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Supporting Infrastructure Growth with Geosynthetics

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Abstract

The Arusha Bypass project necessitated construction integrating a geosynthetic solution on the section of the site that was underlain with "black cotton" soil. This material is classified as a collapsible and an expansive clay that could cause damage to the overlying road structure through continual cycles of heave and shrinkage, with subsequent differential settlements.

The inclusion of geosynthetics in the road layers was envisaged to have benefits of enhancing the load-bearing capacity of the soil, and reducing the differential settlement undergone. A strong and flexible separation geotextile positioned at the soil interface in the construction prevents the migration and mixing of materials, yet allows free movement of water thus preventing the build-up of hydrostatic pressures. The durability and mechanical properties of high quality nonwoven virgin polypropylene geotextiles, with a projected product design life durability beyond that of the design life of the structure, makes them ideal as separation layers in the construction works. The inclusion of a relatively stiff high strength geogrid provided the additional stability to the road embankment structure. This permitted the design and subsequent construction of the road to progress in an area that has limited quality fill material, and extensive environmental restrictions.

Keywords: *Geotextile, Separation, Subgrade, Pavement, Load-Bearing Capacity.*

1 Introduction

With the ever increasing growth of cities, engineers are often faced with construction in sub-optimal soil conditions. In the tropical regions, these weak subgrades with low CBR strengths are classified as "black cotton" soil, characterized by high compressibility and expansive nature. Such conditions render structures unable to withstand required design loads and are thus susceptible to high degrees of differential settlements and heaving associated with excessive distress leading to damage.

The use of imported quality fill materials, if available, to improve the load-bearing capacity of the subgrade has limited benefits, which often necessitates an alternative design approach to optimize on-site conditions within design parameters for long term durability. The accumulation of the load as the construction process progresses including the continuous movement of construction machinery on site; and also the active loading during the design life of the pavement structures sometimes leads to migration of the fine grain particles into the granular fill, and penetration of the large granular particles into the soft subgrade (Love et al. 1987). The consequence of this tends to lead to deterioration in the structure of the soil layers, resulting in deformations and ultimately leading to structural failure. In addition, the limited availability of quality fill to stabilize the weak subgrade is also a problem faced in the construction process. This can cause scheduling delays as a result of having to import the required material from distant quarries to site, or the use of alternative ground improvement methods which are comparatively expensive, affecting the feasibility of projects (Moayed and Nazari 2011).

Innovative ground improvement approaches are now used to solve these unique soil-related problems, and often are considered to be the most economical means to improve an undesirable site condition. Construction with geosynthetics is one of the approaches that have been incorporated in the design of pavement structures. Its aim is to stabilize the soils, making them more suitable for engineering applications (Maxwell et al. 2005). The use of geosynthetics in geotechnical construction projects has gained tremendous popularity over the past 30 years, and their use in large-scale civil construction projects has made the resulting structures safer (Erickson and Drescher, 2001). The inclusion of geosynthetics in soil layers has shown the benefits of enhancing the load-bearing capacity of the soil, and reducing the differential settlement undergone by the structures (Kazimierowicz-Frankowska 2007).

Geosynthetics incorporated at soil interfaces offers separation in soils of different quality, thus reducing the potential mixing of the particles that would result in a reduction in the strength. Geotextile products are primarily used in separation of multi-soil layers; however they also provide adequate reinforcement to the soil, through the tensioned-membrane effect. Where the in situ ground strength is marginal and the bearing capacity is low, the incorporation of geogrids improves the stability, further preventing differential settlement and structural failures.

2 Background

Road transport plays a significant role in the socio-economic development of both Tanzania and Kenya by linking economic centres and accounts for more than 90% of motorized freight and passenger traffic in each of the two countries. The biggest part of the road network in each country forms part of the East African Community (EAC) regional trunk road network, and therefore serves as transit for exports and imports through the Mombasa and Dar-es-Salaam ports for the land locked countries to the west, namely, Rwanda, Burundi, Uganda and Eastern Democratic Republic of Congo (DRC). As such the two countries, Tanzania and Kenya, have developed investment programs in the transport sector to promote inter-state and international trade, enhance economic activity and promote co-operation and integration of the EAC region (Feasibility Studies Report, 2012).

The Arusha-Holili/Taveta-Voi road is one of the transport corridors of the EAC region identified to reduce the cost of doing business, increase competitiveness of the region on the global market and at the same time promote regional integration. Figure 1 shows the overview of the Arusha-Holili/Taveta-Voi road project that links the EAC region to the Port of Mombasa.

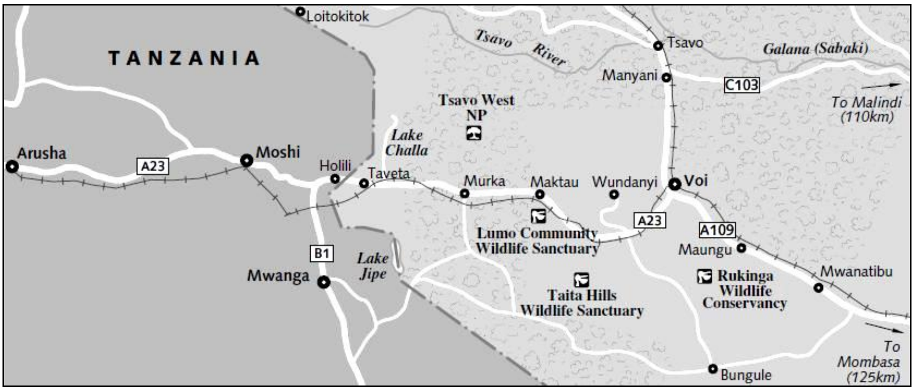

Figure 1: Overview of the Arusha-Holili/Taveta-Voi road project linking to Mombasa Port.

The project entailed the improvement of the regional road network of Tanzania and Kenya as part of the East African road network by constructing the:

- Arusha Bypass (42.2 km)
- Sakina-Tengeru dual carriageway (14.1 km)
- Mwatate-Taveta road (89 km)
- Taveta Bypass (12 km)

The construction is intended to meet the increasing traffic volumes and alleviate the traffic on the existing road network between the two countries. The Arusha bypass road section commences once the Arusha-Holili-Taveta road is complete, which is expected to link the Sakina section with the Tangeru suburb in Arusha. Once completed, the bypass road project is expected to decongest traffic in the growing city of Arusha.

3. Site Conditions

The project area is divided into three climatic zones, namely the upper, middle, and lowland zones. The upper zone lies between 1350 m and 1800 m above sea level (ASL) has average of annual rainfall of 1000 mm, while the middle zone lies between 1000 m and 1350 m a mean annual rainfall 500 m. The lower zone lies below 900m asl and receives an average annual rainfall of below 300 mm. Knowing these climatic zones assists in the road design, specifically the drainage requirements in order to prevent build-up of water and subsequent damage of the structure.

The topography of the project area is characterized by slightly undulating, rolling hills with steep slopes, which are dissected by several perennial and seasonal rivers, with short sections of flat land. The majority of the Arusha – Holili Road lies in the Pangani catchment area, with ranges of mountains, which are sources of most of the rivers between Arusha and Moshi road section in the North of the road.

The project road traverses a total of 57 perennial and seasonal rivers. While most of the rivers in Arusha, Arumeru and Moshi Districts are perennial, all the rivers in the Hai/Siha and Rombo districts project area are seasonal. In addition, a large number of open channels that are used for vegetable garden, orchards, paddy, banana, flower farms are crossed by the project road at several points (Project Appraisal Report, 2013).

3.1 In situ Soil Characteristics

According to the Feasibility Studies Report (2012), the underlying geology of the area surrounding the project road is composed of typically alkaline volcanic; olivine basalt, alkali basalt, phonolite, trachyte, nephelinite, and pyroclastics. Surface soils are derived entirely from volcanic materials and are mainly volcanic ash, sometimes overlying stream deposits. There are four main types of soils: namely Sodiluvic Chernozems (soil with accumulation of high activity clays and high base saturation), Eutric Leptosols (very shallow soils over hard rock), Eutric Nitisols (deep, dark red, brown, or yellow clayey soils), and Eutric Cambisols (weakly or moderately developed soil).

The different clay groups are differentiated by their basal spacing. However, some clays can change the basal spacing as they can vary their layer spacing. This occurs with the intercalation of water, causing swell. Alternatively dehydration occurs, causing shrinkage. The mode of formation of clay varies between the non-expansive and the expansive clays. The most commonly occurring non-expansive clay has a 1:1 lattice type clay mineral, and will typically form by the decomposition of the minerals in rocks in regions of high temperature and rainfall, conditions prevalent in the North-East of Tanzania. The high rainfall removes the bases from the clay as soluble compounds, leaving behind a residue of silicates in which kaolinite is dominant. In areas with low rainfall or impeded drainage, chemical weathering becomes less prevalent and the soluble bases are not leached from the soil. This leads to the formation of 2:1 lattice expansive clay minerals. Water molecules enter between the successive sheets and it is the change in this water content which causes expansion or shrinkage of the sheet structure and hence of the soil mass (Jennings, Brink & Williams, 1973).

Laboratory soil tests on the in situ material resulted a plasticity index of 32%, which indicates a high degree of expansiveness, and an average swell of 2.5% after compaction. The in situ material was classified as slightly moist, black, soft, loose, slickensided clay; also known as “black cotton” soil. Figure 2 shows the depth of the “black cotton” soil at one of the test pits on the road section.

Figure 2. Depth of black cotton soil at road section (Image source: Nabaki Afrika, 2017).

3.2 Imported Fill Material

Prior to selection of the fill material the following was conducted, according to the National Field Testing Manual (2013), in the determination of pavement and earthworks materials:

1. Establish the type of road (bituminized/gravel/earth), whether trunk road or not, road width, design traffic loading and the designers' preliminary views on alternative pavement types and material quantities for pavement construction.
2. Establish whether the horizontal alignment is fixed, or can be moved, or is likely to be moved after the soil survey has been carried out.
3. Obtain as much information as possible about the vertical alignment and areas of likely cut or fill, and the likely depth of cut and fill and locate these areas on maps for use in the field.
4. Estimate the need for earthworks fills and their likely position along the road line.

The proposed natural gravel material (borrow material), which had to meet the national road standard specification for fill layers, had to have a plasticity index of 20%, a swell of 0.67, and a CBR of 19% at a 93% compaction; in order to reduce the effect of the in situ material swelling.

4 Proposed Solution/Project Design

Given the existence of marginal soils, clay with a low load-bearing capacity, this necessitated excavation of the in situ material and importation of quality fill to enhance the strength of the road foundation. In addition, the sections at different locations that crossed valleys required construction of embankments with varying heights of 1 – 5 metres.
The project design for the Arusha bypass consisted of the following layers, from top down:

- 50 mm asphalt concrete (AC) surfacing
- 175 mm Dense Bitumen Macadam (DBM40)
- 200 mm cemented-stabilized sub-base (CM)
- 150 mm improved subgrade (G15)

The 150 mm of the improved G15 subgrade was retained, and the alternative with a crushed stone rock base rejected due to unavailability of good quality road building materials. An envisaged shortage in the supply of angular rock or crushed stone and a determination to conserve the environment dictated the engineering design of the road.

In order to ensure stability in the road section underlain by marginal soils, the design team determined that the incorporation of geosynthetics in the subgrade and sub-base layer would increase the stability of the road embankment. The geosynthetic products incorporated were a separation geotextile, to prevent the mixing of the in situ subgrade clay and the imported fill material, and a reinforcement geogrid that would increase the bearing capacity of the road, minimize the effect of the swelling and heaving clay, and prevent differential settlement and potential structural failure. The functions of geosynthetics in road applications are divided into the categories; separation, stabilization/reinforcement, filtration, and drainage. Regardless of the type of construction, geosynthetics perform at least one of these functions.

4.1 Geotextile Selection

Where the CBR strength of the in situ material is greater than 3%, the use of a geotextile would prevent mixing of in situ subgrade soil and coarse aggregate fill material. However, for in situ soils with CBR less than 3%, it would be recommended to have additional stabilization geosynthetics in addition to the separation requirement, which would adequately be provided by a high tensile strength geogrid. The factors necessary to determine the type of geotextile material to aid in the separation function include, but are not limited to the:

- In situ subgrade soil conditions and strength
- Type of subsoil
- Expected hydraulic flow, to ensure no build-up of hydrostatic pressures
- Construction condition, in terms of vehicular loads and compaction impact
- Expected design traffic loads, for the completed road structure
- Type of fill material, to determine the potential subjected puncture forces

Table 1 shows the input data obtained from the project design information and the soil characteristics studies conducted that were used in selection of the separation geotextile.

Table 1. Input Data used in determination of Separation Geotextile.

Factor (Input Data)	**Value**
In situ subgrade soil strength	< 3% (weak soil)
Type of subsoil	Clay, fine clay
Hydraulic flow	Bi-directional flow/dynamic loads (traffic areas, embankments)
Construction conditions	Heavy construction vehicles and heavy compaction
Traffic loads	High – medium volumes (>500 vehicles)
Filling/aggregate material	Rounded material d_{max} < 64mm
Structure design life	> 25 years

From the input data shown in Table 1, and according to EN 13249 (2001) design standards, the geotextile required should have the material properties as indicated in Table 2.

Table 2. Separation Geotextile minimum Requirement.

Property	**Test Standard**	**Basic Requirement**
Average tensile strength	EN ISO 10319	16 kN/m
Average elongation at maximum elongation	EN ISO 10319	50%
Energy Index	EN ISO 10319	4.0 kN/m
Static Puncture (CBR Test)	EN ISO 12236	3230 N
Dynamic Cone Drop	EN ISO 13433	15 mm
Opening Size ($O_{90\%}$)	EN ISO 12956	70×10^{-3} mm
Velocity Index	EN ISO 11058	0.03 m/s

In order for the selected geotextile material to achieve the desired design life, it should be covered within 2 weeks of installation to prevent deterioration due to weathering. In addition, the geotextile should be installed in natural soils with pH ranging between 2 and 13, and a maximum soil temperature of 25°C. The selected geotextile should meet the mechanical and hydraulic properties as indicated in Table 2, and the durability requirements.

4.2 Geogrid Selection

Due to the subgrade strength lying below 3% there was a necessity for additional stabilization and reinforcement using a geogrid. The design and selection of the type of stabilization and reinforcement geogrid is influenced by, but not limited to, the following factors:

- Subsoil in situ conditions
    - CBR value at the surface of the in situ soil
    - CBR value of the subsoil
    - Soil type (Clay/Silt/Sand/Peat)
    - Ground water level
- Base Course required conditions
    - CBR value required at the surface of the base course
- Fill material for Base Course
    - Type of material (Gravel/Crushed Stone/Recycled Material)
    - Shape of material (Rounded/Angular)
    - Particle size
- Loading conditions (stresses subjected by traffic)

Table 3 shows the input data obtained from the project design information and the soil characteristics studies conducted that were used in selection of the stabilization and reinforcement geogrid.

Table 3. Input Data used in determination of Stabilization and Reinforcement Geogrid.

Factor (Input Data)	**Value**
CBR value at the surface of the in situ subgrade	< 3% (weak soil)
CBR value of the subsoil	≈ 19%
Soil type	Clay, fine clay
Ground water conditions	> 2 m
CBR value required at the surface of the base course	> 50%
Base course material	Crushed stone
Shape of fill material	Rounded
Particle size	d_{max} < 64 mm
Loading conditions	High – medium volumes (>500 vehicles)

From the input data shown in Table 3, and according to EBGEO (2011) design standards, the geogrid required should have the material properties and performance criteria as indicated in Table 4.

Table 4. Stabilization and Reinforcement Geogrid minimum Requirement.

Property	Test Standard	Basic Requirement
Tensile strength at 2% elongation in the machine direction	EN ISO 10319	> 40 kN/m
Average elongation at maximum tensile strength	EN ISO 10319	< 7%
Long term design tensile strength (60 years design life)	BS 8006: 2010	> 80 kN/m
UV-resistance (remaining tensile strength)	EN 12224	> 95%
Weather resistance	FGSV (class)	High

The selected geogrid should meet the properties as indicated in Table 4, and should be inert to biological and chemical degradation. In addition, the geogrid should be installed in natural soils with pH ranging between 2 and 13, and a maximum soil temperature of 25°C.

5. Conclusion

The improvement of the Arusha – Holili/ Taveta – Mwatate road is essential for the development of the economy of the East African Region. This is because the road is a very important link between Tanzania and Kenya as it facilitates most of the cross border trade between Kenya and Northern Tanzania through the port of Mombasa and so will contribute to poverty reduction among the communities along the road provided that the negative impacts identified are adequately mitigated. The road is also used by tourists from Arusha, through Kenya or directly through Kilimanjaro International Airport to other parts of Tanzania.

In order to counter the unavailability of fill material to be used in the construction and the environmental restrictions with regard to establishing new quarries, geosynthetics were envisioned as the solution. The incorporation of a separation geotextile and a stabilization & reinforcement geogrid was undertaken in the design and subsequent construction of the Arusha Bypass road.

At completion of project implementation three outcomes will trigger the achievement of the objectives of the project; reduction of transport costs; reduction in transit and travel times; and better access to social and economic services. Construction of the Arusha Bypass dual carriageway and the ring road will significantly shorten the travel time between Usa River and Arusha city centre as well as Ngaramtoni and Usa River due to reduced traffic congestion. Reduced travel time will result into reduced operating costs of vehicles.

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