Alternative for Gravel

Sanjika Balasubramaniam, Mathivathanan Marimuthu, Anburuvel Arulanantham

Abstract: Gravel is a commercial product with various applications; road construction is one of the main applications as more than 50% of gravel is used for road construction in Sri Lanka. The primary functions of gravel in road construction are providing structural support, improving drainage and reducing the intrusion of fine particles from the subgrade. Recent infrastructure developments in Northern Sri Lanka lead to over exploitation of gravel for various purposes which have made the gravel deposits to decrease drastically. The absence of gravel brought many road construction projects to a halt. Available replacements for gravel such as aggregate base course are costly. To find alternative solutions for material shortage, research studies have been conducted on constructing pavements with stone dust, Fly Ash (FA), Waste Recycled Products (WRP), Construction and Demolition waste (CDW), Recycled Asphalt Pavement (RAP) plastic fibers/strips, scrap tyres, and geosynthetics, instead of conventional materials. This study aims to explore the alternative options to overcome gravel scarcity in Northern Sri Lanka by replacing conventional road construction materials. This paper examines the usage of locally available soil in the region reinforced with waste plastic, waste aggregate and geogrid as a replacement for road construction material instead of gravel. Series of California Bearing Ratio (CBR) tests were conducted on locally available soil reinforced with said materials to find the best alternative pavement construction material in Northern Sri Lanka. Preliminary investigations revealed that placing geogrids between layers of local soil horizontally (transverse to the direction of loading) improves CBR value of local soil significantly. Plastic strips were also found to be effective in improving the CBR values. For immediate replacement for gravel, geogrids are relatively economical over aggregate base course. By reusing waste material, this study promotes an alternative method to mitigate the environmental problems.

Keywords: California Bearing Ratio, Geosynthetics, Gravel

1. Introduction

Gravel is relatively inexpensive material with required strength, mainly used for road construction in Sri Lanka. The primary functions of gravel in road construction are providing structural support, improving drainage and reducing the intrusion of fine particles from the subgrade.

Northern provincial road network comprises of 8, 831 km long roads [national (class A and B) – 1, 271 km; provincial (class C and D) – 1, 960 km; local (class E) – 5, 600 km]. Significant portion of these roads are reported to be in lesser than satisfactory condition [1]. Recently, under the infrastructure restoration projects, substandard roads are being rehabilitated and new roads are being constructed to cater the needs of increasing population. Such road constructions require significant amount of gravel.

The escalating demand of gravel due to recent developments in the Northern Sri Lanka lead to over exploitation of gravel that have made the gravel deposits in the region to decrease drastically [2]. Further, the gravel deposits mainly found in the forests of Mullaitivu in Northern Sri Lanka are prohibited access due to the restrictions enforced by the forest department, central environmental authority and archaeological department in order to preserve natural elements and archaeological entities. Next feasible option is to transport gravel to Northern Sri Lanka from central highlands and south - western region where gravel deposits are found in relatively large quantities, which involves long haulage distance and costs considerable amount of money.

Limited supply and absence of alternatives for gravel brought many road construction projects to a halt in Northern Sri Lanka. To ensure sustainable supply of gravel or alternative materials at low cost with required strength characteristics for road construction projects is therefore an immediate need in Northern Sri Lanka.

***Eng. B. Sanjika**, B. Sc. Eng (Hons), AMIESL, Planning Engineer, Link Engineering Pvt. Ltd., Dehiwala*
***Eng. M. Mathivathanan**, B. Sc. Eng (Hons) AMIESL, Civil Engineer, K.U.S Formwork & Scaffolding Pvt Ltd, Wellampittiya*
***Dr. A. Anburuvel**, PhD (Japan), Senior Lecturer in Civil Engineering, Department of Civil Engineering, University of Jaffna.*

Several studies have been conducted to explore the feasibility of using alternative materials instead of conventional ones for infrastructure construction projects. Many of them use combinations of various materials such as Construction and Demolition Wastes (CDW), geogrids, plastic strips, etc. [3-7]. Suku et al. (2016) studied the application of geocell, a type of geosynthetics, to reinforce the base layer and found that the geocell reduces the deformation of base layer under repeated loading [8]. Perez et al. (2013) conducted a field study aiming at studying the efficiency of using Recycled Concrete Aggregates (RCA) treated with cement in the road construction [9].

This study aims to explore the alternatives for the replacement of gravel in road construction in Northern Sri Lanka. This paper examines the usage of locally available soil in the region reinforced with, waste plastic, waste aggregate and geogrid as a replacement. By reusing waste material, this study promotes an alternative method to mitigate the environmental problems. This study also compares the cost involved in using alternative materials for road construction.

2. Literature Review

Road network of Sri Lanka is dense and well laid-out providing spatial connectivity to the country's population and centres of economic activity [1, 10]. Either rehabilitation or upgrading is required for more than 50% of the entire road network (more than 45, 000 km) [1]. Northern Sri Lanka is one of the active region where lot of road construction projects are presently being carried out [11]. As per Road Development Authority (RDA), there have been serious shortage of gravel even to continue the present projects. If the conventional pavement construction continues, material shortage will be a key challenge to be faced by future road construction projects.

In the attempt to replace conventional road construction materials, variety of studies have been performed on the use of stone dust, Fly Ash (FA), Waste Recycled Products (WRP), CDW, Recycled Asphalt Pavement (RAP), plastic fibers/strips, scrap tyres, and geosynthetics [3-9, 12, 13] Their prime focus was to choose an innovative material/ composites addressing the aspects of strength, durability, environmental impact and economy within the context of road construction. And a few research studies focused on re - designing the structure of the pavement [6, 14]. However, the comparison between different types of locally available reinforcing materials subject to Sri Lankan conditions should be further performed to reach a better understanding of the behaviour of these materials and to formulate generalized conclusions.

The suitability of the above said materials to be used in road construction, were determined either through various laboratory tests or by field tests. Most commonly used laboratory tests are California Bearing Ratio (CBR) test; unconfined compressive strength test; direct shear, resilient modulus test and shear strength test to determine the strength parameters; consolidation and swell test to estimate compressibility parameters, water absorption; grain size distribution and grain shape to classify soil [3, 13, 15]. In parallel, field tests measure the deflection, rutting resistance, etc. of pavements [9, 13].

Researches on the application of High Density Polyethylene (HDPE) as reinforcement in the form of fibers or strips showed improvement in sand in terms of bearing capacity, stiffness, resilient and shear properties [12, 16].

Reinforcing weak soil layers found in pavement, embankment with geosynthetics is one of the established techniques in practice for over 40 years [17]. The inclusion of geosynthetics materials in soils for reinforcing, improves the CBR and therefore the strength of soils [3, 6]. The geocell, a type of geosynthetics, significantly increased the resilient deformation of the RAP base and reduced the vertical stresses transferred to the subgrade by distributing the load over a wider area [8]. Improvement in strength characteristics of base material due to the presence of geosynthetics, significantly reduced the pavement layer thickness [6, 8].

Anand J. Puppala et al. recommends Cemented Limestone Quarry Fines (CQF) and Reclaimed Asphalt Pavement (RAP) to be used for bases for full scale pavement structures which can be used fully or in combination with the other materials [13]. Continuous monitoring of the pavements constructed with CQF and RAP is required to ensure permanent deformation of these materials [13].

Usage waste products such as plastics, waste aggregates in road construction contributes to environment protection by reducing waste released and save significant cost involved in construction materials [5].

3. Materials and Methods

In this study, locally available soil in Ariviyal Nagar, Kilinochchi was used to perform the laboratory experiments. The objective of the experiments is to investigate the improvements in strength characteristics of the locally available soil when reinforcing it with foreign materials. The foreign materials that we used were of three types; plastic waste, waste aggregates and geogrid. The strength parameter choosen for comparsion is CBR value.

3.1. Locally Available Soil

Particle Size Distribution (PSD)

Sieve analysis was done to the soil according to ASTM standard test method C136 to identify the particle size distribution. Figure 1 shows PSD curve from which Uniformity coefficient (C_u), Coeffient of gradient (C_c) of local soil were determined as 5.71 and 1.7, respectively. The fine fraction of local soil is 11.7%. PSD of the soil shows that the soil is poorly graded that does not have a good representation of all size of particles from No 40 to No 200 sieve.

Atterberg limits test was carried out according to ASTM D 4318 from which Liquid limit and plastic limit of local soil were determined as 22.37% and 20.67%, respectively. The plasticity index of it is 1.7.

From the soil classification tests, the locally available soil is categorized as 'Poorly graded Sand with Silt (SP-SM)' in accordance with Unified Soil Classification System (USCS) system. The characteristics of SP-SM is shown in table 1.

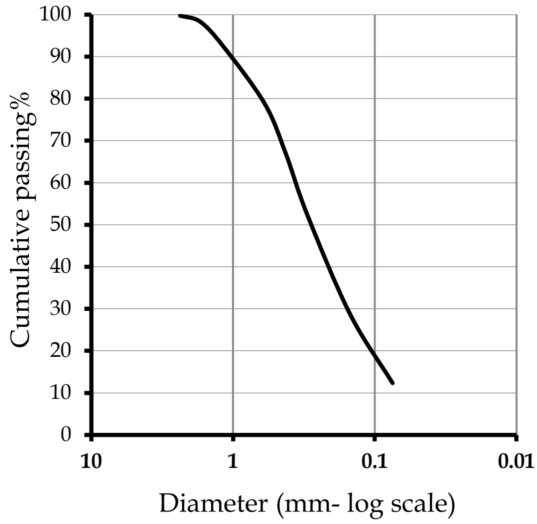

Figure 1: Particle Size Distribution curve

3.2. Reinforcing Materials

Plastic strips

Plastics strips were made by cutting plastic bottles into small pieces of 12 mm width and length, and 0.4 mm thick, keeping the aspect ratio 1.0, as shown in Figure 2 (a). The aspect ratio of 1.0 was decided based on the consideration that there is ample space in the compaction mold which allows strips deformation independent of mold confinement [18].

Waste aggregates

Waste aggregates [Figure 2 (b)] were generated by recovering them from tested concrete blocks and from demolished buildings.

Table 1: Characteristics of Silty Sand (SP) and poorly graded Sand (SM)

Soil Characteristics	Remarks	Remarks
Value as sub base when not subject to frost action	Fair to good	Fair
Value as base when not subject to frost action	Poor	Poor
Drainage characteristics	Fair to poor	Excellent
Workability as a construction material	Fair	Fair
Compressibility/expansion	Very slight to moderate	Negligible
Shear strength when compacted and saturated	Good	Good

Geogrid

Geogrid (Knitted polyester miragrid microgrid) [Figure 2 (c)], purchased from a local supplier was used for experiments. Table 2 summarizes the properties of the geogrid used in the experiments.

(a) Plastic strips

(b) Waste aggregates

(c) Geogrid

Figure 2: Materials used in the experiment

Table 2: Physical and Mechanical Properties of typical Geogrid

Properties	**Value**
Type of product	Knitted Polyester Micro grid
Characteristics short term tensile strength	40 kN/m²
Elongation	12%
Partial factor - creep rupture at 120 years design life	1.45%
Partial factor - construction damage in clay, silt or sand	1.15%
Partial factor - environmental effects	1.1%
Long term design strength at 120 years design life in clay, silt or sand	21.8 kN/m²
Nominal aperture size	7 ± 2 mm

3.3. Compaction

Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of the soil were determined using Modified Proctor test in accordance with ASTM-D1557. Modified Proctor test uses a 4.54 kg hammer falling through 457 mm, with 25 blows on each of five lifts, for a compactive effort of about 2, 695 kJ/m³. During Modified Proctor test, soil samples were prepared using a mould of 101.6 mm diameter and 116.4 mm height, and dry density of each sample and moisture content were measured. OMC and MDD were then obtained as 9.8 % and 19.78 kN/ m³, respectively using compaction curve shown in figure 3.

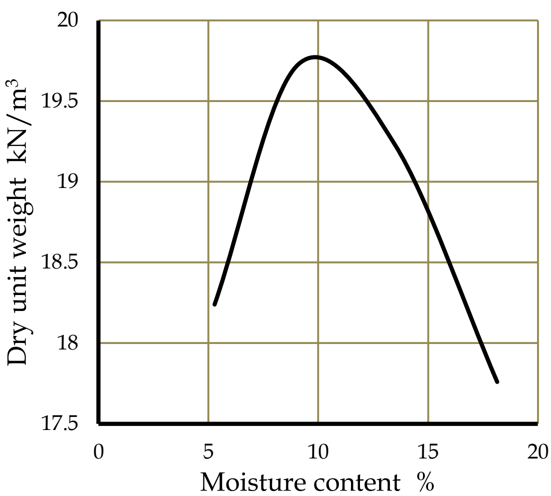

Figure 3: Dry unit weight vs Moisture content

3.4. California Bearing Ratio Test

California Bearing Ratio (CBR) tests were undertaken according to ASTM-D1883. Soil samples were prepared by mixing dry soil with optimum water content obtained from Modified Proctor test. Mixed soil was placed in CBR mould of 150 mm diameter and 175 mm and compacted in five layers. Each layer was compacted with hammer with 25 blows (hammer 4.54 kg, drop height 457 mm). The compacted specimen with the mould was placed on the load frame and a surcharge load weighing 25 N was placed on it. The force applied on sample (in N) against penetration (in mm) was recorded and plotted. The CBR values were calculated for 2.5 mm and 5.0 mm penetration using equation 1. Corrections were applied wherever required to eliminate the disparity in the obtained results due to uncertainties.

$$CBR\ (\%) = \frac{X}{Y} \times 100 \qquad (1)$$

where X is stress on soil and Y is stress on standard soil.

Percentage increase in CBR value was also computed to observe the effectiveness of each reinforcing material with respect to local soil (equation 2).

$$\%\ \text{Increase in CBR} = \frac{CBR_R - CBR_L}{CBR_L} \times 100 \qquad (2)$$

where CBR_R and CBR_L are CBR values of reinfoced soil and local soil, respectively.

4. Experimental Work and Cost Estimation

4.1. Laboratory Tests

Laboratory CBR tests were carried out for eight different scenarios shown in table 3. Each scenario uses different material combination as described below.

For each scenario, eleven similar samples were prepared and tests were performed. In total 88 samples were tested. Due care was taken during each sample preparation and CBR test to maintain similar conditions between tests.

4.2. Cost Estimation

A detailed cost analysis was carried out to investigate the economic aspects of gravel, geogrid and Aggregate Base Coarse (ABC). In the absence of gravel, ABC is widely recommended to replace gravel for road construction in Sri Lanka. The total estimated cost involved in using gravel, geogrid and ABC for constructing a typical 1 km road was computed. The present rates of materials and associated cost for transport and construction were obtained from Road Development Authority (RDA) in Kilinochchi.

Table 3: Details of scenarios used in laboratory experiments

Scenario	Description
A	Local soil Unreinforced
B	Local soil reinforced with the 0.5% plastic strips randomly oriented, homogeneously mixed
C	Local soil reinforced with the 1.0% plastic strips randomly oriented, homogeneously mixed
D	Local soil reinforced with waste aggregate placed as a layer at H/5 from the top of the specimen, H - height of the specimen
E	Local soil reinforced with geogrid placed horizontally (transverse to the direction of loading) at H/5 from the top of the specimen
F	Local soil reinforced with geogrid placed horizontally (transverse to the direction of loading) at 2H/5 from the top of the specimen
G	Local soil reinforced with geogrid placed horizontally (transverse to the direction of loading) at H/5 and 2H/5 from the top of the specimen
H	Local soil reinforced with 0.5% plastic strips randomly oriented and geogrid placed horizontally (transverse to the direction of loading) at H/5

5. Results

From the load – penetration curves obtained from CBR tests, CBR values for 2.5 mm and 5.0 mm penetration were determined for each scenario. Among 11 results obtained for each scenario, the outliers (± 5% of the nominal value) were eliminated and the remaining were used for further analysis.

Table 4 contains the average CBR values of eligible test results for each scenario. It was observed that CBR values of 5.0 mm penetration for all cases were found to be higher than that of 2.5 mm penetration.

Local soil reinforced with geogrids, placed horizontally (transverse to the direction of loading) at H/5 from the top of the specimen (*Scenario E*) and at H/5 and 2H/5 from the top of the specimen (*Scenario G*) showed significant improvement in CBR values for both 2.5 mm and 5.0 mm penetration. The difference in CBR values corresponding to both penetration values remains relatively large.

Secondly, local soil reinforced with 1.0% plastic strips (*Scenario C*) and waste aggregate placed as a layer at H/5 from the top of the specimen (*Scenario D*) exhibited significant improvements for both 2.5 mm and 5.0 mm penetration. However, the difference in CBR values corresponding to both penetration values remains relatively small.

Tables 5 – 7 summarize the costs involved in constructing a typical 1 km road using gravel, geogrid and ABC in Northern Sri Lanka.

Table 4: CBR values and % Increase in CBR values for 2.5 mm & 5.0 mm penetration for different scenarios

Scenario	Description	CBR value for penetration of		% Increase in CBR for penetration of	
		2.5 mm (%)	5.0 mm (%)	2.5 mm (%)	5.0 mm (%)
A	Local soil Unreinforced	6.1	8.0	0.0	0.0
B	Local soil reinforced with the 0.5% plastic strips randomly oriented, homogeneously mixed	7.8	10.6	27.9	32.5
C	Local soil reinforced with the 1.0% plastic strips randomly oriented, homogeneously mixed	10.0	13.0	63.9	62.5
D	Local soil reinforced with waste aggregate placed as a layer at H/5 from the top of the specimen, H - height of the specimen	10.3	13.8	68.9	72.5
E	Local soil reinforced with geogrid placed horizontally (transverse to the direction of loading) at H/5 from the top of the specimen	9.7	15.7	59.0	96.3
F	Local soil reinforced with geogrid placed horizontally (transverse to the direction of loading) at 2H/5 from the top of the specimen	6.2	8.8	1.6	10.0
G	Local soil reinforced with geogrid placed horizontally (transverse to the direction of loading) at H/5 and 2H/5 from the top of the specimen	10.6	16.2	73.8	102.5
H	Local soil reinforced with 0.5% plastic strips randomly oriented and geogrid placed horizontally (transverse to the direction of loading) at H/5	7.9	11.8	29.5	47.5

Table 5: Estimated cost details of road construction using gravel - Northern Sri Lanka

Description	Unit	Quantity	Rate/ LKR	Amount
Excavation of gravel	m^3	1,448	323.00	467,544.00
Spread and rolled machine, hire charges, fuel and watering	m^3	1,448	231.00	334,725.00
Transport	m^3/km	121,666	21.00	2,597,561.00
Total				**3,399,829.00**

Table 6: Estimated cost details of road construction using geogrid - Northern Sri Lanka

Description	Unit	Quantity	Rate/ LKR	Amount
Geogrid	m^2	7,200	500.00	3,600,000.00
Placing of geogrid on prepared surface	m^2	7,200	48.00	348,120.00
Excavation of soil	m^3	1,448	322.00	467,544.00
Spread and rolled machine, hire charges, fuel and watering	m^3	1,448	231.00	334,725.00
Total				**4,750,389.00**

Table 7: Estimated cost details of road construction using ABC - Northern Sri Lanka

Description	Unit	Quantity	Rate/ LKR	Amount
ABC supplying, spreading and compacting	m^3	1,448	2,292.00	3,320,008.00
Transport of Dense graded Aggregate	m^3/km	315,240	21.00	6,730,374.00
Total				**10,050,382.00**

6. Discussions

Geosynthetics provides frictional interaction and interlocking between soil particles by which the shear resistance of soil got enhanced. As a result, CBR values increased when geosynthetics is placed near top and at the top and bottom.

Presence of plastic strips also contributed in increasing effective shearing and thus CBR values improved for samples when local soil is reinforced with 1.0% plastic strips.

7. Conclusions

A laboratory experimental study was performed to find alternative material for gravel in Northern Sri Lanka. To replace gravel, various reinforcing materials were mixed with locally available soil and for each category, CBR tests were conducted to compare the effectiveness in reinforcement.

Preliminary investigations revealed that placing geogrids in between layers of local soil horizontally (transverse to the direction of loading) improves CBR value of local soil significantly. Plastic strips were also effective in improving the CBR values. However, mixing them in large volumes especially when the mixing percentage increases is to be further analysed.

For immediate replacement of gravel, geogrids are relatively economical over aggregate base course.

As an extension to this study, field studies are needed to determine the various loadings on pavements due to vehicular movements. It is advisable to numerically model the pavement and conduct analysis for variety of material combinations and different vehicular loadings.

References

1. *National Road master plan*. 2007, Road Development Authority: Colombo.
2. Rodrigo, M. *Building boom endangers sand and gravel resources*. The Sunday Times [English] 2017 [cited 2017 11 September]; Available from: http://www.sundaytimes.lk/170326/news/building-boom-endangers-sand-and-gravel-resources-234121.html.
3. Eric Duncan-Williams and N.O. Attoh-Okine, *Effect of geogrid in granular base strength – An experimental investigation.* Construction and Building Materials 2008. **Vol. 22**: p. 2180 – 2184.
4. Ossa, A., J.L. García, and E. Botero, *Use of recycled construction and demolition waste (CDW) aggregates: A sustainable alternative for the pavement construction industry.* Journal of Cleaner Production, 2016. **Vol 135**: p. 379 - 386.
5. L.D. Poulikakos, et al., *Harvesting the unexplored potential of European waste materials for road construction.* Resources, Conservation and Recycling, 2017. **Vol. 116**: p. 32 – 44.
6. Tingle, J.S., and Jersey, S. R., *Empirical Design Methods for Geosynthetic-Reinforced Low-Volume Roads.* Transportation Research Record: Journal of the Transportation Research Board, 2007. **No. 1989, Vol. 2**: p. 91–101.
7. Ferrotti, G., Canestrari, F., Pasquini, E., Virgili, A., *Experimental evaluation of the influence of surface coating on fiberglass geogrid performance in asphalt pavements.* Geotextiles and Geomembranes, 2012. **Vol. 34**: p. 11 - 18.
8. Suku, L., Prabhu, S. S., Ramesh, P. and Sivakumar Babu, G. L, *Behavior of Geocell-Reinforced Granular Base Under Repeated Loading.* Transportation Geotechnics, 2016. **Vol. 9**: p. 17-30.
9. Pérez, P., et al., *Application of cement-treated recycled materials in the construction of a section of road in Malaga, Spain.* Construction and Building Materials, 2013. **Vol 44**: p. 593-599.
10. Tissa U. Liyanage and Bandara, H.M.K.G.G., *Road Transportaion and its Future Developments in Sri Lanka*, in *Economic Review*. Aug./ Sept. 2011.
11. Anon. *Ministry of Higher Education and Highways Website*. 2017 [cited 2017 11 September]; Available from: http://www.mohsl.gov.lk/web/index.php?option=com_content&view=article&id=53.
12. Jha, J.N., Choudhary, A. K., Gill, K. S. and Shukla, S. K., *Behavior of plastic waste fiber-reinforced industrial wastes in pavement applications.* International Journal of Geotechnical Engineering, 2014. **Vol 8**: p. 277-286.
13. Anand J. Puppala, Sireesh Saride, and R. Williammee, *Sustainable Reuse of Limestone Quarry Fines and RAP in Pavement Base/Subbase Layers.* Journal of Materials in Civil Engineering, 2012. **Vol. 24**: p. 418 - 429.
14. Giroud, J.P. and J. Han, *Design Method for Geogrid-Reinforced Unpaved Roads. II. Calibration and Applications.* Journal of Geotechnical and Geoenvironmental Engineering, 2004. **Vol. 130**(8): p. 787 - 797.
15. Sireesh Saride and V.V. Kumar, *Influence of geosynthetic-interlayers on the performance of asphalt overlays on pre-cracked pavements.* Journal of Geotextiles and Geomembranes, 2017. **Vol. 45**(3): p. 184 - 196.
16. Choudhary, A., Gill, K. & Jha, J., *Utilization of plastic wastes for improving the sub-grades in flexible pavements.* Journal of Paving Materials and Pavement Analysis, 2010: p. 320 - 326.
17. Kamel, M.A., Chandra, S. and Kumar, P, *Behaviour of Subgrade Soil Reinforced with Geogrid.* International Journal of Pavement Engineering, 2004. **Vol. 5**: p. 201 - 209.
18. Choudhary, A.K., J.N. Jha, and K.S. Gill, *A Study on CBR Behavior of Waste Plastic Strip Reinforced Soil* Emirates Journal for Engineering Research, 2010. **Vol. 15**(1): p. 51 - 57