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Effect of Excavation Dewatering on Adjacent Structures

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Abstract: The study aims to investigate the effect of dewatering technique on retained ground and adjacent existing structures in order to avoid any damages that may occur. The paper presents three cases of potential structure failure caused by ground settlement as a result of dewatering. Two current construction projects in Khartoum North were selected as a case study. The two projects are located near Blue Nile River where ground water table exists at shallow depths. Dewatering to reduce the groundwater level was carried out in the two sites to facilitate excavation works. The buildings and road pavements around the two sites suffered serious damages due to excessive differential settlements of the retained ground. The study results showed that there are numerous sources of risks associated with performing dewatering. Therefore, developing appropriate plan for dewatering before construction is essential to mitigate any adverse impacts and avoid risks.

Keywords: *Damages; dewatering; effect; groundwater*.

1. INTRODUCTION

Foundation excavation when carried out in the present of near water table is difficult to execute and often unstable. Thus, dewatering is a common practice adopted to lower the water level to facilitate the excavation work and construct the foundation in dry soil. In fact, the movement of water through the pores of soils often controls the safe and proper performance of structures. Moreover, the stability of structure is often endangered by excessive seepage forces encountered in cohesionless soils, [1].

Dewatering is effective in improving stability by reducing pore pressures around excavation. Sometimes the dewatering system may fail which bring the water level close to the foundation and reduce the capacity of the soil, which contribute to the settlements and displacements of the adjacent structures. Moreover, stress re-distribution occurred in the nearby structures, and it may cause cracks and eventual failure of the structure if such precaution is not considered at the time of design, [2]. Therefore, it is necessary to assess the damage extent of the structures before start the dewatering, to provide a reliable proposal for the construction management and decision-making and avoid risks.

The purpose of this research is to investigate the problems resulted from lowering water level by dewatering on ground settlement and neighbor structures in Sudan. Two current cases of dewatering in construction projects in Khartoum North were presented in this study.

2. BACKGROUND

Dewatering is the process to extract water from aquifers through number of wells. However, conventional well-point and deep well systems, commonly used for pumping water in coarse soils, are ineffective in fine soils, and vacuum well systems are normally necessary [3].

Excavation dewatering induced differential settlements on surrounding building/structures and road pavements has been observed by many engineers. Dewatering may cause severe ground settlement, tilt or even cracking in adjacent structures. To avoid these problems, the ground settlement induced by dewatering and proposed excavation is to be predicted before construction [4]. Xia *et al*. [5] showed that the range of impact area, the depth of drawdown, the change in pore water pressure and the induced settlements are functions of pumping discharge, soil type and compositions, and varied with shoring type and dewatering device.

Dewatering on construction projects may influence the design, construction time and cost. Thus, dewatering is to be considered in project planning to avoid extra cost. In most contracts, dewatering is the responsibility of the contractor who has to select, design and operate the dewatering method. Contractually, ground problems may cause many claims and work delays. Moreover, it may require redesign or even discarding of the project [6].

2.1 Dewatering Methods

Dewatering has been known in construction industry for a long time. Consequently, many developed techniques have been suggested to lower the groundwater table during excavation. As reported by Ratay [6] the most famous techniques commonly used for dewatering include sumps, wells and well-points.

- Sumps provide localized dewatering at shallow depths less than 1 m and consist of pumping from perforated drums or casings in a gravel-filled back pit. Sumps are preferred in fine grained soils, or very coarse, boulder deposits.
- Wells are large-diameter (greater than 15 cm) holes, drilled relatively deep (greater than 3 m), and contain slotted casings and down hole pumps. Wells work best in soils consisting of sand, or sand and gravel mixtures and can dewater large areas to great depths.
- Well-points are small-diameter (less than 15 cm), shallow wells, and are closely spaced (0.6 to 3 m apart). Well-points effectively dewater in coarse sands and gravels, or silts and clays. They have a wide range of applications. However, well-points use a vacuum system and their depth is limited to about 8 m. Well-point systems generally cost more than either sumps or wells, and requires near-continual maintenance.
- A number of other dewatering techniques are available including ground freezing and electro osmosis. However, such techniques are very costly and used only for particularly difficult dewatering applications [6].

Pat *et al* [7] in their study stated that the zone of influence is a theoretical concept used to visualize how a well is affecting the surrounding aquifer. Imagine a well penetrating an aquifer that has an initial water table or piezometric level at the same elevation everywhere **Fig. 1(a).** When water is first pumped from the well, the water level in the well will be lowered, and flow will occur from the aquifer into the well, as shown in **Fig. 1(b).** This water will be water released from storage in the aquifer around the well. As time passes, the cone of depression will expand away from the well, releasing additional water from storage **Fig. 1(c).** The zone of influence will continue to increase with time, but at a rate until either an aquifer boundary is reached or the infiltration recharge into the aquifer within the zone of influence is sufficient to supply the yield from the well [7].

Aliewi *et al*. [8] designed a dewatering system, using field pumping tests, analytical and numerical models. They illustrated that the water table can be reduced to a maximum of four meter without causing problems of formation stability and without raising the ground water salinity concentration.

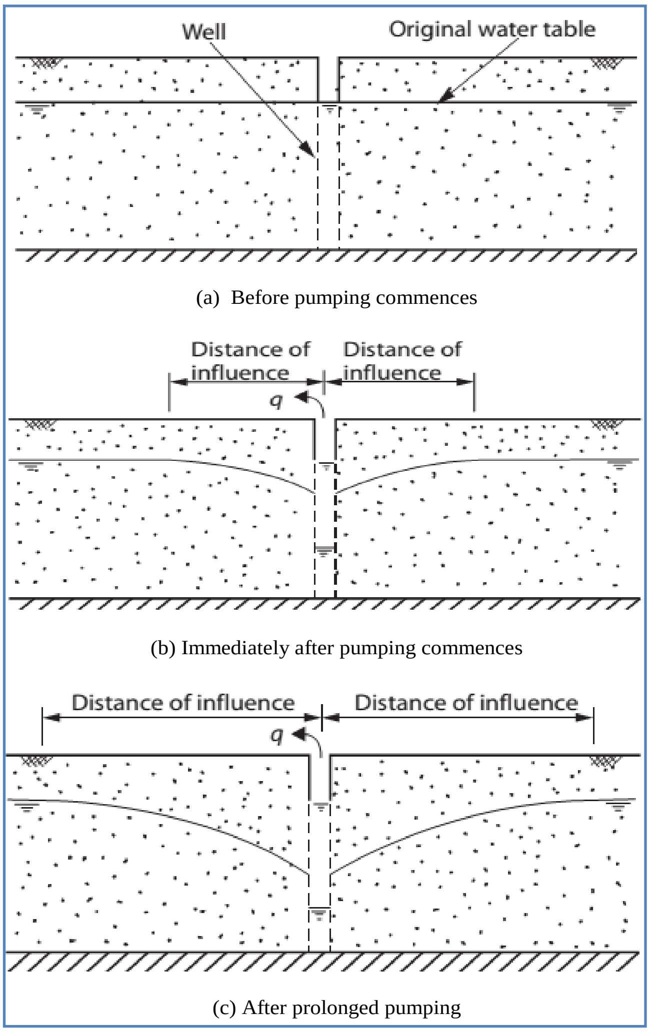

Fig. 1. Effect of dewatering on surrounding aquifer ((a) before (b) after (c) after prolonged) pumping, [4]

2.2 Impacts of Dewatering

The ground water control operations, using pumping methods, have the potential for causing adverse impacts on ground and adjacent structures. A number of adverse impacts may result from ground water abstraction or pumping for dewatering purposes on ground were investigated by many previous researchers [8–9]. These include:

- Ground settlement caused by groundwater lowering may be generated by a number of different mechanisms. Settlement may result from the instability of excavations when groundwater is not adequately controlled. Settlement caused by loss of fines only.
- Dewatering results in derogation or depletion of groundwater dependent features such as rivers and wetlands. Also it causes changes on water levels and water quality in the aquifer as a whole. The changes in groundwater quality include movement of contamination plumes and saline intrusion.
- The discharge flows such as artificial recharge or pollution leaks has adverse impacts on the surface water environment.
- Seepage of groundwater in soil may create artificial water pathways such as poorly sealed boreholes. When low permeability groundwater barriers such as cutoff walls are used.

The impact of ground settlement induced by dewatering has significant effects on structures such as buildings, road pavements and any other infrastructures around the excavation site. Ishihara [10] pointed out that almost no liquefaction induced damage to a house is found when there exists a non-liquefied soil with enough thickness. According to this fact, dewatering can be considered here as a means to mitigate the damage to a house by creating such a layer rather than expecting an increase of liquefaction resistance due to partial saturation of soils, [11]. Monakhov [12] discussed problems involving dewatering during construction of projects in dense urban settings, and also various aspects of the formation of the water table.

2.3 Historical Cases

Many historical cases of structure failure due to dewatering 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 helpful to review these failures and 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 international potential structures failure due to dewatering events are reviewed in this section.

1) Sanitary Sewer in USA

A construction project in a city located in Rocky mountain region of the USA was studied by Mokwa *et al*. [13]. The construction consisted of installation of the main sanitary sewer of 70 cm (27 in.) diameter with a bottom elevation of 5.7 m (19 ft.) below existing grade in the vicinity of the residence area. The actual trench depth is about 7 m (23 ft.) to provide clearance for pipe bedding gravel. The construction plans and specifications required that all work in the trench be conducted in the dry, including placement of the pipe bedding gravel and installation of the sewer pipe. Consequently, because of the presence of groundwater, dewatering was required during trenching and pipe installation. The structure influenced consisted of an approximately 24.4 m^2 (2,200 ft^2) one-story wood house with a finished basement. This house was the closest structure to the trench and the contractor's primary dewatering well. The trench was excavated approximately parallel to the long axis of the house, about 15 m (50 ft.) from the back wall. The dewatering well was located about the same distance from the house as shown in Figure 2. Numerous irregularities in the interior of the subject home occurred, including drywall cracks in the ceiling, walls, and in many of the wall ceiling joints.

A limited geotechnical investigation was conducted along the sewer line alignment during the design phase of the project. Geotechnical reports compiled for the project site indicate that subsurface conditions in the vicinity of the residence consist of fine-grained alluvial soils underlain by coarse-grained alluvium over shale bedrock. Data and information from the geotechnical reports indicate soils at the site generally consist of a stiff surface crust underlain by soft compressible fine-grained soils to a depth of about 15 m. below the ground surface. The available geotechnical data indicates the soil deposit is normally consolidated. The calculated primary consolidation settlement amounts range from about 7.5 to 9.0 cm (3 to 3.5 in.).

Currently available scientific methodologies and analytical methods indicate that the subject residence experienced damaging settlement as a result of groundwater lowering caused by nearby construction dewatering [13].

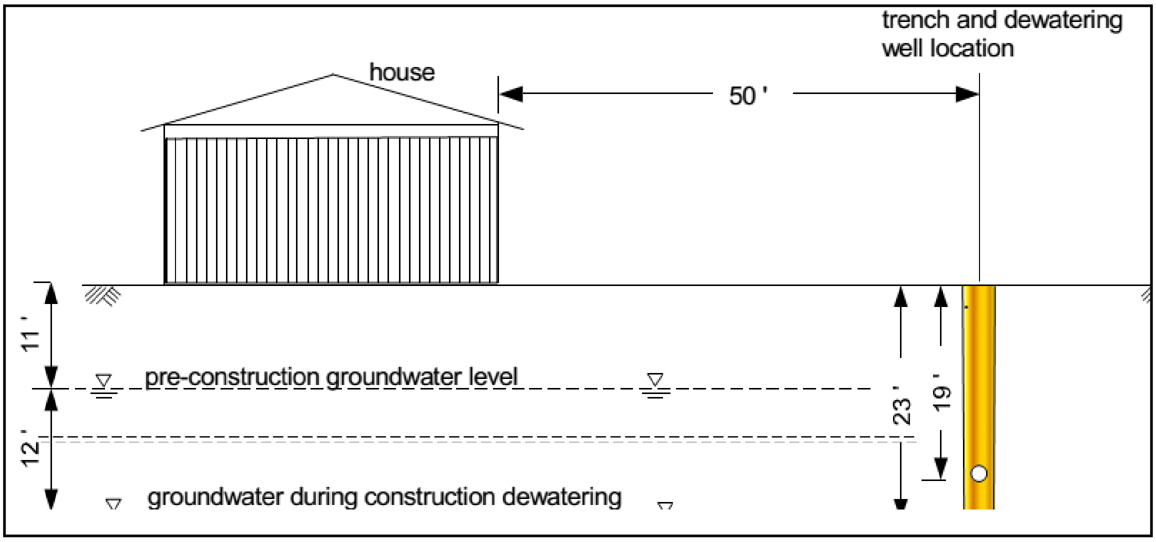

Fig. 2. The trench and dewatering well location at the project site, [13]

2) Basement Excavation in Malaysia

A case of structure collapse event due to dewatering occurred in Malaysia, [14]. The project is a basement excavation in Sarawak Malaysia. Many three-story shop houses surrounding the project site which have suffered cracks and significant settlement of the apron slabs and drains. These shop houses are supported by bakau piles (a type of natural wood piles). The excavation site surrounded by many shop houses with settlements markers lines are shown in **Fig. 3**.

The geotechnical investigation report explained the causes of the problems encountered and recommended monitoring and necessary remedial works. The site is nearby river in swamp alluvium of the Sungai Sarawak and generally consists of inter-bedded layers of sand, silt and clay with some gravels. A layer of peat is sometimes encountered near the ground surface. Figure 4 shows the subsoil profile established during the installation of the piezometers. The subsoil encountered at the site consisted of 10 to 12 m of silty clay underlain by sandy soil, the thickness of the cohesive layer decreased towards the proposed basement excavation site indicating that sandy materials are at the shallower depth of the excavation site. For PZ-1 area, the estimated original groundwater level prior to the excavation ranged from about 1 to 2 m below ground level.

As observed at the site, the final excavation level was mainly at the sandy layer. Dewatering activity within the excavation pit was carried out to facilitate the construction of basement slabs and pile caps. The shop houses around the excavation site had cracked due to excessive differential settlement of the ground. Other than cracks on the brick walls, cracks were also observed on the reinforced concrete beams and columns. On one of the units, the structural cracks were so severe that the structural integrity of the house came into doubt and was declared unsafe for occupation (**Fig. 5**).

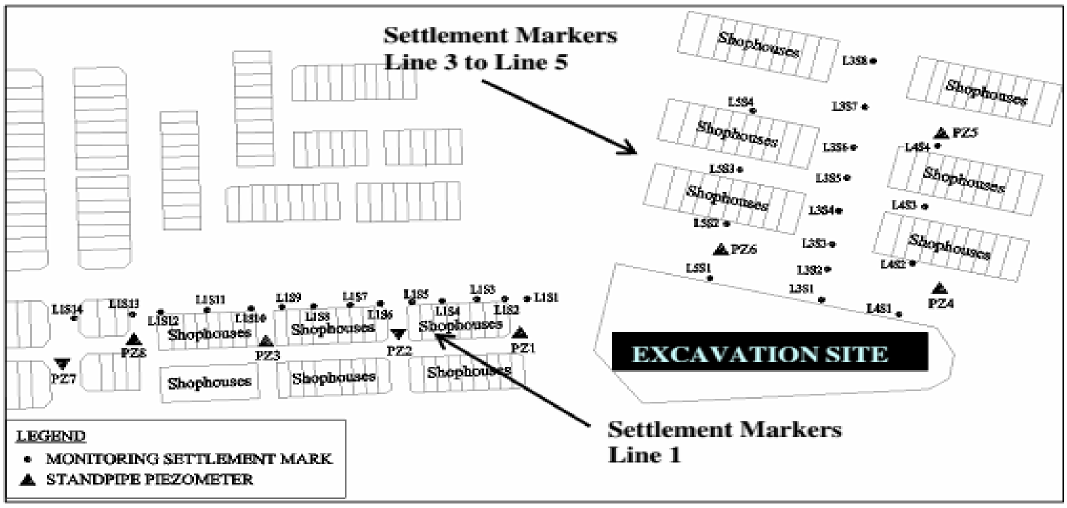

Fig. 3. The project excavation site surrounded by many shop houses, [14]

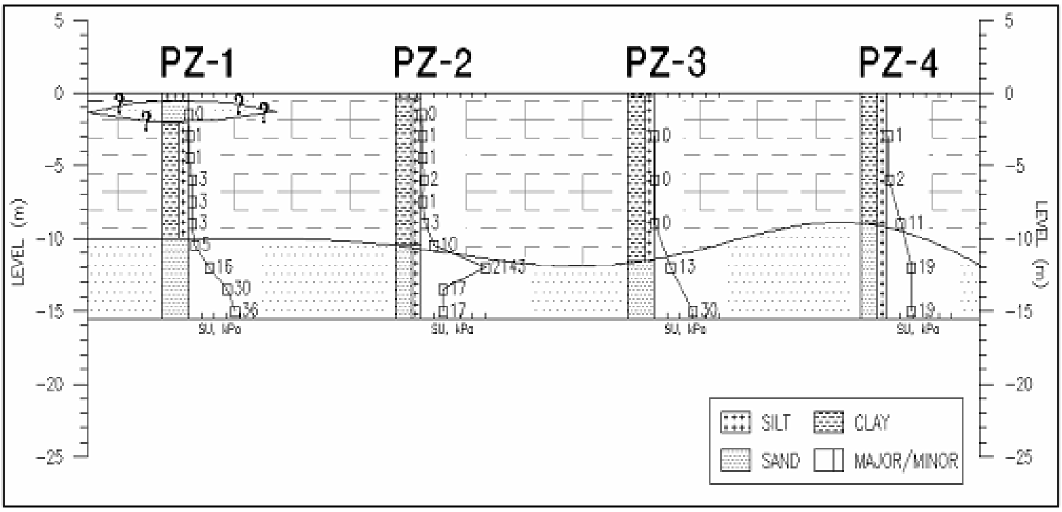

Fig. 4. Subsoil profile of Sarawak site, [14]

Fig. 5. Severe cracks in the external walls of a house, [14]

Many causes of settlement failure in the retained ground could be attributed to the following:

- Loss of materials and stress relief during the installation of the diaphragm wall.
- Loss of materials during installation of temporary ground anchors.
- Deformation of the wall due to earthwork excavation.
- Lowering of groundwater in the retained ground by ground seepage through the sandy layer below the diaphragm wall.
- Loss of water through the drilled holes of the ground anchors.

3) Underground Structure in Canada

The event of an underground structure settlement occurred in Vancouver, Canada was reported by Roy and Robinson [15]. The foundation of the underground structure was constructed at 16 m depth in a soft soil site. The geotechnical report shows the soil profile which consists of three layers. The top layer of soft soils was encountered up to 8 m depth. This followed by a sandstone layer of 8 m thick rested on siltstone bedrock. The structure intersected an aquifer in bedrock under artesian pressure.

Permanent dewatering for the underground structure resulted in settlements as large as 360 mm within 5.75 years of construction completion. The area affected by settlements extended to distances as far as few hundred meters beyond the perimeter of the structure skewed to the North as shown in **Fig. 6**.

Monitoring records indicate that while the groundwater condition (depressurization of the deeper aquifer due to the construction) appears to have stabilized within an area extending to a distance of about two times the width of the underground structure from its perimeter, settlements continue to develop. A simple seepage model was developed

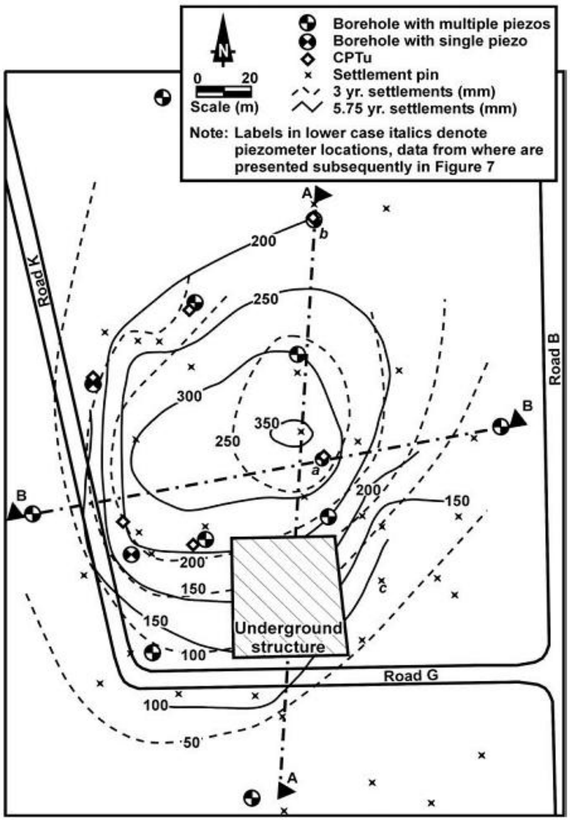

Fig. 6. The project site layout and settlement contours, [15]

in this study to estimate the long term change of effective stress. Using these results, the long term settlements were estimated using conventional uncoupled one dimensional consolidation theory.

While the analytical approach is based on a number of simplifying assumptions, it appears to calibrate reasonably with the observations from the site. Monitoring data obtained over 5.75 years from completion of construction combined with the results from a series of numerical analyses confirm that depressurization of the artesian aquifer within bedrock is mainly responsible for the increasing settlement rates. At soft soil sites underlain by multiple aquifers settlements are unavoidable unless depressurization of all the aquifers is avoided. As the observational evidence and analytical results presented in the study suggested, the consequences of depressurization could affect an area extending to distances of several times the dimension of area within which actual dewatering is taking place, [15].

3. LOCAL CASE STUDY

The current investigation was carried out on two selected projects in Khartoum north namely a sewage pump station and a hotel building. The two projects are located not far from Blue Nile River where groundwater level exists at less than 6 m depth. During foundation excavation, groundwater appeared and obstructed excavation work. Dewatering applied to withdraw water from the excavation site. The investigation consisted of field survey of the sites conditions and data collection about the design and any other useful information. The site visual inspection and photographs taken for the failed portions were used to assist in diagnosing the causes of failures. The site was visited several times to discuss with the contractor and the consultant. Questions had been asked to know the situation and source of problem. Geotechnical report and site photos had been collected.

3.1 Sewage Pump Station

The project is a main pump station to collect sewage in Khartoum North. The station is located in the south west side of Khartoum North locality at Helat Hamad in a built area of 600 m^2.

The geotechnical investigation report indicates the soil profile which consists of four zones, the top layer of 3 m depth is silty clay of high plasticity, followed by sandy silt encountered up to 7 m depth. A layer of saturated silty Sand was encountered between 7 m and 10 m depth. A thick layer of fine to medium sand was extended downward. The ground water table was encountered at 7 m depth. Raft foundation was recommended at a depth 12 m.

The construction of the station started in 2013 with deep excavation. The contractor started to excavate for the foundation and when the excavation reached close to 7m depth, water started to appear from all directions, filling the site and erode the sandy silt layer at that level creating cavities at exavation sides as shown in **Fig. 7**.

To stop water flow, the contractor started dewatering by pumping water from the excavation pit. Due to presence of sandy silt layer at the excavation sides, earth masses had been sheared and fall down and large cavities created as a result of dewatering **(Fig. 8**). Pumps continuously worked to withdraw water from the site in order to facilitate excavation works. Sever cracks and damages due differential settlements were clearly observed on the adjacent buildings and road pavement as shown in **Fig. 9**.

The project had suffered from delay and the contractor raised a claim for the delay more than 6 months. The owner paid much money to cover the sides supporting system, dewatering, special waterproofing system, and delay impacts. Right now, the construction work at the site was stopped completely as observed by the authors.

The possible causes of the critical situation of the site and the problems resulting from dewatering revealed that no detailed design of dewatering system is used. Inadequate control for ground water level during excavation resulted in sliding and failure of the earth sides; no support is used for the deep excavation like sheet piles to protect the sides from failure; and cavities created in soil layers due to dewatering are a complicated problem which needed making plans before starting any works.

Fig. 7. Water filling the site and erode the excavation sides.

Fig. 8. Falling down of excavation sides after dewatering

Fig. 9. Serious cracks in walls of adjacent buildings

3.2 Hotel Building

A hotel building is situated in Khartoum North about 0.5 km east of Blue Nile River. In general, the project site is relatively flat and surrounded by open space. The hotel building consists of two basements, ground floor, mezzanine and typical seven floors with an overall area about 2135 m^2. From the geotechnical investigation report, the subsoil profile is composed of top layer of clayey sand was encountered up to 3 m. This underlain by thick layer of stiff silty clay was encountered between 3 m to 10 m depth.

During the basements excavation, water appeared at a depth of 5.3 m below ground level and started to fill the site as shown in **Fig. 10**. The contractor had to start pumping the water in order to continue the excavation work. Sump pumping system was installed to withdraw water by dewatering.

Sliding of the excavation sides of the sand layer was clearly observed on the north and west sides. The contractor used bentonite in some areas of big sliding, but still falling. Large cavities and damaged earth sides were observed after dewatering (**Fig. 11**). The possible causes of these problems at the site may be due to ineffective dewatering system used and excavation sides were not supported to protect them from sliding failure.

Fig. 10. The project site filled with water before dewatering

Fig. 11. Sliding failure of the excavation sides created large cavities

4. RESULTS AND DISCUSSION

The research focused on the influence of excavation dewatering on ground settlement and nearby structures. The structure failure due to dewatering poses a significant threat not only to human life but also to the environment and in general to economic development. The results obtained from the three events of structures failure previously reviewed in the literature and the two local cases of current projects are discussed in this section.

The possible causes of the ground and nearby structures failure are due to the following:

- Inadequate geotechnical investigation leads to wrong planning of works, construction delays and extra cost.
- Some local techniques commonly used for dewatering are traditional, causes sudden drop in water level which may affect stability of excavation sides.
- Settlements may occur, due to cavity or increase in effective stresses in soil, when no treatment is done.

5. CONCLUSIONS

This study was concerned with the impacts of dewatering on ground and adjacent structures/buildings. Based on the study findings, the following conclusions are drawn.

- Dewatering of excavation is an essential process in areas where water table level encountered at shallow depths. It must be planned, analyzed, designed and controlled by specialist geotechnical engineers.
- Dewatering of excavation could cause a wide range of ground settlements, which leads to serious damage to the surrounding existing buildings. More attention and care must be paid to geotechnical investigation. The investigation must be extended to dewatering influence zone, beside inspection holes to get a complete picture
- Numerous sources of risk associated with performing dewatering in excavations in urban areas, should be considered in the design and execution of the excavation works for a minimum cost.

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