International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES),(UGC APPROVED)
Impact Factor: 5.22 (SJIF-2017),e-ISSN:2455-2585
"International Conference on Modern Trends in Civil Engineering"(ICMTCE-2019)
(Towards Sustainable Development Goals)
Volume 5, Special Issue 02, Feb.-2019

ANALYSIS & DESIGN OF SHORING SYSTEMS: BRIEF OVERVIEW

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Abstract:
High rise construction and the depth of underground levels in buildings has increased significantly in recent years due to the greater demand for space in high-density urban areas. The taller we go, larger is the space required for parking vehicles. Hence, basement construction has become inevitable in residential and commercial projects, being used mainly for parking. Shoring systems are commonly used to facilitate deep vertical excavations for constructing these basements, where loose soils or highly weathered rock are encountered and stepped excavation is not possible. The main aim of this paper is to highlight the characteristics of different types of shoring systems and the suitability of their use. It gives an insight on the design procedure to be adopted for different types of shoring systems such as Cantilever sheet pile, Cantilever shore pile and Anchored shore pile. Precautions to be taken during construction of shoring systems are also mentioned herein.

Keywords: Sheet pile, Shore pile, Diaphragm wall, Contiguous pile, Secant pile, Rock anchor, Strut

1. Introduction:

Scarcity of habitable land in tier 1 and tier 2 cities has compelled the growth of cities in vertical direction instead of expanding horizontally. High rise buildings, even up to 50 to 70 floors, are being constructed in cities like Mumbai and Delhi. These towers are residences of around 200 to 250 families. In some projects multiple towers are also constructed. In a four tower project the number of residential families is around 1000, which means that an equal number of car parking or even to the factor of 1.5 will have to be accommodated in the project. Lack of open parking spaces and limit on the height of building above the ground forces the developers to construct deep basements to accommodate car parking. In some of the projects even five basements have been constructed, thus resulting in depth of excavation in the range of 15m to 20m. To facilitate the construction of these deep basements, stepped excavation can be adopted if there is sufficient distance between the property line and basement line. But, if large expanse is not available, vertical excavation has to be opted for. No deep vertical excavation is possible without a shoring system. Shoring system is a type of temporary soil retaining structure, which prevents the collapse of surrounding strata in the excavation pit. This ensures that the vertical cut at the basement line doesn't pose any damage to adjacent properties. It supports the surrounding loads until the basement walls and underground levels of the building are constructed. It also provides safety for the workers in the trench.

Structures in the immediate vicinity of excavations, dense traffic scenario, presence of underground obstructions and utilities have made excavations a difficult task to execute. In this context, analysis and design of deep excavations and their supporting systems are essential. Many types of shoring systems are available. But one has to exercise great care while selecting the suitable type of shoring, its design and construction. Any shortfall in the design or construction can lead to great damage. There have been numerous incidences of shore pile failure in the past. The reasons can be attributed to incorrect designs, negligence or wrong calculation of surcharge and water table level or sub standard construction practices, such as insufficient pile embedment in rock and poor quality concreting, etc. The failure of shoring systems has also caused the complete collapse of adjacent buildings. The main aim of this paper is to highlight the characteristics of different types of shoring systems and the suitability of their use. It gives an insight on the design procedure to be adopted for different types of shoring systems such as Cantilever sheet pile, Cantilever shore pile and Anchored shore pile. Precautions to be taken during construction of shoring systems are also mentioned herein.

2. Classification of Shoring Systems:

Basically, there are three types of shoring systems – Sheet Pile, Shore Pile and Diaphragm Wall. The flow chart below enlists the types of shoring systems:

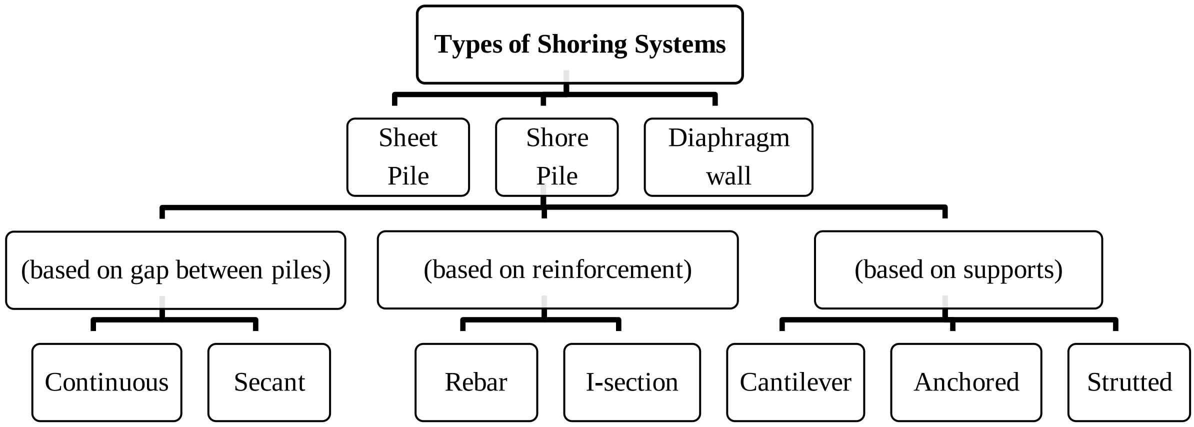


Figure 1. Types of Shoring Systems

2.1 SHEET PILE:

Sheet piles are long structural sections with a vertical interlocking system that creates a contiguous wall, which are most often used to retain either soil and / or water. They are flexible and derive their support from soil itself. Sheet piles can be made from wood, RCC or steel and are embedded in the soil by hammering. But due to limitations such as restricted depth of excavation for wood pile and chances of breaking of RCC pile during embedment, steel piles are most commonly opted for. Another advantage of steel sheet pile is that it is reusable and recyclable; hence offsetting the initial high cost of manufacturing them. Sheet pile being extremely light weight, makes it easier to lift and handle. Thus work progress is faster. There is a long life for it both above and under water. It only requires minimum maintenance. Major challenge in steel sheeting is during the installation process. The sheets must be driven into the ground and they have high resistance to the force of being driven down. It is extremely difficult to install steel sheeting in very stiff clay, highly weathered rock or stratum with large boulders. Many times the sheeting cannot be installed to the required depth. The vibrations from driving the sheets can cause settlement of the adjacent property. The process of driving the piles is noisy and hence cannot be adopted in noise sensitive areas. They are used mainly in the construction of coffer dams to construct bridge foundations in water and rarely used in residential or commercial projects because of their limitations. Steel sheet piles are constructed by interlocking using ball and socket arrangement. The depth of embedment of sheet pile below the level of excavation (dredge level) is very high as it derives its support from soil. For example, an excavation depth of 7m generally requires 8m to 10m embedment below the dredge level. Sheet pile can be cantilever sheet pile or anchored sheet pile.

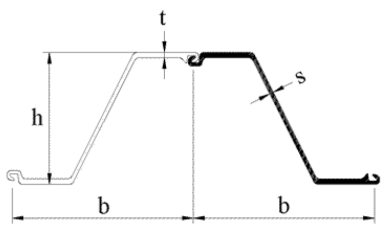


Figure 2. Interlocking arrangement of sheet pile

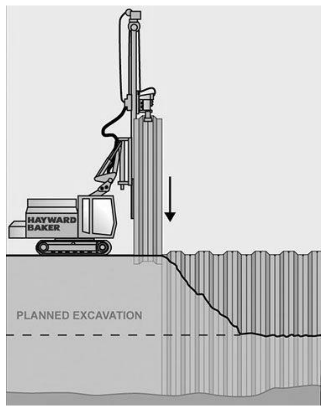


Figure 3. Driving operation of sheet pile

2.2 SHORE PILE:

Shore piles are the most commonly adopted type of shoring system in India, the reason being they are robust in their application and found suitable in almost every situation. Shore piles are bored cast in situ piles and are mostly circular in shape as they are drilled using an auger. Shore piles derive their support from rock socketing or from soil itself, if rock is not available. If the stability is derived from rock embedment, the depth of embedment is generally three to five times the pile diameter. Hence embedment depth below the dredge level is less as compared to the sheet pile. Shore piles are stiffer as compared to the sheet pile. Unlike sheet piles, they can be adopted even in noise sensitive areas as driving operation is not involved. After excavation, the surface of shore piles facing the excavation pit is flushed using PCC to form a plain surface, which is used to apply external water proofing coat to the basement wall. Shore pile can further be classified on the basis of pile continuity, reinforcement and supports.

2.2.1 Contiguous shore pile:

Contiguous shore piles are a series of piles, constructed by keeping a gap of 100mm to 200mm in between the adjacent piles. The cost of piling is reduced as the volume of concreting is less, owing to the gap between the piles. But this type cannot be adopted when the water table is above the depth of excavation or when the surrounding stratum is loose sand. Gaps between the piles may allow ground water ingress resulting in problems of water proofing. In case ingress is substantial, it may result in scouring of surrounding soil causing settlement of adjacent areas. The gap between the piles can be temporarily closed by using planks or by grouting. The advantage of this pile is that load bearing capacity can be generated as required and it can be installed in difficult ground. It is economical compared to the Secant pile, Sheet Pile and also the Diaphragm Wall.

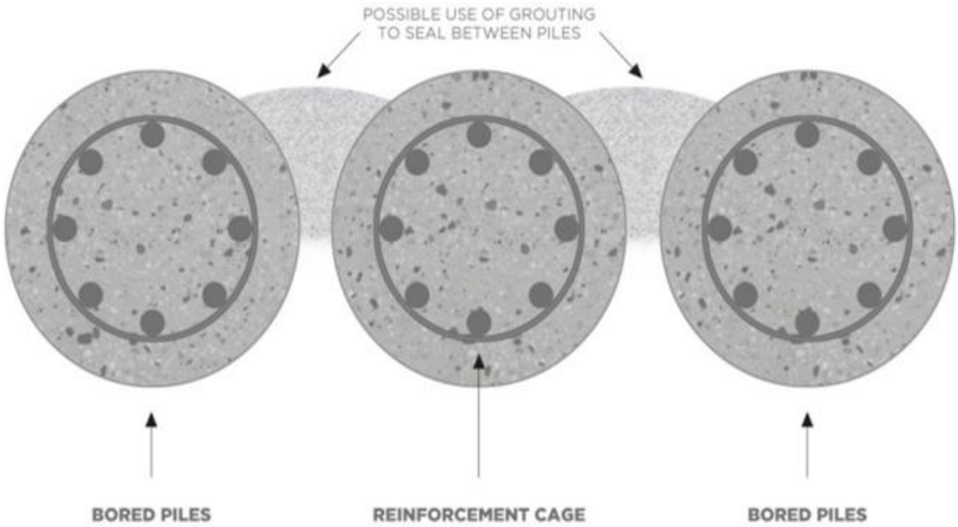


Figure 4. Contiguous Shore Pile

2.2.2 Secant shore pile:

Secant shore piles consist of alternate primary and secondary piles; the primary piles are PCC and the secondary are RCC. The primary piles are constructed and then the secondary piles are constructed with 100mm to 250mm overlap, thus making the system completely water tight. The loads are resisted by secondary RCC piles and the primary PCC piles provide water tightness by keeping no gap in between the piles. Construction of secant piles is costly as compared to contiguous piles because of the extra amount of concreting work involved and higher reinforcement required due to larger tributary area. High precision is required in maintaining the verticality of the piles to avoid gaps between them, as any sort of leakage can have serious repercussions. The leakages can be temporarily closed using bentonite slurry. These types of piles are must for projects near the sea shore. In case of any ambiguity regarding water table level, secant piles should be preferred over contiguous piles without any second thought.

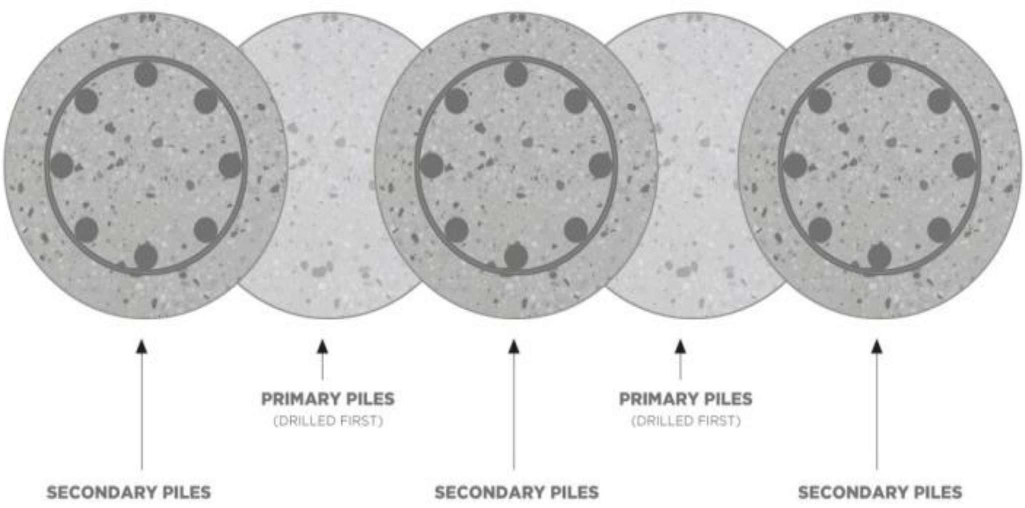


Figure 5. Secant Shore Pile

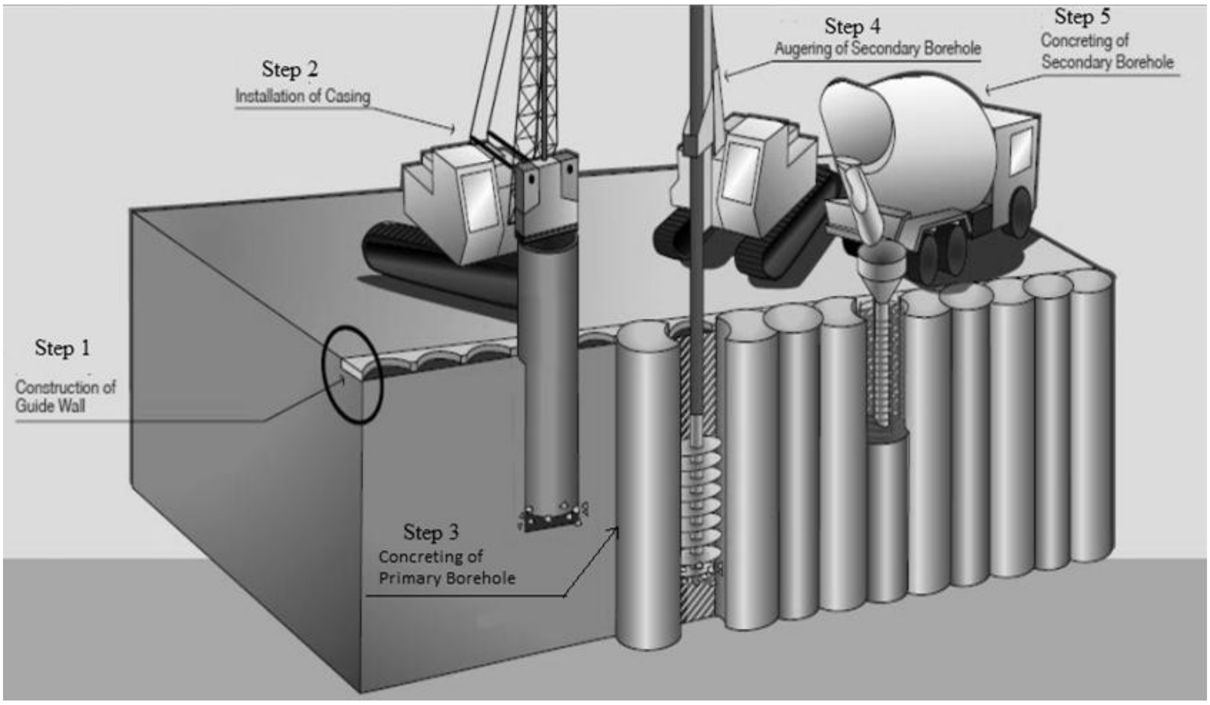


Figure 6. Construction methodology of Secant Shore Pile

2.2.3 Shore pile with rebar / I-section:

Shore piles can be reinforced with HYSD rebar or structural steel I-section. The reinforcement mainly resists the bending tension arising due to lateral loads on the pile and also assists in resisting bending compression and axial forces. For shore pile with rebar, steel cage made on site is inserted in the drilled hole; whereas for pile with I-section, readily available steel sections are used. Where cost of labour is high, piles with steel sections are preferred over piles with rebar.

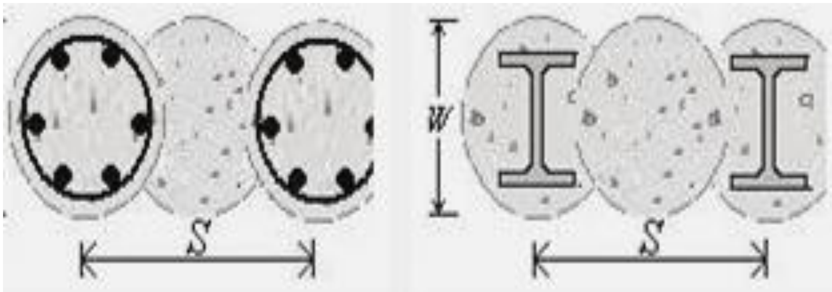


Figure 7. Shore pile with rebar and I-section

2.2.4 Cantilever shore pile:

As the name suggests, this type of pile behaves like a cantilever as it is supported only at the bottom by embedment in rock. Diameter of pile required for larger depths of excavation is high; hence this type of pile is economical for shallow depths. Cantilever shore pile construction is very fast. Rock socketing depth is generally prescribed by the Geotechnical consultant. Sound quality rock is a prime necessity for adopting this type of pile. Pressure on the rock at socketing depth should not exceed the allowable compressive strength, with sufficient margin of safety.

2.2.5 Anchored shore pile:

If the excavation depth or surcharge is higher, cantilever shore pile will have to be anchored at one or multiple levels. The cantilever pile thus behaves like a propped cantilever, thereby reducing the maximum bending moment and hence smaller diameter pile can be adopted. But this involves additional cost of anchoring. Waler beams are provided to transfer the load from the piles to the anchors. The anchors are generally prestressed and rock anchors are more efficient than soil anchors. The stiffness of these anchors should be suitably assigned in the analytical models, as these are yielding type of supports. Pre-stressed anchorages in case of deep basement constructions are very costly.

2.2.6 Strutted shore pile:

In deep excavation, due to site constraints or no possibility of inclined anchoring or small size of the plot, shore piles with steel struts are provided. This reduces the pile diameter, thereby reducing the cost of shoring system. Such struts either span across the length of the plot or across the bollard piles if the spans are large. Bollard piles are piles adjacent to and in front of the main piles. This type of shoring does not disturb the adjacent properties. As compared to anchors it is cheap. Also, the struts have salvage value. Construction process does not require specialized contractors. Drawback of this system is that it obstructs excavation/construction activity and needs heavy equipment to install the struts / bollards.

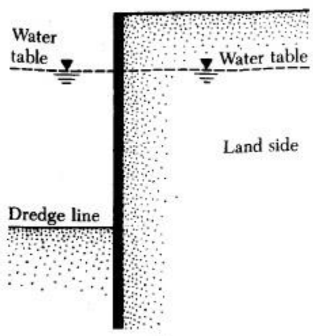


Figure 8.
Cantilever shore pile wall

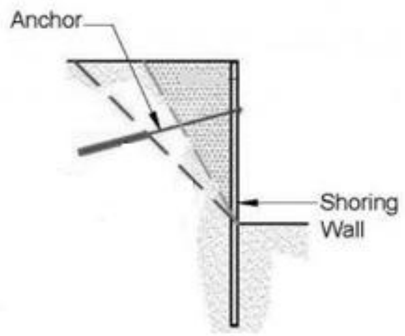


Figure 9.
Anchored shore pile wall

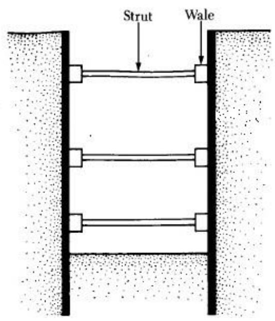


Figure 10.
Strutted shore pile wall

2.3 DIAPHRAGM WALL:

It is a contiguous wall constructed in ground to support deep excavation and facilitate basement construction activity. Thickness of diaphragm wall is usually 600 mm and more. Construction of diaphragm wall is carried out in segments. Advantage of diaphragm wall is that the process of constructing the wall is relatively quiet and has little vibration. The wall can be constructed to greater depths. The wall provides a good water cut-off; so minimum dewatering is required and hence has little effect on adjacent structures. Drawback is that high cost is involved in construction of diaphragm wall. It requires special equipment and skilled personnel. Keeping provisions for utilities is difficult.

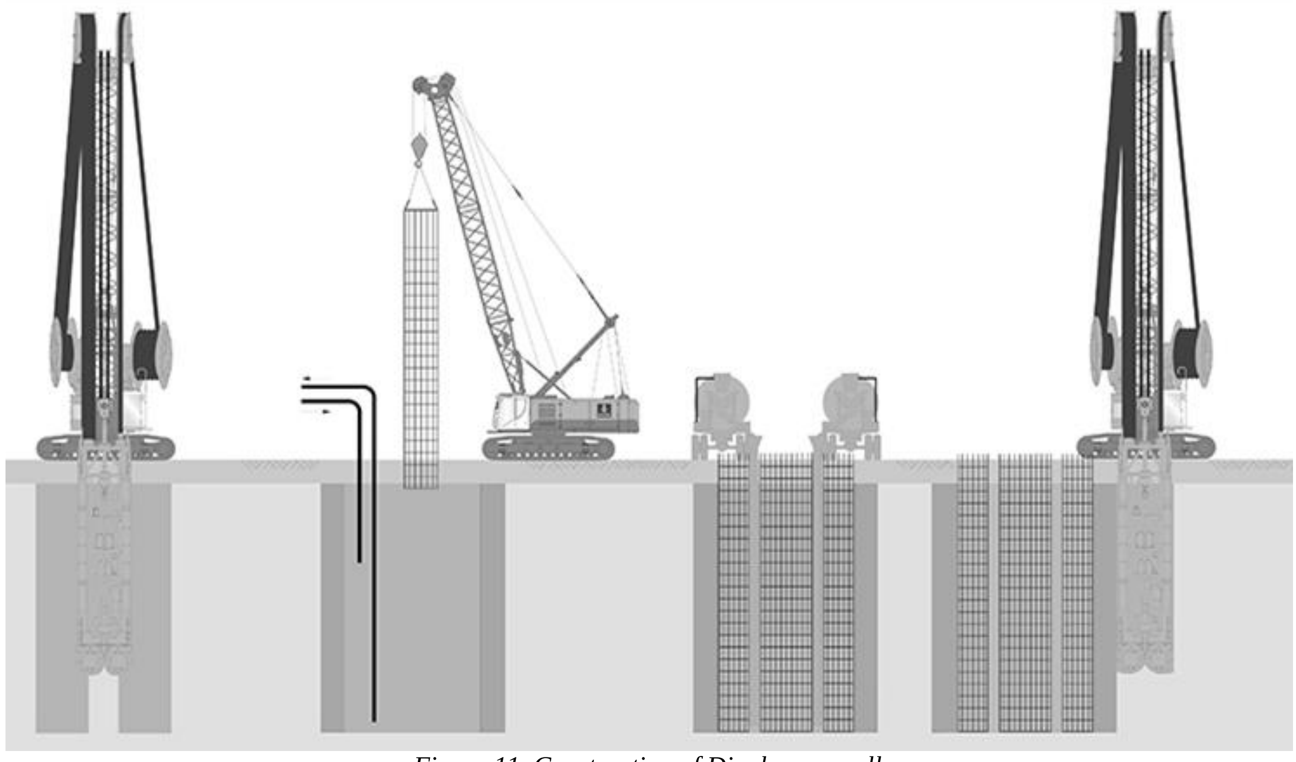


Figure 11. Construction of Diaphragm wall

3. SUITABILITY CRITERIA OF SHORING SYSTEMS:

It can be summarised that type of shoring to be used depends on:

i. Depth of excavation
ii. Nature of underground strata
  a. Type of soil and its profile
  b. Depth of availability of hard rock
  c. Extent of weathering in the rock
  d. Ground water table level
iii. Properties of strata

a. Unit weight
b. Angle of internal friction
c. Cohesion value
d. Rock Quality Designation (RQD) value
e. Compressive strength of rock
f. Chemical composition of ground water

iv. Extent and assessment of surcharge
v. Shape and expanse of basement proposed
vi. Adjoining structures

a. its loading
b. distance from the plot boundary
c. occupancy
d. whether basement exists

Thus one should judiciously select the type of shoring system for a project after considering all the site conditions, Geotechnical recommendations and other constraints.

4.1 DESIGN PROCEDURE FOR CANTILEVER SHEET PILE IN GRANULAR SOIL:

1. Workout the depth of excavation from ground level.
2. Study the geotechnical report and assess site conditions to evaluate feasibility of constructing sheet pile.
3. Prepare profile of the stratum indicating properties of each layer (γ, ϕ, c) along with water table level, rock compressive strength and note the other geotechnical recommendations.
4. Evaluate the lateral earth pressure diagrams (active and passive pressure) and assess the value of surcharge as per site conditions.
5. Find the depth of shore pile embedment (D) using equations stated below. They are derived from equilibrium of forces acting on sheet pile using net pressure diagram.

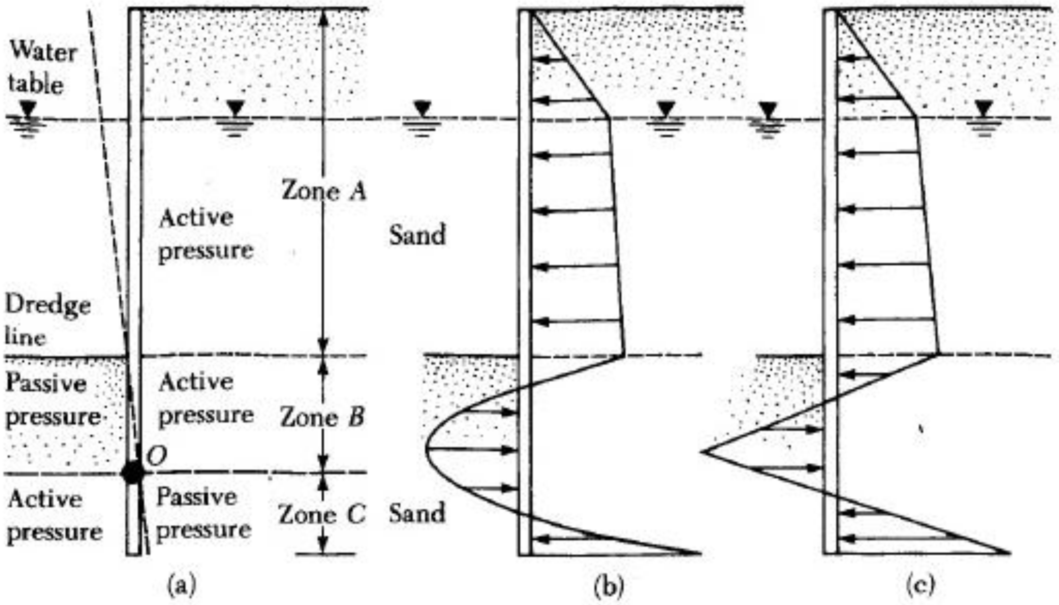


Figure 12.
(a) Deflection of sheet pile (b) Net lateral pressure diagram (c) Simplified net lateral pressure diagram

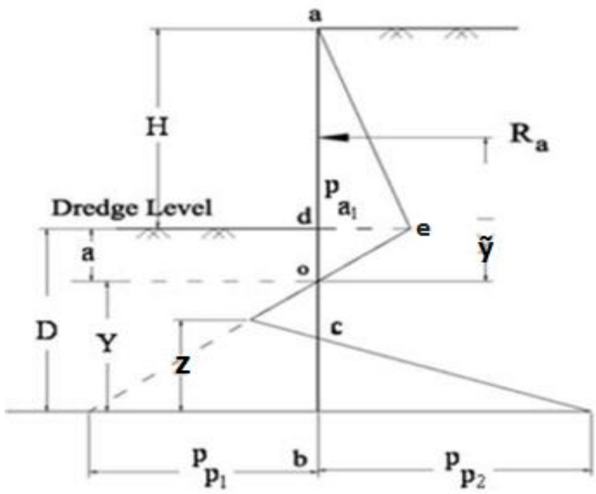


Figure 13. Simplified net pressure diagram

i. Compute active and passive earth pressure coefficients (K_p and K_a)

ii. Compute the value of 'a'

a = depth at which net pressure is equal to zero from dredge level

$$a = \frac{P_{a_1}}{(K_p - K_a)\gamma}$$

iii. Compute the value of total net active pressure R_A, i.e. area of aeo$_1$d shown in figure acting at distance 'ỹ' from O.

iv. Find the value of 'ỹ'

v. Compute the values of P_{P1} and P_{P2} in terms of Y

$$p_{p_1} = (K_p - K_a)\gamma Y$$

$$p_{p_2} = K_p\gamma(H + a + Y) - K_a\gamma(a+Y)$$

vi. Compute the value of Z in terms of Y

Applying the condition $\sum H = 0$

$$R_a + ½(p_{p_1} + p_{p_2})Z - ½p_{p_1}Y = 0$$

vii. Compute the value of Y from following equation derived by using equilibrium equation ΣM@B = 0

$$R_a(\bar{y}+Y) + ½(p_{p_1} + p_{p_2})Z.\frac{Z}{3} - ½p_{p_1}Y.\frac{Y}{3} = 0$$

It will give fourth degree equation in Y. Use trial and error method to arrive at final value such that RHS is close to zero

viii. Calculate the depth of sheet pile embedment D = Y + a and increase it by 20% to 30% to provide additional factor of safety

ix. The value of D can also be obtained by using alternate approximate method of analysis, based on below diagram:

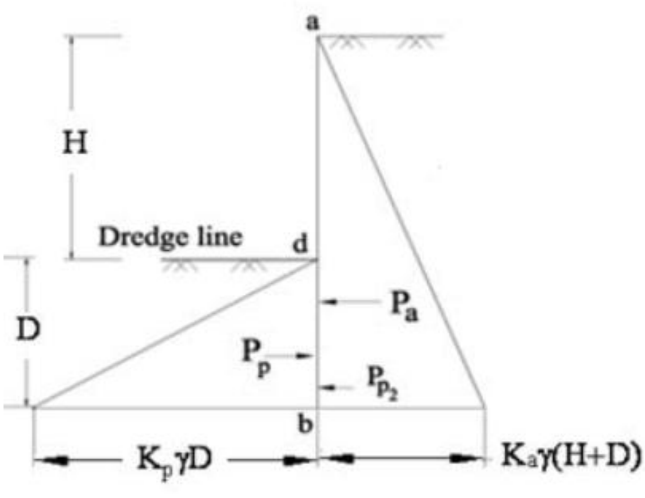


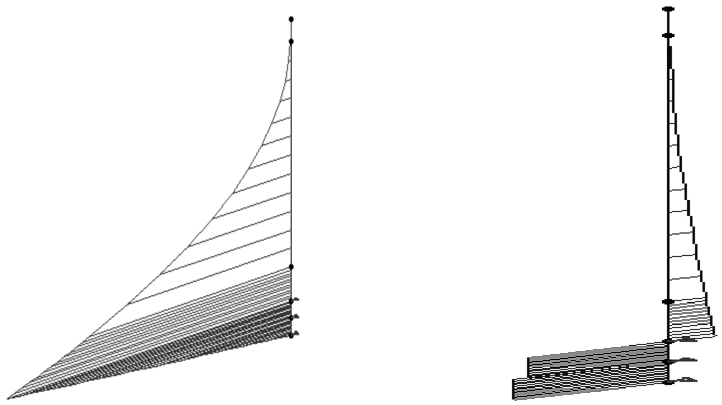
Figure 14. Alternate lateral pressure diagram

x. The active pressure zone at the base is neglected for simplicity

4.2 DESIGN PROCEDURE FOR CANTILEVER SHORE PILE IN GRANULAR SOIL:

Steps 1 to 4 are same as sheet pile design procedure.

5. Assume the initial diameter of shore pile.
6. The wall is modelled as equivalent rectangular section of unit length in any finite element software. The soil/rock support below the dredge level is modelled as spring with stiffness's equal to the sub-grade modulus of reaction in consultation with the geotechnical consultant. The spring supports can be assigned at 0.5m spacing below the dredge level for a depth equal to rock socketing length as per Geotechnical report.



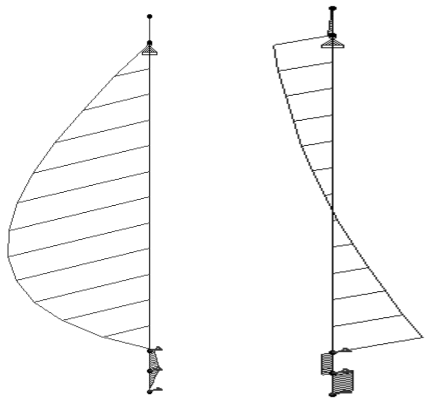
(a) (b)

Figure 15. Cantilever Shore Pile (a) Bending Moment Diagram (b) Shear Force Diagram

7. Evaluate the vertical reinforcement required based on maximum bending moment at support and helicals are calculated from the maximum shear force. Additional links are provided at 1m c/c to increase the stiffness of rebar cage.
8. If worked out reinforcement is too heavy, assume higher diameter of pile in next iteration.
9. For the purpose of analysis, both continuous and secant piles are modelled with unit length. But while designing, the unit length BM and SF are multiplied by spacing between adjacent piles for continuous piles and spacing between consecutive RCC piles for secant piles.
10. Check the pressure on rock at embedment depth by dividing maximum BM at support with the depth of rock embedment. This pressure should be less than the allowable compressive strength of rock with sufficient margin of safety.
11. To be on conservative side, the reinforcement at the bottom can be worked out considering fixed supports and the same can be used to check compressive strength of rock.
12. Vertical reinforcement in the sore pile is concentrated at the side of soil fill, which is subjected to bending tension.
13. Capping beams are provided at top with nominal reinforcement to make the piles act in unison.

4.3 DESIGN PROCEDURE FOR ANCHORED SHORE PILE IN GRANULAR SOIL:

14. The design is similar to that of cantilever shore pile, except anchors are modelled as yielding supports in the analytical model at one or more multiple levels as per the depth of excavation. The properties of anchors are adopted in consultation with the Geotechnical consultants.
15. The capacity of anchors is evaluated from the support reaction at anchor level. This reaction is for unit length of wall. It is then multiplied by the spacing between anchors. If the anchor is inclined at 45°, the forces are resolved accordingly and the capacity of anchors to be provided is decided.
16. Waler beams are used to transfer loads from piles to the anchors. The reaction of unit length of wall at anchor level acts as distributed load per meter on these beams and there span is equal to the spacing between anchors. The beams are placed with their depth perpendicular to the piles.



(a) (b)

Figure 16. Anchored Shore Pile (a) Bending Moment Diagram (b) Shear Force Diagram

5. PRECAUTIONS TO BE TAKEN DURING CONSTRUCTION OF SHORING SYSTEMS:

a. Verticality tolerances should be met with
b. Concreting must be ensured up to bottom of the pile to prevent poor quality pile tips
c. Pile embedment should be adequate; short embedded piles must be pulled down by anchors
d. Water table level should be assumed correctly. In case of monsoon, analysis should be based on GWL preferably at GL
e. Surcharge should not be neglected. It should be calculated very carefully taking into consideration dumped excavated material, moving vehicles, equipments, temporary site structures
f. Structural and Geotechnical engineer must visit the site at various stages of excavation and execution
g. Site should not be left in idle state after deep excavation and with completion of rock anchors work
h. Regular monitoring of site is required from safety point of view
i. Dewatering methodology to drain away surface water has to be in place

Thus shore pile construction is a critical aspect in deep basement construction. If analysis, structural design and execution is carried out judiciously, considering the various parameters and in consultation with Geotechnical and construction experts, then shore pile systems can be used successfully to facilitate deep basement construction.

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