Case Histories of Slope Protection by HDPE Geocells

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ABSTRACT: It has been widely reported that infiltration accounts for 90 % of slope failures (Malone & Ken Ho, 1997). Proper and effective slope protection can reduce infiltration significantly. In fact, bare or poorly protected slopes have 3 to 5 times higher rate of infiltration when compared with well protected slopes. Cut slopes with difficult and adverse conditions such as high cut slopes with acidic graphitic phyllite or schist or highly erodible sandy silt or rocky slope, etc., cannot be effectively protected by normal slope protection methods such as hydroseeding or turfing. Though guniting or sprayed concrete can be effectively used to protect such difficult cut slope conditions, the ungreen or unaesthetic or unenvironment-friendly appearance is generally and increasingly not acceptable by general public and government authorities including JKR Malaysia. Recently, geosynthetic product with generic name called HDPE (high density polyethylene) geocells have been proposed and accepted to be used to vegetate difficult steep acidic and rocky slopes successfully in respect to reduce infiltration to practically nil and to provide green pleasing slope finishes. Unlike normal polymers, HDPE is a durable polymer, inert to chemical attacks and its strength is practically unaffected by UV rays or acids. It is found that HDPE geocell confinement system can effectively retain and preserve the imported topsoil to sustain the vegetative grass growth in difficult slope conditions. This paper will present two case histories illustrating how geosynthetic HDPE geocells are successfully applied to protect difficult cut slope conditions with highly sought "green" aesthetic environment, in addition to improve slope stability through significant reduction of infiltration. Design criteria, construction details and evaluation with other common slope protection methods will also briefly be discussed.

1 INTRODUCTION

Infiltration has been generally and widely accepted as the main cause for slope instability in tropical countries with high annual rainfall exceeding 2m. Slopes without proper and effective slope protection will certainly result in more infiltration and rainfall induced surface erosion. Excessive infiltration during the prolonged rainfall on poorly protected slope will cause extensive saturation, which can trigger slope failure eventually. Excessive surface runoff on inadequately protected slope will also cause excessive slope surface erosion resulting in siltation of drains and subsequent concentrated surface runoff that may cause slope failure, especially slopes that have excessive relict geological discontinuities.

Generally, considerably less or very little attention has been given to the design details related to cut slope protection by slope designers, who are more interested to focus mainly on the slope stability assessment, slope stabilization design and slope drainage design only. More often than not, turfing or hydroseeding with or without biodegradable mat as a norm is simply specified for slope protection without any assessment related to the effectiveness and suitability to the specific site and slope conditions.

The purpose of slope protection is not only to protect the slope from rainfall-induced erosion and to reduce infiltration, but it should also aim to provide a natural matching environment resulting in a pleasant visual impact to the people around the slope. Such requirements are especially necessary and relevant when the slopes are near buildings or in built-up areas.

Common slope protection methods for cut residual slopes in Malaysia are closed turfing, hydroseeding with or without biodegradable mat. These slope protection methods are generally and usually the most economical methods and also cost-effective except in difficult conditions such as acidic soils, dry and granular/rocky slopes, etc. Guniting, gabion mattress, stone pitching, vetiver grass, HDPE geocell, etc., are for special and difficult conditions or special requirements. Factors that should be considered when selecting a suitable slope protection method for a specific site condition or specified requirements are soil types, slope geometry, slope drainage conditions, aesthetic requirement, unit cost, etc. Guides to the selection of a suitable slope protection method a site specific conditions are given in Figure 1.

Generally, vegetative or bioengineering method is the most common and most cost-effective method. However, when the slope is too steep, or too erodible or acidic or too hard or rocky, normal vegetative methods are not suitable and or not effective. In such cases, other methods such as HDPE geocells with suitable infill, guniting or stone pitching or gabion mattress, etc., are the possible solutions. However, if pleasing and natural green environment is also required in addition to the technical requirements, geosynthetic HDPE geocells with infilled topsoil and turf or hydroseeding will be the appropriate answer.

Two case histories where geosynthetic HDPE geocells are successfully used to protect cut slopes with difficult conditions and stringent requirements are discussed in following sections.

2 CASE HISTORY 1

Case history 1 is a building complex project. The site terrain generally is a rolling terrain. It consists of a hill which has a maximum height of about 42m and is cut with 6m vertical height intervals of 1V: 1.5H with 2m wide berm as shown in Figure 2. The excessive cutting to form the necessary building platform is required for the construction of buildings.

The site geology of the hill is very complex. The hill within the 42 m cut slope consists of predominantly grade IV weak to medium strong agglomerate and interbedded tuffaceous sandstone and slate. Slope with such complex geological formation is prone to have numerous relict joints, faults, minor daylighting wedges in slates and tuffaceous sandstones. These relict geological discontinuities in the residual soils usually have lower shear strength and are the preferred water path for the surface runoff. Slips are prone to occur around these discontinuities especially when the slope is subject to infiltration or when the slope is not effectively protected.

Geotechnically, the whole slope consists of completely weathered stiff to hard sandy SILT. The weathered foliated graphitic slate (Grade 5) has high contents of silt (52%) and fine sand (34%) and is non-plastic, highly erodible and acidic (pH values = 2.5 to 3). Some minor localized seepage is also noted. In fact, the slopes, after cut and exposed without protection for about one month, have encountered severe erosion, which has resulted in siltation of the slope drains and some minor shallow localized slips. As there are many buildings near the problematic high cut slope, the Client required to address the problem with the following design criteria and requirements as followed: (a). Factor of safety for the slope should be 1.4 for local and global stability and only cost-effective slope stabilization method should be adopted, (b). Suitable slope protection method shall be recommended to address erosion problem in graphitic acidic conditions and highly granular soil. Effective mitigations against infiltration into the extensive relict geological discontinuities and daylightings shall be included and (c). Green slope to match the surrounding environments is required and preferred.

Based on slope stability assessment carried out, slope stabilization by short soil nails or dowels of 3 meters long are adequate and cost-effective to prevent localized shallow slips due to abundant daylighting wedges (relict joints). However, to address the slope protection problem with green vegetative growth plus other requirements, the following potential methods are assessed in following sections

2.1 *Close Turfing*

Generally, close turfing with thick cohesive topsoil of 100mm is feasible according to Figure 1, except at some localized hard and very hard slope surface, where pegging the turf on the slope by bamboo or timber pegs may be difficult. The acidic residual soils of graphitic slate are likely to affect the growth of the roots unless sufficient topsoil is maintained. Instability problem may be encountered if effective slope protection is doubtful. Close turfing may not effectively mitigate against infiltration into excessive relict geological discontinuities especially when some turf may not grow well in acidic conditions. Close turfing is also labour intensive and very slow. Hence, close turfing option is not considered and not preferred.

2.2 *Hydroseeding With Biodegradable Erosion Control Mat*

According to Figure 1, this method is not suitable for acidic soil. In fact, this method has been found unsuccessful for the similar acidic soils in other locations. Hence, it is not considered.

2.3 *Guniting*

Guniting is commonly used to protect the slopes that have difficulties to enable vegetative grass or shrubs to grow well, i.e. slopes that are too steep, too rocky or containing acidic soils, etc. Guniting is proven very effective to prevent infiltration. Reference can be made to Fig 1 for guidance. Guniting with weep holes and dowels is certainly very effective to check erosion and infiltration. Of course, horizontal drains are also necessary at the interfaces of slate and sandstone or relict joints where seepage is noted. However, due to the requirements of "green" slope by the Client, this method of slope protection, though technically superior, is not acceptable unless a layer of HDPE geocells is laid over the gunited slope with necessary topsoil infill and hydroseeding. Gunite with green pigment cement is not acceptable as there are many proven cases that the green pigment is not lasting and easily overgrown with black fungus, etc.

2.4 *HDPE Geocells*

Based on Figure 1, HDPE geocell slope protection is the only method that can satisfy all the requirements, including acidic soil and "green" requirement by the Client after the slope is stabilized adequately by the dowels, which can be effectively secured in the geocells to provide the necessary facing resistance. The geocell confinement system can effectively retain and maintain the imported topsoil to provide favorable conditions to enable the grass to flourish. The inclusion of underlying polypropylene membrane and geomaterials at seepage spots will practically reduce infiltration to nil. This option not only can comply with all the design criteria, but also comparatively cheaper than that of the guniting generally. Hence, this option is accepted by the Client for implementation. Design details and quality control requirements are given in Figure 2.

3 CASE HISTORY 2

The site of the second case history is located in a school in Gopeng, Perak. A stretch of cut slope of about 200m long and about 20m high in 3 to 4 berms formed at an average inclination of 330 has suffered a severe landslide and slope instability problems. The landslide slope consists of mainly residual soils of shale and sandstone with some localized black graphitic phyllite soil, which is very acidic (pH = 3 to 4). The subsoil within the cut depths generally consists of stiff to hard sandy clayey silt with traces of gravels. Water table based on the 2 month monitoring by 4 stand pipes along the slope varied from 3.3m to 8.8m below the ground level at the crest of the slope. Based on the investigation carried out, the main causes for the landslide are address below:

- Presence of extensive localized relict geological discontinuities/joints and daylightings within the slope body
- Presence of localized perched water table
- Inadequate and ineffective slope protection by normal grass vegetation has resulted in excessive siltation of the drains and infiltration into the excessive relict geological discontinuities.

As the landslide has deteriorated and endangered the total collapse of the access road to the college at the upslope, the Client specified the following design criteria & requirements:

- The slope shall be immediately and effectively covered and protected by tarpaulin sheet from further infiltration and deterioration.
- Factor of safety (FOS) against local and global slip shall be at least 1.4 based on lower bound shear strength parameters or critical shear strength.
- The failed slope shall be reconstructed to the original geometry and the finished slope shall be green to match the existing nearby slopes
- The slope repair works under design & build basis shall be completed within 7 months.
- Only cost-effective methods shall be considered.

Based on the site conditions and the above design criteria and requirements, several options were considered and evaluated. The accepted proposals to rehabilitate the failed and unstable slope within the specified scope of works consist of the following works:

- Remove the slided materials or loose or soft materials and reconstruct the slope with rock reinforced fill supported by RC slab and GI pipe piles. These are necessary to ensure FOS>1.4 required.
- Stabilize the unfailed but unstable slope by soil nailing and guniting to ensure adequate FOS required.
- Scheme of QA/QC to check and verify important design assumptions and performance requirements.

	Methods *	Close Turfing	Hydro-Seeding	Hydro Seedings With Biomat	Vetiver Grass	HDPE Geocell	Gabion Mattress	Stone Pitching	Gunite	RC Skin Wall
1.0	SOIL TYPE									
1.1	Silty/Sandy CLAY	✓✓	✓✓	✓✓	✓✓	✓✓	✓✓	✓	✓	✓
1.2	Sandy SILT	✓	?	✓	✓	✓✓	✓	✓	✓	✓
1.3	Silty SAND	✓	x	?	?	✓✓	✓✓	✓	✓	✓
1.4	Fractured/Rocky/Boulderly	x	x	?	x	✓	✓	✓	✓	✓
1.5	Very stiff/hard	?	?	✓	?	✓	✓	✓	✓	✓
1.6	Acidic	?	x	x	?	✓	?	✓	✓	✓
2.0	SLOPE GEOMETRY									
2.1	Gentle slope, $B < 35^0$	✓✓	✓✓	✓✓	✓✓	✓✓	✓✓	✓	✓	✓
2.2	Medium slope	?	✓	✓	✓	✓	?	✓	✓	✓
2.3	Steep slope, $B > 42^0$	x	?	✓	?	✓	x	✓	✓	✓
2.4	Down-slope length, L > 10m	✓	✓	✓	✓	✓	✓	✓	✓	✓
3.0	MISCELLANEOUS									
3.1	Aesthetic	✓	✓	✓	?	✓	?	✓	✓	✓
3.2	"Green" requirement	✓	✓	✓	✓	✓	x	x	x	x
3.3	High water table	✓	✓	✓	✓	✓	✓	?	x	x
3.4	Poor slope surface drainage	?	?	?	✓	✓	✓	✓	✓	✓
3.5	Shady area	?	?	?	x	?	✓	✓	✓	✓
3.6	Unit cost (RM/m^2)	< 8	< 3	< 5	< 5	< 50	< 70	< 70	< 90	< 100

Legends

✓✓ = Very suitable

✓ = Suitable

? = Doubtful

x = Not suitable

Figure 1: Slope Protection Selection Chart

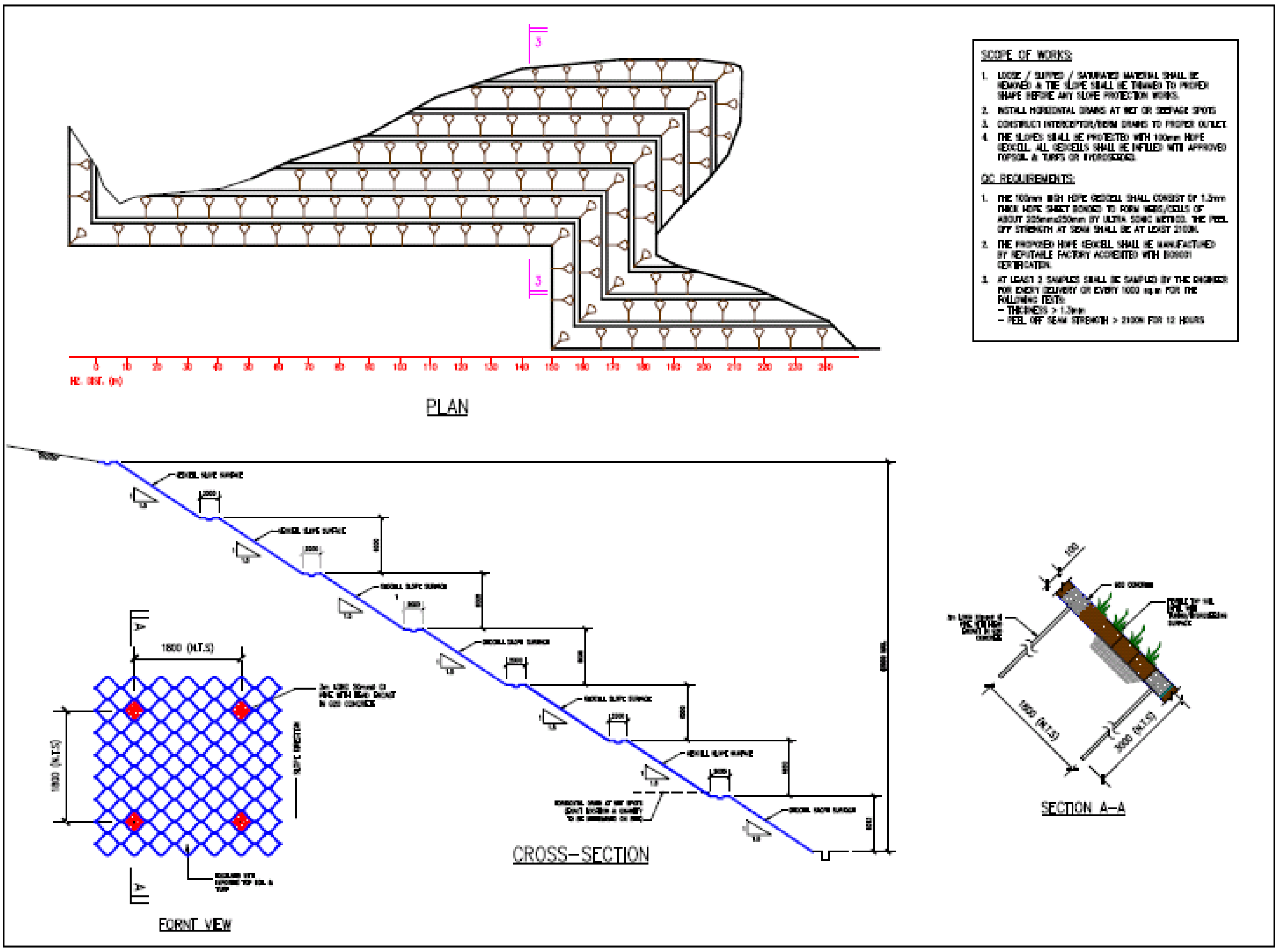

Figure 2: Proposed Slope Protection by HDPE Geocells

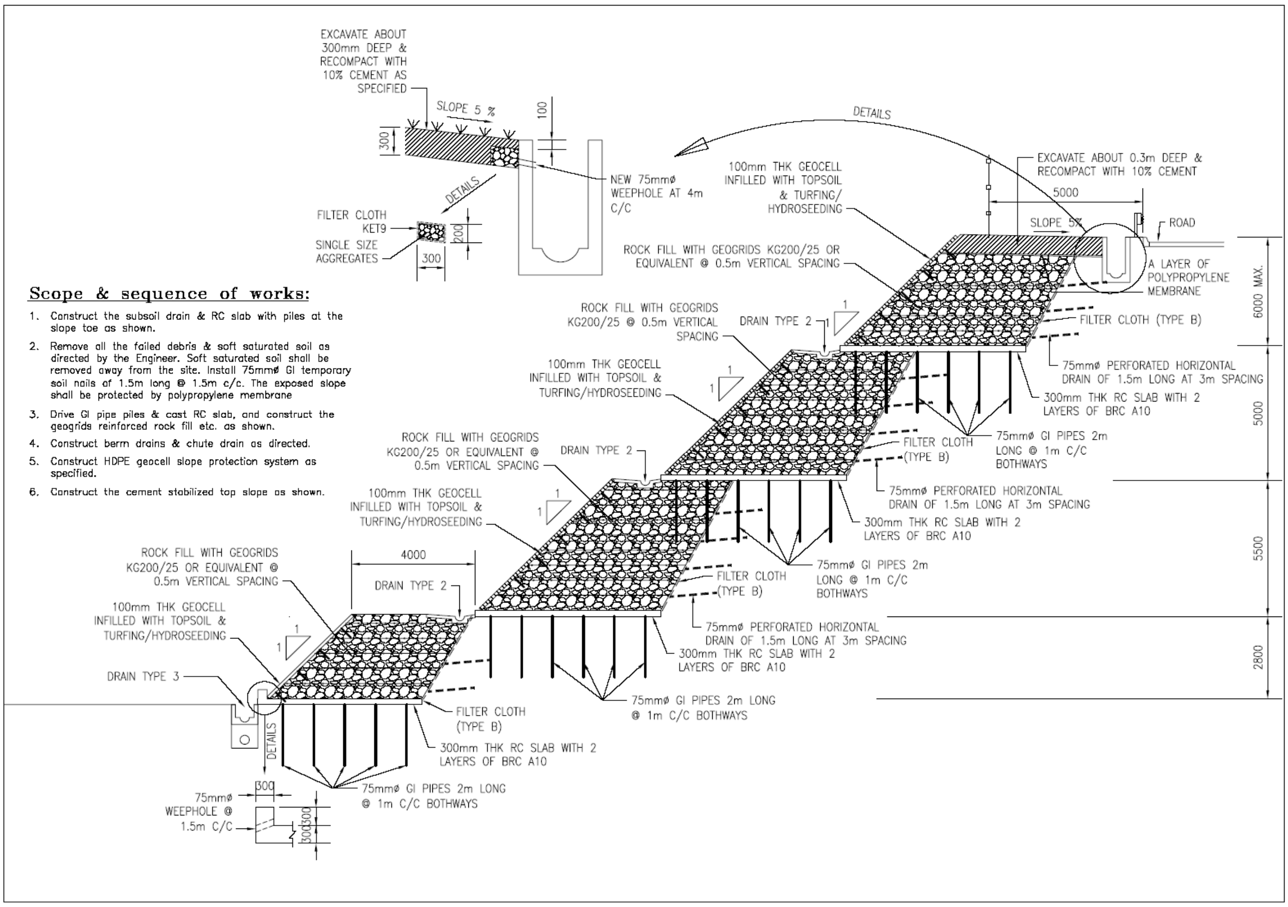

Figure 3: Proposed Slope Rehabilitation (Type2) – SMA Gopeng, Perak.

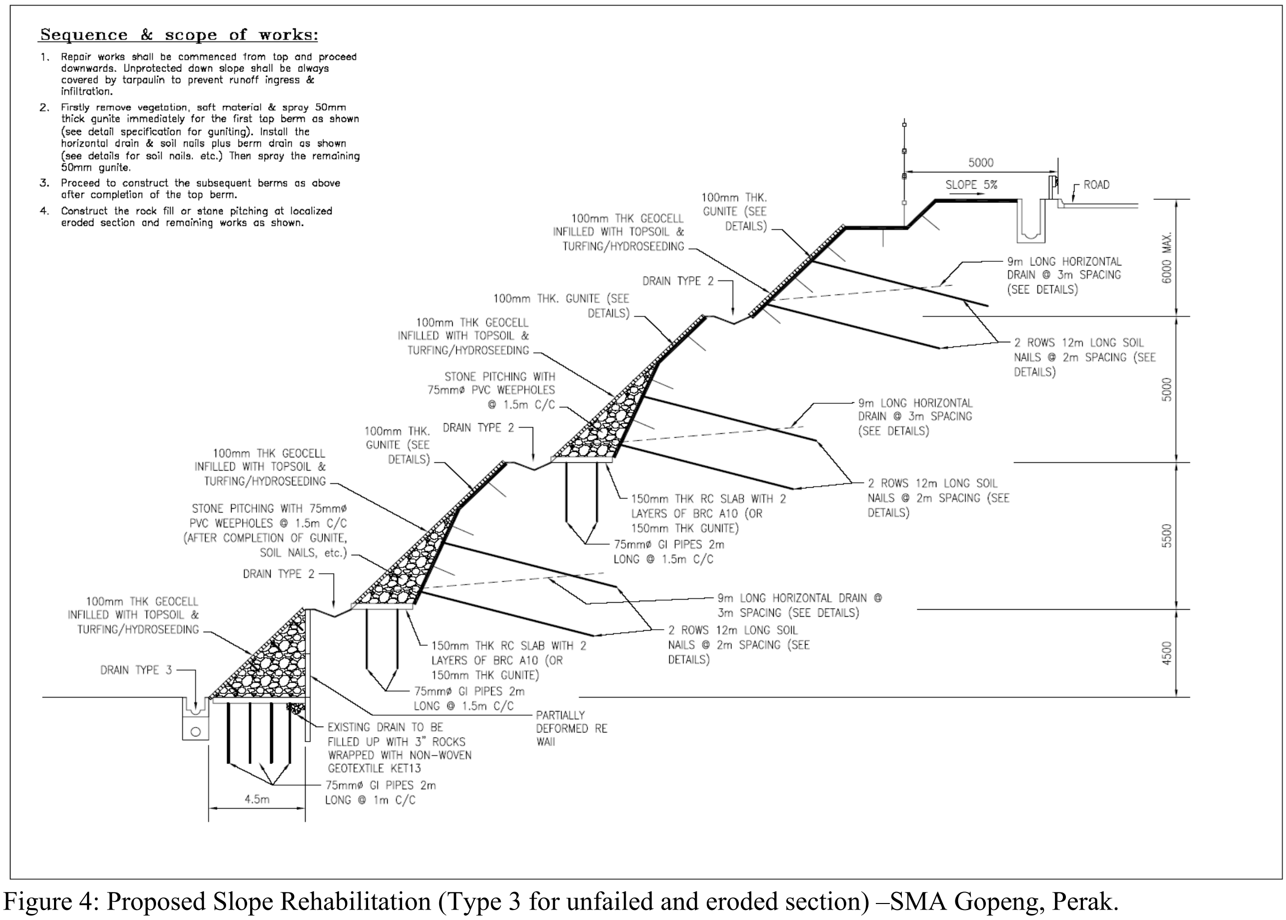

Figure 4: Proposed Slope Rehabilitation (Type 3 for unfailed and eroded section) –SMA Gopeng, Perak.

The above slope stabilization proposals based on detail analysis and as shown in Fig 3 and 4 have been found to be cost effective and have complied with the Client's design criteria fully except the requirement to have green slope to match the adjacent green slopes or green environments. To achieve this, geosynthetic HDPE geocell (100mm thick) as shown in Fig 2 was proposed to cover the completed rock reinforced slope and gunited slope. The geocells were infilled with suitable topsoil plus hydroseeding.

Instrumentation including piezometers, inclinometers and surface markers were installed to check and verify the important design assumptions and performance requirements and the results are satisfactory generally.

4 CONCLUSIONS

Two case histories showing how difficult slopes and site conditions plus stringent requirements including the need of green environmentally-friendly finishes can be achieved by HDPE geocell slope protection system are presented. Factors that can influence selection and design of appropriate slope protection are also evaluated. It is found that the geosynthetic HDPE geocell slope protection system is the most versatile slope protection method (as shown in Fig 1) and can effectively retain and preserve the imported topsoil to allow and ensure grass to flourish in difficult slope conditions such as acidic soil, rocky or unfertile gravelly soils. HDPE geocells with underlying polypropylene and geocomposite material can also effectively replace gunite to mitigate against infiltration, which is the main cause for most slope failures, especially when the slopes are not adequately protected by suitable methods or measures against infiltration are not properly and adequately provided.

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