Lesson Learned

Collapse of Diaphragm Wall Trench

Case study

Suez Canal Syphon Project
List of Contents

1. Introduction........................................................................................................ 3
2. Project Description............................................................................................ 3
3. Collapse................................................................................................................ 4
4. Known Issues Versus Reality ............................................................................. 5
5. Causes of Collapse.............................................................................................. 6
6. Conclusion and Recommendations .................................................................... 8
1. INTRODUCTION

It was noted in many small size sites, mainly shafts that trenches tends to collapses when approaching the closure of the box or shaft (specifically during construction of last panel).

This phenomenon was recorded and studied thoroughly during many years. Bauer Egypt came up with some precautions and recommendation to consider when executing small size closed sites. These precautions were successful to avoid collapses of last panel for many projects.

All of these precautions and recommendations were fulfilled during the execution of the shafts needed for the “Suez Canal Syphon Project”. However, a new factor interfered that caused the collapse of the last panel while trenching. Trials to pull out the cutter failed and we had to pour concrete on top of the cutter in order not to risk the whole shaft.

In this document, project is briefly described, causes of collapse are discussed and finally some precautions are recommended to reduce the risk of such expensive collapses are suggested.

2. PROJECT DESCRIPTION

A Syphon was constructed to cross the fresh water underneath the new Suez Canal. To deal with this problem, two shafts were to be constructed at each side of the New Suez Canal and the shafts had to be connected together by tunnels to transfer the water from the west to the east (Figure 1).

Bauer’s task was to construct the shafts and a bottom grout plug for groundwater control. Each shaft was of diameter 18.40m comprising of 24 diaphragm wall panels of thickness 1.20m. Panels were connected together by overcutting. Depth of excavation inside the shafts was 52.0m and the depth of wall was 120m. A grout plug had to be installed near bottom of the shaft. Hence a trench cutter MC 128 was mobilized to the site at beginning of January 2015.

Soil consisted of about 4.0m of poorly graded sand followed by 8.0 to 9.0m of clay. After that very dense sand continued till the end of shaft. Water was at a depth of 8.0m.
3. **COLLAPSE**

During the excavation of the last panel, trench suddenly collapsed at a depth of 116.0m. Most of the soil collapsed above and within the cutter frame, which was partially removed by airlifting aided by the use of water jets. However all trials to pull out the cutter finally failed.

After two weeks of trials, a decision was taken to pour the panel in order to save the shaft and the total project. Steel cage was modified in a way to allow for installation in trench obstructed by the cutter hoses and wires, and then concrete was poured filling all the cavities within the cutter frame.

From the consumption curve of concrete, it is estimated that the collapse took the shape shown in **Figure 3** below. Most probably, collapse started in sand and then the top clay started to fall down. All that at a depth of about 110m.
4. **Known Issues Versus Reality**

<table>
<thead>
<tr>
<th>Known Issues</th>
<th>Actual Conditions</th>
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<tbody>
<tr>
<td>A differential head of <strong>1.0 meter</strong> between slurry and the GWT is sufficient to assure trench stability</td>
<td>Trench collapsed although the differential head was <strong>8.0 meters</strong></td>
</tr>
<tr>
<td>Any analytical method shows that the lowest safety factor is always near the top of trench and that it increases as we go deeper</td>
<td>Collapse happened at a depth of <strong>104 to 116 meters</strong> near the bottom</td>
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<tr>
<td>Below 13.0m, soil is mainly <strong>Sand</strong> with high permeability</td>
<td>Below 13.0m, soil is stratified with <strong>alternating</strong> layers of <strong>Sand and Silty Clay</strong> (permeable and impermeable layers)</td>
</tr>
</tbody>
</table>
5. **CAUSES OF COLLAPSE**

5.1 **PAST EXPERIENCE**

We noted in previous small site projects that there is always a problem when executing the last panel. Trench tends to collapse after a long duration of trenching, while exchanging Bentonite or, in most cases, while lowering the steel cage or sometimes during concreting.

It was believed that the reason behind this phenomenon is the increase of pore water pressure within the sandy permeable layers. To check the validity of this assumption, two deep wells were installed at the two sides of a trench at a small site; one well inside the box (between the chains of the cutter) and the other outside the box. The wells were equipped with pumps that were adjusted to run automatically when water level rises more than 50cm from its original level.

It is noted, after some trenching, that the pump in the inner well ran nearly continuously indicating that the water level inside the shaft was rising all the time. The outer well rarely worked.

We came to the conclusion that the fluid loss of slurry, resulting from the differential head between the slurry and GWT, causes water to expel into the surrounding soil. Outside the shaft, water dissipates easily. However, inside the shaft, water is prevented from dissipation by the surrounding walls and causes the water level to rise inside the shaft. The situation gets worse if the aquifer(s) is confined from top and bottom by impermeable layers.

Water loss of slurry keeps increasing the pore water pressure inside the shaft till it equalizes with the head of slurry. At this critical stage, any drop of slurry level or density (or long time waiting) endangers the trench stability. It should be noted that after exchanging the contaminated with clean slurry, the slurry density is less. For more details refer to Figure 4.

The following should be noted:

- The risk is higher for deep trenches as the rate of fluid loss increases with depth (higher pressure)
- The last panel is always a secondary one. Contamination due to cutting through primary panel concrete increases the fluid loss
- If trenching ends safely, the long duration for cage installation increases the fluid loss
- Risk increases for the cases of stratified soil with alternating permeable/impermeable layers as the rate of increase of pore water pressure is higher in the confined aquifers. Sometimes soil tends to liquefy.

To reduce the risk of increase of pore water pressure, Bauer Egypt always installs deep well(s) that keep running automatically reduce the water pressure to its original level and to assure the differential head between slurry and pore water pressure in all layers.

The well should penetrate through all aquifers to be trenched and should be perforated along its full length.
Stage 1; Water resulting from fluid loss flows into the site

Stage 2; Pore water pressure increases till equalizing with slurry pressure

Figure 5; Trench Instability due to Increase of Pore Water Pressure
5.2 **This Particular Shaft**

For this particular shaft, a well was installed but did not penetrate through the lower aquifer were collapse occurred. This was due the wrong information given in the soil report. Also there was no feedback from the site about the existence of these impermeable layers. Site staff believed that the existence of these high strength increases the safety of the shaft.

6. **Conclusion and Recommendations**

It is noted that there is a very high risk of collapse of the last diaphragm wall panel(s) while closing small boxes or shafts of (sites of about 500m²). This risk is due to the effect of fluid loss of drilling slurry on the pore water pressure inside the box/shaft.

Based on the above and on the lessons learned from previous sites, especially the last expensive one, the following is recommended to avoid the risk of collapse of the last panel:

   a) Exploratory drilling should be conducted to assure the soil stratification and to define the different aquifers along the full depth of diaphragm walls.

   b) Any variation of soil stratification from that given in the soil report or the shop drawings should be reported even if it is thought to be in the safe side.

   c) At least one well should be installed to relief the rise in pore-water pressure. Well should not be far from the last panel to be trenched. It should be fully perforated and should penetrate all aquifers.

   d) If barrettes or bored piles are to be installed inside a small box or shaft without the use of full casing, they should be installed prior to installing the surrounding walls.

   e) The same problem arises for the case of open bore drilling inside a box or shaft to install micro-piles or grout lances. Dewatering is required to relief the increase of pore water pressure resulting from drilling operations.

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