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CONSTRUCTION AND CHALLENGES OF THE DIAPHRAGM WALL IN FINE SANDY SOIL

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Abstract: The Rapid growth of urbanisation in major metro cities in India, the urge for the construction of underground spaces has become a highly commendable topic around the corner in recent times. With the continuous development of social economy, the construction of projects has also shown a trend of rapid rise. With the exploration of construction techniques, comes the challenges of construction in heterogeneous geology at different project location. The subsurface characteristics and its behaviours is well studied and understood before proceeding towards the execution of the project. This helps in minimising Project cost and avoiding major losses due to surprises the Geological Characteristic of the Projects has. Various advanced technologies and the comparison of the construction machine and equipment have been applied to conclude the methods for construction projects in underground Spaces. One of which is the underground diaphragm wall, which is widely used in engineering construction technology. The construction period is short, for less affected by the geological conditions, the construction efficiency is relatively high, and the subject has been widely used in the current construction Scenarios in Underground space. This article will analyse the application of the construction technology of the diaphragm wall construction and put forward corresponding measures.

This work performs an extensive literature survey and example investigation on the mitigation of slurry wall trenches during the construction of diaphragm wall panel trenches, and the failure modes of slurry wall trench instability, the stability theoretical analysis models and methods, the slurry formation and its protection mechanism, the influence of related factors on slurry wall trench stabilisation, and other related problems are summarized and analysed emphatically.

Furthermore, an example application shows that the established slurry unit weight design method is reliable. At last, this paper also proposes the focus and direction for follow-up work, that is, to construct an accurate and effective theoretical analysis model of slurry wall trench instability considering the influence of multiple factors and the calculation method of the slurry cake and its mechanical or mathematical relationship with slurry quality.

I. INTRODUCTION

1.1 General

Diaphragm walls, also known as slurry walls, are a commonly practiced engineering technique for creating deep excavations and retaining structures in urban environments where space is limited. These walls are particularly useful in areas with complex geological conditions, including fine sand soil ground. Fine sand, with its unique properties and challenges, can significantly influence the construction process and overall performance of diaphragm walls.

1.2 Diaphragm Wall

Diaphragm walls are excavated rectangular structures formed in place through complete removal of soil, resulting in an underground concrete barrier. These walls primarily serve as retaining structures and find application in scenarios like wharfs. Employing a rectangular excavation tool, the soil is extracted, shaping the wall into a series of interconnected rectangular panels. This design ensures both structural strength and impermeability. The process of constructing diaphragm wall panels involves three main stages: establishment of a guiding wall, excavation of panels (involving demolition, removal, and stabilization), and the final construction phase (comprising the installation of reinforcing cages, concrete pouring, and curing).

There are several types of diaphragm walls, each designed to cater to specific engineering requirements and ground conditions. Here are some most common types:

- Slurry Wall (Traditional Diaphragm Wall): This is most widely used type of diaphragm wall. It involves excavating a trench while supporting the sides with a slurry fluid (usually bentonite) to prevent collapse. Once the trench is excavated, concrete is poured in to create the wall. Slurry walls are used for retaining structures, cut-off walls, and underground structures.
- Cutter Soil Mix (CSM) Wall: CSM walls involve a continuous in-situ mixing process where a stabilizing agent (often cement) is injected into the soil as it is being excavated. This creates a soil-cement mixture that forms a retaining wall after setting. CSM walls are less dependent on external support fluids and are suitable for cohesive soils.
- Trench Cutter Wall: In this method, a mechanical trench cutter is used to excavate and form the trench. The trench cutter can cut through various soil types, even hard rock, while water or bentonite slurry is used to eliminate the soil cuttings. Reinforcement cages are then lowered into trench, and concrete is poured to create the wall.
- Secant Pile Wall: Secant pile walls consist of interlocking concrete piles that are constructed alternately to form a continuous wall. There are "soft" piles, which are constructed first, and "hard" piles, are constructed later and interlock with the previously installed piles. This method is effective for groundwater control and retaining walls.
- Hard/Soft Mixed Wall: This is a combination of secant pile and slurry wall techniques. The "soft" piles are typically constructed using slurry support, while the "hard" piles are made of unreinforced concrete and interlock with the soft piles.
- Diaphragm Wall with Anchors: Anchors or tie-backs can be integrated into diaphragm walls to provide additional lateral support. These anchors are often tensioned after the wall is constructed, enhancing its stability and load-bearing capacity.
- Diaphragm Wall with Vertical Drains: In areas with poor soil drainage, vertical drains can be incorporated into diaphragm wall to improve consolidation of surrounding soil.
- Diaphragm Wall with Jet Grouting: Jet grouting involves injecting high-pressure grout into the soil to create columns of improved soil. This method could be used in combination with diaphragm walls to create mixed walls with enhanced structural and geotechnical properties.

The choice of diaphragm wall type depends on factors such as the soil characteristics, groundwater conditions, engineering requirements, and project constraints. Every type has its advantages and limitations, making it important to carefully evaluate the site conditions and select the most suitable approach for the specific project.

1.3 Applications

- Retaining Walls: Diaphragm walls are used to create retaining walls for excavations where adjacent structures need to be supported and protected. They are commonly employed in basements of buildings and underground structures.
- Cut-off Walls: In situations where groundwater flow needs to be controlled, diaphragm walls could be constructed as cut-off walls to prevent the movement of water through the ground.
- Foundation Elements: Diaphragm walls could serve as foundation elements for buildings, bridges, and other structures. They provide stability and distribute loads from the structure to the underlying soil or rock.
- Tunnel Construction: In tunnelling projects, diaphragm walls can be used to create vertical shafts or access points, providing stability during excavation.

1.4 Advantages

- Diaphragm walls offer high load-bearing capacity and can withstand substantial lateral pressures.
- They provide a watertight solution for groundwater control and cut-off applications.
- The technique is suitable for a variety of soil types, including soft and cohesive soils, as well as sands and gravels.
- Diaphragm walls can be constructed in tight urban spaces and areas with limited headroom.

1.5 Challenges

- The construction process could be complex and requires specialized equipment and skilled personnel.
- Ensuring the homogeneity of the concrete and proper consolidation is crucial to avoid weak points or voids in the wall.
- Controlling the slurry properties to prevent collapse and maintain trench stability can be challenging, especially in soils with low cohesion like fine sand.

II. INTERPRETATION OF DIAPHRAGM WALL

To establish a continuous diaphragm wall, the initial step involves constructing primary panels, which are spaced slightly wider than actual panel width. Subsequently, the secondary panels are developed within the gaps present between the primary ones.

The construction process of diaphragm walls necessitates adherence to a specific sequence of tasks. Generally, a rectangular-section tool is employed to excavate the soil, resulting in the creation of a rectangular trench. The primary tool for excavating panels is known as a grab, which matches the dimensions of the component it intends to dig. The holes created are then stabilized using a bentonite slurry. When it comes to concreting, the tremie technique is employed, akin to its usage in the construction of cast-in-place piles.

This is to discuss how utilising the standard Hydraulic grab technology, the Project Team (Tata Projects Limited Team working on the Chennai Metro Rail Project, Phase 02, TU01 Contract) tackled the geotechnical challenges of constructing 1 m thick, 24.4m deep diaphragm walls through highly variable geology comprising sand up to depth of 15m below the ground level followed by highly weathered rock grade V and IV and overcame the significant impact that the ground condition had on grab productivity, excavation rate, wear and tear of the equipment and delivered a high quality diaphragm wall, with zero lost time accident, on programme and on budget.

In addition, this work will present how the project team overcame the difficulties with the procedures and innovation developed to successfully excavate the trench for construction of diaphragm wall panel with cut off levels up to 10m below the working platform. Geology: The geology of the station box, the site of Diaphragm wall construction comprises of mainly sand till depth of 16m in ground approximately followed by completely weathered rock, grade V (RQD: 0-10) and highly weathered rock grade IV with Charnockite/Granite.

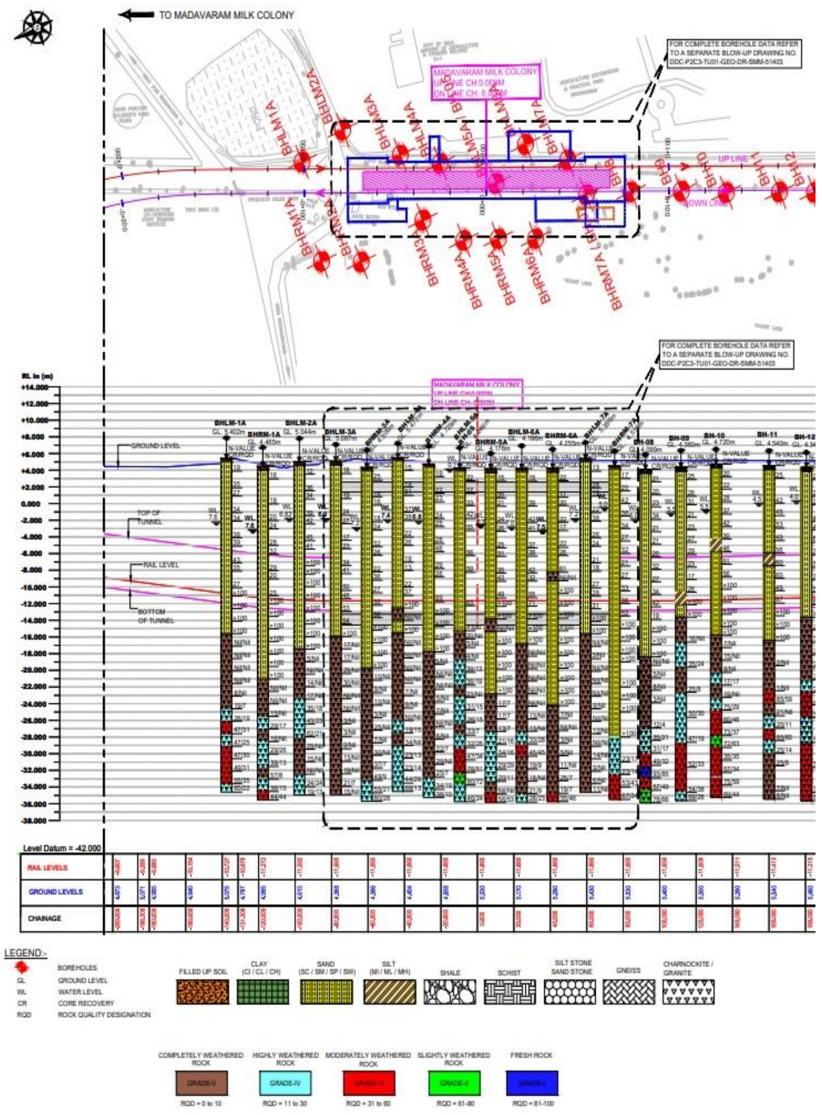

Fig 3.1: Geotechnical Interpretation of diaphragm Wall at site.

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III. FEATURES OF DIAPHRAGM WALL

A diaphragm wall takes shape as an in-situ constructed rectangular section beneath the soil, resulting in an underground concrete barrier. The construction occurs incrementally, with each panel being interconnected to guarantee both structural integrity and water resistance. These diaphragm walls can vary in thickness, spanning from 60cm to 150cm, and possess a width ranging between 2.0 and 3.5m. The potential depth for constructing these diaphragm walls extends up to 60 meters.

1. The process of constructing Diaphragm Wall is relatively quiet and has little vibration
2. The Diaphragm Wall can be constructed to great depths (more than 80m)
3. The Diaphragm Wall could be constructed on various soil types and rocks
4. The Diaphragm Wall is watertight; no dewatering is required and hence has little effects on adjacent structures.
5. The Diaphragm Wall serves both as an external wall for the basement and foundation for the superstructure.

IV. RESULTS AND DISCUSSIONS

Several different pre-drilled configurations were considered before opting for a single pre-drill in the geometrical centre of each panel. The Project Specification allowed for a maximum verticality of 1:200 over the exposed face of the diaphragm wall and so there was a risk that any pilot hole, pre-drilled with a verticality less than 1:200, may cause problems with grab verticality during subsequent diaphragm wall excavation.

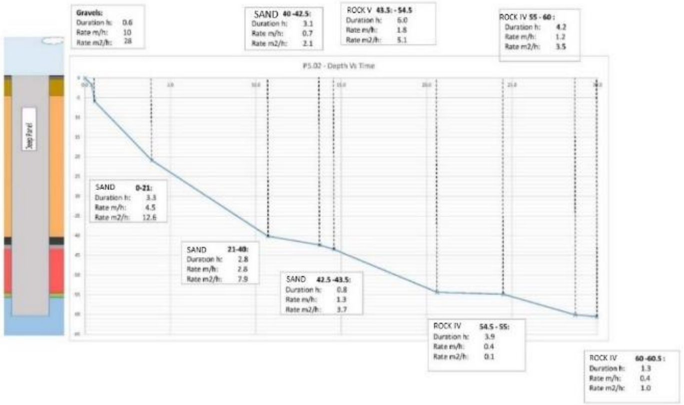

Fig 4.1: Typical plot of grab excavation rates against depth versus time against strata

The maintenance programme proved successful in limiting the amount of non-productive time as can be seen, where during the last 18 weeks of the Project grab productivity reached its highest levels and grab break down time was minimised.

It was decided that an 880mm temporary cased, 800mm diameter pilot hole, drilled centrally within the 1200mm thick diaphragm wall would offer sufficient improvement to grab excavation rates and with a [target] tolerance of 1:125, provided sufficient mitigation to the risk that the pilot hole would not adversely impact the verticality of the later diaphragm wall excavation.

The Geotechnical Baseline Report for the site, stated that the Harwich Beds contained bands (up to 100mm) of hard strata with a maximum unconfined compressive strength of 100MPa. Our construction records showed that grab excavation rates reduced to as little as 0.3m2/hr and that the band ranged in thickness from 0.6m to 3.5m. In its in-situ state the grabs simply could not penetrate the strata. However, experience of piling through the same strata presented no significant difficulty to conventional piling techniques. It was therefore considered that a central pre-drill through this hard band would create a weak spot that would assist the grabs in breaking up the material.

A similar theory had developed for the class IV and V rock strata. Excavation rates through these strata varied from between 1.9m2/hr and 3.0m2/hr. The strata consist of an unpredictable make up of sandy soil, rock class IV and V. In its confined in-situ state, a 27-tonne grab could at best only scrape across the excavation face and in turn achieve very little penetration. However, traditional piling techniques had again no significant difficulty excavating through the same strata.

It was considered that the single central pre-drill would put the strata into an “unconfined” state and provide a pathway into which the material could fail into with each bite of the grab.

The success of the pre-drilling was immediate and is presented in Figure 07. Excavation rates through the Harwich Beds increased to an average of 2.9m2/hr and through the Lambeth Group, increased to an average of 5.1m2/hr.

The occurrence of major breakdowns was of significant concern and detailed record keeping of productive verses non-productive time identified that there was a re-occurring pattern to the major breakdowns. From the graph presented fig 4.1, cumulatively and approximately every 10 to 11 weeks, the grabs experienced some kind of significant breakdown. A programme of preventative maintenance, over and above what would normally be considered as routine preventative maintenance was introduced. This included the strip down and structural checking and testing of all major welds on the body of each grab.

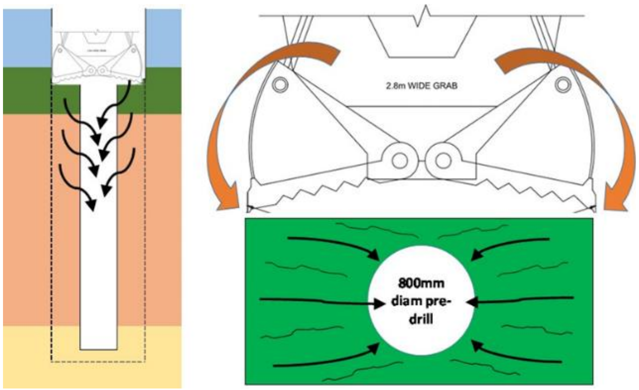

Fig 4.2: Schematic showing the location of the centrally drilled pre-drill in each of the 60m deep panels.

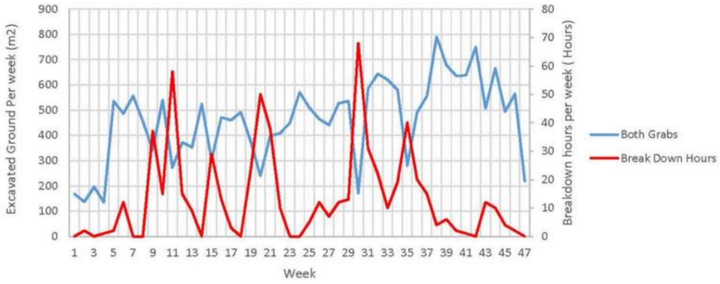

Fig 4.3: Graphical representation of the 10–11-week cycle of major grab breakdown (Note: the impact of each breakdown can be seen in the corresponding reduction in excavated m2).

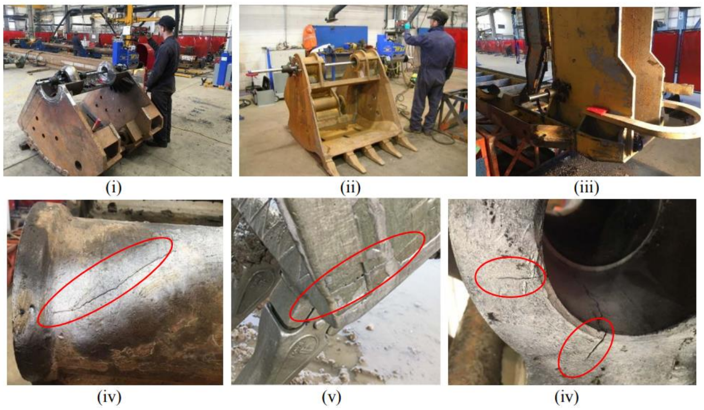
(i) (ii) (iii)
(iv) (v) (iv)

Fig 4.4: Different pattern of damages recorded on the equipment.

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Details of the damages recorded and the repair details:

Clockwise
(i) Replacement of spring bushes
(ii) In line boring of grab jaw
(iii) Replacement pivot bosses
(iv) Structural cracking to grab body.
(v) Structural cracking to the jaws of the grab
(vi) Structural cracking to the jaw pivot, repaired by specialist welding techniques.

V. CONCLUSION

Identifying the challenges in construction of Diaphragm wall.

Site setup and mobilization of the excavation equipment and auxiliary facilities and survey mark outs.

Before construction of the diaphragm wall, site utilisation plan or the site layout plan plays an important role. The Site setup must be planned in such a way that it facilitates the short and easy flow of slurry from the bentonite slurry storage tank to the location of operation of the grabbing equipment for construction of diaphragm wall in located panel. The De-sanding unit or the slurry separation unit should be planned in such a place which is near to all possible location of the construction of diaphragm wall. This will ensure the outward flow of the slurry with the excavated material or earth to easily flow towards the separation plant. The overall site should we well setup to ensure efficient refilling of the bentonite powder into the bentonite storage of the plant. The mucking or the disposal of the treated excavated material should be planned nearest to the exit location of the site where the dumpers and the excavators can easily arrange the waste removal from site.

The site planning is mostly challenged during construction of the diaphragm wall in high traffic dwellings and in between cities like Chennai and Mumbai in India, where traffic density is thick and traffic load on road is high. A proper site traffic management system with a well-established site becomes essential and a key performance Index of the construction of the Diaphragm wall projects.

Important points

Traffic diversion must be planned and followed.

All bentonite/Polymer tanks & other treatment facilities should be in the vicinity of the location of work.

Adequate working areas demarcation at site as per site utilization plan.

Good firm access to be provided to allow safe passage of plant and equipment throughout the working area of Diaphragm wall.

Set out of the guide wall and the proposed diaphragm wall locations on ground.

Verticality of the trench within construction tolerances is achieved with advanced machineries used to guide the whole trenching process with great precision. Koden is one of the advanced equipment used to guide trenching to meet verticality of the trench with project tolerances.

Investigate soil behaviour in diaphragm wall construction in fine sandy soil. Basically, Sandy soils are naturally occurring, finely divided rock characterised by less than 18% of content of clay and more than 68% content of Sand. Sand is anywhere in between 625 microns to 2mm particle size. These soils have a low water retention capacity and drain quickly when in water submergence and are hard to hold up the overall volume of the excavation material with water. Sandy soils are often very acidic in nature.

Some of the main challenges with the geology where the diaphragm wall is to be construction are.
Trench collapse.
Slurry loss
Water retention capabilities

There is a very high chances of water loss in a confined trench of excavation with water with any additives involved.
Developing specialized construction techniques suitable for fine sandy soil conditions.

So there comes the need for producing a film which can resist the low water retaining capability of sandy soil ground condition and can provide containing the slurry of excavated material in confined trenches. These are mainly done with the help of adding bentonite to the water in the trench with step excavation. The bentonite in the slurry helps forming a thin layer of cake on the face of excavation of the sandy soil and enhance its anti-collapse nature and face retaining capability.

Enhancing trench stability through effective support systems and slurry materials.

Higher strength stability is achieved by using effective support systems like the suitable maintenance and dosage of bentonite in the slurry in a control manner. Another supports system for better control on excavation of the diaphragm wall is the construction of guide wall with precision.

Implementing stringent quality assurance measures to ensure adherence to design and safety standards.

With efficient control of the key performance index like density, viscosity, slurry loss, pH value and sand content. These are maintained by conducting test on site on the slurry coming out of the diaphragm wall trench during excavation and adequate dosing of bentonite in the slurry to maintain the adequate key performing index of the slurry content.

Establishing effective and planned maintenance of the trenching equipment An effective and planned maintenance of the trenching equipment on regular interval of time proved to increase the project productivity and efficiency of the trench during construction of the Diaphragm Wall. The interval of the maintenance was once every 10 weeks for each trench excavation. It was found that the trenching with planned maintenance of the plant and equipment significantly improved the project performance and performance of the trench of bentonite slurry in sandy soil and fine ground.

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