excavation depth can be sources of risk. The higher the trench depth, increase the difficulties of achieving not only work but also risks for themselves or for construction work in the neighborhood, to their stability, to be taken into account, [3].

A major concern with deep excavation projects is the potentially large ground deformations in and around the excavation, which might cause damage to the adjacent buildings and utilities, [3].The damage criterion are angular distortion and lateral extension strain that develops within a structure due to lateral and vertical ground movements acting on the structure foundation. Sources of ground movement are lateral displacement of excavation wall and displacement due to support system installation. Patterns of ground movement are settlement at the ground surface and lateral displacements of the ground surface (see Fig. 1). It is important to understand how the ground movements due to excavations influence nearby structures, [3]. The response of buildings to excavation-related ground movements is dependent on the source and pattern of the ground movements, the type and condition of the structure, and the mitigation measures employed to protect the building, [5].

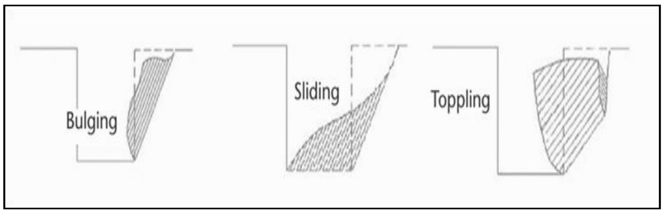

Fig. 1 Different pattern of ground movement, [3]

The primary factors that influence the deformation of the system and the retained ground include type of subsoil, lowering of groundwater level, depth and width of excavation, stability of the bottom of excavation, stiffness of the support system, construction technique, surcharge load, ground movement and quality of investigation and design.

2.2 Historical Events of Structures Failures

Many historical events of structure failure due to deep excavation have been recorded in many countries. Structure failure events pose a significant threat not only to human life but also to the environment and in general to economic development. Thus, it is essential to investigate properly these failures and to find out technical solutions to reduce their risk of occurrence. Recently, project safety draws increasing attention from the public authorities. This is because damages resulting from structure failure can lead to terrible disasters with tremendous loss of life and properties, especially in densely populated areas. Three potential structures failure events reviewed in this section.

One of the world's worst building disaster occurred in Shanghai in China, in June 2009, when a 13 floors building under construction at Lian huanan Road in Min hang district of Shanghai city collapsed. It was reported that one worker was killed. The collapse was caused by the deep excavation of 4.6m made for an underground car park alongside the building, being piled to depths of up to 10 m on the other side of the structure. The weight of the pile created a pressure differential which led to a shift in the soil structure, eventually weakening the foundations and causing them to fail (see Fig. 2). This situation may have been aggravated by several days of heavy rain leading up to the collapse. Improper construction methods are believed to be the reason of building collapse, according to the investigation team report, [6]. They stated that workers dug an underground garage on one side of the building while on the other side earth was heaped up to 10m high, which was apparently an error in construction.

Fig. 2 Building Collapsed in Shanghai, [6]

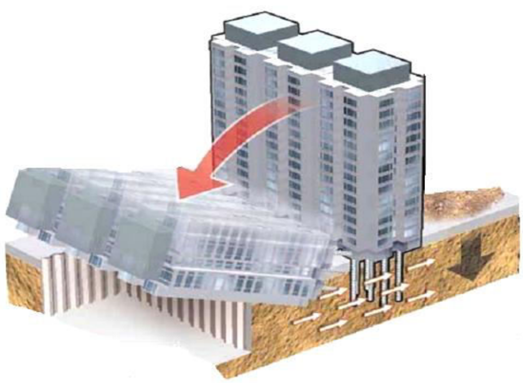

Fig. 3 Sketch illustrating failure of Shanghai building, [6]

Another case of structure collapse event occurred on 20 April 2004 in Singapore. Nicoll Highway collapse was a construction accident that occurred when a tunnel being constructed for use by Mass Rapid Transit (MRT) (Singapore) trains collapsed. The tunnel was part of the construction of the underground Circle Line, near Nicoll Highway MRT Station, [7]. As reported, the supporting structure for the deep excavation work failed, resulting in a 30m deep cave-in that spread across six lanes of Nicoll Highway. The collapse killed four people and injured three. The accident delayed the construction end date for the MRT Station. Investigations found that the most apparent cause of the collapse was the retaining wall which could not handle the stress of holding up the tunnel, forcing it to give way. The accident left a collapse zone 150 m wide, 100 m long, and 30 m deep. As can be seen in Fig. 4, Steel beams were twisted, with two construction cranes being swallowed up. A substantial chunk of the main highway running over the tunnel was also knocked out. All six lanes of the Nicoll Highway were heavily damaged, rendering the road unusable. A committee of inquiry found main contractor Nishimatsu Construction Company and its officers as well as Land Transport Authority officers responsible for the collapse. As a result of the accident, Stages 1 and 2 of the Circle line were delayed. The partially built station structure was abandoned, and the affected station has been shifted about 100 m away from the accident site. Eventually, Nicoll Highway station started operations on 17 April 2010.

Fig. 4 Collapse of Nicoll Highway at MRT Station in Singapore, [7]

A Basement Excavation in Penang is a case history of a shopping mall with proposed two levels of basement. A 15m deep double sheet pile walls supported by internal struts acting as a temporary coffer dam had been completed, [8]. Forty percent of the plan area of excavation reached a general depth of 7m except at certain locations for lift pits where the excavation reached a depth of 10m. Fig. 5 shows the site condition upon reaching the final excavation level andFigure5 shows a typical section of the temporary sheet pile wall installed at the site. The plan area involved approximately 20,000 m^2. Before the basement slab was cast at the site, hydraulic failure had already taken place and water flow into the clayey subsoil at the base of the excavation pit was evident. The continued pumping out of the water from the pit unknowingly by the contractor caused significant drawdown in the groundwater in the surrounding retained ground. The lowering of the groundwater in the retained ground induced significant settlement (both immediate and consolidation) resulting in large cracks and differential settlement of the pre-war (1930+) houses that were supported by shallow block foundation with or without one length (4m to 5m) of bakau piles. On complaints from the residents of the affected houses, the Local Authority ordered the project to be stopped pending investigation.

Significant damage was clearly visible to the surrounding 300 houses though some houses were more than 300m away from the retaining wall.

From Fig. 6, it is very clear that the 15 m deep sheet pile had not extended beyond the sandy layer to ensure a proper hydraulic cut-off. Therefore, detailed hydraulic uplift calculations are required to check the stability of the excavation in terms of hydraulic failure. Simple calculations showed that the clayey subsoil is likely to fail in heaving due to hydrostatic pressure. This indicates insufficient penetration depth of the sheet pile.

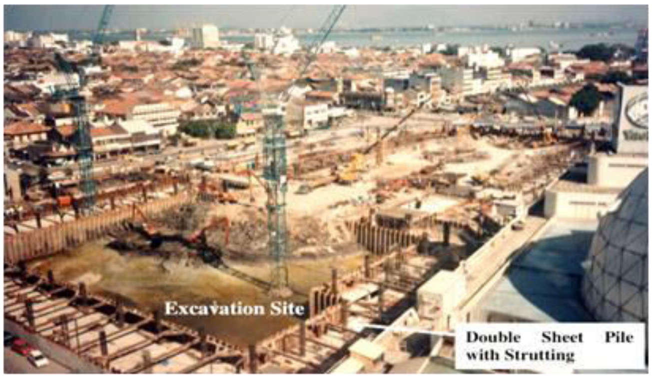

Fig. 5 The Site Condition of Penang upon Reaching the Final Excavation Level [8]

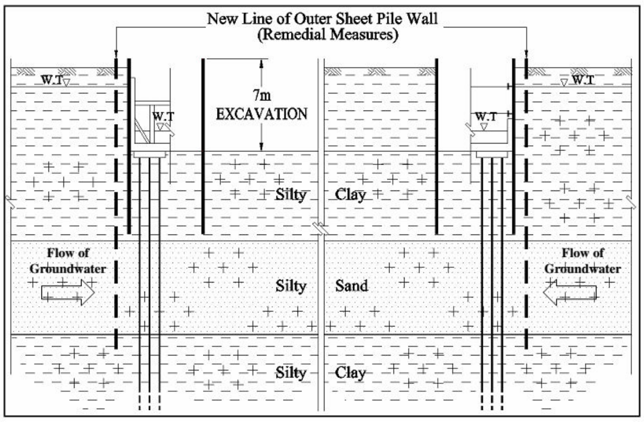

Fig. 6 A Typical Section of the Temporary Sheet Pile Wall Installed At the Site of Penang [8]

3. Case Study

The current investigation was carried out on selected two projects in Khartoum state. These projects have been affected by their excavation during their construction. The investigation consisted of field survey of the site condition and data collection about the design and any other information assist in investigation. The site visual inspection and photographs taken for the failed portions were used to assist in diagnosis the causes of failures. The two cases selected for this study are located at Al-Tayef in Khartoum and Kafoori in Khartoum North.

3.1 Hospital Building

The project is a hospital building consists of two basements plus six floors in 50 by 50 square meter plot. The plot is a single land surrounded by main roads from North and West sides and branch ones from other sides.

A geotechnical study had been done prior to design. Five boreholes had been excavated (2 to 20 m, 2 to 25 m and 1 to 35m).Soil profile shows that the subsoil is generally dense to very dense silty to clayey sand (SM, SP-SM, SP, and SW-SM to SC). Some intermediate layers of sand, high plastic silty clay (CH) at 4.5 – 6 m down to 10.5 m. Ground water table level was recorded at 12 m. During drilling of boreholes, perched water had been noticed at 6 m depth. For foundation, raft and piles were recommended.

As per design, excavation should be carried down to 8 m depth. Before any excavation, the contractor decided to do shoring system using 50 cm bored, cast in situ piles with 8 m length starting from 5 m depth. 13 m holes were bored and then the reinforced 8 m piles were casted. Due to undefined well-shoring item in the bill of quantity and not giving any attention but to ground water table and the dense soil layers, the consultant and the contractor with confidence did the shoring piles distributed all around the perimeter with different gaps in between reach to more than 1 meter in some places as shown in Fig. 7.

Fig. 7 The shoring piles distributed all around the perimeter of the building basement

3.1.1 Water Problem

The contractor started to excavate for the basements. When the excavation reach close to 6m depth, water started to appear from all directions, filling the site and erode the sand layer at that level creating cavities behind the piles and beneath the top dense soil. At the same time many piles appeared to be casted more than their planned length.

To collect the flowing water, the contractor decided to excavate trenches in front of piles all around the perimeter and start dewatering (4 to 10m^3/hr. – 20 hrs./day pumps). Due to sand layer at 6 m depth, piles concrete compressed the sand and created necks at that level. These necks allocated inside the line of basement retaining walls. When the excavation reached this level, 11 piles in the eastern side had been sheared and fall down letting an approximately 1m wide of supported soil collapse.

The project suffers from delay and the contractor raised a claim for the delay 4 months out of 14 months, the project duration. The owner paid and still will payextra amounts to cover shoring system, dewatering, more thickness plain concrete, special waterproofing system, and delay impacts.

Fig. 8 Subsurface Water Filling the Site and Erode the Sand Layer Creating Cavities behind the Shoring Piles.

3.1.2 Causes of Failure

Based on the above analysis of the site conditions and the data collected from thecontractor, the causes of the foundation failure briefly outlined below:

- Not giving more attention to the geotechnical report, which clearly mentioned the 6 m perched water and the intermediate layers of sand.
- Cast the shoring piles without adequate control, making their additional cantilevers suffering without any reinforcement.
- Cast the piles with gaps in between let this mater to be amplified.

3.2 Residential Building

The project is a residential building at Kafoori in Khartoum North. The building is a multi-story with a basement. The contractor excavated all the area of the plot for a depth of 4.1m, keeping 90cm between the building and the western neighbor building. During the foundation processes, the attached compound wall for this neighbor collapsed as shown in Fig. 9.

The case took a liability path and the work stopped for a while till the situation had been settled and the contractor erected a temporary fence with a commitment to erect the compound wall on his charge.

Fig. 9 The Shoring Piles Distributed All Around

4. EXCAVATION SUPPORT GUIDELINES

These guidelines describe supports that functions to retain earth and adjacent structures when an excavation is required. The designer has to consider factors that influence the behavior of the excavation support. Typically, there are two types of excavation supports that must be designed:

1) The Earth Retention Type that contains the earth i.e. the support wall (sheet pile, diaphragm wall, etc.).
2) The Bracing Support Type (i.e. the internal or external bracing such as rakers, struts, or tiebacks) that supports the earth retention type.

For construction projects that require supported excavation, the following are suggested types of supports derived from previous experience sand recommendations:

1. Diaphragm Wall is a continuous supporting wall comprised of concrete or a mixture of cement and soil (usually with embedded vertical steel members) that is drilled or excavated in place prior to excavation in order to support lateral loads from retained soil and water. They are typically analyzed on a longitudinal wall (unit) basis for the lateral pressures computed. The wall is designed for the unit bending moments and shears resulting from the lateral pressures acting on the wall. When the wall is designed to support vertical loads, these loads must be considered in the design as well.
2. Sheet Piling is a vertical steel shapes that are driven into the ground and interlocked with each other to form a continuous wall in order to support lateral loads from retained soil and water. The structural strength of the wall is provided by sheets themselves. Wide flange sections installed in deep soil are the primary structural elements for this type.
3. Slurry Wall is a continuous, reinforced concrete wall constructed by filling a series of discrete trenches with tremie concrete. Tremie concrete displaces bentonite or polymer slurry that is in the trench. The slurry is used to prevent collapse of the trench during excavation for slurry wall placement. The resulting concrete barrier wall retains soil and groundwater on the exterior side of the slurry wall, and permits excavation and removal of soil on the interior side of the wall. Walls may be reinforced or non-reinforced.
4. Preloaded Bracing: Preloading of bracing elements can reduce shoring deflection and ground settlement during excavation and assure good bearing and a tight fit between supporting elements. Where feasible, struts shall be preloaded to about 50% of their design load to achieve adequate bearing between connected supporting elements and to reduce the track settlement that can occur during excavation.

5. CONCLUSION

This paper focused on influence of deep excavation on either projects or neighbor buildings and properly described the modes and causes of failures. Based on the review of literature, previous experiences and the case study results, the following conclusions are drawn.

- Lowering of groundwater in the retained ground caused by basement excavation will cause to the surrounding buildings problems such as cracks and settlement.
- While analyzing the specific design or execution situations one should take into consideration individual influences, which can occur, as well as corresponding to its impact zones.
- Appropriately designed temporary earth-retaining structures should be provided to protect the sides of the excavation, even for shallow excavation. The design should take into consideration the effects of severe weather and existence of foundation of existing buildings.
- Extra protective actions should be taken when working close to existing building.
- Risk management involves identifying a hazard, evaluating the probability of the hazard occurring, assessing the consequences of the occurrence and developing a plan to minimize either the probability or consequences of the hazard.

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