INNOVATIVE EARTH RETAINING SYSTEM ADOPTED AT THE PROPOSED PRINTING COMPLEX PROJECT FOR AITKEN SPENCE (PVT) LTD. AT MAWARAMANDIYA

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Abstract: Retaining earth is a predominant requirement in sloped land constructions. Holding back ground in the most economical and efficient manner, while preserving constructive areas at required levels for intended developments, is the main objective of any earth retaining system. Gravity walls, cantilevered walls, sheet pile walls and anchored walls are few commonly using retaining wall types. In addition to above conventional methods, soil nailing, gabion walls, stabilization with artificial reinforcement, etc are increasingly use in modern constructions. However, selection of the most appropriate system to resist the lateral earth and hydrostatic pressure and/or to stabilize the slopes depends on several factors such as the retaining height, available area, properties of soil to be retained, cost of construction, etc.

The land selected for the construction of proposed printing complex for Aitken Spence (Pvt) Ltd is located in an undulant terrain and thus requires earth retaining, both along the site boundary and at intermediate locations within the premises. The heights to be retained vary from 1m to 7m. Few distinct systems including anchored gravity walls and soil nailing were innovatively adopted at different locations as appropriate, depending on the height of the slope to be retained, space availability and cost considerations. This paper discusses the design aspects and modifications adapted to the conventional design and construction procedures of soil nail retaining systems, possible alternative configurations and other earth retaining methods implemented at the site. The paper includes recommendations and precautions to be taken with the specified soil nailing system and a cost comparison between conventional gravity walls and cantilevered RC walls, as well.

1. Introduction

A variety of methods are being used by people, from ancient times to date, to retain earth. Gravity type retaining walls are the oldest among them. The laterally excreted earth pressures on these walls are counterbalanced by their own self weights. These walls are still commonly used in the construction industry due to their simple nature. Though the wall widths can be maintained at reasonable levels with firm soils, loose soils may require considerable wall thicknesses, requiring large quantities of material, space, excavation, cost, etc. Cantilevered or freestanding walls without any supporting system at the top, is the most commonly using retaining wall type. This type of walls requires a lesseramount of material and space compared to traditional gravity walls. Tie backs or buttresses can be introduced to these walls to enhance the earth retaining capacity.

Sheet pile retaining walls can be constructed with steel, vinyl or wooden planks. Since the piles are to be driven installed in the ground, the method is usually adopted with soft soil conditions. Sheet pile walls are ideal for limited space constructions. These walls may require an additional supporting system in the form of anchors or tie backs when the freestanding walls are incapable of retaining the anticipated heights.In addition to above conventional retaining wall types, internally stabilized type retaining systems such as soil nailing, reinforcing with geotextiles or metal strips, etc. are increasingly used in modern constructions due to the comparatively low cost, limited space requirement, etc. Providing a reinforced concrete covering slab on the sloped surface is a usual practice in this type of retaining systems.

1.2 Earth Retaining at Marawamandiya

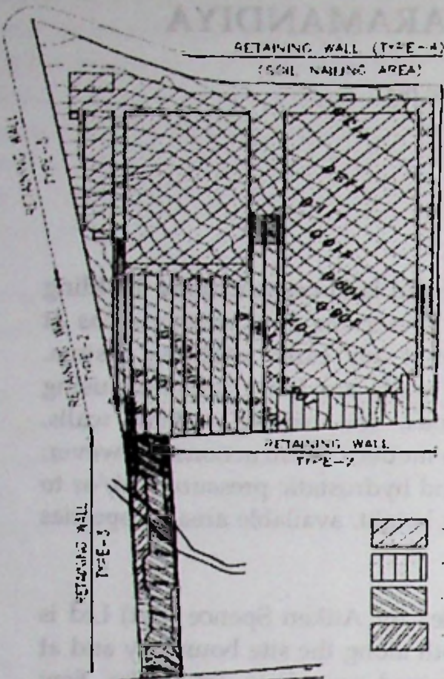


Figure 01: Contour Plan and Proposed Final Levels of the Site

Selecting the most appropriate and economical retaining system to retain available soil masses or landfills was a major task in the land. Figure 01 shows the original contour plan and the final expected formation levels of the proposed land for the printing complex. It shows that earth heights ranging from 1m to 7m are to be retained appropriately to maintain the final site levels. This paper describes how different types of retaining systems were effectively used in this particular site and the affected factors in selections so that both economical and spatial requirements are satisfied. The paper describes the advantages and disadvantages of each system as well.

2. Objectives and Methodology

2.1 Objectives

Main objectives of the paper are describing how conventional retaining walls were innovatively used in the proposed construction site at Mawaramandiya and to compare the cost of different wall types.

2.2 Proposed Methodology

Following facts were implicitly described differentiating between each type to reach above objectives.

1. Description of different types of retaining systems used at Mawaramandiya and the affected factors for selection
2. Comparison of Different Wall Types
   - Gravity type retaining walls
   - Replacement of gravity wall with a cantilevered type RC retaining wall
   - Gravity type retaining walls with tie backs (anchor blocks)
   - Comparison of cost and other aspects
3. Soil Nailing System
   - Stabilization of slopes with soil nailing
   - Adopted modifications to conventional soil nailing system

3. Earth Retaining Systems Adopted at Mawaramandiya

Several distinct types of earth retaining systems had to be adopted at the proposed construction site giving consideration to the proposed development, soil condition at site, expected retaining heights, and post construction changes in adjacent lands. Different retaining systems used to achieve above requirements are described in following paragraphs. Layout of each type of retaining wall is shown in Figure 01. According to the figure, five different types of retaining systems had to be used at the site to retain the earth appropriately.

3.1 Retaining Wall Type 1

The first retaining wall type is a conventional gravity type wall and was constructed along a part of the western site boundary (refer Figure 01). The final proposed formation level of the site at the retaining wall is 108.0m. A private land sloping towards the north is located on the opposite side after the wall is constructed. Section of the retaining wall used to retain the earth along the road is shown in Figure 02.

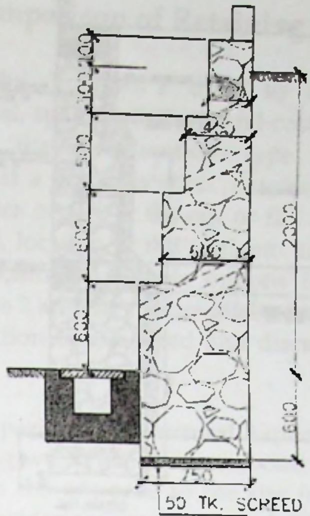


Figure 02: Retaining Wall - Type 1

Since the final site elevation is lower than that of the adjacent land, the steps had to be faced to the land. 750mm of the land had to be allocated for the retaining wall. Minimum or insufficient availability of dead weight to counterbalance the lateral loads, difficulties in supporting the land at a higher elevation during construction, possible interference of proposed building foundations with the retaining wall foundation and comparatively high cost, eliminated the possibility of using a cantilevered type, reinforced concrete retaining wall at the particular location.

Rankines Theory was used to calculate the forces on the retaining walls. Though the geotechnical investigation report indicates the angle of repose of soil as 28^0, (which is a very low value) it could be observed from the cut surfaces that the soil possess a higher internal friction than above recommended value (refer Figure 03). Therefore a friction angle of 45^0 was used in the design to avoid large wall cross sections.

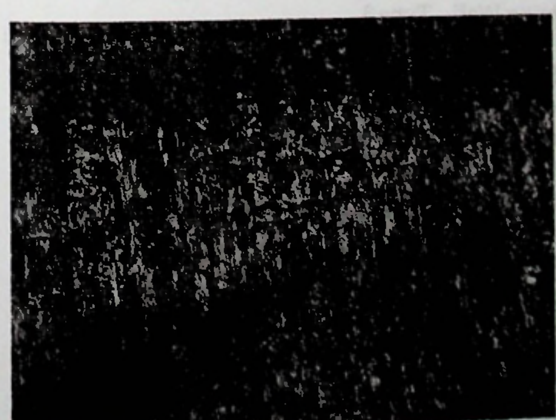


Figure 03: Cut Surface along the Boundary at Retaining Wall - Type 1

3.2 Retaining Wall Type 2

The second retaining wall type associates with relatively larger retaining heights ranging from 1m to 7m. Single or double reinforced concrete anchor blocks in combination with normal gravity walls were introduced to compensate the large lateral loads that would arise from the retained soil masses. Adjacent lands are unoccupied at present and are covered with vegetation. These lands would lie at lower elevations than the final site level (refer Figure 04). A section through retaining wall Type 2 adopted at site is shown in Figure 05.

Figure 04: Neighbours Side of Retaining Wall - Type 2

Since a filled soil mass is to be retained, it was not safe to design the retaining wall with an increased friction angle even with proper compaction. Therefore the value specified in the geotechnical investigation report was used in the design. It was found that counterbalancing the lateral loads with adequate safety was possible with traditional rubble retaining walls with extraordinary wall sections were used. Such walls may require massive amounts of material, labour hours, cost, space, etc. leading to uneconomical designs. Adopting reinforced concrete cantilevered walls as well, were ended up with high cost estimates (refer Section 4 for more details) due to large concrete volumes encountered.

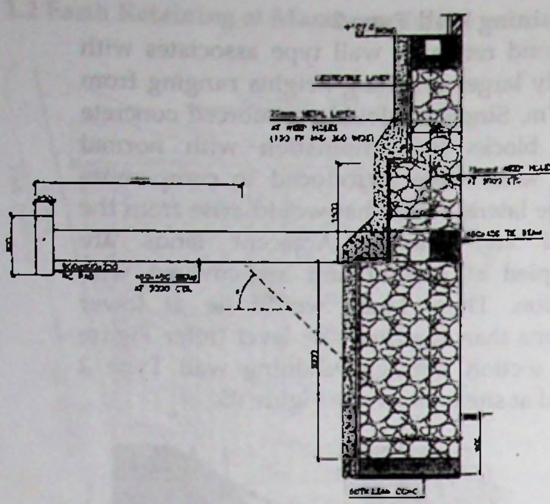


Figure 05: Retaining Wall – Type 2

In order to arrive at an economical and efficient solution, traditional rubble walls were held back by reinforced concrete anchor blocks at suitable elevations. Most of the lateral earth forces were thus carried by the combination of tension in anchor ties, skin friction and bearing at the anchor blocks. However locating and sizing of anchor blocks had to be done with care so that the blocks are not pulled out by overturning or sliding of the wall; thus the reinforced concrete bearing pads were placed sufficiently apart from the assumed soil failure plane (refer Figure 05 and Figure 06).

Figure 06: Construction of Anchor Blocks

3.3 Retaining Wall Type 3

Retaining wall Type 3 was proposed along the entrance path to the site. The entrance path was at a lower elevation relative to the final site formation levels. Therefore the access road including the ramp had to be prepared with a soil fill ranging approximately from 1m to 7m. Proposed section for the retaining wall is shown in Figure 07.

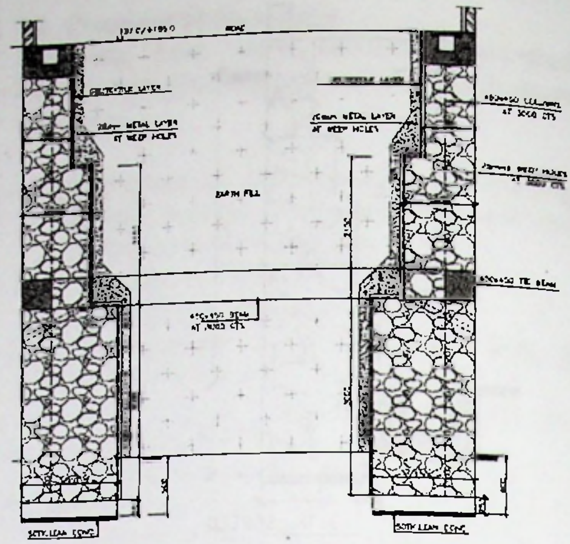


Figure 07: Retaining Wall – Type 3

This retaining wall is almost similar to Type 2. Distance between the two opposite site boundaries at the entrance is approximately 7m. Difficulties in providing anchor blocks in this limited available space were overcome by counterbalancing the lateral earth pressure on each wall by the dead weight of the other wall (refer Figure 07). The link between two walls was made through a reinforced Concrete tie beam (refer Figure 08).

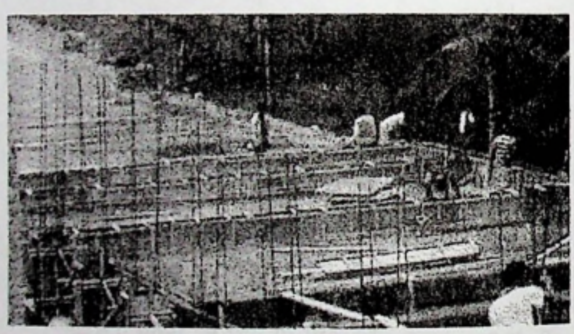


Figure 08: Construction of Connecting Beam at Retaining Wall – Type 3

At the locations where soil masses higher than 5m were to be retained, two anchor blocks or tie beams had to be provided to stabilize both retaining walls Type 1 and Type 2 (refer Figure 10.2(c)). However provision of such anchor blocks would be economical only when a filled soil mass is to be retained..

Proper compaction of the backfill was always guaranteed to ensure efficient behaviour of the anchor blocks as poor compaction would cause reduction in soil skin friction and bearing capacity and increase secondary settlements.

4. Comparison of Retaining Walls

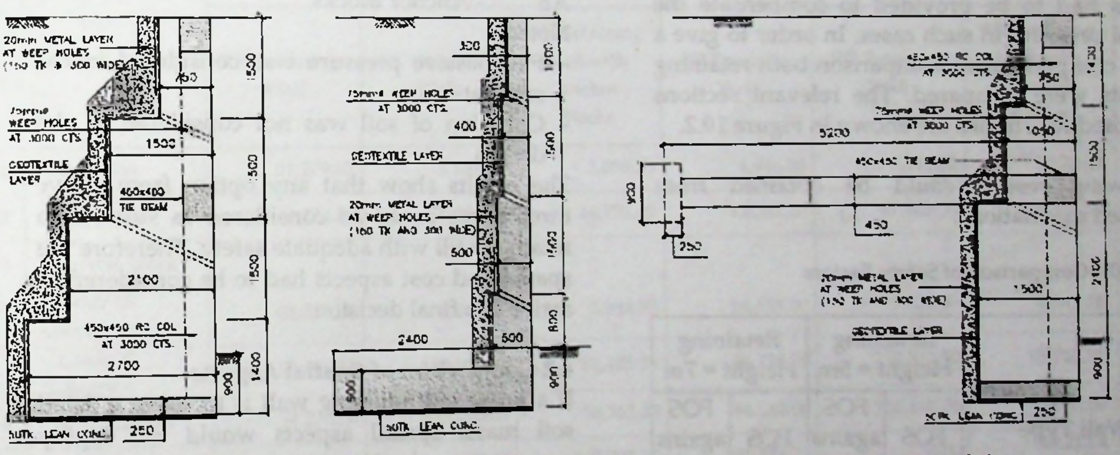
It is the Engineer's duty to consider all structural, spatial, aesthetic and cost aspects and provide the most suitable type of retaining system at a given location. Parameters such as properties of soil in the cut or fill, height to be retained, location of the wall, etc. can affect the final decision. Available options for retaining wall type 2 and the factors affected in selecting a final section is compared and discussed in this section.

4.1 Comparison of Structural Aspects

Retaining wall Type 2 was selected to construct closer to the entrance to the site (refer Section 3.2), considering the associated filling depths. Three possible options were selected as suitable for the purpose. Rankine Theory with following design parameters was adopted in the designs. Since adequate seepage of water is allowed through the weep holes, water pressure was not considered in the design.

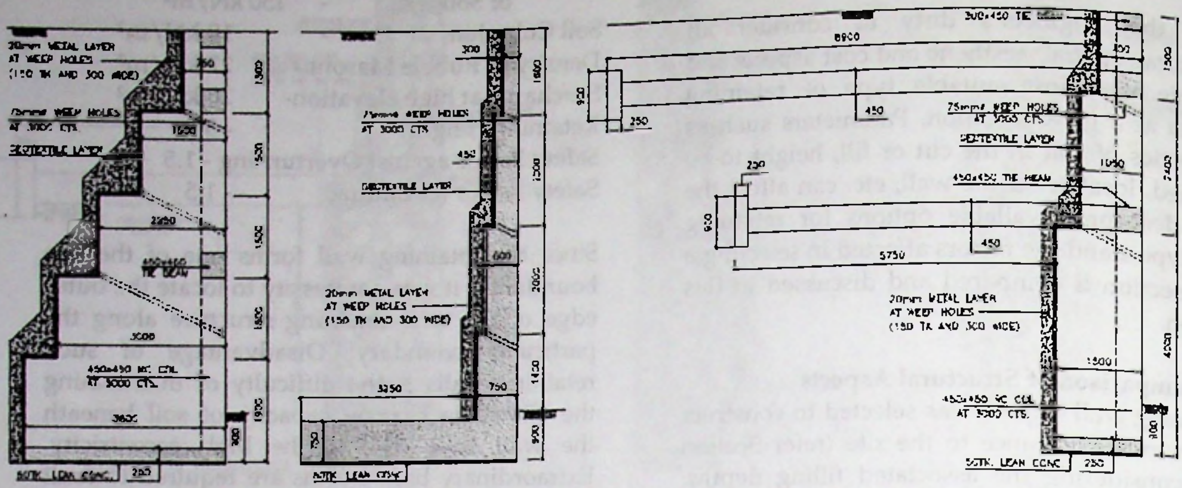
Density of Soil	- 18 kN/m^3
Angle of Internal Friction	- 28^0
Allowable Bearing Capacity of Soil	- 150 kN/m^2
Soil Cohesion	- 10 kN/m^2
Density of Rubble Masonr	- 22 kN/m^3
Surcharge at high elevation	- 10 kN/m^2
Retaining Height	- 5 m
Safety Factor against Overturning	- 1.5
Safety Factor for Sliding	- 1.5

Since the retaining wall forms one of the site boundaries, it was a necessity to locate the outer edge of the total retaining structure along the particular boundary. Disadvantage of such retaining walls is the difficulty of maintaining the allowable bearing capacity of soil beneath the wall base due to the high eccentricity. Extraordinary base widths are required to limit the bearing pressure to the allowable value. For the purpose of this comparison the retaining walls were not designed to satisfy the bearing capacity requirements of soil and were designed only to have specified safety factors against overturning and sliding. The three retaining wall sections selected as above, for the comparison is shown in Figure 10.1.



(a) Conventional Gravity type retaining wall
(b) RC cantilivered type retaining wall
(c) Gravity type retaining wall anchor blocks

Figure 10.1: Possible Retaining Wall Types to Retain 5m Fills



(b) Conventional Gravity type retaining wall

(b) RC cantilivered type retaining wall

(c) Gravity type retaining wall anchor blocks

Figure 10.2: Possible Retaining Wall Types to Retain 7m Fills

It is clear from Figure 1 that filling heights at certain areas closer to the entrance exceeds 5m and reaches approximately 7m. Two anchor blocks had to be provided to compensate the lateral pressure in such cases. In order to give a more comprehensive comparison both retaining heights were compared. The relevant sections proposed for 7m fills are shown in Figure 10.2.

Following results could be obtained from detailed calculations.

Table 01: Comparison of Safety Factors

Wall Type		Retaining Height = 5m		Retaining Height = 7m	
		FOS against OT	FOS against Sliding	FOS against OT	FOS against Sliding
(a) Conventional Gravity Type Retaining Wall		1.64	1.55	1.69	1.51
(b) RC Cantilevered Type Retaining Wall		1.92	1.62	1.96	1.57
(c) Gravity Type Retaining Wall	Without AB	0.54	0.94	0.31	0.70
	With AB	1.86	1.59	2.51	1.66

Notations

FOS - Factor of Safety

OT - Overturning

AB - Anchor Blocks

Notes

- Full passive pressure was considered in the calculations
- Cohesion of soil was not considered in the design

The results show that any option from above three types could be considered as suitable to retain the fill with adequate safety. Therefore the spatial and cost aspects had to be considered to arrive at a final decision.

4.2 Comparison of Spatial Aspects

If a proposed retaining wall is to retain a filled soil mass, spatial aspects would not highly govern the selection, as most of the area that would be allocated for the retaining structure is reusable for construction purposes. However if the retaining wall is very closer to proposed buildings, possible interference of building foundations with the wall and the increase in lateral surcharge pressure due to building loads should be considered in the design. At this particular situation, proposed buildings are far apart from the retaining wall and thus all three options can be adopted to retain the fill.

Spatial aspects will highly govern the type of retaining wall if a cut surface is to be retained. In order to have an economical structure, the steps cantilevered type reinforced concrete wall should be sufficiently placed with in the active side. This would result in large amounts of cutting and filling volumes which would eventually affect the final cost. On the other hand, if the retaining is to be carried out along a boundary, the total space of the wall will be lost from the available area. Therefore in such situations, minimizing the retaining wall section is the most advisable solution.

4.3 Comparison of Cost Aspects

Cost is the most important factor that governs the selection of a suitable earth retaining system. Therefore the construction cost of above three walls were evaluated separately and compared. Backfilling along 3m and 4m wide strips at the two different retaining heights was considered for easy comparison. The cost increase in alternative proposals (for 100m lengths) is compared and summarized in Table 2.

It is clear from the table that a considerable cost saving can be made by adopting the third of a conventional gravity wall or the base of a option, i.e. the random rubble retaining wall with anchor blocks. The highest saving is due to the reduction in material cost. Though the volume of backfilling increases as a result of reducing the rubble area, the rate of backfilling is substantially lesser than that for rubble work. Cost increase in the case of a reinforced concrete retaining wall is incomparable and is not recommendable for the purpose. However at the situations of highly limited space or in the case of retaining walls encounter as internal or external walls of building structures, this option has to be considered. A cost saving can be tried by introducing similar anchor blocks as described above. However consideration should be made on the method of deposing water at the backside of the wall, which will incur an additional cost for the water disposal system. As an alternative, walls can be designed to resist the water pressure. This would in turn increase the cost due to the increase in wall thicknesses

Table 2: Comparison of Cost

Item		Amount (Rs)					
		Retaining Height = 5m			Retaining Height = 7m		
		RR Retaining Wall	RC Retaining Wall	RR Retaining Wall with Anchor Blocks	RR Retaining Wall	RC Retaining Wall	RR Retaining Wall with Anchor Blocks
1	Excavation	05,279.63	5,557.50	3,089.53	6,946.88	7,410.00	3,122.44
2	Form Work	08,632.50	35,400.00	14,775.00	11,062.50	47,400.00	27,307.50
3	Concrete Work						
	- *Grade 15 Concrete*	04,738.50	5,265.00	3,948.75	06,318.00	7,020.00	6,541.76
	- *Grade 25 Concrete*	53,095.50	159,930.00	58,425.19	66.798.00	230,332.50	95,710.50
4	Reinforcement	54,270.00	235,440.00	58,363.20	84,510.00	350,460.00	91,638.00
5	Rubble Work	160,278.75	0.00	107,709.75	291,881.11	0.00	148,213.48
6	Weep Holes	42,683.75	30,145.50	35,953.77	58,779.88	40,290.77	45,957.25
7	Back Filling	31,660.88	544,338.30	331,603.39	596,611.22	816,533.67	522,049.87
Total Cost per 3m long wall		360,639.50	572,034.15	310,794.40	580,553.95	854,809.99	499,219.26
Total Cost per 100m long wall		12,021,316.67	18,144,610.00	11,053,446.30	19,887,040.62	27,217,788.86	17,401,662.29
Cost Increase relative to adopted section		967,870.37	7,091,163.70	0.00	2,485,378.32	9,816,126.57	0.00
		(0.97 Million)	(7.09 Million)	-	(2.49 Million)	(9.82 Million)	-
Percentage Cost Increase		8.76%	64.15%	-	14.28%	56.41%	-

5. Soil Nailing

Soil nailing is a relatively modern system that is used in stabilising cut slopes. The method comprises of mobilising the available tensile strength of steel reinforcement as a result of slight outward movements of retained soil masses and is typically used to stabilise existing natural slopes and excavations. Steel reinforcement bars are place in pre drilled holes at predetermined vertical and horizontal spacing and at a predetermined angle (refer Figure 11). The annular space between the drill hole and the reinforcement is then filled with an appropriate grout. The method generally involves a top to bottom installation sequence, i.e. the slope in generated in steps while installing a row of nails at each particular cut height. Though the cut face can be maintained vertical, general practice is to have a slight slope to the vertical to increase the factor of safety against sliding. All the soil nails protruded from the cut face are then combined with a reinforced shotcrete face to unify the system. Consideration should be given to provision of proper site drainage system. Providing geocomposite strip drains behind the shotcrete facing combined with a toe drain is the general practice in these retaining systems.

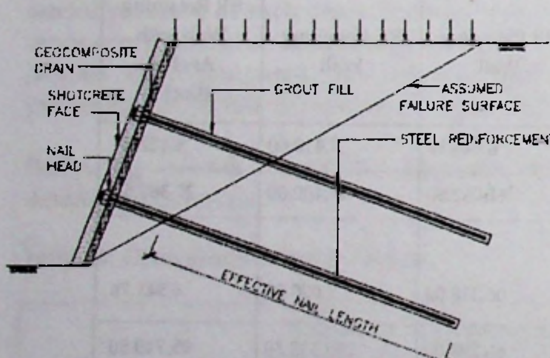


Figure 11: Main Elements of a Soil Nailing System

Efficiency of such soil nail walls is entirely dependent on the friction between the cement grout and the existing soil. Therefore providing adequate number of nails, extended to sufficient lengths beyond possible failure planes, at adequate spacing is essential to obtain the required safety. Distance between the cut face and the site boundary would be a limiting factor to the length of any soil nail as all the nails should be placed within the site boundary, both for safety and legal requirements. Proper quality control should be maintained throughout construction to avoid all possible modes of failures. Adequate tests should be performed at the end to ascertain the availability of expected safety.

5.1 Site Configuration

Cut slopes along the length indicated as "Retaining Wall Type 4" in Figure 01 were stabilized by soil nailing technique. The small space between the proposed building and the site boundary forced to retain the cuts by this method. The associated cut heights range from approximately 5.0 to 6.5m.

All design parameters, except the surcharge at the side of higher elevation, as given in Section 4.1 are assumed to be same. Giving consideration to any possible future constructions, an increased surcharge of 20kN/m² was assumed in the design. The cut slope was considered as 20^0 to the vertical, to increase the factor of safety for any loading condition. The schematic diagram of considered cut is shown in Figure 12.

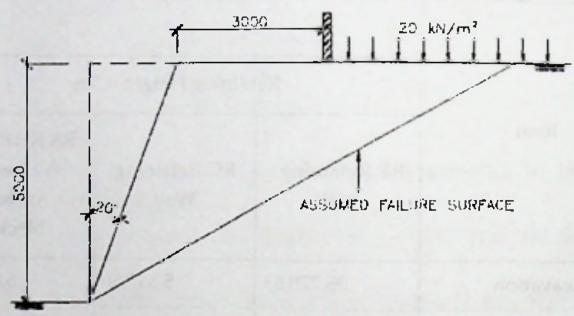
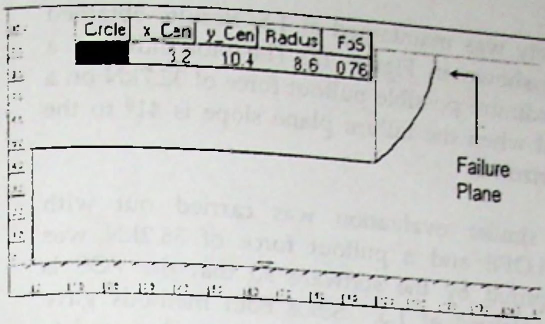


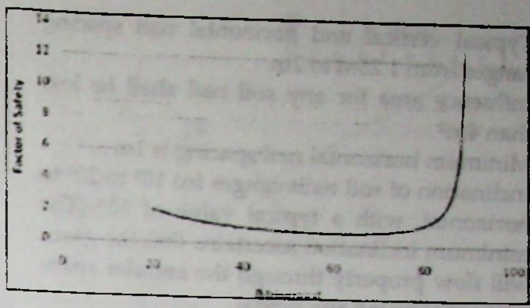
Figure 12: Schematic Diagram of Considered Cut

5.2 Design Approach

Stabilising slopes with soil nailing mainly involve identifying the most critical failure plane(s) since the diameter, length, vertical and horizontal spacing, inclination, etc. of the nails entirely depend on this. Therefore the most critical failure plane(s) relevant to the site configurations were determined with the software XSLOPE and compared using a spreadsheet prepared according to Coulomb's method. As a preliminary estimate the cut slope was considered as vertical and it was assumed that no surcharge pressure would encounter at the side of high elevation.



(a) FOS from XSLOPE



(b) FOS from Spreadsheet

Figure 13: FOS against Slip

The software XSLOPE gave a minimum factor of safety of 0.76 against slip and this corresponds to the toe circle failure of the slope [Figure 13(a)]. Variation of the factors of safety with the slope of the cut, obtained from the spreadsheet is shown in Figure 13(b). The graph indicates the lowest factor of safety as 0.82 against slip and this corresponds to a cut inclination of 61^0 to the horizontal.

The results indicate that the cut is not stable if the soil actually possesses the properties in Section 4.1.

Since the soil at the cut has better properties than specified in the geotechnical investigation report. It was decided to cut the slope as to a steeper slope and used soil nailing technique to achieve the recommended safety of the slope according to the standard.

5.3 Layout of Soil Nails

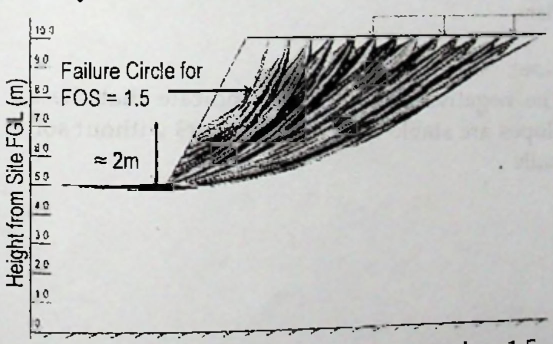


Figure 14: Failure Circles for FOS lesser than 1.5

Soil nails should be placed in such a manner that the pullout resistance or friction between the grout cover and soil provided by the effective nail length (refer Figure 11) is sufficient to resist the sliding of considered soil mass.

...re 12, while maintaining 20^0 to the vertical, the failure circles up to a factor of safety of 1.5, without any nails, were plotted with the software XSLOPE. Results obtained from the software are shown in Figure 14.

Results indicate that all failure circles above 2m from the toe of the slope have a FOS greater than 1.5, even without any supports. On the other hand, though it is the normal practice to provide several vertical soil nail rows for stabilising earth, as shown in Figure 15, the effective length that would contribute at a time of sliding reduces toward top.

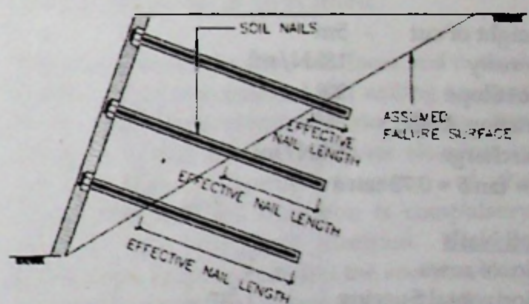


Figure 15: Effective Nail Length

Therefore it was decided to deviate from the conventional soil retaining systems and to provide only a single set of soil nails at the most effective height so that the required safety is achieved and would get a cost saving at the same time. Since it was observed that the soil mass is stable with adequate safety even without soil nails, the shotcrete facing could be terminated at 2m height, thus the nails were placed at the midway of wall, i.e. at 1m height.

Following guidelines suggested by Lazarate, Elias, Espinoza, and Sabatani in 2003, was used as a general guide in selecting a final soil nail layout.

- Typical vertical and horizontal nail spacing ranges from 1.25m to 2m.
- Influence area for any soil nail shall be less than $4m^2$
- Minimum horizontal nail spacing is 1m
- Inclination of soil nails ranges fro 10^0 to 20^0 to horizontal, with a typical value of 15^0 (The minimum inclination ascertains that the grout will flow properly through the annular space without forming any voids)
- Typical drill hole diameters are 100mm and 200mm (A minimum of 25mm grout cover should be available throughout the length of the soil nail)

5.4 Final Design

The final soil nail system for the site was proposed base on the conclusions made by previous calculations and above guidelines.

The design was carried out for the dimensions shown in Figure 16(a) and considering the equilibrium of soil wedge subjected to the forces shown in Figure 16(b) and using following parameters.

Site Conditions and Soil Properties

Height of cut	-	5m
Density	-	$18kN/m^3$
Cut Slope	-	20^0
Friction Angle	-	28^0
Surcharge	-	$20kN/m^2$

$\mu = \tan\delta = 0.75 \tan\phi$

Soil Nails

No. of rows	-	1
Horizontal Spacing	-	1.5m
Inclination	-	20^0 to Vertical

In order to design the soil nails with the required factor of safety, the maximum pullout force on a nail had to be evaluated. The maximum pullout force on a soil nail assuming one row of anchors at 1.5m spacing was evaluated using a spread sheet. The factor of safety was maintained at 1.5. Results obtained are shown in Figure 17. The plot indicates a maximum possible pullout force of 32.7kN on a nail when the failure plane slope is 41^0 to the horizontal.

A similar evaluation was carried out with XSLOPE and a pullout force of 38.2kN was required by the software so that the FOS is maintained at 1.5. Since both methods gave almost same results, the nails were designed to sustain a maximum pullout force of 38.2kN. Equation 1 which can be derived from simple integration of frictional resistance provided through soil-grout interaction is used to calculate the required nail length. The calculated nail length for the requirement is 8m.

$$T_p = \frac{\left[\gamma\pi D_{DH} \tan\delta\left\{h'L + \frac{L^2\sin(i)}{2}\right\}\right]}{FOS} \quad \text{-- (Eq. 01)}$$

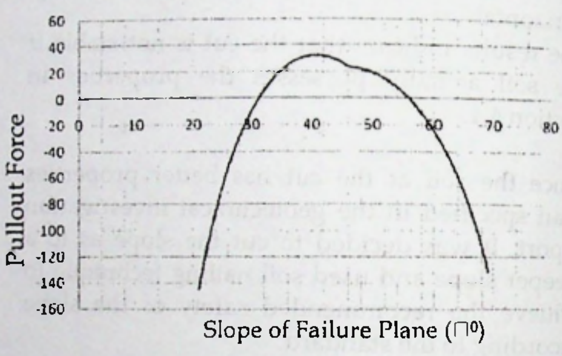
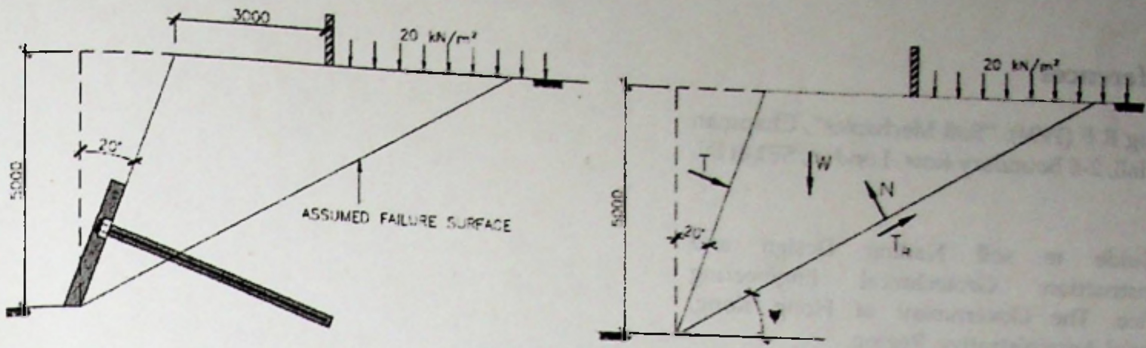


Figure 17: Variation of Pullout Force with Failure Plane

Note:
The negative pullout forces indicate that these slopes are stable with required FOS without soil nails



(a) Site Configuration

(b) Forces in soil wedge

Figure 16: Forces on Soil Wedge

Proposed soil nail system designed as above and provided along the southern and part of the western boundaries and which is denoted as 'Retaining Wall - Type 4' in Figure 01 is shown below.

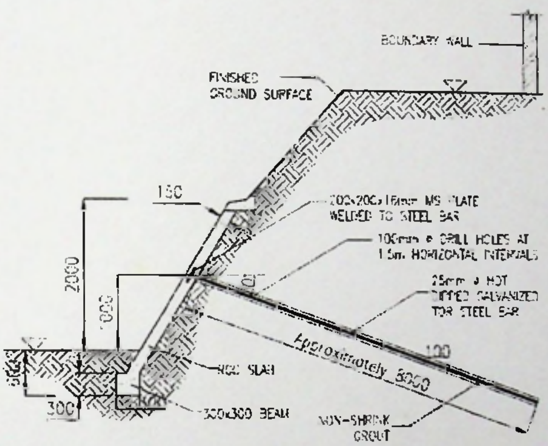


Figure 18: Proposed Soil Nail System for Mawaramandiya

6. Discussion and Conclusions

Conventional retaining systems can be used to retain earth with relatively low heights and less surcharge loads. As the retaining height increases suitable modifications may be needed to reach economical solutions. Further to this all relevant factors such as available land, location of wall, type of retained earth (cut or fill), etc. pertaining to the situation should be considered prior to reach a final decision.

Introducing anchor blocks to conventional rubble walls is advantageous due to the additional resistance provided by the self weight of the anchor block and soil with a large lever arm which would result in a high resistance for overturning and the resistance provided to sliding by the combination of end bearing and skin friction. The amount of material (rubble) can be drastically reduced by this method. The effectiveness of the system increases with the height (Refer Table 02). However, the allowable bearing capacity and skin friction of soil can be limiting factors for the solution. The method can be used only in retaining filled soil masses due to the wastage of space and unnecessary cost that may encounter in excavations.

The upper part of the shotcrete faces and nails at upper rows of conventional soil nailing systems can be effectively eliminated due to the less contribution that is made by those elements to stabilize slopes. Careful evaluation of the existing site and soil condition is compulsory prior to take any such decision. Distance between the proposed cut and the site boundary is a limiting factor for the length of soil nail.

From above explanations it is clear that providing a retaining wall at any particular requirement would be specific for that location. It is the structural engineer's duty to select the most appropriate solution for any given problem. Adoption of conventional methods can lead to reasonable solution for retaining systems. However innovative modifications can upgrade the implementations, enhance the performance and economize the structures.

7. References

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