STABILISATION OF BIOSOLIDS WITH ADMIXTURES FOR POTENTIAL USE AS AN EMBANKMENT FILL MATERIAL

V. Suthagaran[1], A. Arulrajah[1], M.W. Bo[2] and J. Wilson[1]
[1]*Faculty of Engineering and Industrial Science, Swinburne University of Technology, Melbourne, Australia*
[2]DST Consulting Engineers, Ontario, Canada

ABSTRACT

Biosolids are an end product of the wastewater treatment process and contain many of the constituents removed from the influent wastewater. This paper is based on a project currently implemented in Victoria to assess the viability of using biosolids as engineered fill material for road embankments. A series of geotechnical lab tests were conducted to evaluate the engineering properties of biosolids samples retrieved from Western Treatment Plant (WTP) in Victoria, Australia. The laboratory tests undertaken include particle density, moisture content, organic content, Atterberg limits, particle-size distribution, proctor compaction, California Bearing Ratio (CBR) and consolidation tests. Geotechnical laboratory tests were carried out on untreated biosolids as well as biosolids stabilised with 1%, 3% and 5% by weight of cement and lime. The test results were subsequently compared with the existing local road authority specification for embankment fill material.

1 INTRODUCTION

The quantity of the municipal biosolids produced annually in the world has increased dramatically over the decades. Annually 66,700 dry tonnes of biosolids are produced from wastewater treatment plants in Victoria, Australia. This comprises 39,700 dry tonnes per annum of biosolids from the Eastern and Western treatment plants managed by the Melbourne Water Corporation (Department of Natural Resources and Environment, 2002).

The Western Treatment Plant treats about 52% of Melbourne's sewage where the sewage is mostly treated in vast lagoon systems. Sludge, which settles to the bottom of the lagoons, is pumped into a contained area where it isdried to create biosolids. Biosolids refers to dried sludge having the characteristics of a solid typically containing 50% to 70% by weight of oven dried solids and sludge containing between 2% to 15% of oven dried solids. A project was initiated at Western Treatment Plant (WTP) to investigate the geotechnical engineering properties of biosolids and to assess the viability of using biosolids as stabilised fill material for embankment.

The characteristics of the biosolids depend on various factors such as the type of waste, type of treatment process and age of the biosolids. The geotechnical engineering properties of untreated biosolids and stabilised biosolids with 1%, 3% and 5% cement and lime were determined from various laboratory tests and subsequently compared with the existing local road authority specification for fill material. Ordinary Portland cement and hydrated lime were used to stabilise the biosolids in this research. Laboratory tests undertaken include particle density, moisture content, organic content, Atterberg limits, particle-size distribution, compaction, California Bearing Ratio (CBR) and consolidation.

Geotechnical sampling was carried out from the top of three existing biosolids stockpiles at the Western Treatment Plant which is located approximately 50 km to the west of Melbourne. Approximately 2500 kg of bulk biosolids samples were obtained from two different locations in the three existing biosolids stockpiles for laboratory testing purposes. Bulk samples were collected in large bags, which were sealed to maintain the natural moisture content of the biosolids.

The engineering characteristics of biosolids in other parts of the world have previously been reported by Hundal *et al.* (2005), Reinhart (2003) and O'Kelly (2005, 2006).

2 LOCAL ROAD WORK SPECIFICATION FOR EMBANKMENT FILL

VicRoads is the local road governing authority in Victoria, Australia and classifies fill material for earthworks into three types; type A, B and C. VicRoads also classifies fill material based on the type, particle size and physical and mechanical properties of the material. The VicRoads requirement for type B fill is a California Bearing Ratio (CBR) value of 2 to 5 % (VicRoads, 2006). VicRoads (2006) defines Type C fill as lesser quality material than Type B.

3 INDEX AND PHYSICAL PROPERTIES

Index and physical properties of biosolids were measured from various geotechnical laboratory tests including particle density, moisture content, organic content, Atterberg limit, and particle size distribution. Table 1 summarises the index and physical properties of the untreated biosolids.

Table 1 Index and physical properties of untreated biosolids

Index and physical properties	Value	Unit
Moisture content	46.8 – 58.6	%
Organic content	27.6 – 29.0	%
Particle density	1.75 – 1.79	t/m^3
Liquid limit - LL	100 – 110	%
Plastic limit - PL	79 – 83	%
Plasticity index - PI	21 – 27	%
Gravel size particle	2 – 4	%
Sand size particle	44 – 58	%
Silt size particle	34 – 51	%
Clay size particle	1 – 4	%

The particle density of biosolids was measured using the small pyknometer method and was found to vary between 1.75 t/m^3 to 1.79 t/m^3. Kerosene was used instead of distilled water as the density fluid in the pyknometer in order to prevent the decomposition of biosolids during the tests. The particle density was found to be low when compared to natural soils.

The natural moisture content of biosolids was found to vary between 48.6% and 58.6%. The moisture content was determined on the basis of the oven dry mass corresponding to a drying temperature of 50°C instead of the standard drying temperature of 105°C. This was to prevent charring of the organic particles.

The organic content was found to range between 27.6% and 29.0% in the biosolids. The organic content was measured by igniting dry powdered biosolids material in a muffle furnace at a temperature of 550°C. Ignition loss is an indirect measure of the organic content of the dry specimen mass, which can be used to assess the state of biodegradation of biosolids.

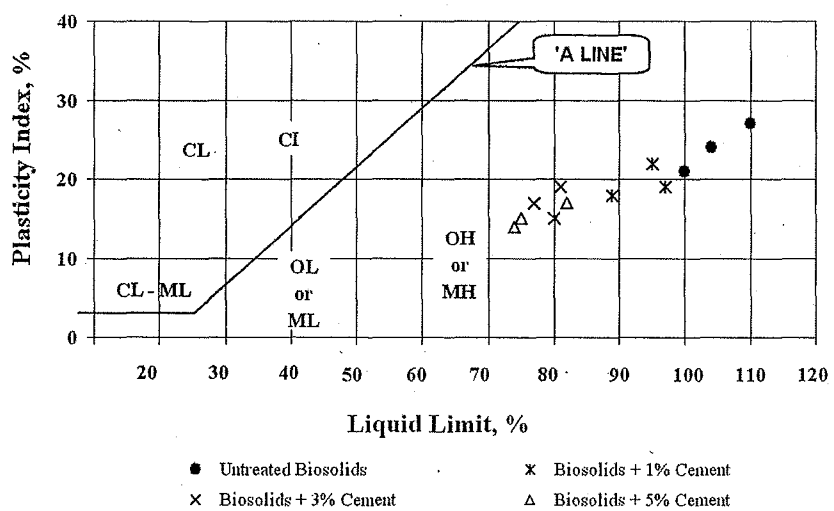

Figure 1: Plasticity chart for untreated biosolids and biosolids stabilised with cement.

The plasticity characteristics of biosolids were assessed from Atterberg limit tests carried out on air-dried biosolids. The liquid limit (LL) of biosolids ranged between 100% and 110%, while the plastic limit (PL) of biosolids ranged between 79% and 83% and the plasticity index (PI) ranged between 21% and 27%. The plasticity chart for untreated biosolids is presented in Figure 1.

Based on the Atterberg limit test results on three replicate samples, it can be concluded that the biosolids largely comprised organic silt-sized particles and is classified according to the Unified Soil Classification System (USCS) as organic silt of medium to high plasticity.

Atterberg test results of untreated and stabilised biosolids with cement is presented in Figure 1 and the range of test results is summarised in Table 2. The Atterberg test results of untreated and stabilised biosolids with lime is presented in Figure 2 and also summarised in Table 3. Atterberg limit test results of stabilized biosolids with cement and lime indicates that the liquid limit, plastic limit and plastic index in all three stockpiles decreased with the addition of increasing amounts of cement and lime.

Table 2: Atterberg limits of biosolids stabilised with cement

Atterberg limits	Unit	Percentage of Cement		
		1	3	5
Liquid limit	%	89 - 97	77 - 81	74 - 82
Plastic limit	%	71 - 78	60 - 65	60 - 65
Plasticity index	%	18 - 22	15 - 19	14 - 17

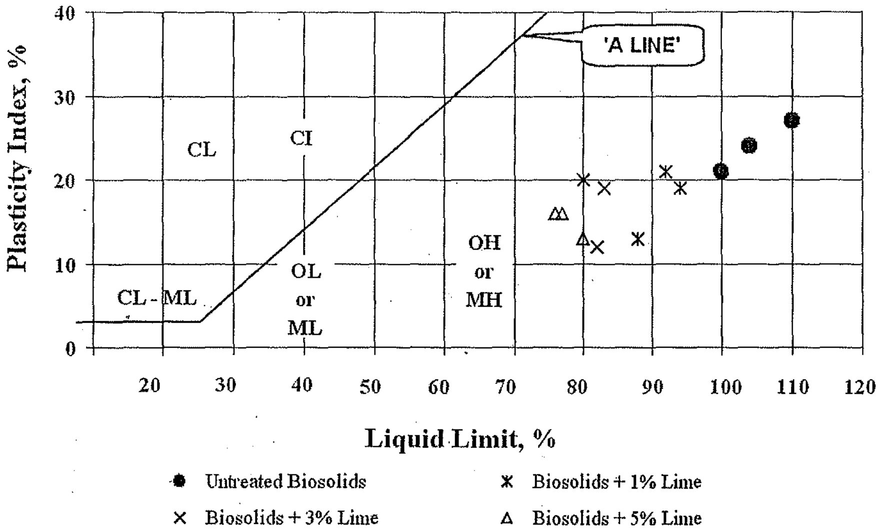

Figure 2: Plasticity chart for untreated biosolids and biosolids stabilised with lime.

Table 3: Atterberg limits of biosolids stabilised with lime.

Atterberg limits	Unit	Percentage of Lime		
		1	3	5
Liquid limit	%	88 - 94	80 - 83	76 - 80
Plastic limit	%	71 - 75	60 - 70	60 - 67
Plasticity index	%	13 - 21	12 - 20	13 - 16

4 COMPACTION CHARACTERISTICS

Standard proctor compaction tests were performed to determine the compaction characteristics of the untreated biosolids as well as stabilised biosolids samples with cement and lime. Optimum moisture contents (OMC) at which the dry densities are highest, known as maximum dry density (MDD) were determined for each three stockpiles. The maximum dry density of untreated biosolids was found to range between 0.83t/m^3 and 0.87t/m^3. The optimum moisture content of untreated biosolids was found to vary between 48% and 56%.

Figure 3 illustrates the variation of dry density of biosolids with the amount of cement added to stabilise the biosolids in percentage. The maximum dry density of stabilised biosolids varied from 0.84t/m^3 to 0.85t/m^3 with the addition of 1% of cement, 0.86t/m^3 to 0.88t/m^3 with the addition of 3% of cement and between 0.87t/m^3 to 0.88t/m^3 with the addition of 5% of cement. Therefore maximum dry density is increasing with increasing cement content. Figure 4 presents the variation of optimum moisture content with the amount of cement added to biosolids. The optimum moisture content of stabilised biosolids was 38% to 40% with 1 % of cement; 38% to 40% with 3 % of cement and 37% to 40% with 5% of cement. As can be seen in the figures, OMC significantly reduces after addition of 1 % cement and thereafter no significant reduction of OMC was found when additional cement is added.

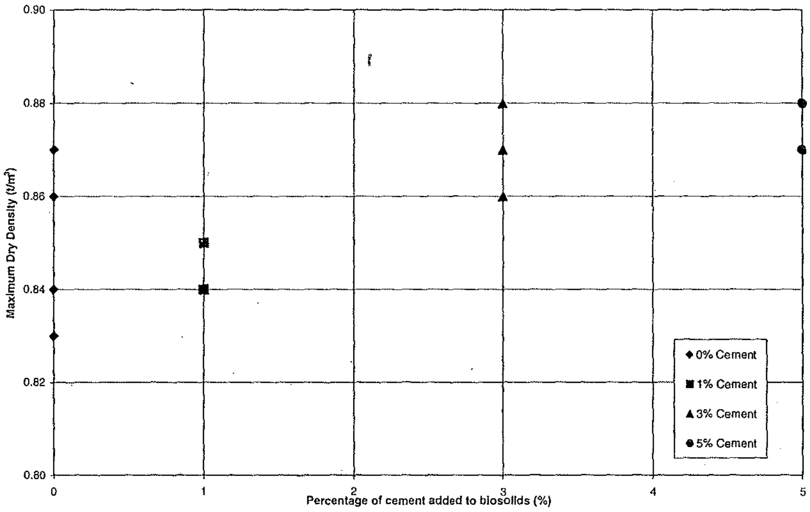

Figure 3: Maximum dry density of biosolids stabilised with cement.

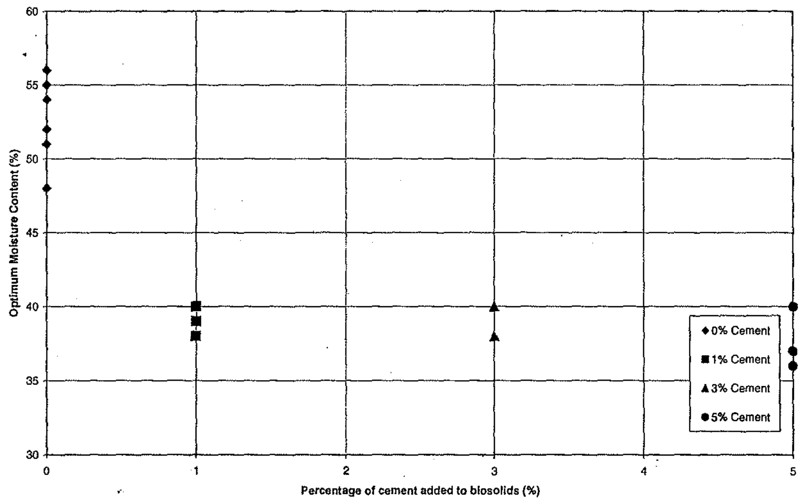

Figure 4: Optimum moisture content of biosolids stabilised with cement.

Figure 5 presents the variation of dry density of biosolids with the amount of lime added. The maximum dry density of stabilised biosolids varied from 0.88 t/m^3 to 0.91 t/m^3 with the addition of 1% of lime; 0.90 t/m^3 to 0.93 t/m^3 with the addition of 3% of lime and between 0.89 t/m^3 to 0.91 t/m^3 with the addition of 5% of lime. Figure 6 presents the variation of optimum moisture content with the amount of lime added to biosolids. The optimum moisture content of stabilised biosolids was 40% to 43% with 1% of lime; 38% to 42% with 3% of lime and 39% to 42% with 5% of lime. In general, it was found that increasing the proportion of cement and lime had little effect on the maximum dry density and the optimum moisture content of the biosolids.

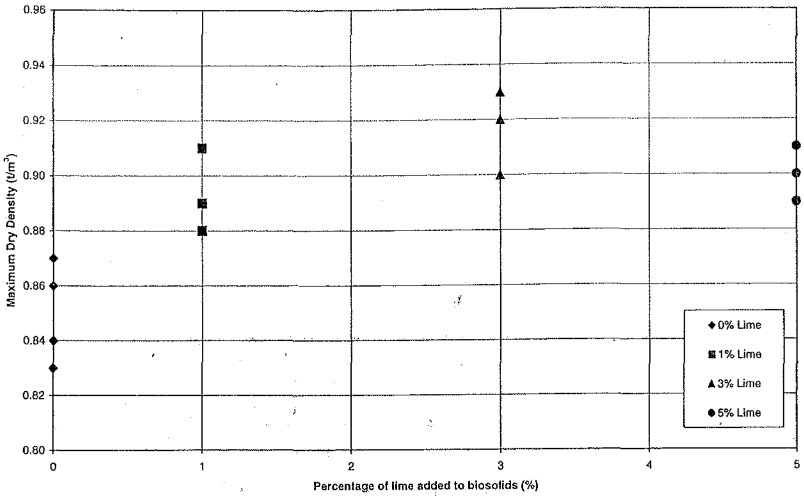

Figure 5: Maximum dry density of biosolids stabilised with lime.

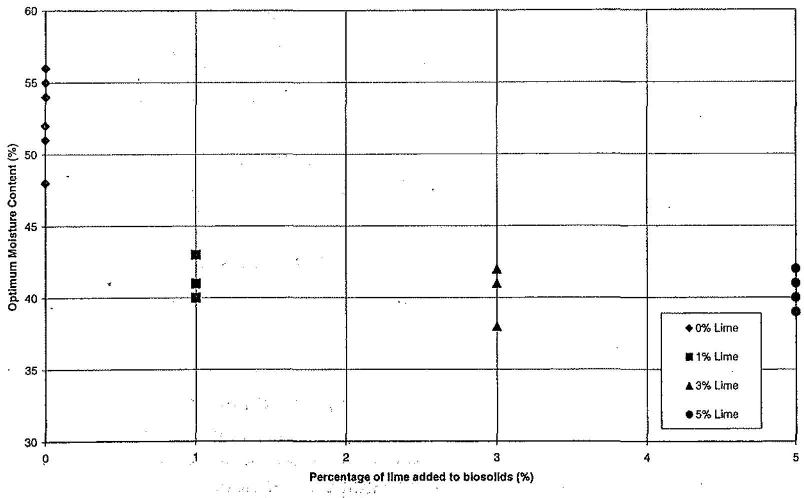

Figure 6: Optimum moisture content of biosolids stabilised with lime.

5 STRENGTH PROPERTIES

California Bearing Ratio (CBR) tests were undertaken to determine the strength of compacted biosolids. The CBR value is an indicator of soil shear strength and bearing capacity and useful for assessing the suitability of biosolids as engineered fill material. The CBR values were tested after 4 days of soaking in water under a surcharge weight of 4.5 kg and measured according to Australian standard for soil testing. To simulate the compaction carried out in the field, untreated and stabilised biosolids mixtures were compacted to 95% of the maximum dry density at the optimum moisture content obtained from the standard compaction test results.

The CBR test results of untreated biosolids and biosolids stabilised with 1%, 3% and 5% cement are summarised in Table 4. The CBR values were found to vary from 0.8% to 1.1% for the untreated biosolids and from 1.7% to 2.0% with the addition of 1% of cement; 2.0% to 2.4% with the addition of 3% of cement and 3.8% to 4.6% with the addition of 5% of cement.

Table 4: CBR test results of biosolids stabilised with cement.

Strength properties		Untreated Biosolids	Biosolids stabilised with cement		
			1% Cement	3% Cement	5% Cement
CBR Swell	%	0.30 - 0.73	0.31 - 0.84	0.14 - 0.95	0.17 - 0.52
CBR Value	%	0.8 - 1.1	1.2 - 1.6	1.4 - 1.7	3.3 - 4.7

The CBR test results of untreated biosolids and biosolids stabilised with 1%, 3% and 5% cement are summarised in Table 5. The CBR value of stabilised biosolids was found to vary from 1.2% to 1.6% with the addition of 1% of lime; 1.4% to 1.7% with the addition of 3% of lime and 3.3% to 4.7% with the addition of 5% of lime.

Table 5: CBR test results of biosolids stabilised with lime.

Strength properties		Untreated Biosolids	Biosolids stabilised with lime		
			1% Lime	3% Lime	5% Lime
CBR Swell	%	0.30 - 0.73	0.34 - 0.52	0.12 - 0.77	0.28 - 1.29
CBR Value	%	0.8 - 1.1	1.7 - 2.0	2.0 - 2.4	3.8 - 4.6

In general, it was found that the stabilisation of biosolids with cement and lime increases the CBR value of biosolids as compared with untreated biosolids.

6 CONSOLIDATION PROPERTIES

The compressibility characteristics of biosolids were determined from oedometer tests carried out using a 63.5 mm diameter oedometer ring. The consolidation tests were carried out on the prepared samples compacted to 95% of maximum dry density at Optimum moisture content both on untreated biosolids and stabilised biosolids with 1%, 3% and 5% of cement and lime and the duration fixed at 24 hours for each loading. The consolidation test samples were compacted with standard compaction effort prior to consolidation stresses of between 50 kPa and 800 kPa being applied.

The consolidation properties of untreated biosolids are presented in Table 6. The initial void ratio which represents the void ratio of the compacted untreated biosolids with standard compaction effort was found to range from 0.865 to 1.048. The compression index values of untreated biosolids were found to vary from 0.563 to 0.640 whilst the recompression index varied from 0.020 to 0.030.

Table 6: Consolidation properties of untreated and stabilised biosolids.

Compressibility Properties	Untreated Biosolids	Percentage of cement		Percentage of lime	
		3	5	3	5
Initial void ratio - e_o	0.865 - 1.048	0.638 - 0.851	0.785 - 0.809	0.808 - 0.909	0.699 - 0.872
Compression Index - C_c	0.563 - 0.640	0.395 - 0.410	0.275 - 0.325	0.513 - 0.537	0.458 - 0.475
Recompression Index - C_r	0.038 - 0.045	0.022 - 0.029	0.021 - 0.028	0.031 - 0.040	0.024 - 0.029

The consolidation properties of biosolids stabilised with 3% and 5% of cement are presented in Table 6. The initial void ratio of stabilised biosolids was found to range from 0.638 to 0.851 with addition of 3% cement and 0.785 to 0.809 with addition of 5% cement. The compression index values of stabilized biosolids were found to vary from 0.395 and 0.410 with addition of 3% cement and 0.275 to 0.325 with addition of 5% cement. The recompression index values of stabilized biosolids were found to vary from 0.022 and 0.029 with addition of 3% cement and 0.021 to 0.028 with addition of 5% cement.

The consolidation properties of biosolids stabilised with 3% and 5% of lime are presented in Table 6. The initial void ratio of stabilised biosolids was found to range from 0.808 to 0.909 with addition of 3% lime and 0.699 to 0.872 with addition of 5% lime. The compression index values of stabilized biosolids were found to vary from 0.513 and 0.537 with addition of 3% lime and 0.458 to 0.475 with addition of 5% lime. The recompression index values of stabilized biosolids were found to vary from 0.037 and 0.040 with addition of 3% lime and 0.024 to 0.029 with addition of 5% lime.

It was found that the compression index of the stabilised biosolids with cement and lime was less than untreated biosolids. Furthermore the compression index decreases with the amount of cement and lime added to the biosolids.

7 COMPARISON WITH LOCAL ROADWORK SPECIFICATION

The laboratory test results were compared with existing local roadwork specifications for embankment fill. Figure 7 presents the CBR results for biosolids stabilised with 1%, 3% and 5% of cement as compared to untreated biosolids as well as CBR requirement of type B fill material by VicRoads. From the results in Figure 7, it is apparent that biosolids stabilised with 3% and 5% cement satisfy the VicRoads minimum requirement of 2% CBR for type B fill material.

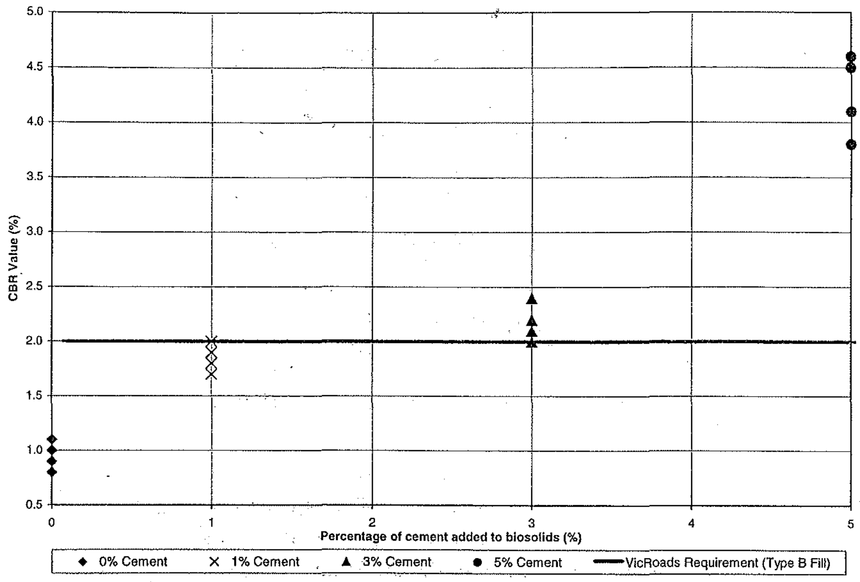

Figure 7: CBR results of biosolids stabilised with cement.

Figure 8 presents the CBR results for biosolids stabilised with 1%, 3% and 5% of lime as compared to untreated biosolids as well as CBR requirement of type B fill material by VicRoads. From the results in Figure 8, it is apparent that biosolids stabilised with 3% and 5% cement satisfy the VicRoads minimum requirement of 2% CBR for type B fill material.

From the results it is apparent that the CBR value of biosolids stabilised with 3%, 5% cement and 5% lime satisfy the VicRoads specification for type B fill material. This is a significant improvement on the untreated biosolids which do not satisfy the VicRoads specification.

8 CONCLUSIONS

Biosolids samples were obtained from three stockpiles at Biosolids Stockpile Area, Western Treatment Plant in Victoria, Australia. The biosolids were tested to investigate the geotechnical characteristics of biosolids and the suitability of biosolids as stabilised fill material for road embankment.

It was found that the biosolids can be classified as organic fined-grained soils of medium to high plasticity with a group symbol of 'OH' as Unified Soil Classification System (USCS). The biosolids samples contain approximately 5% gravel size, 50% sand size, 40% silt size and 5% clay sized particles. The biosolids samples in the three stockpiles were found to have high moisture content, liquid limit and plasticity indices that are comparable to common inorganic soils. The moisture content, liquid limit and plasticity indices were found to decrease when biosolids were stabilised with lime and cement. The particle density of untreated biosolids was found to be approximately 1.75 t/m^3, which is substantially less than natural inorganic soils.

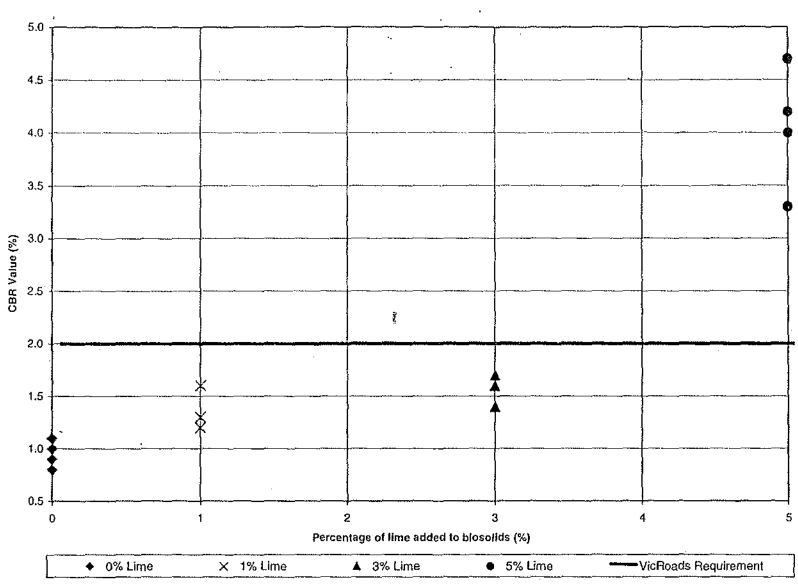

Figure 8: CBR results of biosolids stabilised with lime.

The compaction tests results indicated that maximum dry density varied only slightly with the moisture content changes. The density of the dried compacted material was low in comparison with inorganic soils consistent with the low particle density of solids measured.

The coefficient of compression index of untreated biosolids was found to range between 0.563 and 0.640 whilst the coefficient of recompression index ranged between 0.038 and 0.045. It was found that the compression index of the stabilised biosolids with cement and lime was less than untreated biosolids. Furthermore the compression index decreases with the amount of cement and lime added to the biosolids.

The untreated biosolids have relatively low soil bearing capacity based on CBR test results. It was found that the bearing capacity of the biosolids could however be increased by adding admixtures such as cement and lime. The CBR values of biosolids stabilised with a minimum of 5% lime and minimum of 3% cement were found to satisfy the VicRoads specification for Type B fill material which requires a minimum CBR of 2%.

9 ACKNOWLEDGEMENTS

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