EVALUATION OF COST MATRIX FOR STEEL SHEET PILING

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Abstract

With the advancement in underground construction, the construction technology for deep excavation is gaining importance. Excavation support is generally required to be planned specifically when the depth of excavation exceeds 10 to 20 feet or if the excavation is not sloppy. Excavation support systems help in minimizing the excavation area and to maintain the stability of the sides of the deep excavation. Steel sheet piling is one of the earth retention system which is made up of long structural section that uses steel sheets with interlocking edges to retain earth or water. Sheet pile walls have been used to support excavations for underground parking structures, basements, pump houses, and foundations, to construct cofferdams, and to construct seawalls and bulkheads. This paper describes the cost involved in the method of steel sheet piling to support the sandy soil with different site conditions. A relationship between the cost and parameters like retention height, embedment depth, bending moment, section sizes is obtained which could help in assessing the cost implication of steel sheet piling on the project, hence helping in the forecasting cost, both for client and other building contractors.

Keywords: Earth retention system, Deep excavation, Cost analysis, Cantilever steel sheet pile, Anchored steel sheet pile, Graphical relationships

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I. INTRODUCTION

In order to accommodate the growing demands of parking space, transportation facilities, housing, amusement spaces etc., it is required to either go vertically up or down due to limitation of expanding horizontally. One of the major challenges faced during deep excavation which requires engineering solution is to select suitable method to support the deep excavation.

Excavation support is generally required to be planned specifically when the depth of excavation exceeds 10 to 20 feet or if the excavation is not sloppy [1]. Excavation support for deep excavation means providing an additional support in the form of sheet pile, diaphragm wall, soldier pile, soil nailing etc. that is required to stabilize the soil so that the soil does not fall back into the excavation pit and obstruct the deep digging process.

Excavation support systems are required in order to minimize the excavation area and to maintain the stability of the sides of the deep excavation. Excavation support system are also known as earth retaining structures.

O'Rourke and Jones in 1990 classified earth retaining structures into two categories namely externally stabilized systems and internally stabilized systems.

Externally stabilized systems are those that resist the applied earth load by the virtue of their weight and stiffness whereas internally stabilized systems are those which reinforce the soil to provide the necessary stability [2].

Some of the excavation support methods are:

- Soldier piles
- Soil nailing
- Diaphragm wall
- Sheet pile

II. STEEL SHEET PILE

Sheet piles walls are the retaining walls constructed to retain earth, water or any other material. These walls are thinner in sections as compared to gravity or cantilever walls [3].

Steel sheet piling are the long structural section which uses steel sheets with interlocking edges to retain earth or water. Sheet pile walls have been used to support excavations for below-grade parking structures, basements, pump houses, and foundations, to construct cofferdams, and to construct seawalls and bulkheads. Permanent steel sheet piles are designed to provide a long service life.

Vibratory hammers are typically used to install sheet piles. If soils are too hard or dense, an impact hammer can be used to complete the installation. At certain sites where vibrations are a concern, the sheets can be hydraulically pushed into the ground.

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Sheet piles could be made of recycled steel and the piles can often be reused. Cold rolled sheet piling is less expensive but provides less water resistance. Hot rolled sheet piling is more traditional and provides better water resistance. The common uses of sheet piles are:

- It supports excavation.
- Creation of barrier to the groundwater flow.
- Construct seawalls and bulkheads.

Some of the advantages of steel sheet are given below:

- It is relatively light weight.
- It is easier to increase the pile length (either by bolting or welding).
- Its service life is comparatively more both above and below the water table with modest protection.
- It is resistant to high driving stresses which might developed in rocky or hard materials.
- Moreover, steel sheet piles could be withdrawn and reused.

A. *Types of Sheet Piles*

Steel sheet piles are classified on the basis of two types

(a) On the basis of mechanism of stability derived

(b) On the basis of shape of the pile.

On the basis of mechanism of stability derived, the steel pile is divided into three categories namely cantilever steel sheet pile, anchored steel sheet pile and braced steel sheet pile

Cantilever steel sheet pile are used when the height of the fill retained is small (<5m), sheet pile is simply driven into the ground. It acts as a cantilever (as shown in Figure 1) and therefore termed as cantilever sheet pile. The pile derived its stability from the portion below the dredge line. This embedded portion in the soil is termed as embedment depth.

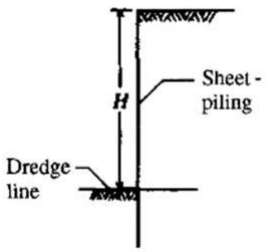


Figure 1: Cantilever Sheet Pile

When the height of the fill retained is relatively large, the passive resistance of the soil in front of the embedded portion of the sheet pile may not be sufficient to keep the wall stable. To make the pile stable, it is held near the top using a tie bar which is suitably anchored at some distance behind the wall. This type of sheet pile is termed as anchored sheet pile or anchored bulkhead (as shown in Figure 2). The use of anchor tends to decrease lateral deflection, bending moment and the depth of penetration of the pile [3].

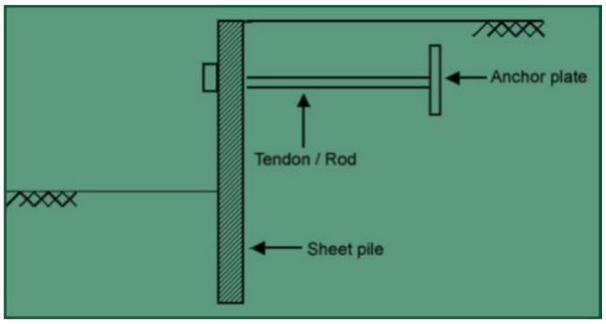


Figure 2: Anchored Sheet Pile

Braced sheeting in cuts are used when the depth pf excavation is more than 4m, steel sheet piles are driven along the length of the cut. As excavation proceeds, wales and struts are inserted. The wales are made up of steel and struts are made up of steel or wood. Excavation then proceeds to lower level, and another set of wales and struts is installed (as shown in Figure 3). This process is repeated till the excavation reached the desired depth. It is advisable to drive the sheet piles several meters below the bottom of the excavation to prevent the local heaves.

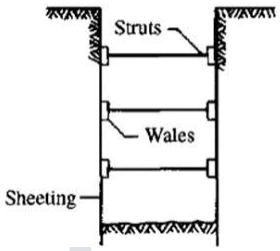


Figure 3: Braced Sheeting

III. DESIGN METHODOLOGY FOR STEEL SHEET PILE

The loads governing the design of a sheet pile wall include applied forces from soils, water, surface surcharges and impact from external objects.

Horizontal forces applied by soils include at-rest pressures, active pressures and passive pressures. Water forces include hydrostatic pressures, which can occur due to differential water levels on either side of the wall.

Surcharges include uniform or variable, strip or line and point loads, which rest on the soil surface in the vicinity of the wall and can increase the lateral pressures on the wall.

The design of a sheet pile retaining wall involves the following steps:

- Evaluation of forces and lateral pressures acting on the wall.
- Determination of required depth of penetration which is known as embedment depth.
- Design of anchorage and waling system (if applicable).
- Calculation of maximum bending moments and
- Selection of the appropriate piling section based on allowable stresses.

In this paper, the result is obtained by using the renowned geotechnical software 'Tedds 2017' by Tekla. This software is used by most of the reputed consultants in the world for

the designing of earth retention structures.

IV. COST ANALYSIS OF STEEL SHEET PILE

Cost analysis of steel sheet pile, here, refers to the cost computation of the steel sheet pile for both cantilever and anchorage condition in case of sandy soil only. The rates used in the calculation are derived from the market based on the quotation received from the vendors for the specialized work. Four cases have been assumed for cost calculation of steel sheet pile and based on these cases conclusions were obtained.

A. Assumptions in the analysis

- Four cases have been assumed for the designing of steel sheet pile and cost have been calculated for these four cases only.
- Anchors are considered at a centre to centre distance of 1m along the width of the sheet pile.
- The length of anchors is assumed to be 8m so that uniform base could be achieved for comparison.
- Anchors are installed at an angle of 20˚ to the horizontal.
- Anchors are installed at a height of 1.5m from the ground level.
- Waler beams are installed at the level of anchors only.

B. Cost assumed in analysis

- Rate of steel sheet pile is taken as ₹45/kg.
- Rate of anchor is taken as ₹49/kg.
- Rate of waler beam is assumed to be ₹45/kg.
- The crane used for holding the vibratory hammer for the installation of steel sheet pile charges rent @ ₹2.5 lac to 3 lacs per month (i.e. 260 hours) for 4 tonnes capacity. This information is provided by Auskini Infraqp PVt. Ltd. Sector 5, Noida who are specialized vendor for the selling and renting of heavy construction equipments.
- The vibratory hammer used for the installation of steel sheet pile charges rent @ 5 lacs per month (i.e. 260 hours) for 4 tonnes capacity. This information is provided by *Indigo Infra Delhi* who are the prime vendor for vibratory hammer (selling and renting) in Delhi-NCR.
- The productivity of vibratory hammer is assumed to be 0.6m/min (i.e. approx. 20 minutes for 12m installation) which includes lifting of steel pile, placing in position and driving it to the desired depth. Based on the length of the sheet pile, corresponding rent is calculated for the installation on the basis of vibratory hammer productivity.
- The cost of anchorage is taken as ₹6000/m which
- includes the labour and the machine cost.
- The rates of steel sheet pile were taken from the following vendors and is tabulated in Table 1 as per their quotations.

Table I: Quotations of steel sheet pile as received from vendors

S.No.	Type of Sheet pile	₹ (Cost/kg)	Name of the vendor's company	Location
1	U-type	**46**	Hambro Tech India Ltd.	Ballabhgarh, Faridabad
2	U-type	**45**	Oriental Steel Pvt. Ltd.	Hatin, Palwal
3	U-type	**46**	Orient Steel & Industries Ltd.	Ballabhgarh, Faridabad

V. ANALYSIS

For the purpose of analysis of cost the following four cases have been used. The embedment depth for the four cases are computed for different retention height and suitable section of the steel sheet pile is chosen.

Case 1: Sandy soil with no water table and surcharge

Soil type: Dense sand
Bulk Density of soil in kN/m3 = 18
Submerged Density of soil in kN/m3 = 22
Angle of internal friction = 30˚

Case 2: Sandy soil with water table at 4m

Soil type: Dense sand
Bulk Density of soil in kN/m3 = 18
Submerged Density of soil in kN/m = 22
Angle of internal friction = 30˚
Depth of water table from ground level = 4m

Case 3: Sandy soil with variable surcharge and no water table

Soil type: Dense sand
Bulk Density of soil in kN/m3 = 18
Submerged Density of soil in kN/m3 = 22
Angle of internal friction = 30˚
Surcharge as per IRC-6:2016 for adjacent road in kN/m2 = 24

Case 4: Sandy soil with variable surcharge and water table at 4m

Soil type: Dense sand
Bulk Density of soil in kN/m3 = 18
Submerged Density of soil in kN/m = 22
Angle of internal friction = 30˚
Depth of water table from ground level = 4m
Surcharge as per IRC-6:2016 for adjacent road in kN/m2 = 24

Table II and Table XIII showing the results obtained from the design calculation of steel sheet pile for the four cases assumed. Furthermore, the results obtained from the cost analysis are presented in the self-explanatory graphical form from graph 1 to graph 4.

Table II: Sandy soil with no water table and surcharge

Cantilever													
Height of Excavation (m)	Embedment Depth (m)	Max Moment in kN-m/m	Required Section Modulus (cm3)	Provided Section	Provided Section Modulus (cm3/m)	Section width in mm	Number of section required per m length	Weight (kg/m)	Cost (₹/kg)	Cost of sheet pile per m width(₹) and length	Cost of installation of sheet pile (in ₹) for per m width	Total Cost (₹)	Cost of sheet pile for entire height and unit width,₹
3	3.27	84.6	313	HGU 6N	625	600	1.67	41.9	45	3142.50	533	3675.45	₹ 23,045
4	4.36	200.5	743	HGU 7HWS	745	600	1.67	47.4	45	3555.00	711	4265.86	₹ 35,675
5	5.45	391.6	1450	OSZ	1474	400	2.50	45.21	45	5086.13	889	5974.72	₹ 62,460
6	6.54	676.8	2507	HGU 27N	2680	600	1.67	97.4	45	7305.00	1066	8370.90	₹ 1,04,971
7	7.64	1074.7	3980	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	45	[illegible]	1244	[illegible]	-
													-

Table III: Sandy soil with no water table and surcharge

Anchored																			
Height of Excavation (m)	Embedment Depth (m)	Max Moment in kN-m/m	Required Section Modulus (cm3)	Force Required in Anchorage (in kN/m)	Provided Anchorage (as per IS 14268:1995)			Provided Section of sheet pile	Provided Section Modulus (cm3/m)	Section width in mm	Number of section required per m length	Weight of sheet pile (kg/m)	Cost (₹/kg)	Cost of anchorage (₹/kg)	Cost of sheet pile per m width and length (₹)	Material Cost of anchorage for the entire length (₹)	Cost of installation of anchorage	Cost of installation of sheet pile (in ₹) per m width	Total Cost (₹)	Cost of sheet pile for entire height and unit width,₹
					Dia (in mm)	length (in m)	weight (kg/m)													
6	3.7	83.5	309	64	9.5	8	0.405	HGU 6N	625	600	1.67	41.9	45	49	₹ 3,142.50	158.76	48000	824.50	₹ 3,301.26	₹ 82,331.42
7	4.30	141.6	524	80	11.1	8	0.548	HGU 6N	625	600	1.67	41.9	45	49	₹ 3,142.50	214.816	48000	960.50	₹ 3,357.32	₹ 88,697.67
8	5.00	220	815	102	11.1	8	0.548	HGU 8S	820	600	1.67	50.8	45	49	₹ 3,810.00	214.816	48000	1105.00	₹ 4,024.82	₹ 1,03,726.61
9	5.70	320.17	1186	126	12.7	8	0.73	HGU 13N	1270	600	1.67	59.9	45	49	₹ 4,492.50	286.16	48000	1249.50	₹ 4,778.66	₹ 1,21,926.30
10	6.30	450	1667	152	12.7	8	0.73	HGU 16N	1670	600	1.67	72.6	45	49	₹ 5,445.00	286.16	48000	1385.50	₹ 5,731.16	₹ 1,46,661.91
11	7.00	606.3	2246	182	15.2	8	1.094	HGU 23N	2335	600	1.67	90.4	45	49	₹ 6,780.00	428.848	48000	1530.00	₹ 7,208.85	₹ 1,83,923.26

Table IV: Waler beam sections used at anchorage locations
(for height of excavation of 6 to 11m)

Waler Beam, Universal Beam section				
Designation	weight (kg/m)	Section modulus (in cm3)	cost ₹ (kg/m)	Total cost of waler for unit width (₹)
UB 203X133X25	25.1	230.3	46	2309.2
UB 203X133X30	30	280	46	2760
UB 254X146X37	37	432.6	46	3404
UB 305X165X40	40	560.5	46	3680
UB 356X171X57	57	896	46	5244
UB 457X152X67	67	1263	46	6164

Cantilever

Table V: Sandy soil with water table only

Height of Excavation (m)	Embedment Depth (m)	Max Moment in kN-m/m	Required Section Modulus (cm3)	Provided Section	Provided Section Modulus (cm3/m)	Section width in mm	Number of section required per m length	Weight (kg/m)	Cost (₹/kg)	Cost of sheet pile per m width(₹) and length	Cost of installation (in ₹) for per m width	Total Cost (₹)	cost of sheet pile for entire height and unit width,₹
3	3.625	97	359	HGU 6N	625	600	1.67	41.9	45	3142.50	563.13	3705.63	₹ 24,550
4	5.50	245.0	907	HPU 12	1200	600	1.67	66.1	45	4957.50	807.50	5765.00	₹ 54,768
5	6.53	435	1611	HGU 16N	1670	600	1.67	72.6	45	5445.00	980.05	6425.05	₹ 74,081
6	7.60	696	2578	HGU 27N	2680	600	1.67	97.4	45	7305.00	1156.00	8461.00	₹ 1,15,070
7	8.70	1037	3841	NA section					45	-	1334.50	-	-

Table VI: Sandy soil with water table only

Anchored

Height of Excavation (m)	Embedment Depth (m)	Max Moment in kN-m/m	Required Section Modulus (cm3)	Force Required in Anchorage (in kN/m)	Provided Anchorage (as per IS 14268:1995)			Provided Section of sheet pile	Provided Section Modulus (cm3/m)	Section width in mm	Number of section required per m length	Weight of sheet pile (kg/m)	Cost (₹/kg)	Cost of anchorage (₹/kg)	Cost of sheet pile per m width and length (₹)	Material cost of anchorage (₹)	Cost of installation of anchorage	Cost of installation of sheet pile (in ₹) per m width	Total Cost (₹) of sheet pile per m width & length	cost of sheet pile for entire height and unit width,₹
					Dia (in mm)	length (in	weight (kg/m)													
4	3.2	27	100	46.9	9.5	8	0.405	HGU 6N	625	600	1.67	41.9	45	49	₹ 3,142.50	158.76	48000	612	₹ 3,301.26	₹ 72,723.11
5	4.00	60.0	222	62.1	9.5	8	0.405	HGU 6N	625	600	1.67	41.9	45	49	₹ 3,142.50	158.76	48000	765	₹ 3,301.26	₹ 79,125.38
6	4.70	106.67	395	80	9.5	8	0.405	HGU 6N	625	600	1.67	41.9	45	49	₹ 3,142.50	158.76	48000	909.5	₹ 3,301.26	₹ 85,631.76
7	5.40	170	630	99	11.1	8	0.548	HGU 7N	675	600	1.67	44.1	45	49	₹ 3,307.50	214.816	48000	1054	₹ 3,522.32	₹ 94,537.92
8	6.10	251	930	120.4	2 x 9.5	8	0.405	HGU 13N	1270	600	1.67	59.9	45	49	₹ 4,492.50	317.52	48000	1198.5	₹ 4,810.02	₹ 1,19,225.28
9	6.80	353	1307	143.5	12.7	8	0.73	HGU 14N	1400	600	1.67	64.3	45	49	₹ 4,822.50	572.32	48000	1343	₹ 5,394.82	₹ 1,37,378.16
10	7.5	476.2	1764	168.5	2 X 11.1	8	0.548	HGU 18 N	1800	600	1.67	76.9	45	49	₹ 5,767.50	429.632	48000	1487.5	₹ 6,197.13	₹ 1,61,417.81
11	8.20	625	2315	195.2	2 X 11.1	8	0.548	HGU 23 N	2335	600	1.67	90.4	45	49	₹ 6,780.00	429.632	48000	1632	₹ 7,209.63	₹ 1,92,607.33
12	8.8	800	2963	224	2 X 12.7	8	0.73	HGU 30N	3000	600	1.67	106.2	45	49	₹ 7,965.00	572.32	48000	1768	₹ 8,537.32	₹ 2,33,028.26
13	9.50	1004	3719	243.5	12.7	8	0.002	Section NA	-	600	1.67	-	45	49	-	1.568	48000	-	-	-

Table VII: Waler beam sections used at anchorage locations
(for height of excavation of 4 to 12m)

Waler Beam, Universal Beam section				
Designation	weight (kg/m)	Section modulus (in cm3)	cost ₹ (kg/m)	Total cost of waler for unit width (₹)
NPB 120X60	10.37	53	46	954.04
NPB 180X90	15.37	120.1	46	1414.04
NPB 200X100	25.09	218.9	46	2308.28
UB 254X146X31	31.1	351.1	46	2861.2
UB 254X146X37	37	432.6	46	3404
UB 356X171X45	45	686.7	46	4140
UB 406X178X54	54	930	46	4968
UB 457X152X67	67.2	1263	46	6182.4
UB 356X171X47	81	1659.9	46	7452

Table VIII: Sandy soil with surcharge only

Cantilever

Height of Excavation (m)	Embedment Depth (m)	Max Moment in kN-m/m	Required Section Modulus (cm3)	Provided Section	Provided Section Modulus (cm3/m)	Section width in mm	Number of section required per m length	Weight (kg/m)	Cost (₹/kg)	Cost of sheet pile per m width (₹) and length	Cost of installation (in ₹) for per m width	Total Cost (₹)	cost of sheet pile for entire height and unit width,₹
3	4.7	186.8	692	HGU 7H	740	600	1.67	46.3	45	3472.50	654.5	4127.00	₹ 31,778
4	6.60	426.1	1578	HAU 16	1600	750	1.33	86.3	45	5178.00	901	6079.00	₹ 64,437
5	7.72	703.7	2606	HPU 28-1	2680	600	1.67	97.4	45	7305.00	1081.2	8386.20	₹ 1,06,672
6	8.21	1068	3956	NA Section	*	700	1.43	134	45	8614.29	1207.85	9822.14	₹ 1,39,573
7	9.89	1529	5663	NA section			-		45	-	-	-	-

Table IX: Sandy soil with surcharge only

Anchored

Height of Excavation (m)	Embedment Depth (m)	Max Moment in kN-m/m	Required Section Modulus (cm3)	Force Required in Anchorage (in kN/m)	Provided Anchorage (as per IS 14268:1995)			Provided Section of sheet pile	Provided Section Modulus (cm3/m)	Section width in mm	Number of section required per m length	Weight of sheet pile (kg/m)	Cost (₹/kg)	Cost of anchorage (₹/kg)	Cost of sheet pile per m width and length (₹)	Material cost of anchorage (₹)	Cost of installation of anchorage	Cost of installation of sheet pile (in ₹) per m width	Total Cost (₹) of sheet pile per m width & length	Cost of sheet pile for entire height and unit width,₹
					Dia (in mm)	length (in m)	weight (kg/m)													
5	4.5	83	307	95	9.5	8	0.405	HGU 6N	625	600	1.67	41.9	45	49	₹ 3,142.50	158.76	48000	807.5	₹ 3,301.26	₹ 81,671.17
6	5.30	143.0	530	116.4	11.1	8	0.548	HGU 6N	625	600	1.67	41.9	45	49	₹ 3,142.50	214.816	48000	960.5	₹ 3,357.32	₹ 88,697.67
7	6.10	223	826	140.1	2 x 9.5	8	0.405	HGU 13N	1270	600	1.67	59.8	45	49	₹ 4,485.00	317.52	48000	1113.5	₹ 4,802.52	₹ 99,000.00
8	6.75	324	1200	165.8	2 x 9.5	8	0.405	HGU 13N	1270	600	1.67	59.9	45	49	₹ 4,492.50	317.52	48000	1253.75	₹ 4,810.02	₹ 1,23,189.00
9	7.45	448	1659	194	2 x 11.1	8	0.548	HGU 16N	1670	600	1.67	72.6	45	49	₹ 5,445.00	429.632	48000	1398.25	₹ 5,874.63	₹ 1,49,881.70
10	8.20	597	2211	223	15.2	8	1.094	HGU 23N	2335	600	1.67	90.4	45	49	₹ 6,780.00	428.848	48000	1547	₹ 7,208.85	₹ 1,85,365.03
11	8.85	773	2863	254	2 x 12.7	8	0.73	HGU 30N	3000	600	1.67	106.2	45	49	₹ 7,965.00	572.32	48000	1687.25	₹ 8,537.32	₹ 2,25,009.80

Table X: Waler beam sections used at anchorage locations
(for height of excavation of 5 to 11m)

Waler Beam, Universal Beam section				
Designation	weight (kg/m)	Section modulus (in cm3)	cost ₹ (kg/m)	Total cost of waler for unit width (₹)
UB 203X133X25	25.1	230.3	46	2309.2
UB 203X133X30	30	280	46	2760
UB 254X146X37	37	432.6	46	3404
UB 305X165X46	46.1	645.7	46	4241.2
UB 356X171X57	57	896	46	5244
UB 457X152X67	67	1263	46	6164
UB 457X152X82	82	1571	46	7544

Table XI: Sandy soil with surcharge and water table only

Cantilever

Height of Excavation (m)	Embedment Depth (m)	Max Moment in kN-m/m	Required Section Modulus (cm3)	Provided Section	Provided Section Modulus (cm3/m)	Section width in mm	Number of section required per m length	Weight (kg/m)	Cost (₹/kg)	Cost of sheet pile per m width(₹) and length	Cost of installation (in ₹) for per m width	Total Cost (₹)	cost of sheet pile for entire height and unit width,₹
3	4.625	186.8	692	HGU 7S	740	600	1.67	46.3	45	3472.50	648.125	4120.63	₹ 31,420
4	6.60	426.1	1578	HAU 16	1600	750	1.33	86.3	45	5178.00	901	6079.00	₹ 64,437
5	7.72	703.7	2606	HPU 28-1	2680	600	1.67	97.4	45	7305.00	1081.2	8386.20	₹ 1,06,672
6	8.81	1068	3956	No Section	*	700	1.43	134	45	8614.29	1258.85	9873.14	₹ 1,46,221

Table XII: Sandy soil with surcharge and water table only

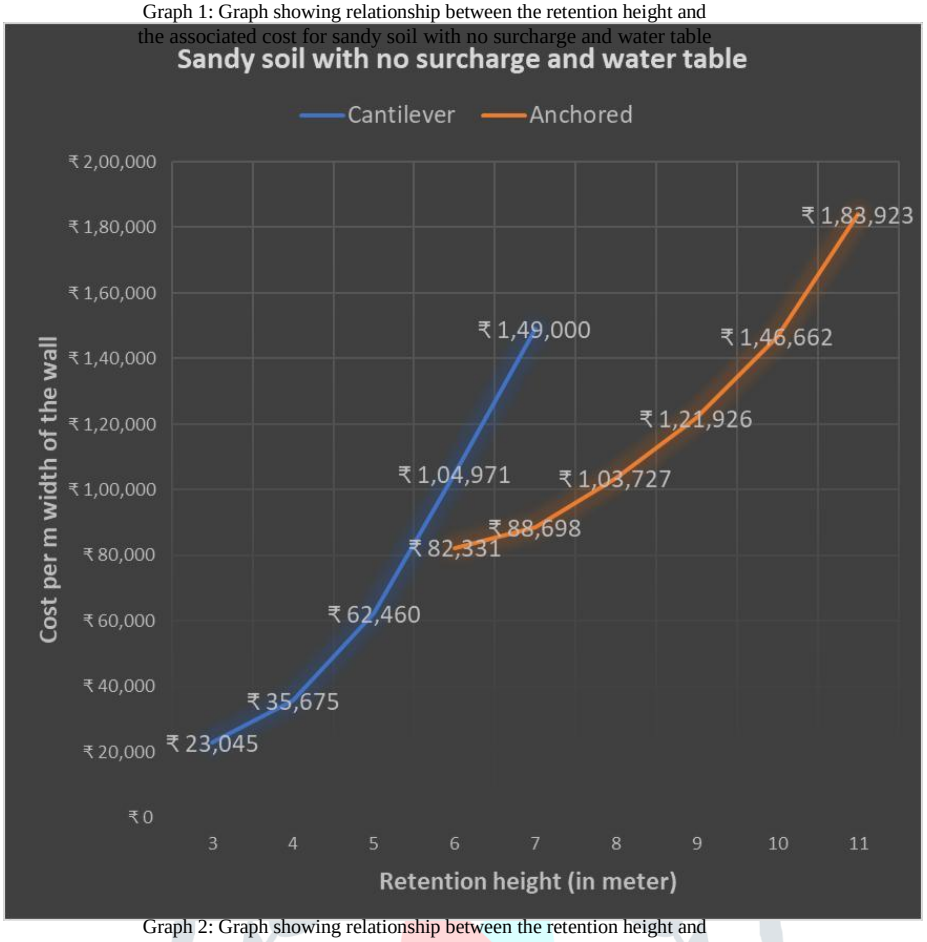
Anchored

Height of Excavation (m)	Embedment Depth (m)	Max Moment in kN-m/m	Required Section Modulus (cm3)	Force Required in Anchorage (in kN/m)	Provided Anchorage (as per IS 14268:1995)			Provided Section of sheet pile	Provided Section Modulus (cm3/m)	Section width in mm	Number of section required per m length	Weight of sheet pile (kg/m)	Cost (₹/kg)	Cost of anchorage (₹/kg)	Cost of sheet pile per m width and length (₹)	Material cost of anchorage (₹)	Cost of installation of anchorage	Cost of installation of sheet pile (in ₹) per m width	Total Cost (₹)	Cost of sheet pile for entire height and unit width,₹
					Dia (in mm)	length (in m)	weight (kg/m)													
5	4.5	83	307	95	9.5	8	0.405	HGU 6N	625	600	1.67	41.9	45	49	₹ 3,142.50	158.76	48000	807.5	₹ 3,301.26	₹ 81,671.17
6	5.26	143.0	530	116.4	11.1	8	0.548	HGU 6N	625	600	1.67	41.9	45	49	₹ 3,142.50	214.816	48000	957.1	₹ 3,357.32	₹ 88,563.38
7	6.01	223	826	140.1	2 x 9.5	8	0.405	HGU 13N	1270	600	1.67	59.8	45	49	₹ 4,485.00	317.52	48000	1105.85	₹ 4,802.52	₹ 1,02,000.00
8	6.80	324	1200	165.8	2 x 9.5	8	0.405	HGU 13N	1270	600	1.67	59.9	45	49	₹ 4,492.50	317.52	48000	1258	₹ 4,810.02	₹ 1,23,429.50
9	7.50	448	1659	194	2 x 11.1	8	0.548	HGU 16N	1670	600	1.67	72.6	45	49	₹ 5,445.00	429.632	48000	1402.5	₹ 5,874.63	₹ 1,50,175.43
10	8.20	597	2211	223	15.2	8	1.094	HGU 23N	2335	600	1.67	90.4	45	49	₹ 6,780.00	428.848	48000	1547	₹ 7,208.85	₹ 1,85,365.03
11	8.9	773	2863	254	2 x 12.7	8	0.73	HGU 30N	3000	600	1.67	106.2	45	49	₹ 7,965.00	572.32	48000	1691.5	₹ 8,537.32	₹ 2,25,436.67

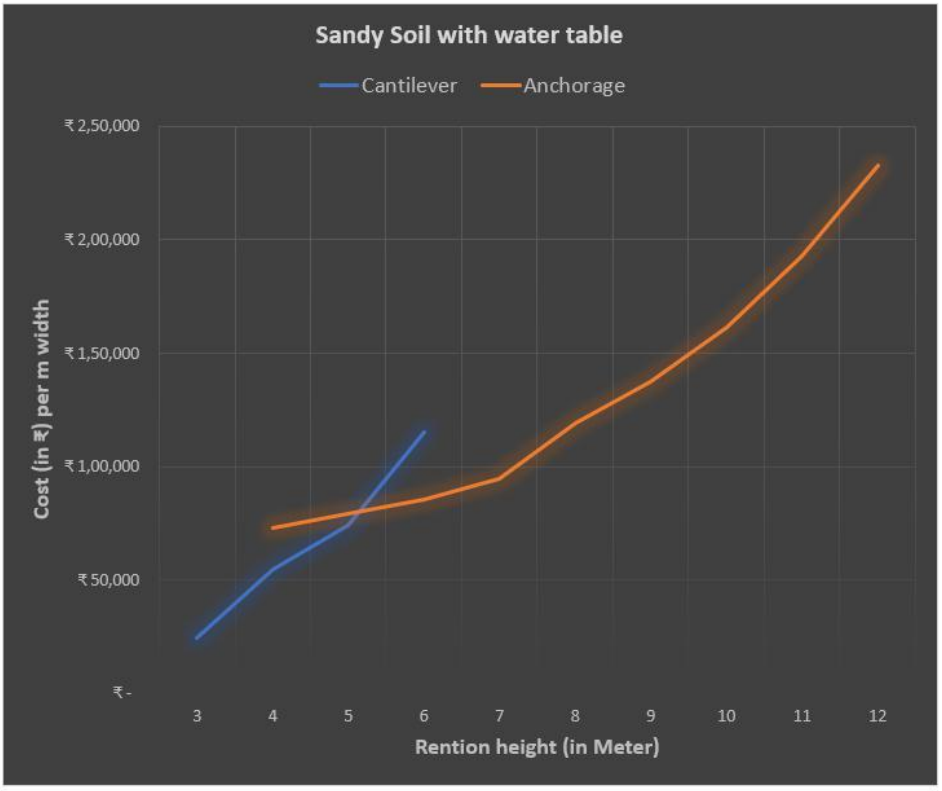
Table XIII: Waler beam sections used at anchorage locations
(for height of excavation of 5 to 11m)

Waler Beam, Universal Beam section				
Designation	weight (kg/m)	Section modulus (in cm3)	cost ₹ (kg/m)	Total cost of waler for unit width (₹)
UB 203X133X25	25.1	230.3	46	2309.2
UB 203X133X30	30	280	46	2760
UB 254X146X37	37	432.6	46	3404
UB 305X165X46	46.1	645.7	46	4241.2
UB 356X171X57	57	896	46	5244
UB 457X152X67	67	1263	46	6164
UB 457X152X82	82	1571	46	7544

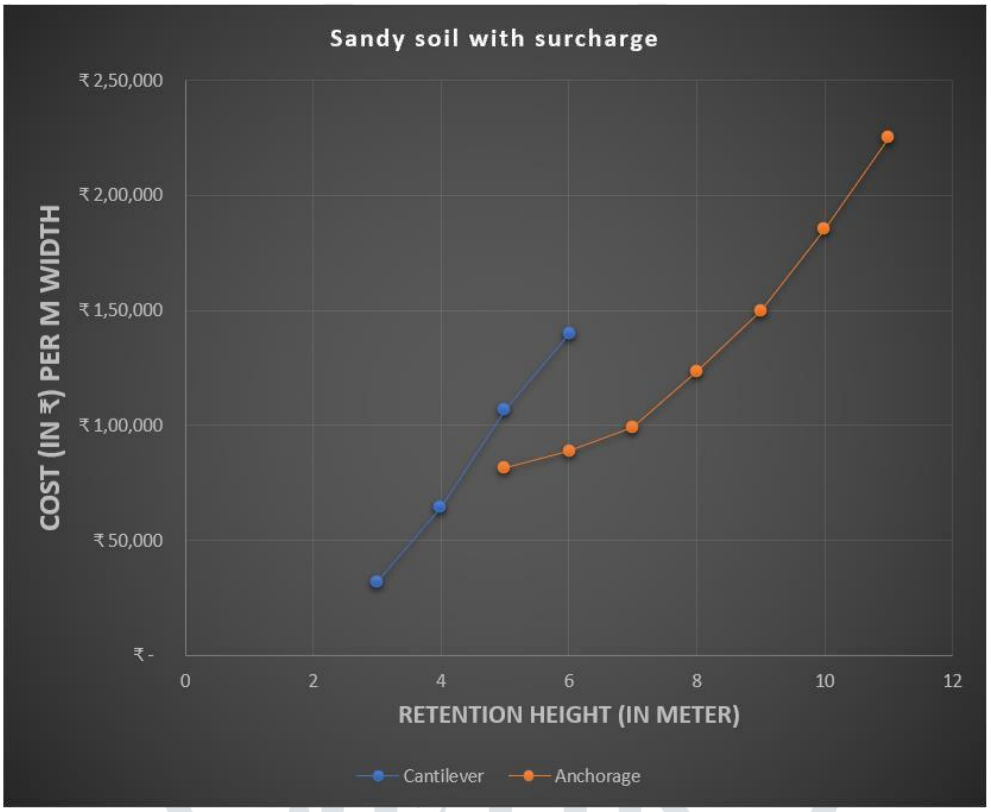
Graph 1: Graph showing relationship between the retention height and the associated cost for sandy soil with no surcharge and water table



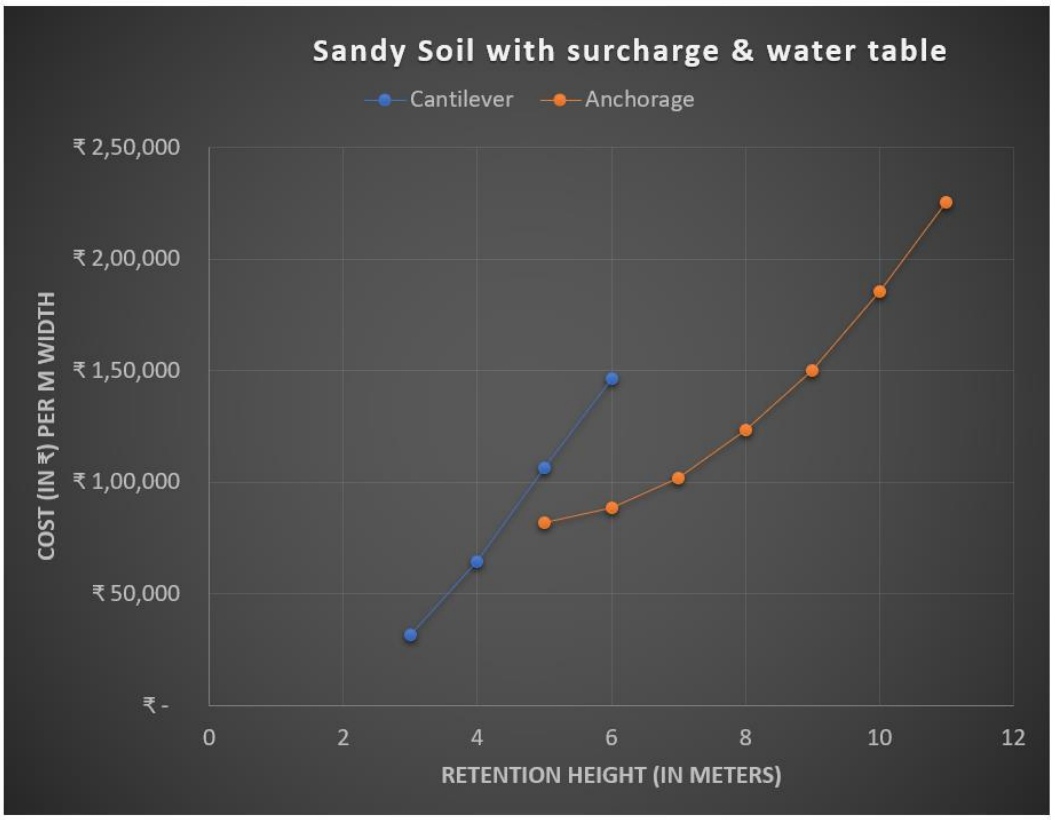
Graph 2: Graph showing relationship between the retention height and the associated cost for sandy soil with water table



Graph 3: Graph showing relationship between the retention height and the associated cost for sandy soil with surcharge



Graph 4: Graph showing relationship between the retention height and the associated cost for sandy soil with surcharge and water table



The results obtained from the calculations of the four cases assumed are summarized in the matrix form (as shown in table XIV and XV) for both cantilever and anchorage steel sheet pile and are given below.

Table XIV: Comparative Matrix for Cantilever Steel Sheet Pile

Retention Height (in m)	Condition	Embedment Depth (in m)	Bending Moment (kN-m/m)	Section width (in mm)	Section Thickness (in mm)	Section Weigth (kg/m)	Cost per unit Width (in ₹)
3	Sandy Soil with No Water Table and Surcharge	3.27	84.6	600	6	41.9	₹ 23,045.00
	Sandy Soil with Water Table only	3.625	97	625	6	41.9	₹ 24,550.00
	Sandy Soil with Surcharge only	4.62	186.8	600	7.2	46.3	₹ 31,420.00
	Sandy Soil with Water Table and Surcharge	4.7	186.8	600	7.2	46.3	₹ 31,778.00
4	Sandy Soil with No Water Table and Surcharge	4.36	200.5	600	7.3	47.4	₹ 35,675.00
	Sandy Soil with Water Table only	5.5	245	600	9.8	66.1	₹ 54,768.00
	Sandy Soil with Surcharge only	6.6	426.1	750	9.3	86.3	₹ 64,437.00
	Sandy Soil with Water Table and Surcharge	6.6	426.1	750	9.3	86.3	₹ 64,437.00
5	Sandy Soil with No Water Table and Surcharge	5.45	391.6	400	9	45.21	₹ 62,460.00
	Sandy Soil with Water Table only	6.53	435	600	10.2	72.6	₹ 74,081.00
	Sandy Soil with Surcharge only	7.72	703.7	600	16.2	97.4	₹ 1,06,672.00
	Sandy Soil with Water Table and Surcharge	7.72	703.7	600	16.2	97.4	₹ 1,06,672.00
6	Sandy Soil with No Water Table and Surcharge	6.54	676.8	600	14.2	97.4	₹ 1,04,971.00
	Sandy Soil with Water Table only	7.6	696	600	14.2	97.4	₹ 1,15,070.00
	Sandy Soil with Surcharge only	8.21	1068	700	-	-	₹ 1,39,573.00
	Sandy Soil with Water Table and Surcharge	8.81	1068	-	-	-	₹ 1,46,221.00

Table XV: Comparative Matrix
for Anchorage Steel Sheet Pile

Retention Height (in m)	Condition	Embedment Depth (in m)	Bending Moment (kN-m/m)	Section width (in mm)	Section Thickness (in mm)	Section Weigth (kg/m)	Cost per unit Width (in ₹)
5	Sandy Soil with No Water Table and Surcharge	-	-	-	-	-	-
	Sandy Soil with Water Table only	4	60	600	6	41.9	₹ 79,125.00
	Sandy Soil with Surcharge only	4.5	83	600	6	41.9	₹ 81,671.00
	Sandy Soil with Water Table and Surcharge	4.5	83	600	6	41.9	₹ 81,672.00
6	Sandy Soil with No Water Table and Surcharge	3.7	83.5	600	6	41.9	₹ 82,331.00
	Sandy Soil with Water Table only	4.7	106.67	600	6	41.9	₹ 85,631.00
	Sandy Soil with Surcharge only	5.2	143	600	6	41.9	₹ 88,563.00
	Sandy Soil with Water Table and Surcharge	5.3	143	600	6	41.9	₹ 88,698.00
7	Sandy Soil with No Water Table and Surcharge	4.3	141.6	600	6	41.9	₹ 88,697.00
	Sandy Soil with Water Table only	5.4	170	600	6.5	44.1	₹ 94,537.00
	Sandy Soil with Surcharge only	6.1	223	600	9	59.8	₹ 99,000.00
	Sandy Soil with Water Table and Surcharge	6.01	223	600	9	59.8	₹ 1,02,000.00
8	Sandy Soil with No Water Table and Surcharge	5	220	600	8	50.8	₹ 1,03,726.00
	Sandy Soil with Water Table only	6.1	251	600	9	59.9	₹ 1,19,225.00
	Sandy Soil with Surcharge only	6.75	324	600	9	59.9	₹ 1,23,189.00
	Sandy Soil with Water Table and Surcharge	6.8	324	600	9	59.9	₹ 1,23,430.00
9	Sandy Soil with No Water Table and Surcharge	5.7	320	600	9	59.9	₹ 1,21,926.30
	Sandy Soil with Water Table only	6.8	353	600	10	64.3	₹ 1,37,378.00
	Sandy Soil with Surcharge only	7.45	448	600	10.2	72.6	₹ 1,49,882.00
	Sandy Soil with Water Table and Surcharge	7.5	448	600	10.2	72.6	₹ 1,50,176.00

VI. CONCLUSION

On the basis of the analysis done following conclusions are derived for different cases as discussed below

Case 1: Sandy soil with no surcharge and water table

- In case of sandy soil with no surcharge and water table, it is observed that the cantilever sheet pile is cost effective only up to a retention height of 5m.
- By providing anchorage sheet pile for the retention height of 6m, it is observed that the approximate saving in cost is 20% as compared to the cost of cantilever sheet pile.

Case 2: Sandy soil with water table at 4m

- In case of sandy soil with water table at 4m and no surcharge, it is observed that the increase in cost from retention height of 3m to 4m (retention height is equal to the depth of ground water table) is more than twice. It is because of the additional lateral pore water pressure exerted by the soil.
- Cantilever sheet pile is observed to be cost effective only up to a retention height of 5m.
- By providing anchorage sheet pile for the retention height of 6m, it is observed that the approximate saving in cost is 25% as compared to the cost of cantilever sheet pile.

Case 3: Sandy soil with variable surcharge and no water table

- In case of sandy soil with variable surcharge (due to vehicular traffic), it is observed that the increase in cost from retention height of 3m to 4m is more than twice.
- Cantilever sheet pile is observed to be cost effective only up to a retention height of 4m.
- By providing anchorage sheet pile for the retention height of 5m, it is observed that the approximate saving in cost is 23% as compared to the cost of cantilever sheet pile.
- By providing anchorage sheet pile for the retention height of 6m, it is observed that the approximate saving in cost is 35% as compared to the cost of cantilever sheet pile.

Case 4: Sandy soil with variable surcharge and water table at 4m

- In case of sandy soil with water table at 4m and variable surcharge, it is observed that the increase in cost from retention height of 3m to 4m (retention height is equal to the depth of ground water table) is more than twice. It is because of the additional lateral pore water pressure exerted by the soil and the variable surcharge.
- Cantilever sheet pile is observed to be cost effective only up to a retention height of 4m.
- By providing anchorage sheet pile for the retention height of 5m, it is observed that the approximate saving in cost is 23% as compared to cost of cantilever sheet pile.
- By providing anchorage sheet pile for the retention height of 6m, it is observed that the approximate saving in cost is 40% as compared to cost of cantilever sheet pile.

In general, following conclusions can be derived from the analysis done:

- Cantilever sheet piles are found to be cost effective up to a retained height of 4m to 5m.
- Anchored sheet piles are observed to be cost effective up to a retained height of 9m to 11m.
- Comparative matrix is developed based on the cost analysis performed for different conditions.
- These matrices could be used to understand the variation of embedment depth, maximum bending moment, sections used and the associated cost for different soil conditions.
- These matrices could be used for developing preliminary estimates, bidding etc.

VII. REFERENCES

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