

Evaluation of the Use of Recycled Construction and Demolition Waste for Road Construction in Sri Lanka

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Abstract - The annual amount of construction and demolition waste produced in Sri Lanka is about 4.0 million tons and this has already become an environmental problem. In order to provide a sustainable environment, alternative solutions of utilizing these waste materials are needed. On the other hand, highways are constructed rapidly, causing depletion of natural resources like gravel. Therefore, this paper investigates the feasibility of using recycled construction and demolition waste in the road construction of Sri Lanka for road bases and sub-bases to provide a feasible solution for the said problem. This study used Recycled Concrete Aggregates and Crushed Brick and gravel from an excavation site where gravel was the control sample. Different mixes with various proportions of these materials were prepared and subjected to a series of tests in accordance with ICTAD specifications of Sri Lanka to determine their physical and mechanical properties. The results of particle size distribution, consistency tests, compaction test and CBR test indicate that the potential of using these materials in embankments, lower sub base, upper sub base for flexible pavement and road shoulder material. Moreover, the geotechnical properties of cement-treated C&D materials were also evaluated and found to be satisfactory for road and sub-base.

Keywords: Cement treated aggregates, Crushed Bricks, Demolished Concrete, flexible pavement, sub base

Nomenclature

CB - Crushed Bricks
C_C - Coefficient of Gradation
CBR - California Bearing Ratio
CD - Construction and Demolition
C_U - Uniformity Coefficient
ICTAD - Institute of Construction Training and Development
MDD - Maximum Dry Density
OMC - Ordinary Moisture Content
OPC - Ordinary Portland Cement
RCA - Recycled Concrete Aggregates
UCS - Unconfined compressive strength
USCS - Unified Soil Classification System

1. INTRODUCTION

Research on the use of commercial and industrial waste materials in civil engineering applications has generated interest in recent years. The reuse of these recycled materials will result in a low carbon footprint, considering that these recycled materials have significant

carbon savings compared with extracting virgin quarried materials. Construction and demolition (C&D) materials constitute a major proportion of waste materials present in landfills worldwide. The C&D materials have been used in recent years in various civil engineering applications such as roads, embankments, pipe bedding, and backfilling.

Economic, industrial and population growth in Sri Lanka will generate increasing amounts of waste materials that must be disposed of. As the volume of wastes continues to grow, the approval and availability of facilities for waste processing and proper disposal will become more difficult to obtain. Out of this waste the major proportion result in C&D waste; i.e. mainly demolished concrete and crushed bricks. These materials are stockpiled annually.

Evidences show that approximately 40% of waste generated globally originates from construction and demolition of buildings (Roach, 2001). C&D waste constitutes an increasingly significant problem in society leading to harmful effects environmentally as well as economically, not so much because of its hazardous nature, as it can be inert, but because of the volume generated which renders sustainable management and disposal problematic. According to Deiyagala (2017), the annual amount of construction and demolished waste produced in Sri Lanka is about 4.0 million tons and the management of that waste has already become an environmental problem. Therefore, there is urgency on finding innovative ways of recycling and reusing these materials.

In some countries, over 50% of C&D waste is sent to land filling areas. However, C&D waste is possible to be developed, that can be used in road constructions, i.e. in embankment, sub bases etc. Relevant tests have been carried out in developed countries and laboratory test results have shown positive results that the materials are viable to be used in road construction (Mohammadina *et al.* 2015).

Currently, the Road Development Authority in Sri Lanka uses only traditional materials for these purposes as per the Sri Lankan specifications (ICTAD, 2009) i.e. for road constructions, materials taken from gravel excavations are used, but these resources are depleting due to large scale excavations and rapid development in road constructions. According to Taha, et al. (2014) waste materials are commonly used in construction projects in order to save natural resources for future generations. Road construction is one of the main users of these natural resources. Utilizing these materials in unbound base/sub-base construction will provide sustainable development in a country by saving virgin materials, conserving energy and diverting materials from landfills. Therefore, this research will assess the suitability of recycled concrete aggregates and brick blends as embankment, road sub base and shoulder materials and gravel surfacing, and the improvement of the strength parameter of cement treated blended samples. This would provide substantial benefits to the industry in terms of reduced material supply and waste disposal cost, increased sustainability and reduced environmental impact.

Thus, the main objective of this research study was to investigate the potential for constructing road bases and sub-bases from waste materials generated in Sri Lanka. To meet this objective, physical and mechanical properties of C&D, crushed bricks were determined. Then combinations of C&D, CB and gravel (control sample) were subjected to Atterberg Limit tests, compaction and California Bearing Ratio (CBR) tests. Results were compared with ICTAD Specifications (2009) to establish the viability of using such materials in road base and sub-base structure, shoulder material and embankments.

2. PREVIOUS RESEARCH

Although the use of demolished construction waste is not still popular in Sri Lanka, internationally, there has already been much research done and applications identified in this regard.

Arulrajah (2012) reports of a laboratory investigation of the geotechnical properties of RCA. The properties of RCA were compared with state road authority requirements to assess its performance as a pavement sub-base material. The experimental programme consisted of tests such as particle size distribution, modified Proctor compaction, particle density, water absorption, CBR, Los Angeles abrasion, pH, organic content, static triaxial, and repeated load triaxial tests. The Los Angeles abrasion loss tests indicated that the RCA is durable. CBR values were found to satisfy the local state road authority requirements for a lower sub-base material. Repeated load triaxial tests established that the RCA would perform satisfactorily as a pavement sub-base material in the field.

Jayakody et al. (2012) investigated performance characteristics of blends of reclaimed asphalt pavement (RAP) with RCA. A series of "repeated load tri-axial (RLT)" test was conducted on RAP blended RCA samples to evaluate the elastic and plastic deformation characteristics with increase of load cycles. The elastic deformation was characterised by resilient modulus and slightly dropped with increase of RAP from 0, 5, 10 to 15% in RCA. Moreover, they have observed a trend of small increase of the plastic deformation of the RCA with the increase of rap portion. However, presence of RAP up to about 15% in RCA did not significantly affect on the accumulation of permanent strain.

An extensive laboratory program is conducted to study the feasibility of using RCA mixed with traditional limestone aggregate (LSA) by Behiry (2013). Moreover, the influence of mixture variables on the mechanical properties of cement treated recycled aggregate (CTRA) was also investigated. The results show that the adding of RCA improves the mechanical properties of the mixture where the UCS is taken as an important quality indicator.

Mohammadinia et al., (2015) investigated cement treated reclaimed asphalt pavement (RAP), RCA, and CB to assess their performance in pavement base/sub base applications. The effect of curing duration on the strength of the C&D materials was analyzed by conducting unconfined compression strength and repeated load triaxial tests. The RAP required 2% cement (by weight) and either 7 or 28 days of curing to meet the local road-authority requirements, whereas RCA and CB required 4% cement and 28 days of curing. It was reported that the RAP exhibited the highest strength in all cases, with the same cement content and for the same curing duration, followed by RCA and CB. The resilient moduli of C&D materials increased with an increase in cement content, curing duration, and confining pressure. Humidity curing was found to play an important role in the strength development of cement-treated C&D materials. This study indicates the potential of using cement-treated C&D materials for pavement base/sub base applications.

A series of extensive geotechnical laboratory tests was undertaken on CB blended with gravel in the varying proportions of 100%, 50%, 30% and 15%. Particle size distribution tests, Atterberg limit tests, Modified Proctor compaction tests and 4-day soaked CBR at 98% MDD (Modified) tests were carried out. The geotechnical properties obtained by the tests were compared with ICTAD requirements of sub-base specifications for pavement base and sub-base applications. The grading of all the blends tested satisfied the grading requirement for sub-base construction as per the ICTAD specifications. The 100% recycled brick sample achieved a maximum dry density of 2020 kg/m³ and a CBR value of 113% and satisfied the standard requirement. In addition, the blend of 50% crushed bricks and 50% gravel also satisfied the Atterberg limit dry density (1779 kg/m³) and CBR value (32%) requirements of ICTAD standards. The findings reveal that the two blends of recycled bricks and gravel are viable materials for pavement base or sub-base as a substitute material for gravels (Wijewardena, 2015).

Sirin (2013) reports of the evaluation of reclaimed asphalt pavement (RAP) aggregates and excavation waste (EW) materials obtained from road and building construction projects in for road bases and sub bases. Different combinations of such materials were prepared and subjected to a series of tests in accordance with Qatar's Construction Specifications (QCS) to determine their physical and mechanical properties. Results indicate a weak potential for

using RAP aggregates, EW materials, or a combination of the two in road bases and sub-bases.

Pourkhorshidi, (2020) reports the use of the construction and demolition waste aggregates in unbound layers of pavements and compare the in-hand results from various engineering assessments of these aggregates and mixes. A number of tests and evaluations are applied in order to enhance the required quality and durability of the pavements under given traffic volumes traffic loads and climate actions. Although the unbound recycled aggregates (RA) are mainly used in the lower layers, such as sub grade, capping, sub-base and base, he but suggested that the material can be used in rural roads for bound layers, towards the surface of the structure and may be for constituents of bound layers and of novel surfacing applications.

3. MATERIALS AND METHODOLOGY

Lateritic soil, crushed bricks and demolished concrete were the main materials used. Different blends of these materials were prepared and subjected to a series of tests in accordance with ICTAD specifications of Sri Lanka to determine their physical and mechanical properties.

A laboratory evaluation was also carried out to determine the engineering properties of cement-treated C&D materials. To assess this all the blends were treated with 5%, 6% and 7% of Ordinary Portland Cement (OPC) to evaluate the adequacy of strength and to assess their performance in pavement base/sub base applications.

All the results were compared with ICTAD Specifications (2009) to establish the viability of using such materials in the base and sub-base structures, shoulder material and road embankments.

3.1 Soil

Soil was collected from a borrow pit at Galagedara, Kandy which is used by Road Development Authority (RDA), Sri Lanka for road construction. This was in conformity with RDA material classifications. The soil from this borrow pit was classified as "Type I" soil.

3.2 Demolished Concrete

Demolished Concrete was from the Construction Waste Management Center, Galle.

3.3 Crushed Bricks

The cement containing particles attached to bricks were removed and were hand crushed to obtain the particle sizes specified in ICTAD specifications for road constructions.

3.4 Tests

The samples (soil, demolished concrete and crushed bricks) brought to the laboratory were tested individually to determine the material properties prior to mixing according to standard test methods. Following tests were conducted. The particle size distribution of samples was analyzed According to BS 1377-2:1990 (BS 1377: Part 2, 1990). Specific gravity of materials was obtained using pycnometer method as described in BS 1377: Part 2, 1990 for determination of particle density. Water absorption of the soil sample was determined using the oven drying method as described in BS 1377-2:1990.

To obtain the liquid limit and plastic limits of materials, the Casagrande Apparatus method was used as per the BS 1377-2:1990 part 2.

Both Standard Proctor Compaction test (BS 1377-2:1990) and Modified Proctor Compaction test (AASHTO T 180) was performed to determine the MDD and OMC of the samples.

For CBR test, samples were compacted at 95% and 98% MDD were soaked for 96 hours and the CBR values were evaluated as per the test procedure AASHTO 193.

Unconfined compressive strength test on cement treated materials were conducted as per the ASTM D2166. The cement treated samples were compacted according to AASHTO T180, heavy compaction using 4.5kg hammer with a free fall of 450cm. In order to achieve a 97% MDD compaction, samples were compacted in into 5 layers, giving 25 blows to each layer at its OMC. A cylindrical mould having an average height of 116.2 mm and an average diameter of 101.5 mm was used for the compaction. Compacted samples were extruded carefully and care was taken not to damage the surface area, especially top and bottom surfaces and left in humid conditions for 24 hours. Then the samples were cured in water for 7 days prior to test for its unconfined compressive strength using a standard compressive strength testing machine.

3.5 Material mix proportions

Different combinations of samples including the control sample were prepared as described in Table 1 and tests were conducted to evaluate the necessary engineering properties of each mixes and were compared with the specifications used by Road Development (ICTAD, 2009) of Sri Lanka to assess the suitability in road construction.

Table 1: Material mix proportions in sampling.

Test Series	Sample Code	Material Percentage (%)		
		Natural Gravel	Crushed Concrete	Crushed Bricks
	CS	100	-	-
T1	T1S1	65	35	-
	T1S2	60	40	-
	T1S3	55	45	-
	T1S4	50	50	-
T2	T2S1	65	-	35
	T2S2	60	-	40
	T2S3	55	-	45
	T2S4	50	-	50
T3	T3S1	65	17.5	17.5
	T3S2	60	20	20
	T3S3	55	22.5	22.5
	T3S4	50	25	25

3.6 Material Mixing

In order to maintain the consistency of the mix, first coarse and fine particles of each RCA and CB was mixed for several minutes separately and after it was mixed with soil in different proportions until a homogeneous mix was formed using a mechanical mixer.

4. RESULTS AND DISCUSSION

A summary of test results of physical and geotechnical properties of gravel, RCA and CB are presented in Table 2 and 3 respectively.

Table 2: Physical properties of gravel, RCA, CB.

Physical Property		Natural Gravel	RCA	CB
Standard test method	Property			
Sieve Analysis Test (BS 1377)	Fine Percentage (%)	<5%	<5%	<5%
	Cu	8.00	17.00	25.44
	Cc	1.62	1.75	2.44
	USCS Classification	SW-SM	SW-SM	SW-SM
Pycnometer Test (BS 1377)	Specific Gravity	2.80	2.80	2.67

Table 3: Geotechnical properties of gravel, RCA, CB.

Geotechnical Property		Natural Gravel	RCA	CB
Standard test method	Property			
Consistency Test (BS 1377)	Liquid Limit (%)	33	-	-
	Plastic Limit (%)	24	-	-
	Plasticity Index (%)	9	N.O.	N.O.
Standard Proctor Compaction (BS 1377)	Maximum Dry Density (kg/m ³)	2100	1910	1560
	Optimum Moisture Content (%)	11.2	15.2	23.8

4.1 Particle Size Distribution

Figures 1, 2, 3 and 4 illustrate the Sieve Analysis Test results of virgin materials and the blends. From these it can be seen that gradation curves of the virgin materials as well as the blends lie within the specified limits of ICTAD (2009) standards.

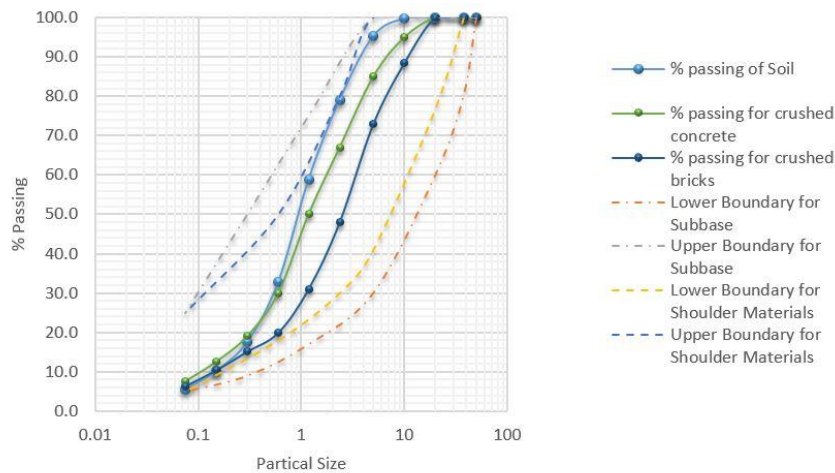


Figure 1: Sieve Analysis Test Results of Gravel, RCA and CB.

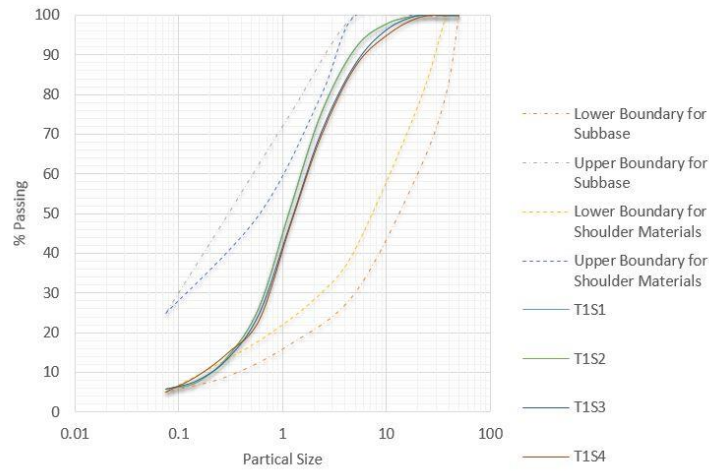


Figure 2: Sieve Analysis Test Results of Gravel + RCA Series.

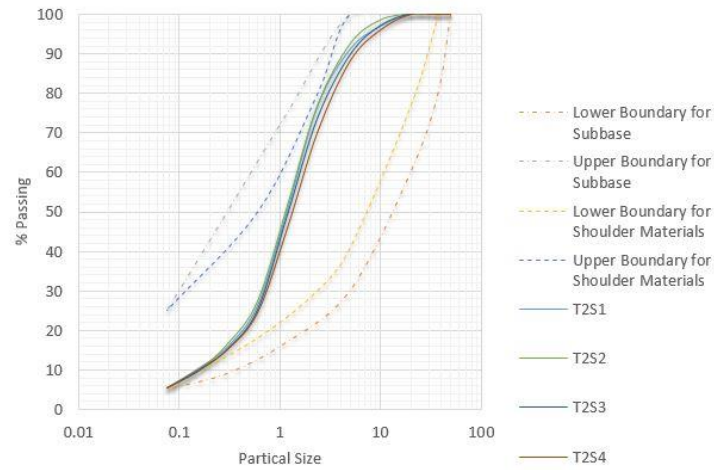


Figure 3: Sieve Analysis Test Results of Gravel + CB Series.

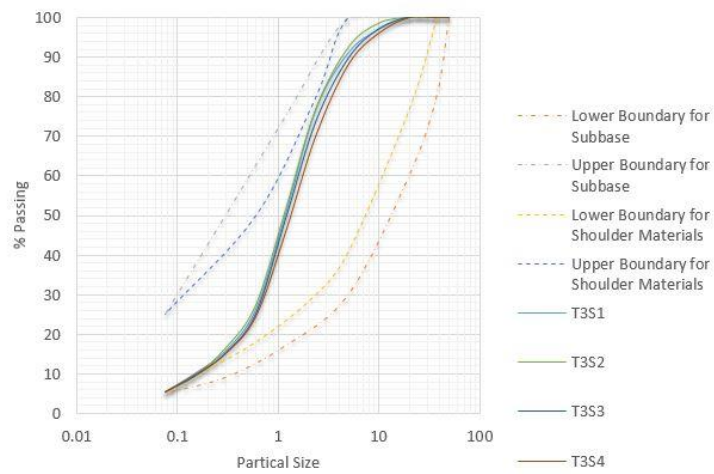


Figure 4: Sieve Analysis Test Results of Gravel + RCA + CB Series.

4.2 Atterberg Limits

The Liquid Limit, Plastic Limit and the Plasticity Index of the gravel sample were 33.2%, 23.6% and 9.6% respectively. The virgin RCA and CB were found to be non-plastic.

Table 3 illustrates the consistency limits of blends. Accordingly, a gradual decrease in Liquid Limit, an increase in Plastic Limit and a decrease in Plasticity Index in comparison to gravel was observable with the increase of replacement ratio of RCA and CB. This loss of consistency of natural gravel may be due to the fact that RCA and CB being non plastic.

Table 3: Consistency Limit test results

Material Percentage	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
100% gravel	33.2	23.6	9.6
65 % gravel + 35% RCA	29.9	23.6	6.3
60% gravel + 40% RCA	29	24.1	4.9
55% gravel + 45% RCA	26.9	24.7	2.4
50% gravel + 50% RCA	26.6	25.9	0.7
65% gravel + 35% CB	29.3	23	6.3
60% gravel + 40% CB	28.4	23.9	4.5
55% gravel + 45% CB	26.7	25.1	1.6
50% gravel + 50% CB	25.9	25.3	0.6
65% gravel + 17.5% RCA + 17.5% CB	29.9	23.7	6.2
60% gravel + 20% RCA + 20% CB	29.6	24.7	4.9
55% gravel + 22.5% RCA + 22.5% CB	27.8	25.1	2.7
50% gravel + 25% RCA + 25% CB	26.3	25.6	0.7

The Table 4 presents the Liquid Limits of the blends along with the respective ICTAD specifications. As can be seen from Table 4 except for the ICTAD (2009) requirement of sub bases of rigid pavement rest are complied with the specifications. The results of all the blends were found to exceed the maximum specified value of 25%.

Table 4: Liquid Limit values and the respective ICTAD (2009) standards.

Soil Percentage (%)	Liquid Limit for Each Blend (%)						Specifications		
	Gravel + RCA	Gravel + CB	Gravel + RCA + CB	Upper Limit for Embankment Type I	Upper Limit for Embankment Type II	Upper Limit for Upper Sub base (Flexible)	Upper Limit for Upper Sub base (Rigid)	Upper Limit for Lower Sub base	Upper Limit for Earthen Road Shoulders
100	33.2	33.2	33.2	50	55	40	25	40	55
65	29.9	29.1	29.9	50	55	40	25	40	55
60	29	28.5	29	50	55	40	25	40	55
5	27.2	27	27.2	50	55	40	25	40	55
50	26.9	25.9	26.9	50	55	40	25	40	55

4.3 Maximum Dry Density

Table 5 illustrates the results of the Modified Proctor compaction test.

The maximum dry density of gravel is found to be higher than that of RCA and CB. As can be seen the maximum dry densities have decreased with the increase of C&D waste percentage and OMC vice versa. However, as per the figure 5, 6, 7 it can be concluded that all the blends tested did comply with the ICTAD (2009) specification for all the structures of road construction

Table 5: Standard Proctor Compaction Test Results.

Test Sample	OMC (%)	MDD (kg/m ³)
100% gravel	9	2170
65 % gravel + 35% RCA	8.4	2155
60% gravel + 40% RCA	9.1	2145
55% gravel + 45% RCA	9.2	2095
50% gravel + 50% RCA	9.2	2075
65% gravel + 35% CB	9.5	2100
60% gravel + 40% CB	8.9	2060
55% gravel + 45% CB	9.8	2070
50% gravel + 50% CB	10.5	2000
65% gravel + 17.5% RCA + 17.5% CB	8.5	2100
60% gravel + 20% RCA + 20% CB	9	2080
55% gravel + 22.5% RCA + 22.5% CB	8.9	2030
50% gravel + 25% RCA + 25% CB	10.1	2010

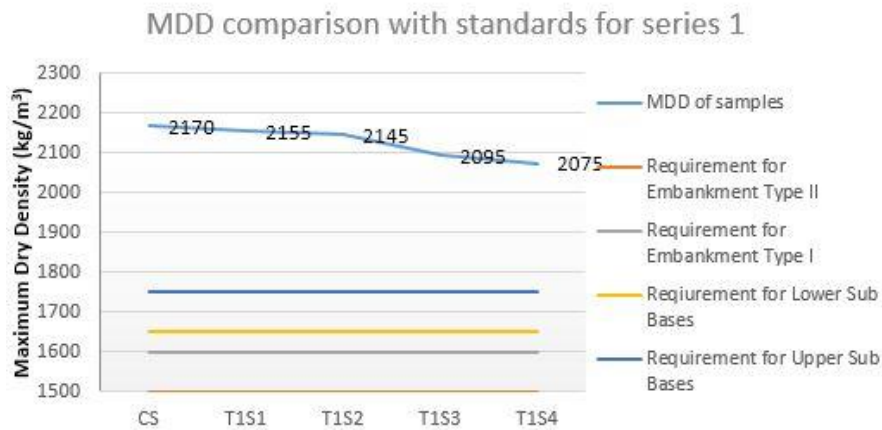


Figure 5: Comparison of MDD for gravel + RCA samples with standards



Figure 6: Comparison of MDD for gravel + CB samples with standards.

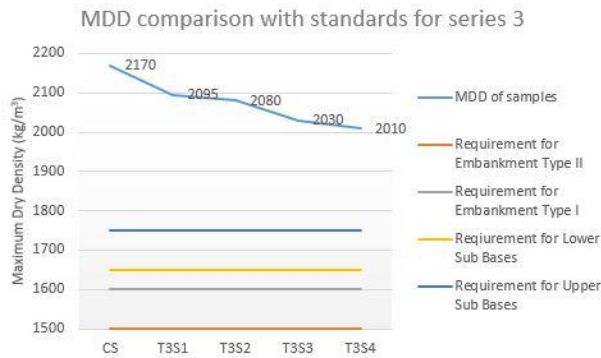


Figure 7: Comparison of MDD for gravel + RCA + CB samples with standards.

4.4 California Bearing Ratio

A summary of CBR Test results are presented in Figures 8 and 9. As the percentage of C&D is increased in the mixture there was an increase in the CBR value. Gravel + CB blends showed a significant increase in the CBR values than the Gravel + RCA blends. The CBR at 98% MDD for natural gravel was only 28% which was below the specified value for upper sub bases i.e., 30%. However, with increasing the proportion of C&D waste the CBR value can be increased.

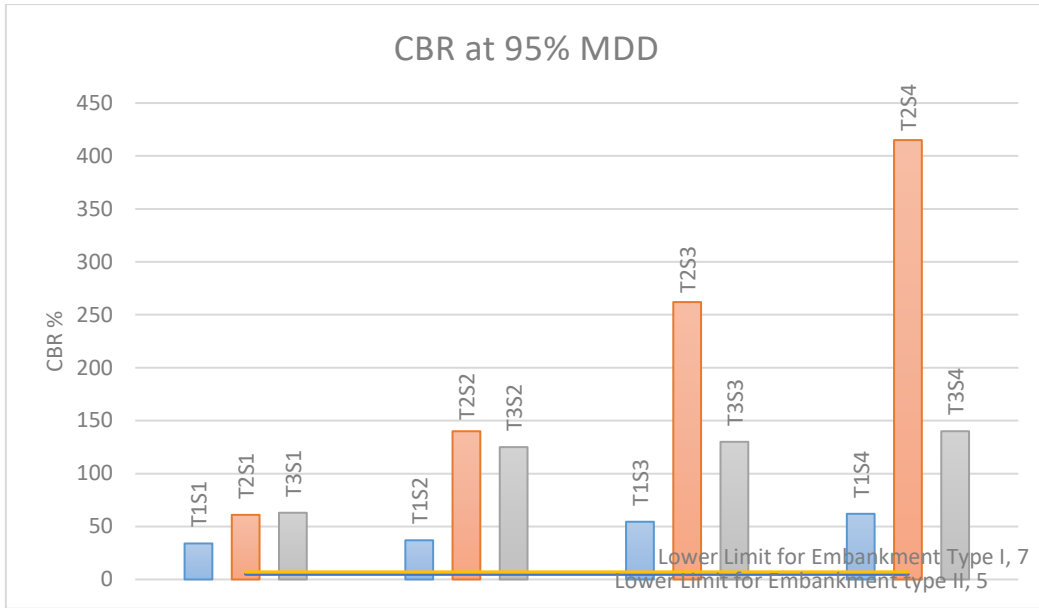


Figure 8: CBR at 95% MDD

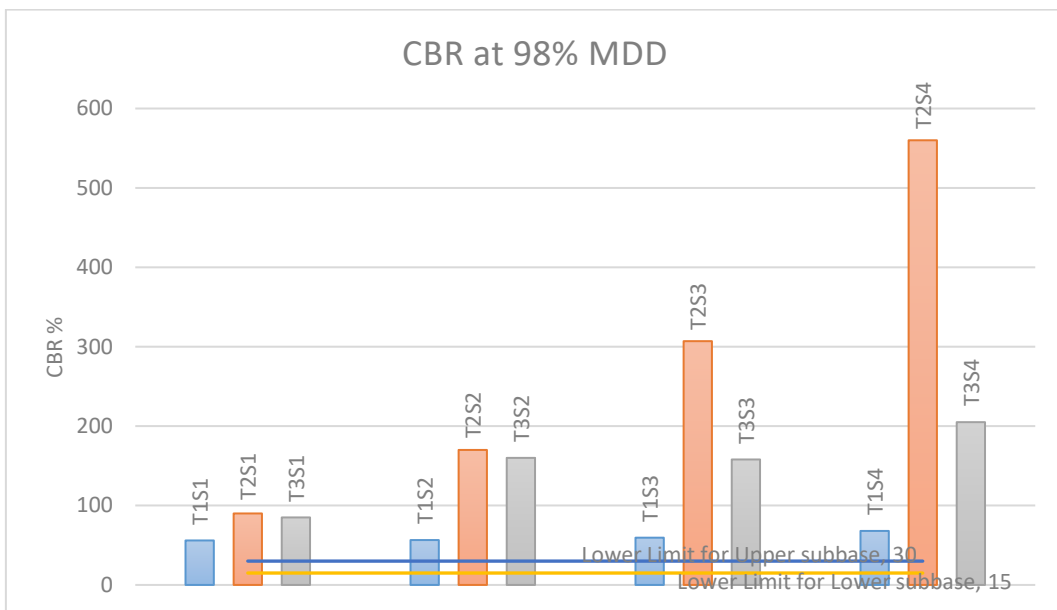


Figure 9: CBR at 98% MDD

4.5 Unconfined Compressive Strength test

To analyse the effect of cement on the strength of the C&D materials was analysed by conducting unconfined compressive strength test.

The unconfined compressive strength test results of gravel + RCA, gravel + CB and Gravel + RCA + CB blends with the addition of 5%, 6% and 7% cement are shown in Figures 10, 11 and 12 respectively.

The Gravel + RCA + CB exhibited the highest strength in all cases, with the same cement content and for the same curing duration, followed by RCA and CB.

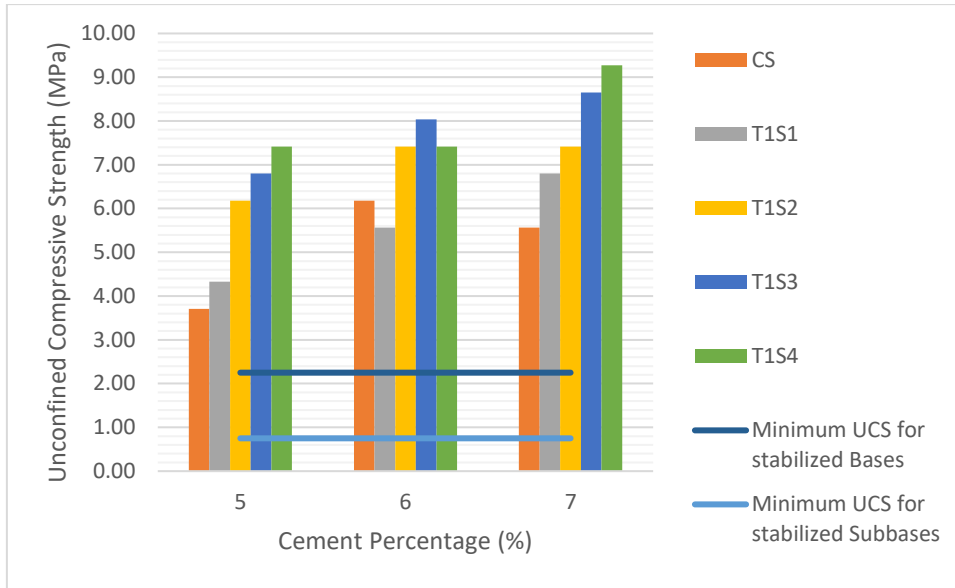


Figure 10: UCS results for Gravel + RCA series

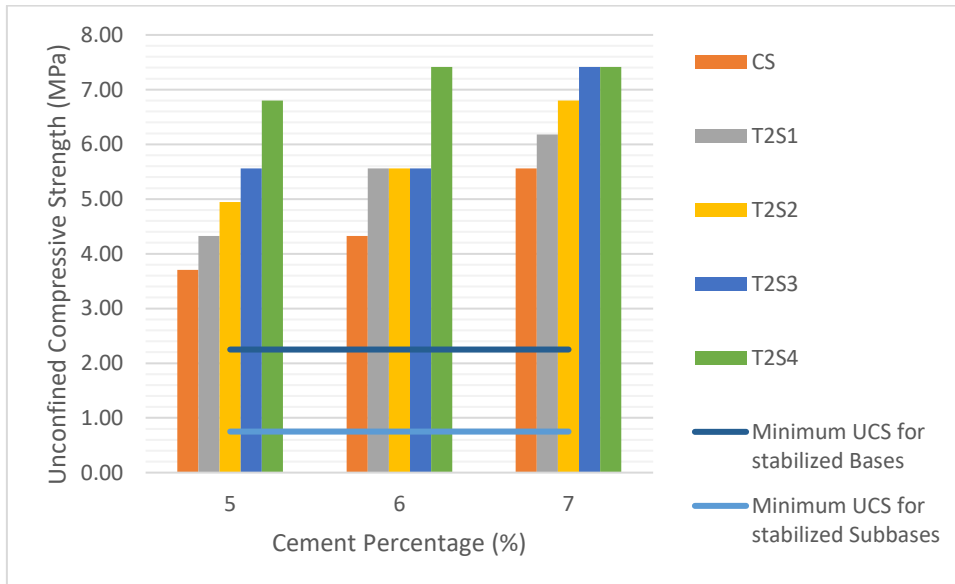


Figure 11: UCS results for Gravel + CB series

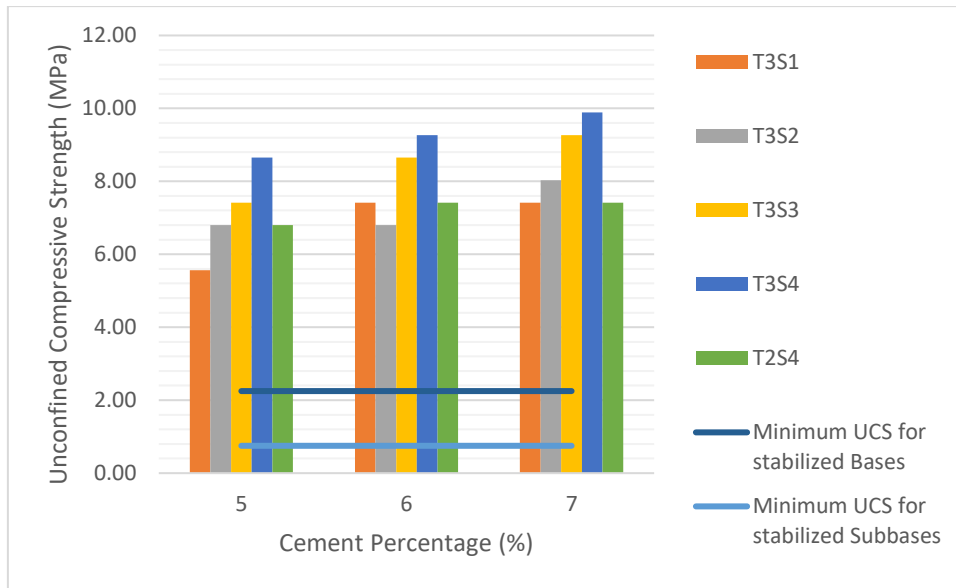


Figure 12: UCS results for Gravel + RCA + CB series

The UCS values as per the standards are 0.75-1.5 for stabilized road sub bases and 1.5-6.0 for stabilized road bases. Hence it can be seen from Figures 10, 11 and 12 that all the cement treated samples comply with standards for bases and sub bases.

5. CONCLUSION

Based on the outcomes of the study following conclusions can be drawn:

According to the results of particle size distribution, consistency tests, compaction test and CBR test, it can be concluded that with reference to the ICTAD specifications for road and bridge construction in Sri Lanka, proportions of C&D waste and gravel used were in conformity with the requirements to be used in embankments, lower sub base, upper sub base for flexible pavement construction as well as to be used as a road shoulder material. However, these samples did not meet with the consistency requirement of standard given for sub bases of Rigid Pavement since the observed values exceeded the maximum specified value of 25% Liquid Limit. Therefore the samples are considered not to be used in upper sub bases for rigid pavements.

In unconfined compressive strength test, it was observed a linear variation of the strength parameter with the increase of RCA and OPC percentage in the blend. The UCS values did satisfy with the local authority standards and hence cement treated construction and demolition waste is viable solution for road bases and sub bases of the country.

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