Constructing Excellence in Wales

Testing Recycled Aggregates for Minor Schemes (TRAMS)

April 2011

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CONSTRUCTING EXCELLENCE IN WALES

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1 Executive Summary

1.1 The Testing of Recycled Aggregate for Minor Schemes Project (TRAMS) commenced in February 2010 with the objective of accumulating a body of test data for recycled aggregate produced by recycling operations throughout Wales. This was in line with long term aims of diverting waste from landfill (estimated to be 10,000 tonnes per annum in Wales) and reducing demands on virgin material by addressing the barriers to the use recycled aggregate.

This report concludes that the materials, as tested, represent an adequate source of suitable recycled aggregate which could and should be utilised in minor engineering schemes within Wales. This would ensure avoidance of landfill and lessen the demand on finite sources of virgin stone.

The project objective was to recruit 20 recycled aggregate producers in Wales to take part in the programme. However, due to the downturn in construction activity only 15 producers participated.

The project has carried out a series of 7 laboratory tests on 15 No sources of recycled material and one source of virgin quarry stone as a control.

The tests were chosen based on the requirements of the 800 series of the Specification for Highway Works (SHW) plus additional tests considered to be relevant in order to provide an appropriate level of confidence for the specifying engineer when procuring unbound aggregate for use in Minor Schemes.

The overall outcome of this testing programme indicates that recycled inert aggregate processed from construction waste consistently meets most of the criteria specified in the 800 series of the SHW.

For the most part non-compliances in accordance with the SHW tend, particularly in North Wales, to be as a result of the material being outside the specification for Particle Size Distribution (PSD) at the upper end of the distribution curve due to an excess of coarse (too large) material. This problem can be easily remedied by further or modified crushing and should not be seen as a barrier to use.

It is important to note that any process by which materials are produced from construction waste should be carried out in accordance with the Quality Protocol for the Production of Aggregate from Inert waste.

2 Background, Brief and Objectives

2.1 Background

2.1.1 Jacobs undertook a study on behalf of the Environment Agency reviewing the application of aggregates quality protocol amongst recycled aggregate producers[i] in the UK. The outcome of the survey identified major deficiencies in inspection and testing regimes amongst more than 360 recycled aggregate producers. A large number of deficiencies were associated with costs, production capacity and disparity between testing regimes.

2.1.2 In 2009 Constructing Excellence in Wales (CEW) and Tarmac initiated the Construction and Demolition Waste Programme Recycled Aggregate for Minor Schemes (RAMS) R&D project to identify suitable applications for skip waste materials produced in Wales.

2.1.3 The project identified that inert recyclate generated from a limited number of selected recycling facilities in Wales showed marked consistency of physical properties. The project also highlighted that there is a potential route to market for the recycled product as unbound material. In 2009 the market for unbound aggregates such as Type 1 sub-base for use in pavement structures and drainage was in excess of 15mt per annum in Wales.

2.1.4 RAMS test results examined the properties of blends of recycled aggregate ranging from 100:0 (coarse:fine) to 50:50 (coarse:fine). The “coarse”material being the product of reprocessing which currently finds a market and the “fine” material being the by-product which historically had gone to landfill. The outcome of the project indicates that even at the finest blend (50:50) the material would the fall within the Particle Size Distribution (PSD) boundaries of the Specification for Highway Works 800 series (SHW), However, the California Bearing Ratio (CBR) performance of the finer blends would limit the use of the material where SHW is being applied.

2.1.5 Further analysis of these materials undertaken as part of the TRAMS project will provide greater information on their physical properties and demonstrate their suitability for market if appropriately classified. It is expected that TRAMS will build industry confidence in the use of recycled aggregate through the generation of a sound data set.

[i] An organisation which processes inert waste into recycled aggregate product in accordance with the quality protocol for the production of aggregates from inert waste.

2.2 Project brief

2.2.1 To provide a comprehensive testing regime for the products of twenty selected aggregate recycling operations in Wales.

To examine the full range of the potential risks perceived to be associated with the use of inert waste materials from multiple sources as an aggregate, thus providing the evidence on which to grow a market.

To provide a body of evidence to underpin user confidence and facilitate increased application of recycled aggregates in minor schemes.[ii]

2.3 Long term Objectives

2.3.1 Divert waste from landfill (target figure is >10,000t p.a in Wales)

Overcome market barriers currently restricting the use of recycled aggregates

Influence local government procurement policy through the development of a specification or technical guidance note based on sound evidence.

[ii] Minor works are defined as low grade engineering applications including, car parks, cycle paths, tennis courts, bridleways, and footpaths.

3 Laboratory testing programme

3.1 Laboratory tests

To verify the physical and chemical properties of the recycled aggregate 7 individual tests have been carried out on unbound recycled aggregate at intervals throughout a 12 month testing programme. The testing programme as shown in Appendix 1, Table 1.1 provides a summary of the tests completed on a monthly basis.

The tests completed were determined from research and development studies carried out as part of CEW's recycled aggregate for minor schemes (RAMS) project phase 1.

Reference is made to SHW 801-809 which details unbound mixtures for sub-base and sets the criteria a material must meet, in order to be used in sub-base applications that are fit for purpose on road schemes.

3.1.1 Plasticity Index (PI)

The PI is simply the numerical difference between the liquid limit and the plastic limit for a particular material and indicates the magnitude of the range of moisture content over which the soil remains plastic. It is a measure of the cohesive qualities of the binder resulting from the clay content. Also, it gives some indication of the amount of swelling and shrinkage that will result in the wetting and drying of that fraction tested. If some soils do not have sufficient mechanical interlock they require amounts of cohesive materials to give a satisfactory performance.

3.1.2 Particle Size Distribution (PSD)

Identifies the proportion of different size fractions in a mixture, the overall mixture must comply with the relevant standard in order to be suitable for the application. The PSD is important in understanding physical properties of a material and can affect the strength and load bearing properties of a material.

3.1.3 Los Angeles Abrasion (LAA)

The LAA test is a common test method used to indicate aggregate toughness and abrasion characteristics. Aggregate abrasion characteristics are important because the constituent aggregate must resist crushing, degradation and disintegration in order to produce and maintain a quality sub-base.

The standard LAA test subjects a coarse aggregate sample (retained on the No. 12 (1.70 mm) sieve) to abrasion, impact, and grinding in a rotating steel drum containing a specified number of steel spheres.

After being subjected to the rotating drum, the weight of aggregate that is retained on a No. 12 (1.70 mm) sieve is subtracted from the original weight to obtain a percentage of the total aggregate weight that has broken down and passed through the No. 12 (1.70 mm) sieve. Therefore, an L.A. abrasion loss value of 40 indicates that 40% of the original sample passed through the No. 12 (1.70 mm) sieve.[iii]

3.1.4 California Bearing Ratio (CBR)

CBR is a common assessment for type 1 sub-base. It is a test for the evaluation of mechanical strength and measures resistance to penetrations of a material as a ratio to that of a benchmark limestone from California. The test method is detailed in BS 1377: 1990: Part 4: Method 7

The test is performed by measuring the pressure required to penetrate a soil sample with a plunger of standard area. The measured pressure is then divided by the pressure required to achieve an equal penetration on a standard crushed rock material (California limestone which has a value of 100.)

3.1.5 Waste Acceptance Criteria (WAC)

The WAC test provides basic chemical characterisation; it is a compliance test against regulatory limit values, namely inert waste, stable non reactive hazardous waste and hazardous waste landfill limits. The test involves applying an acceptance leaching test, which requires the taking of a representative sample of waste and subjecting it to leaching in water under specific test conditions. <u>It is important to note that the WAC test is specifically aimed at materials intended for landfill and is used to characterize materials prior to disposal.</u> It is not entirely appropriate to the purposes of this project and has been included as a guide only and to inform the overall conclusion of the project.

The waste acceptance procedures and criteria are set out in the Council Decision (2003/33/EC), and in Schedule 10 of the Environmental Permitting (England and Wales) Regulations 2007.

3.1.6 Horizontal Permeability (HP)

Horizontal permeability or Hydraulic conductivity describes how easy or difficult it is for water to pass through an aggregate or soil. Values typically range from 1m/s for gravels down to 10^{-9} for clays.

3.1.7 Frost Heave (FH)

FH is caused by the formation of ice lenses below the pavement surface. The formation of these lenses depends on three critical factors: the presence of available moisture; both macro and micro pore size within the susceptible material and a continuous descending freezing front. As the moisture freezes ice lenses are formed. This process creates a suction pressure which draws moisture from below by capillarity causing the ice lenses to increase in size. The process is halted if the freezing stops or if the pore sizes within the matrix are of a size to allow the

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[iii] http://pavementinteractive.org/index.php?title=Los_Angeles_Abrasion

suction pressures to be dissipated. Some soils are more susceptible to the formation of ice lenses than others. Pure clays and clean gravels are effectively not susceptible to Frost Heave, between these two extremes all soils (including aggregates) may be considered to be susceptible by degree. Silts and silty clay soils are considered amongst the most frost susceptible.

SHW specifies that no frost susceptible material[iv] can be used within the top 450mm of any road pavement or 350mm if the Mean Annual Frost Index (MAFI) of the site is less than 50.

[iv] Material is classified as non-frost-susceptible if the mean heave is 15mm or less when tested in accordance with BS 812-124:1989.

4 Success Criteria for aggregate testing

Where recycled materials are intended for use as type 1 or type 2 sub-base they must conform to a recognised industry standard where applicable. Table 1 below details the proposed tests and benchmark values that should be considered when assessing the results from the recycled aggregate tests.

The physical tests and associated benchmark data is highly regarded in the industry and appropriate for the analysis of the unbound recycled aggregate. In the absence of any other commonly accepted regime the WAC test was used to give a guide to the chemical composition of the material and was deemed the most appropriate test available for the scheme; however it is recognised that the test is used for classifying landfill waste, as inert or hazardous and is not intended for the purpose of classifying a processed product. Additional testing may be required to further classify the waste and identify the elemental composition if there is reasonable cause for suspecting the presence of harmful leachate.

Table 1: Benchmark Values and British Standard test Criteria

Test	Benchmark Value	Reference Benchmark Value	BS Test criteria
PI	Non plastic	Volume 1: Specification for Highway Works – Series 800 – 803 4 (11/04)	BS 1377-2
PSD	Within grading envelope	Volume 1: Specification for Highway Works – Series 800 - Table 8/5: (11/07) Summary Grading Requirements for Type 1 and Type 4 Unbound Mixtures	BS EN 13285
LAA	<50	Volume 1: Specification for Highway Works – Series 800 - Table 8/2 (05/09) Requirements for Aggregate Used in Unbound Mixtures	BS EN 1097-2
CBR	>30	Volume 1: Specification for Highway Works – Series 800 – Appendix 7/1	BS 1377-4
HP	- A reference value to provide information regarding material properties	N/A	HA 41/90
WAC	Inert landfill value	Landfill waste acceptance criteria for granular wastes – Pollution Prevention and control (England and Wales) Regulations 2000 (as amended)	BS EN 12457-3
FH	<15	Manual of contract documents for highways works – Volume 1 Specification for Highway Works – Series 800 Table 8/5	BS 812-124:1989

5 Aggregate producers

5.1 Definition

An aggregate producer is an organisation which processes inert waste into recycled product in accordance with the quality protocol for the production of aggregates from inert waste.

5.2 Aggregate producers

The TRAMs project proposed a testing regime for the products of twenty selected aggregate recycling operations pan Wales.

The recycled aggregate market fundamentally relies on the construction and demolition market. The downturn in construction linked to the current recession provided numerous challenges for 'recycled markets' and led to a reduced number of aggregate producers committing to the TRAMs scheme.

Aggregate producer facilities range from mobile crushers to full washing plants which will provide an opportunity for recycling methodology's to be compared.

6 Results

6.1 Deliverables

A comprehensive set of results has been collected from six North Wales sites, nine South Wales and one quarry control. Appendix 2 provides results summaries for the testing on a test by test basis. In addition to the programmed seven laboratory tests, additional testing has been introduced to determine the chemical composition of the recycled aggregate. This is further discussed in section 7 below.

7 Discussion

7.1 Interpretation of results

Analysis of the results is carried out on an individual test by test basis however where clear correlations exist they will be linked accordingly. The results have been split into two distinct categories, Physical and Chemical testing.

7.2 Physical Testing

7.2.1 Plasticity Index

160 No. samples were tested for plasticity index. Each sample tested was found to be 'Non-plastic' as required for SHW Type 1 sub base. This indicates that plasticity is not a cause concern for application of the material for minor schemes.

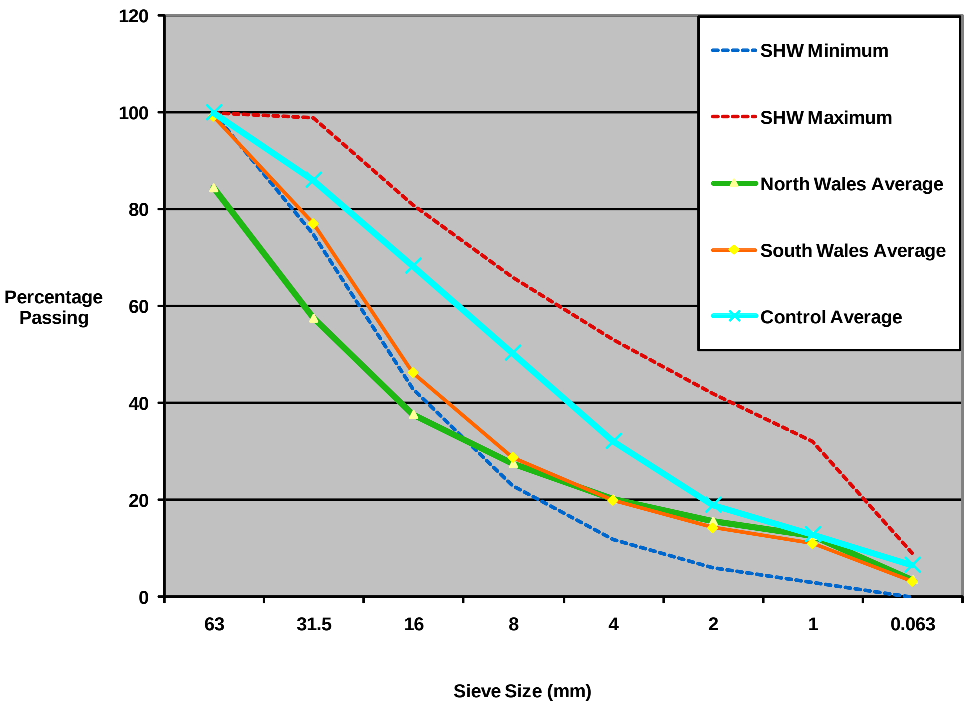
7.2.2 Particle Size Distribution (PSD)

157 Particle Size Distribution tests comprise the data set. All test results are detailed in Appendix 2 Table 2.1 and the aggregated PSD is displayed on Figure 1 below.

Figure 1 and Table 2 below provide a summary of the results comparing the North and South Wales results to the control sample.

Figure 1 Average Particle Size Distribution

Note: PSD gradings should be within the SHW maximum and minimum values.



It is evident from Figure 1 the control sample perfectly fits within the grading curve for Type 1 specification. The average gradings for the South Wales sites also conform to the Type 1 grading envelope; however at the larger sieve sizes (63, 31.5 and 16mm) the material is very close to the minimum limit (i.e. too coarse). The North Wales sites do not conform to the grading requirements for a Type 1. Failure to comply is associated with the three largest sieves where the material is too coarse.

Table 2: Sieve summary from Particles Size Distribution testing

Sample	South Wales	North Wales	Control	Total
No of PSD's [1]	89	57	11	157
No of sieves [2] *([1]*8)*	712	456	88	1256
Below minimum limit (failure to comply – material too coarse) [3] [no of sieves]	114	151	0	265
Below minimum limit (failure to comply – material too coarse) [4] *([3]/[2]*100)* [%]	16	33	0	49
Above maximum limit (failure to comply – material too fine) [5] [no of sieves]	18	4	0	22
Above maximum limit (failure to comply – material too fine) [6] *([5]/[2]*100)* [%]	2.5	0.8	0	3.3

Further analysis (from Table 2.1 Appendix 2) assessing the individual fractions from each PSD reaffirms the previous trend that generally material from North Wales sites is too coarse. With 49% of the samples being outside the grading curve the North Wales sites are producing the coarsest material – this is a clear reflection of the current markets in North Wales where use as "hardcore" in farming applications predominate.

Reprocessing coarse material and/or making changes to the screening process could readily reduce percentage of the coarser fractions which would bring the PSD into compliance with Specification for Highway Works Type 1 grading curve.

Table 2 highlights that 2.5% of the South Wales samples are too fine. This is more of a concern to 'engineers' from a workability perspective; in particular where non-compliance occurs at the finer sieve fractions. However Table 2.2 in Appendix 2 shows that 10 of the 18 results which fail in respect of excess material passing the 31.5mm and 16mm sieves are from a single source. Furthermore the results indicate that the material is very marginally (1%) fine in respect of material passing the

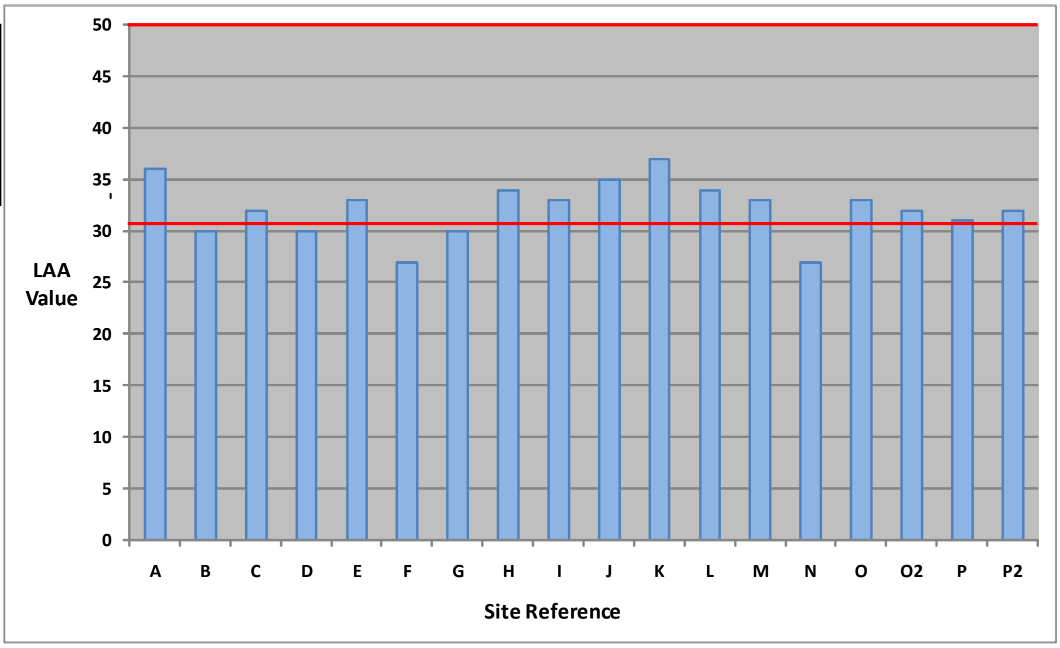
31.5mm and 16mm sieves. These results would not be a major concern for applications on minor schemes.

7.2.3 Los Angeles Abrasion

18 tests were completed and all tests produced results below the 50% threshold value in the Specification for Highway Works for Type 1. The SHW states 'Evidence of satisfactory performance in similar mixtures shall be provided where aggregates with a value of Los Angeles coefficient greater than 30 are used'. Figure 2 below identifies that 13 of the 18 samples tested would require additional evidence of satisfactory use. The Los Angeles Abrasion test indicates an aggregates resistance to degradation in use as a result of traffic loading. On non-motorway and non-trunk road schemes the traffic loadings would be reduced and the results obtained from recycled aggregate would be perfectly acceptable for lighter traffic loading applications and minor schemes.

Figure 2 Los Angeles Abrasion

Note: According to SHW, LAA value must be lower than 50 and ideally lower than 30.

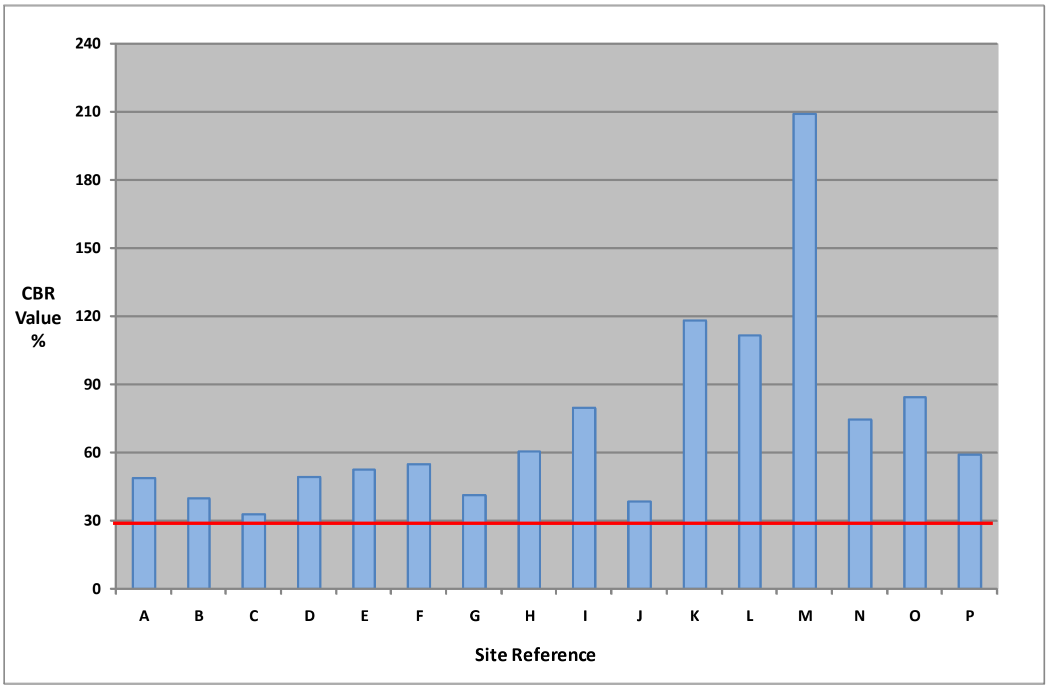


California Bearing Ratio

30 CBRs have been completed – Full results are detailed in Appendix 2 in Table 2.3. Figure 3 below indicates that average CBR's for all sites exceed the requirement of 30% in accordance with the SHW Type 1. It is also evident that a trend exists highlighting that North Wales sites have a higher CBR. Three of the six sites in North Wales have a higher average CBR than the quarried primary aggregate. These findings correlate to the higher Los Angeles Abrasion and coarser grading curves previously identified.

Figure 3 Average CBR Values for All Sites

Note: According to SHW, CBR value must be higher than 30.



The lowest CBR values are observed from site C. Analysing Table 2.3 (Appendix 2) indicates the first sample collected is below the required threshold of 30. Subsequent testing suggests that sample C1 is anomalous. Furthermore it should be considered that a CBR of 30 is not necessarily required for a minor scheme application.

7.2.4 Horizontal Permeability

Horizontal permeability was a test introduced to assist in the characterisation of recycled material. There is no specific requirement in the SHW for Horizontal permeability, however free draining materials are preferential for most sub base applications. The permeability of the 30 samples identified on Figure 4indicate the permeability is between $7.6x10^{-2}$ and $3.9x10^{-3}$

Figure 4 Horizontal Permeability

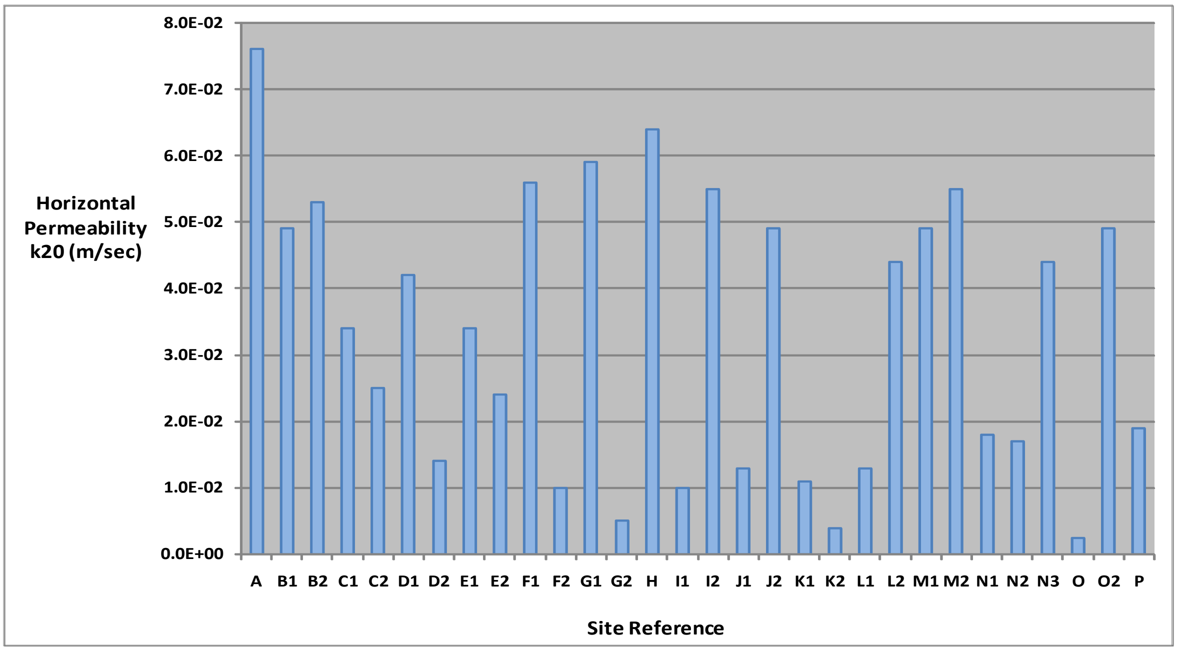


Figure 5 confirms that soils within a permeability range as highlighted by Figure 4 possess 'good' drainage.

Figure 5 – Permeability of soils (Terzaghi et al)

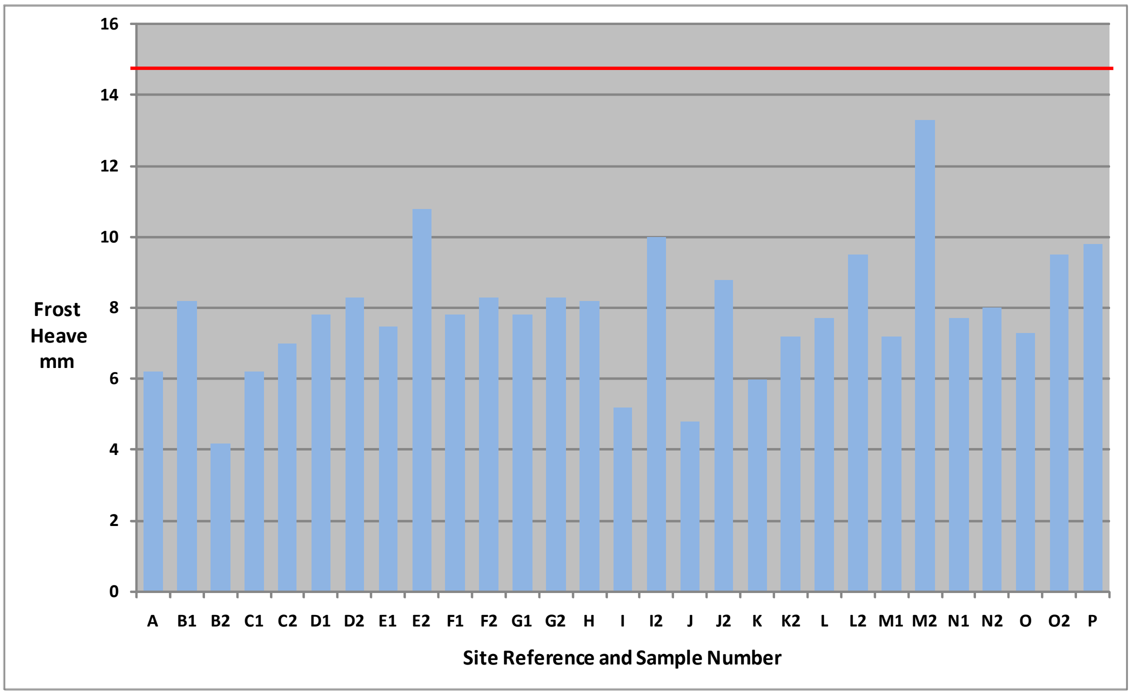
Permeability (m/s)	10^{0}	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}	10^{-10}	10^{-11}
Drainage	Good						Poor		Practically impervious			
Soil Types	Clean gravel		Clean sands, clean sand & gravel mixtures			Very fine sands, organic & inorganic silts, mixtures of sand silt & clay, glacial till, stratified clay deposits, etc.				Impervious soils e.g., homogeneous clays below zone of weathering		
					"Impervious" soils modified by effects of vegetation & weathering							

7.2.5 Frost Heave

From analysing the frost heave data and the graph in Figure 6 it is clear that recycled aggregate does not present a problem in regards to frost susceptibility. All results are below the SHW limit (15mm) and the mean frost heave value for all tests is 7.5mm.

Figure 6 Frost Heave Test Results

Note: According to SHW, Frost heave (mm) value must be lower than 15.



7.3 Chemical Testing

Due to the large volume of data the results have been presented in tabular format on Table 2.6 (Appendix 2). The discussion will focus on general trend as opposed to individual results to provide an overall summary of the findings.

Focusing on the solid waste analysis it is apparent that 21 out of the 49 WAC tests completed exceeded the limit on the fraction of organic carbon, commonly known as TOC (Total Organic Carbon). This could be attributable to planings present in the recycled aggregate, which is likely to contain bitumen or tar, depending the road age. There is also a possibility that the high values could be associated with naturally occurring organic matter such as detritus or peat.

The WAC test does not differentiate the Tar and Bitumen fractions and therefore additional testing was considered necessary to try to determine the source of the high values. In respect of landfill acceptance criteria tar is considered a 'hazardous' material whereas bitumen is inert. In assessing risk it is also important to recognise that tar has not been commonly used in road surfacings since the early 1970's other than in very specific applications such as bus stations and laybys where resistance to diesel spillage was a requirement. "Blacktop" planings are therefore unlikely to contain significant quantities of tar and the source of the planings should be noted. If there is cause to suspect the presence of tar a simple diesel wash test will confirm its presence Bitumen is extremely soluble in diesel – tar is not.

There is a strong correlation between Total Organic Content (TOC), Total Poly Hydrocarbons (TPH) and Poly Aromatic Hydrocarbons (PAH) which justifies the associated high values where TOC exceeds the limit for inert waste. Again it is important to understand that selected analyses is intended for classification of landfill materials where there would be concern that when recycled aggregate is used as a capping material applied to landfills, high TOC material may form a weak carbonic acid. This would have the effect of lowering pH leading to a potential to mobilise other contaminants and heavy metals..

It should be further noted that TOC calculated in the WAC suite is based on a solid waste analysis and not a leachate analysis. For the intended use of the recycled aggregates (minor pavement works) it may be more appropriate to complete a leachate analysis on the TOC.

The leachate analysis detected high sulphate and total dissolved solids present in approximately half of the WAC tests completed. Sites I to L and O, all located in North Wales, exceeds the limits most significantly. The high total dissolved solids would appear to be associated with the secondary processing operation (i.e. crushing and screening) whilst the high sulphate may to be attributable to brick, crushed concrete or gypsum – all items commonly found in construction and demolition skip waste. In a landfill environment these results would be of concern, however in use as unbound aggregate in minor engineering works these concerns would be inconsequential.

7.4 Additional testing

7.4.1 Chemical testing

As a result of the lack of clarity provided by the WAC test on the TOC additional testing has been carried out. Further chemical analysis utilised incorporates XRay Fluorescent Spectrophotometry (XRF) and Bitumen and Tar profiling. Both tests were undertaken to identify the composition of a target material. XRF focuses on elemental composition while bitumen profiling provides product identifications based on TPH.

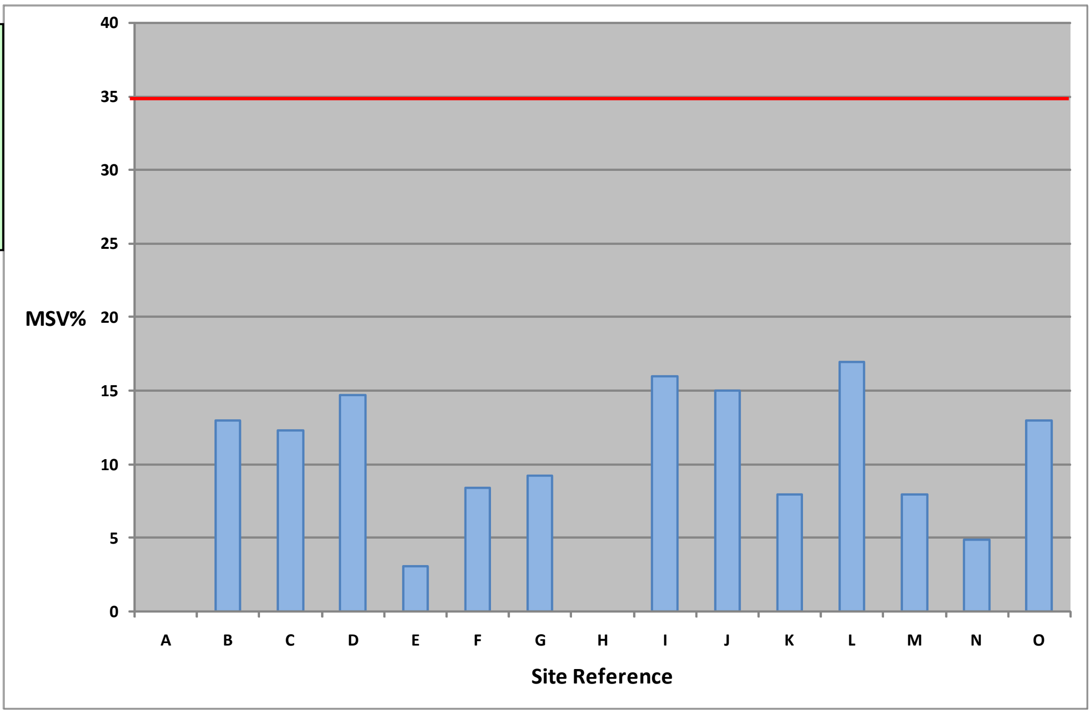
The tar/bitumen profiling identified that all five tested samples contained traces of mineral oil and were inconclusive as to source. It would be purely speculative to attempt to identify the origins of the materials.

7.4.2 Physical testing

The project steering group proposed that additional testing should be introduced to assess the aggregates resistance to weathering. The Magnesium Sulphate soundness test simulates weathering characteristics of an aggregate or more precisely its ability to resist weathering. The aggregate under test is subjected to a number of immersions in an aggressive solution of magnesium sulphate to hasten and simulate the degradation which results in cyclical freezing and thawing. 13 No tests have been carried out and the results are displayed on Figure 7. It clearly indicates that the weathering characteristics of the recycled aggregate are within the requirements of the Specification for Highway Works i.e. below a value of 35.

Figure 7 Magnesium Sulphate Soundness Value

Note: According to SHW, MSSV (mm) value must be lower than 35.



8 Conclusion

8.1 Project conclusion

The aim of the project was provide a comprehensive testing regime for the products of twenty selected aggregate recycling operations in Wales. Whilst this has been successful to a degree, only 16 (including the control site) aggregate producers took part in the scheme. The project has identified how reliant the recycled aggregate industry is on construction and demolition and a 'dip' in the economy has detrimental effects recognised in this project by lower quantity of feedstock and limited market demands. It is evident that the availability and process speed of recycled aggregate will limit its application to minor schemes until the scale of recycling facilities are increased. Constructing Excellence in Wales and Transport Research Laboratory (TRL) are working in conjunction to deliver a logistics study that will inform economics and market values.

The project has examined the potential risk elements perceived to be associated with the use of inert waste materials – specifically Type 1 sub-base from multiple sources via a rigorous testing regime. 494 tests have been completed over a 12 month programme.

The physical tests have identified the material closely conforms to the accepted industry standards as detailed in the Specification for Highway Works. Where non conformities have occurred e.g oversize material causing non compliance with particle size distribution limits, additional processing or screen modifications would easily rectify the non-compliance.

The whole basis of this project and the associated RAMS project is directed at diverting from landfill materials which could fulfil the requirements of a new standard/specification specifically designed for minor schemes such as pedestrian areas, footpaths, cycle paths, bridal paths and similar applications. The associated risks with such minor works must be considered negligible

The choice of the WAC test for the chemical analyses of the materials has led to the conclusion that the suite of tests is inappropriate for the purpose of this project. At the start of the project it was considered to be the only available recognised standard suite of tests which could apply to the materials under examination. With hindsight it is apparent that the threshold levels and determinants selected are clearly applicable to landfill materials. It is not the intention that the materials selected for this project will be so used.

The project has provided a body of evidence to underpin user confidence and facilitate increased application of recycled aggregates in minor schemes. Additional testing may be needed on a project by project basis to evidence suitability for highway applications however the results indicate the material is adequate for the proposed minor scheme market.

8.2 Future studies

There is the potential to investigate the use of recycled aggregate in Hydraulically Bound Materials using Pulverised Fly Ash (PFA) or Ground Granulated Slag as the binder. This would have multiple benefits

- It would add value to the material
- It would remove all perceived risk
- It would utilise readily available (in Wales) secondary/waste materials

Any such investigation would, however, need to closely examine the economic, environmental and logistic parameters of converting unbound recycled materials from many sources, many of which produce relatively small weekly tonnages, into higher value more robust engineering products.

A study to investigate the feasibility of transporting materials to strategically located aggregation centres which could accommodate the necessary mixing plant capable of producing HBM on an on-demand basis may be of value.

Appendix 1

Table 1.1 : Testing programme

Testing program: Testing Recylced Aggregate for Minor Schemes

Date Nov-10
Rev 0
By AJWJ

As you can see from the attached table the samples collected and tested from each site vary on a monthly basis. I have not put exact dates on the sampling as the collection dates varied on a month by month basis. To ensure we provide a full set of results testing planned for December 2009 and January 2010 was rearranged for sampling/testing in June and August. We sampled at the beginning and end of the two months identified. Cuddy joined the scheme in October and are providing different materials from a range of sites and will therefore not be included in the results.

Key:-

Acronym	Test
PI	Plasticity Index
PSD	Particle Size Distribution
LAA	Los Angeles Abrasion
CBR	California Bearing Ratio
WAC	Waste Acceptance Criteria
MS	Magnesium Sulphate
FH	Frost Heave
HP	Horizontal Permeability

Three laboratories are undertaking the testing for the programme. Exova are responsible for the chemical testing whilst the physical testing is split between Geolab and Celtest.

North Wales Sites (blue)
South Wales Sites (yellow)

		February	March	April	May	June		July	August		September	October	November	December	January	February	TOTAL
		Mid	Mid	Mid	Mid	Start	End	Mid	Start	End	Mid	Mid	Mid				
North Wales Sites	**Test**																0
	PI	4	4	4	4	5	5	5	5	5	5	5	5	2	1		59
	PSD	4	4	4	4	5	5	5	4	5	5	5	5	2	1		58
	LAA	4					1							1	1		7
	CBR	4							5			3		2	2		16
	FH	4									4		5	2			15
	HP	4					1	5						2			12
	WAC	4			4			5		1	1	5		2			22
	Mag soundness									5				1			6
	Tar and Bitumen profiling						4										4
	Asbestos						1		1								2
South Wales Sites	PI	8	7	7	7	7	7	7	7	7	7	7	10	9	4		101
	PSD	8	7	7	7	7	7	7	7	7	7	7	10	6	5		99
	LAA	9											1		1		11
	CBR	6			6								1		1		14
	FH	8		4										2			14
	HP	9		7	1								1				18
	MS									7							7
	WAC	8		6				6			4			3			27
	Tar and Bitumen profiling								1								1
	Asbestos										1						1
																Total Samples	**494**

Appendix 2

Table 2.1: Particle Size Distribution for Each Site

KEY

Sample is not within the acceptable limits for the Specification for Highways Works.

Site			A		B											
Test number			1	2	1	2	3	4	5	6	7	8	9	10	11	12
Sieve Size	Min Value	Max Value														
63	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
31.5	75	99	38	71	86	95	87	89	85	91	89	87	78	92	53	87
16	43	81	17	37	37	45	24	62	38	32	37	40	27	53	22	44
8	23	66	10	23	26	31	22	49	25	20	21	24	14	36	19	34
4	12	53	8	17	17	23	9	36	18	15	17	19	11	28	14	24
2	6	42	6	13	13	11	7	22	9	9	13	13	8	20	9	14
1	3	32	5	11	10	6	6	14	6	7	10	10	6	16	6	9
0.063	0	9	1	4	1	1	2	3	1	1	2	2	1	2	1	2

Site			C											
Test number			1	2	3	4	5	6	7	8	9	10	11	12
Sieve Size	Min Value	Max Value												
63	100	100	100	100	100	100	100	100	100	100	100	100	100	100
31.5	75	99	96	72	70	82	79	73	75	77	71	72	90	81
16	43	81	88	54	44	55	58	35	42	52	45	52	67	50
8	23	66	58	21	24	34	42	10	21	31	27	36	30	29
4	12	53	29	7	13	22	25	5	13	22	19	28	17	18
2	6	42	17	5	7	14	17	4	7	14	10	19	10	8
1	3	32	10	4	4	9	12	4	4	11	6	13	7	5
0.063	0	9	2	2	0	3	2	0	1	2	2	2	1	1

Site			D											
Test number			1	2	3	4	5	6	7	8	9	10	11	12
Sieve Size	Min Value	Max Value												
63	100	100	100	100	100	100	100	100	100	100	100	100	100	100
31.5	75	99	85	100	88	100	100	53	100	100	100	100	79	92
16	43	81	69	85	51	87	87	28	79	63	72	66	45	58
8	23	66	46	60	37	65	64	16	40	23	30	28	19	24
4	12	53	28	39	24	44	42	11	28	12	16	16	10	11
2	6	42	20	23	20	31	24	8	17	8	10	11	5	6
1	3	32	16	16	17	23	15	7	13	6	8	9	3	4
0.063	0	9	3	5	9	4	3	3	3	2	2	2	1	1

Site			E											
Test number			1	2	3	4	5	6	7	8	9	10	11	12
Sieve Size	Min Value	Max Value												
63	100	100	100	100	100	100	100	100	100	100	100	100	100	100
31.5	75	99	81	92	86	87	80	74	58	83	73	85	80	82
16	43	81	57	71	51	58	45	52	21	45	46	52	53	22
8	23	66	39	55	35	41	26	36	14	21	27	33	36	10
4	12	53	27	40	24	30	17	26	10	14	18	24	26	9
2	6	42	18	30	19	22	13	15	6	11	13	16	17	8
1	3	32	10	22	16	17	11	11	5	10	11	12	13	7
0.063	0	9	2	6	4	6	4	4	1	4	5	3	3	3

Site			F											
Test number			1	2	3	4	5	6	7	8	9	10	11	12
Sieve Size	Min Value	Max Value												
63	100	100	97	93	100	100	100	100	100	100	96	100	100	100
31.5	75	99	74	76	55	90	66	53	63	61	44	78	75	82
16	43	81	63	56	16	62	34	28	31	14	10	44	32	53
8	23	66	51	36	3	26	18	16	17	9	6	27	11	37
4	12	53	39	24	2	18	12	11	12	7	4	19	7	28
2	6	42	23	23	1	16	10	8	8	6	4	14	5	21
1	3	32	14	23	1	15	9	7	5	5	3	11	4	17
0.063	0	9	9	21	1	13	4	3	0	2	1	3	1	5

Site			G												H
Test number			1	2	3	4	5	6	7	8	9	10	11	12	1
Sieve Size	Min Value	Max Value													
63	100	100	100	100	100	100	100	100	100	100	100	100	100	100	95
31.5	75	99	87	95	94	91	55	86	66	78	68	80	92	89	75
16	43	81	35	58	67	52	27	56	29	49	32	40	60	55	54
8	23	66	19	28	45	33	14	34	10	31	11	15	38	27	42
4	12	53	13	18	32	23	9	24	5	21	5	8	29	16	33
2	6	42	9	13	23	19	7	18	4	16	4	5	20	9	27
1	3	32	6	11	18	15	6	13	4	12	3	4	15	5	22
0.063	0	9	3	4.3	7	6	3	1	1	3	1	1	3	1	5.8

Site			I											
Test number			1	2	3	4	5	6	7	8	9	10	11	12
Sieve Size	Min Value	Max Value												
63	100	100	83	94	91	95	79	77	90	96	93	94	100	82
31.5	75	99	44	64	46	59	42	43	80	58	72	66	84	49
16	43	81	24	42	16	33	18	26	70	34	50	39	60	16
8	23	66	13	30	4	22	8	17	57	24	37	22	55	10
4	12	53	9	22	2	14	4	12	43	18	25	15	39	5
2	6	42	7	17	1	9	3	10	34	13	18	11	28	4
1	3	32	5	13	1	6	2	8	31	10	14	10	22	3
0.063	0	9	1	3.1	0.1	1.8	0.6	1.3	3.8	1.8	3.3	2.6	6.4	0.3

Site			J											
Test number			1	2	3	4	5	6	7	8	9	10	11	12
Sieve Size	Min Value	Max Value												
63	100	100	96	73	57	65	58	69	72	100	95	100	100	100
31.5	75	99	66	51	11	44	19	57	61	64	57	85	98	96
16	43	81	40	41	5	28	10	44	51	45	37	56	57	59
8	23	66	28	31	3	21	6	34	39	33	29	37	51	52
4	12	53	21	24	2	15	5	26	29	22	22	27	35	36
2	6	42	17	19	2	12	4	20	21	17	15	20	23	23
1	3	32	13	15	1	9	3	16	15	13	11	16	16	16
0.063	0	9	4	5.1	0.5	1.3	0.9	4.8	5.3	3.6	2.9	5.7	3.9	3.9

Site			K											
Test number			1	2	3	4	5	6	7	8	9	10	11	12
Sieve Size	Min Value	Max Value												
63	100	100	77	91	62	92	62	82	83	100	88	100	93	61
31.5	75	99	49	62	31	77	14	63	68	63	63	72	58	38
16	43	81	36	47	21	59	4	46	48	44	46	49	27	31
8	23	66	27	38	16	47	2	35	35	33	41	36	22	28
4	12	53	21	29	12	37	2	27	26	26	35	27	16	22
2	6	42	18	26	10	31	2	22	26	19	25	22	12	14
1	3	32	16	22	9	27	2	19	26	14	17	16	10	11
0.063	0	9	5.1	4.7	0.7	8.8	0.5	4.5	25.1	2.2	2.7	1.4	3.2	1.8

Site			L										
Test number			1	2	3	4	5	6	7	8	9	10	11
Sieve Size	Min Value	Max Value											
63	100	100	67	100	100	77	92	68	90	80	86	82	100
31.5	75	99	51	73	93	64	75	46	81	62	72	49	92
16	43	81	37	45	42	48	44	33	74	48	55	26	58
8	23	66	27	27	33	37	31	25	45	38	42	13	24
4	12	53	21	20	28	28	19	20	36	31	32	7	11
2	6	42	17	17	25	20	14	17	31	26	26	5	6
1	3	32	14	15	23	18	13	15	26	22	22	3	4
0.063	0	9	2.7	3.5	9.5	4.8	2.8	6.1	8	8.8	5.2	0.2	1

Site			M						
Test number			1	2	3	4	5	6	7
Sieve Size	Min Value	Max Value							
63	100	100	83	50	89	93	100	69	96
31.5	75	99	54	6	55	59	70	42	38
16	43	81	36	1	43	35	44	26	18
8	23	66	23	1	32	29	29	22	15
4	12	53	17	1	24	20	21	17	10
2	6	42	14	0	18	14	17	13	7
1	3	32	11	0	15	11	15	11	6
0.063	0	9	3.7	0.2	3.8	2.3	1.3	4.5	1

Site			N										
Test number			1	2	3	4	5	6	7	8	9	10	11
Sieve Size	Min Value	Max Value											
63	100	100	100	100	100	100	100	100	100	100	100	100	100
31.5	75	99	92	88	76	77	84	88	81	83	96	92	90
16	43	81	48	73	53	64	71	76	72	78	62	75	80
8	23	66	32	55	40	45	53	61	44	57	44	58	64
4	12	53	26	32	25	31	34	41	27	41	15	38	42
2	6	42	18	20	17	20	21	24	15	24	8	23	19
1	3	32	13	15	13	14	15	13	11	15	6	15	12
0.063	0	9	3.7	6	7	7	7	8	6	10	3	7	7

Site			O		
Test number			1	2	3
Sieve Size	Min Value	Max Value			
63	100	100	100	100	100
31.5	75	99	98	70	83
16	43	81	50	28	56
8	23	66	41	23	42
4	12	53	28	13	29
2	6	42	19	8	19
1	3	32	16	7	15
0.063	0	9	2.9	0	4.3

Site			P													
Test number			1	2	3	4	5	6	7	8	9	10	11	12	13	14
Sieve Size	Min Value	Max Value														
63	100	100	92	92	92	100	100	100	96	84	94	95	100	100	100	100
31.5	75	99	57	56	57	89	84	85	69	64	66	72	99	99	96	99
16	43	81	55	55	55	46	47	43	52	48	52	55	69	64	63	68
8	23	66	34	34	34	31	33	29	37	33	39	42	36	33	31	33
4	12	53	27	27	27	23	24	28	27	24	29	33	20	19	30	22
2	6	42	24	24	24	15	16	22	18	17	20	23	12	11	23	13
1	3	32	22	22	22	11	11	17	13	13	15	17	8	8	20	8
0.063	0	9	13	14	13	4	3	10	4	3	5	6	5	4	16	5

Table 2.2: Los Angeles Abrasion

A	36
B	30
C	32
D	30
E	33
F	27
G	30
H	34
I	33
J	35
K	37
L	34
M	33
N	27
O	33
O2	32
P	31
P2	32

Table 2.3: CBR all sites

A	49
B1	41
B2	38.2
C1	20
C2	45.6
D1	58
D2	40.1
E1	62
E2	42
F1	59.3
F2	50.5
G1	38
G2	44.9
H1	60
I1	92
I2	67
J1	46
J2	31
K1	67
K2	46
L1	31
L2	67
M1	169
M2	88
N1	135
N2	209
O1	105
O2	103
P1	46.5
P2	130

Table 2.4: Horizontal permeability

A	0.076
B1	0.049
B2	0.053
C1	0.034
C2	0.025
D1	0.042
D2	0.014
E1	0.034
E2	0.024
F1	0.056
F2	0.01
G1	0.059
G2	0.005
H1	0.064
I1	0.01
I2	0.055
J1	0.013
J2	0.049
K1	0.011
K2	0.0039
L1	0.013
L2	0.044
M1	0.049
M2	0.055
N1	0.018
N2	0.017
N3	0.044
O1	0.0025
O2	0.049
P1	0.019

Table 2.5: Frost Heave all sites

A	6.2
B1	8.2
B2	4.2
C1	6.2
C2	7
D1	7.8
D2	8.3
E1	7.5
E2	10.8
F1	7.8
F2	8.3
G1	7.8
G2	8.3
H1	8.2
I1	5.2
I2	10
J1	4.8
J2	8.8
K1	6
K2	7.2
L1	7.7
L2	9.5
M1	7.2
M2	13.3
N1	7.7
N2	8
O1	7.3
O2	9.5
P1	9.8

Table 2.6: Chemical Analyses Results

KEY

[Orange-yellow box] Sample is not within the acceptable limits for Waste Acceptance Criteria.

Site	Inert waste	units	A	B				C			
Test number			1	1	2	3	4	1	2	3	4
Solid Waste Analysis											
Fraction of Organic Carbon	3	%w/w	1.2	0.8	13.5	1.5	7.3	2.6	7.4	9.7	2.5
Loss On Ignition		%w/w	3.6	2.4	3.9	5.6	2.9	6	3.9	5.4	4.2
BTEX	6	µg/kg	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.046	0.01
PCB	1	µg/kg	0.008	0.005	0.005	0.005	0.005	0.035	0.059	0.071	0.017
TPH (GC)	500	mg/kg	169	410	257	371	143	993	644	107	192
PAH (Total)	100	mg/kg	4.4	38.8	41.6	45.4	10.6	166	72.5	3.6	18.2
pH		-	8.2	10.3	10.1	10.1	8.9	9.2	10.4	11.8	11.6
Acid Neutralisation Capacity		mol/kg	7.3	5.7	6.8	8	4.8	6.6	7.7	7.7	6.9
Base Neutralisation Capacity		mol/kg	0	0	0	0	0	0	0	0	0
Leachate analysis											
pH			0	0	0	0	0	0	0	0	0
Conductivity			0	0	0	0	0	0	0	0	0
Arsenic	0.5		0.062	0.038	0.055	0.04	0.087	0.057	0.02	0.003	0.003
Barium	20		0.53	0.12	0.22	0.28	0.06	0.1	0.23	3.44	0.72
Cadmium	0.04		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Chromium	0.5		0.015	0.044	0.03	0.058	0.001	0.047	0.056	0.326	0.192
Copper	2		0.153	0.121	0.064	0.101	0.132	0.366	0.173	0.131	0.169
Mercury	0.01		0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum	0.5		0.042	0.023	0.038	0.042	0.026	0.045	0.03	0.083	0.045
Nickel	0.4		0.025	0.002	0.002	0.002	0.021	0.015	0.017	0.029	0.012
Lead	0.5		0.002	0.002	0.002	0.002	0.004	0.0002	0.002	0.002	0.002
Antimony	0.06		0.049	0.03	0.088	0.067	0.009	0.032	0.012	0.002	0.002
Selenium	0.1		0.013	0.006	0.022	0.02	0.002	0.015	0.015	0.031	0.005
Zinc	4		0.022	0.002	0.002	0.002	0.026	0.002	0.005	0.002	0.002
Chloride	800		22	26	34	20	19	1979	158	273	785
Fluoride	10		2	2	2	2	2	2	2	2	2
Sulphate	1000		9015	257	393	265	149	465	252	16	176
Total dissolved solids	4000		13116	987	1856	1716	409	5699	1950	5863	3931
Phenols	1		0.2	0.2	0.2	0.2	0.2	0.2	0.7	0.2	0.2
Dissolved Organic Carbon	500		13	10	19	0.2	0.2	35	62	0.2	0.2

Site			D				E			
Test number			1	2	3	4	1	2	3	4
Solid Waste Analysis	**Inert waste**	**units**								
Fraction of Organic Carbon	3	%w/w	0.4	9.1	2.8	6.2	3.9	5.2	9.2	3.1
Loss On Ignition		%w/w	2.7	2.4	4.5	4.1	5	5.2	5	5.8
BTEX	6	µg/kg	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
PCB	1	µg/kg	0.005	0.005	1.76	10.5	0.005	0.005	0.005	0.015
TPH (GC)	500	mg/kg	56	63	89	45	741	354	374	340
PAH (Total)	100	mg/kg	0.2	0.3	2.8	0.2	80	91	61	39.6
pH		-	10	10.6	8.8	9.8	9.4	9.9	8.5	10
Acid Neutralisation Capacity		mol/kg	8.8	9.3	7.4	7.4	6	6.6	5.2	7.6
Base Neutralisation Capacity		mol/kg	0	0	0	0	0	0	0	0
Leachate analysis										
pH			0	0	0	0	0	0	0	0
Conductivity			0	0	0	0	0	0	0	0
Arsenic	0.5		0.024	0.002	0.032	0.025	0.032	0.002	0.038	0.017
Barium	20		0.12	0.44	0.18	0.14	0.13	0.25	0.27	0.35
Cadmium	0.04		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Chromium	0.5		0.031	0.083	0.046	0.024	0.049	0.045	0.02	0.133
Copper	2		0.176	0.199	0.047	0.087	0.207	0.088	0.074	0.17
Mercury	0.01		0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum	0.5		0.006	0.021	0.009	0.002	0.021	0.011	0.032	0.11
Nickel	0.4		0.006	0.032	0.004	0.002	0.005	0.005	0.015	0.02
Lead	0.5		0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Antimony	0.06		0.002	0.002	0.004	0.002	0.03	0.033	0.013	0.038
Selenium	0.1		0.002	0.004	0.002	0.002	0.003	0.003	0.01	0.003
Zinc	4		0.034	0.002	0.017	0.002	0.002	0.003	0.023	0.002
Chloride	800		19	34	10	10	122	27	22	219
Fluoride	10		2	2	2	2	2	2	2	2
Sulphate	1000		56	269	77	53	1131	1042	1468	2976
Total dissolved solids	4000		1710	2380	946	327	2324	2372	3022	5693
Phenols	1		0.2	0.4	0.2	0.2	0.2	0.2	0.2	0.2
Dissolved Organic Carbon	500		8	49	0.2	0.2	18	32	0.2	0.2

Site			F				G		
Test number			1	2	3	4	1	2	3
Solid Waste Analysis	**Inert waste**	**units**							
Fraction of Organic Carbon	3	%w/w	1.4	13.7	11.9	0.1	5.2	10.6	1.6
Loss On Ignition		%w/w	4.5	2.2	4.4	4.5	2.9	5.6	6.8
BTEX	6	µg/kg	0.01	0.01	0.125	0.01	0.01	0.032	12
PCB	1	µg/kg	0.005	0.005	0.005	0.059	0.005	0.095	81
TPH (GC)	500	mg/kg	66	13	90	241	10	433	240
PAH (Total)	100	mg/kg	5.1	1.6	9.3	5.7	0.1	4.9	2
pH		-	9.5	8.7	10.5	11.4	8.9	11.1	11.8
Acid Neutralisation Capacity		mol/kg	3	3.1	6.8	7.6	9.3	6.7	8.2
Base Neutralisation Capacity		mol/kg	0	0	0	0	0	0	0
Leachate analysis									
pH			0	0	0	0	0	0	0
Conductivity			0	0	0	0	0	0	0
Arsenic	0.5		0.132	0.144	0.05	0.002	0.003	0.022	0.003
Barium	20		0.05	0.16	0.2	1.07	1.04	1.04	6.34
Cadmium	0.04		0.001	0.001	0.001	0.001	0.001	0.001	0.001
Chromium	0.5		0.007	0.003	0.023	0.088	0.005	0.134	0.181
Copper	2		0.141	0.009	0.114	0.115	0.039	0.216	0.201
Mercury	0.01		0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum	0.5		0.012	0.014	0.035	0.031	0.006	0.066	0.06
Nickel	0.4		0.01	0.015	0.003	0.005	0.002	0.005	0.017
Lead	0.5		0.002	0.002	0.002	0.002	0.002	0.002	0.003
Antimony	0.06		0.005	0.005	0.023	0.002	0.002	0.02	0.002
Selenium	0.1		0.005	0.008	0.015	0.002	0.002	0.03	0.008
Zinc	4		0.002	0.003	0.002	0.002	0.002	0.018	0.002
Chloride	800		11	10	36	30	162	50	50
Fluoride	10		2	2	2	2	2	2	2
Sulphate	1000		80	149	263	181	78	213	20
Total dissolved solids	4000		724	1249	2443	2645	1136	3599	4470
Phenols	1		0.2	0.2	0.2	0.2	0.2	0.2	0.2
Dissolved Organic Carbon	500		5	10	0.2	0.2	2	0.2	0.2

Site			I			J		
Test number			1	2	3	1	2	3
Solid Waste Analysis	Inert waste limits	units						
Fraction of Organic Carbon	3	%w/w	1.7	6.6	5	2	5.1	5.6
Loss On Ignition		%w/w	2.3	2.7	2.7	3.1	3.1	1.6
BTEX	6	µg/kg	0.01	0.01	0.01	0.01	0.01	0.01
PCB	1	µg/kg	0.005	0.005	0.005	0.005	0.01	0.005
TPH (GC)	500	mg/kg	235	2170	73	215	351	28
PAH (Total)	100	mg/kg	1	0.6	3	71.5	20	3.6
pH		-	9.2	9.9	10.7	10.1	9.3	9.5
Acid Neutralisation Capacity		mol/kg	4.6	5	4.9	6.6	5.5	9.3
Base Neutralisation Capacity		mol/kg	0	0	0	0	0	0
Leachate analysis								
pH			0	0	0	0	0	0
Conductivity			0	0	0	0	0	0
Arsenic	0.5		0.07	0.005	0.002	0.045	0.017	0.002
Barium	20		0.24	0.26	0.15	0.35	0.36	0.05
Cadmium	0.04		0.001	0.001	0.001	0.001	0.001	0.001
Chromium	0.5		0.134	0.612	0.103	0.113	0.239	0.039
Copper	2		0.127	0.176	0.048	0.22	0.165	0.062
Mercury	0.01		0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum	0.5		0.035	0.076	0.015	0.033	0.079	0.021
Nickel	0.4		0.004	0.013	0.003	0.053	0.033	0.003
Lead	0.5		0.002	0.002	0.002	0.002	0.002	0.002
Antimony	0.06		0.002	0.037	0.002	0.002	0.03	0.013
Selenium	0.1		0.002	0.005	0.002	0.002	0.006	0.002
Zinc	4		0.02	0.002	0.002	0.002	0.002	0.027
Chloride	800		98	139	80	45	86	8
Fluoride	10		2	2	2	2	2	2
Sulphate	1000		6512	3846	1396	1733	5096	885
Total dissolved solids	4000		11714	7896	2972	2284	9505	2130
Phenols	1		0.2	0.2	0.2	0.2	0.2	0.2
Dissolved Organic Carbon	500		32	68	0.2	45	81	0.2

Site			K				L		
Test number			1	2	3	4	1	2	3
Solid Waste Analysis	Inert waste limits	units							
Fraction of Organic Carbon	3	%w/w	0.4	6.3	4.6	1.1	2	4.8	4.4
Loss On Ignition		%w/w	3.2	3.9	5	3.3	3.1	4.1	4.6
BTEX	6	µg/kg	0.04	0.01	0.01	0.01	0.01	0.01	0.01
PCB	1	µg/kg	0.0035	0.005	0.007	0.005	0.005	0.006	0.005
TPH (GC)	500	mg/kg	350	272	37	50	427	354	285
PAH (Total)	100	mg/kg	13	8.4	5.7	3.4	14	9.8	5.1
pH		-	11	9.6	10.4	10.9	10.3	9.2	10.4
Acid Neutralisation Capacity		mol/kg	2	7.3	7.3	5.8	6.3	6	4.9
Base Neutralisation Capacity		mol/kg	0	0	0	0	0	0	0
Leachate analysis									
pH			0	0	0	0	0	0	0
Conductivity			0	0	0	0	0	0	0
Arsenic	0.5		0.041	0.026	0.014	0.006	0.057	0.051	0.006
Barium	20		0.34	0.44	0.16	0.4	0.23	0.37	0.15
Cadmium	0.04		0.00032	0.001	0.001	0.001	0.001	0.001	0.001
Chromium	0.5		0.25	0.297	0.097	0.278	0.097	0.132	0.166
Copper	2		0.21	0.379	0.169	0.482	0.17	0.171	0.165
Mercury	0.01		0.00061	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum	0.5		0.097	0.152	0.052	0.098	0.097	0.163	0.082
Nickel	0.4		0.092	0.051	0.013	0.08	0.037	0.031	0.015
Lead	0.5		0.003	0.002	0.002	0.002	0.006	0.002	0.002
Antimony	0.06		0.059	0.02	0.001	0.002	0.002	0.037	0.002
Selenium	0.1		0.023	0.007	0.001	0.003	0.002	0.017	0.003
Zinc	4		0.055	0.002	0.002	0.002	0.019	0.002	0.002
Chloride	800		270	241	165	173	54	162	103
Fluoride	10		15	2	2	2	2	2	2
Sulphate	1000		4000	7131	5291	4073	1150	9704	3808
Total dissolved solids	4000		5300	12826	10383	3179	4000	16258	7459
Phenols	1		1	1	0.2	0.2	0.2	0.4	0.2
Dissolved Organic Carbon	500		430	128	159	166	32	84	0.2

Site			M				N		
Test number			1	2	3	4	1	2	3
Solid Waste Analysis	Inert waste limits	units							
Fraction of Organic Carbon	3	%w/w	9.9	1.2	1.2	1.4	2.2	2.6	0.3
Loss On Ignition		%w/w	2.9	2.9	3.7	3.6	3.1	1.6	1.5
BTEX	6	µg/kg	0.01	0.01	0.01	0.01	0.01	0.01	0.01
PCB	1	µg/kg	0.005	0.005	0.005	0.005	0.005	0.005	0.005
TPH (GC)	500	mg/kg	86	46	46	594	21	22	55
PAH (Total)	100	mg/kg	0.1	3.5	1.7	8.6	0.1	0.1	0.1
pH		-	11.4	11.2	11.4	9.5	9.3	9.4	9.3
Acid Neutralisation Capacity		mol/kg	5.8	4.8	7.5	6.6	9.4	9.5	9.4
Base Neutralisation Capacity		mol/kg	0	0	0	0	0	0	0
Leachate analysis									
pH			0	0	0	0	0	0	0
Conductivity			0	0	0	0	0	0	0
Arsenic	0.5		0.005	0.003	0.005	0.016	0.002	0.004	0.002
Barium	20		0.29	0.98	0.15	0.26	0.05	0.04	0.03
Cadmium	0.04		0.001	0.001	0.001	0.001	0.001	0.001	0.001
Chromium	0.5		0.206	0.143	0.068	0.112	0.005	0.004	0.002
Copper	2		0.343	0.705	0.339	0.079	0.008	0.034	0.06
Mercury	0.01		0.0002	0.002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum	0.5		0.043	0.047	0.046	0.042	0.01	0.004	0.002
Nickel	0.4		0.022	0.098	0.053	0.006	0.002	0.002	0.002
Lead	0.5		0.002	0.02	0.002	0.002	0.002	0.002	0.002
Antimony	0.06		0.01	0.002	0.002	0.022	0.002	0.002	0.002
Selenium	0.1		0.011	0.007	0.007	0.002	0.003	0.002	0.002
Zinc	4		0.002	0.002	0.002	0.002	0.002	0.05	0.002
Chloride	800		27	17	47	48	10	10	10
Fluoride	10		2	2	2	2	2	2	2
Sulphate	1000		190	20	24	2859	286	24	20
Total dissolved solids	4000		3162	6903	1133	2391	827	857	51
Phenols	1		0.2	0.2	0.2	0.2	0.2	0.2	0.2
Dissolved Organic Carbon	500		62	0.2	6	6	12	0.2	0.2

Site	Inert waste limits	units	O		P		
Test number			1	2	1	2	3
Solid Waste Analysis							
Fraction of Organic Carbon	3	%w/w	1.7	1.7	0.4	2.2	0.6
Loss On Ignition		%w/w	3.9	3.9	0.7	3.8	0.8
BTEX	6	µg/kg	0.01	0.01	0.01	0.01	0.01
PCB	1	µg/kg	0.005	0.005	0.005	120	0.005
TPH (GC)	500	mg/kg	748	406	0.01	29	27
PAH (Total)	100	mg/kg	31.5	24.6	0.1	1.6	0.2
pH		-	11.2	10.6	9.1	10.5	9.6
Acid Neutralisation Capacity		mol/kg	7.9	8.1	9.6	9	7.6
Base Neutralisation Capacity		mol/kg	0	0	0	0	0
Leachate analysis							
pH			0	0	0	0	0
Conductivity			0	0	0	0	0
Arsenic	0.5		0.012	0.002	0.002	0.02	0.002
Barium	20		0.05	0.13	0.05	0.35	0.62
Cadmium	0.04		0.001	0.001	0.001	0.001	0.001
Chromium	0.5		0.209	0.155	0.0002	0.195	0.0002
Copper	2		0.08	0.06	0.007	0.153	0.021
Mercury	0.01		0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum	0.5		0.07	0.028	0.026	0.06	0.002
Nickel	0.4		0.008	0.005	0.002	0.019	0.002
Lead	0.5		0.002	0.002	0.002	0.002	0.002
Antimony	0.06		0.012	0.012	0.003	0.002	0.002
Selenium	0.1		0.002	0.002	0.002	0.008	0.003
Zinc	4		0.002	0.002	0.002	0.002	0.002
Chloride	800		98	104	10	19	10
Fluoride	10		2	2	2	2	2
Sulphate	1000		701	474	91	1514	4905
Total dissolved solids	4000		921	754	163	2324	7246
Phenols	1		0.2	0.2	0.2	0.2	0.2
Dissolved Organic Carbon	500		6	6	6	6	6

Table 2.7: Magnesium Sulphate Soundness Value

A	-
B	13
C	12
D	15
E	3
F	8.4
G	9
H	-
I	16
J	15
K	8
L	17
M	8
N	5
O	13

RECYCLED AGGREGATES FOR MINOR SCHEMES (RAMS)

Project Report

May 2011

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EXECUTIVE SUMMARY

The Recycled Aggregates for Minor Schemes (RAMS) project recognises that the use and value of recycled aggregates within Wales remains low whilst high quality aggregates are being specified as sub-base materials for minor schemes such as car parks, cycle paths, estate roads, footpaths, etc where very low traffic is imposed. This misuse or over specifying approach has been tolerated over the last 15 years or so due mainly to lack of confidence in the performance of alternative options. However, most clients and specifiers are now more focused on resource efficiency and the fitness for purpose approach and in situ performance is becoming the main criteria for assessing the suitability of materials in service. Managing possible risks is now a well adopted strategy by designers comparing to avoiding or minimising the risks. This cultural change is providing a good engineering value to the designers and therefore cost savings to the clients. In addition the diversion from landfill and disposal of 'fit-for-purpose' material is increasingly being implemented by clients at procurement level and targets are being set by decision makers for designers and contractors to achieve.

The initial project brief was to characterise the skip waste materials produced in South Wales and identify suitable applications where they can be used as unbound aggregates. This work was completed under Phase 1 of the project which identified specific blends of RAMS materials (namely blends of 0/25mm and 0/50mm aggregates) that they can be used as Type-1 sub-base. Nationally, Type 1 sub-base has a market demand in excess of 40 MT per annum; works have been initiated to identify the opportunity to use the skip waste as a partial replacement to a complete sub-base alternative.

For a material to be suitable for a subbase application the mixture must comply with the Specification for Highway Works 800 series (SHW), including grading of the mixture and the aggregates complying with BS EN 13285. Additional to this a Californian Bearing Ratio in access of 30% is desirable; this is generally accepted in the industry as a subbase benchmark to deem fitness for purpose.

Following the completion and reporting of Phase 1 it was agreed to carry out advanced and focused testing on the RAMS materials to confirm the findings of phase 1 testing and also to generate supplementary data which enable the market exploitation.

This report describes the additional testing that was carried out in Phase 2 and draw conclusions and recommendations regarding the performance and use of the RAMS materials as unbound aggregates. The findings presented in this report demonstrate the structural performance of the identified unbound mixes and the effect of water ingress on their integral durability. The report recommends the applications and therefore the limit on the imposed traffic loading where these mixtures can be used as unbound materials. Recommendations are also given with regard to upgrading the performance of these mixtures for higher traffic load applications.

1. Laboratory testing programme – Phase 1

Particle Size Distribution

Identifies the proportions of different size fractions in a mixture, the overall mixture must comply with the relevant standard if to be suitable for the application. The PSD is important in understanding physical properties of a material and can affect the strength and load bearing properties of a mineral.

Compressive Strength (HBM – BS EN 14227)

A common assessment for concrete and bound materials to establish the strength and load bearing capabilities of the mixture.

Petrographic Analysis

Increasing understanding of the mixture, an in depth composition of the mineral and from this suitable applications can be identified or eliminated.

XRF and Dangerous Chemicals

Detailed break down of composition, highlighting any chemicals/constituents that may be of concern or limit the opportunities available to the material

Californian Bearing Ratio (various blends)

Common assessment for Type 1 subbase mixtures and for this reason an extensive testing programme has been carried out, which is detailed in the project report. The CBR measures the resistance to penetration of a material as a ratio to that of a benchmark limestone from California, BS 1377.

Bulk Density

It is critical to understand the density of a material when highlighting applications, particularly as various mixtures were manufactured at different blends of materials and therefore the density will be directly affected.

Optimum Moisture Content

A mixture is anticipated to perform greater if manufactured and installed at its OMC, any fluctuations around this figure would anticipate a loss in stability in typical subbase materials, however, this programme aims to identify the susceptibility to moisture change of the skip waste.

Organic Content Assessment

Organic materials are a known retarder of hydraulic reactions and therefore it is essential to understand the organic content of the material when using in hydraulic materials such as HBM.

Following the initial programme of works there is a clearer understanding of the regularity of the material produced and its potential applications, now that the materials are understood. Phase 2 proposes to transfer the technologies developed in Phase 1 in to in situ application trials and to analyse materials via a robust laboratory programme to discriminate between different mixtures and establish fitness for purpose.

Some of the key criteria from the relevant specifications that the skip waste must comply with to be used in these applications are detailed in the following chapter.

Frost Susceptibility

Material shall not be frost susceptible if it is used within 450mm of the designed final surface of a road or paved central reserve, or 350mm if the Mean Annual Frost Index (MAFI) of the site is less than 50. Material is classed as non-frost-susceptible if the mean heave is 15mm or less, when tested in accordance with **BS 812-124:1989**.

Target Grading of Type 1 Unbound Mixtures

Shall be made from crushed rock, crushed slag, crushed concrete, **recycled aggregates** or well bunt non-plastic shale and may contain up to 10% by mass of natural sand that passes the 4mm test sieve

The mixture shall comply with BS EN 13285 and the requirements of Table 8/1. The grading requirements for the mixture are summarised below in Table 8/5 below:

Sieve Size (mm)	Percentage by mass passing		
	Overall grading range	**Supplier declared value grading range**	**Tolerance on the supplier declared value**
63	100		
31.5	75 – 99		
16	43 – 81	54 – 72	+/- 15
8	23 – 66	33 – 52	+/- 15
4	12 – 53	21 – 38	+/- 15
2	6 – 42	14 – 27	+/- 13
1	3 – 32	9 – 20	+/- 10
0.063	0 – 9		
Grading of individual batches – differences in values passing selected sieves			
Retained Sieve Size, mm	Passing Sieve Size, mm	Percentage by mass passing	
		Not less than	Not more than
8	16	7	30
4	8	7	30

Table 8/5 Summary of Requirements for Type 1 and Type 4 Unbound Mixtures (Extract from SHW)

- All aggregates used in mixture shall be in accordance with **BS EN 13242** and **Table 8/2.**
- The size fraction of the unbound mixture passing the 0.425 mm size test sieve shall be non-plastic as defined by **BS 1377-2.**
- Recycled coarse aggregate or recycled concrete aggregate shall comply with sub-Clause 801.5.

2. Laboratory testing programme – Phase 2

This work is focused on the two blends identified in Phase 1, namely: (1) :50% 0/50mm aggregates and 50% 0/25mm aggregates, and (2) 65% 0/50mm aggregates and 35% 0/25mm aggregates. The main objective of this testing work is to confirm the findings of the phase 1 testing and also to demonstrate the in-situ performance of the RAMS unbound materials under loading conditions for the two blends identified in Phase 1. The latter is carried by the installation of large scale pit trials at the University of Birmingham

2.1 Bench top testing

This work included the following tests:

- Permeability test – Unbound
- Frost Heave – Unbound
- Plasticity Index - Unbound
- Optimum Moisture Content (OMC) - Unbound
- Total Organic Content (TOC)
- Loss on Ignition (LOI)

The following sections provide the main findings for the above tests:

Permeability (HA 41/90)

	Parle 50:50 Blend Type 1	**Parle 65:35 Blend Type 1**
Permeability Coefficient m/sec	4.2×10^{-5}	2.1×10^{-5}

Typical permeability value for gravel is over 10^{-2} m/sec and for coarse sands the typical permeability is between 10^{-5} and 10^{-3} m/sec. The above values demonstrate that both RAMS blends are permeable.

Frost Heave BS 812 - 124

	Parle 50:50 Blend Type 1	**Parle 65:35 Blend Type 1**
Mean Frost Heave (mm) (n=6)	13.2mm	11.2mm
Maximum Allowed (SHW, 800 series)	15mm	15mm

The above results show that both blends have a frost heave value of less than the threshold of 15mm specified by the SHW

Plasticity Index – BS 1377 – 2

	Parle 50:50 Blend Type 1	**Parle 65:35 Blend Type 1**
Plasticity Index	Non-Plastic	Non-Plastic

The above results show both blends to be non-plastic

Optimum Moisture Content (OMC) – BS 1377 – 4

	Parle 50:50 Blend Type 1	Parle 65:35 Blend Type 1
Optimum Moisture Content (OMC)	15%	14%
Maximum Dry Density (Mg/m3)	1.86	1.86

The omc results for both blends show higher results than that for primary aggregates

Loss on Ignition

	Parle 50:50 Blend Type 1	Parle 65:35 Blend Type 1
LOI-Blend 1	7.37%	-
LOI-Blend 2	7.59%	-
LOI-Blend 3	6.54%	-
LOI-Blend 4	-	6.01%
LOI-Blend 5	-	5.66%
LOI-Blend 6	-	5.73%

The above LOI results show that both blends have a comparable LOI and that the magnitude ranges between 7.59% and 6.54% for Blend 1 and 6.01% and 5.66% for Blend 2.

Total Organic Content

	Parle 50:50 Blend Type 1	Parle 65:35 Blend Type 1
TOC – Blend 1	3.4% at 16.6% passing 2mm sieve	2.6% at 12% passing 2mm sieve
TOC – Blend 2	3.5% at 12% passing 2mm sieve	2.4% at 11% passing 2mm sieve
TOC – Blend 3	3.1% at 17% passing 2mm sieve	2.5% at 13% passing 2mm sieve

The above results show that the TOC for Blend 1 varies between 3.1% and 3.4% and for Blend 2 the TOC varies between 2.4% and 2.6%. These findings are in line with the LOI values.

In conclusion and based on the findings obtained in Phase 2 testing, the results do not show any major convern and confirm the findings of Phase 1 testing.

2.2 Large Pit Test

The purpose of this large scale test is to determine the performance of the blended RAMS materials under vertical loading which simulate traffic loading. The effect of water ingress into the material is then evaluated under vertical loading to determine the level and speed of deterioration under water conditions.

Test Set up

A test pit measuring 3m x 2.3 m x 1.8 m deep was used for the investigation. The bottom 1.55 m of the pit was filled with compacted building sand. The pit was then divided into two sections. Sections 1 and Section 2 were each 1.5m wide and extended the full width of the pit. A 150mm thick layer of sub-base was compacted into each test section, referred to as Areas 1 and 2. Blacktop to a thickness of 80 mm was then compacted on the subbase. Both the subbase and the blacktop were placed by Tarmac to their requirements. Two holes were bored at opposite corners of the pit and 74 mm diameter slotted piles were installed to the base of the pit. An additional shorter slotted pipe was installed between the two areas to the base of the sub-base. These clotted pipes were use to insert water into the test bed. Approximately 400 mm diameter holes were excavated to the top of the sub-base at the centre of each tests area. A thin layer of blinding sand was placed on subbase and a 300 mm diameter 25 mm thick rigid steel plate was then levelled on the sand layer. See Figure 1.

Load actuator capable of applying up to 125 kN dynamic load was then centred on the plate. Four LVDTs were installed at a range of distances from the edge of the pit wall to measure displacement of the top of the sub-base. The base of the LVDT shaft was positioned on the top of the sub-base. See Figure 2

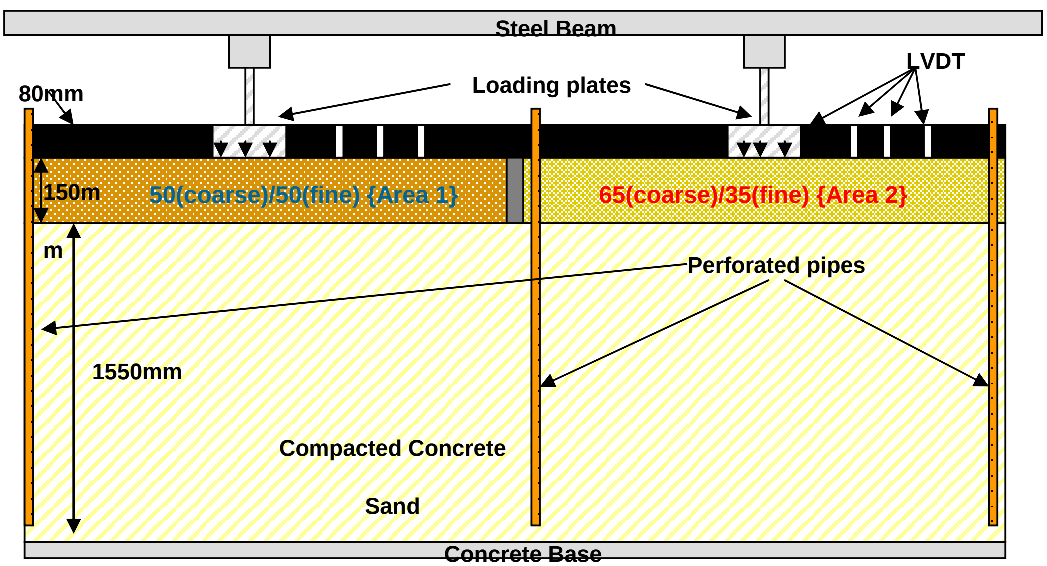


Figure 1: Pit Test Layout

Figures 2: Materials Installation

Figure 3: Pit test layout

Test Procedures

Load was applied to each area in a sequence shown in Table 1. In each case loading frequency was 3 hz applied in a sinusoidal form and the target was 250,000 cycles.

Table 1: Load Sequence Applied to both Areas

Test condition	Maximum Load (kN)
Dry	10, 30, 50, 70
Water at midpoint of sub-base layer	10. 30
Water raised to top of sub-base	10, 30

At the end of the end of the "dry" tests, water was added to test bed firstly to mid level of sub-base and secondly to top of sub-base. After water levels were raised to the correct level, a period of 24 hours allowed before proceeding with further tests. This was done to enable the strata to reach equilibrium.

Data for each test was collected at 100 cycles.

Results

Sixteen load tests were conducted on both the areas. Results of deformation and load cycles and stiffness and load cycles for Areas 1 and 2 are given in Appendices A and B respectively. They are also summarised in Table 2. Results of deformation of the sub-base are also shown in Table 2.

Table 2: Summary of Test Results

				Water	Disp . of	Displacement transducers (on top of subbase)*				Stiffness
		Max load	Min load	level	plate	1	2	3	4	kN/mm
dist from edge of plate						30	290	530	860	
	Area									
	1	10	5	d	3.77	1.603	1.657	1.684	1.709	9.6
	1	30	5	d	11	0.885	1.301	1.656	1.704	20.1
	1	50	5	d	16.3	0.785	0.976	1.626	1.726	23.7
	1	70	5	d	42.1	0.856	1.181	1.631	1.722	29
distance from edge of plate						25	170	310	565	
	1	10	5	f	4.83	0.456	1.679	1.724	1.253	8
	1(a)	30	5	f	193.2	0.862	-3.258	-2.243	-4.035	0.7
	1	10	5	ff	19.5	-2.099	1.583	1.687	1.759	8.2
	1	30	5	ff	135.6	-0.015	-0.663	0.282	0.605	16.54
distance from edge of plate						40	160	270	540	
	2	10	5	d	3.5	1.735	1.77	1.722	1.875	9.9
	2	30	5	d	14.3	0.752	0.457	0.879	1.347	22.3
	2	50	5	d	22.6	0.522	-0.215	0.231	0.655	28
	2	70	5	d	59.5	1.167	0.601	0.554	0.877	29.5
	2	10	5	f	7.7	1.987	1.63	1.98	3.001	8
	2 (a)	30	5	f	126.7	1.294	0.831	1.077	1.227	16.4
	2	10	5	ff	12.5	1.552	1.027	0.953	0.935	7.5
	2	30	5	ff	107.8	0.759	-0.204	0.628	0.967	15.5
	d = dry					* End of test displacement.				
	f = flooded to mid level of subbase									
	ff = flooded to top of subbase									
	negative values indicate heave									
	(a) - test terminated due to excessive settelement									

In all the tests for 30 kN loading, when the sub-grade was inundated, excessive deformation occurred. On two occasions, the load actuator exceeded the travel full target number of cycles could not be achieved.

An example of excessive deformation of the load plate is shown in Figure 5. In the event of excessive deformation, the level of the subbase was raised to the original level with a new layer of compacted subbase before proceeding with further tests. An example of the plate exhibiting excessive deformation is shown in Figure 6 (water drained after test). It clearly shows that subbase has rolled on to the load plate during the test and suggests that a punching failure of subbase occurred.

Figure 4: Typical example of excessive deformation of plate – at the end of the test

Figure 5: Typical example of excessive deformation of plate – after water was drained

Prediction of material durability

Under dry conditions, both the sub-base types were able to sustain up to 5 tons wheel load limiting damage to sub-base to less than 25mm in terms of settlement. Settlement greater than 40mm occurred under 70KN wheel load. In order to estimate load relative to Standard Wheel load, it was assumed that deformation of the sub-base was limited to 10mm. This value was chosen as when wet, the two types of sub-base exhibited very large deformation. Since even when sealed, there may be inundation of the underlying layers, it was felt that a lower limit of deformation should be considered as being more suitable under "dry" conditions. Ratio of number repetitions (N) of wheel load that give 10mm deformation at the sub-base level and the number of load repetitions (Ns) under Standard axles load for the same level of damage were plotted against a range of wheel loads. See Figure 7. Results show that the two areas follow different power laws: for Area 1- Ns/N = 0.0013(wheel load)$^{5.03}$ and for area 2, Ns/N = 0.02810(wheel load)$^{3.23}$. If the outlier data is ignored for Area 2, then Ns/N = 0.0005(wheel load)$^{5.57}$. See Figure 8. It is suggested that fifth power law equation, with constants that give conservative design should be used.

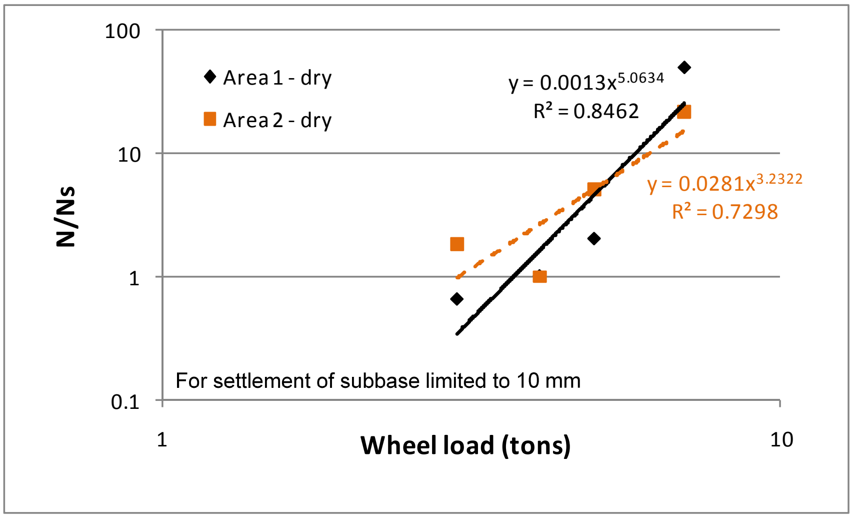


Figure 6: N/Ns versus wheel load

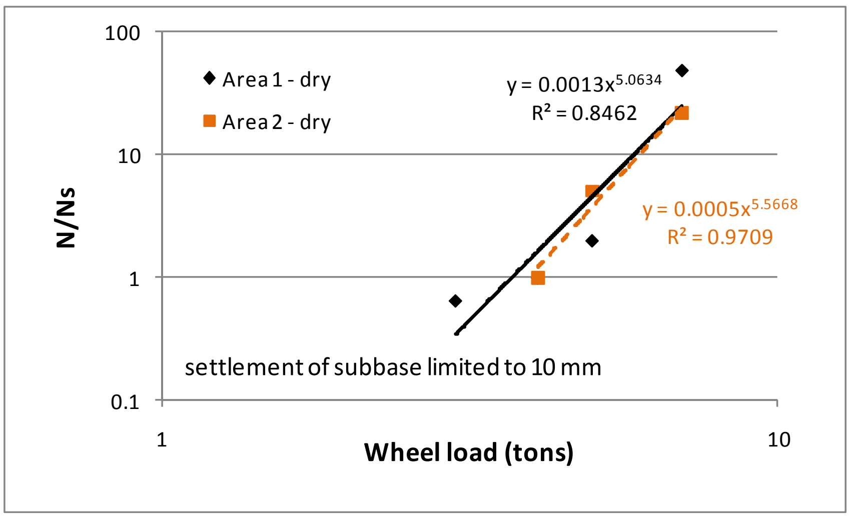


Figure 7: N/Ns versus wheel load (with outlier data removed)

Summary of results

The following tables summarises the main findings of the pit testing.

(a) Cumulative Deformation

DRY CONDITIONS	50:50	65:35
10 KN at 50,000 cycles	3.3mm	2.6mm
30 KN at 50,000 cycles	9mm	8.1mm
50 KN at 50,000 cycles	11mm	15mm
70 KN at 50,000 cycles	28mm	40mm

(b) Effect of water on the cumulative deformation at 10 KN loading

10 KN APPLIED LOAD AT 3 HZ FREQUENCY	Dry Sub-base	Half Submerged Sub-base	Fully Submerged Sub-base
50 (Coarse) + 50 (Fine)	3.3mm (50k cycles) 3.7mm (100k cycles)	4.5mm (50k cycles) 4.8mm (100k cycles)	17mm (50k cycles) 18mm (100k cycles)
65 (Coarse) + 35 (Fine	2.6mm (50k cycles) 3mm (100k cycles)	5.5mm (50k cycles) 6.2mm (100k cycles)	11mm (50k cycles) 12mm (100k cycles)

(c) Effect of water on the cumulative deformation at 30 KN loading

30 KN APPLIED LOAD AT 3 HZ FREQUENCY	**Dry Sub-base**	**Half Submerged Sub-base**	**Fully Submerged Sub-base**
50 (Coarse) + 50 (Fine)	9mm (50k cycles) 10mm (100k cycles)	190mm (50k cycles) 200mm(100k cycles) **FAILURE BY PUNCTURE**	80mm (50k cycles) 100mm (100k cycles) **FAILURE BY DEFORMATION**
65 (Coarse) + 35 (Fine	8mm (50k cycles) 10mm (100k cycles)	120mm (50k cycles) 200mm (100k cycles) **FAILURE BY PUNCTURE**	60mm (50k cycles) 80mm (100k cycles) **FAILURE BY DEFORMATION**

3. Conclusions

Based on the findings obtained from the testing work carried out under Phase 1 and Phase 2 of this project, the following conclusions are drawn.

Both blends (Blend 1: 50% 0/50mm aggregates and 50% 0/25mm aggregates and Blend 2: 65% 0/50mm aggregates and 35% 0/25mm aggregates) meet the following requirements as set by the Highways Agency - Specifications for Highway Works (SHW):

- Constituents – Within the HA limits for Sub-base materials
- Grading - Within the HA limits for Type-1 Sub-base materials
- Frost/Heave - Within the HA limits for Sub-base materials
- Plasticity - Within the HA limits for Sub-base materials
- The Optimum Moisture Content (OMC) is 2.5 times higher than for a crushed rock sub-base
- The Loss On Ignition values range from 5.7% to 7.6% for both blends
- The Total Organic Content values range from 2.4% to 3.5%

The large scale pit test has demonstrated the structural performance of the RAMS materials under traffic loading and the main conclusions from this work are:

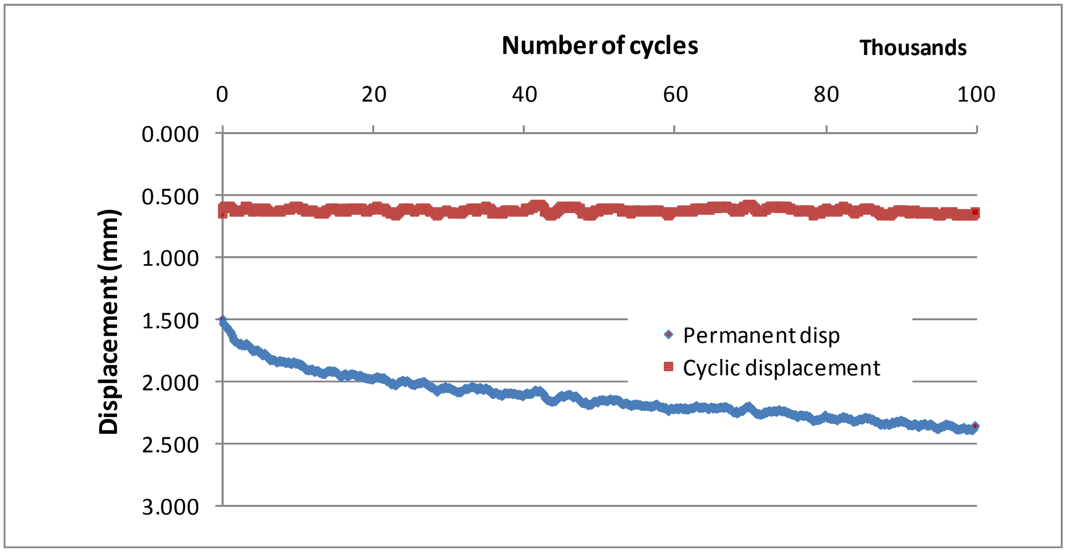
- For Minor Schemes where low traffic loading is imposed (i.e., traffic loading<0.5 msa) which includes Cars Loading (1 ton load per axle), both blends should structurally perform providing the materials are not subjected to increased water ingress and ponding of water within the sub-base materials. The latter could potentially lead to material failure by puncture.

- If the imposed traffic loading is increased beyond 0.5 msa, for example Bus loading or HGV loading, both mixtures will fail under this increased loading by excessive vertical deformation

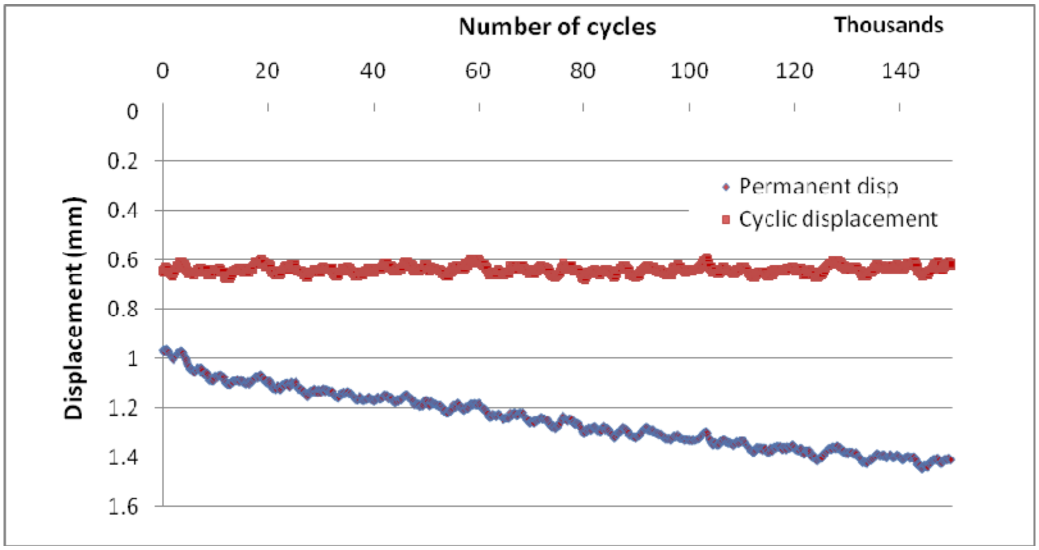
- If either blends are to be used in areas that could be subjected to increased loading either occasionally or routinely in this case it is recommended that the material structural performance is upgraded. Phase 1 testing has demonstrated that this can be achieved by introducing a hydraulic binder into the mixture such BOS slag and/or PFA which will provide a bound mixture by slow hydration of these binders leading to a monolith over time. Subject to pavement trial demonstration this could potentially allow the RAMS materials to be used as sub-base materials in heavier traffic loading applications

APPENDIX A – AREA 1

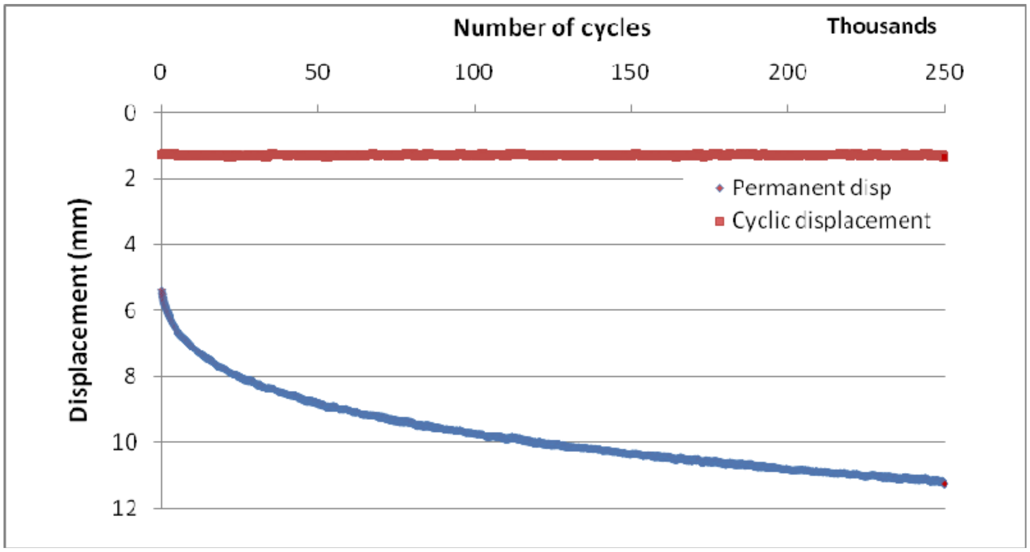
AREA 1 - DISPLACEMENT OF LOAD PLATE UNDER "DRY CONDITIONS"



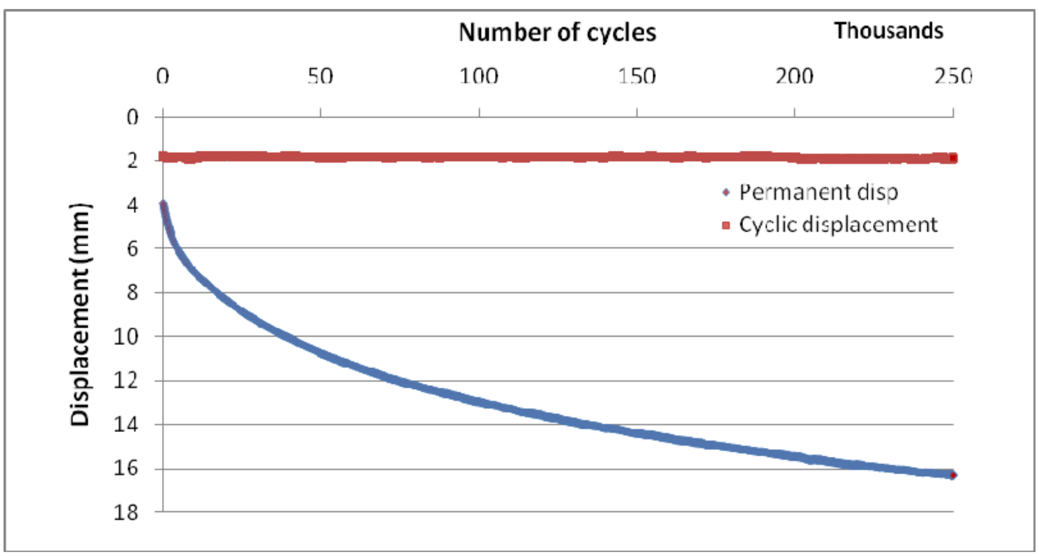
Area 1 – Displacement/loading relationship for 10kN



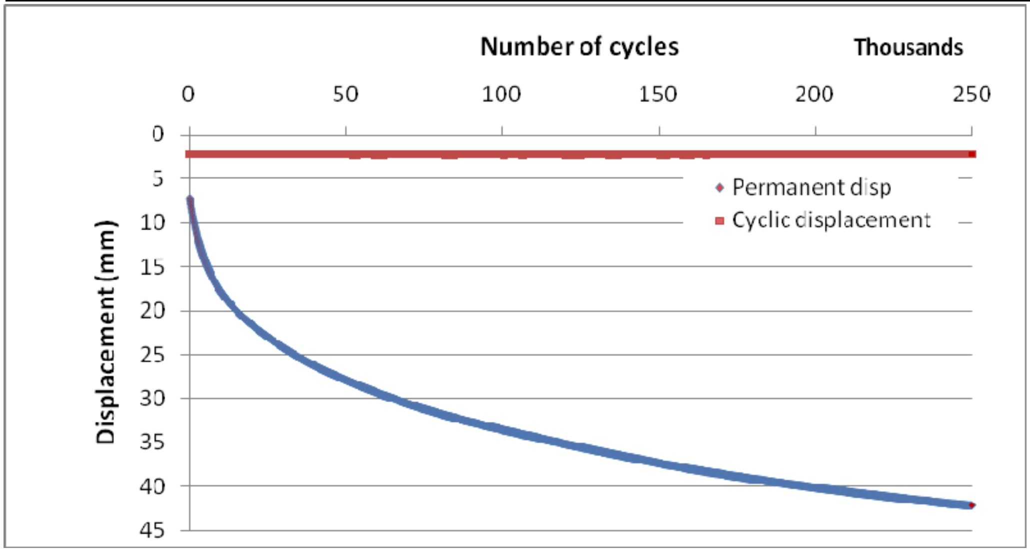
Area 1 – Displacement/loading relationship for 10kN for additional 150 thousand cycles



Area 1 – Displacement/loading relationship for 30kN

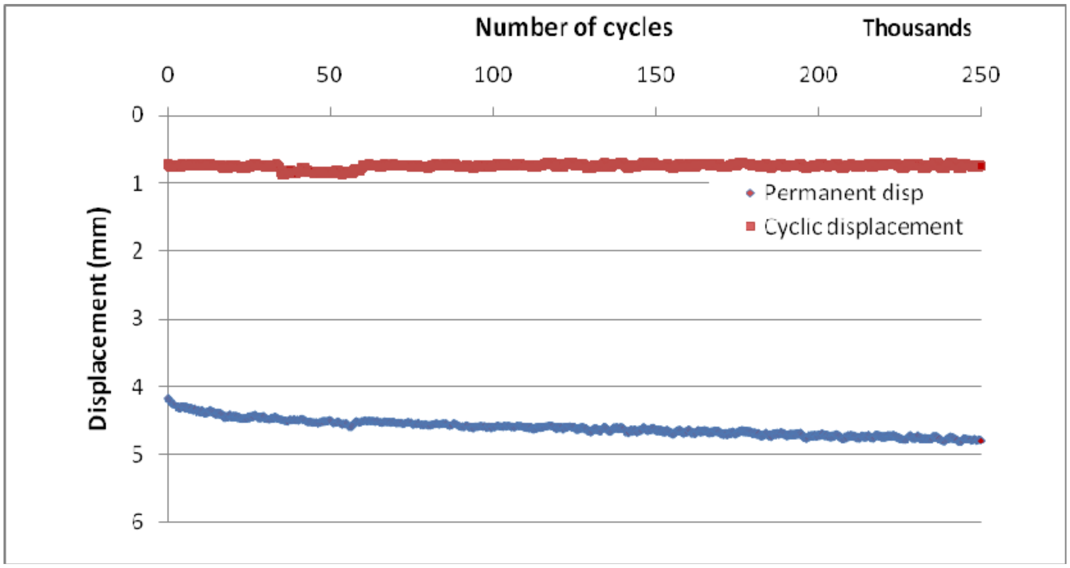


Area 1 – Displacement/loading relationship for 50kN

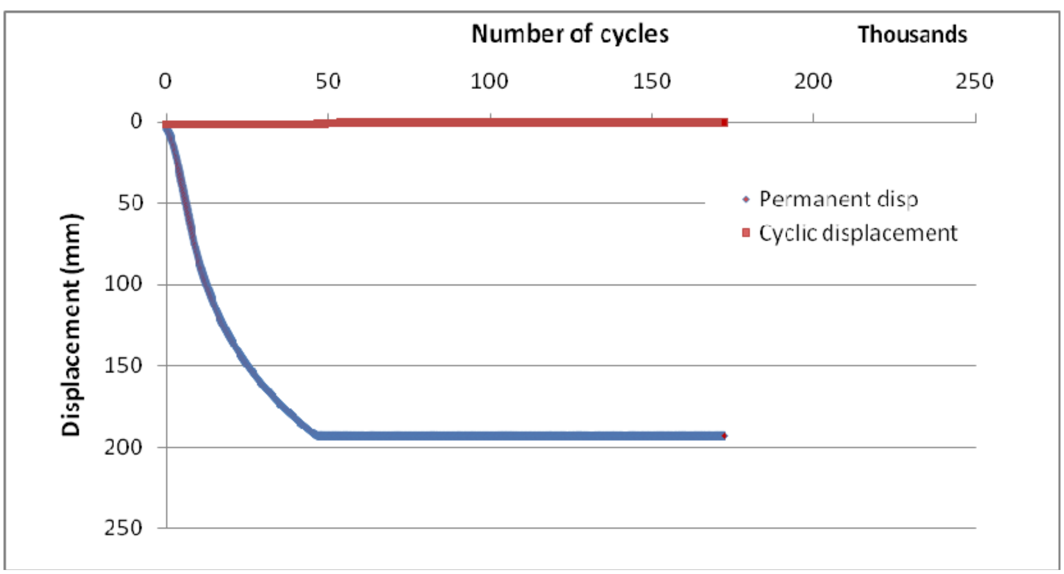


Area 1 – Displacement/loading relationship for 70kN

AREA 1 - DISPLACEMENT OF LOAD PLATE - WATER LEVEL AT MID HEIGHT OF SUBBASE



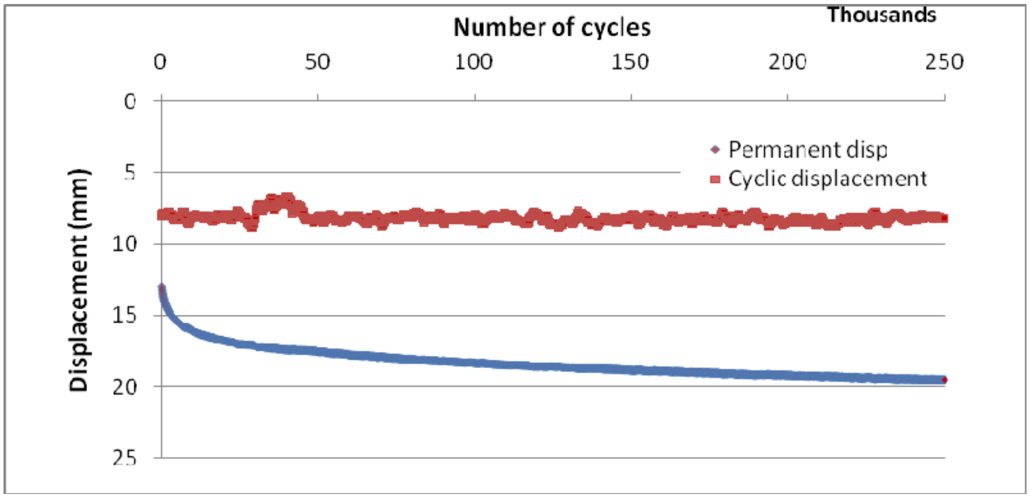
Area 1 – Displacement/loading relationship for 10kN - water at mid height of subbase



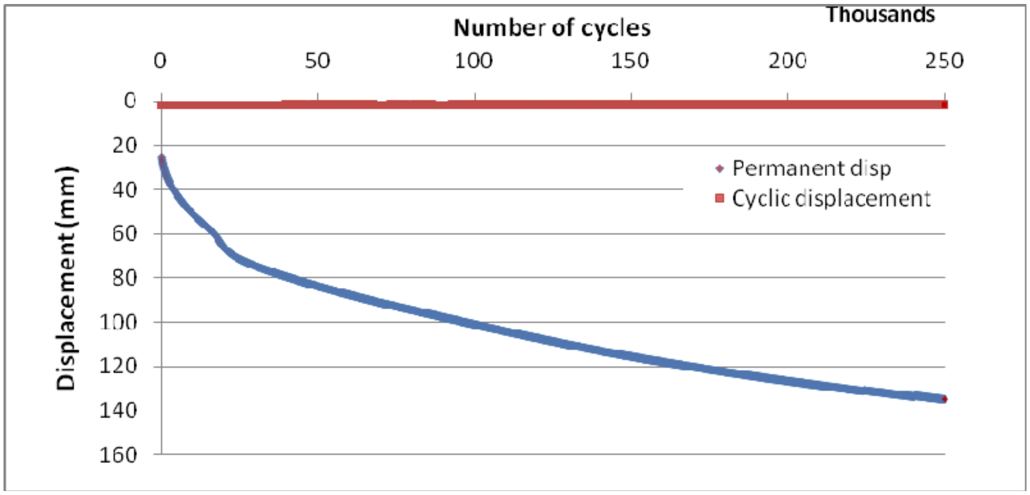
Load actuator reached limit at about 50k cycles.

Area 1 – Displacement/loading relationship for 30kN - water at mid height of subbase

AREA 1 - DISPLACEMENT OF LOAD PLATE - WATER LEVEL AT TOP OF SUBBASE



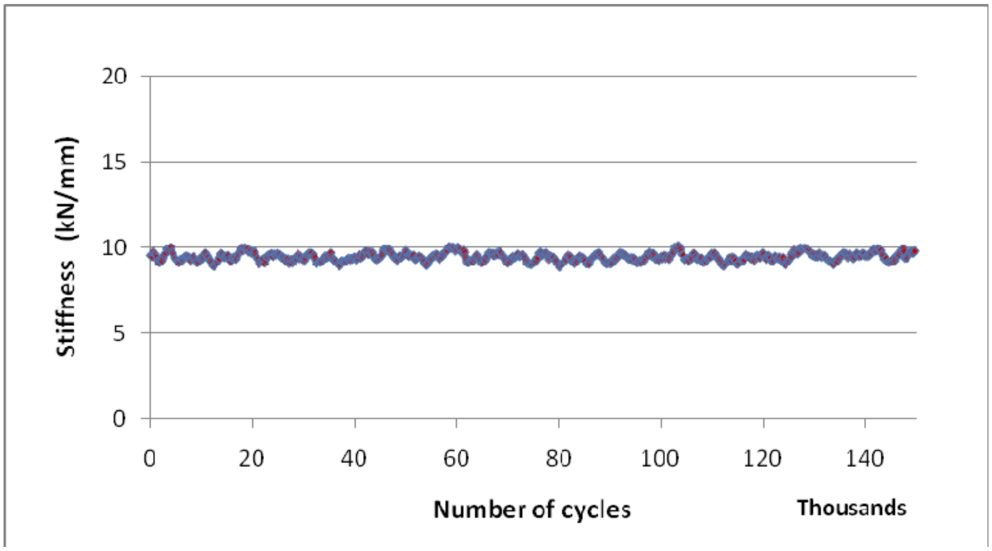
Area 1 – Displacement/loading relationship for 10kN - water at top of subbase



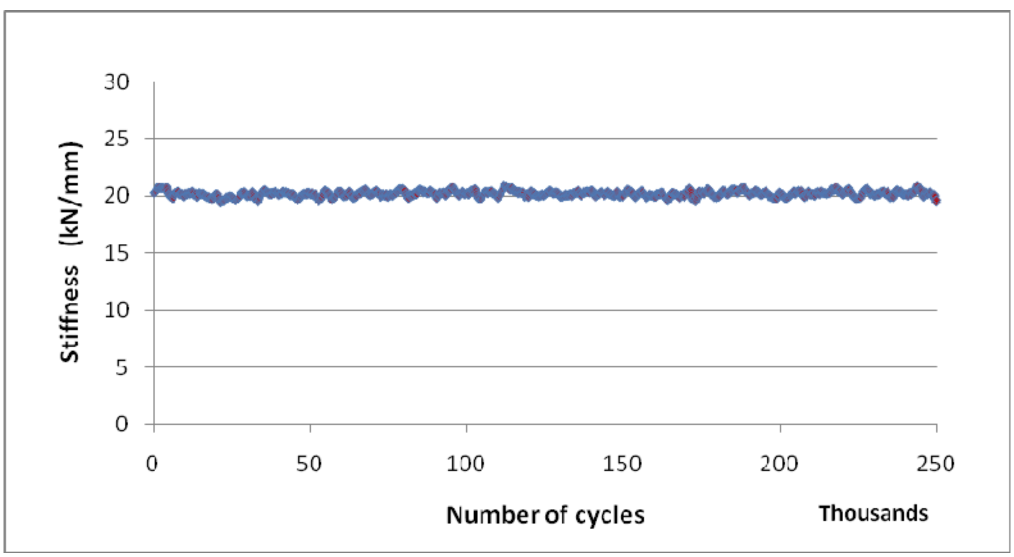
Area 1 – Displacement/loading relationship for 30kN - water at top of subbase

AREA 1 – STIFFNESS OF MATERIALS SUPPORTING LOAD PLATE UNDER "DRY CONDITIONS"

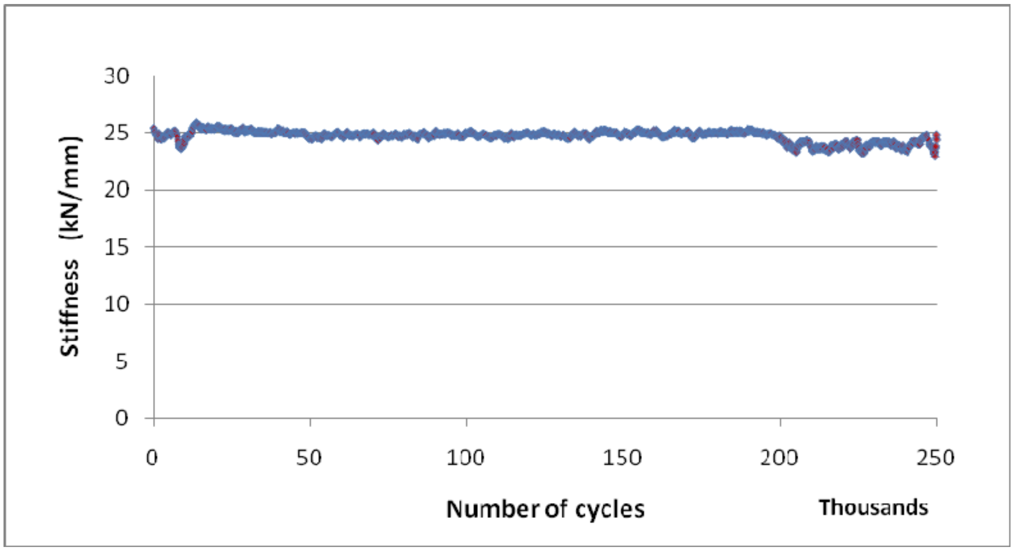
Area 1 – Stiffness/loading relationship for 10kN



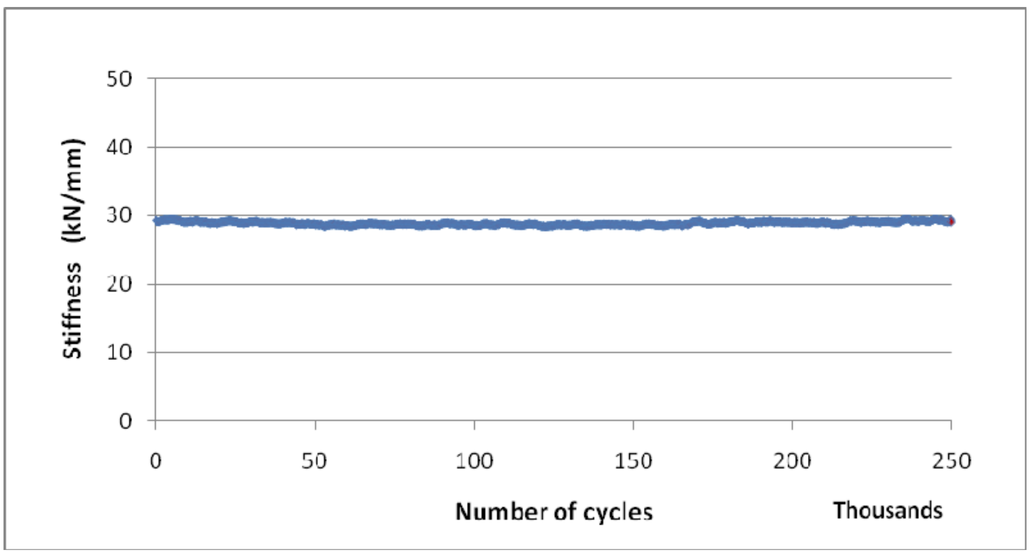
Area 1 – Stiffness /loading relationship for 10kN for additional 150 thousand cycles



Area 1 – Stiffness /loading relationship for 30kN

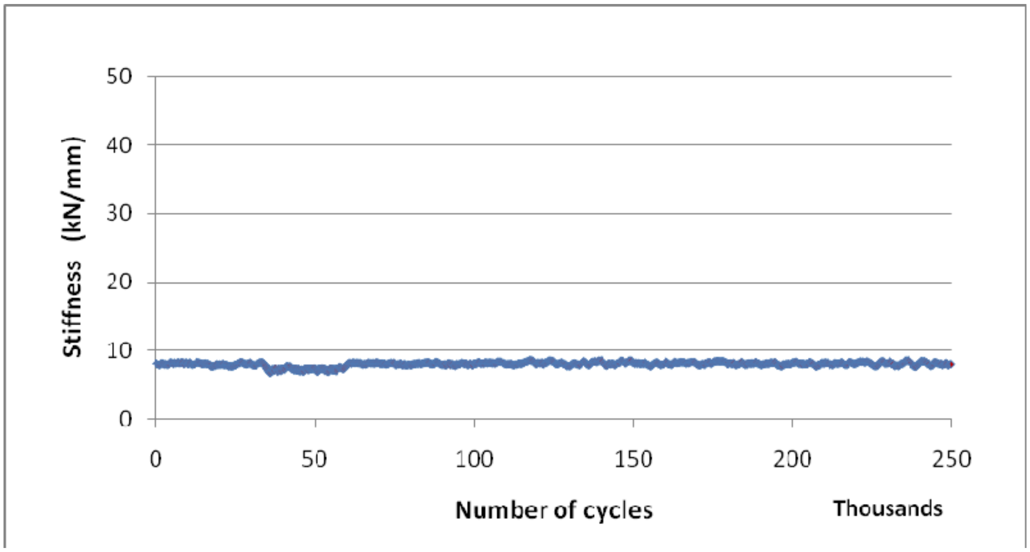


Area 1 – Stiffness /loading relationship for 50kN

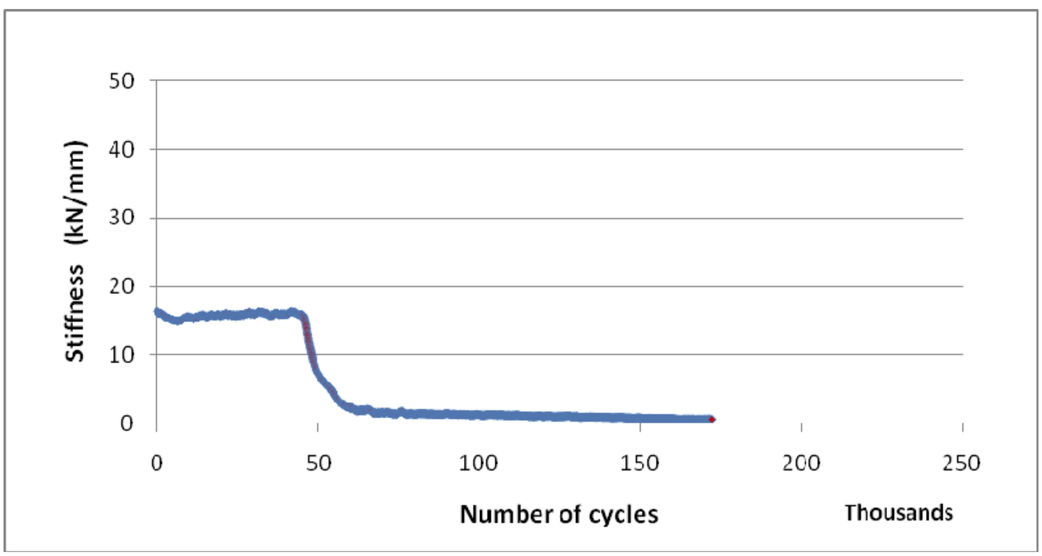


Area 1 – Stiffness /loading relationship for 70kN

AREA 1 - STIFFNESS OF MATERIALS UNDER LOAD PLATE - WATER LEVEL AT MID HEIGHT OF SUBBASE



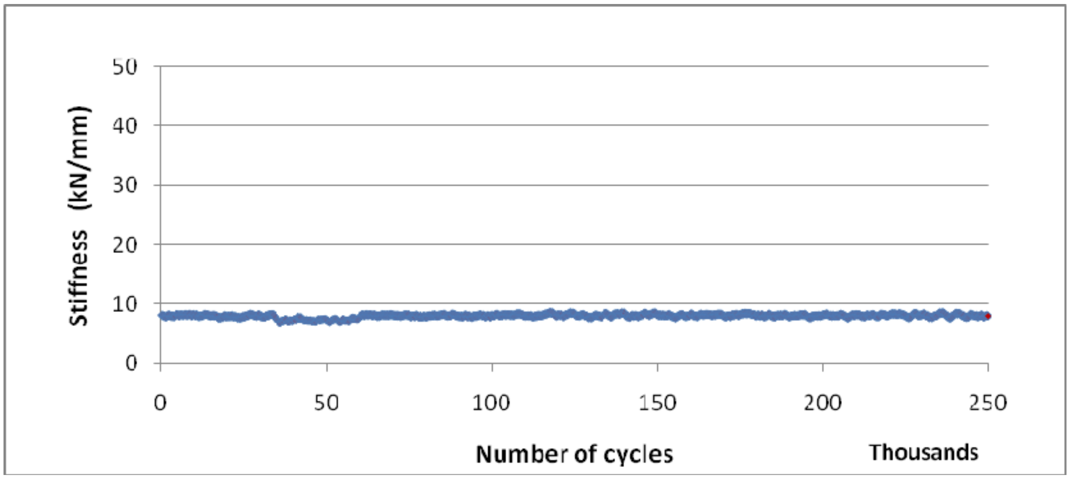
Area 1 – Stiffness /loading relationship for 10kN - water at mid height of sub-base



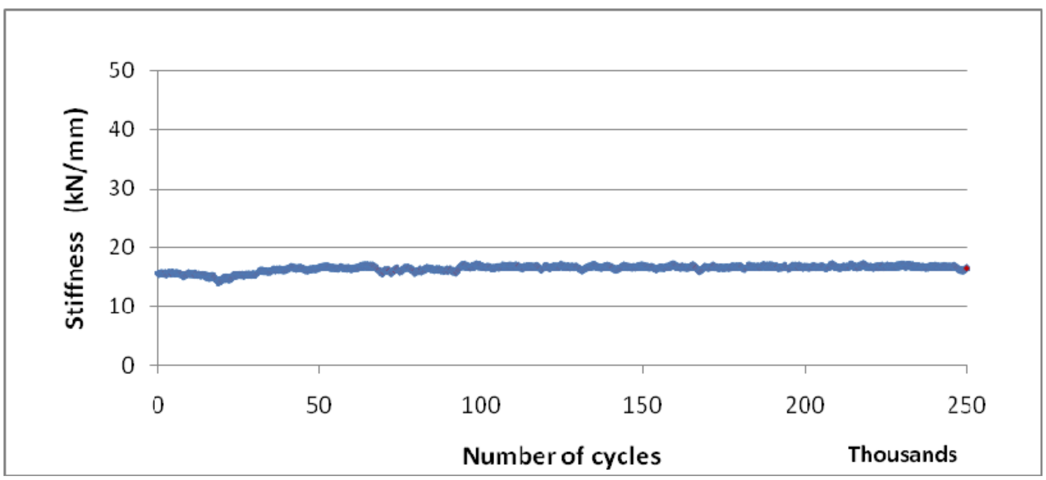
Load actuator reached limit at about 50k cycles.

Area 1 – Stiffness /loading relationship for 30kN - water at mid height of sub-base

AREA 1 - STIFFNESS OF MATERIALS UNDER LOAD PLATE - WATER LEVEL AT TOP OF SUBBASE



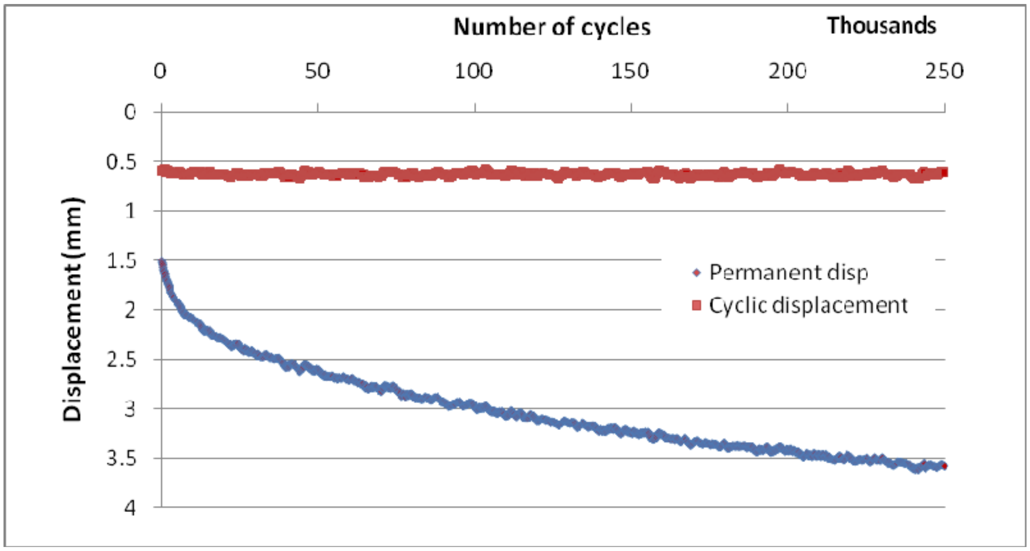
Area 1 – Stiffness /loading relationship for 10kN - water at top of sub-base



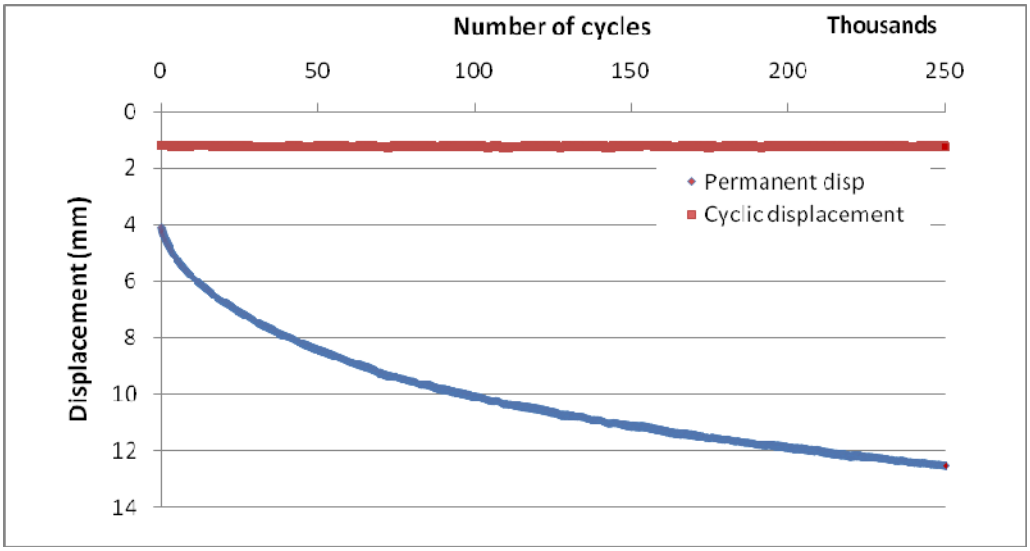
Area 1 – Stiffness /loading relationship for 30kN - water at top of sub-base

APPENDIX B – AREA 2

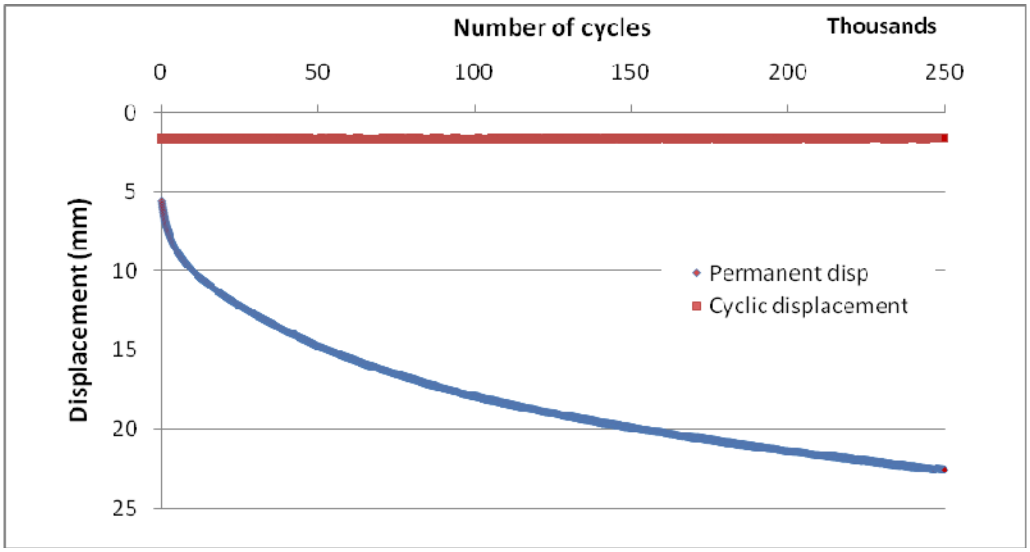
AREA 2 - DISPLACEMENT OF LOAD PLATE UNDER "DRY CONDITIONS"



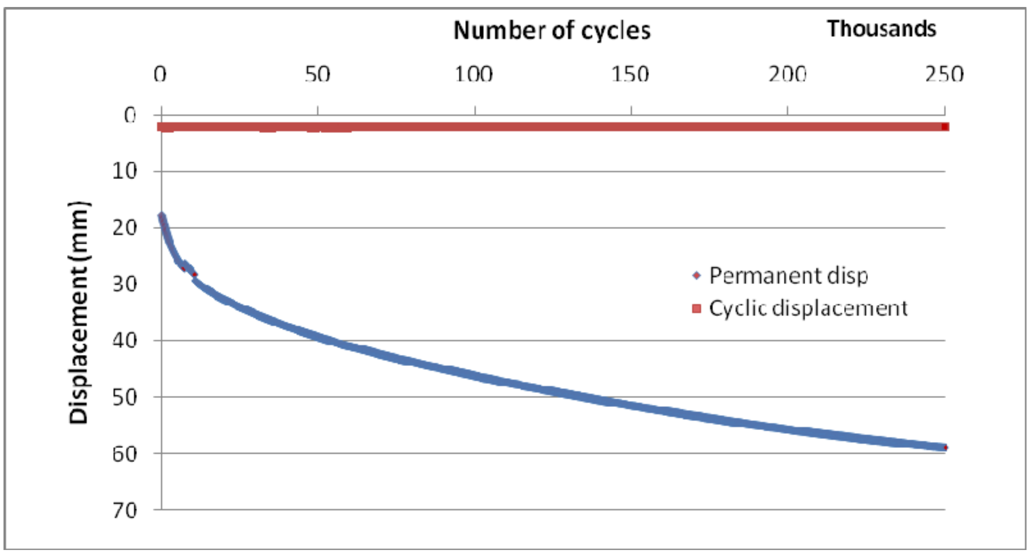
Area 2 – Displacement/loading relationship for 10kN



Area 2 – Displacement/loading relationship for 30kN

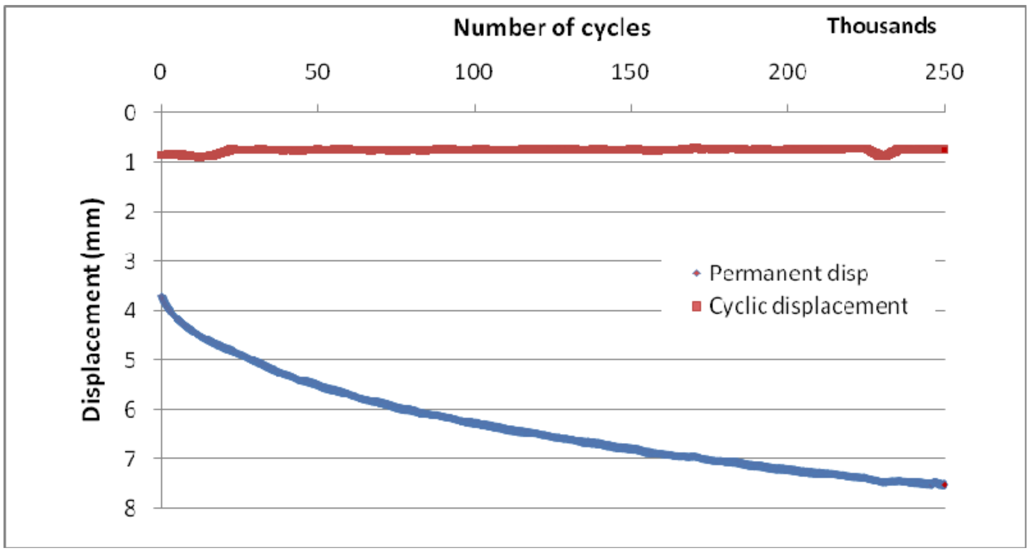


Area 2 – Displacement/loading relationship for 50kN

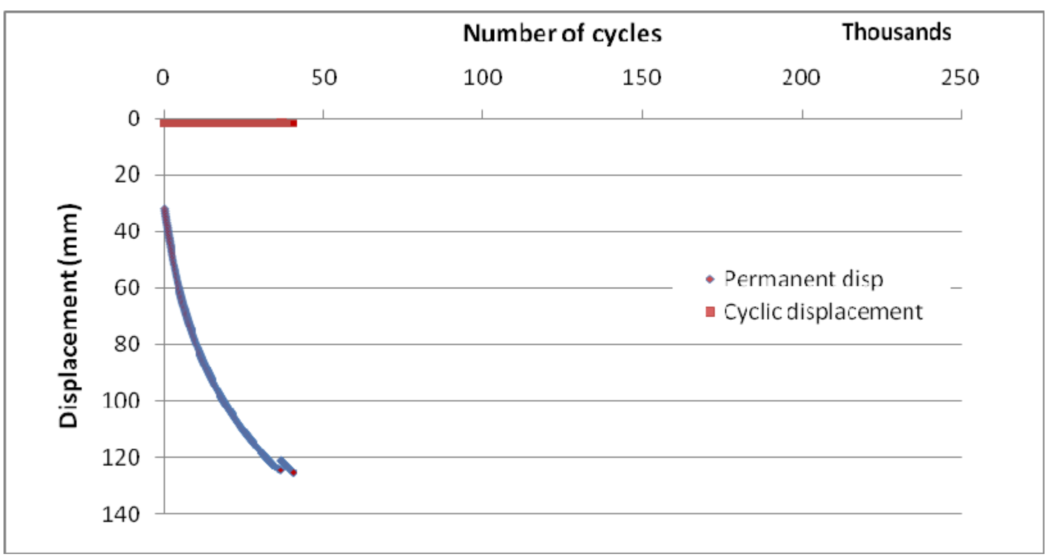


Area 2 – Displacement/loading relationship for 70kN

AREA 2 - DISPLACEMENT OF LOAD PLATE – WATER AT MID HEIGHT OF SUBBASE



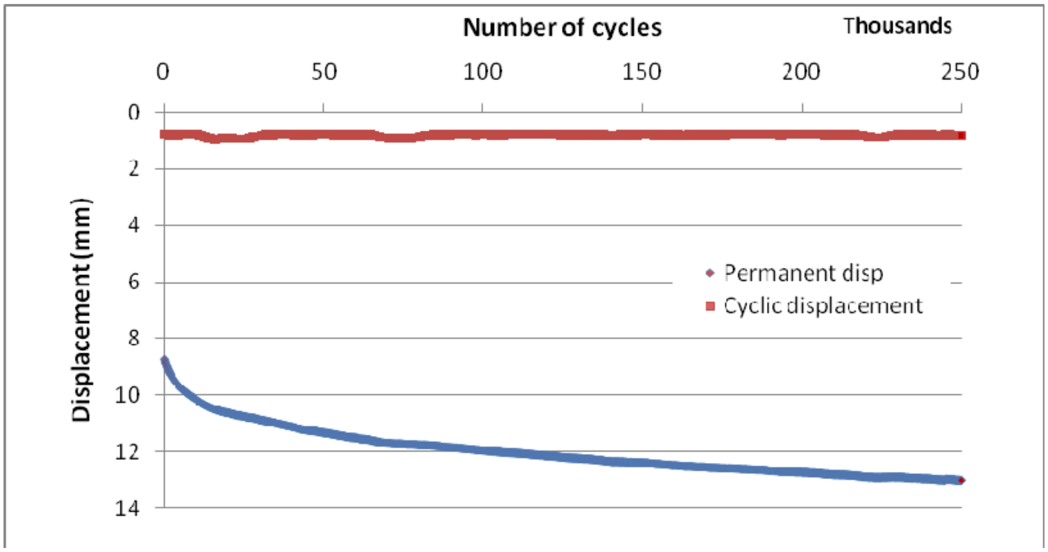
Area 2 – Displacement/loading relationship for 10kN – water at mid height of sub-base



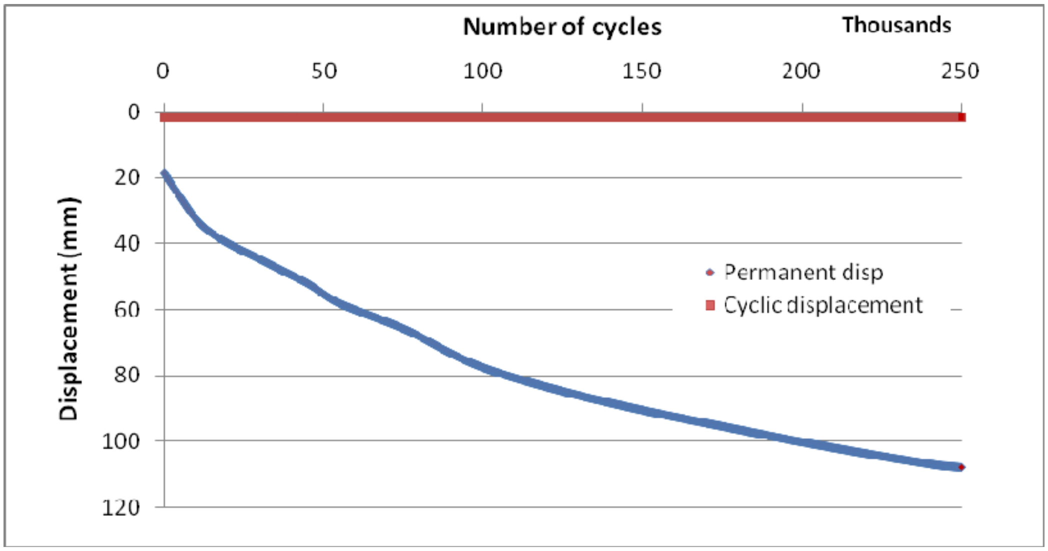
Limit of actuator plunger reached at about 40k cycles.

Area 2 – Displacement/loading relationship for 30kN– water at mid height of sub-base

AREA 2 - DISPLACEMENT OF LOAD PLATE – WATER AT TOP OF SUBBASE

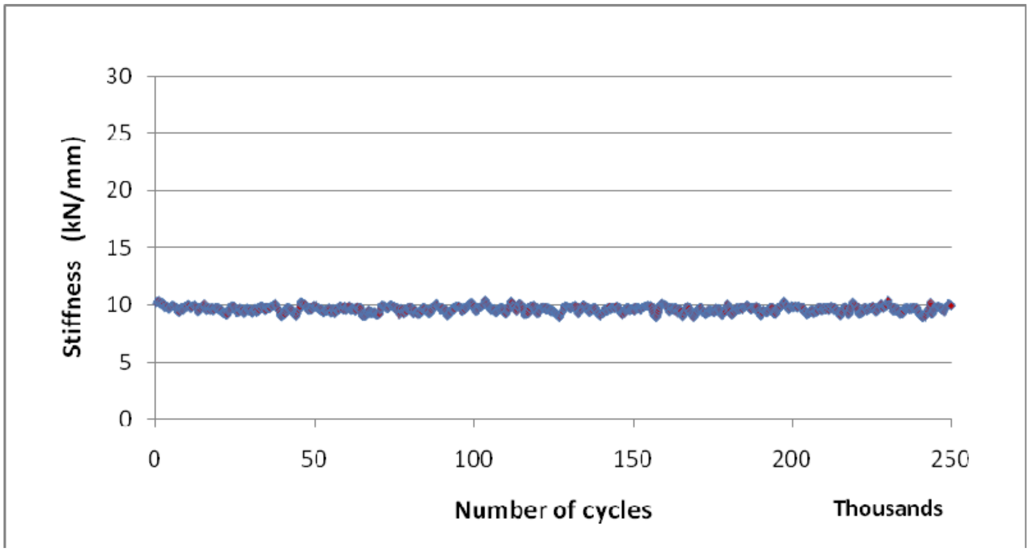


Area 2 – Displacement/loading relationship for 10kN– water at top of sub-base

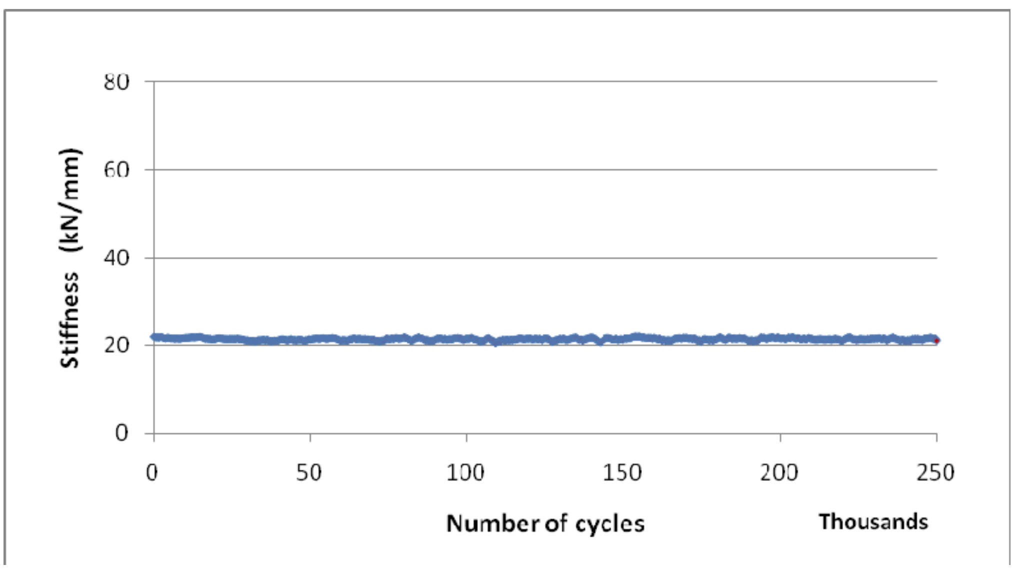


Area 2 – Displacement/loading relationship for 30kN– water at top of sub-base

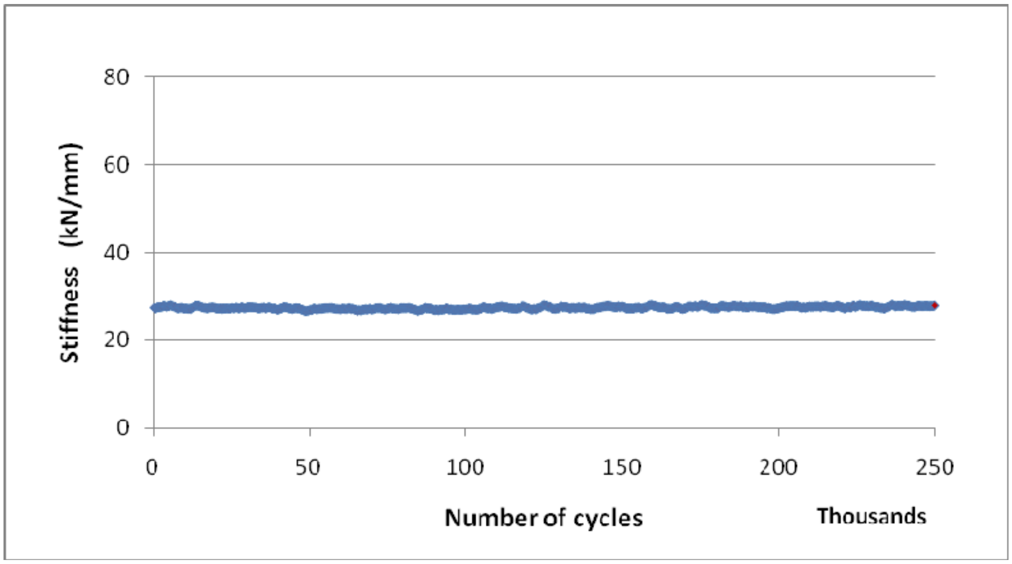
AREA 2 – STIFFNESS OF MATERIALS UNDER LOAD PLATE UNDER "DRY CONDITIONS"



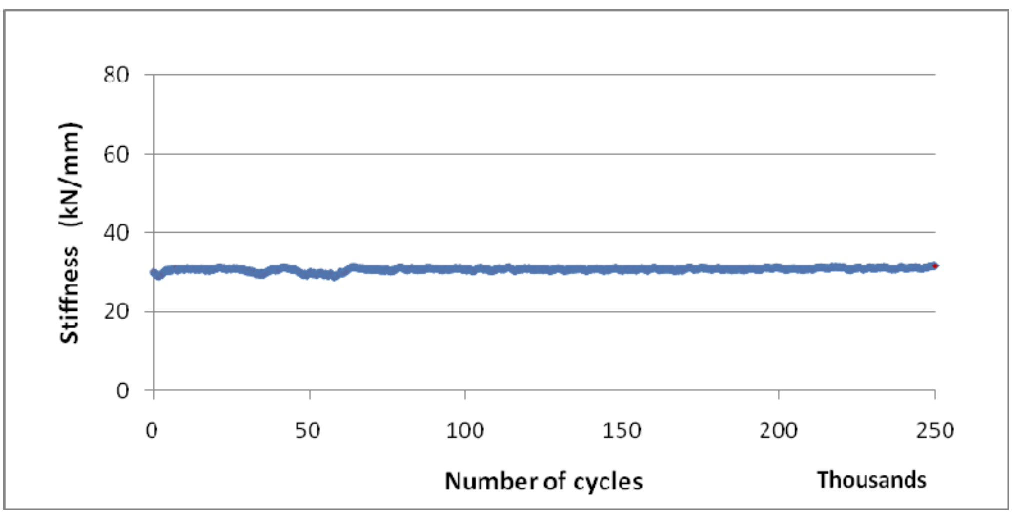
Area 2 – Stiffness/loading relationship for 10kN



Area 2 – Stiffness /loading relationship for 30kN

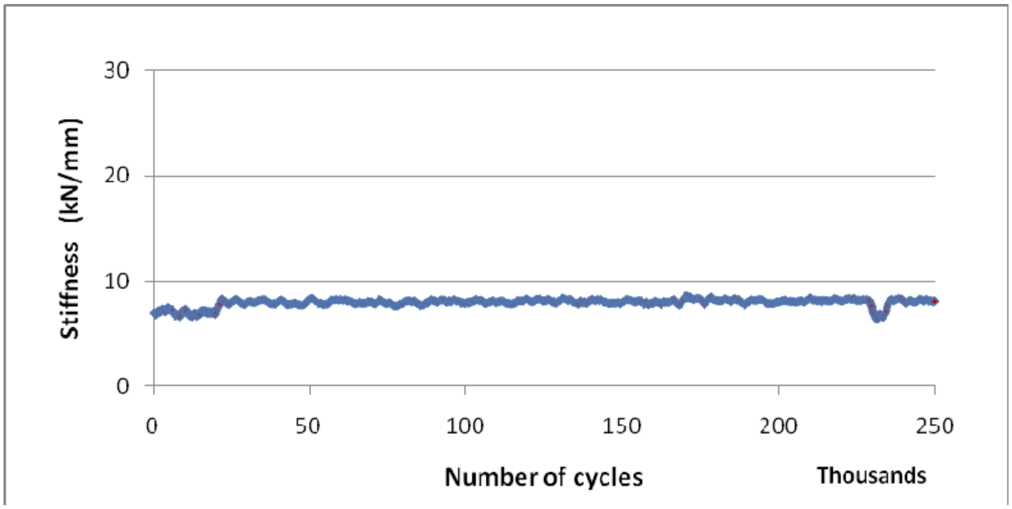


Area 2 – Stiffness /loading relationship for 50kN

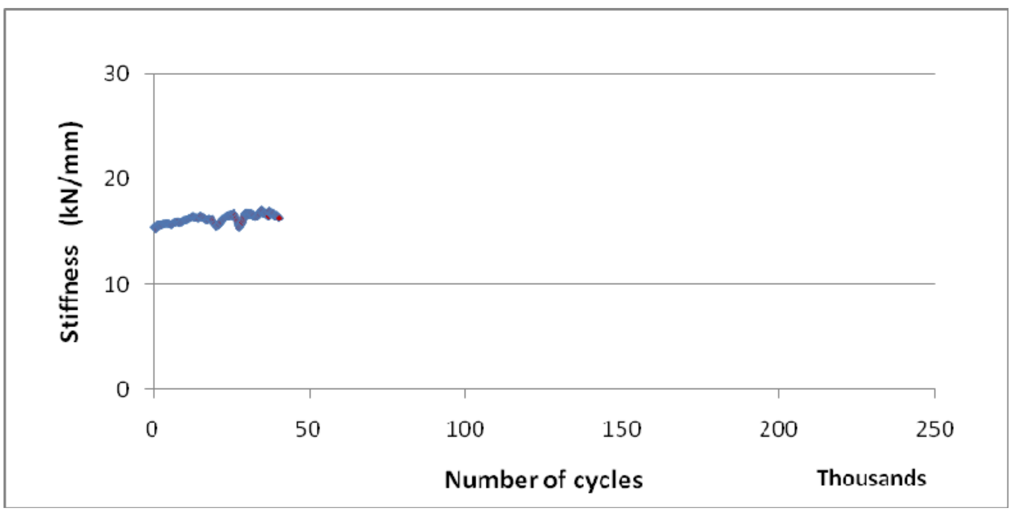


Area 2 – Stiffness /loading relationship for 70kN

AREA 2 – STIFFNESS OF MATERIALS UNDER LOAD PLATE - WATER LEVEL AT MID HEIGHT OF SUB-BASE

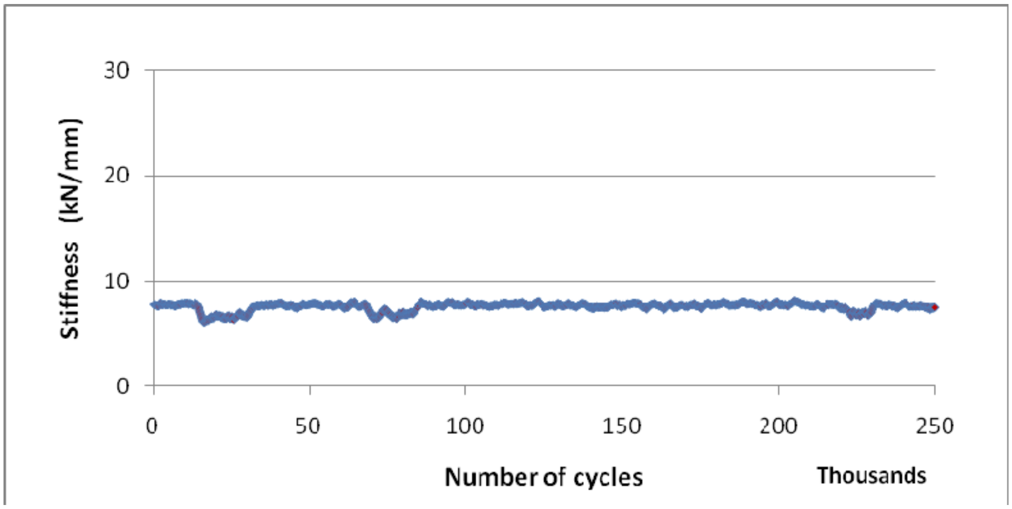


Area2– Stiffness /loading relationship for 10kN - water at mid height of sub-base

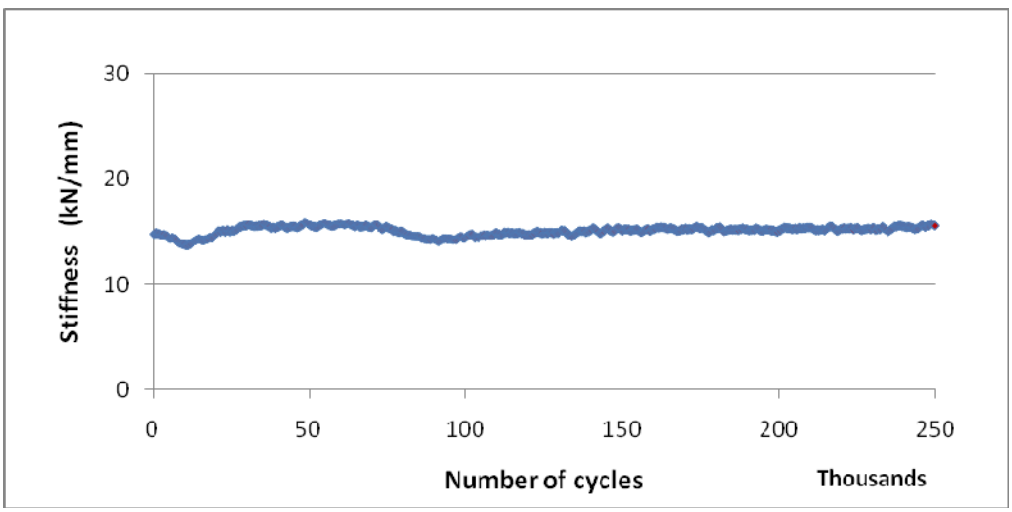


Area 2 – Stiffness /loading relationship for 30kN - water at mid height of sub-base

AREA 2 - STIFFNESS OF MATERIALS UNDER LOAD PLATE - WATER LEVEL AT TOP OF SUBBASE



Area 2 – Stiffness /loading relationship for 10kN - Water level at top of sub-base



Area 2 – Stiffness /loading relationship for 30kN - water at top of sub-base

Transport Research Laboratory

Recycled Aggregates for Minor Schemes

Logistics Study

by M Lamb, S Reeves, B Cordell

RPN1569

FINAL PROJECT REPORT

Transport Research Laboratory

FINAL PROJECT REPORT RPN1569

Recycled Aggregates for Minor Schemes

Logistics Study

by M Lamb, S Reeves, B Cordell (TRL)

Prepared for: Project Record: **Recycled Aggregates for Minor Schemes**

Client: **Constructing Excellence in Wales**
(Paul Jennings)

This Final Report has been prepared for Constructing Excellence in Wales for the sole purpose of Project Report Review. It may only be disseminated once it has been completed and issued with a final TRL Report Number.

The views expressed are those of the author(s) and not necessarily those of Constructing Excellence in Wales.

	Name	Date Approved
Project Manager	Martin Lamb	09/02/2011
Technical Referee	Murray Reid	09/02/2011

Contents Amendment Record

This report has been issued and amended as follows

Version	Date	Description	Editors	Technical Referee
0.1	25/11/10	First draft to be submitted to CEW. (Missing LCA section).	Martin Lamb Sarah Reeves	Murray Reid
0.2	17/12/10	Draft with LCA section included submitted to CEW.	Martin Lamb Brad Cordell	Murray Reid
0.3	09/02/2011	Final copy agreed with CEW	Martin Lamb	Murray Reid

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Executive summary

Constructing Excellence in Wales commissioned TRL to undertake a logistics study to build on the previous work carried out by TRL and Tarmac on Recycled Aggregates for Minor Schemes (RAMS) in 2009. High quality aggregate is often used in minor schemes, where lower grade material could be utilised. The lack of a suitable specification and detailed information on the properties of lower quality material has resulted in significant quantities of lower quality material being sent to landfill. Significant quantities of lower grade recycled aggregates are produced in Wales, mostly by small producers, who do not always work to national standards or follow the WRAP Quality Protocol. These recycled aggregates are not suitable for use in high grade applications such as those covered by the Specification for Highway Works, but may be suitable for use in low risk applications. The RAMS project is looking at how this material could be used more effectively. The test results so far indicate that lower grade material could be suitable for some minor works schemes.

In order to fulfil this potential increase in use, the material needs to be readily available, cost-effective and, ideally, have lower carbon emissions than primary aggregates. This related project focused on these issues. It involved an assessment of the availability of recycled aggregates in Wales, looking at the location of producers and the area they served. The project also looked at the economic costs and carbon emissions associated with using lower grade recycled aggregates where suitable applications arise, comparing it to virgin aggregates and Type 1 recycled aggregate. Information for the study was gathered from telephone interviews and questionnaires with recycled aggregate producers in Wales and a site visit to a producer near Cardiff.

Aggregates are a low value, high volume product which makes transport costs a high proportion of their price. In order for their use to be cost-effective, aggregates cannot be transported by road over large distances; the source needs to be close to the point of use, especially for low value applications such as those being investigated in the RAMS project. The study found that the average distance of recycled aggregate customers from the producer was 14 miles. The majority of construction activity is carried out in urban areas and this is also where recycled aggregate producers are normally situated; close to sources of feedstock and customers. The locations of recycled aggregate producers in Wales were obtained and plotted on a map with a radius of 30 minutes travel time marked out. This showed that there is a good coverage, with sufficient producers to serve all the major urban areas where the majority of construction work occurs.

The study also found that where lower grade recycled aggregate can be used (i.e. it meets the performance requirements of an application) it generally was cost-effective to do so. The price of recycled aggregates varied widely, but is normally cheaper than virgin aggregates; the lower grade recycled aggregate was on average £3 per tonne cheaper than Type 1 recycled aggregate. In addition recycled aggregate tends to be less dense than virgin aggregate, so a greater volume is obtained for the same weight. Similarly, the lower grade recycled aggregate was found to be less dense than Type 1 recycled aggregate. In addition to the difference in material cost, recycled aggregate sources are more likely to be close to urban areas where much of construction work takes place, whereas quarries for virgin aggregates tend to be in more rural areas. The average transport distance by road for virgin aggregates is 29 miles (UK average in 2006)[1] compared to the average of 14 miles that lower grade recycled aggregate travels. In Wales, the large number of quarries is such that the average distance to be travelled is shorter. However, in many cases the transport distances for lower grade recycled aggregates will still be less than for virgin aggregate,

[1] Aggregate Levy Sustainability Fund, Reducing the environmental effect of transporting aggregate

hence reducing transport costs. This also reduces transport emissions feeding into the Life Cycle Assessment (LCA) carried out as part of the study.

The Life Cycle Analysis has shown that there is a significant carbon saving in the production of lower grade recycled aggregates compared to that of virgin aggregate. The results indicate, that the use of lower grade materials would emit less carbon even if transported up to nine miles further than virgin aggregate.

The project has thus shown that, where it is suitable for the proposed application, lower grade recycled aggregates are likely to be readily available and cost effective compared to virgin and higher quality recycled aggregates and will yield benefits in reduced carbon emission compared to these alternatives.

The applications for which the lower grade recycled aggregate are suitable are considered in the main RAMS project, which is reported separately from this study.

1 Introduction

The Constructing Excellence in Wales (CEW) Waste Programme is undertaking a number of projects to improve the management of construction waste in Wales, and to increase the use of recycled aggregates. One of these projects is the Recycled Aggregates for Minor Schemes (RAMS) project. High quality primary and recycled aggregate is often used in minor schemes, such as cycle paths, car parks and minor estate roads, where lower grade material could be used. At the same time, significant quantities of lower quality material are being sent to landfill. The RAMS project is looking at how this material could be used more effectively. The project aims to produce a Technical Specification for adoption in Wales to:

- Maximise the use of lower utility recycled aggregates in low grade engineering pavements e.g. footpaths and car parks,
- Reduce engineers risk through the production of a nationally recognised specification for inclusion of such aggregates in low grade, low risk schemes,
- Make recycled aggregate the aggregate of choice,
- Reduce landfill by 500,000 tonnes per year in Wales

The first phase of the project was carried out by Tarmac, Birmingham University and TRL in 2009. It involved testing lower grade recycled aggregates produced by a selected group of producers against various standards. The material was then trialled under loading at a testing pit in Birmingham University. During the trials, assessments were made on the strength and durability of the material. A further phase of testing from producers around Wales has been instigated, and the results from the Phase 1 testing undertaken by Tarmac, and testing under the TRAMS project, indicate that there is significant potential for the material to be used for the minor schemes envisaged.

The market for recycled material in Wales suffers due to the presence of significant number of virgin quarries producing crushed rock at a competitive price. The cost differential between virgin and recycled aggregate is minimal and therefore transport cost becomes a major factor. For a lower grade recycled aggregate, the situation is more acute.

In order to overcome this challenge, it is necessary firstly to prove fitness for purpose. The lower grade recycled aggregate is not intended to be used in major schemes, due to the potential risk, and in any case, the quantities available would be insufficient. The balance of evidence suggests that this material could be better used in low risk applications in minor road schemes. It was therefore considered important to improve understanding of the locations where the material is produced in Wales, and to suggest measures for improving the infrastructure if necessary. This study aims to help identify:

- the locations of producers of lower grade recycled aggregate in Wales;
- the price compared to virgin and higher quality (Type 1) recycled aggregate;
- transport costs compared to virgin and higher quality (Type 1) recycled aggregate; and
- environmental implications of the use of lower grade recycled aggregates.

The report describes the results of this study.

2 Methodology for data collection

In order to carry out the study, information was required on the number and location of recycled aggregate producers in Wales, the typical distance products are transported, product and transport costs and the types of plant used in processing. This information was gathered using three methods:

- A short questionnaire (given in Appendix A) was developed. The names and address of recycled aggregate producers were extracted from the Environment Agency, Wales Environment Trust and WRAP websites and the questionnaire was sent to the approximately 100 recycled aggregate producers throughout Wales.
- In-depth telephone interviews were carried out with the producers involved in the first phase of the project.
- One of the project team visited a recycled aggregate production site to gather more detailed data on plant fuel consumption for the embodied carbon calculation.

Twelve questionnaires were returned to the product team, and out of the 12 producers involved in the initial project, seven were available for interview during the project time frame.

3 Data collection findings

A summary of the information collected from the returned questionnaires and interviews is provided in this section; further details are given in the appendices. This section provides general background information on recycled aggregate producers in Wales as well as specific information for the cost and carbon analysis.

3.1 Organisations

The types of organisations that produce recycled aggregates are:

- Specialist recycled aggregate producers.
- Skip hire companies that also process and sell the material they collect;
- Mobile operators which take the crusher to the construction site, where the majority of the material is processed and reused on site. Any excess is sold;
- Waste transfer stations which accept a variety of types of waste, process it and sell on the products;
- Quarries which produce recycled aggregate in addition to virgin material;
- Demolition companies that process and sell the demolition waste they produce;
- Plant hire and haulage companies.

Of these, only the quarries and specialist producers are likely to produce high quality recycled aggregate in accordance with national standards and the WRAP Quality Protocol. Many of the other categories of producer are likely to produce lower grade recycled aggregates, which are the focus of the RAMS project.

3.2 Products produced

Most organisations produce two or three types of aggregate. The most commonly produced materials are given as Type 1 (unbound sub base), 6F2 (or 6F5, coarse grained capping) and non-standard aggregates (e.g. hardcore, general fill, crushed concrete). A minority of larger producers sell a greater range of higher value aggregates such as pipe bedding and singe size clean material. The lower grade recycled aggregate is sold as hardcore, general fill, landfill, crusher run, crush, infill and general gravel fill. Many producers also sell topsoil or other recycled materials such as wood chippings.

The amount of recycled aggregate produced at each site ranges from less than 5,000 tonnes per annum to one organisation who produced over 200,000 tonnes per annum. The majority of producers (68% of respondents) produce less than 10,000 tonnes per annum. Selling recycled aggregates is often combined with another business (e.g. skip hire) rather than being the sole source of income.

3.3 Feedstock for recycled aggregates

Sources of feedstock for recycled aggregates include:

- skips from demolition and construction projects;,
- utility arisings;
- local builders;
- local authority highway departments;
- soils that contain a large amount of stones; and
- waste transfer stations.

Reports on the reliability of the source varied. Some people stated that the source was reliable and steady throughout the year, while others reported a drop in the volume available during the winter and autumn or variability depending on the number of construction projects being carried out locally. One interviewee reported that wet weather impeded production of the aggregates and they kept a stockpile for the winter months. Others said they had been hit by the recession and the decrease in construction work being carried out.

3.4 Processing and testing

Most organisations carried out crushing, screening and grading on the feedstock before selling it. The majority of the plant used is basic jaw crushers and screeners. One manufacturer listed higher quality plant including a finger screen, but this was probably as he also hired out equipment as part of his business. Some organisations hire in the plant, so the plant manufacturer can vary. Table 4 in Appendix D provides a list of the types of plant used in processing recycled aggregate.

The producers were not always explicit about testing regimes. A few replied they carried out testing as per the WRAP Quality Protocol, that Constructing Excellence is carrying out testing or that testing was provided by an independent laboratory. Those that did give more detailed indicated that basic tests such as grading, particle shape and density and material composition were carried out. Tests such as Los Angeles, $MgSO_4$ durability and frost heave that are normally carried out for Type 1 were not mentioned. This confirms that the majority of producers are probably not working to national standards and the WRAP Quality Protocol. Thus some products that are sold as Type 1 or 6F2/6F5 may not comply with all the requirements for these applications in the Specification for Highway Works.

3.5 Market for recycled aggregates

The customers for recycled aggregates include local builders, local authority highway departments, utility companies, farmers, local outlet sales and occasionally private individuals. The types of applications the products are used for are mostly low level such as landfill cover, access roads and general fill in building works. However some higher level applications such as sub base, pipe bedding and under floor slabs were also mentioned.

3.6 Transporting aggregates

Aggregates are expensive to transport due to their volume and weight, therefore the feedstock source and the purchasers of the product tend to be local to the recycling site. Feedstock comes on average from within a 12 miles radius of the site, travelling a maximum of around 25 miles. The feedstock is normally transported in eight-wheel tipper trucks or skips with a capacity of up to 20 tonnes.

The recycled aggregate products are sold to clients within a similar range of the production site. The product may be collected by the client or delivered by the producer. The average distance the product travels is around 14 miles and the maximum 23 miles. The vehicles used for collection/delivery are usually similar to those used for the feedstock.

3.7 Aggregate costs

Recycled aggregate ranges in price from £2 to £12 per tonne depending on the product and supplier. Lower grade recycled aggregate is sold for around £5 per tonne, whereas Type 1 or other higher quality products are normally sold for around £8 per tonne. If clients are unable to collect the aggregate, transport is provided by the producer at extra cost. The cost is usually based on distance and tonnage using a zone system. In some cases transport is charged per hour travelled, or by load. The average transport cost was found to be around £3.10 per tonne within a radius of 15 miles equivalent to £0.21 per mile per tonne.

3.8 General comments on the recycled aggregate market in Wales

Several people commented on the reluctance of local authorities to use recycled aggregates. One person felt that this was not due to price or quality, but a reflection of the preconceptions and reluctance to change found within organisations. Conversely another interviewee felt things were becoming more positive and clients were more aware of recycled aggregates. He felt that blue chip companies were more open to using them than they had been in the past and tenders often included the option for both virgin and recycled aggregate with a decision made on price.

Several people commented on the impact of the recession on the construction industry and therefore the amount of recycled aggregates produced and sold.

4 Analysis and discussion

While there are widely acknowledged environmental and economic benefits from using recycled aggregates in place of virgin material, provided they are suitable for the proposed application, it is important when promoting their use to first examine the aggregate market specific to an area. In order to achieve the benefits of using recycled aggregates they need to be:

- Readily available – with reliable sources close to the point of use.
- Cost-effective – cost the same or less than the alternatives.
- Sustainable – produce less carbon emissions than the alternatives.

This section analyses the data collected in order to address these three points and discusses the implications for the use of lower grade recycled aggregates in Wales.

4.1 Availability

Figure 1 shows the identified locations of C&D processing facilities in Wales (in blue) and transfer facilities (in red).

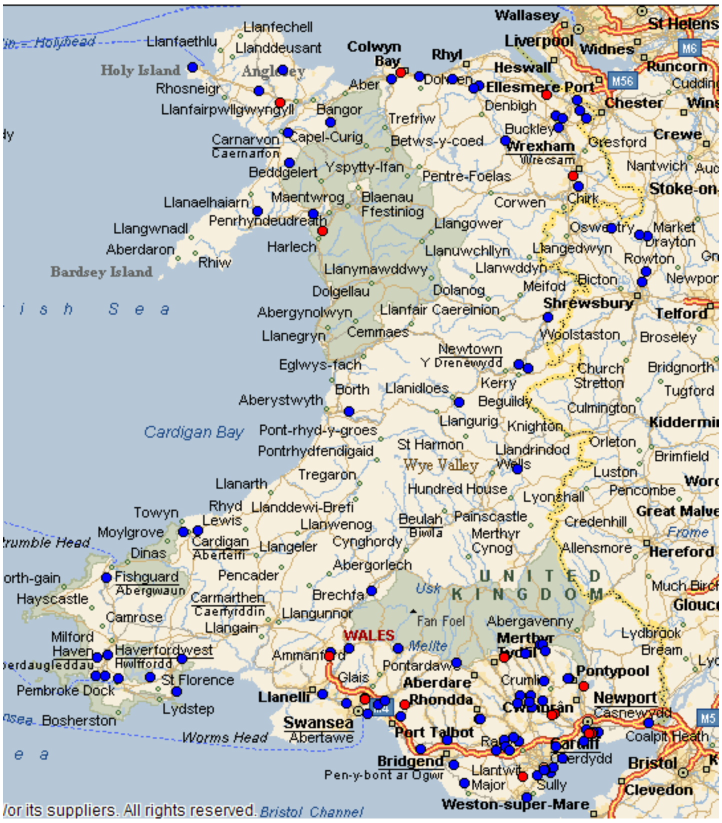

Figure 1 Locations of identified waste processing facilities and transfer facilities in Wales

TRL considered that the likely transport distances for recycled aggregates to be in the order of 15 miles or around 30 minutes, and this is backed up by the average of 14 miles found in the responses to the questionnaire and interviews (Section 3.6). This average distance needs to be considered in the context of population, geography and transport links. Aggregates might travel further in more rural areas where there are fewer sources of supply. The transport links running east-west in both the north and south, along the A55 and M4 corridors respectively are very good, whilst some of the north-south links do not meet the same standards. Conversely, the narrow South Wales valleys run more or less north-south, and transport links to neighbouring valleys are sometimes limited, despite the short distances as the crow flies.

Maps were prepared showing both 15 mile radii and 30 minute travel time from the C&D processing facilities shown on Figure 1 (see Appendix B for details). Neither option is perfect, but travel time maps (Figure 2) offer a better indication, as they take account of both where the roads are, and set average speeds for certain types of road. Taken together, the distance and travel time maps give a good indication of the overall infrastructure in Wales.

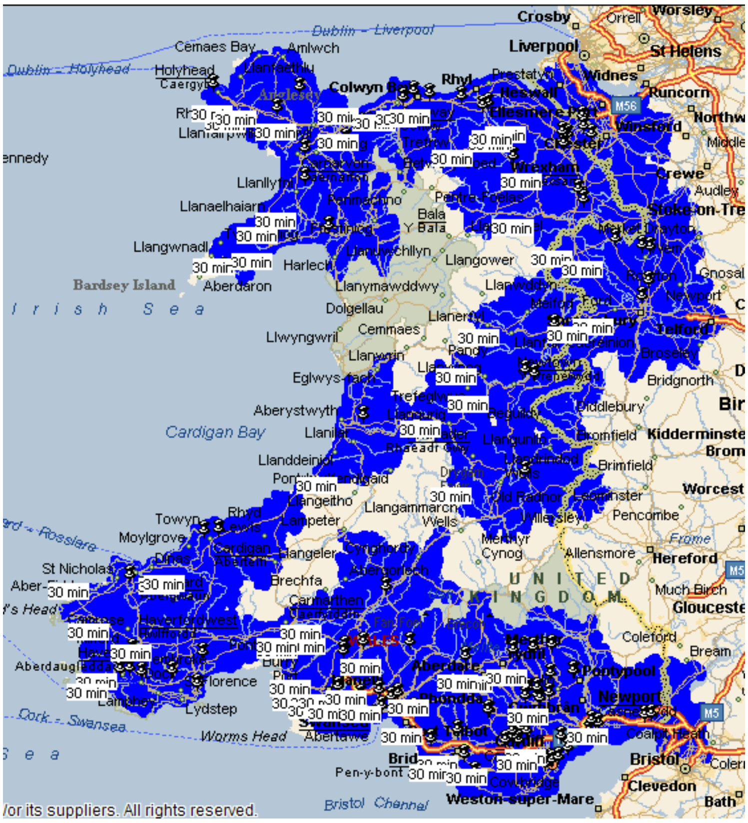

Figure 2 Approximate 30 minute drive times around facilities

The travel time plot shows that the majority of locations in Wales are within 30 minutes of at least one recycled aggregate producer. There are a few gaps in North West Wales and above the South Wales coalfield area shown in green on the map (Figure 2). However two of the major gaps represent the Snowdonia and Brecon Beacons National Parks. Whilst there are housing and businesses within the parks, the scale and control of developments is limited, i.e. there is likely to be very limited generation of, and requirement for recycled aggregates in the first place, and even if there were, the likelihood of gaining planning consent for a recycling facility or transfer site would be slim.

There are gaps in southern Ceredigion and on the Pembrokeshire / Carmarthenshire border. The potential for the development of a storage or bulking site could be explored, although it should be recognised that Ceredigion (42 people per square kilometre) has the second lowest population density in Wales, and Pembrokeshire (71 people per square kilometre) and Carmarthenshire (73 people per square kilometre) the fourth and fifth lowest respectively, compared to a Wales average of 140 people per square kilometre and typically a range of 300 – 700 in the South Wales Valleys and around 2,200 in Cardiff, based on 2001 figures from the office for National Statistics[2]. Hence, demand for aggregates is likely to be much lower in these areas, so the gaps are not significant in terms of the overall supply and demand picture for Wales.

When considering areas with higher population centres, the coverage of facilities is far denser, as presented in Figure 6 and Figure 7 in Appendix B.1, which show the identified facilities in North and South Wales respectively, with a 5 mile radius. Clearly, not all facilities are equal in terms of the volume, source or quality of materials; there are some large facilities specifically set up to deal with C&D waste, with very sophisticated

[2] http://www.statistics.gov.uk/statbase/Product.asp?vlnk=9550&More=Y

crushing, screening and in one case washing plant, whilst others may operate on a very limited scale, as part of a wider business.

Nonetheless, there is clearly an opportunity to establish a network of facilities, which would serve the majority of the population centres in Wales, with recycled aggregates, including lower grade recycled aggregate material. It is suggested that this could be combined with the ongoing roll-out of Green Compass accredited facilities, and also with a design guide and/or specification produced as a result of the RAMS project testing and possible future site trial.

The potential for a network of Green Compass sites could be explored, and presented on a map. TRL understands that an accreditation scheme is underway following the initial pathfinder scheme.

The study has thus shown that the lower grade recycled aggregates meet the first criterion, namely that they are readily available, with reliable sources close to the point of use.

As a means of comparison, the Mineral Products Associate (MPA) website[3] states that its members have fifty four quarries in Wales, although contact details are not provided, which is assumed to comprise the bulk of the major quarries. TRL undertook a search of the five main quarry companies (Tarmac, Cemex, Lafarge, Aggregate Industries and Hanson) and found forty two locations where crushed rock was produced from four companies (Aggregate Industries website indicated no such facilities in Wales).

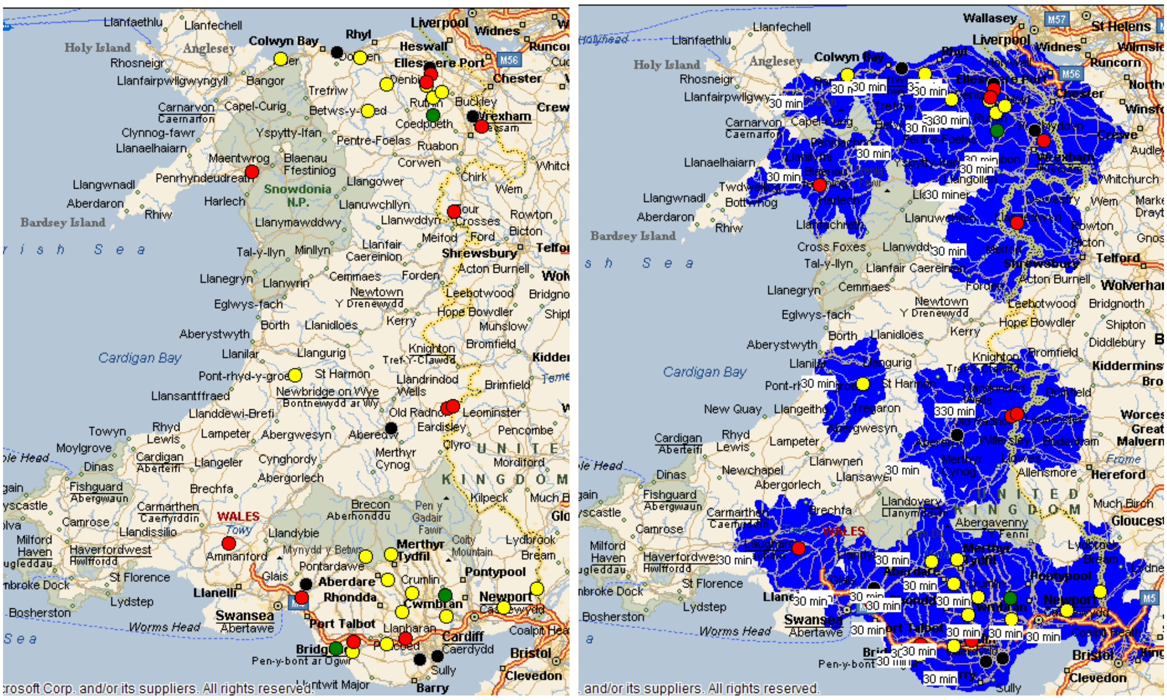

Figure 3 Virgin Quarry Location and 30 minute drive time

The figures above, suggest that the quarry network has more gaps than the recycled aggregate network, although it still covers the main population centres. It should also be recognised that there may be other quarries that were not identified that would extend the network, and that unlike some producers of recycled aggregate such as skip hire companies, all of the quarries have the production of aggregate as their sole business.

What the maps show overall however, is that there is a supply of virgin and recycled aggregate in the main population centres of Wales, and that there should be opportunities for the producers of lower grade materials to supply minor schemes,

[3] http://www.mineralproducts.org/qua_yourarea02.htm

whereas the major producers would be more likely to supply major schemes where the standards and quantities required are significantly higher.

4.2 Cost-effectiveness

The costs involved in purchasing aggregates are a combination of the cost of the material and the cost of transportation. The large weight and bulk of aggregates means that transportation costs are high, whereas production costs are relatively low making transport a major part of the cost associated with aggregates.

4.2.1 Material costs

The material cost of aggregates is normally given by tonne, but may be quoted by load. The cost will depend on the quality of the material required, with products with tighter grading and performance specifications being sold at a higher price due to the additional processing and testing required. There may be a minimum amount that can be purchased, e.g. 10 tonnes. The material cost also varies according to the producer, reflecting the local market. In this project we found significant variations in aggregate prices for apparently similar products.

From the questionnaire and interviews carried out, the cost of recycled aggregate was found to range from £2 to £12 per tonne, with an average of £5 for lower grade recycled aggregates and £8 for Type 1. Information obtained from quarries suggests that the cost of virgin Type 1 is around £1.50 per tonne greater than recycled Type 1. In part the difference in price between virgin and recycled aggregate is due to the Aggregates Levy[4], which currently adds £2 per tonne to the cost of virgin aggregate (it will increase to £2.10 per tonne on 1 April 2011).

A further factor to consider is that although aggregates are normally purchased by weight (tonne), in practice it is usually the compacted volume (m^3) of aggregates that is the important aspect during construction; aggregates are specified by volume in Bills of Quantities. Virgin aggregate such as the sandstone and limestone that is found in Wales has a particle density[5] of around 2.7 Mg/m^3. High quality recycled aggregate tends to be less dense, typically around 2.3 Mg/m^3, due to the inclusion of lighter materials such as brick and mortar. This means recycled aggregate can have around 15% more volume than the same weight of virgin aggregate. Consequently, less tonnage of recycled aggregate would be required for the same application. Lower grade recycled aggregate tends to be lighter than higher grade recycled aggregate increasing this difference in price. For example, in Phase I of this project the tests gave a compacted bulk density at optimum moisture content of around 1.95Mg/m^3 for lower grade recycled aggregate compared to a typical value for limestone Type 1 of 2.45Mg/m^3.[6] On projects where large volumes of aggregates are required, this could make a significant difference to the overall cost.

4.2.2 Transport costs

Transport cost does not depend on the product type, but tonnage and distance. Transport is a large component of aggregate costs. The responses from the questionnaires and interviews suggest that 30 - 45% of aggregate cost is for transportation, consequently the distance from the source of materials an important influence on cost. Realistically, road transport of aggregates is not competitive beyond 30 miles from the aggregate source and recycled aggregates are unlikely to be

[4] http://customs.hmrc.gov.uk/channelsPortalWebApp/channelsPortalWebApp.portal?_nfpb=true&_pageLabel=pageImport_ShowContent&propertyType=document&columns=1&id=HMCE_CL_001169

[5] Particle density is defined as the ratio of dry mass and volume.

[6] ALT-MAT Deliverable D4 European Project under the 4th Framework Programme, 1999.

transported more than half this distance. There are certain exceptions such as the transport of high friction Pennant sandstone, from South Wales, that has specific qualities required for road surfacing, which will allow it to be transported further.

Transport may be provided by the producer or purchaser, but regardless the cost is borne by the purchaser making sources of aggregate closer to the construction site more cost effective. Transport costs are usually charged at cost per tonne within a radius of the site, e.g. 10 or 15 miles. From the questionnaire and interviews, transport costs were found to be around £3.10 per tonne within a radius of 15 miles equivalent to £0.21 per mile per tonne.

Typical vehicles for virgin aggregate transport are 32 tonne, rigid chassis tippers. Recycled aggregates are normally transported by smaller vehicles such as 20 tonne tippers. The transport price charged appears to be similar for both types of vehicle.

As discussed in Section 4.1, recycled aggregate producers tend to be located close to urban centres near the source of the feedstock meaning that these materials are generally available near the point of use. The locations of the virgin quarries may be marginally further away from the centres of population, than recycled producers, but nonetheless, there is a plentiful supply of virgin aggregates within a close distance of the majority of the population centres in Wales.

4.2.3 Cost comparison

Using these average material and transport costs, and assuming that the lower grade recycled aggregate is suitable for the application, the following comparisons can be made. If sources of virgin, recycled type 1 and lower grade recycled aggregate are all within 15 miles of the construction site, around £45 (36%) could be saved on purchasing 10 tonnes of aggregate by using lower grade recycled aggregate instead of virgin and £30 (27%) instead of Recycled Type 1 (see Table 1).

Table 1 Comparison of the costs for purchasing 10 tonnes of aggregate

	Virgin aggregate	**Recycled aggregate Type 1**	**Lower grade recycled aggregate**
Product price per 10 tonnes (£)	£95	£80	£50
Transport cost for 15 miles (£)	£31	£31	£31
Total cost (£)	£126	£111	£81

The costs fluctuate significantly between producers, so that the range of prices for recycled aggregates overlaps with the range for virgin material. Consequently, in some cases recycled aggregates may be closer in price to virgin aggregates. However, this does not take into account the likely locations and travel distances. Construction sites are usually situated within urban areas where the population density is highest. Recycled aggregate producers also tend to be located in urban areas close to the sources of feedstock. However quarries are more likely to be in rural locations. Even if the prices of lower grade recycled aggregate and virgin aggregate were identical, if the source of virgin aggregate was located only slightly further away it is likely to be sufficient enough to make it more cost effective to purchase lower grade recycled aggregate. There is also the difference in density to take into account. If $10m^3$ of aggregates were specified, this would equate to 24 tonnes of virgin aggregate and 20 tonnes of lower grade recycled aggregate – requiring an extra four tonnes of material to be purchased.

The lower grade recycled aggregates thus satisfy the second criterion for use, namely that they are cost-effective, i.e. they cost the same or less than the alternatives.

4.3 Life Cycle Assessment

A life cycle assessment was undertaken, which focused on measuring the contribution to climate change of low quality recycled aggregate and comparative virgin aggregate scenarios: the "carbon footprint". Life cycle assessment (LCA) is a method by which environmental impacts associated with a product or service can be calculated. A carbon footprint uses LCA methodology and is limited to only investigating the carbon dioxide (CO_2) emissions. With increasing pressure on all areas of UK industry to improve energy efficiency and reduce CO_2 emissions through their activities and supply chain, a measurement of the carbon footprint of their product is an essential starting point for emissions reduction strategies.

A site visit was conducted to allow familiarisation with the processes involved and to initiate data collection on resource use and energy consumption. Despite the site visit, very limited primary data on fuel consumption was forthcoming to form the basis of the assessment. Instead, various data and estimations were used to make a preliminary assessment. Since the data is not firsthand nor specific, the assessment should be regarded as indicative rather than an accurate portrayal of the situation at any particular quarry or recycling centre. Figure 4 shows the lifecycle considered for the production of a lower quality recycled aggregate. There is a large variety of processes and equipment available which can be used to recycle construction and demolition waste into a useful construction material; the simple setup investigated is only one possibility of many.

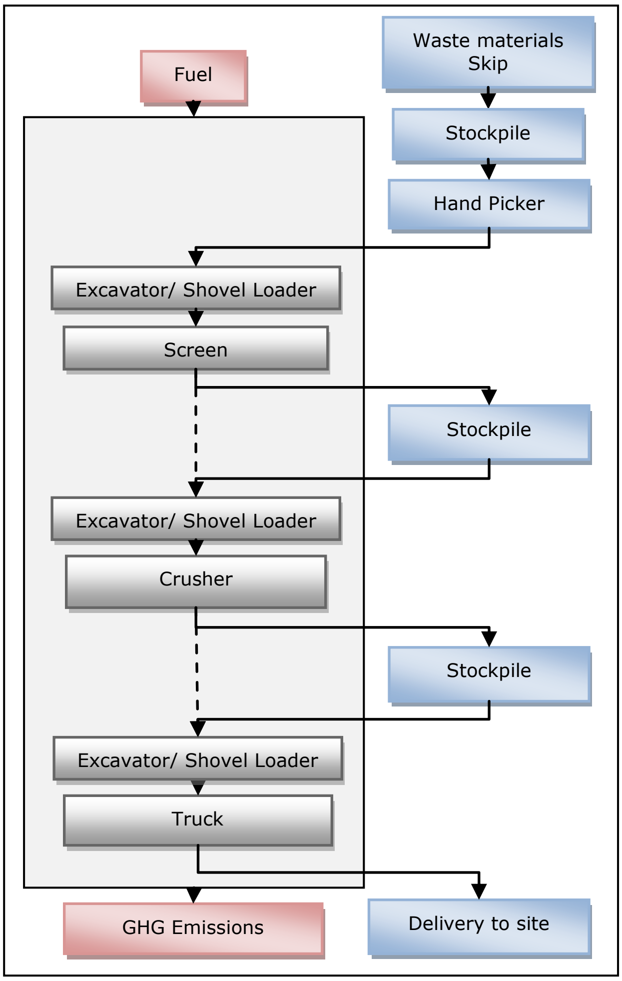

Figure 4 Modelled system for production of recycled aggregate

The selected virgin aggregate carbon footprint figure for production used is 4.32 $kgCO_2$/tonne, as taken from the Mineral Product Association's (MPA) 2009 Sustainability Report[7].

The approach used to calculate the recycled aggregate carbon footprint figure was to consider the list of commonly used machinery in the production of recycled aggregates, presented in Table 4, in the configuration shown in Figure 4. Average fuel consumption for this equipment was calculated using the method devised by the United Nations for engine work rates[8], see Equation 1 displayed below. Litres of fuel used per machine hour (LMPH) is calculated by multiplying together the mass of fuel needed to create 1 brake horsepower (K), the gross horsepower (GHP) of the engine being used and the load factor (LF) on the engine. This is then divided by the mass per litre of the fuel. Table 2 gives the standard data designated for use with Equation 1.

Equation 1 United Nations equation for estimate of fuel consumption

$$LMPH = \frac{K \times GHP \times LF}{KPL}$$

Table 2 Standard data for use with Equation 1

Engine	Weight (KPL) kg/litre	Fuel Consumption (K) kg/brake hp-hour	Load Factor (LF)		
			Low	Med	High
Gasoline	0.72	0.21	0.38	0.54	0.70
Diesel	0.84	0.17	0.38	0.54	0.70

The 2010 Defra carbon dioxide conversion factor[9] for diesel fuel was then applied to these average figures. There are several options available regarding the "scope" of emissions represented in the emissions factor. In order to ensure direct comparability with the MPA figure, the figure which included only "direct" CO_2 emissions was used; no consideration was given to "pre-combustion" emissions associated with fuel supply, nor the other greenhouse gases that contribute to climate change.

In the model it was assumed that each piece of equipment operated with a high level of engine loading. The site visit highlighted that aggregate recycling was often done in batches, thus allowing a high level of equipment loading. The average fuel consumptions for the different pieces of equipment were calculated based on sample sizes of 2 loaders, 10 screens and 11 crushers. Data was compiled for engine output and potential material throughput. The fuel consumptions of each type of equipment were equated to CO_2 emissions and compiled into the model.

The recycled aggregate carbon footprint figure for production was calculated at 1.33$kgCO_2$/tonne. This shows that a saving of approximately 2.99$kgCO_2$/tonne is possible when considering only the production processes. The MPA CO_2 figure for the production of virgin aggregate is much greater than the recycled aggregate figure. The lifecycle for the production of virgin aggregate includes a number of operations and

[7] http://www.mineralproducts.org/documents/MPA_SD_Report_2009.pdf
[8] http://www.fao.org/docrep/t0579e/t0579e05.htm
[9] http://www.defra.gov.uk/environment/business/reporting/conversion-factors.htm (Annex 1 Table 1b)

stages which are not required when recycling aggregate. This includes overburden removal, drilling, blasting and additional crushing, transportation, washing and screening, in order to produce a higher quality aggregate. The MPA figure was generated from member companies providing energy use data and allocating it to a product. There is a variation in quality and accuracy of the data provided to the MPA so this should be considered an approximate figure. Work is continuing to produce a more accurate figure; this will be available in the first half of 2011.

Emissions due to transport were calculated from the 2010 Defra GHG conversion factors[10] for freight vehicles. The 'Rigid >17t' vehicle value was used on a tonne kilometre basis, for the distances for each material transport was the same as used for the cost comparison, namely 15 miles. Utilisation of the vehicle was based on the UK average for a vehicle of that size, which is 53%. Due to the potential CO_2 saving associated with using the recycled aggregates obtained from the system considered, extra transport could be undertaken up to the breakeven point and some benefit would still be realised. Extrapolating the results allows the added distance that recycled aggregate could be transported to be calculated. This was calculated to be 9 miles, thus there is a potential environmental argument for transporting recycled aggregate up to 24 miles from the site where it is produced in the scenario considered.

Table 3 Potential kgCO_2/tonne saving and transport distance increase

Material	Production (kgCO_2/t)	Transport (kgCO_2/t)	Total (kgCO_2/t)	Potential saving (kgCO_2/t)	Potential transport increase (miles)
Virgin Aggregate	4.32	4.83	9.15	-	-
RAMS	1.33	4.83	6.16	2.99	9

It should be considered therefore that the carbon footprint conducted shows a further benefit of lower quality recycled aggregate over virgin aggregates in terms of sustainability; they are responsible for the production of less CO_2 than virgin aggregates.

5 Conclusions

Tests carried out as part of the previous work for the Constructing Excellence in Wales Recycled Aggregates in Minor Schemes project indicate that lower grade recycled aggregates could be suitable for some minor works schemes. In order for the use of this type of material to be expanded it needs not just to meet performance specifications, but also to be readily available throughout Wales, cost-effective to use and help towards meeting sustainability targets by reducing carbon emissions. This project looked at these points.

The majority of construction work takes place in urban centres, where there is the highest population, e.g. in the South Wales Valleys. Therefore the greatest demand for aggregates is within these areas, rather than for example around Snowdonia or the Brecon Beacons. In addition to generating the demand for aggregates, construction work also produces the feedstock for recycled aggregates. Consequently recycled aggregate producers tend to be located near urban areas where the feedstock sources and demand is found. This study found that there was a good coverage of recycled aggregate

[10] http://www.defra.gov.uk/environment/business/reporting/conversion-factors.htm (Annex 7 Table 7e)

producers throughout Wales and that the urban areas, where the majority of aggregates are used, are well served with a number of recycled aggregate producers. In general there are sufficient producers throughout the populated areas of Wales for a source of recycled aggregate to be less than 30 minutes drive from a construction site, which is usually closer than sources of virgin aggregates. From the information gathered it appears that although, in some cases, the amount of material available can fluctuate with season and the amount of local construction activity, these sources are generally reliable. There has been some impact on the amount of material available from the reduction of construction work due to the recession, but there is still sufficient material to meet demand.

The project also demonstrated that there are substantial cost savings to be achieved from using lower grade recycled aggregates, where suitable, instead of virgin aggregates and less but still significant savings compared to using recycled Type 1 aggregate. The price of aggregates can vary widely, but lower grade recycled aggregate can cost £4.50 per tonne less than virgin aggregate and £3 per tonne less than recycled aggregate Type 1. In addition, lower grade recycled aggregate is less dense than virgin aggregate, which means fewer tonnes need to be purchased to obtain the same volume of material. Construction sites are normally located close to urban centres, as are recycled aggregate producers, whereas quarries are usually in more rural locations. Transport costs are a large component of aggregate costs and shorter transport distances can mean that recycled aggregates are significantly cheaper than virgin material.

Shorter transport distance also reduces the carbon emissions associated with using aggregates. The Life Cycle Assessment also indicates that the production of lower grade recycled aggregates produces far less CO_2 than the production of virgin aggregates.

The study has thus shown that, where it is suitable for the proposed application, lower grade recycled aggregates are likely to be readily available, cost effective compared to virgin and higher quality recycled aggregates and will yield benefits in reduced carbon emission compared to these alternatives.

The applications for which the lower grade recycled aggregate are suitable are considered in the main RAMS project, which is reported separately from this study.

Acknowledgements

The work described in this report was carried out by the Wales Office of the Transport Research Laboratory. The authors are grateful to Dr. Murray Reid who carried out the technical review and auditing of this report.

Appendix A Recycled aggregate producers questionnaire

Company Name:	
Address of production site inc. postcode:	
Contact Name:	
Contact Tel:	
Contact Email:	

1. **What types of product do you produce?**
Natural aggregate ☐ *Recycled aggregate Type 1* ☐ *Recycled aggregate unspecified* ☐

2. **What do you sell unspecified recycled aggregate as?**
Hardcore ☐ *General fill* ☐ *Other* _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

3. **How much unspecified recycled aggregate do you produce per annum in tonnes?**
0 to 5,000 ☐ *5,000 to 10,000* ☐ *10,000 to 50,000* ☐ *Over 50,000* ☐

4. **Does this vary with season? How reliable would you say the source is?**

_ _

_ _

5. **What is the source of your recycled aggregate?**
Local construction skips ☐ *Quarry waste* ☐ *Trench arisings* ☐

Other _

6. **What processing do you carry out on the unspecified recycled aggregate?**
None ☐ *Crushing* ☐ *Grading & Screening* ☐ *Washing* ☐

Other _

7. **What type of plant do you use for processing?** (please list the manufacturer if possible so we can ascertain fuel consumption)

_ _

_ _

8. What tests do you carry out on the unspecified recycled aggregate?

None ☐ *Visual inspection* ☐ *Grading* ☐

Other _

9. What exemptions or waste management permits does the site have?

_ _

10. Who are your main customers and what applications do they use the material for? (e.g. landfill cover, estate roads etc.)

_ _

_ _

11. What is the price per tonne of your product? (if you sell different types of recycled aggregate please list by type, if there is a minimum amount that can be purchased please specify)

_ _

_ _

12. Does this price include transport to the client's site? If not how much is the transport cost?

_ _

13. Please fill in the transport details

	Average distance travelled	**Maximum distance travelled**	**Type of vehicle used inc. capacity**
Incoming feedstock			
Transport of product			

14.Do you have any other comments about the use of recycled aggregates?

_ _

_ _

_ _

_ _

Appendix B Mapping the coverage of recycled aggregates

The location of waste processing facilities was largely obtained from the Environment Agency, Netregs Waste Directory Site, which allows searches to be made under a number of categories and for a given location. The sub-categories of building waste searched for were clay, hardcore, inert waste, rubble, subsoil and topsoil. For each location searched, a number of companies were identified that matched certain criteria, along with their contact details. It was felt that this was the most likely to be the most up to date source of information, as the companies would be registered with the Environment Agency.

In order to set the context of the supply and demand of recycled aggregate in Wales, the existing recycling infrastructure and any gaps, it is useful to consider the population distribution, as there should be a direct correlation between centres of population and density of recycling facilities, i.e. in areas of high population density there will be more construction activity which will both generate waste, and also potentially purchase recycled material. Of the population of approximately 3 million in Wales, around 60% live in the South Wales valleys in the area of the former South Wales coalfield stretching from Swansea in the west to Newport in the east and Merthyr Tydfil in the north, with over 10% living in the Cardiff unitary authority. With the exception of Flintshire and Denbighshire in the north east corner of Wales, the north, centre and western regions of Wales are largely rural with few major centres of population, as reflected in the low population densities. Figure 1 indicates there is a very strong correlation of the location of recycled aggregate producers with population centres.

In considering the requirement for a network of recycled aggregate producers, it should be recognised that a one size fits all approach is unlikely to be suitable or feasible, and that in the more rural areas of Wales, the spacing of the infrastructure might be greater, or the potential for centres for bulking up might be considered.

TRL considered that the likely transport distances to be in the order of 15 miles or around 30 minutes. Maps have been prepared showing both distance and travel time from these locations.

B.1 Production of distance maps

Maps were produced showing 15 mile radii around the location of the recycled aggregate producers. Figure 5 demonstrates extremely good coverage, with very few gaps and only one gap of any size in the Snowdonia area.

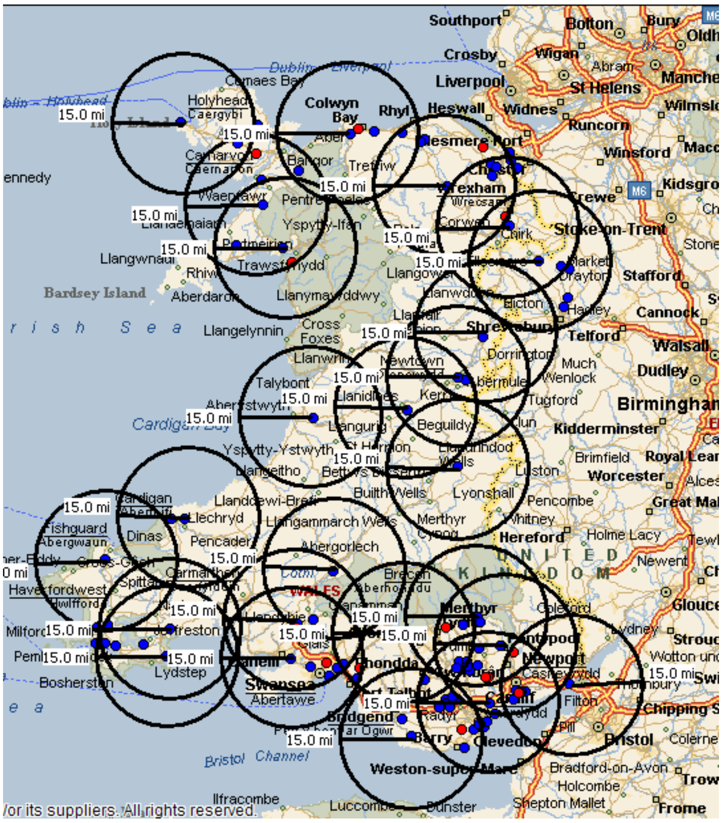

Figure 5 Map showing 15 mile radius around Wales C&D waste facilities

When considering areas with higher population centres, the coverage of facilities is far denser, as presented in Figure 6 and Figure 7, which show the identified facilities in North and South Wales respectively, with a 5 mile radius; even with such a small radius, it can be seen in both cases, and particularly in South Wales, that there is extensive coverage.

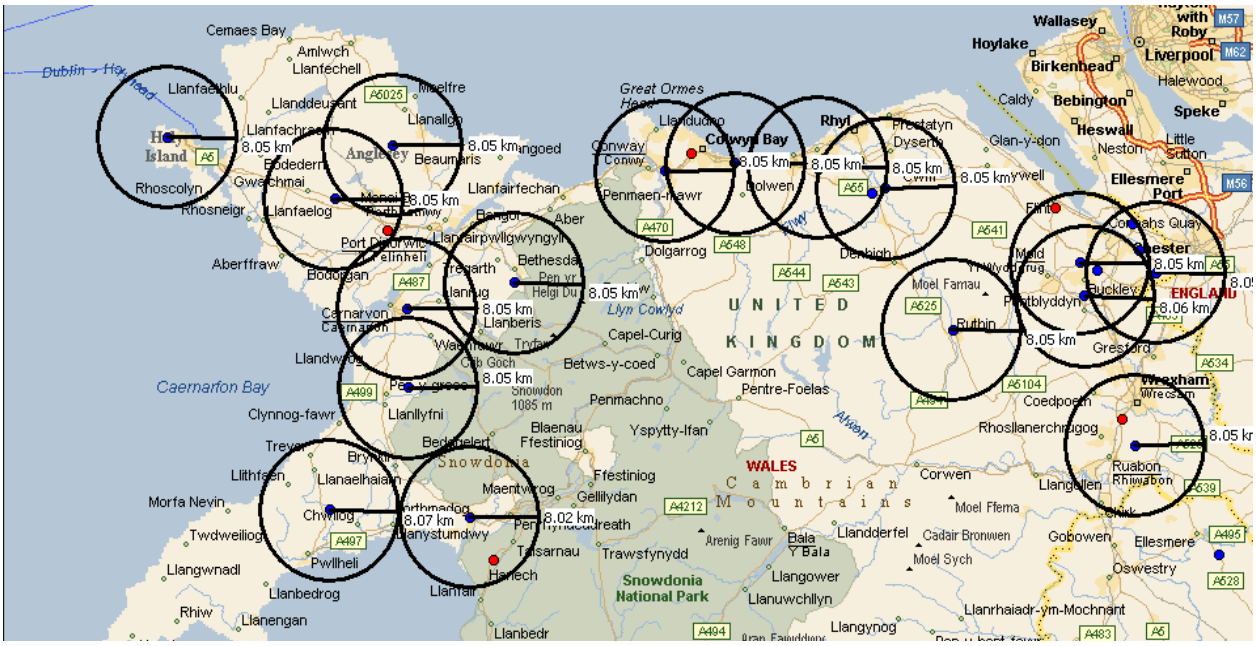

Figure 6 Recycling facilities in North Wales – 5 mile radius

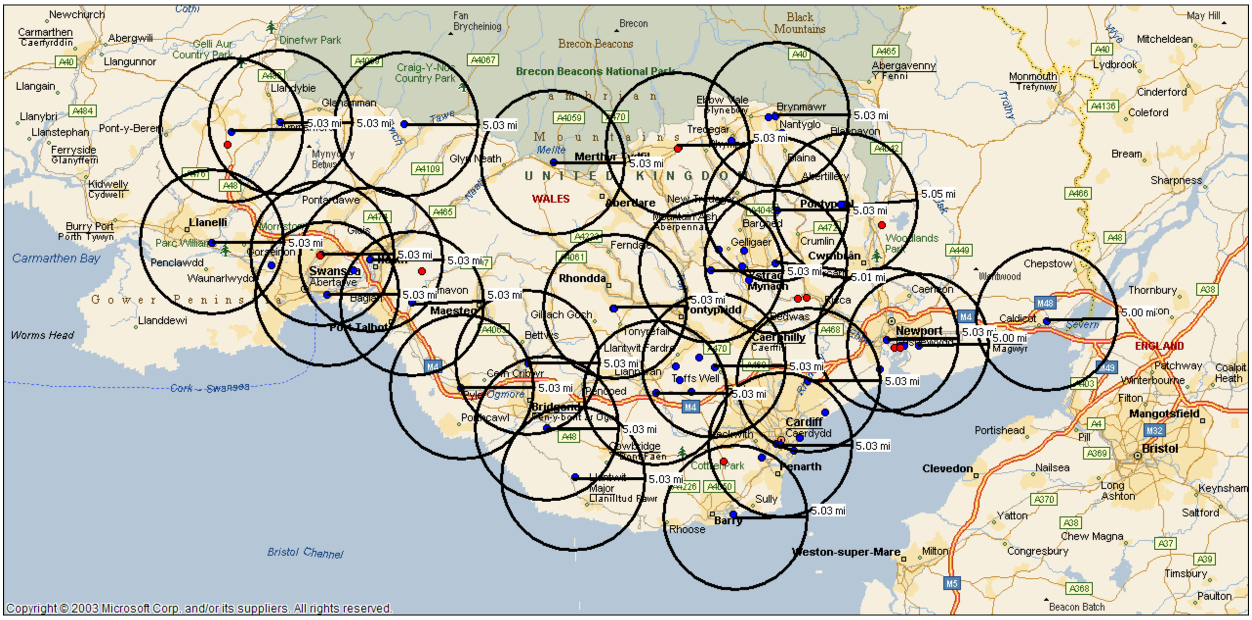

Figure 7 Recycling Facilities in South Wales – 5 mile radius

B.2 Production of travel time maps

Travel time maps might offer a better indication of coverage, as they take account of both where the roads are, and set average speeds for certain types of road. The average speeds chosen for the study are as follows:

Motorways:	50mph
Other limited access roads:	50mph
Major roads:	40 mph
Minor roads:	34 mph
Streets:	19mph

The speeds chosen were based on what would seem reasonable for a vehicle that would be limited to 56mph to achieve on motorways and limited access roads (mainly dual carriageways), and a conservative estimate for other roads. The software is set to always observe local speed limits. It should be noted that for presentation purposes, in areas where there were numerous facilities, not every facility has been shown with a radius, i.e. where radii overlapped, additional points with the radii were not considered.

It should be noted that the software is unable to distinguish between the A470 that runs as a dual carriageway from Cardiff to Merthyr Tydfil, and the A470 which is a single lane, winding road in north west Wales.

As would be expected, the map showing approximate 30 minute drive times around sites (Figure 2) shows a decrease in the coverage of facilities compared to the 15 mile radii distance maps. However, all the major urban areas are adequately covered.

Appendix C Products: results of questionnaire and interviews

The types of aggregate product produced include:

- Type 1
- 6F2
- 6F5
- 6F1
- Hardcore
- General fill
- Pipe bedding
- Planings
- Sandfills
- Single size (clean)
- Crushed concrete
- 40mm clean stone
- 125mm clean
- 4mm grit sand

Appendix D Plant details: results of questionnaire and interviews

Table 4 List of plant used in processing recycled aggregates

Crushers	Screens	Other
Rubbelmaster	Trommel Screens	Komatsu 20 ton excavator
Parker	Extec	jcb 316 loading shovel
Rubble Master- Compact Recycler	Power Grid	
Boxler Screener Crusher		
Extec C10 Jaw Crusher	Extec 53 screen	
Gippo	power screen warrior 1400 finger screen	
OM Apollo	Fintec 640	
Fintec 1107	Extec robotrack	
Extec c12	Extec E7	
Parker Crusher	Power screen Trommel 600 and picking belt with blower	
Hartl jaw crusher	Svedala Trommel screen - ALLU Screening Bucket	
Pegson 830 crusher	Finlay 883/593 screens	
Pegson XR400	Extec S3 screen	
Pegson 428	Powerscreen warrior screen	
Extec crusher	Extec 3 way screen	
Terex Pegson	Power Screen	
Extec T2 crusher	Rubbelmaster	
	Warrior 1808 screener	
	Robotrac screener	
	Chieftain 1400 screener	