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JHORA TRAINING AND SLIP REPAIR WORKS WITH GEOSYNTHETICS — A CASE STUDY

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ABSTRACT

Unstable hill slopes along a Jhora (storm water mountain stream) at 6th mile, Tadong, Sikkim was found unstable showing horizontal and vertical movement of the hill slope due to inadequate drainage facilities, seepage and percolation of rain water through the cracks and joints developed over the hill slope surface. For a sloping stretch length of about 150 m where the hill slope has manifested into a major sinking zone, control of damages to large number of buildings and the main road had become essential. This was provided through a landslide control and weir training programme using Geosynthetics.

INTRODUCTION

Sikkim is a valley situated in the eastern Himalayan mountain region, which is in the latest stage of mountain building. At 6th mile Tadong, located on NH-31/ A, that abutting hill slopes along a Jhora (mountain stream) which flows at right angles to the National Highway, is unstable, showing movement of the hill slope due to lack of drainage facilities provided to the road passing up-hill of the unstable site. Liquefaction and sliding of the soil/rock mass has occurred due to seepage and percolation of rain water through the cracks and joints developed over the hill slope.

The geological terrain in the downslope adjoining the Jhora is sloping downhill with angle of Dip at 15°-35°. The sheet rock is mostly present on right side of the Jhora going downhill, while the left side of the Jhora is a conglomeration of loose deposits, debris and partially stable land mass.

In multiple locations downslope for a stretch of 250m leading to river Rani Khola, localised shear failure planes are identified to have developed, causing intermittent horizontal and vertical movement of the slopes towards the Jhora. Also top soil erosion has occurred over the slopes due to heavy rain water splash in this region. The detail of the site is shown in Fig - 1.

Such weir channel had been constructed in the past conventionally with stone soling at the bottom, with plum concrete lining of 1:2:4 on top. The sausage walls on both sides of the channel are masonry wire crate construction. Under consistent impact of rolling boulders on to the channel, the plum concrete lining is damaged considerably. Through the cracks water seeps through the adjacent areas inducing landslides in the adjacent hill slope. Also due to the accumulation of debris the existing channel has clogged, making the structure flooded, overflowing and ineffective. Typical conventional structure is shown in Fig - 2.

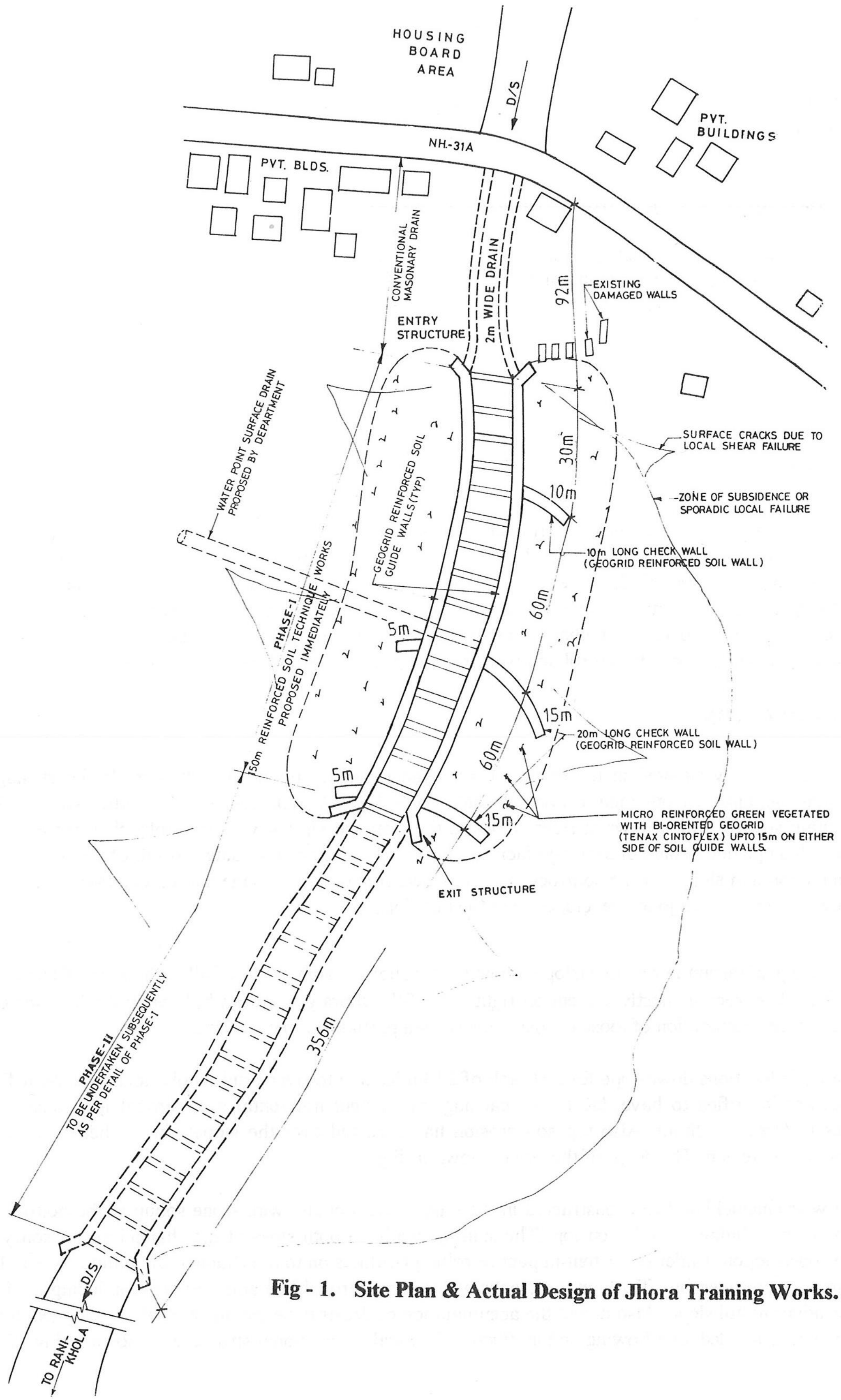
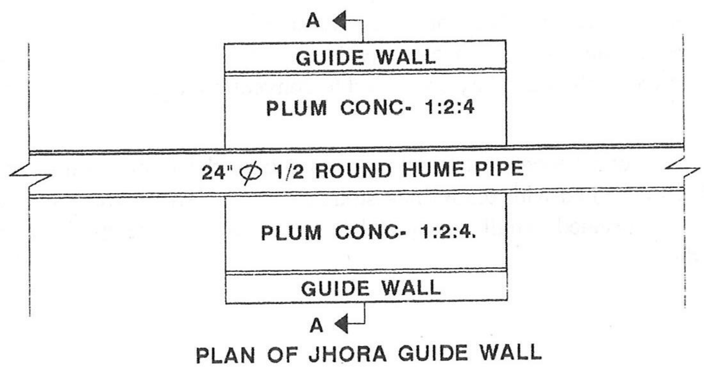


Fig - 1. Site Plan & Actual Design of Jhora Training Works.

Considering the localised shear failure planes and continuing creep behaviour of this hill slope, it was not technically desirable to construct any conventional rigid structure to restrict its movement which would affect the long term performance and destabilise the affected area. Keeping in view the geotechnical and hydraulic reasons as mentioned above and existing site condition, the proposed design for Jhora training works and hill slope stabilisation envisaged construction of flexible structures using Geosynthetic reinforced soil technique to provide Check walls and lined weir through the Jhora flow path.

Geosynthetic reinforced soil structures are most ideally suited compared to conventional rigid structures, as they can withstand the differential soil movements without causing any serious damage to its structural performance.

Recommended design comprises Geogrid reinforced soil guide walls of varying heights all along on both sides of weir channel, 1 m thick stone filled Geocell mattress of Mono-oriented Geogrids as steps of the guided Weir channel (Jhora flow path), Geogrid reinforced soil Check walls of height of 4 m on both sides of the guided Weir channel perpendicular to the Jhora at regular intervals and stabilisation of the sloping surface soil of the hill between check walls and the guided weir channel with Bi-oriented micro-reinforced vegetation, as shown in fig.1.



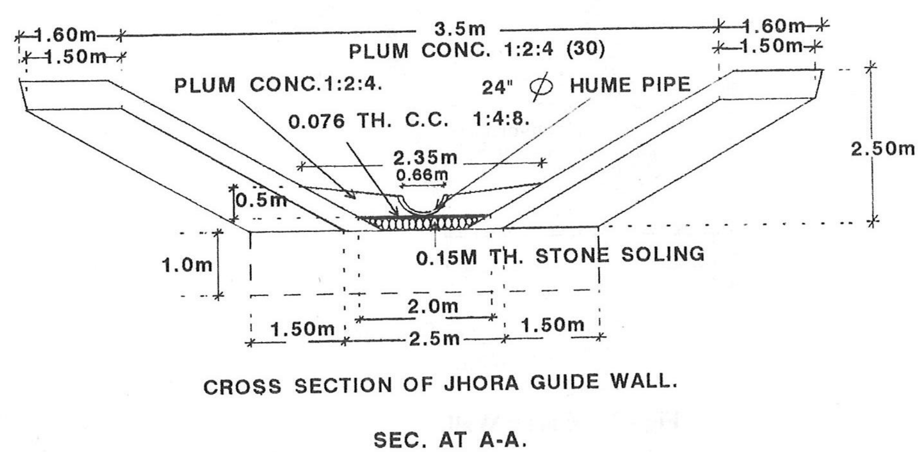


Fig - 2. Conventinoal Design of Jhora Project.

GUIDED WEIR DESIGN

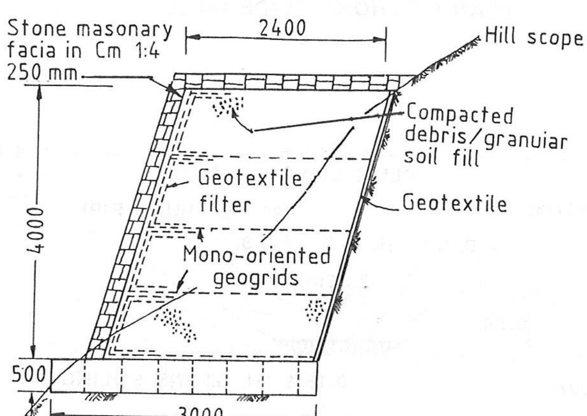
The first phase of Jhora training works was proposed for a stretch length of 150 M along the slope, starting from a distance of 92m down stream of the Jhora at its intersection with NH-31/A. 150 m of this stretch was designed using Geosynthetic reinforced soil technique and the remaining portion including the exit structure was to be constructed by conventional technique as per departmental practice.

Geogrid Reinforced Walls

Geogrid reinforced soil walls (guide walls as well as the check walls) is designed by using suitable free draining granular soil/debris fill ($\phi > 28°$). The face of these walls slope at 75° from horizontal. The granular soil/debris fill is compacted in layers 30 cm thick, incorporating horizontal layers of mono-oriented Geogrid reinforcement at suitable intervals as per standard detail requirements of Geogrid wrap around technique, detailed in Fig - 3 & Fig - 4. As it is a hilly terrain at the proposed site, soil compaction is carried out using hand-held plate vibrators, to achieve 95% Proctor density.

Within the Geogrid cverlaps, a non-woven Geotextile filter has been provided to prevent the migration of soil fines due to pore water dissipation. Similarly at the back of the Guide wall as well as the Check walls, a drainage bay of a suitable non-woven Geotextile has been designed replacing the conventional drainage bay needed to dissipate the sub surface water pressure, not allowing it to enter into reinforced soil portion, which will otherwise increase the pore pressure coefficient as well as induce migration of fines endangering the stability of the wall. The non-woven Geotextile filter/drain is easier and cheaper to lay at site and are more effective as drainage bay compared to conventional graded granular drains.

Keeping in view the structural requirement and fragile site condition, the foundation of the Check wall, 4m high, (Fig - 3.), has been designed with 0.5m thick stone-filled Geocell mattress in Chevron pattern. The Geocell mattress so provided shall adequately cater to the probable differential soil settlements/movements at the site.



Cross-Section of Geogrid Reinforced Soil Check Walls
Scale 1:50

Fig - 3. Check Wall.

The outer face of the Geogrid reinforced soil guide walls are lined with 35 cm thick stone masonary in cement mortar. This stone masonary is needed to protect the Geogrid from likely chances of eco-vandalism. The stone masonry facia underlined by Geomembrane liner in Guide walls is needed to allow free and uninterrupted flow of water through the guided Weir channel without entering into the Geogrid reinforced soil wall portion.

Check Walls

The Geogrid reinforced check walls of height of 4m and lengths varying from 10m to 20m at intervals indicated in Fig No -1. have been designed to stabilise the hillslope against localised plane slipping failure. The hill slope surface between the Guide walls and the Check walls needs to be protected against soil erosion due to surface water flow. Reinforced green vegetation with a suitable bi oriented micro-reinforcement protects the slope from soil erosion. The micro-reinforcement provided with 15 cm thick top soil cover allows the roots of the vegetation to establish permanently over the hill slope catering to mitigate the soil erosion due to surface water flow as well as splash of rain water.

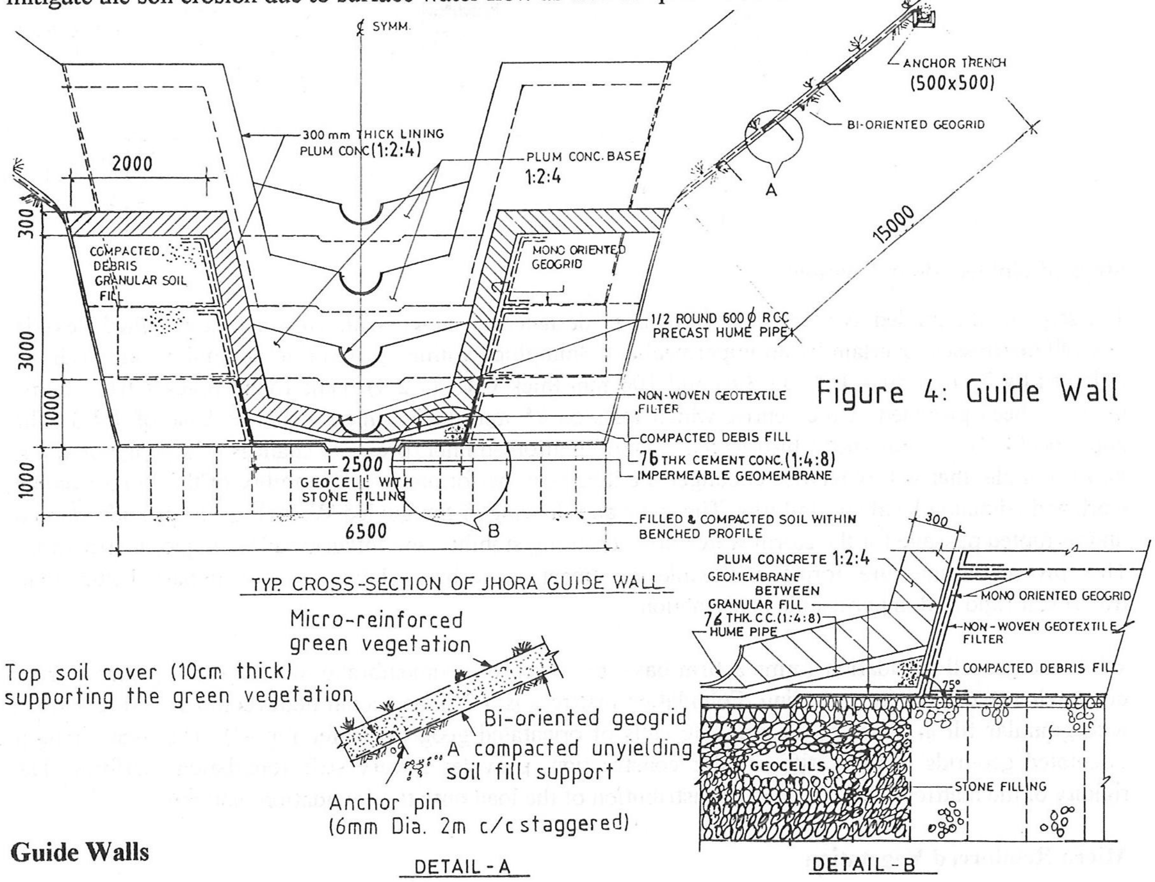


Figure 4: Guide Wall

Guide Walls

Geogrid reinforced guide walls of height 3m have been provided all along on both sides of the weir channel as shown in Fig - 4. Reinforced soil walls Catch pits have been provided at intervals of 27 m horizontal travel (17 m vertical drop) to collect rolling stones and reduce flow velocity of water by using water bath as cushion (Fig - 5.). The catch pits allow silt accumulation so as to ensure that there is no restriction in the flow path and a self cleansing mechanism is ensured.

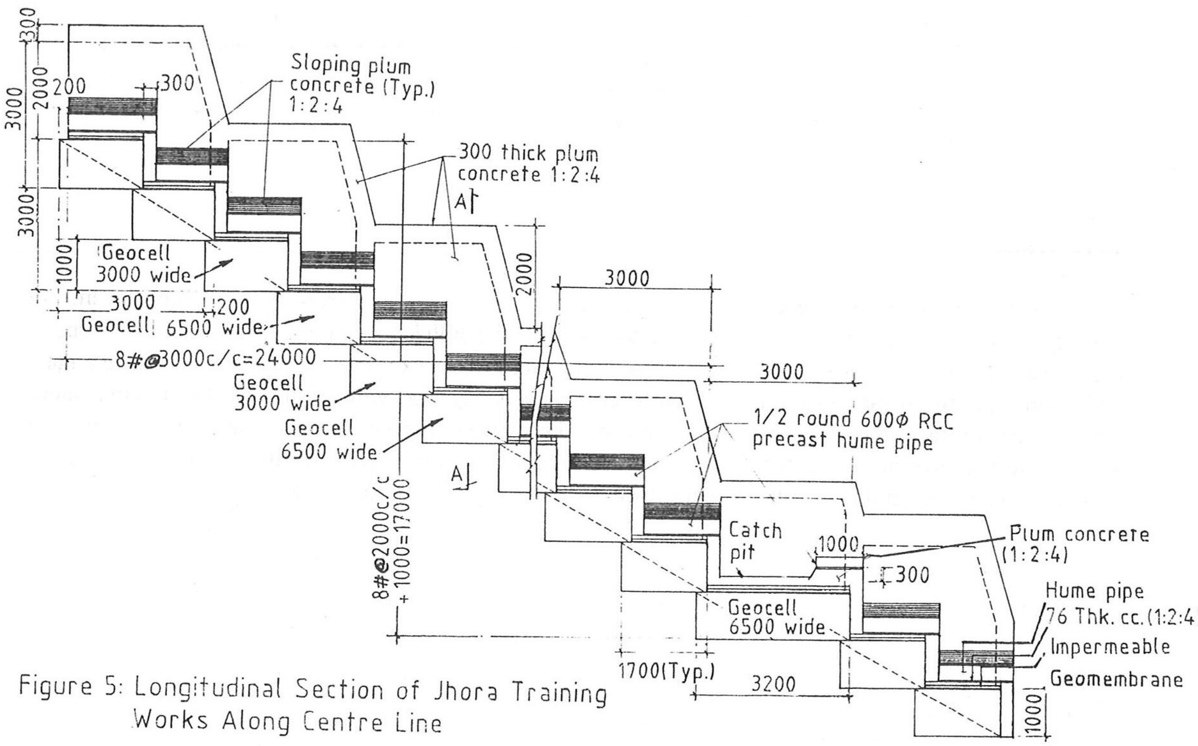


Figure 5: Longitudinal Section of Jhora Training Works Along Centre Line

Steps of Guided Weir Channel

The steps of the guided Weir channel have been designed all along with 1m thick stone filled flexible Geocell mattresses, overlain by an impermeable 0.8mm thick within 75 mm thick granular sand cushion, followed by 75 mm thick C.C. (1:3:6) and 100 mm thick C.C. (1:2:4). Half round precast RCC hume pipe has been provided at the centre, which rests on 75 mm thick cement concrete base of 1:4:8. The impermeable Geomembrane, a bi-oriented Geogrid reinforced liner, prevents chances of seepage of water into subgrade, that will otherwise endanger the long term performance and stability of the Jhora training work and adjoining local slip failures. The steps and flooring of the guided Weir (Fig - 5) provide smooth uninterrupted passage for the storm water flow, ensuring stability and integrity of the adjacent structures. This protection measure forms a flexible revetment, absorbing flowing water impact better than traditional rigid and impermeable construction.

While the geocell foundation forms a firm base, provision of geomembrane minimises the water ingress due to chance damage of screeding. Foundation mattress is a 3-dimensional honeycomb structure formed with granular fill in series of interlocking cells of orientated geogrids (refer Fig -3). The high strength orientated geogrids form a stiff cellular construction, provides a very stiff foundation platform. The rigidity of the mattress ensures an even distribution of the load onto the foundation material.

Micro Reinforced Vegetation

The sloping surface soil of the hill between check walls and the guided Weir channel have been stabilised with Bi-oriented micro-reinforced vegetation to provide a stable soil surface for vegetation growth upto an average width of 10 M. The micro reinforced vegetation is provided for a width of 10m.

REINFORCED SOIL WALL DESIGN METHODOLOGY

The Geogrid reinforced soil walls are designed using Limit Equilibrium analysis. Internal, external stability checks, Local stability and global stability analysis needs to be considered. The internal stability analysis considers failure surface to be passing within the reinforced soil block, while external stability analysis considers the reinforced soil block as a rigid body and looks at the failure mechanism passing partially or totally outside the block..

Internal stability Analysis

Internal Stability analysis are adopted using "tie back-wedge" method as recommended by BS 8006 (1994) "Strengthening/Reinforced soils and other fills". Internal stability are essentially associated with Tension and Wedge/pull-out failure mechanism. The tie back wedge analysis for the internal stability of reinforced soil considers the stability of each reinforcement layer, the resistance to horizontal sliding of the upper element of the wall and the stability of the wedges within the fill.

Tensile Failure

The grid element will carry tension as a result of surcharge load (Fig -6a), in our case being a sloping fill.
The tensile force(T) per meter width in the grid at depth h is given by:

$$T_i = K_{aw} Y_w h_i + W_s + K_{ab} + (Y_b h_i + 3W_s).\ (h_i/L)^2\ ]\ V_i$$

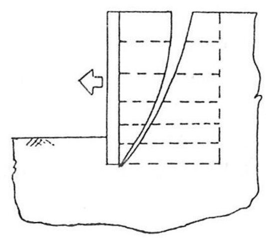


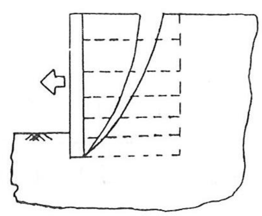
Figure 6a: Tension Failure

Wedge/Pull-out failure

In addition to internal mechanism of tension, it is required to investigate if the inclined failure planes passing through the wall forming unsuitable wedges of soil bounded by the front face of the wall, the top ground and the failure plane(Fig - 6 b&c). The analysis of Mobilizing force gives us:

T = Total force in Grids

$$= \frac{h.\tan\beta.\ (\gamma_w h + 2W_s)}{2\tan.\ (\varnothing + \beta)}$$



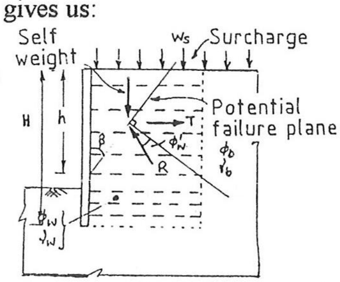


Figure 6b: Pull-out Failure Figure 6c: Wedge Failure

The anchorage force T available in a grid at a depth h with anchorage length L is determine using a sloping backfill is determined from following equation :

$$T_{ai} = \frac{L_{ip}.\ 2\tan\varnothing\ .h_{av}}{\text{Factor of safety}}$$

External stability analysis

The reinforced soil-geogrid volume is assumed to act as a rigid block (Fig - 6d). This block is subject to conventional retaining wall failure mechanisms such as: Sliding, Overturning and Bearing Capacity failure. This design step identifies the dimensions of the area to be reinforced.

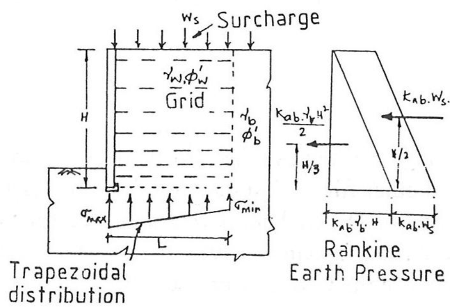


Figure 6d: External Stability

External Stability

The possible external failure mechanism are shown in the Fig - 6e. We would consider the external stability of the surcharge vertical wall assuming a Rankine distribution of lateral earth pressure and a trapezoidal distribution of ground earth pressure.The active earth pressure coefficient K is then used to relate the horizontal to vertical stresses. This is considered appropriate as the deformation required for the K to fall from "at rest" value to Ka, is very small and less than deformation allowed in this design.

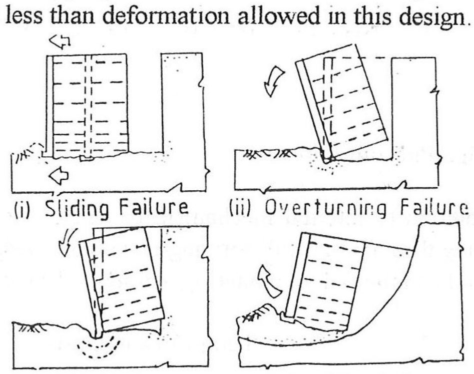


Figure 6e: External Failure Mechanism

a) **Sliding**

$$\text{Factor of Safety} = \frac{2\,\mu\,.\,(\gamma_w H + W_s)}{K_{ab}\,.\,(\gamma_b H + 2W_s).\,(H/L)}$$

b) **Overturning**

$$\text{Factor of Safety} = \frac{3\,.\,(\gamma_w H + W_s)}{K_{ab}\,.\,(\gamma_b H + 3W_s).\,(H/L)^2}$$

c) **Tilting/Bearing**

Maximum and minimum ground pressure are given by :

$$G_{max} = (\gamma_w H + W_s) + K_{ab} \cdot (\gamma_b H + 3W_s) \cdot (H/L)^2$$

$$G_{min} = (\gamma_w H + W_s) - K_{ab} \cdot (\gamma_b H + 3W_s) \cdot (H/L)^2$$

d) Slip failure

All potential slip surfaces are investigated where slip plane exists, suitable F.O.S. of 1.3 is adopted.

Local stability analysis

This analysis is carried out for segmental retaining walls to ensure that the column of concrete block units remain intact without bulging, facing connections are safe and the maximum unreinforced height is safe.

Global stability analysis

This analysis is performed on the overall structure including the retained backfill and the foundation soil. This analysis should be performed according to the classical slope stability procedures, such as Bishop's modified method of slices. The minimum recommended safety factor for this analysis ranges between 1.3 and 1.4.

SPECIFICATION

Specifications of the geosynthetics used are shown in table

TECHNICAL DATA	MONO ORIENTED GEOGRID kN/m			BI ORIENTED GEOGRID kN/m
	TT060	TT090	TT120	C FLEX
LONG TERM DESIGN STRENGTH	25.0	37.0	50.0	2.5

COST ESTIMATE

Items	**Cost of Geosynthetics** Rs/meter length	**Cost of other Materials** Rs/meter length	**Total cost** Rs/meter
Check Wall	13060.00	9708.00	22768.00
Guide Wall	4763.00	5611.00	10374.00
Drain Flooring	4121.00	2747.20	6868.00
Green Vegetation over the hill slope.	1250.00	150.00	1400.00

Total Cost of the project is Rs. 57,53,564.00

CONCLUSION

The provision of Reinforced soil guide walls all along the Jhora and check walls at regular intervals on the hill slope ensures that localised shear failure planes are minimised and the continuous creeping behavior of the hill slope is kept in check. The pore water pressure is prevented from damaging the structure by providing a geotextile filter layer at the end of the reinforced slope. The geocell mattress foundation of the guided weir, with an impermeable membrane at the top, provides a well mechanised path for the flow of water in the Jhora. The micro reinforced vegetation on the hill slope reduces the percolation of water to the lower layers, together with strengthening the slope with vegetation and preventing further denudation of the slope.

The flexible structure envisaged for the stabilisation and rehabilitation work in the area with Geosynthetic reinforced soilo concept is the ideal solution as they have the capacity to withstand differential soil movements without causing any serious damage to the performance of the structure.

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