Contiguous Pile Wall as a Deep Excavation Supporting System

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Abstract

Providing space for parking, public amenities, etc in multi-storey buildings at town centres has created a need to go deep excavations into ground. Deep excavations are supported by systems like conventional retaining walls, sheet pile walls, braced walls, diaphragm walls and pile walls. This article describes various excavation supporting systems that are in vogue essentially contiguous pile wall and its advantages. A detailed design methodology of an excavation supporting system is furnished in this study. A case study on the Contiguous pile wall retaining system for supporting a deep excavation at a town centre is presented.

Keywords

Deep Excavation; Excavation supporting system; Contiguous Pile wall.

Introduction

Urbanisation made cost of land high and it necessitated to go deeper into the ground and also towering vertically towards the sky. A deep excavation into the ground is indispensible to create additional floor space to meet increasing space requirements for parking for multi-storey buildings at the town centres. Numbers of deep excavation pits in city centers are increasing every year [1]. Structures in the immediate vicinity of excavations, dense traffic scenario, presence of underground obstructions and utilities have made excavations a difficult task to execute [2]. In this context, analysis and design of proper deep excavations and their supporting systems are essential. Even in complicated urban settings, deep retaining systems have been deployed successfully by overcoming construction challenges.

An Excavation is basic phase in the construction of foundations or basements of high rise buildings, underground oil tanks, subway stations etc [3]. The process of an excavation may encounter different kinds of soils underneath the same excavation site-from soft clay to hard rocks. During excavation, some soil types pose greater problems than others. Sandy soil is always considered dangerous even when it is allowed to stand for a period of time after a vertical cut. Vibration from blasting, traffic and heavy machinery movement, and material loads near the cut can also cause earth to collapse in sandy soil. The instability can be caused by moisture changes in the surrounding air or changes in the water table. Clayey soils in general, present less risk than sand; however, soft clay can prove to be very treacherous. Silty soils are also unreliable and require the same precautions and support provision as sand.

To engineer an excavation, the basic steps which should be carried out by design engineer are: site characterisation; selecting dimensions of excavation; surveying adjacent structures; establishing permissible movements; selecting earth retaining system; selecting supporting and construction scheme; predicting movements; compare predicted with permissible movements; alter supporting (bracing) and construction scheme; if needed; monitor instrumentation, alter as needed; compare monitored results with predicted and permissible values; alter bracing and construction scheme, if needed [4, 5]. Site characterisation is the first major step to be taken by a geotechnical engineer. Most common practices tend to greatly simplify soil profile and to select appropriate design parameters like strength, and compressibility as the basis of simple laboratory tests. Since deep excavation is a total technique, proper coordination and integration of design and construction are of utmost important [3].

In this study, details of various deep excavation supporting systems are furnished and comprehensive design philosophy of an excavation supporting systems is presented. This paper also contains details of a case study on the analysis and design of a Contiguous pile wall for supporting deep excavation at a town centre.

Material and Method

Deep Excavation Supporting Systems

Unsupported excavations pose hazard to workers and equipment. Prevention and minimising damages to surrounding is of utmost concern to the design engineers and constructor for any excavation work. A variety of excavation methods and lateral supporting systems are to be practiced based on local soil, ground water and environmental conditions, allowable construction period, money and machinery. Excavation methods include full open cut methods, braced excavation methods, anchored excavation methods, island excavation (partial excavation) methods, and top-down construction methods and zoned excavation methods. Types of deep vertical soil support systems [3, 6] are commonly used in metropolitan cities are Conventional retaining walls (figure 1), Soldier pile with wooden lagging walls (figure 2), Sheet pile walls (figure 3, 4 and 5), Diaphragm walls (figure 6) and Pile walls-Contiguous, Secant or Tangent (figure 7). Apart from retaining walls to resist lateral earth pressure a supplementary strutting systems are also required. A strut is made of wood, reinforced concrete or steel. Based on function of a strut, it may classify as an earth berm, a horizontal strut, an anchor or as a top-down floor slab. During construction of excavation supporting system, the adjacent facilities may damage. Vibration due to adjacent machinery, vehicles, rail-roads, blasting and other sources require that additional bracing precautions are to be taken. This may avoided by taking some ground improvement measures such as grouting the ground between the excavation site and adjacent building. Dewatering should be done if the soil at the site is relatively impervious like clayey soil.

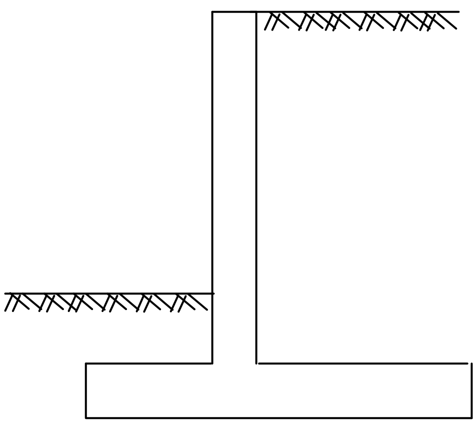

Figure 1. *Retaining wall*

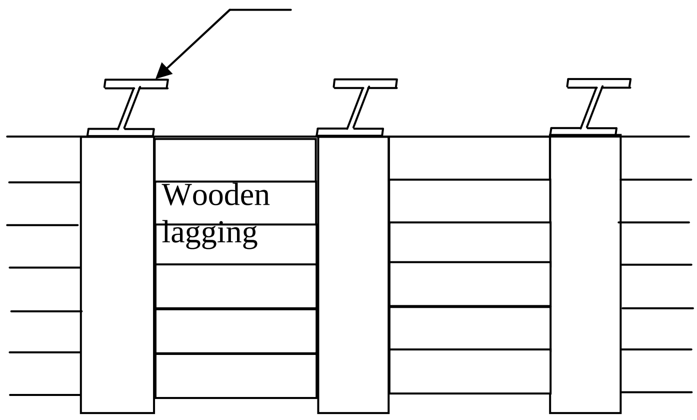

Figure 2. *Soldier pile with wooden lagging walls*

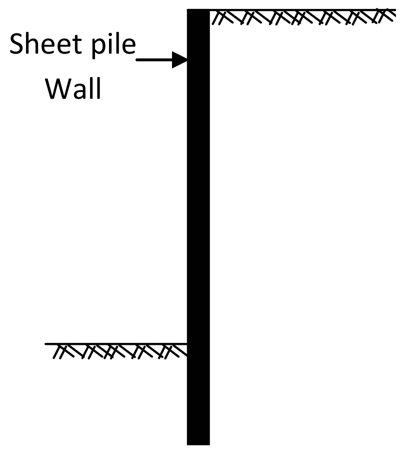

Figure 3. *Sheet pile wall*

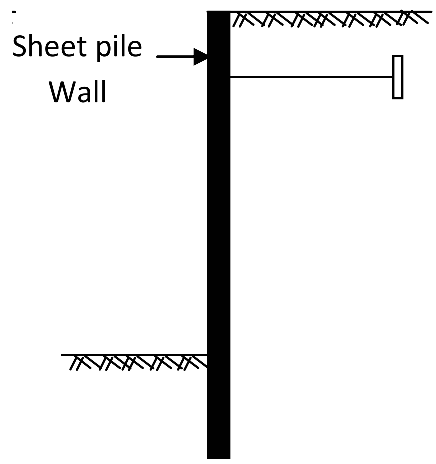

Figure 4. *Anchored Sheet pile wall*

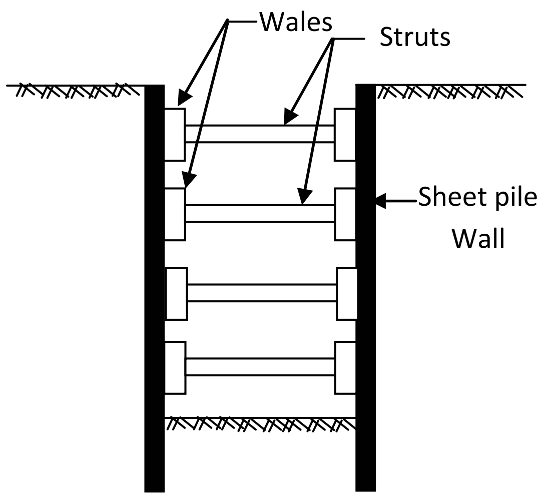

Figure 5. *Braced wall*

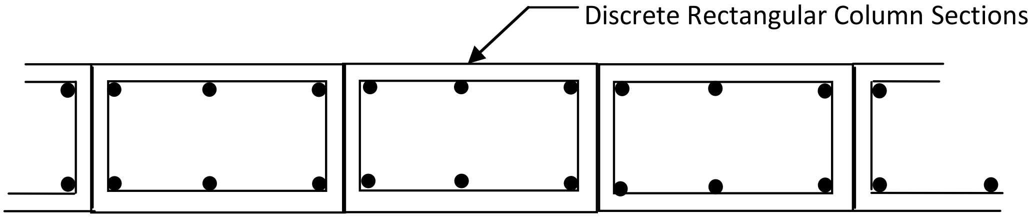

Figure 6. *Diaphragm Wall*

Embedded walls take up little lateral space as compared to the conventional retaining walls. Soldier pile and lagging walls are the most economical systems compared to other retaining walls. In granular soils where the groundwater is below proposed subgrade or can be economically drawn down by dewatering, a soldier beam and lagging system remains the most widely used approach. This type of retaining system involves the following broad based activities: (i) Constructing soldier piles at regular intervals (1 to 3m on centre typically) (ii) Excavating in small stages and installing wooden lagging. (iii) Backfilling and compacting void space behind the lagging. Moment resistance in soldier pile and lagging walls is provided solely by the soldier piles. Passive soil resistance is obtained by embedding the soldier piles beneath the excavation grade. The lagging bridges and retains soil across piles and transfers the lateral load to the soldier pile system. They are also very easy and fast to construct. The major disadvantages of soldier pile and lagging systems are that they are primarily limited to temporary construction. They cannot be used in high water table conditions without extensive dewatering. They are not as rigid as other retaining systems because flange of the soldier pile is only embedded beneath subgrade. When soils are not conducive to dewatering, sheet piling capable of withstanding the hydrostatic pressure may be the more appropriate option. For deep cuts, lateral restraint can be provided by horizontal wales with either raker braces or by tieback anchors. For shallow excavations, a cantilevered wall is generally sufficient to resist earth pressures. Narrower excavations can be braced with cross struts.

Diaphragm walling is a technique of constructing a continuous underground wall from the ground level. These reinforced concrete diaphragm walls are also called Slurry trench walls due to the reference given to the construction technique where excavation is made possible by filling and keeping the wall cavity full with bentonite-water mixture during excavation to prevent collapse of vertical excavated surfaces. Typical wall thickness varies between 0.6 to 1.1m. The wall is constructed panel by panel in full depth. Panel width varies from 2.5m to about 6m. Short widths of 2.5m are selected in less stable soils, under very high surcharge or for very deep walls. It must be remembered that Diaphragm walls are constructed as a series of alternating primary and secondary panels. Alternate primary panels are constructed first which are restrained on either side by stop-end pipes. Before the intermediate secondary panel excavation is taken up, the pipes are removed and the panel is cast against two primary panels on either side to maintain continuity. The major disadvantage of Diaphragm wall is it requires massive equipment, long construction period, and huge cost.

Piled Retaining Walls

In-situ pile retaining walls also called column piles are rows of concrete piles either cast-in situ pile method or precast pile method. Merits of column piles are less noise or vibration than produced by the installation of solider piles or sheet piles. Colum piles have greater stiffness than soldier piles or steel sheet piles. They avoid excessive bulk excavation and help to control ground movements. There are three distinct bored pile wall options in current use: Contiguous wall, Secant wall and tangent wall.

Contiguous pile walls are constructed with small gaps between adjacent piles. The use of low-cost augers and, more particularly, Contiguous Flight Auger (CFA) rigs to drill successive unconnected piles provide an economical wall. Diameter and spacing of the piles is decided based on soil type, ground water level and magnitude of design pressures. Large spacing is avoided as it can result in caving of soil through gaps. CFA pile diameters range from 300mm to 1000mm. CFA piles are considered more economical than diaphragm wall in small to medium scale excavations due to reduction in cost and time of site operations. Besides, no bentonite mud is needed for the excavation. Contiguous piles are suitable in crowded urban areas, where traditional retaining methods would otherwise encroach the adjoining properties, these piles restricts ground movements on the backfill side. The pile is formed by first drilling into the ground with a CFA. Cement-sand grout or concrete is then injected under pressure through the auger’s hollow stem as it is being withdrawn. The grout or concrete pressure is maintained during the auger withdrawal so that it assists the extraction as well as exerting a lateral pressure on the surrounding soils. On completion of this operation, a reinforcing cage is placed into the fluid column of grout or concrete. When CFA pile combined with capping beams/breasting beams can show savings in cost and time. Capping beams at the top to help equitable pressure distributions in piles. Separate facing usually

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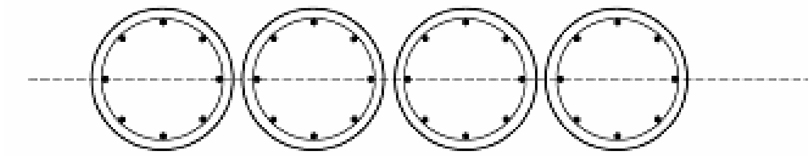
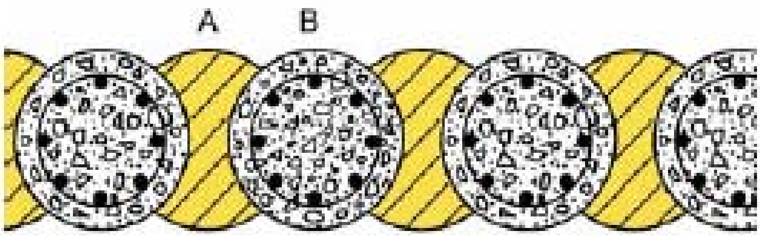
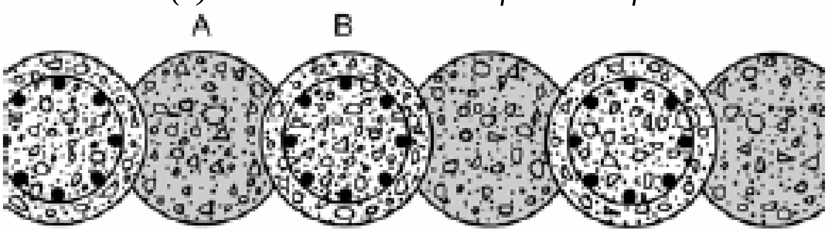
provided to improve looks. The range of soil conditions in which CFA piles can be used are granular soils, cohesive soils, soft rocks. Soft clays, weak organic soils are unsuitable due to wall bulging. Hard rocks are also not suitable. The Contiguous wall can only be used where ground water is not a hazard or where grouting or jet grouting is used can be used to remedy leakage between the piles. However, some acceptable amount of water can be collected at the base and pumped out. The principal disadvantages of contiguous pile walls-the gaps between piles and the resulting problems of lack of water proofness have been effectively overcome by interlocking or secant piles.



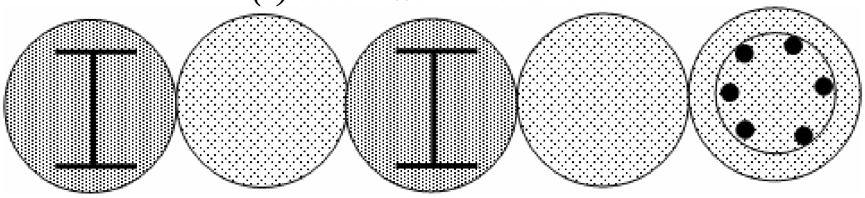
(a) Contiguous Pile Wall



(b) Secant Wall – hard/soft or hard/firm



(c) Secant Wall – hard/hard



(d) Tangent Pile Wall

Figure 7. *Pile Walls*

Secant Pile Walls are formed by constructing intersecting piles. Secant bored pile walls are formed by keeping spacing of piles less than diameter. Secant pile walls are used to build cut off walls for the control of groundwater inflow and to minimize movement in weak and wet soils. Secant Wall constructed in the form of hard/soft or hard/firm and Secant Wall Hard/hard wall. Secant Wall-hard/soft or hard/firm is similar to the contiguous bored pile wall but the gap between piles is filled with an unreinforced cement/bentonite mix for the hard/soft wall and weak concrete for the hard/firm wall. Construction is carried out by installing the primary piles (A) and then the secondary piles (B) are formed in reinforced concrete, cutting into the primary piles. Diameters can range from 500mm to 1200mm. Secant Wall Hard/hard wall construction procedure is very similar to a hard/firm wall but in this case the primary piles (A) are constructed in high strength concrete and may be reinforced. The Secondary piles (B) are cut into the concrete primary piles (A) using heavy duty piling rigs fitted with specially designed cutting heads. Tangent pile walls consist of a series of drilled shafts located such that the adjacent shafts touch each other, hence the name tangent wall. Secant pile walls are stiffer than tangent piles walls and are more effective in keeping ground water out of the excavation.

Results and Discussion

Design Methodology Involving Excavation Retaining Systems

Stability of excavation is the major design criterion in order to avoid collapse of excavations [3]. Stability analysis involves the distribution of earth pressures. Stability analyses include push-in failure analysis, sand boiling analysis, and upheaval analysis. To excavate in a sandy soil one should consider push-in and sand boiling. To excavate in a clayey soil one should consider push-in and upheaval. In alternated layers of sand (or gravel) and clay, push-in and upheaval should consider. The penetration depth of a retaining wall is usually determined according to results of push-in failure because sand boiling is normally not a main controlling factor. Goals of lowering the ground water level are to keep the excavation bottom dry, to prevent leakage of water or sand, to avoid sand boiling or upheaval failure, and to prevent the occurrence of floating basements.

Distribution of earth pressure influences stability, stress, and deformation analysis of the deep excavation. For problems of excavation, considering that the active earth pressure is usually the main force leading to the failure of the excavation supporting systems. The passive earth pressure is usually the force resisting the failure. The pressure distribution shall depend on the nature of backfill. An excavation will encounter various soil layers. Earth pressure computed on the basis of Rankine’s earth pressure theory. If working with long term behaviour, effective stress analysis should be applied to both cohesive and cohesionless soils and water pressure should be computed separately. Recharge wells may be required outside the walls if drops in water level are not allowed. If there are compressible soils in the profile, buildings and lifeline structures are expected to settle due to groundwater lowering. Dewatering methods are applied in cases where there is need for control of water pressures and/or flow [7].

There are two analysis methods for push-in failure: free-earth support method and fixed earth support method [8, 9]. The free earth support method assumes that the embedment of retaining wall is allowed to move a certain distance under the action of lateral earth pressure. The fixed earth support method is to assume that embedment of the retaining wall seems to be fixed at a point below the excavation surface. The embedded part may rotate about fixed point. Thus, when the retaining wall is in the limiting state, the lateral earth pressure around the fixed point on the two sides of the retaining wall does not necessarily reach the active or passive pressures. If a cantilever wall is designed based on the free support method, no fixed point is supposed to exist in the embedded part of the wall, as discussed above. The external forces, only active and passive forces, on the retaining wall are not to come to equilibrium. Therefore, the free earth support method is not applicable to cantilever walls. A simplified analysis [10] of considering active force on one side and passive force on the other side of excavation supporting system is used to simplify the calculation of necessary depth of penetration or depth of embedment (D_P). D_P is found by applying moment equilibrium about the bottom of the wall. The computed may be increased by 20 to 40% beyond the point required by equilibrium or the effective horizontal pressure on the passive side may be reduced by applying a factor of safety of 1.5 to 2.0 before the embedment depth of pile is computed.

The upward flow may cause the effective stress at a point in soil to be zero, which means that the soil is unable to bear any load, and the phenomenon is called sand boiling. The hydraulic gradient when the effective stress equals zero is called critical hydraulic gradient (i_{cr}), which can be expressed as follows:

$$i_{cr} = \frac{\gamma^1}{\gamma_w} \tag{1}$$

The factor of safety against boiling can be estimated by Harza’s method, Terzaghi’s method or simplified one-dimensional method. For excavations, a reasonable factor of safety is around 1.5-2.0 [11]. The simplified one-dimensional method is presented in figure 8.

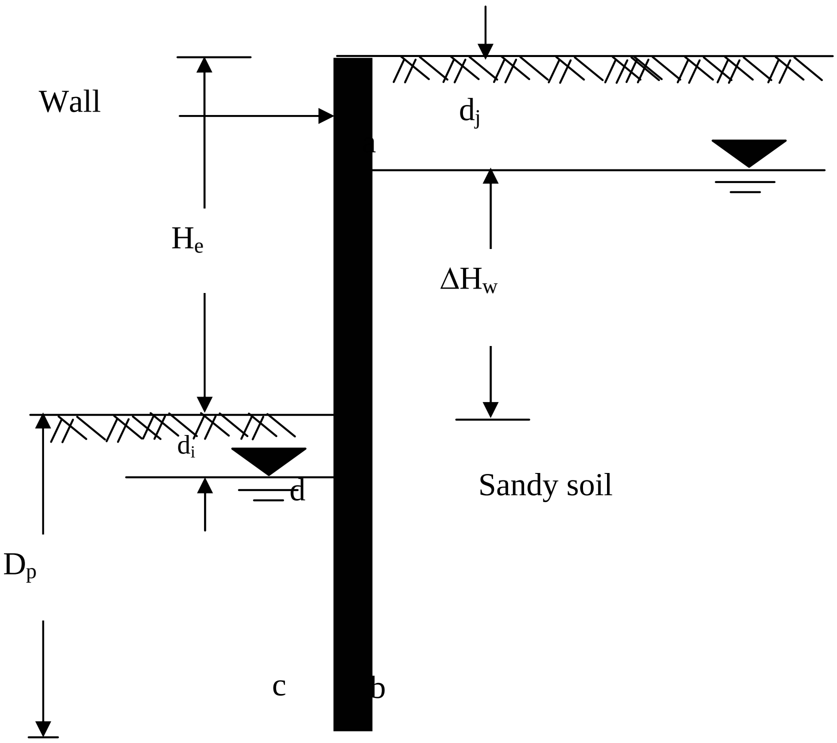


Figure 8. *Analysis of Sand boiling*

The hydraulic gradient will be:

$$i_{avg} = \frac{\nabla H_w}{H_e - d_j + d_i + 2(D_p - d_i)} = \frac{\nabla H_w}{(H_e + 2D_p - d_i - d_j)} \quad (2)$$

The factor of safety against sand boiling will be:

$$F_s = \frac{i_{cr}}{i_{avg}} = \frac{\gamma^1 (H_e + 2D_p - d_i - d_j)}{\gamma_w \nabla H_w} \quad (3)$$

The required F_s for the above equation should be greater than or equal to 1.5.

If below the excavation surface there exists a permeable layer (such as or gravel soils) underlying an impermeable layer, the impermeable layer has a tendency to be lifted by the water pressure from the permeable layer. The safety, against upheaval, of the impermeable layer should be examined. As shown in figure 9, the factor of safety against upheaval is:

$$F_{up} = \frac{\sum_i \gamma_{ti} h_i}{H_w . \gamma_w} \quad (4)$$

where, F_{up}=factor of safety against upheaval, γ_{ti}= unit weight of soil in each layer above the bottom of the impermeable layer, h_i = thickness of each soil layer above the bottom of the impermeable layer, H_w= head of the water pressure in the permeable layer, and γ_w = unit weight of the ground water. The factor of safety against upheaval F_{up} should be larger than or equal to 1.2. The factor of safety against of excavation construction, the possibilities (of the occurrence) of upheaval at each stage of excavation should be analysed. If drilling within the excavation zone is required (e.g. in order to place piezometers or build a well), the possible paths of water flow should be verified and the possible upheaval induced by drilling should be prevented to secure the excavation.

With the stability analysis of an excavation, the penetration depth of retaining wall can be determined. With the stress and deformation analysis, the bending moment and shear of the retaining wall can be determined. The thus obtained bending moment and shear envelopes are then used for the design of reinforced concrete columns. Basically, the stiffness of the reinforced concrete pile is the highest. Colum piles bear the axial load and flexural load simultaneously. Therefore, their behaviour is similar to that of the reinforced concrete columns.

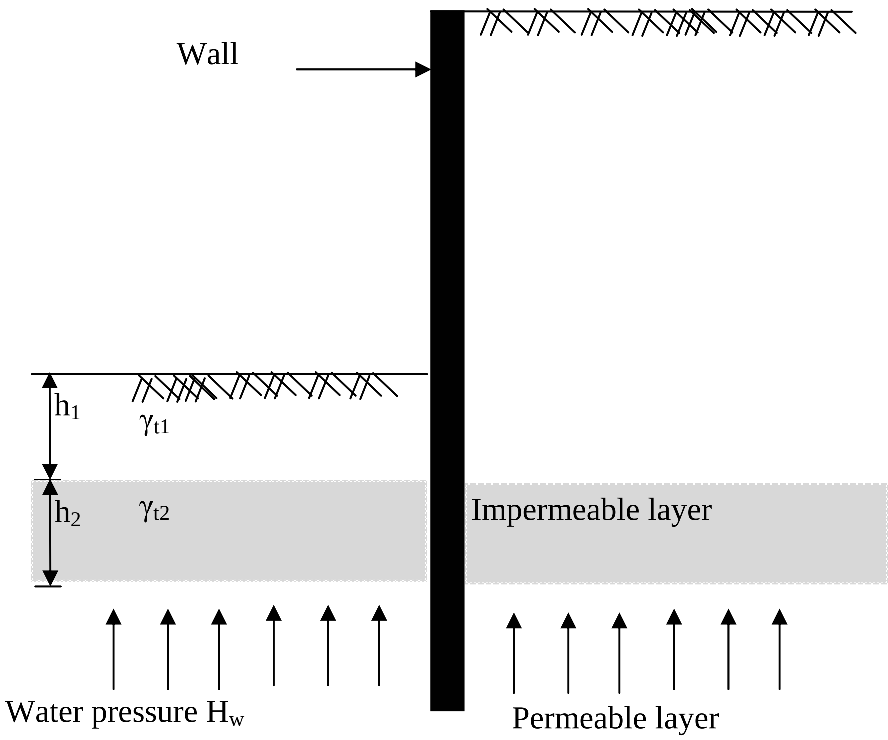


Figure 9. *Analysis of Upheaval*

Contiguous Pile Wall as Deep Excavation Supporting System at a Commercial Complex in Vijayawada, Andhra Pradesh, India – Case History

A supporting system for proposed 11.2m deep excavation was necessary for a commercial complex at Vijayawada, India. The planning of sub-soil has been carried as per the Indian standard codal provisions [12]. Five bore holes of 25m deep are taken in such a way that one at centre and one at each corner of the site. Average profile and properties of soil layers are evaluated as per Indian standard soil laboratory testing and classification procedures [13, 14] and are presented in figure 10. Presence of footings of adjacent buildings and underground utilities were some of the decisive factors that eliminated choice of diaphragm wall for supporting the excavation. In this situation, contiguous pile wall for supporting the excavation is the right the choice.

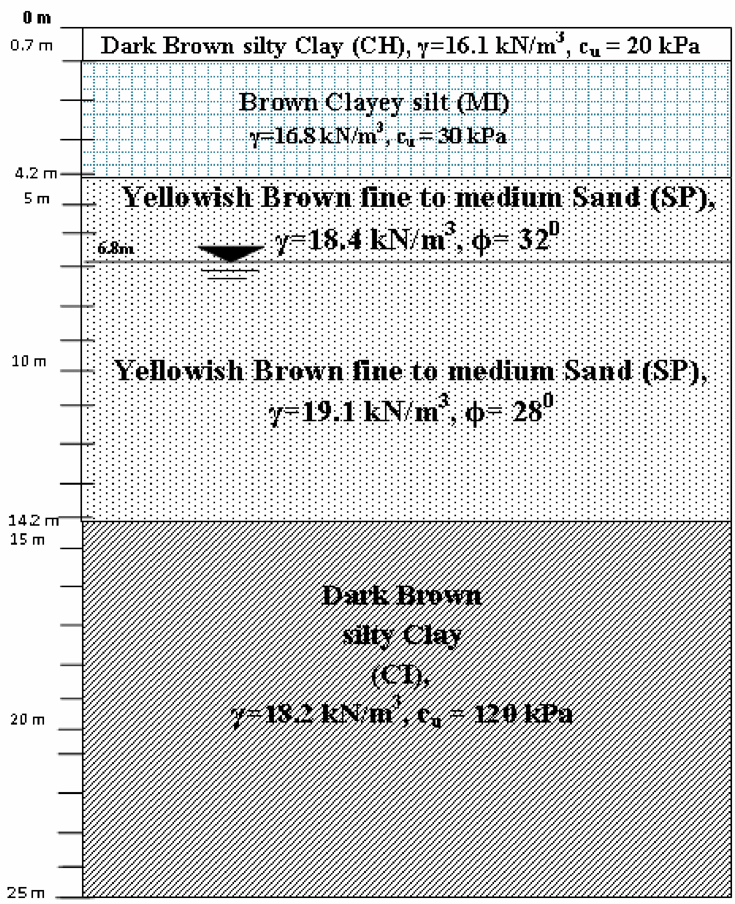


Figure 10. *Bore Hole*

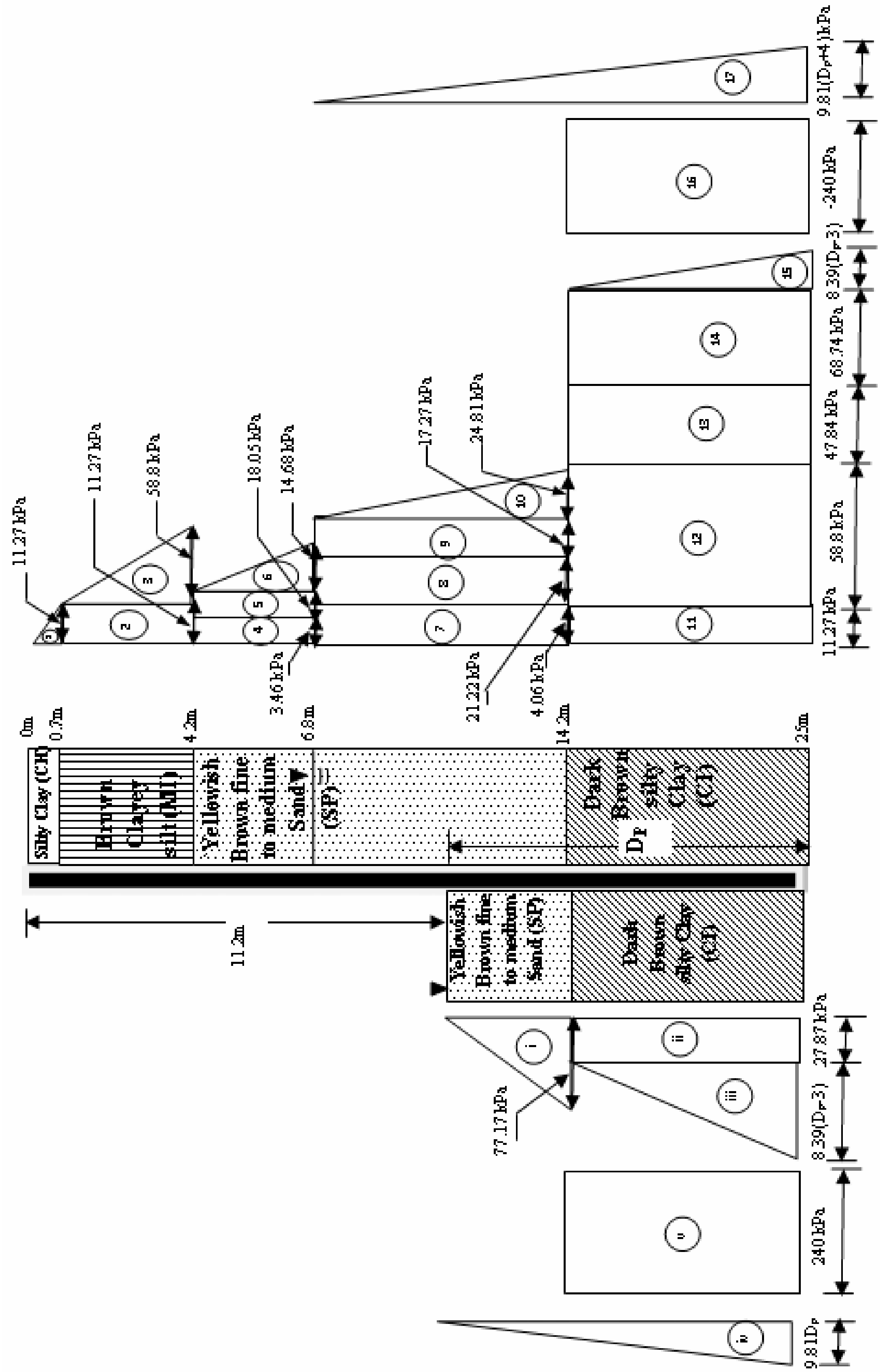
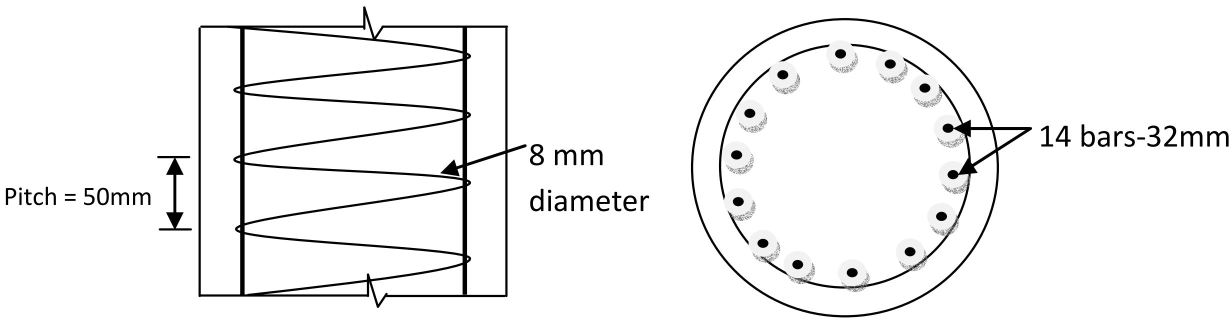


Figure 11. *Lateral Earth Pressures acting on the Wall*

Detailed lateral earth pressures acting on the wall are calculated and shown in figure 11. Stability analysis of the wall has been carried to evaluate the depth of penetration (D_P) by equating active pressure on right side of the wall to passive pressure on left side of the wall. For the present case, D_P is 5.64m. By applying factor of safety of 1.5 to coefficient of passive earth pressure, D_P is 7.79m. An actual penetration depth (D_P) of 9.8m (=1.25×7.79m) is adopted. The factor of safety against sand boiling is 5.16 obtained by using equation (3) with consideration of sand layer throughout the penetration depth. This value is greater than 1.5. Hence, wall is stable against sand boiling also.

The diameter of pile used is 600mm. M30 grade concrete and Fe500 grade steel are used for making each pile. For contiguous piles, the c/c spacing is used for estimating reinforcement quantity. The pile is designed to resist the moment caused by the lateral earth pressure. The pile is designed to resist a maximum bending moment of 726.82 kN-m. This moment is evaluated from deducting moment due to the active force and moment due to the passive force with respect to pile bottom. Area of reinforcement required for the pile section is 10,179 mm^2 which can be obtained from Indian standard design aids [15]. A clear cover of 50mm provided to the pile section. The required area of main reinforcement is satisfied by providing 14 bars of 32mm diameter. The strength of the core concrete is enhanced by the confinement through spiral (helical) reinforcement [16, 17]. Therefore, helical reinforcement of 8mm Diameter and 50mm Pitch are provided. Reinforcement details are presented in the figure 12.



(a) Sectional Elevation *(b) Cross-section (Plan)*

Figure 12. *Reinforcement Details*

The pile wall comprised 600mm diameter bored cast-in-situ piles spaced at 0.7m c/c, with an average embedment depth of 9.8m. These shall be installed vertically along the proposed line of excavation. These piles were designed as cantilever retaining system without provision of anchors. Capping beam of 1200 x 750mm size was cast along the alignment of the pile which was designed to take care of differential changes in the earth pressures in the adjacent piles. The peripheral length of excavation was 310m and 442 piles were involved in the support work. Individual piles were constructed in the same way as a typical Bored Cast-in-situ piles using temporary casings and bentonite slurry.

Excavation operations proceeded only in those areas where pile concrete attained maturity. General construction sequence for the piling operation is: (i) Centering of rotary rig on the proposed pile point (ii) Carrying out the boring operation upto the upto about 21m below the existing ground level (iii) Driving the casing if needed (iv) Maintaining the stability of the borehole simultaneously with bentonite slurry (v) Continuing boring operation in soil using soil bucket and/or Soil auger depending on the stratum (vi) After completion of boring, cleaning of borehole by bentonite flushing (vii) Lowering of reinforcement cage into the borehole (viii) Repeat bentonite flushing operation and subsequently (ix) Pouring M30 grade concrete through tremie. The water drained out shall be let away from the site such that it does not re-enter in to the site. If ground water table is encountered in the region of operation, then suitable well point dewatering system should be activated to avoid flooding and subsequent collapse. Plate 1 shows the contiguous pile wall constructed at the site.

Plate 1. *Contiguous Pile Retaining System for Commercial a Complex Vijayawada*

Conclusions

Lack of inadequate space at town centres goes for deep vertical excavations, which require supports that are designed to consume minimum construction space. Various excavation supporting systems are presented in this study. Contiguous pile wall is one good choice of earth retention systems in the urban context. The detailed analysis and design of a contiguous pile wall is explained by a Case study which uses contiguous pile wall as an excavation supporting system at an urban centre.

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References

1. Ergun M.U., *Deep Excavations,* Electronic Journal of Geotechnical Engineering, Available at: www.ejge.com/Bouquet08/UfukErgun_ppr.pdf, 2008.
2. Manish Kumar, *Deep support systems using diaphragm walls and contiguous piles,* National Seminar on Deep Excavation in Urban Environment, Mumbai, 2008, p. 1-18.
3. Chang-Yu Ou, *Deep Excavation: Theory and Practice,* Taylor and Francis Group, London, UK, 2006.
4. Puller, M., *Deep Excavations: A practical Manual,* Thomas Telford, London, UK, 1998.
5. Moh Z.C., Chin C.T., *Deep Excavation in Soft ground,* Proceedings of ASIA Construction: New Frontiers, Singapore, 1991.
6. BD 42/00, *Design of Embedded Retaining Walls and Bridge Abutments,* Department for Regional Development, Scottish Executive Development Department, Northern Ireland.
7. Bureau of Indian Standards, *Guidelines for Dewatering during Construction* (IS: 9759),

New Delhi, India, 1981.

8. Das B.M., *Principles of Geotechnical Engineering*, Cengage Learning, CT, USA, 2010.

9. Clayton C.R.I., Milititsky J., Woods R.I., *Earth Pressure and Earth Retaining Structures*, Blackie Academic & Professional, London, 1993.

10. Teng W.C., *Foundation Design*, Prentice Hall, Englewood Cliffs, NJ, 1962.

11. NAVFAC, *Foundations and Earth Structures*, Design Manual 7.02, Department of the Navy Naval Facilities Engineering Command, Alexandria, Virginia, 1982.

12. Bureau of Indian Standards, *Code of practice for Subsurface Investigations for foundations* (IS: 1892), New Delhi, India, 1979.

13. Bureau of Indian Standards, *Compendium of Indian Standards of Soil Engineering*, Laboratory Testing of soils for civil engineering (SP 36 Part 1), New Delhi, India.

14. Bureau of Indian Standards, *Classification and Identification of soils for general engineering purpose*, IS 1498, New Delhi, India, 1970.

15. Bureau of Indian Standards, *Design Aids for Reinforced concrete to IS: 456-1978 (SP 16)*, New Delhi, India.

16. Dayaratnam P., *Limit State Design of Reinforced Concrete structures*, Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi, India, 2004.

17. Shah H.J., *Reinforced Concrete Vol.1 (Elementary Reinforced Concrete)*, Charotar Book House, Anand, Gujarat, India, 2005.