Advance in Geogrid Reinforced Slopes in Malaysia

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ABSTRACT: Geogrid product was formally introduced into and developed in Malaysia after Pilecon Holdings Sdn Bhd signed a distributorship agreement with Netlon Ltd (now Tensar International Ltd) United Kingdom in 1985. Prior to that Star Art Sdn Bhd was the distributor of Netlon product in Malaysia. Ooi &Tee (2004) examines the various case histories of slope repair and the role of geosynthetic reinforcement used in slope reconstruction and their performances for the last twenty years since the introduction of geogrids to Malaysia. Slope failure is not uncommon in many parts of Malaysia. Asahari (2009) reported more than 100 landslide incidences a year in Malaysia at a seminar on safe hill-site development in Kuala Lumpur. The frequency of occurrence of slope failure increases during the monsoon seasons where incessant rain extended over long period of time caused the slope to fail despite the fact that it may be stable for a long time. The infiltration of rainwater causes the reduction of soil suction, rise in water table and reduction of the shear strength of soil. In the case of un-compacted fill slope massive failures have occurred and lives and properties were lost. The Landmark case Highland Towers Condominium collapse in December 1993 and the high profile December 2008 Bukit Antarabangsa massive landslide are the worst landslides that have happened in Malaysia. The Public Works Department set up Slope Engineering Branch in 2004 to specifically manage and control the landslide problems faced by Malaysia. Many natural slopes are in fact in limiting equilibrium. Cutting in slope reduces the stability of slope and yet it is a common practice. Of course surface water is an important factor in causing instability of slope. Surface runoff must be taken away from the slope as quickly as possible in order to ensure the safety of slope. Over the last forty years, various methods of slope repair have been used. The stability of slope can be increased by the introduction of geosynthetics as soil reinforcement so that steep engineered slope can be formed. This paper presents the various case histories of slope repair and the role of geosynthetic reinforcement in the slope reconstruction and their performances.

Keywords: Soft Ground; Geo-synthetics; Slope failure; Slope rehabilitation

1. INTRODUCTION

Pilecon Holdings Sdn Berhad (Pilecon), a holding company of a public listed engineering construction company in Kuala Lumpur signed a distributorship agreement with Netlon Ltd, (now Tensar International Ltd) in Blackburn, United Kingdom on 13th February 1985. Figure 1 shows picture taken at Blackburn during the signing of Agreement at the office of the inventor of Netlon and Tensar products, the late Dr. F. B. Mercer. Pilecon was a geotechnical engineering based construction company having in house expertise offering Design and Build services in Geotechnical Works including Earthworks, Deep Excavation, Deep Foundation, Diaphragm Wall, Foundation Underpinning and Slope Rehabilitation. Pilecon spear-headed numerous projects using geogrid in civil engineering works. Examples of rehabilitation of very high slopes are Motel Desa slope failure (Toh *et al*, 1986), Fraser's Hill Petronas bungalow cut slope failure (Chin *et al*, 1989), Zooview slope failure (Ooi, 2008). Use of geogrid in pavement design started with the Sungei Way Quarry Trial in 1985. Ooi et al (2004) reported the results of the quarry trial and the performances of geogrid reinforced roads and platform for steel fabrication yard. Use of geogrid in asphalt reinforcement was also carried out in 1985 but with limited success due to very high laying temperature of the asphalt mix. Star Art Sdn Bhd (Star Art) was the distributor of Netlon product in Malaysia. Star Art was unable to market geogrid product effectively for the initial two years prior to the signing of the Agreement between Pilecon and Netlon.

In 1984, under the stewardship of the late Dr. Mercer and strong support of The Institution of Civil Engineers, (ICE), an important symposium/conference sponsored by the Science and Engineering Research Council of the United Kingdom and Netlon Limited was held in London. The conference discussed and set direction for the research and development programmes for polymer grid reinforcement in Civil Engineering. Geogrids are produced in two categories namely, uniaxial geogrid which is a reinforcing element manufactured from high density polyethylene (HDPE) sheet, orientated in one direction so that the resulting ribs shall have a high degree of molecular orientation which is continued through the integral traverse bar and biaxial geogrid which is a mechanical stabilization element manufactured from a punched polypropylene sheet, which is then oriented in two directions so that the resulting ribs shall have a high degree of molecular orientation, which continues through the mass of the integral node. The conference has indeed laid the foundation for a healthy development in the use of geosynthetics in slopes, embankments, road foundations and other retaining walls. Thomas Telford Ltd. published the proceeding of the conference in 1985.

Murray (1985) reported failure of motorway cut slopes and embankment in the United Kingdom. The results of survey of 300km of selected lengths of motorway showed that 10 years after the completion of construction, an average of 10% of the slope have failed. The repair of slope uses geosynthetic meshes and the insitu (founder) material with 2% of quicklime. Forsyth and Bieber (1985) in the United States of America and Bushbridge (1985) in Canada reported similar repair works among others.

With the rapid infrastructure and building development that took place from the 1980s onwards in Malaysia, failure of slopes posed great challenge to engineers who have to seek viable solution for the repair of such slope failures.

Ting (1984) gave a comprehensive review of the slope stability problem in Malaysia. The Southeast Asian Geotechnical Society held the first symposium on the application of geosynthetic and geofibre in Southeast Asia in 1989 in Kuala Lumpur, Malaysia. There was only one paper on reconstruction of failed slope by Chin *et al*., (1989) which described the careful reconstruction work of a 16m high slope failure in Fraser's Hill using a 7m high geogrid reinforced wall. This was the geogrid reinforced wall built in 1987 in Malaysia by the late Professor Chin. Figure 2 shows pictures of the failed slope and its rehabilitation and subsequent performances.

Figure 1 Signing of Agreement on 13th February 1985 Picture from left to right: Dr. Brian Mercer, Dr. Ooi Teik Aun and Mr. Roger Duckworth

Figure 2a Petronas bungalow with failed slope in 1987

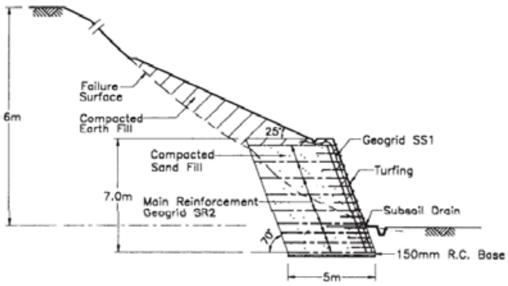

Figure 2b Scheme of rehabilitation using geogrid reinforced slope

Figure 2c Slope rehabilitation in progress, 1987

Figure 2d Rehabilitation in progress with upper slope, 1987

Figure 2e Petronas bungalow slope rehabilitation, 1987 K.Y. Yong shown in the picture visited the site

Figure 2f View of Petronas bungalow slope in 1989 by courtesy of Mike Dobie

Figure 2g View of Petronas bungalow slope in 1998 by courtesy of Mike Dobie

Figure 2h View of Petronas bungalow slope in 2010
by courtesy of Mike Dobie

Figure 2i Petronas bungalow slope failure rehabilitation 2010
by courtesy of Mike Dobie

Figure 2 Petronas bungalow slope failure rehabilitation, 1987

The use of geosynthetics for the reinforcement of road embankment was introduced into the Public Works Department (JKR) in early 1985 in the Temerloh – Mentakab bypass. Figure 3 shows picture of the repair. The embankment slope was 45 degree and SR2 uniaxial geogrid was used. Thus geogrid had enabled a steep slope to be built with a turfed surface with less favorable insitu materials of residual soil derived from Kenny Hills Formation consisting of sandstone and shale.

In the Jitra-Butterworth stretch of the North South Highway, SR2 uniaxial and SS2 biaxial geogrids were used to rehabilitate an embankment failure. This is the first time (1984/85) in Malaysia that geogrid was used successfully as basal reinforcement to overcome the bearing capacity problem of soft ground for a 4m high embankment. Figure 4 shows the pictures of the work on site. The same design concept was used for 6m high geogrid reinforced embankment in the Muar Flat Trial. 3m high embankment without and with geogrid reinforcement were used as control (see Figure 4e.) The test results were published in the conference proceedings of the Muar Flat Trial in 1989 (MHA, 1989).

The 2nd Asian Geosynthetic Conference was held in Kuala Lumpur in year 2000. There was a special lecture on Reinforced Soil Structure using geogrids by Chan (2000) and one paper by Tang *et al*. (2000) on an instrumented slope repair of a 40m high slope failure in Singapore. Chan (2000) gave a review of the design method of geosynthetics in soil reinforcement and some case histories of applications including slope repairs. The geogrid reinforced structures are largely performance base and monitoring of their performances during construction and in service is important. Geogrid structures are more resilient and can accommodate deformation without total collapse.

The Jubilee Symposium on Polymer Geogrid Reinforcement held in London in September 2009 under the auspices of The Institution of Civil Engineers London is another important milestone for the development of geogrids. The twenty-five years of practical use of geogrid material has seen the approval and acceptance of geogrids as a soil reinforcement material using the less favorable insitu material through the publication of a BS Code of Practice BS8006 in the mid 1990s. The Jubilee Symposium was therefore to celebrate the achievements of the use of geogrids in civil engineering works. The introduction of geogrids in the repair of slope and construction of vertical walls with hard facing has made the construction of many steep slopes and vertical walls a reality. With the introduction of triaxial geogrid in road construction the efficiency of geogrids has been greatly enhanced. Firstly, triaxial geogrid is more economic and sustainable when compared with its predecessor the biaxial geogrid. Secondly it is a redundant structured grid and therefore more rigid than the biaxial grid thereby enable better load transfer between soil and geogrid. In Malaysia, the triaxial geogrid was used in 2008/2009 at a Q-Cell solar plant in Cyberjaya in Selangor for the heavily loaded container traffic within the factory internal and the approach roads. Prior to the full scale laying using the triaxial geogrids in a two-layer system, performance trials were carried out first. (See Figure 5).

This paper examines the various case histories of slope repair and the role of geosynthetic reinforcement in the slope reconstruction and their performances for the last twenty-five years. In these case histories, the geosynthetic reinforcement used is a geogrid manufactured from high density polyethylene (HDPE) sheet, punched and oriented to produce excellent strength and stiffness properties to act as a soil reinforcement known as Tensar geogrids.

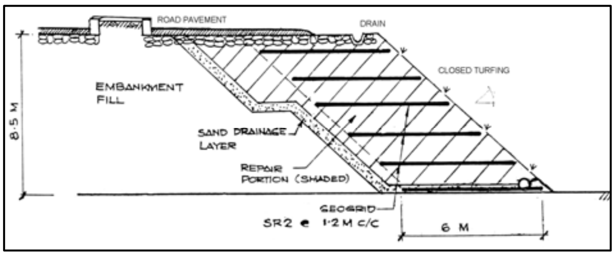

Figure 3a Schematic repair using geogrid, Temerloh Mentakab, 1985

Figure 3b Rehabilitation in progress; laying of geogrid

Figure 3 Temerloh-Mentakab Bypass road embankment rehabilitation in Pahang, 1985

Figure 4a Crack in embankment

Figure4b Excavation in embankment

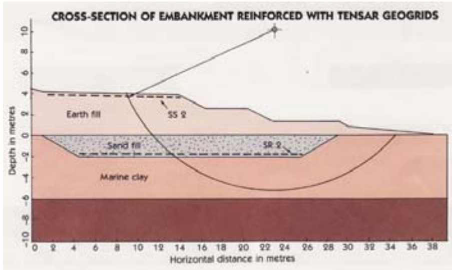

Figure 4c Embankment slip circle analysis

Figure 4d Laying of SR2 uniaxial geogrid

Figure 4e Muar Flat Trial 1987, laying of geogrids

Figure 4 Jitra –Butterworth embankment failure and soft ground improvement for 4m high embankment (1984/85)

Figure 5a Location of Missing Link and Q-Cell internal roads

Figure 5b Test Truck 40.74 tones on Missing Link, 2008

Figure 5c 100mm rut depth @ 120 passes Missing Link unpaved section

Figure 5d Laying of TriAx geogrid at Q-Cell in progress, 2008/2009

Figure 5 Triaxial geogrid used in Cyberjaya Q-Cell solar factory in Selangor Science Park

2. USE OF GEOGRID IN ROAD EMBANKMENT

2.1 Jitra-Butterworth Highway Embankment

The Jitra – Butterworth Highway Embankment was the first to use geogrid in Malaysia in year 1984/85 as basal reinforcement to rehabilitate an embankment failure due to failure of a 4m high embankment during construction in soft marine clay. Chan (2000) has reported this work. Prior to the use of geogrid basal reinforcement, bakau mats, made from a local species of tree with aerial roots with up to 150mm diameter trunk that grows well in brackish water in coastal swamp land, are placed on top of the soft ground before placement of the soil fill. Figure 6 shows picture of such application. After 1970s geotextiles were later used in its place. The disadvantage of geotextile is the large extension during placement of fill material and large lateral displacement of the embankment. In 1984, uniaxial geogrid was used in Jitra - Butterworth Highway as basal reinforcement in order to build higher embankment on coastal marine clay as shown in Figure 4. A layer of biaxial geogrid was used to control surface cracking of the embankment. Figure 7 shows picture of fill placement using biaxial geogrids in soft ground. Ooi *et al* (2004) reported the performance of biaxial geogrid in road pavement and fabrication yard for offshore structures. Figure 8 shows the load transfer mechanisms in geogrids and geotextiles respectively. Geotextile is commonly used as separator. The geotextile transfers load based on membrane tension while geogrid transfers load by shearing of interlocked soil particles. Figure 9 shows the rutting of the geotextile-reinforced section under vehicular load. Ooi *et al* (2004) shows geogrid significantly reduced the rutting of pavement at the Sungei Way Trial.

Figure 6 Laying of bakau mats for soft ground stabilization

Figure 7 Laying of geogrid in soft ground

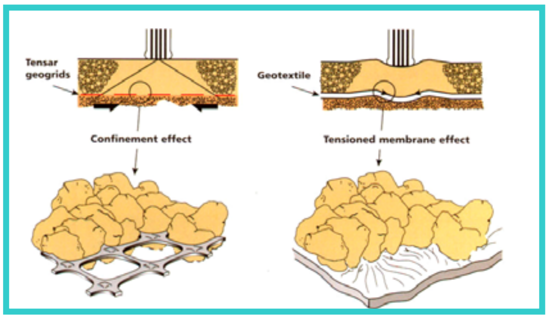

Figure 8 Load transfer in geogrid and geotextile

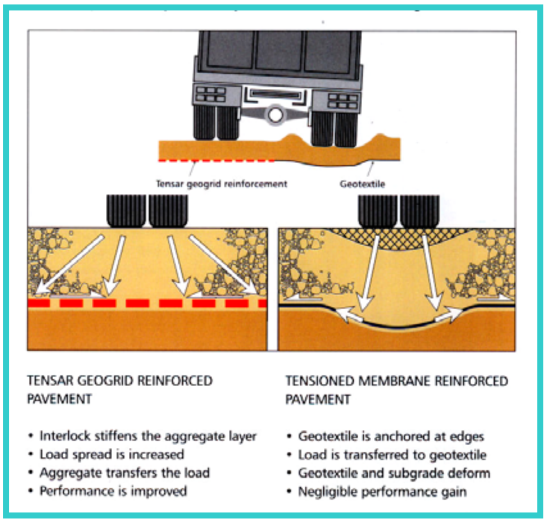

Figure 9 Rutting in geotextile under wheel load

2.2 Temerloh-Mentakab ByPass

In Malaysia, the use of geosynthetics for reinforcement of road embankment was introduced into JKR in early 1985 in the Temerloh – Mentakab bypass. In this instant, it was not possible to use stabilizing berm technique due to the limited width of the road reserve and the embankment had failed. In order not to encroach into private land, a 45° slope with 8.5m high embankment was reconstructed and reinforced with 6m length of SR2 uniaxial geogrid at 1.2m. The material used was residual soil of sandstone / shale compacted to wet of optimum moisture content at 90% degree of compaction using B. S. heavy compaction. An internal drainage system using sand drainage layer was provided at the back of the cut back slope and the base of the embankment with suitable drainage outfall as shown in Figure 3. This embankment has remained stable for 25 years.

2.3 Senawang -Air Keroh Expressway Embankment Failure

The Senawang – Air Keroh road embankment slope failure happened as a result of not cutting back the loose overfill on slope which has moved down the slope with passage of time. Figure 10a shows picture of the failure. Figure 10b & 10c show typical sections of the schemes for slope rehabilitation. The geogrid alternative was selected by the client in preference to the exhibited design using crib wall supported on precast reinforced concrete (RC) piles. The geogrid solution is more cost and time effective and blends in well with the existing green environment. This method of rehabilitation was often preferred by the client.

The repair work was carried out in 1989 using uniaxial and biaxial geogrids.The depth of excavation of the failed slope was determined using the JKR probe, a light dynamic cone penetrometer. The rehabilitated embankment was about 12.5m high with a slope angle of 33° and reinforced with geogrids and compacted in layers using insitu residual soil. A berm was provided at mid height so that surface and subsoil water can be drained out and collected and led away from the slope. Internal drainage was provided using sand counterfort drain spaced at 3m centres. A rock fill toe and toe drain was also provided to avoid toe softening due to poor drainage. Figure 10d shows rehabilitation in progress. Figure 10e shows picture of rehabilitated slope.

This type of slope repair is commonly accepted along the North South Highway in Malaysia. Ooi and Tee (2004) reported some significant slope repair projects in Malaysia. Table 1 shows an updated significant slope repair projects.

Figure 10a Picture of embankment failure, 1989.

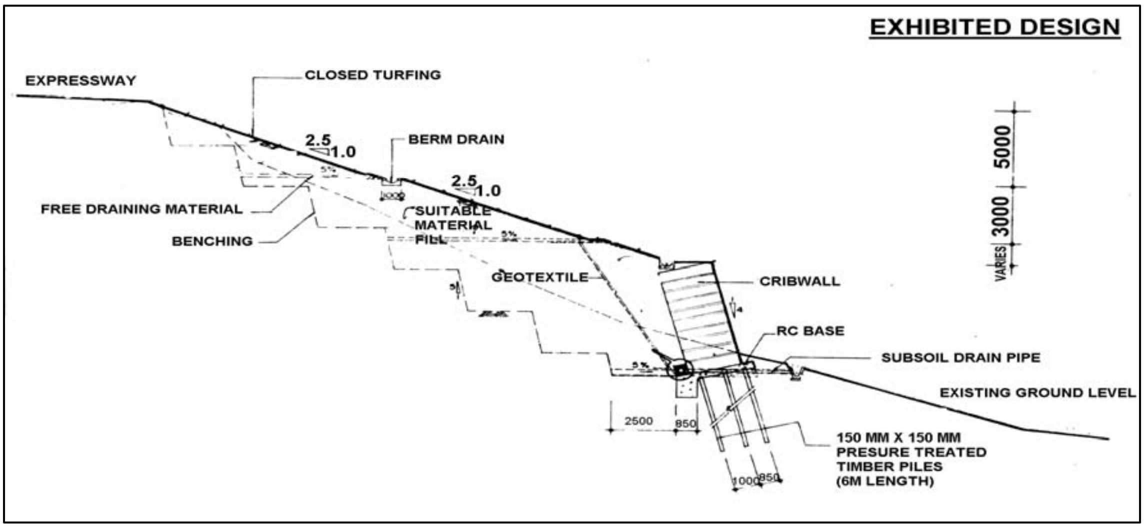

Figure 10b Exhibited design

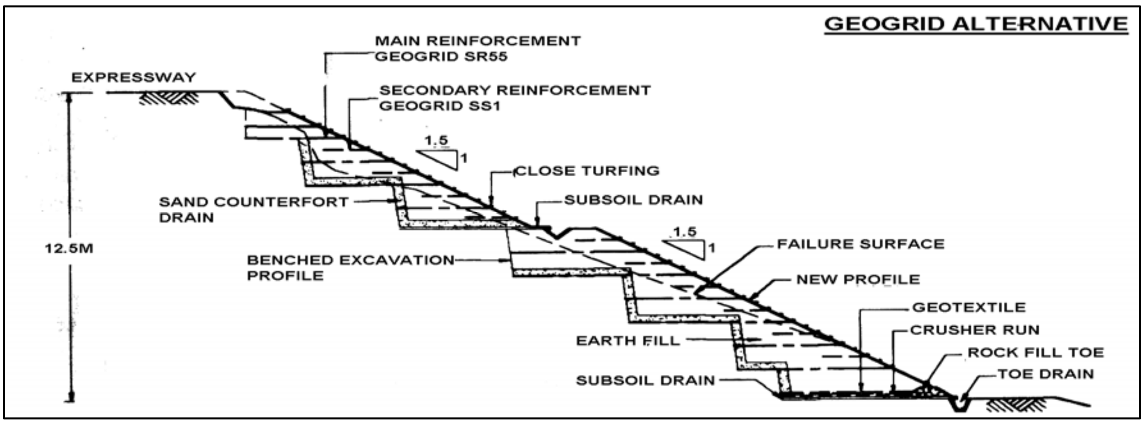

Figure 10c Alternative design

Figure 10d Rehabilitation in progress, 1989

Figure 10e Picture of rehabilitated slope, 1989

Figure 10 Senawang – Ayer Keroh landslide and slope rehabilitation.

Table 1 Some Significant Geogrid Slope Repair Projects in Malaysia

Project Description	Approximate Height (m)		Geosynthetic Elements	Infill Material		Surface		Remarks
	Reinforced Slope	Reinforced Wall		Sand	Insitu	Turf	Others	
Temerloh – Mentakab Bypass, JKR (1985)	8.5m (45º)	-	SR2	Internal drainage layer	Residual sandstone / shale	Closed turf (reinforced slope)	-	Road embankment slope repair.
Motel Desa, Kuala Terengganu (1985)	Total 30m (27º)	6.75m (75º)	SR2 SS1	Geogrid reinforced block	-	Closed turf on (Unreinforced slopes)	Creepers (reinforced wall)	Slope repair 6.75m high 75º geogrid wall on micro pile at mid slope.
Petronas bungalow, Fraser's Hill (1987)	Total 16m (25º)	7.0m (70º)	SR2 SS1	Geogrid reinforced block	Residual granite soil	Closed turf	-	Slope repair 7m high 70º geogrid wall at the bottom of slope.
Sg Serai Treatment Plant, Hulu Langat (1987)	Total 33m (31º)	5m (Tailed Gabion)	SR2 SS1 GM1	Internal drainage columns	Residual granite soil	Closed turf	5m high Tailed Gabion	Slope repair with treatment tank at top of slope.
Senawang – Air Keroh Expressway (1989)	Reinforced 12.5m (33º)	-	SR80 SR55 SS1	Internal drainage	Residual granite soil	Closed turf (Slope)	Rock-toe	Slope repair to failure of poor edge compaction.
Asrama SM Tun Saban, Pengkalan Hulu (1998)	Total 18.4m Reinforced 11.6m (46º)	6.8m	120RE 80RE 55RE 40RE	Modular Block Wall	Residual soil Reinforce d Slope	Closed turf (Slope)	Modular Block (Wall)	Soil nailing; Modular Block facing; Combined Technology; Geosynthetic and nailing.
Cut slope in Kaolin, Federal Road FT01, Tapah (2003)	Reinforced 17.1m (33º)	-	40RE	Drainage base and column	Residual soil	Closed turf (Slope)	Rock-toe	Kaolin cut slope rock toe.
Sains Kolej in Kuching (2004)	Total 10.6m Reinforced7.6m (37º)	3m	55RE 40RE SS20	Modular Block Wall	Residual soil	Closed turf (Slope)	Modular Block (Wall)	Modular Block facing.

Project Description	Approximate Height (m)		Geosynthetic Elements	Infill Material		Surface		Remarks
	Reinforced Slope	Reinforced Wall		Sand	Insitu	Turf	Others	
University Malaya, Kuala Lumpur (2004)	Total 18m Reinforced 12m (45°)	6m	80RE 40RE SS20	Modular Block Wall	Residual soil	Closed Turf (Slope)	Modular Block (Wall)	Soil nailing; Modular Block facing; Geogrid reinforced slope.
Kuantan-Kerteh Railway Project (2005)	Total collapsed 36m (45º) Unreinforced cut slope 28m (30°)	8m (70°)	40RE SS20	Internal drainage column	Residual soil	Closed Turf	-	Slope repair 8m high 70º geogrid wall at the bottom of slope.
Cameron Highland (2007)	Total 9m Reinforced 4.0m (45°)	5m 70º Rock-filled facing	40RE SS20	Internal drainage column	Residual soil	Closed Turf	Rock-filled facing	45º& 70º Geogrid reinforced soil slope founded on piles.
Kampung Pasir (2008)	Total 60m Reinforced Slope 40m (45° & 27°) Unreinforced 5m (22°)	15m Rock fill	40RE	Internal drainage column	Residual soil	Closed Turf	-	60m high slope repair with geogrid reinforced soil slope founded on rock fill base.
Kota Damansara (2009)	Total 13m Reinforced 6m (45°) Unreinforced 2m	5m Rock fill	RE520 SS20	Internal drainage column	Residual soil	Closed Turf	-	Reinforced soil slope founded on rock fill base as pond lining.
Seksyen U9, Shah Alam (2009)	Total Failed 19m Reinforced 12m (37°)	5m	SS20, 40RE, 80RE	Internal drainage column	Residual Soil	Closed Turf	Modular Block Wall	5m Modular Block Wall 12m geogrid slope 2m Unreinforced slope

Note : SR & RE are uniaxial geogrids and SS & GM are biaxial geogrids.

3. USE OF GEOSYNTHETICS IN THE REHABILITATION OF FAILURE OF HIGH SLOPES

3.1 Motel Desa Slope Failure

In Malaysia, very careful works has been done in pioneering the use of geosynthetics in very high slope as early as 1985 in a slope failure at Motel Desa, Kuala Terengganu. This is because for the first time geogrid is being designed for the rehabilitation of such a high slope. The total height of the slope failure was about 30m. A geosynthetics reinforced wall of about 7m high was constructed with full instrumentation at about 12m above the toe level of the slope to provide support for the unreinforced top 11m high section of the slope compacted at 25° slope angle. Figure 11 shows a schematic profile of the slope together with the micro pile supported platform and the geogrid reinforced wall at mid-slope. Toh *et al.* (1986) and Chan (1996) reported the details of construction and monitoring work. Subsequent to this work, numerous slopes have been repaired using the same basic principle but improvements to construction methodology and design have been made. The instrumentation shows that the bottom un-reinforced portion of the slope was subject to settlement movement of 200mm and a lateral displacement of 87mm. For the reinforced soil block, SR2 uniaxial geogrid was used as main reinforced element and SS1 biaxial geogrid was used as surface wrapping and secondary reinforcement. Closed turf and creepers were used as surface finish.

Ooi & Tee (2011) discourages the use of geogrid-reinforced slope or wall on slope supported on piles especially small pre-cast reinforced concrete piles. In this case API pipe micro piles were used and as such bending and shear resistance are adequate. Notwithstanding such provision, its use is discouraged because of global stability and robustness of the design.

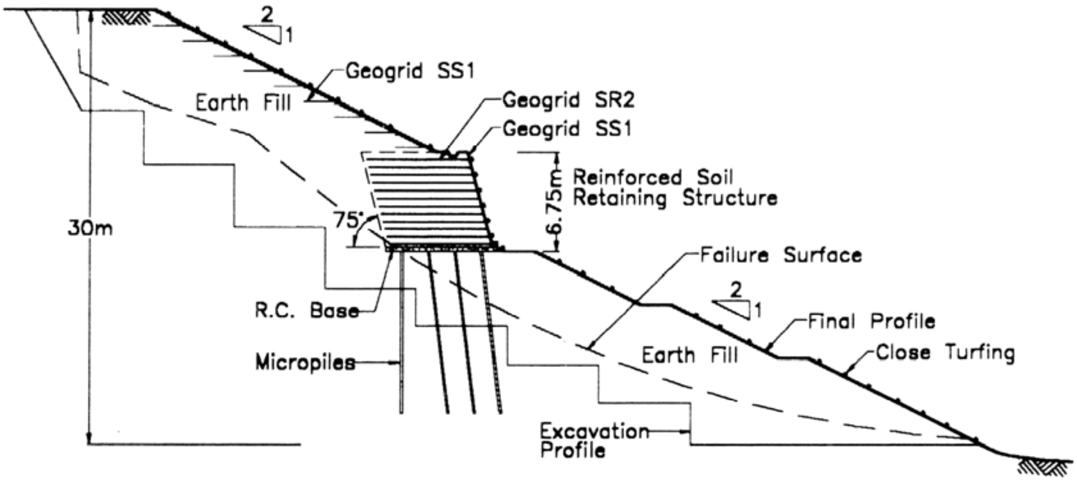

Figure 11 Motel Desa slope failure rehabilitation (after Toh *et al.,* 1986).

3.2 Fraser's Hill Petronas Bungalow Slope Failure

This work was carried out by the late Professor Chin Fung Kee in 1987 and reported by Chin *et al* (1989) at the first symposium on the application of geosynthetic and geofibre in Southeast Asia. Figure 2 shows the collapse of the cut slope and the subsequent rehabilitation. Pictures taken over the years were also included to show the conditions of the rehabilitated slope. The exposed SS1 biaxial geogrid is in perfect condition. The instrumentation and finite element analysis showed that the movements are within acceptable limits.

3.3 Sungai Serai Treatment Plant Slope Failures

The Sungai Serai treatment plant landslide in Hulu Langat, Selangor is an important milestone for the repair of slope using geosynthetics. The landslide that occurred in January 1987 affected the 6m diameter R.C. circular tank structure located at the top of the failed slope of 33m high. Water from the scour pipe washed away part of the slope and left the tank perched precariously at the top of the slope. The slope has been stable for more than 50 years since completion. Ooi & Tee (2004) at the Malaysian Geotechnical Conference held in Kuala Lumpur in 2004 reported this rehabilitation work. Urgent action was required to immediately reinstate the slope and no insurance company was prepared to issue an insurance cover for the Contractor All Risk (CAR) policy for the work. Work started at the toe of the slope near the river with mattress and tail-in gabions together with rip rap for protection of the river bank for the first 8m height. Another 5m high of tail-in gabions were constructed to provide support for 23m high SR2 uniaxial geogrid reinforced slope with a slope angle of 33º. The slope surface was reinforced with SS1 biaxial geogrid to facilitate turfing and to contain the compacted residual soil. A berm was provided at mid height of the upper slope in order take away the surface run off as well as the subsoil drainage water. Figure 12 shows the schematic view of the section of the slope rehabilitation and picture of work in progress when construction has reached a safe height. In-situ residual granite soil was used in 300mm layers and compacted with geogrid reinforcements to 90% B.S heavy compaction. Internal drainage of the reinforced slope was facilitated by using sand column and 150mm diameter PVC pipes. The completed surface was close turfed and trees planted. Monitoring of slope movement after completion was carried out. To date 23 years after rehabilitation, the slope remains stable. The slope rehabilitation was the first of its kind in putting sustainable development effort into practice by using insitu residual granite soil having angle of internal friction of 26 degree for the reconstruction of a failed slope to 33° slope angle.

It is environmentally friendly since green environment is preserved by turfing and tree planting. Though the turing and creepers were used in Motel Desa slope rehabilitation in 1985, imported fills consisting of sand and residual granite soils from outside source used, creepers were also used for the new geogrid reinforced retaining wall scheme with 75° in the Verona Townhouses in Bangsar in Kuala Lumpur in 1986 as well in the Normah Kuching Medical Cenre reinforced soil wall in Kuching. This is a new vertical turf face geogrid wall constructed in 1986 as shown in Figure 13.

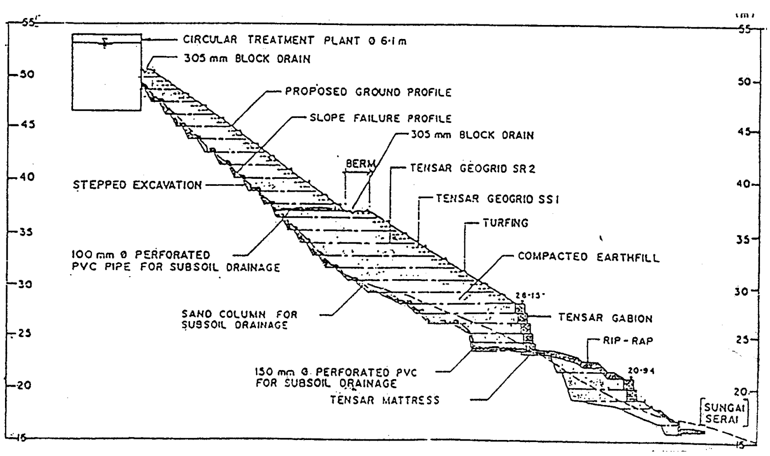

Figure 12a Schematic rehabilitation (Figure are in metres)

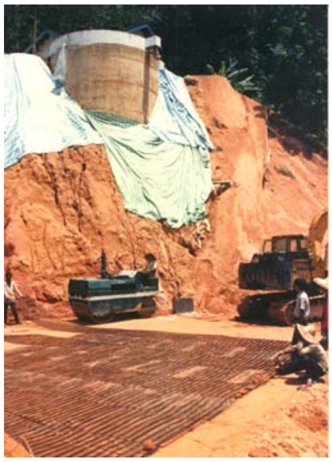

Figure 12b Construction at safe height

Figure 12 Sungai Serai landslide and slope rehabilitation, 1987

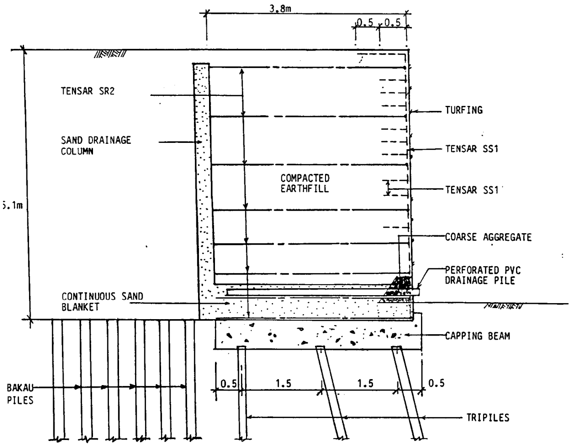

Figure13a Schematic geogrid wall

Figure 13b Completed wall

Figure 13c Wall with turfing

Figure 13 Normah Medical Centre 5.1m high vertical wall, 1986.

3.4 Asrama S. M. Tun Saban Slope Failure

In 1997 landslide occurred behind a school hostel at Tun Saban secondary school in Pengkalan Hulu, Perak as a result of incessant rain in the monsoon season. The 17m high slope was stabilized first by using soil nails at 1.5m intervals as the failed slope was being excavated to profile for the geogrid reinforced slope. Soil nails were necessary to provide the required factor of safety of 1.2 for temporary stage during the construction of the slope. Two levels of 3.6m high geogrid reinforced vertical Modular Block wall were used. The method of construction enables rapid building up of the walls without temporary forms. Figure 14 shows picture of the slope failure, a schematic slope rehabilitation and picture of the completed repair work. The Modular Block wall also provided the support for the upper geogrid reinforced slope of 11.6m high with slope angle of 46º. It carries the perimeter fencing and drainage at the top of the slope. The reinforcement elements used were 160RE, 120RE, 80RE, 55RE, 40RE uniaxial geogrids and SS20 biaxial geogrid. The completed slope was close turfed. The soil nails, apart from giving the required safety factor for temporary stage, also prevented deep seated slope failure and increased the overall safety factor of the geogrid reinforced slope and that of the Modular Block wall. This type of combined technology in soil reinforcement was carried out for the first time. The combined technology was also used in the case of Motel Desa slope rehabilitation where micropiles were used to support the geogrid reinforced soil wall. During that time terminologies such as sustainability and combined technology were not used.

3.5 Federal Road FT01, Tapah Perak

In the October - December 2002 monsoon, landslide occurred at Seksyen 536 along Federal Road FT01 at Tapah, Perak. The slide involved the bottom 17m of a 20m high slope cuttings in Kaolin formation. The client opted for a geosynthetic solution with turfed slope for the rehabilitation work. Rock toe was first constructed at the bottom of the slope with sandfill as the base with two layers of uniaxial geogrid reinforcement. Sandfill base serves as a internal drainage for the sand drainage columns of 1m x 0.5m spaced at 5m centres at the back of the re-profiled slope. On top of the sandfill, base layers of uniaxial geogrid were placed within the residual soil fill compacted in layers to the original slope profile of approximately 32º. Residual soil was used in the reinforced block to replace the existing Kaolin which has high moisture content and is susceptible to softening and landslide. Sandfill is also used extensively because of its low cost, better strength and well drained properties. Figure 15 shows picture of slope failure, a schematic slope rehabilitation, construction of sand layer with rock toe and the rehabilitated slope.

Figure 14a Slope failure above toe wall close to the school block

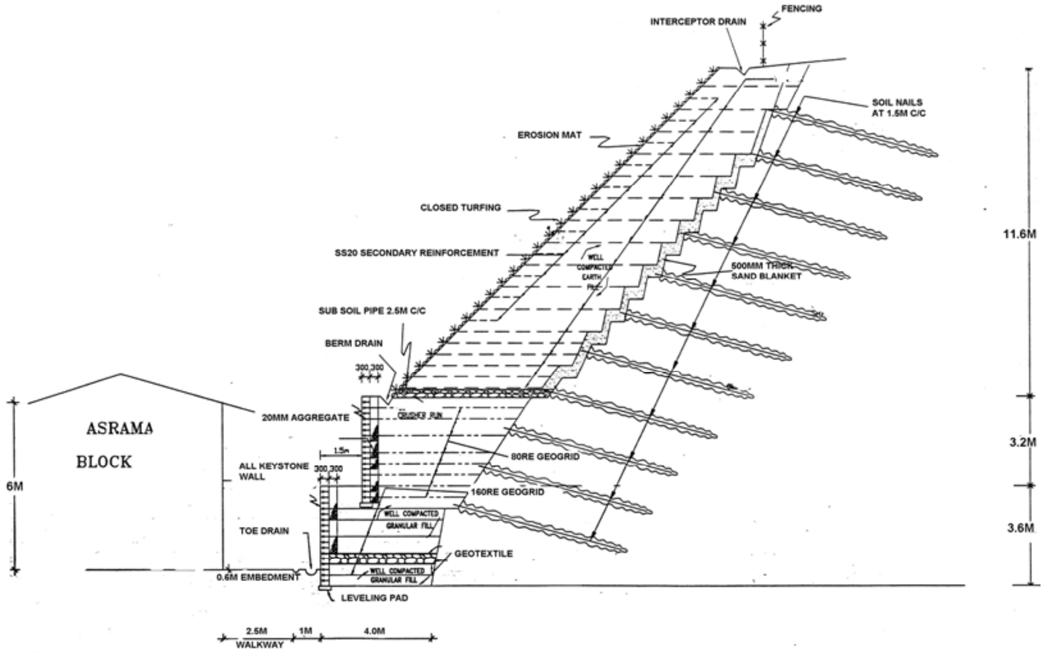

Figure 14b Schematic rehabilitation using combined technology of soil nails, modular block wall and geogrid reinforced slope.

Figure 14c View of Rehabilitated Slope

Figure 14 Asrama SM Tun Saban slope failure and rehabilitation.

Figure 15a View of slope failure

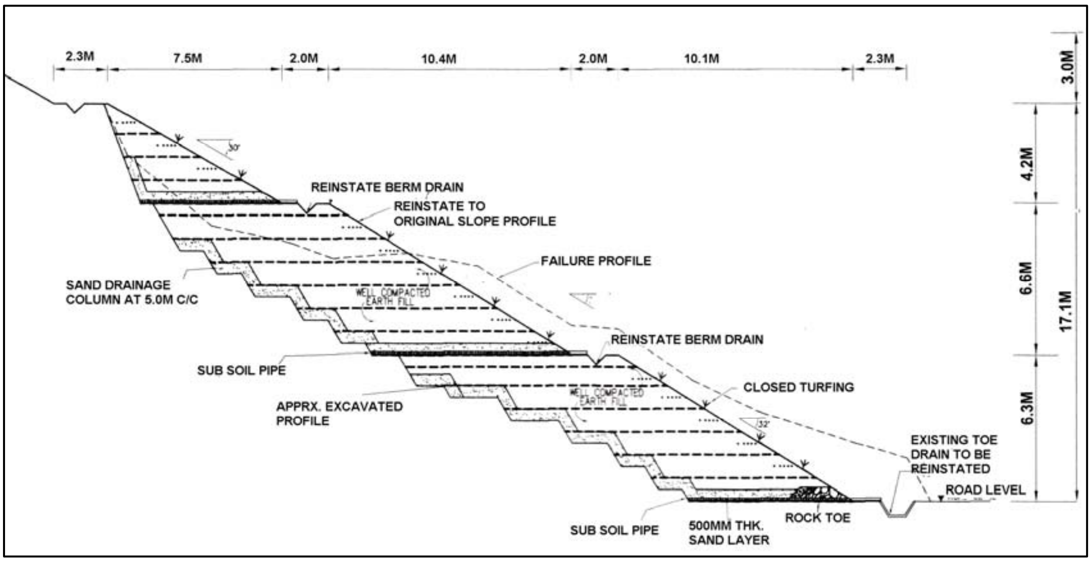

Figure15b Schematic rehabilitation with emphasis on drainage

Figure15c Rehabilitation in progress

Figure15d Rehabilitated slope

Figure 15 Cut slope in Kaolin, Tapah, Perak Darul Ridzuan

3.6 Sains Kolej, Kuching, Sarawak

In late 2002, a landslide occurred at a slope behind the Lecture Block of a Sains Kolej in Kuching, Sarawak. An 11m high slope with existing 3m high gabion toe wall moved laterally towards the building columns and burying them. Fortunately, the movement did not cause the collapse of the lecture block columns. Figure 16 shows picture of the slope failure, the schematic slope rehabilitation and the rehabilitated slope. A 3m high basal block of geogrid reinforced Modular Block wall was constructed to replace the damaged gabion wall. From the figure it can be seen that internal drainage was provided by the sand columns spaced at 6m centres. The sand columns are connected to basal block of geogrid reinforced Modular Block wall with granular backfill and aggregate drainage layer at the back of the wall. 100mmØ UPVC drainage pipes are provided at 6m centres to lead the subsoil water to the existing drain. External drainage was also provided by cut-off drain at the top of the slope.

Figure 16a Slope failure affecting the lecture block

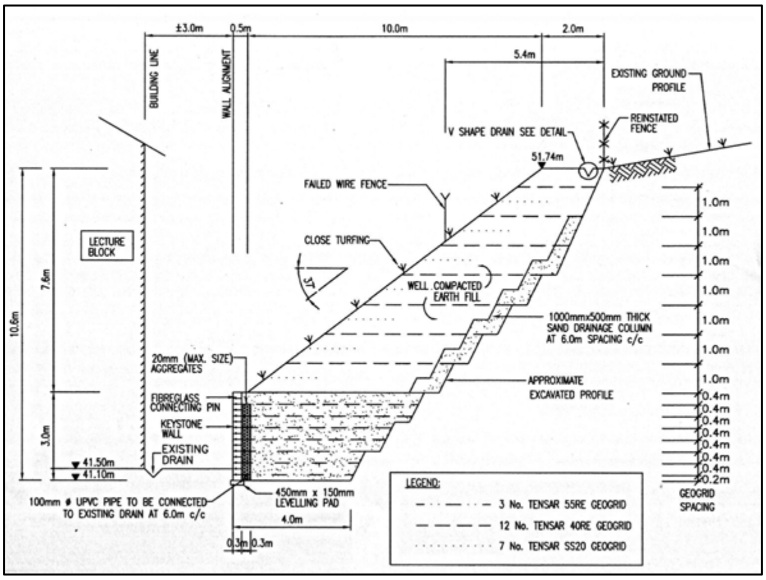

Figure16b Schematic slope rehabilitation

Figure 16c Removal of debris and cutting back of slope

Figure16d Rehabilitated slope

Figure 16 Slope rehabilitation to lecture block Sains Kolej, Kuching, Sarawak

3.7 University Malaya Cut Slope Stabilization

The Faculty of Economics of University Malaya in Kuala Lumpur was constructing an additional block of building in 2004 near a filled slope that was constructed some 40 years ago. The site was very restricted as can be seen from Figure 17. At the top of this slope was a double story university residence. In order to gain space for the construction of an additional block of buildings with car parking bays, it was necessary to cut the former filled slope to a steeper slope angle. Originally, soil nails were prescribed for stabilizing the cut slopes. As the soil nailing work was proceeding for other lower sections of the slope, the higher section of the cut slope collapsed leaving the building on top of the slope perching precariously. Figure 17 shows picture of the failed slope, the scheme for the rehabilitation of slope, stability analysis, construction of Modular Block wall and the rehabilitated slope. It was clear that the 17 m high cut slope collapsed due to inadequate provision or precaution taken by the soil nail contractor to ensure that the slope had an adequate factor of safety during the temporary stage. Had a proper and comprehensive method statement of work been closely followed by the contractor it would have been clear that soil nails should have been installed following closely the cutting down of the slope. The contractor should have soil nailed the slope immediately after cutting instead of doing the soil nailing after completion of the entire excavation. The proposed scheme of rehabilitation as shown in Figure 17 considered both short term as well as long term stability of the cut slope. The high slope was located in a former fill over a valley where a stream existed. Despite the fact that filling was done over forty years ago, the material remained a loose tipped fill except for perhaps significant "collapse settlement" that had taken place within the soil fill during the repeated wetting and drying process. Continuous heavy rainfall that happened after the cutting of the former fill slope to a steeper angle was obviously the cause of the slope failure that had affected the perimeter drains and caused cracking of the concrete drain apron. The strategy for reconstruction of this slope is to soil nail the cut slope first to provide the short-term stability and then construct a 5.4 m high geogrid reinforced wall at the toe of the slope to provide for the long-term stability. This also provided a solid base to support the upper reinforced soil slope. The combined technology is employed here to solve a unique problem. Internal drainage system is provided to ensure that the ground water table level is controlled. This method of combined technology using soil nail, Modular Block wall and geogrid reinforcement has been widely used in slope rehabilitation of a number of restricted sites.

Figure17a Collapse of cut slope during soil nailing

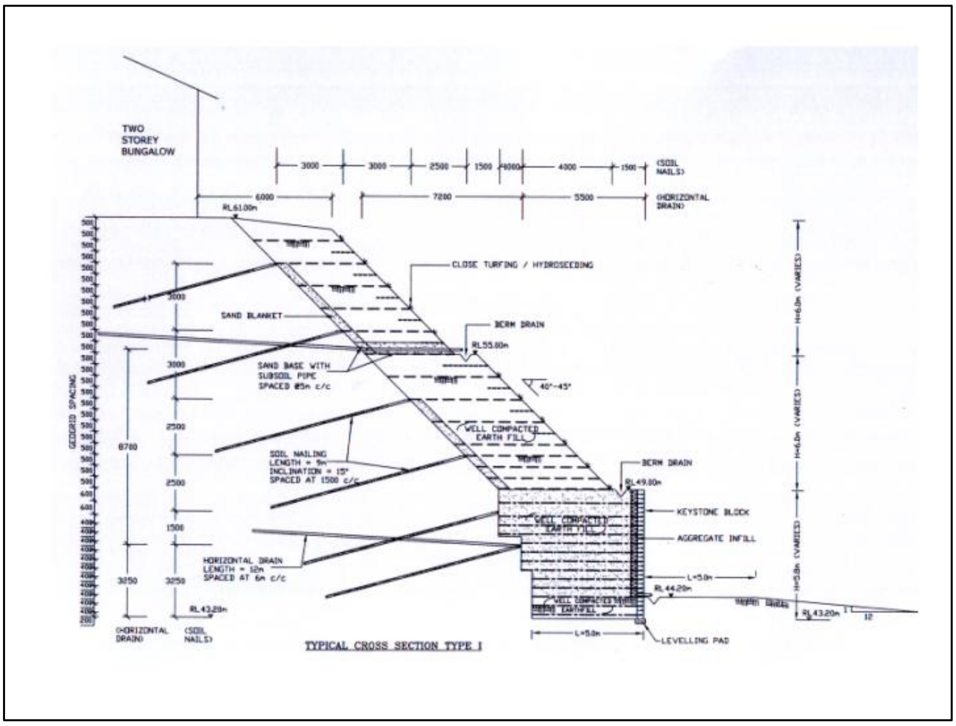

Figure17b Scheme of slope rehabilitation

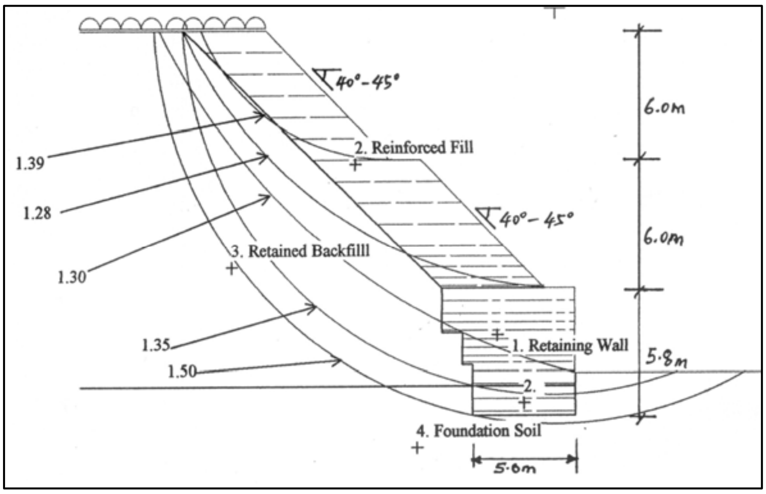

Figure17c Stability analysis of the rehabilitation scheme.

Figure 17d Construction of Modular Block wall with geogrid.

Figure 17e Picture of rehabilitated slope.

Figure 17 Failure and rehabilitation in cut of old fill slope

3.8 Kuantan-Kerteh Railway Landslide

The Kuantan – Kerteh railway landslide at Chainage 19700 happened during the monsoon period of November – December 2005 soon after the project was completed and in operation. The cut slope of more than 40m high consists of residual soil of sandstone/shale formation. Poor drainage caused serious soil erosion and slope toe softening. The slope failure involved a slope height of 37m. Sheet piles were driven in an attempt to prevent the slope toe from encroaching into the ballast of the railway lines. The sheet piles tilted badly shortly after installation and threatened to endanger the safe operation of the railway lines. The slope toe including the railway lines were all waterlogged. The detail of this slope repair was reported by Ooi *et al* (2007). Figure 18 shows the picture of the slope movement and the railway lines, the schematic rehabilitation, the construction of the geogrid block and the rehabilitated slope.

Figure 18a Overview of cut slope failure

Figure 18b Collapse of slope and sheet pile movement

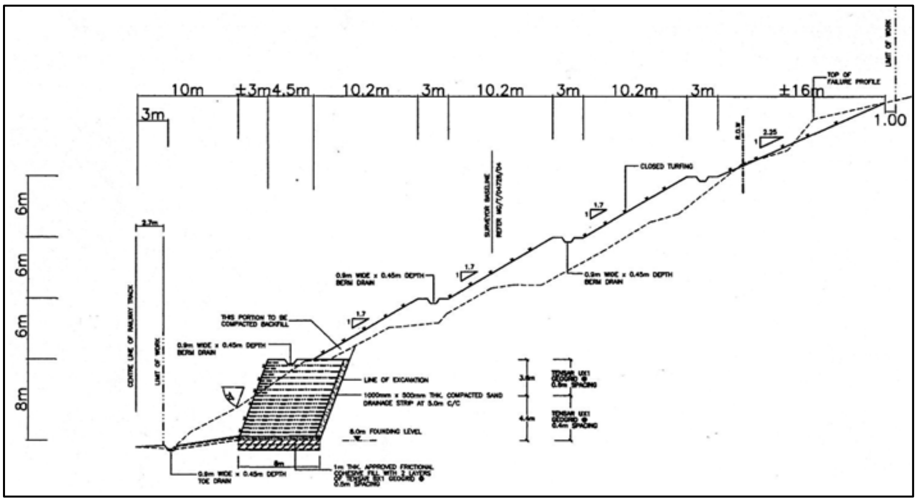

Figure 18c Schematic rehabilitation with setback of slope using reinforced geogrid block

Figure 18d Construction of geogrid block on stabilized base

Figure 18e Turfing of geogrid block

Figure 18f View of rehabilitated slope

Figure 18g Overall view of rehabilitated slope

Figure 18 Cut slope failure endangered railway lines

3.9 Tapah-Ringlet Road, Cameron Highland

The Tapah-Ringlet Road is a 2-laned road built in the 1920s. It was common in those days to build roads along the hilly terrain with narrow access and generally with steep cut on one side and filled slopes adjacent to valleys on the other. The slope angles are between 40 to 70 degrees. Typically cut slopes are on the left with filled slope on the right when going up to Cameron Highland and always with narrow and tight turnings/corners commonly referred to as hair pin bends. The road often crosses small valley and drainage paths as it winds up the hills. Landslips of filled slopes are often caused by over-fills and water from incessant rains, uncontrolled surface runoff and sub-surface seepage. The problems of road cuttings in West Malaysia were reported by Bulman (1967) and Ting (1984).

In 2007 a slip occurred at the road embankment of the Tapah-Ringlet road in Batang Padang in the Perak state of Malaysia. The slip affected the traffic flow between Tapah and Cameron Highland. The slip also affected a culvert and the cascading drain of the road. It was observed that the slip was caused by surface water flowing over the embankment during exceptional monsoon rainstorm. Figure 19 shows picture of the collapsed embankment, the schematic rehabilitation, the construction in progress and picture of the rehabilitated slope. It can be seen that for vertical face wall the galvanized, PVC coated rock-filled gabion was used with geogrid as reinforcement and tailed in of gabions to prevent any tilting of the gabions. For slope with 70 degree, steel mesh was used as permanent formwork and 0.5m thick rock-filled faced, wrapped around and reinforced with geogrid. In the case of 45 degree slope closed turfing (full-grown cow-grass cut-out with top soil in size of 300mmX300mm and secured with timber pegs) was adopted. It is important to water and maintain the new turfing for initial period of few weeks until it is capable of being self-sustained. It is normally good practice to provide wide road shoulder to ease traffic flow and to allow easier negotiation of tight corners/turnings and bearing in mind that all overfill on slope must be trimmed back and re-compacted.

The following considerations are important in the rehabilitation works:

i. Road shoulder should be widened to allow space for self cleansing over-sized roadside drains, walkway for Orang Asli (the Natives) and safety guardrails;

ii. Roadside drain must also take into consideration of possible damage by tyres of cornering vegetable-laden trucks plying the road sending vegetable produce from Cameron Highland to Kuala Lumpur and that it should also not be hazardous to motor-cyclists.

iii. It is preferable to allow surface water to flow along the road with suitable scupper take off and collection points for the road surface runoff. The premixed road surface must be suitably super-elevated to ensure safety to traffic. Cross over pipe culverts are provided for road surface super-elevated towards the cut slope and over capacity sumps and cascading drains are adequately provided and discharge to proper reinforced concrete outflow structures with rock-fills rip rap to safe ground.

iv. It is generally cheaper to use compacted earth fills, but in this case sand is relatively cheap and easily available and hence good to use with better strength and drainage properties.

v. Filling of access road to the bottom of slope is tricky and care must be taken not to cause over-fill and over-stress the lower slope

vi. Benched excavation is important to ensure the new construction is well-keyed into existing ground and all loose materials at inter-face are removed.

vii. Ensure sand columns and drainage base with proper usage of geotextiles for filtration, drainage and separation functions and ensure no softening of slope toes.

Figure 19a Collapse of embankment

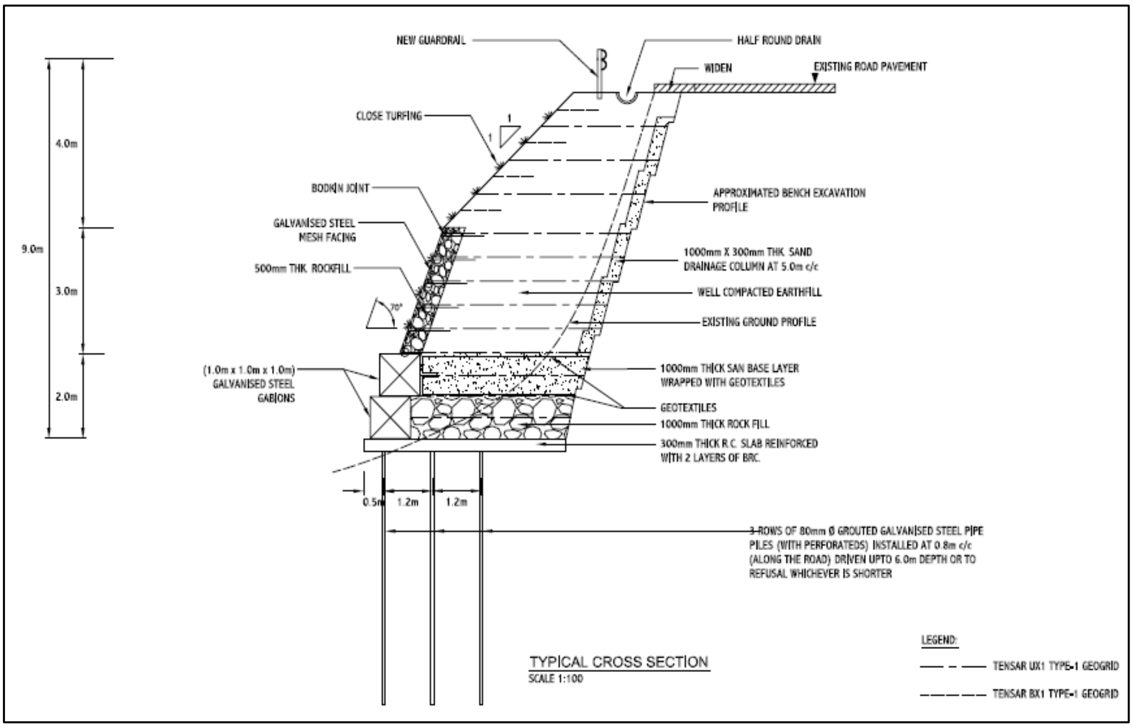

Figure 19b Schematic rehabilitation of embankment failure

Figure 19c View of slope on rehabilitation

Figure 19d view of slope on rehabilitation

Figure 19e Recent view of rehabilitated slope

Figure 19 Collapse of Tapah-Ringlet Road embankment, Tapah, Cameron Highland.

3.10 Zooview Landslide, Ulu Klang, Selangor

An old filled slope of an existing housing scheme has been a constant source of worries and nightmares to the row of terrace houses on top of the Taman Zooview slope with a commanding view of Kuala Lumpur city centre. The site was a former valley filled by the Taman Zooview developer. Figure 20 shows the condition of the site two years before the landslide, the construction of the anchored reinforced soil wall, the rainfall histogram, the landslide, the rehabilitation and the completed geogrid reinforced soil slope. Figure 20a shows picture of the Zooview slope in 2004 all covered with plastic sheets. Behind the plastic sheets all is not well. An anchored reinforced soil wall was constructed in 2006 as shown in Figure 20b. The year 2006 has been particularly wetter than previous years. Figure 20c shows the histogram of the rainfall 2005 and mean.

Figure 20d shows the collapse of the anchored reinforced soil wall 10 days after completion during the May 2006 monsoon season. Figure 20e shows a distant view of the landslide area covered in plastic sheets. Figure 20f shows the condition of the slope behind the plastic sheets. Figure 20g shows the schematic of rehabilitation of failed slope. Figure 20h and 20i show the respective picture of lower rock fill and upper geogrid embankment. Figure 20j and 20k shows the earthworks at formation level of the backyard. Figure 20l shows the spacious back garden. Figure 20m shows the devastated condition of the back yard before rehabilitation. Figure 20n shows the rehabilitated slope on completion. Figure 20p shows the rehabilitated slope with turf established.

Figure 20a Condition of Zooview slope in 2004

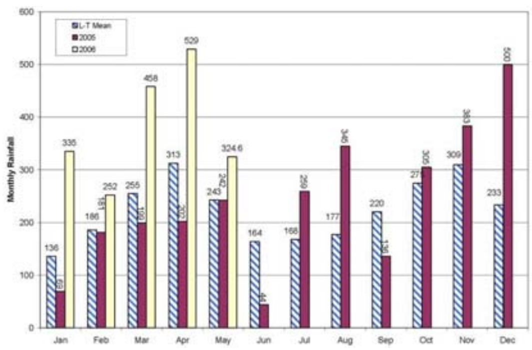

Figure 20c Histogram of monthly rainfall record for 2005 & 2006

Figure 20b Anchored soil wall completed on 21st May 2006

Figure 20d Collapse of anchored soil wall 31st May 2006

Figure 20e A distant view of the Zooview landslide with plastic sheet cover

Figure 20f View behind the plastic sheets

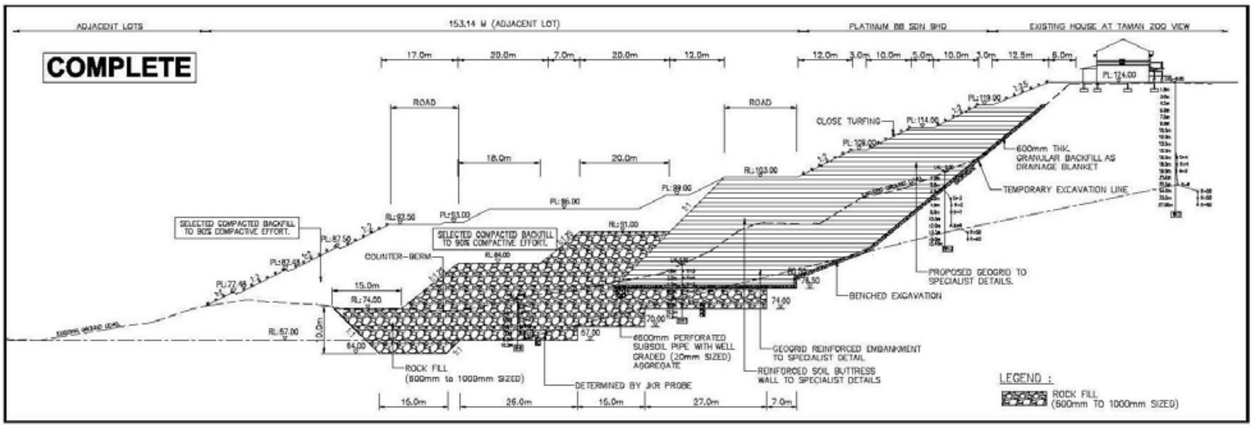

Figure 20g Schematic rehabilitation of slope failure

Figure 20h Construction of lower rock fill embankment

Figure 20i Construction of upper geogrid embankment

Figure 20j View of earthwork reaching the top at the backyard.

Figure 20k View of earthwork reaching the top at the backyard.

Figure 20l View of rehabilitated spacious backyard

Figure 20m Condition of backyard before rehabilitation

Figure 20n Rehabilitated slope on completion.

Figure 20p Rehabilitated slope with turf established

Figure 20 Pictures showing histories of slope instability and rehabilitation of landslide at Zooview.

3.11 U9 Shah Alam Slope Failures

U9 slope is a residual soil slope of Kenny Hill Formation consisting of sandstone and shale with quartzite intrusions. The slope is about 25m high and has been cut back for housing development. Figure 21a shows the slope failures. In 2004 a tender was called to rehabilitate the slope. Unfortunately, the slope collapsed during the midst of rehabilitation and affected the sale of the houses. Figure 21b shows the schematic rehabilitation using Terramesh solution. Figures 21c and 21d show the conditions of the site after the collapse. The toe wall at the bottom of slope had moved and tilted and were demolished. Figure 21e shows Terramesh in slope area not affected by landslide. The slope failure had caused the developer to hold back construction of houses near the slope.

In September 2007 another tender was called to rehabilitate the failed slope as a Design and Build project. Geogrid solution was selected based on the schematic rehabilitation proposal as shown in Figure 21f. This proposal has a minimum factor of safety of 1.55 as shown in the slope stability analysis in Figure 21g. It was the most competitive tender accepted by the client.

Figure 21h shows the commencement of rehabilitation works in November 2007. It can be seen that the landslide has encroached into the housing development site. Figure 21i shows the construction of slope drainage and Modular Block wall in progress. The rehabilitation work was completed with turfing in July 2008. The exposed fissures of the boulders were patched with cement mortars and formed part of the landscape features of the upper turfed slope. Figure 21j shows the view of completed slope rehabilitation with Modular Block wall and construction of houses in September 2008. Figure 21k shows the picture of the completed slope rehabilitation, Modular Block wall and houses in April 2009.The construction of houses were completed in October 2008. Modular Block wall, geogrid reinforced slopes complete with drainage and turfing were completed in December 2008. By April/June 2009 all houses were constructed, sold and occupied. This is a project where the purchasers are comfortable with the idea of living near a slope. Throughout the design and construction of slope rehabilitation, public safety and drainage were both amongst the top most priority of the client.

Figure 21a View of slope failure in March 2004.

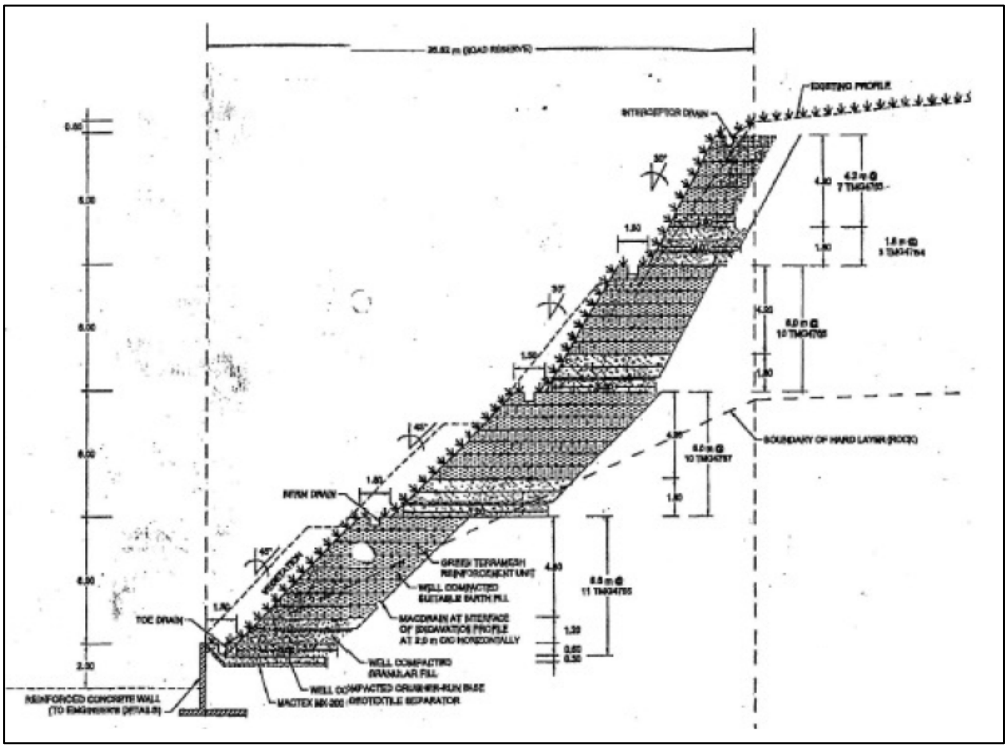

Figure 21b Terramesh solution was used in the 2004 rehabilitation.

Figure 21c Picture shows tilting of RC toe wall.

Figure 21d Picture shows RC toe wall and Terramesh after slope collapsed.

Figure 21e Picture shows Terramesh in slope area not affected by landslide.

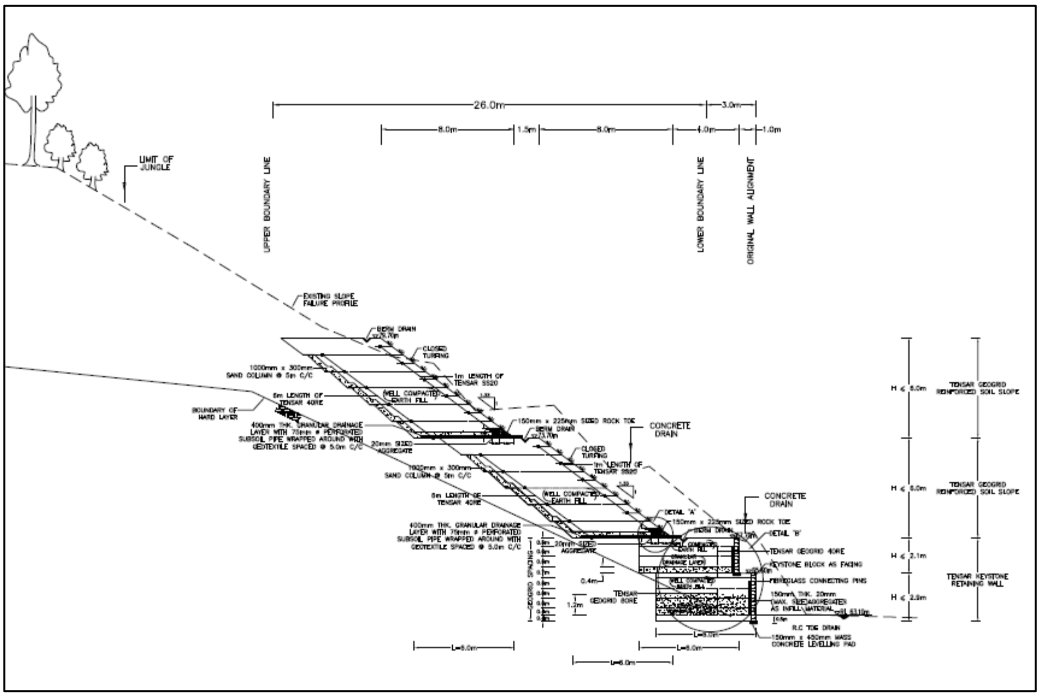

Figure 21f Geogrid solution for rehabilitation of failed slope.

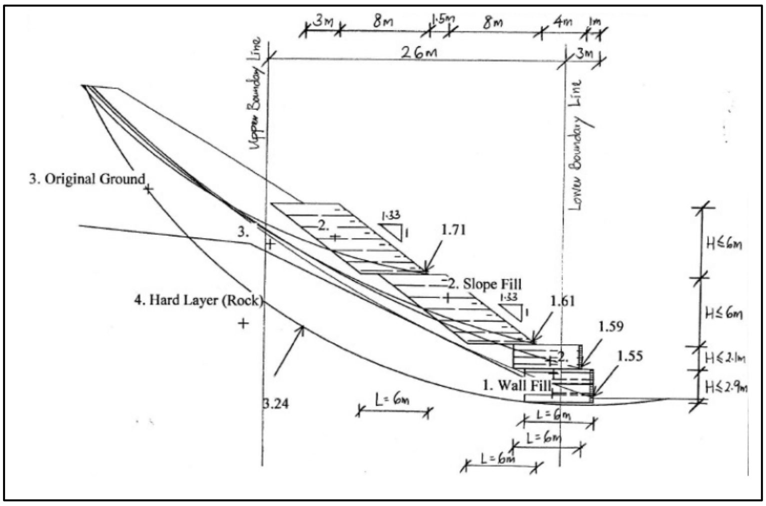

Figure 21g Slope stability analysis.

Figure 21h Picture shows clearing for access to site.

Figure 21i (i)

Figure 21i (ii)

Figure 21i (iii)

Figure 21i Constructions of slope drainage structures and Modular Block walls in progress.

Figure 21j (i) September 2008

Figure 21j (ii) October 2008

Figure 21j (iii) December 2008

Figure 21j View of completed slope rehabilitation of Modular Block walls and slopes.

Figure 21k (i) June 2010 showing slope and houses

Figure 21k (ii) April 2009 showing houses and walls

Figure 21k (iii) April 2009 showing houses and slope with trees

Figure 21k View of completed slope rehabilitation and houses, April 2009 & June 2010

Figure 21 Rehabilitation of U9 Shah Alam slope failures.

4. SINGAPORE EXPERIENCE

Yong *et al* (2007) reported in the 40th Anniversary SEAGS volume that in Singapore, the Public Works Department (now known as Land Transport Authority (LTA)) specified horizontal layers of geogrids or polymer mesh to reinstate slope failures. The stronger or main geogrids were laid at every 1.0 m vertical intervals with two layers of secondary geogrids in between. The geogrids were placed to intersect potential failure planes and they helped to reinforce the slopes. A 300 mm thick drainage layer of sand was also provided at the excavation surfaces in order to control any groundwater seepage as shown in Figure 22.

In December 1993, earth slips formed on the hill slopes located at the Telok Blangah Hill Park along Depot Road (Tang et al, 2000). The height of the failed slope was about 40 metres, and the width of the affected portion was about 20 metres. The slope is geologically located in the Jurong Formation, which consists of sedimentary rocks such as sandstone, siltstone and shale. The failure surfaces were found to be shallow, at about 1.5 to 2 metres below the ground surface. The stabilization works involved soil reinforcement and slope regrading. The upper half of the failed slope was reinforced with geogrids made of high strength polymer (high density polyethylene). The bottom half portion of the failed slope was regraded to a gradient which is gentler than 1:2. The geogrids were laid horizontally in continuous strips which had been cut to the design lengths of about 7.5 to 10 metres. The geogrid reinforced soil layers were 800mm thick. As there was a possibility that the slope surface might bulge due to the lateral pressures from the confined backfilled soils, additional 2 layers of 1 metre length secondary geogrids, which act as intermediate reinforcement layers, were laid in between every geogrid reinforced soil layers. Mattings for erosion control were installed at the geogrid reinforced slope. The purpose of the mattings were to facilitate the growth of grasses on the slope surface, as the slope angle of 35° was rather steep. Close turfing and top soil were placed on the stabilized slope surface to prevent erosion and to create a natural and aesthetic appearance.

This report is in general consistent with the practice in Malaysia as shown in this paper. However, Malaysian experiences showed that close turfing is generally preferred in Malaysia though matting has also been used in certain projects.

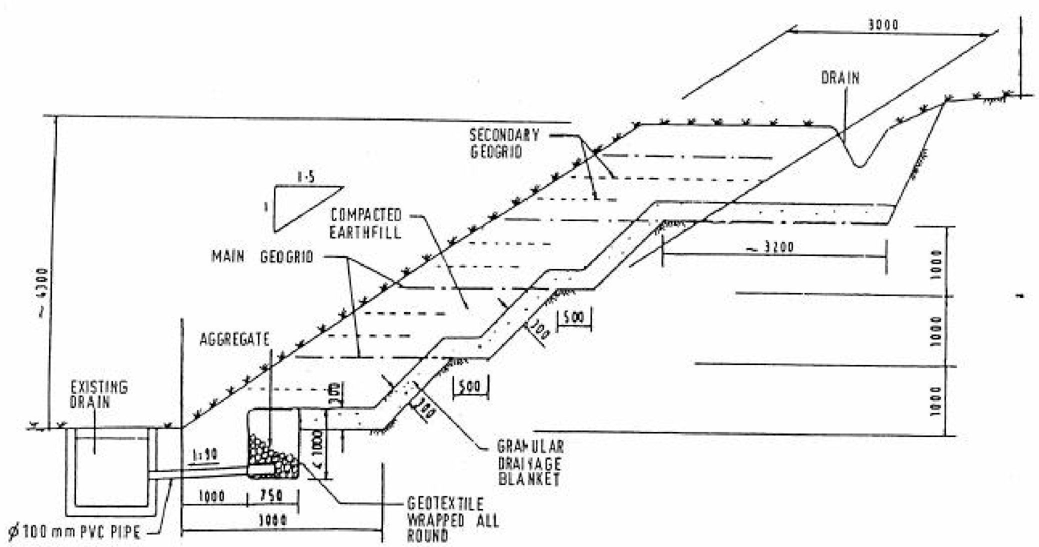

Figure 22 Slope stabilization using geogrids in Singapore (after Tan S. B., 1997, Yong *et al* 2007)

5. SUMMARY AND DISCUSSION

1. The first project in Malaysia to use geogrid is the basal reinforcement of the Jitra-Butterworth Highway in 1984/1985 where a 4m high embankment experienced instability problem in December 1984. This project is already 26 years old.
2. The successful geogrid projects reported at the Symposium on Polymer Grid Reinforcement held in London in 1984 gave encouragement to the use of geogrid in Civil Engineering Works in general and the rehabilitation of failed slopes and embankments in particular.
3. In Malaysia early works on slope repair were carefully instrumented as in the case of Motel Desa and Fraser's Hill Petronas Bangalow slope failures respectively (Toh *et al*, 1986 and Chin *et al*, 1989). The results were used to improve design and construction methodology in subsequent projects.
4. In 1985 the Public Works Department Malaysia was the first to use geogrid reinforcement to rehabilitate a failed road embankment slope in the Temerloh- Mentakab Bypass and it has been performing satisfactorily for the last 25 years. Since then many such rehabilitation works have been carried out.
5. The Air Keroh -Senawang Expressway Embankment failure was due to loose overfill on slope. The slope rehabilitation was carried out in 1989 which is about 20 years old and had performed satisfactorily. This case history has also shown that precast reinforced concrete piled retaining wall exhibited design is less sustainable when compare to geogrid reinforced soil. Besides, it is not stable due to the poor bending and shear capacity of the small precast piles as discussed by Ooi & Tee (2011). Yee & Ooi (2010) has shown that the carbon footprint of precast reinforced concrete piles to be significantly higher than using insitu materials.
6. Sg. Serai used tailed-in gabion to support the geogrid reinforced slope using insitu granite residual soil. Turfing and tree planting were used to green the environment. The slope remains stable after 23 years.
7. Normah Medical Centre in Kuching, Sarawak has its vertical geogrid reinforced retaining wall with turfed face built in 1986. This is so far the only vertical geogrid turfed face wall.
8. Asrama SM Tun Saban used soil nails to provide the temporary stage cut back of the slope. The soil nails also provided the required overall global slope stability for the Modular Block walls.
9. Tapah cut slope failure in Kaolin was also first in Malaysia in the stabilization of Kaolin slope using geogrid reinforcement. The use of drainage technique was crucial for its successful implementation.
10. Sains Kolej Kuching uses only Modular Block wall and geogrid reinforcement for the rehabilitation of the failed slope.
11. In the case of University of Malaya (UM) cut slope stabilization, the slope was a former fill ground of uncompact fill over a slope. The contractor should have installed the soil nails at each level of cutting. Instead the slope was cut in one operation and it collapsed before soil nailing. Hence it is important to spell out the methodology of work clearly so that failure can be avoided.
12. The repair work at UM used the combined technology of soil nails and geogrid and Modular Block wall. This combined technology is a robust solution and has been used in many similar slope repairs successfully.
13. Kuantan Kertih cut slope failure was due to poor drainage design as evidenced by the broken berm drains on slope and waterlogged ground at the toe of the slope and near the railway lines. The slope was cut back with a geogrid reinforced wall to provide better sight distance and clearance for the railway line. Internal and surface drainage were highlighted in the design for the slope rehabilitation. Safety of slope was monitored at all stages of construction.
14. Tapah-Ringlet road rehabilitation presented great challenge because of the site constraints. It can be seen that the finished product blends in well with environment and is a preferred solution of slope repair in the push towards the use of green technology.
15. Zooview landslide, like the landmark case of the Highland Towers Condominum and the high profile Bukit Antarabangsa landslides involves man made fill over a former valley. These old fill grounds became unstable during exceptional monsoon period when the drainage system was not working properly due lack of maintenance. During the rehabilitation of failed slope at Zooview, the rock fill and geogrid embankments were carefully monitored during the rehabilitation work to ensure safety of the houses during construction. When completed the house owners moved back within two years from the date of the landslide with spacious backyard. In contrast, the Highland Towers Condominium owners had to fight their case in court and still could not move back to their houses after 18 years. The key lies in getting the failed slope rehabilitated. The rehabilitation of Bukit Antarabangsa massive landslide, taking the cue from the Zooview precedent, also proceeded with Government initiatives.
16. Kota Damansara slope failure rehabilitation has been submitted by Ooi and Tee (2011) to the 14ARC to be held in May 2011 in Hong Kong. The rehabilitation work modelled on the concept of slope repair of that of Zooview where rock fill was used as the first embankment to provide the stability of the rehabilitation work. The rock fill also provided the lining for the pond. Geogrid embankment was then built on top of the rock fill embankment. Construction of food court on top of the slope proceeded after slope rehabilitation and the place has been occupied for the last two years.
17. The U9 Shah Alam slope repair shows that it pays to get it right the first time. The two tiers Modular Block wall and the geogrid reinforced slopes were designed with factor of safety of 1.55 because of the proximity of the walls and slopes to the houses. Public Safety and generous drainage are two key elements that Professional Engineers cannot compromise to ensure successful project delivery beyond client expectation. Geogrid has again proven to be most cost effective and safe solution in this case. House owners are comfortable to live next to a geogrid reinforced slope as shown by the sale of the houses.
18. Geogrid technologies help to save materials and resources. It is a sustainable construction method.
19. Geogrid technologies utilize inferior in-situ materials and reduce waste.
20. Geogrid technologies reduce CO_2 emission (less transport less CO_2).
21. Geotechnical design is often associated with risks, failures, disputes, rehabilitations and mitigations. The introduction of reduction in carbon footprint in geotechnical works will no doubt add to complicate the issues discussed above. Ooi & Ooi (2010) has comprehensively dealt with the subject matter at the 19th Professor Chin Fung Kee Lecture in 1999.
22. Triaxial Geogrid has been used at Cyberjaya Q-Cell Factory located in the Selangor Science Park after a full scale trial in 2008/2009. Triaxial Geogrid is becoming popular and used in other JKR road projects.

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