Geocell Fascia Reinforced Soil Wall – A Green Solution

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ABSTRACT: Over the past three decades, reinforced soil wall technology has fostered the growth of infrastructure in India. This is largely due to the system being environment friendly, speed of implementation, flexibility, cost-effectiveness and aesthetic and architectural features. Several types of fascia elements have been adopted in the construction of the reinforced soil structure such as modular precast concrete blocks, precast reinforced concrete panels, wrap-around fascia with geosynthetics etc. The choice of facing is often dependent on aesthetics and cost; However out of environmental concerns, a fascia fostering greenery is appreciated. Such "green" approach can be realised by deploying three dimensional honeycomb structured geocells as fascia.
This paper highlights an approach of design and efficacy of reinforced soil walls using geocells as the facing element. A case study illustrates geocell fascia being used in mountainous terrain where rainfall intensity is high and the region is highly seismic, in the sub-Himalayan regions of the Indian State of Sikkim. A geocell fascia solution can be effective for time bound projects, providing sustainable solutions in difficult terrain.

Keywords: Reinforced soil, geosynthetics, geocells, geogrids, green fascia

1 INTRODUCTION

Reinforced soil structures have gained preference for grade separators as against conventional concrete structures in India. Geosynthetic reinforced systems have replaced reinforced concrete retaining walls by virtue of their simplicity of construction, speed of erection, significant cost economics and essentially use of less natural resources. Reinforced soil retaining structures, being flexible in nature, are extensively used not only for roads in plain terrain but also along hill roads. While concrete fascia are commonly used either as precast modular blocks or precast panels, the authors also hold brief for fascia comprising of High Density Polyethylene (HDPE) geocells. These geocells are essentially engineered three dimensional systems comprising of textured and perforated HDPE straps, ultrasonically welded at precise intervals to create the honeycombed profile.
Studies carried out by several researchers and practitioners have highlighted various aspects and relative advantages of facing elements. Bathurst (1992) presented a numerous concept design approaches for reinforced soil wall and gravity wall using geocells which widened the

practical use of such flexible structures. Studies conducted by Mehdipour et.al. (2013) carried out numerical analysis on geocell reinforced soil structure using Fast Lagrangian Analysis of Continua (FLAC) 2D programme cited benefits of geocells in reinforced soil structures. Ling et.al. (2009) and Latha (2016) conducted and simulated laboratory shaking table test to analyse the performance of geocell retaining wall and concluded its benefits. However, very few field case studies were presented for such type of applications.
The authors of this paper have introduced a simple design approach with connection between geogrid reinforcement and geocell fascia based on friction and hinge height along with construction methodology. A reference is made to a case study in hilly terrain susceptible to high seismic events.

2 TYPES OF FASCIA ELEMENTS

Facing elements may be "hard" or "soft" and are provided to retain fill material, prevent local slumping and erosion of steeply sloping faces, and to lend to environmental aesthetics.

2.1 *Hard Concrete fascia elements*

Hard facing may consist of concrete, steel sheet, steel grids or meshes, timber or combination of any of these. In general in India, the following two types are widely used:

i. Reinforced concrete panels;
ii. Modular precast concrete blocks.

These typical facings types are shown Fig. 1 and Fig. 2.

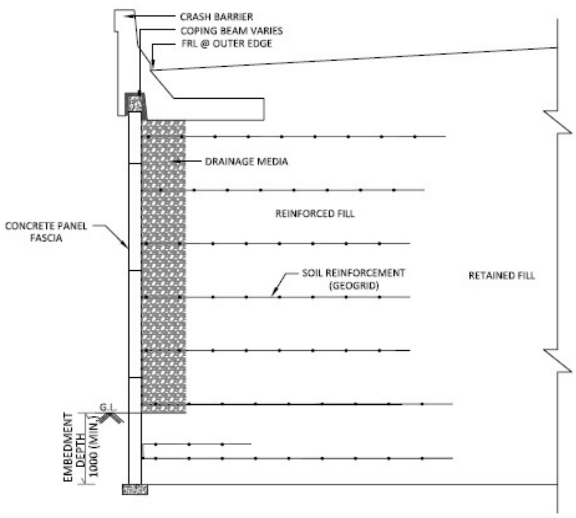

Figure 1 Reinforced soil wall with panel fascia

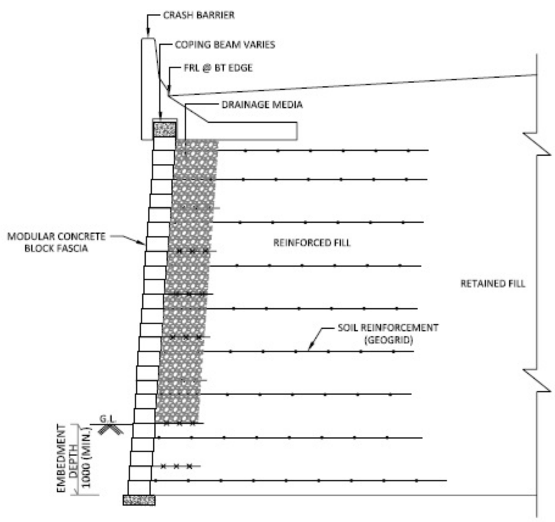

Figure 2 Reinforced soil wall with modular block fascia

2.2 *Soft fascia elements*

Soft fascia generally requires external temporary form work to support facing elements. However construction can be expedited using these facing elements with minimal labour as compared with concrete facing elements. Furthermore, soft facing requires less storage space with minimal handling. Broadly two major categories of soft fascia element includes following facing types:

i. Wrap around facing elements
ii. Geocell fascia elements

In case of wrap around facing elements, the geogrids are wrapped around at the face and returned into soil directly below the next layer. This process could impede the work. However, geocells having a three dimensional rhomboidal structure, it confines the soil within the geocell pockets and is flexible and robust. Thus, the speed of construction is relatively faster as compared with reinforced soil wall with wrap around fascia. Typical cross-section of these facing elements is shown in Fig. 3 and Fig. 4.

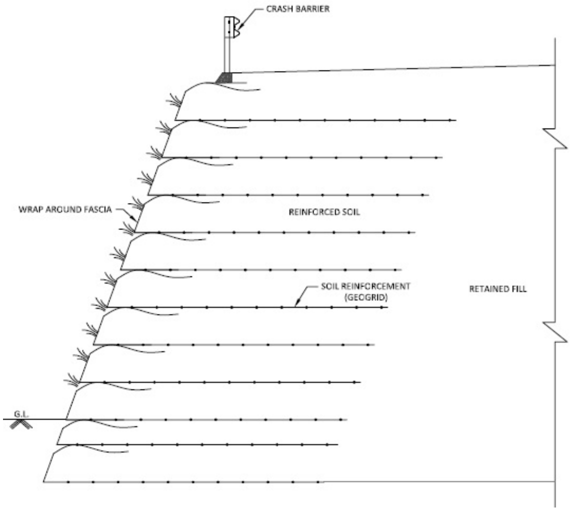

Figure 3 Reinforced soil wall with wrap around fascia

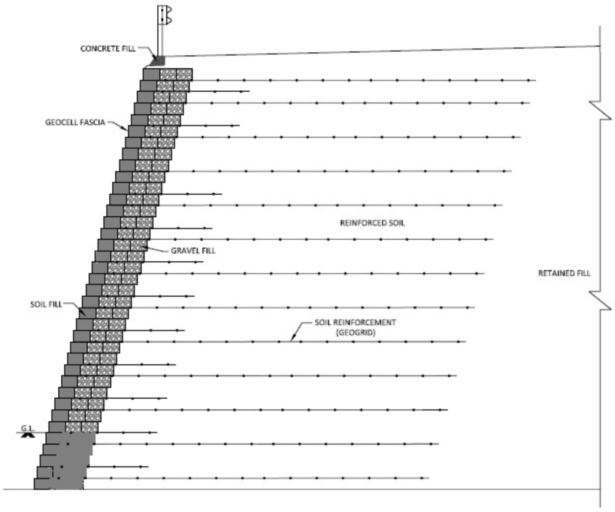

Figure 4 Reinforced soil wall with geocell fascia

3 ADVANTAGES OF GEOCELL FASCIA

The Sikkim case study addressed here uses StrataWeb® geocells of Strata Geosystems (India) Pvt. Ltd. These are fabricated from ultrasonically-welded HDPE strips that are expandable at site to form a honeycombed panel. In order to mobilise connection strength, the geocells are essentially filled with non-plastic soil. Confinement of such material lends rigidity to the fascia. Geocell fascia is particularly beneficial in hilly terrain where there is little space adequate enough to cast concrete blocks or panels. It may be noted that the essential advantage of concrete blocks and panels lies in economies of scale. In hilly terrain, the required fascia area may not be large enough to warrant setting up of casting yards for economic scales. Besides, level land for such yards may not be available. Geocells are transported and stored in collapsed form and are expanded into panels at site. Hence logistics to site would not be a major problem. Being light and flexible and filled in place, geocells can be manually handled. On the contrary, concrete blocks may weigh as much as 40kg and panels as much as 1000kg. each. Also, flexibility of geocells permits smoother and sharper curves and corners.

4 WIDENING OF APPROACH ROAD FOR ARMY OFFICERS’ MESS IN SIKKIM

4.1 *Project background and analysis*

This case study addresses widening of an approach road at an Army Officers’ Mess located in hilly terrain in Sikkim State of India. Satellite imagery of the case study is shown in Fig. 5. The road was at a level of 2m to 6m above the Mess. This required widening by 3m for commute and parking lot. Length of the road is about 100m. The region is within Seismic Zone IV and is also subject to heavy rainfall, annually 2,000mm to 5,000mm. With such conditions, a reinforced soil structure with geocell fascia was considered appropriate, and proposed.

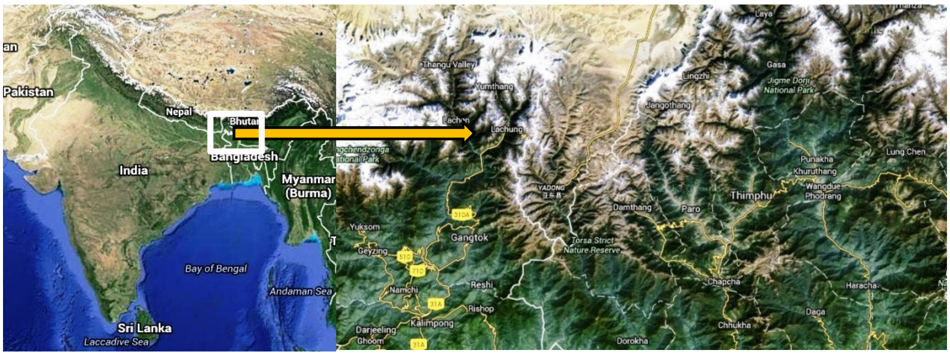

Figure 5(a) Satellite imagery of the project site

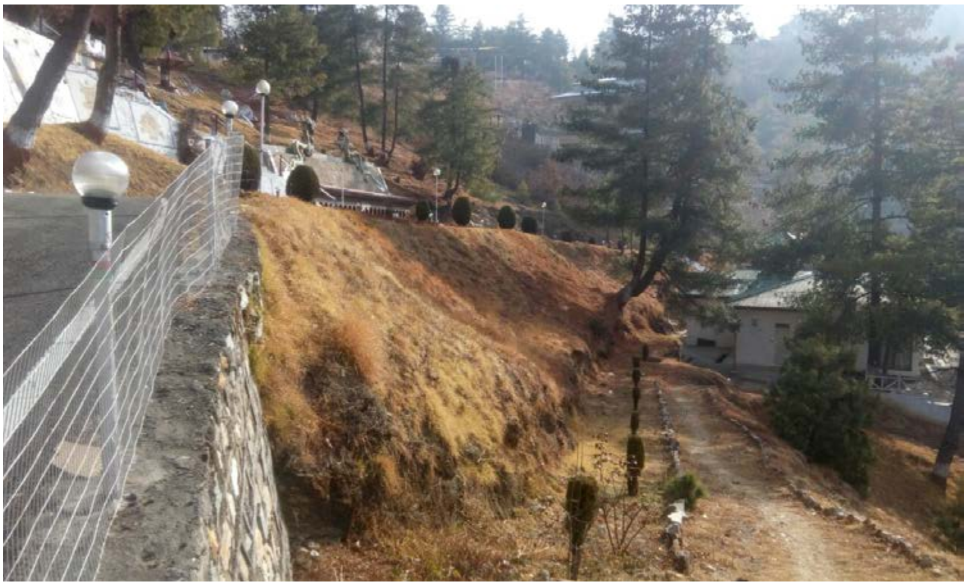
Figure 5(b) Proposed RS wall location

For analysis of the reinforced soil structure, MSEW (Mechanically Stabilized Earth Wall) software recommended by FHWA (Federal Highway Administration) was used. Input parameters considered for analyses and are listed in Table 1.

Table 1. Input parameters

Material Properties	**Value**
Reinforced Soil	γ_1 – 18.5 kN/m^3, φ - 30° , c – 0 kPa
Retained Fill	γ_2 – 18.5 kN/m^3, φ - 28° , c – 0 kPa
Foundation Soil	γ_3 – 18 kN/m^3, φ - 30° , c – 0 kPa
Seismic Zone & Factor (IS 1893 (Part 1) : 2002)	Zone IV (0.24)
Geogrid (StrataGrid™ Systems)	SGi 40 (Short Term Ultimate tensile strength – 40 kN/m) SGi 60 (Short Term Ultimate tensile strength – 60 kN/m) SGi 80 (Short Term Ultimate tensile strength – 80 kN/m) SGi 100 (Short Term Ultimate tensile strength – 100 kN/m)
Geocell (StrataWeb® Systems)	SW445-200 (Weld spacing – 445mm, depth – 200mm)

where, γ is the unit weight of soil, φ is internal friction angle of soil, c is cohesion of the soil

Geocell style SW445-200 is textured and perforated. The perforations ensure that pore water pressures are relieved and the reinforced soil structure need not be designed for hydrostatic pressures within the structure. The depth of 200mm was selected to ensure adequate compaction within the geocell. The depth of 200mm also ensures that each soil; layer of the reinforced backfill does not exceed 200mm and serves as a quality control tool.

4.1.1 *Static Analysis*

As per FHWA-NHI-10-024 (2009) guidelines, analysis was carried out using MSEW Software and exported into ReSSA (Reinforced Slope Stability Analysis) for evaluation of global stability. For evaluation of local stability of geocell fascia, connection strength between geocell and geogrid was evaluated using frictional resistance of geocell infill soil and geogrid with hinge height corresponding to a batter of 20° with the vertical. Connection Strength versus Normal Load relationship is shown in Fig. 6.

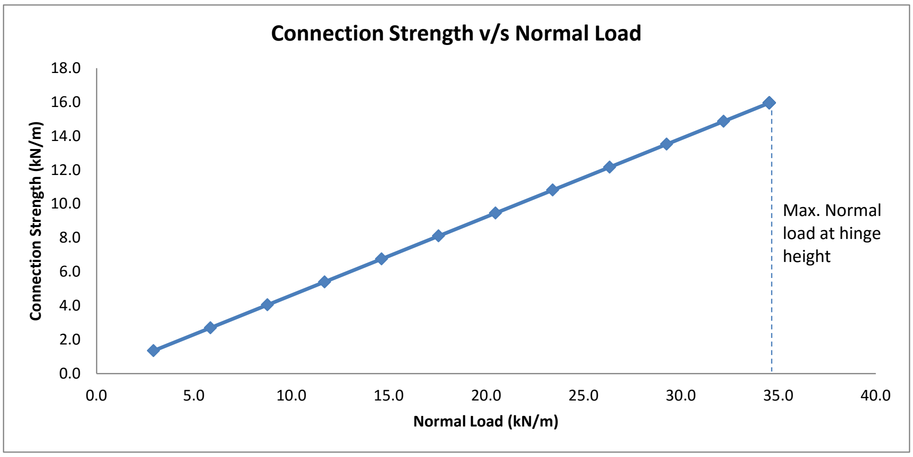

Figure 6 Connection Strength v/s Normal Load

Safety of reinforced soil structure was evaluated against sliding, overturning, geogrid pullout failure, geogrid tensile failure considering the determined long term tensile strength (LTDS) and bearing capacity by using MSEW. The system was proven to be safe for both internal and external stability.
Further global stability analysis through ReSSA carried out after MSEW indicated a safety factor against global failure of 1.75 as against the required value of 1.3 as shown in Fig. 7.

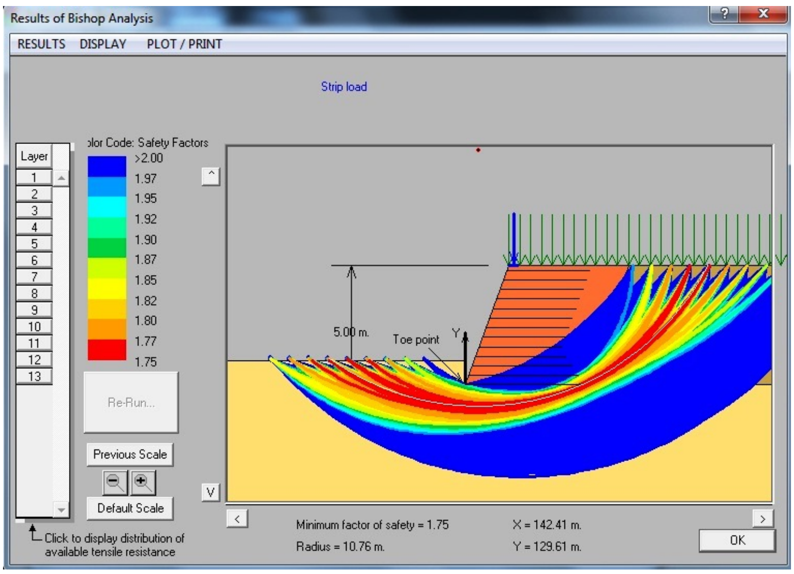

Figure 7 Global stability analyses

4.1.2 *Seismic Analysis*

During an earthquake event, the retained fill would exert additional dynamic horizontal thrust P_{AE} along with the static thrust. Additionally as per FHWA-NHI-10-024 guidelines, reinforced soil is also subjected to horizontal inertia force $P_{IR} = M*A_m$, where M is the mass of active portion of reinforced soil considered at a base width of 0.5H and A_m is the maximum horizontal ground acceleration in the structure (Equation 1). This total horizontal seismic thrust is calculated as follows,

Maximum horizontal acceleration is given as,

$$A_m = (1.45 - A_h) \times A_h \tag{1}$$

Where A_h is maximum ground acceleration coefficient (Calculated as per IS 1893 Part 1 : 2002) is shown by equation 2.

$$A_h = \frac{Z \times I \times S_a}{2 \times R \times g} \tag{2}$$

Where, IS 1893 (Part - 1) : 2002 suggests,
Z = Zone factor (0.24 for Zone IV),
I = Importance factor (1.5),
R = Response reduction factor (3),
S_a/g = Average response acceleration coefficient (2.5),

$A_h = 0.15,$

$A_m = 0.195$

$$k_{ae} = \frac{cos^2(\phi'_b - \xi - 90 + \theta)}{cos\xi\, cos^2(90-\theta) cos(\delta + 90 - \theta + \xi)\left[1 + \sqrt{\frac{sin(\phi'_b + \delta) sin(\phi'_b - \xi - I)}{cos(\delta + 90 - \theta + \xi) cos(I - 90 + \theta)}}\right]^2} \tag{3}$$

where,

$\xi = tan^{-1}\left(\frac{A_m}{1 - A_m}\right)$

δ = angle of wall friction
I = Backfill slope angle
ϕ_b' = angle of internal friction for retained backfill
θ = slope angle of the face
$K_{ae} = 0.3892$

$\Delta k_{ae} = (k_{ae} - k_a)$
= (0.3892 - 0.2399)
= 0.1493

P_{AE} = Horizontal Seismic Thrust = $0.5 \times \Delta K_{ae} \times \gamma_2 \times H^2$
P_{IR} = Horizontal Inertial thrust = $0.5 \times A_m \times \gamma_1 \times H^2$

Total seismic horizontal thrust = $P_{IR}+P_{AE}$

The reinforced soil structure was analysed for seismic stability considering the total seismic horizontal force which adds to the static horizontal forces increasing the risk of sliding failure. Here, the concept of “Capacity to Demand Ratio” (CDR) is used, wherein CDR must exceed 1. This ratio defines the capacity of the structure as against the factored load onto / within the structure. In this case, the seismic analysis output showed that the structure is safe against sliding failure with a CDR-sliding = 1.40 (in excess of 1) for external stability and likewise found safe against sliding in internal stability at all geogrid reinforcement levels. Fig. 8 illustrates the designed cross section of the reinforced soil structure with geocell fascia for a height of 5m.

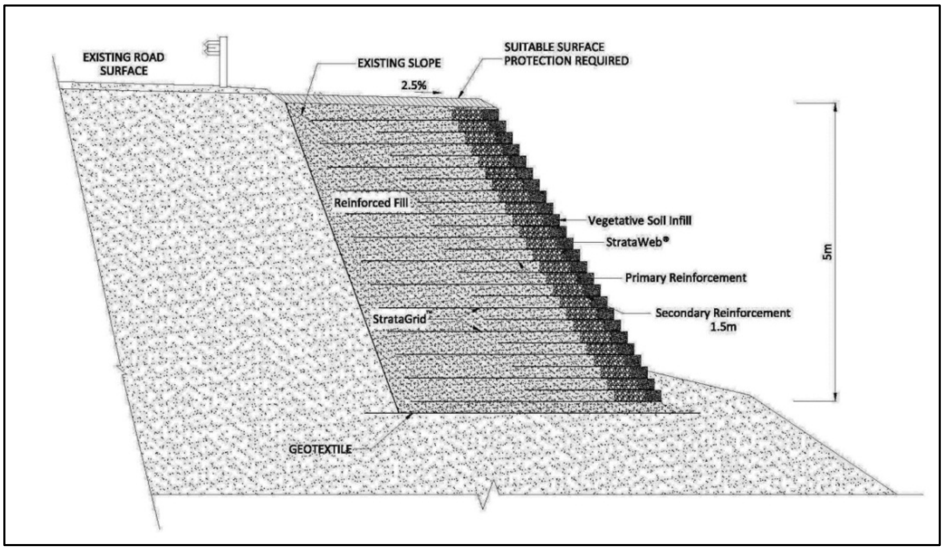

Figure 8 Cross section of 5m high reinforced soil structure with geocell fascia

4.2 *Construction Sequence*

4.2.1 *Site Preparation*

Stone, debris, rank material, dead wood etc. was removed from the site. The subgrade was compacted by a vibratory roller. Compaction was specified to better 95% modified Proctor density.

4.2.2 *Laying of geocell*

The levelled ground was marked to locate and align geocell fascia. The first layer of geogrid was laid as per design. The geocell panels were expanded and placed uniformly using the temporary alignment stakes. Fig. 9 shows typical placement of geogrid and geocell.
The geocell fascia was of three-cell width. The outermost strap of the geocell fascia was coloured green as per Client requirements.

Figure 9 Laying of geogrid and geocell

4.2.3 *Infilling and Compaction*

Backfill for reinforced fill was placed and compacted in layers of 200mm. Compaction control was achieved with soil layers restricted to 200mm (Fig. 10). Non-plastic soil was infilled within geocells and compacted with a hand held mechanised vibratory compactor. After achieving required compaction, excess infill material was scrapped out to facilitate placement of the next geogrid and subsequent geocell layer.

Figure 10 Infilling and compaction

4.2.4 *Aesthetic appearance*

For a pleasing aesthetic look, geocells for this project were manufactured with the outer strip of geocell given a green coloration (Fig. 11). An offset of 70mm to 75mm was maintained between successive layers of geocells for vegetation growth. This batter also ensured a general slope of 20° with the vertical. The sequence of laying geogrids, placing and aligning geocells, placing and compaction of soil was done till completion of the reinforced soil structure to its required height.


Figure 11 Green appearance of reinforced soil wall

5 CONCLUSIONS

The work was completed in September 2015 and has witnessed heavy rainfalls since. Sikkim has also experienced at least 10 seismic activities ever since with magnitudes as high as 4.3. This case study highlights that geocells can be effective as flexible fascia elements for reinforced soil structures in hilly terrain with challenging contours. Unlike hard fascia which is vulnerable to cracking during major seismic events, flexible geocell facia perform better.

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