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RISK ASSESSMENT IN SOIL RETAINING SYSTEM CONSTRUCTION

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Abstract: Diaphragm walls (slurry trenches) is more needed nowadays in urban areas and crowded cities where underground constructions as subways, deep basements and utilities as pump stations, underground tanks and tunnels mainly depending on drilling methodology using slurry trenches. Many researchers and different codes of buildings have discussed the risk issues related to design analysis or materials but hardly find scientific researches discussing quality control on site during construction process and its effect on the overall quality of the work needed. Some of these issues is geometrical imperfections such as the positioning error of drilling rigs during trenching, small seepage passages through the diaphragm wall may occasionally occur, which will undermine its water-tightness and lead to significant leakages. This study focus on examination of penetration of seepage passages and it further quantitatively estimates the flow rate through the diaphragm wall under certain circumstances.

Keywords: Diaphragm wall, Risk assessment, Bentonite slurry, Hydro fraise, Leakage.

1. INTRODUCTION

As the main advantage of using slurry trenches methodology is to avoid huge excavation in areas where no availability for open excavation or dewatering process can't be performed, the diaphragm wall is constructed by replacing the bentonite slurry with lighter density with reinforced concrete in pre-excavated trenches to achieve waterproof overlapping panels; This technique proved its success depending on engineering specific scenarios, budget and availability of equipment, the analytical issues always concentrating on how to estimate the deformation of the trench sides for design and determine the bentonite slurry properties to achieve the stability of the trench or studying the structural system of the wall to afford different loads on it. However, the construction process is always accompanied with a lot of difficulties and problems and cause huge risks and effects on the overall project quality, schedule and budget. Mainly due to the intervention of the human factor which is not considered in design methodology based on data available from different projects. These risks multiply in case of very deep excavations as development of drilling machines and bentonite slurry plants allow drilling to 120m blow ground level. In this paper as we are specialists in geotechnical engineering, we tried to present major problems encountered with such construction technique and providing some solutions.

2.Verticality

In many projects using diaphragm works with high depth, and as the Egyptian code specification for deviation of diaphragm walls (1/100: 1/200) and for ideal cases can reach to (1/500) [1].

At some cases when the deviation is more than the specification of the project and effect on the steel cage of other panels, it is a solution to pour it with cemented sand with compressive strength reach to 10^4KN/m2 and repeat drilling it after 24 hours from pouring.

The time between pouring concrete of the primary panel and excavation of the secondary panel next to it shall not be less than 48hr, but in case that one of the two primary panels was poured many days ago and reached to high compressive strength and the other one was newly poured with less strength than the other, it cause more inclination towards the soft one during drilling the secondary panel in between, and that referred to the work schedule in the project and the extent of commitment to it.

At some cases, the deviation of the excavated trench depends on the qualified operator of the machine and his experience in dealing with soil problems encountered during drilling.

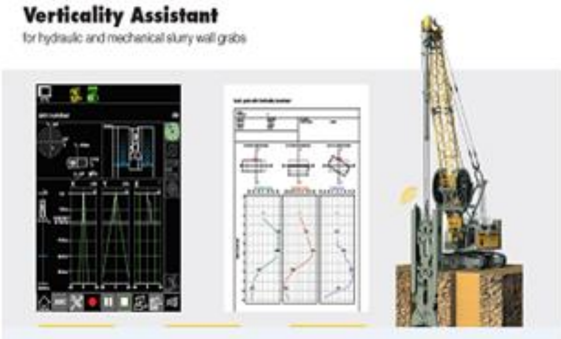


Fig 1: Operator computer screen at drilling rigs.

One of the factors which affect the deviation during excavation is Steering flaps for verticality correction during operation (in case of inclination) and the quality of its work, Thus, as soon as the first sign of deviation has been transmitted, the operator can take the following actions to correct it:

- If the deviation occurs perpendicularly to the sides of the diaphragm wall trench, the direction can be controlled by activating hydraulic jacks that work on pads to push the Hydro -fraise against the trench sides to correct the deviation or by moving the rig boom.
- If the Hydro fraise tends to deviate longitudinally to the sides of the diaphragm wall trench, the corrective actions consist of varying the relative rotational speed of the cutter wheels and the power delivered to them and/or acting on the relevant pads to push the Hydro fraise against the diaphragm wall trench sides [2.[

The inner faces of the guide walls shall be vertical with a tolerance of 1/200 and the nominal clear distance between the two inner faces of the guide walls will be, on each side, 0.025m, indicatively wider than the thickness of the panels, not to allow any inclination of the machine cutter the guide walls are also used to clamp the guide frame of the Hydro fraise.

1- Robust cutter steel frame (name gives an indication of the cutter weight)
2- Steering flaps for verticality correction during operation (in case of inclination)
3- Pressure balance for major components (2 gearboxes, 1 mud pump)
4- 0.1524m mud′s pump (up to 0.125 m³/sec mud flow) max. Diameter of cobbles 0.08m
5- Powerful cutter with shock absorbers (BC 40 with 100 KN.M, fitted with a series of teeth are fixed to the gearbox and rotating in an opposite direction
6- Suction box where the excavated soil is pumped towards mud pump.

Fig 2: components of hydro fraise cutter [3].

3.Trench stability and slurry properties

As per Egyptian code for soil mechanics and foundations [1], the bentonite slurry properties for freshly mixed as follow: Plasticity index ≥250%

Table1: Allowable values for Bentonite slurry tests.

Property	Stages		
	Fresh	Ready for re-use	Before RFT installation (before concrete)
Density	< 11 KN/m3	< 12.5 KN/m3	< 11.5 KN/m3
Marsh Value	32 to 50 sec	32 to 60 sec	32 to 50 sec
Fluid loss	< .00003m3	< .00005m3	N/A
PH	7 to 11	7 to 12	N/A
Sand Content	N/A	N/A	< 4%
Filter Cake	< .003m	< .006m	N/A
N/A : not applicable			
Place to take the samples	From storage silos bentonite plant		From the bottom of panel

- The filter cake thickness which made up under pressure 700KN/m2 for 30min.
- The density of the slurry over the level of trench bottom before pouring concrete shall not exceed the value (12KN/m3 .(

*In case of high porous soil, Rock soil with breaks, Rise of underground water table, Present of artesian pressure, very weak soil or very saline soil, the bentonite slurry can be used with the change of the mentioned limits above; Without any definition for the values of that change or additional tests.

In case of using hydro fraise, the water tightness between the panels shall be achieved by overcutting between the primary panels and secondary panel. The minimum overcut between panels is 0.15m. On the both ends the cutter wheels will overcutting into the ends of the primary panels, resulting in a rough surface leading to a better interlocking connection between the primary and secondary panels and to insure rough surface the teeth of cutting wheels much be checked and changed when get smoothed. And after the end of excavation of secondary panels, steel brush is used by crane under its own weight to clean cut in the concrete at ends from the mud cake.

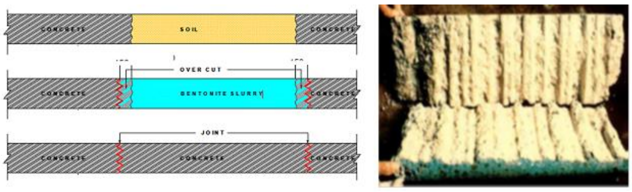


Fig 3: Hydro fraise overcutting between panels. [4]

There must be using of steel brush after drilling secondary panels and before installation of steel cage to assure of removing all the bentonite filter cake from the overcutting in the concrete of the primary panels, it shall be installed in the trench for number of times that it come out clear from all the slurry, and after every time shall be washed outside the trench before installing it again.

Monitoring of all neighboring properties, highways, services, and underground structures shall be take in consider by surveyors, in case of settlement at any property, the work must be stopped till inspecting reasons and find appropriate solution.

In case of any sudden huge increase or decrease of slurry level inside the excavated trench due to collapse of the soil, work shall be stopped and casting the trench with cemented sand with cements content 100kg/m3.

After installation of steel cage inside the trench, in case of trench sides collapse, and no possibility of lifting the steel cage out of the trench, there must be casting or concrete inside the trench, and study possibility of construction a replacement panel behind or at front of the spoiled panel, and redesign to distribute loads, I case of excavation at front of diaphragm walls, jet injection with high pressure must be done at joints of the replacement panel to avoid water leakage.

The external stresses of equipment (Hydro fraise) load shall be considered in the analysis. The equipment details are in Annex C. The total load of the equipment shall be approximately 1200Kg. This load is distributed to both crawlers asymmetrically with 70% and 30%. And the load of any service crawler used for steel cage or concrete Casting must be studied to require the factor of safety of the trench stability and must keep the safe distance to the trench.

The stability of the trench side depends on the drilling rate which can be (0.0025:0.0033 m/sec) to give enough time to the bentonite slurry to get absorbed in the soil portions and generate the filter cake to avoid collapsing of the soil. That rate depends on the bar of the slurry suction pump, the rate of pumping bentonite in the trench and the drilling output behind the desander. This all process depends on the soil type and experience of machine operator as if there was drilling with high rate in soft loose soil, it will cause collapsing of soil from trench sides.

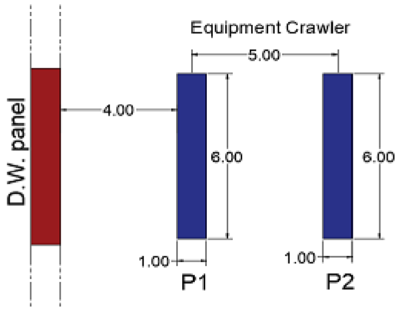


Fig 4: Layout of the equipment loads and distance from the trench.

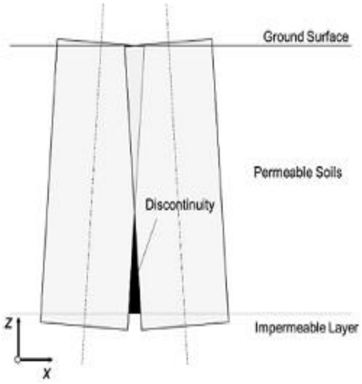
4.Probability of leakage with diaphragm walls construction

According to [5] the possibility of leakage into a building pit with diaphragm walls is small, but the consequences may be very serious in case groundwater flows into the building pit. Especially in an urban environment a sand carrying leak is seen as a huge risk. There are several possible causes for leakage out of this sand layer:

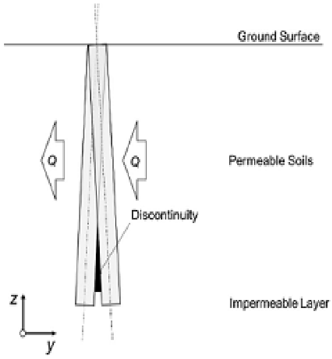
The panels of the diaphragm wall are insufficiently connected.The base of the panel is not or insufficiently connected to the impermeable layer, for example as a result of the presence of an obstacle.

The concrete of the panel contains intrusions of sand, peat or clay that form weak spots in the diaphragm wall.

The concrete of the panel contains bentonite that forms weak spots in the diaphragm wall.



a



b

Fig 5: Two possible modes of seepage passage, (a) devia tion in the wall plane (x-z- plane); (b) deviation in the out-of-wall plane (y-z plane).

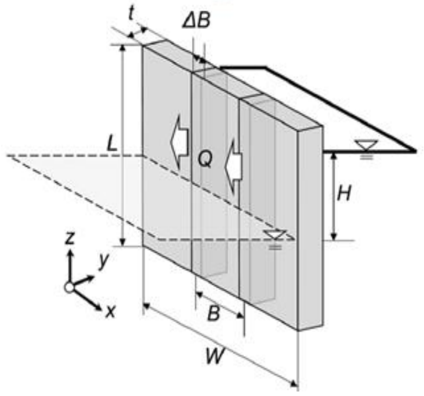


Fig 6: three-dimensional view of the diaphragm wall.

wall geometric parameters (L, W and t are the length, width and thickness of the wall; B and ΔB are the center to center distance of two adjacent panels and overlapping distances, respectively; H is the water head difference) For grabs with cutting drums and pumps systems that evacuate loosen soils continuously, only one bite is involved though the zigzags still exist due to the occasional deviation.

When the diaphragm wall is not penetrated in the seepage direction, the minimum thickness (t min) will act as a key indicator of the cut-off performance [6].

The thickness can be evaluated by the number of concrete nodes along the seepage direction (y-direction). Then the minimum thickness in the diaphragm wall can be evaluated by taking the minimum value.

The flow rate through the wall can be conservatively estimated as

$$Q=\frac{Kt\ H\ A}{tmin}=\frac{Ku\ H\ \tilde{A}t}{t} \qquad (1)$$

And the normalized flow rate (Ω):

$$\Omega=\frac{Qt}{Ku\ H\ A}=\frac{\tilde{A}t}{A} \qquad (2)$$

Where (kt) is the permeability coefficient of concrete, permeability coefficient of soil (Ku) and (A) is the area of the diaphragm wall.

In reality, a limitation of flow rate δ is applied to conform to various codes and action standards. For a typical deep excavation project, the drainage capability is limited by 0.0005m3/s per 1000m2 of plan area to ensure that the drainage machines can be readily deployed [7].

For coffer dams or buried waste, the discharge rate is also limited as per the corresponding standards or owner's requests. a dimensionless parameter $B\Omega/t$ is used as the y coordinate of the design chart to ensure the unknown value t is separated from the known values. In the limit state, the flow rate is equal to limit flow rate δ and we have.

4.1. Methodology

As we measured the discontinuity area in (X-Z) plane:

$$Ax=\frac{h^2\sigma x}{2}+\frac{\Delta B^2}{2\sigma x}-\Delta Bh \qquad (3)$$

And the discontinuity area in (Y-Z) plane as:

$$Ay=\frac{h^2\sigma y}{2}+\frac{(t-D)^2}{2\sigma y}-(t-D)h \qquad (4)$$

Using Hydro fraise in the construction of diaphragm walls can be accompanied by deviation in the verticality in both X, Y directions which effect on the water tightness off the diaphragm walls since parametric study reveals that the cut-off performance is sensitive to the wall length, width, thickness, overlapping distance and the standard deviation of the inclination angle. Hence these parameters are considered in the production runs.

Statistical parameters: The allowable verticality tolerance ranges from 1/200 to 1/100 according to various codes and standards. If the specified tolerance corresponds to an exceeding probability of 0.3%, then the tolerance of 1/200 corresponds to a standard deviation of inclination angle [std(β)] of 0.1°. With the field since most codes specify a verticality tolerance of 1/200–1/100, the std (β) of 0.1° and 0.2° are used. A standard deviation of rotation angle of std(θ)=0.1° is used though it does not affect the result.

Table2: Reference case for wall geometric parameters.[6]

Remarks	Center to center distance	Interaction between panels	Wall thickness (t)	deviation in X-direction.	Deviation in Y-direction.
	B	ΔB	t	σx	σy
Refrence Case	3	0.2	1	0.007	0.007
B	2	0.2	1	0.007	0.007
	3	0.2	1	0.007	0.007
	4	0.2	1	0.007	0.007
ΔB	3	0.1	1	0.007	0.007
	3	0.2	1	0.007	0.007
	3	0.3	1	0.007	0.007
t	3	0.2	0.6	0.007	0.007
	3	0.2	1	0.007	0.007
	3	0.2	1.5	0.007	0.007
σx	3	0.2	1	0.005	0.007
	3	0.2	1	0.007	0.007
	3	0.2	1	0.01	0.007
σy	3	0.2	1	0.007	0.005
	3	0.2	1	0.007	0.007
	3	0.2	1	0.007	0.01

Symbol key

h	Diaphragm Wall Height (m)
H	Water Head Difference (m)
B	Diaphragm Wall Width (m)
ΔB	Overlape (m)
t	Diaphragm Wall Thickness (m)
σx	Slope @ X dir.
σy	Slope @ y dir.
θ	Rotation Angle in Degree
Ax	Seepage Area @ X dir. (m2)
Ay	Seepage Area @ y dir. (m2)
At	Total Seepage Area (m2)
Ku	Soil Permeability
Q	Discharge (m3/s)
Ω	Flow Rate

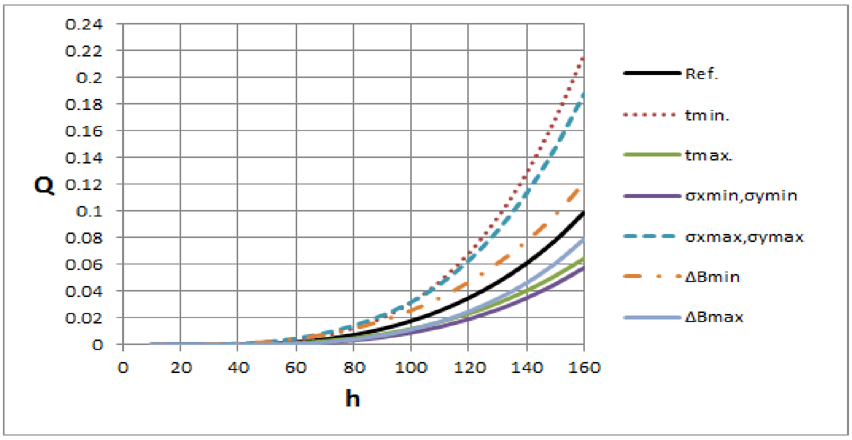


Fig 7: Effect of geometrical parameters on discharge.

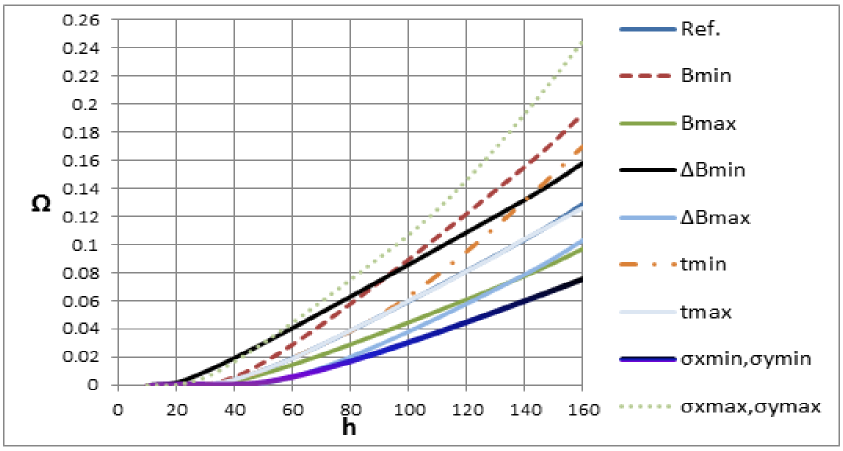


Fig 8: Effect of geometrical parameters on flow rate.

The change of center to center distance between panels (B) has very low effect on discharge however it has effect on the flow rate.

A standard deviation of rotation angle of std(θ) =0.1° is used though it does not affect the result.

It should be noted that in the analysis, only the effect of geometric imperfection caused by the inclination of drilling is considered. Other effects due to soil collapse, inclusion of soil is not considered in the study.

5. Case study In Alamein project for construction of Pump Stations [8]:

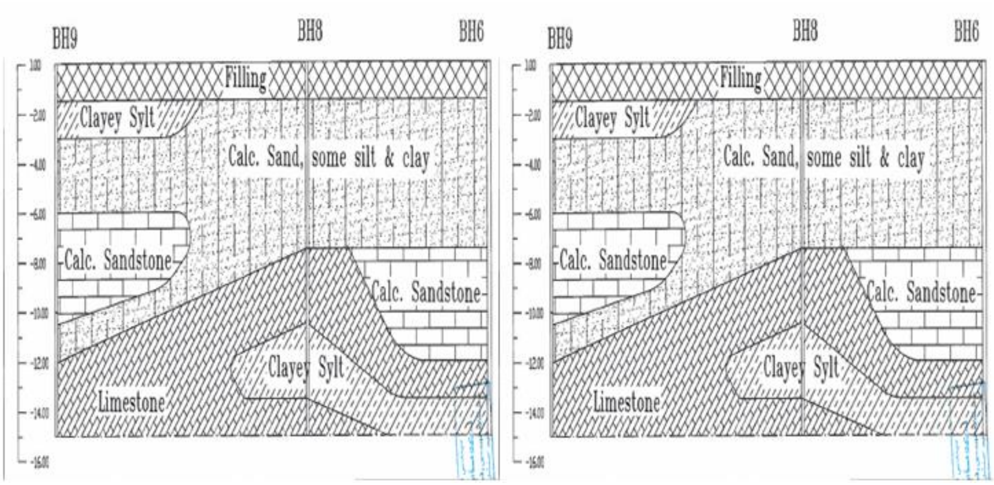


Fig 9: Soil profile of Alamein project.

.(underground water table (-0.5m*

Ground level was raised with compacted sand to form working platform to reach the level of (+2.35m). The guide wall was constructed with depth 1.5m. The bentonite slurry was used with mix 30kg/m3 and with depth inside the trench not less than 0.25m under the guide wall top level during excavation, with monitoring tests as follows:

Table3: Bentonite tests result variance of Alamein project.

Property to be Measured	**Test Method and Apparatus**	**Compliance Values Measured at 20°C**		
		Freshly Mixed	**Ready for Re-use**	**Sample from Excavation to Concreting**
Density	Mud balance	< 11 KN/m3	< 12.5 KN/m3	< 11.5 KN/m3
Fluid loss (30-minute test)	Low-temp. test fluid loss	< .00003m3	< .00005m3	N/A
Filter cake thickness	Low-temp. test fluid loss	< .003m	< .006m	N/A
Viscosity	Marsh cone	32 to 50 sec	32 to 60 sec	32 to 50 sec
Shear strength (100 minutes get strength)	Fann viscometer	5 to 30 N/m2	5 to 40 N/m2	N/A
Sand content	Sand screen	N/A	N/A	< 4%
pH	Electrical pH meter BS 3445; range pH to 14	7 to 11	7 to 12	N/A

Notes:

a) Where the Fann Viscometer is used, the fluid sample should be screened by a 300 micron sieve before testing.

b) Use of polymers as support fluid shall not be allowed without specific approval from the Engineer.

During excavation of trenches and when reaching to level (-8.00m) it was noticed occurrence of collapse and landslide around the trench and in the distance between the trench and drilling machine and sudden lowering the level of slurry inside the trench to the groundwater table.

As per consultant engineer: the stability of trench excavation is affected by the weakness of soil profile due to the low relative density of fine silty sand and possibility of presence of gabs and cavities in layers of stone in addition to water pressure in soil profile. Excess drilling can also occur in the transition area between the weak soil layers and stone layers due to the change in the performance of drilling tool, although the balance review under hydrostatic pressure of water at recorded water depth in boreholes profiles doesn't indicate the presence of imbalance. The increase of the water pressure inside soil layers as a result of added load from raising the ground level with height 2m in addition to the increase of the percent of fine soil passing through sieve No.200, which reaches 45% in clayey silty sand present in site which leads to imbalance of the excavated trench, And by assuming the raising of water pressure inside fine clayey silty sand layers as a result of addition load, the factor of safety of trench stability is reduced to less than the permissible values(1.1) at depths lower than 7.00m. And based on it, the reason of imbalance of excavated trenches is due to the weakness of soil profile represented in the low number of SPT of fine silty sand layers which indicates low relative density and possibility of addition drilling at the transition area between weak soil layers and stone layers and the possibility of presence of gabs and cavities in stone layers, in addition to increase in water pressure due to addition load from raising ground level.

The recommendations [9:[

- Consider using bentonite slurry with high quality with taking into account high salinity of ground water and recommends increase of percent of bentonite powder in slurry up to 50kg /m3 to increase the density with monitoring the quality of the slurry by specified tests.
- Continue the drilling carefully with rates and pressures suitable to the weak soil especially in the transition area between weak soil layers and stone layers.
- In case of evidences of drilling slurry smuggling due to collapse of trench sides or presence of cavities with amount that can't be compensated, drilling must stop at once and pouring the trench with cemented sand with cement content 150kg/m3, and repeat the drilling after stabilizing of collapse.
- Be sure to check the backfilling under the drilling machine with substitution soil with level reach to guide wall top level, with depth of 1.00m on 3 compacted layers to reach dry density not lower than 95% from the highest dry density from modified proctor test, with using two orthogonal layers of geogrid with total maximum tensile strength of 50KN/m in all directions for each layer .

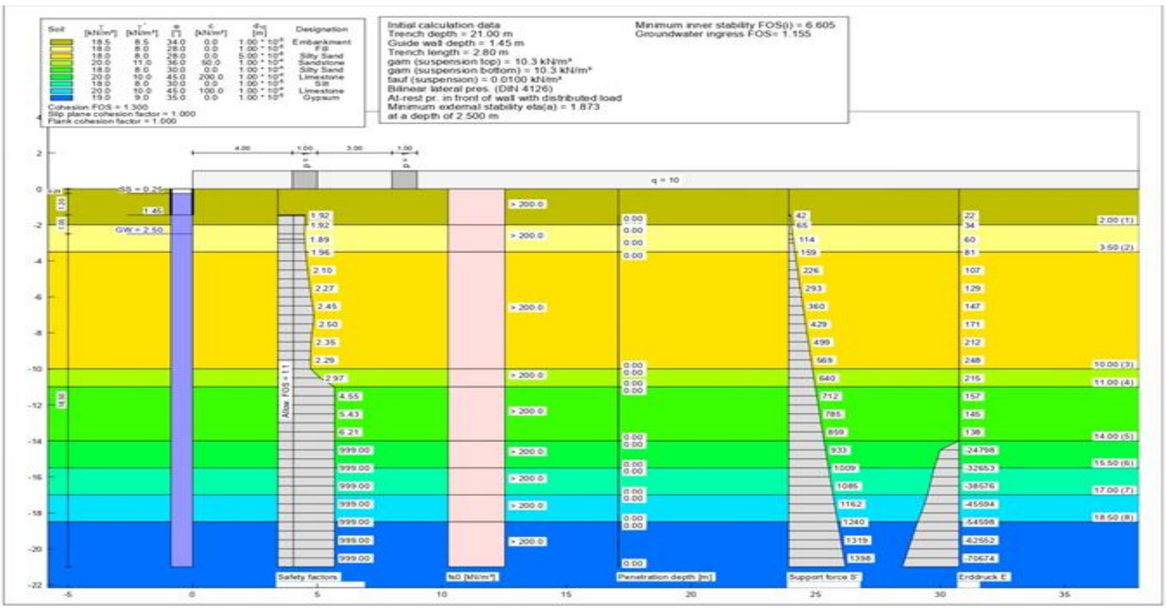
With taking all recommendations into account:

- The trench collapse occurred in about 75% of the trenches in the project.
- The collapse occurred for the second or third time at the same trench after filling it with cemented sand and repeat drilling in about 50% of the collapsed trenches.

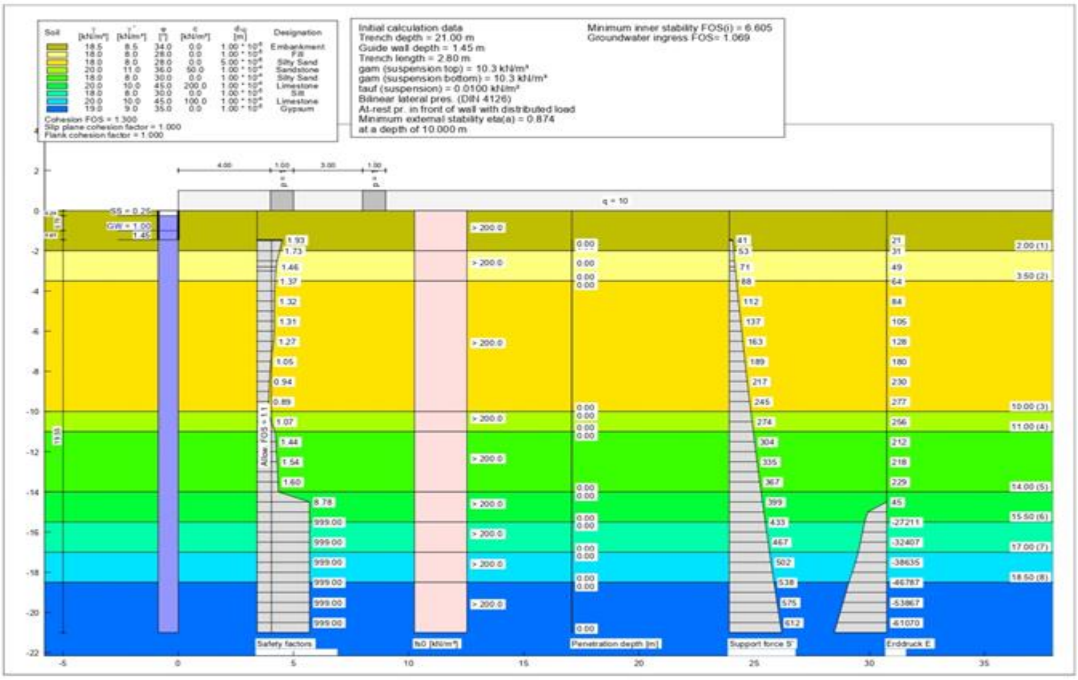
This all affected on the project schedule and cost and quality .

For the several factors which mentioned previously that raised the risk in the construction of diaphragm wall shafts for the pump station including high ground water level. There was leakage from many weak points in the western north corner of the structure during excavation works at level of (-9,00m) for construction of the reinforced raft, however there was dewatering works from inside the shafts using deep wells but it didn't control on the discharge of water which leaded to failure in completing works

Fig 11: Leakage from weak points in diaphragm walls during excavation



(a)



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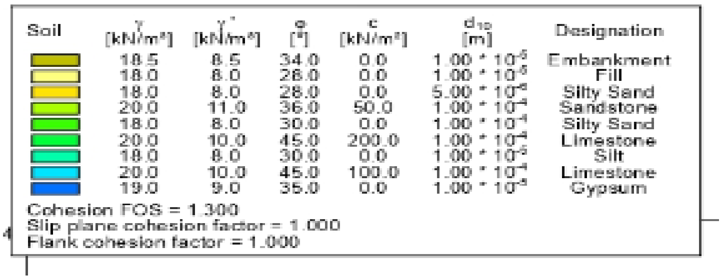

Soil	γ [kN/m³]	γ' [kN/m³]	φ [°]	c [kN/m²]	d_{10} [m]	Designation
	18.5	8.5	34.0	0.0	1.00 * 10⁻⁵	Embankment
	18.0	8.0	28.0	0.0	1.00 * 10⁻⁵	Fill
	18.0	8.0	28.0	0.0	5.00 * 10⁻⁶	Silty Sand
	20.0	11.0	36.0	50.0	1.00 * 10⁻⁴	Sandstone
	18.0	8.0	30.0	0.0	1.00 * 10⁻⁴	Silty Sand
	20.0	10.0	45.0	200.0	1.00 * 10⁻⁴	Limestone
	18.0	8.0	30.0	0.0	1.00 * 10⁻⁵	Silt
	20.0	10.0	45.0	100.0	1.00 * 10⁻⁴	Limestone
	19.0	9.0	35.0	0.0	1.00 * 10⁻⁵	Gypsum

Cohesion FOS = 1.300
Slip plane cohesion factor = 1.000
Flank cohesion factor = 1.000

(c)

Fig 10: (a,b,c) Plaxis model for storm shaft[9].

There were many solutions for the issue to stop the leakage that dewatering works can control on the groundwater level and continue the work such as:

-increasing the excavation to (-12.50m) and pouring concrete under water as plug to prevent water from coming upwards. But it was high risk on the diaphragm wall itself as with the increase of excavation there is increase of ground water boiling through the wall and may lead to collapse of the wall, the difference of water head under the plug will be very high to afford it and may lead to failure in the plug itself

-using dewatering deep wells outside the diaphragm wall in the western north side at the leakage points, 7 wells at the overlapping between panels in the north side and 5 wells in west side with depth of 45m, outer diameter 0.40m and discharge of 0.05m3/sec. But it wasn't sure to decrease the water and allow completing excavation works till construction of the reinforced raft.

-construction of plastic concrete secant pile wall with minimum compressive strength of 4000kN/m2 after 28 days, with diameter of 0.50m and depth of 23m blew ground level with minimum overlapping between piles 0.15m. as follows:

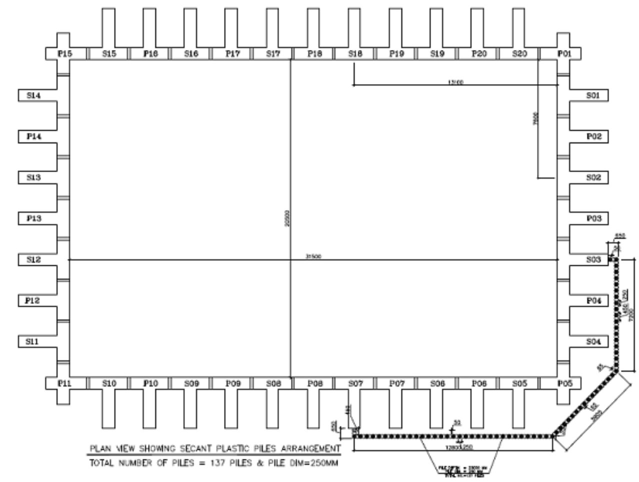

Fig 12: Secant plastic piles arrangement.

Fig 13: the diaphragm wall shaft after construction of plastic secant pile.

6.Conclusion:

Performance of cut-off projects are widely undermined by geometrical imperfections of diaphragm walls due to construction errors. More often than not, only remedial works can be taken when leakage problems are observed (after excavation) or detected (after construction and before excavation). In this study, we focused on the common issues at different stages of diaphragm wall construction, the geometrical imperfections led by off-verticality of drilling rig axis during trenching were considered and its impact on the leakage through the cut-off walls. This enables a quantitatively-based relation between geometrical imperfections and leakage in the subsequent construction stage. It also discussed a case study under special circumstances and remedial works which taken when leakage problems were observed.

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