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

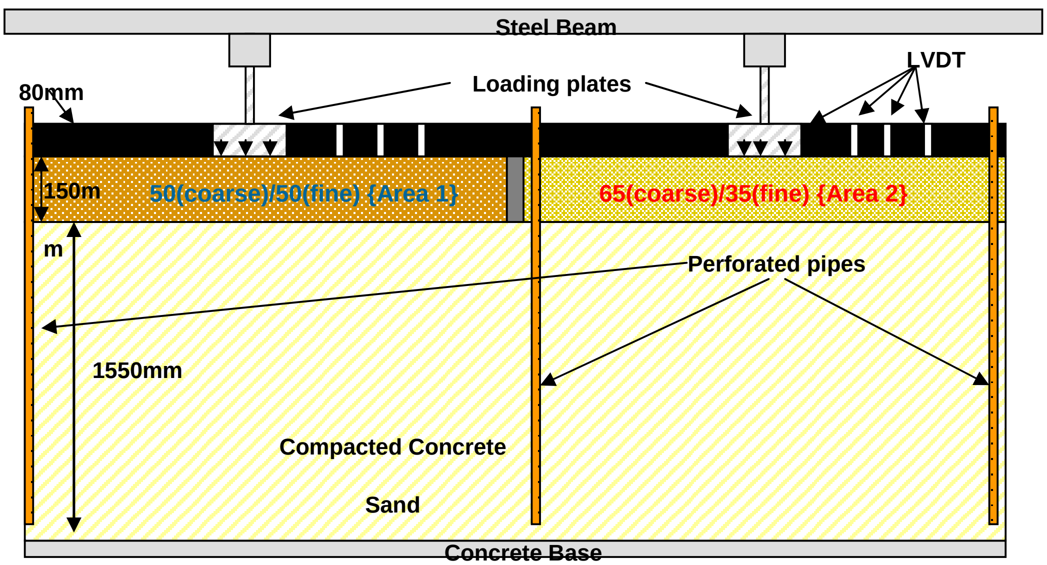


Figure 1: Pit Test Layout

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.

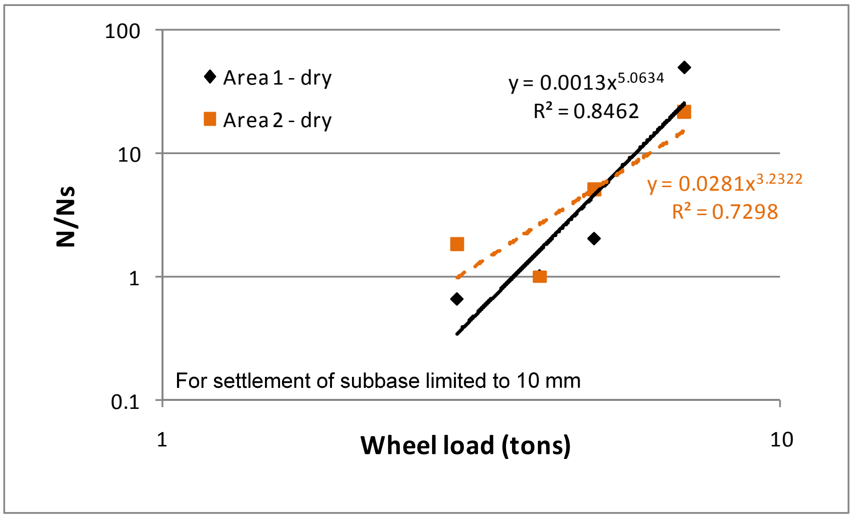


Figure 6: N/Ns versus wheel load

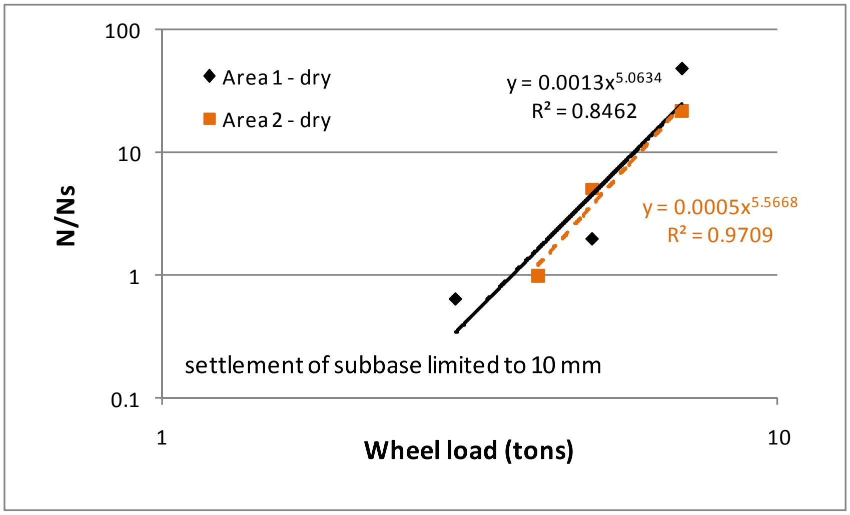


Figure 7: N/Ns versus wheel load (with outlier data removed)

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:

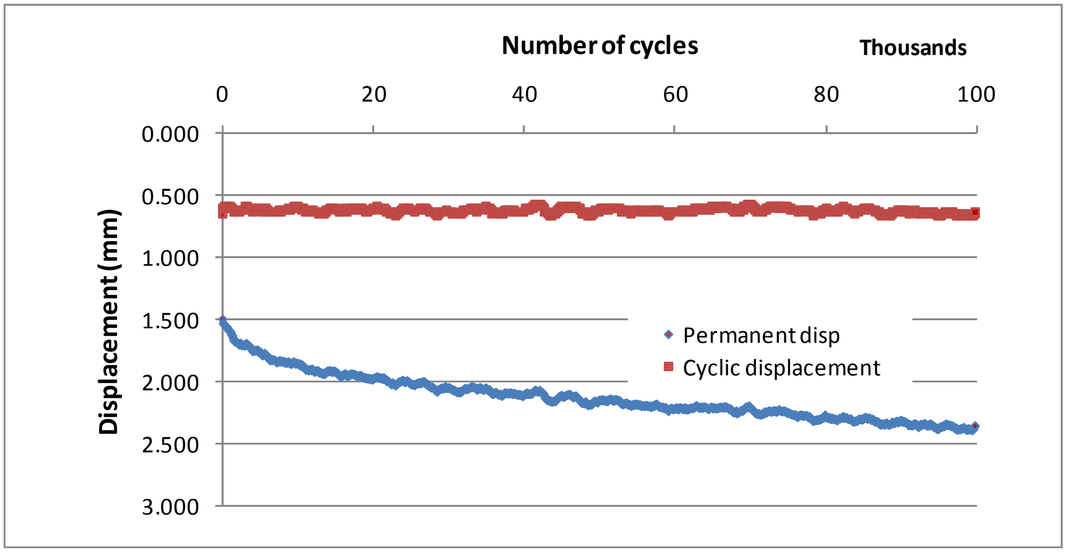
- For Minor Schemes where low traffic loading is imposed (i.e., traffic loading<0.5 msa) which includes Cars Loading (1 ton load per axle), both blends should structurally perform providing the materials are not subjected to increased water ingress and ponding of water within the sub-base materials.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

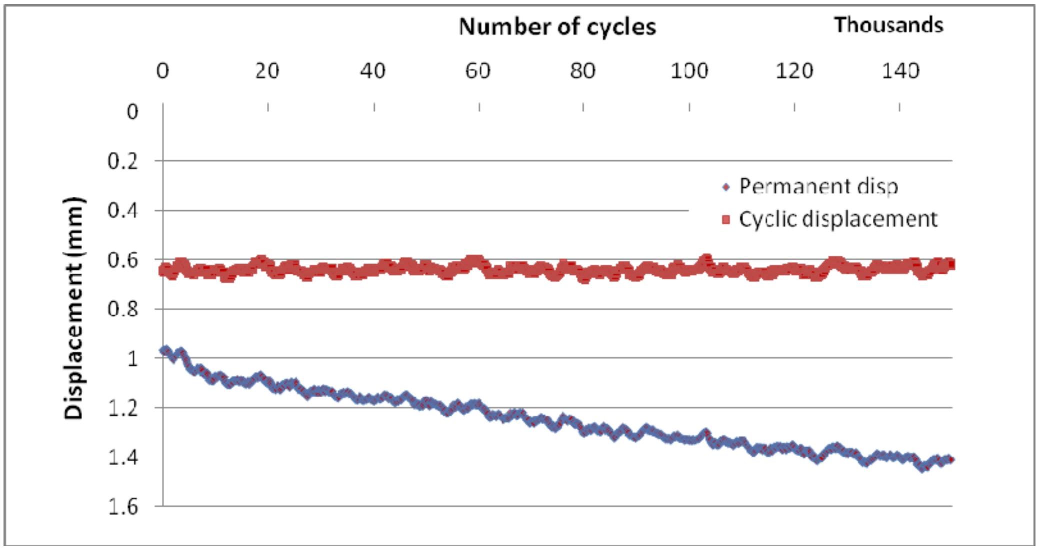
- If either blends are to be used in areas that could be subjected to increased loading either occasionally or routinely in this case it is recommended that the material structural performance is upgraded. Phase 1 testing has demonstrated that this can be achieved by introducing a hydraulic binder into 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

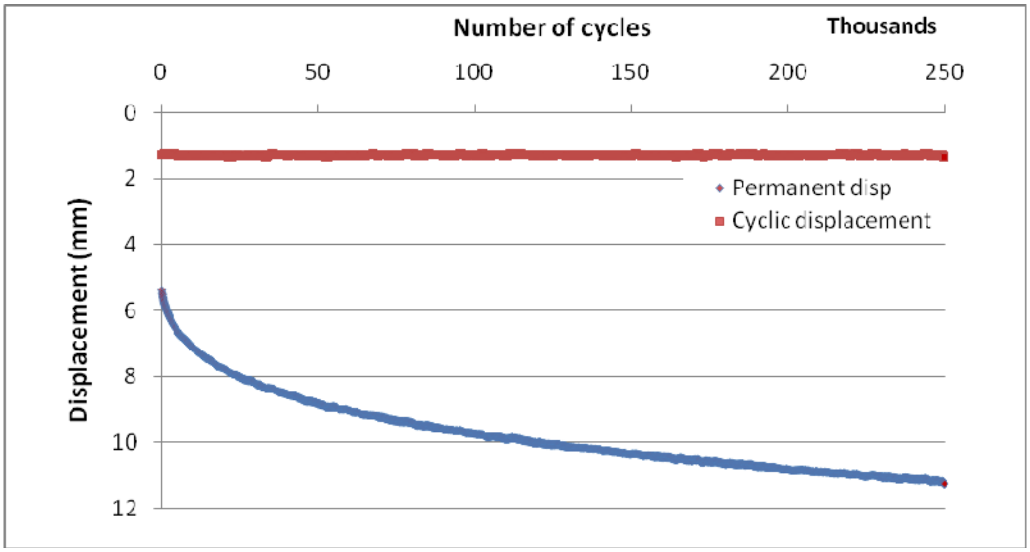
AREA 1 - DISPLACEMENT OF LOAD PLATE UNDER "DRY CONDITIONS"



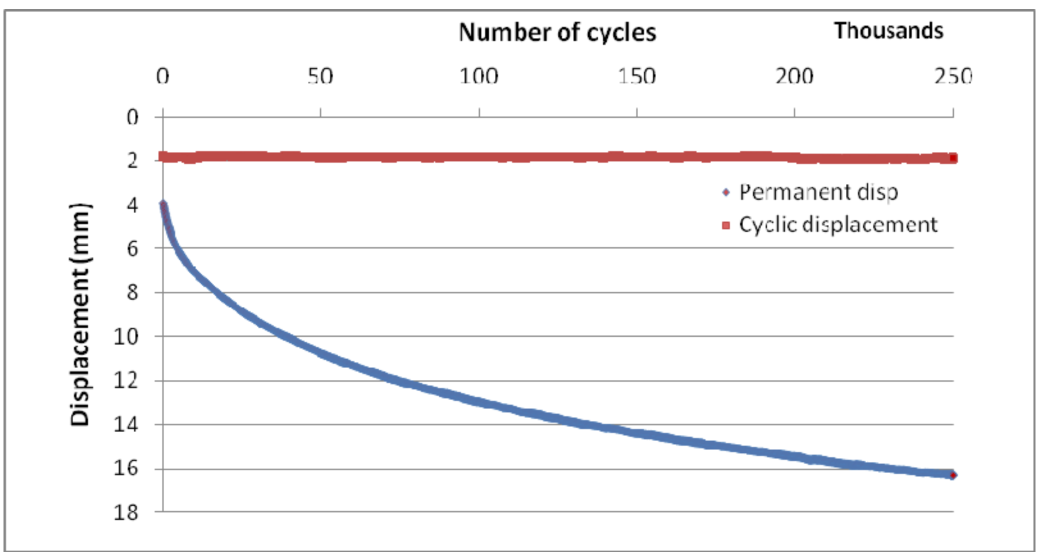
Area 1 – Displacement/loading relationship for 10kN



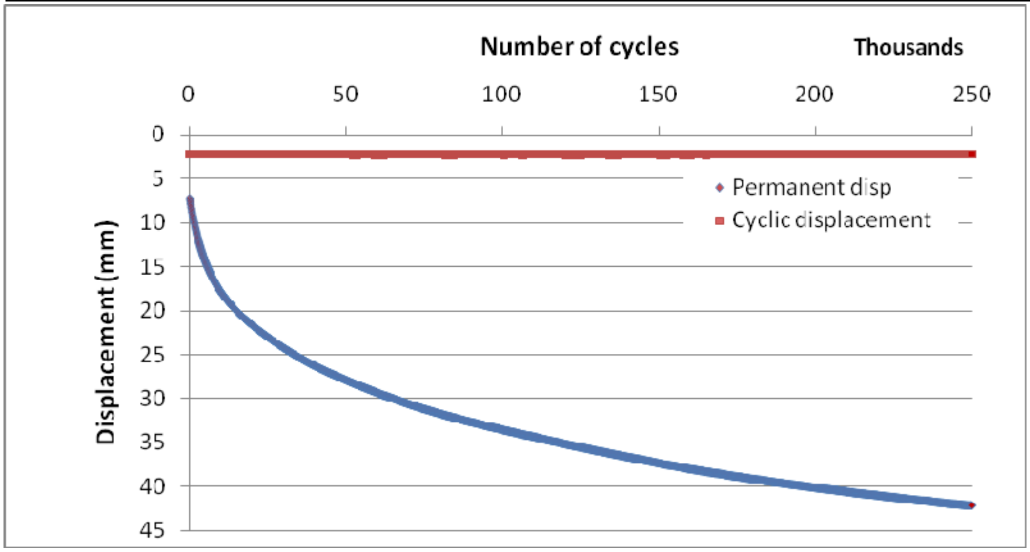
Area 1 – Displacement/loading relationship for 10kN for additional 150 thousand cycles



Area 1 – Displacement/loading relationship for 30kN

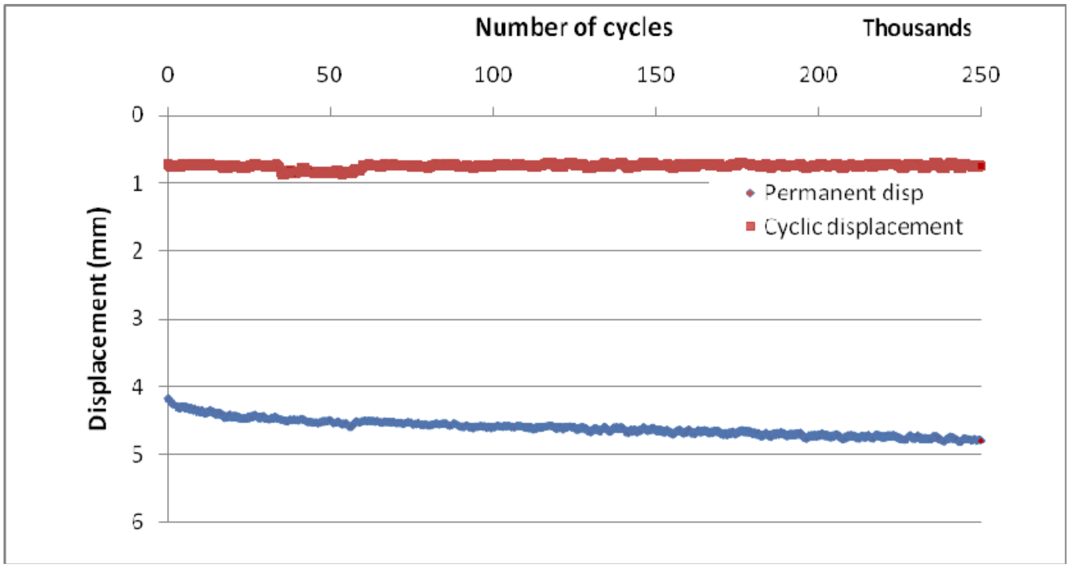


Area 1 – Displacement/loading relationship for 50kN

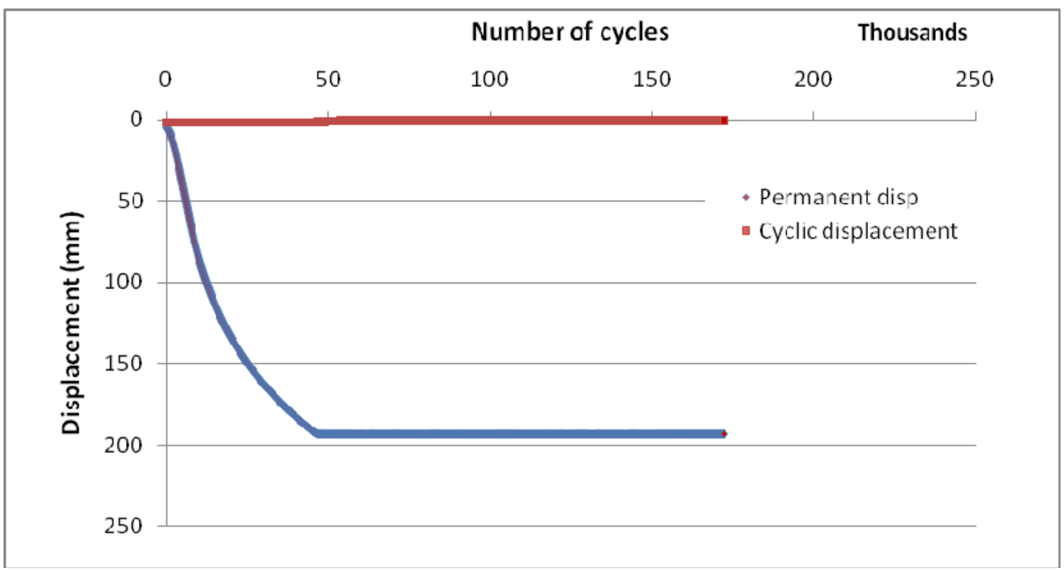


Area 1 – Displacement/loading relationship for 70kN

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



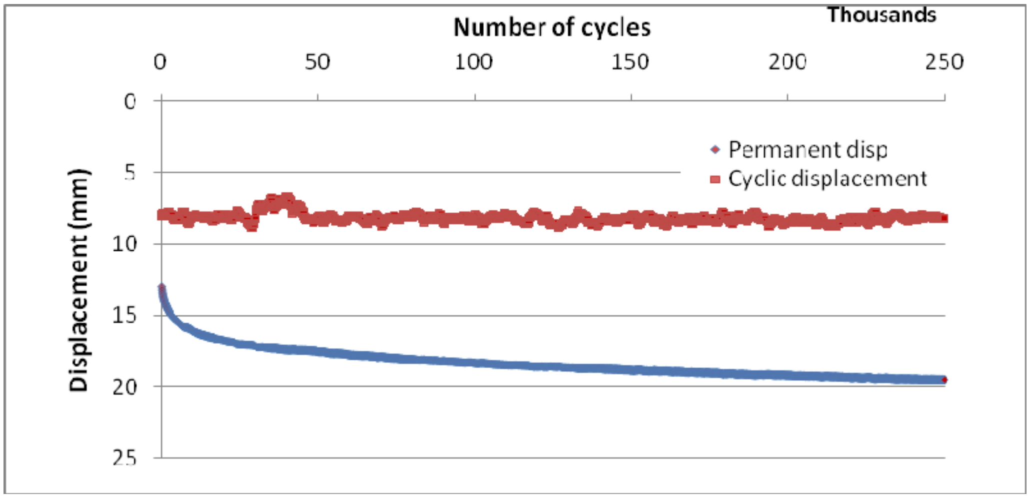
Area 1 – Displacement/loading relationship for 10kN - water at mid height of subbase



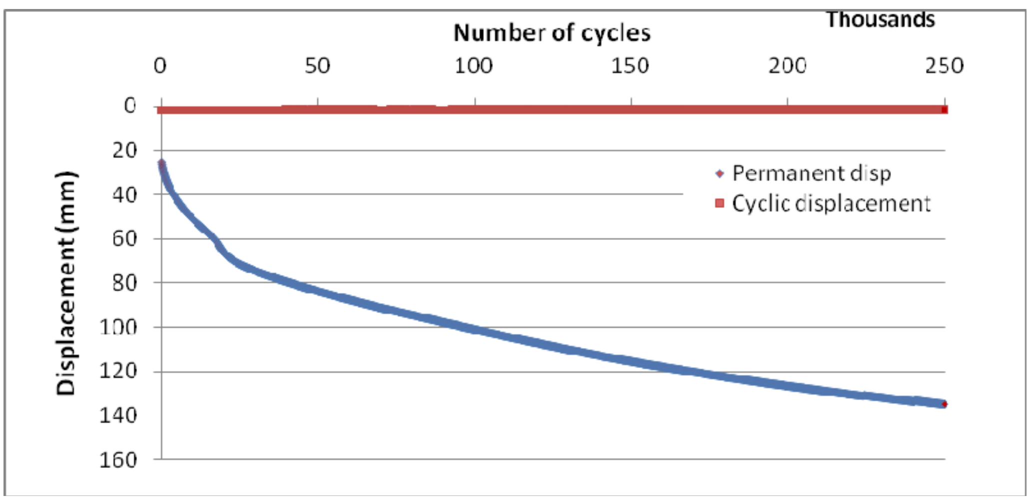
Load actuator reached limit at about 50k cycles.

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



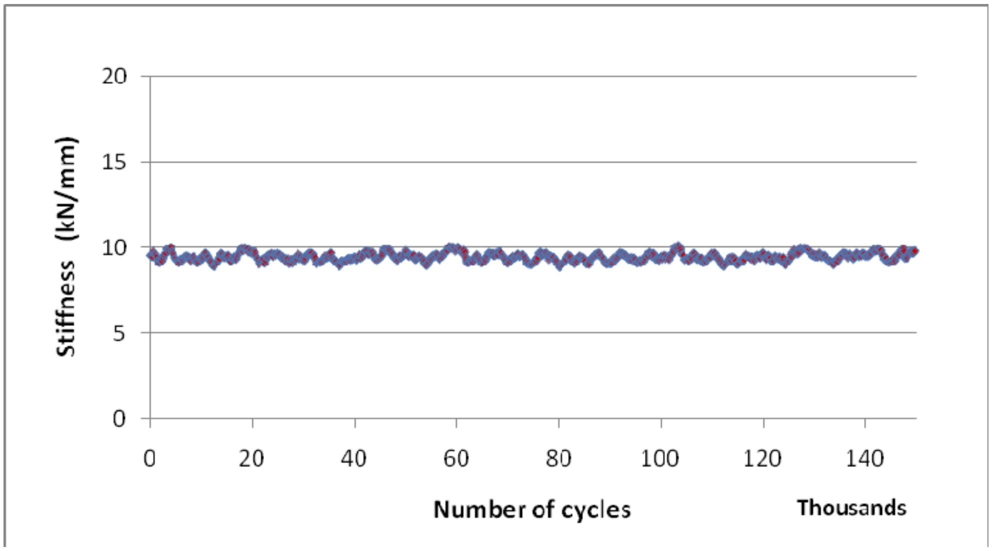
Area 1 – Displacement/loading relationship for 10kN - water at top of subbase



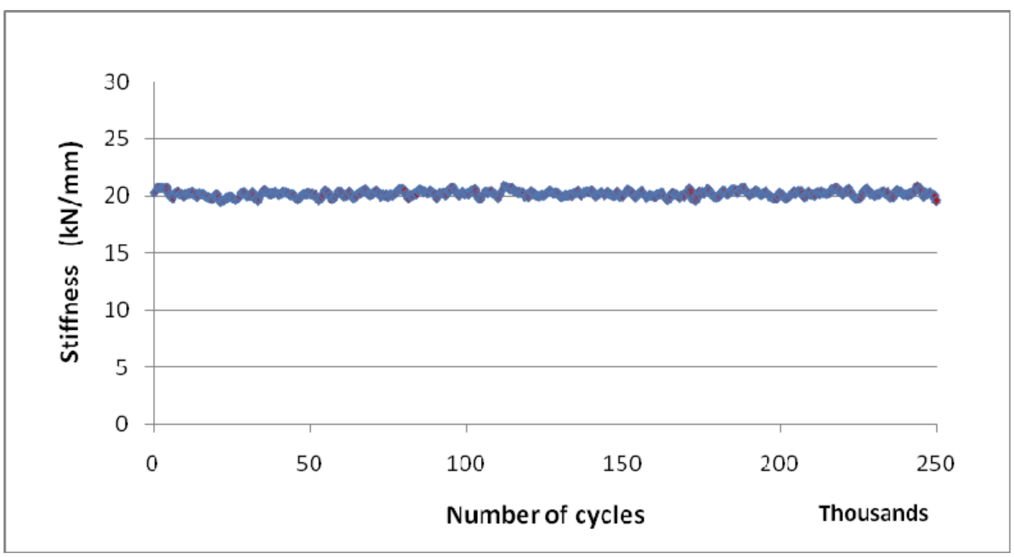
Area 1 – Displacement/loading relationship for 30kN - water at top of subbase

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

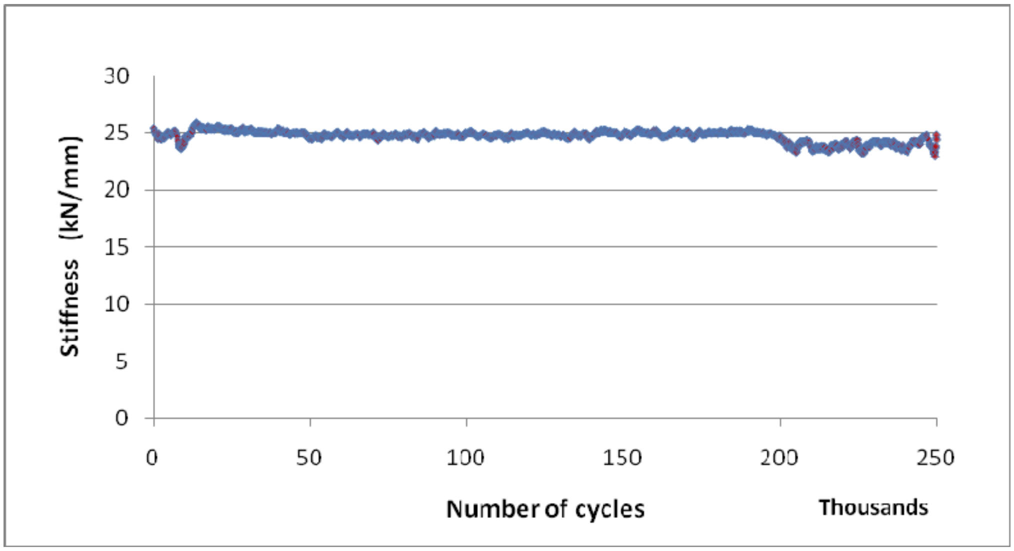
Area 1 – Stiffness/loading relationship for 10kN



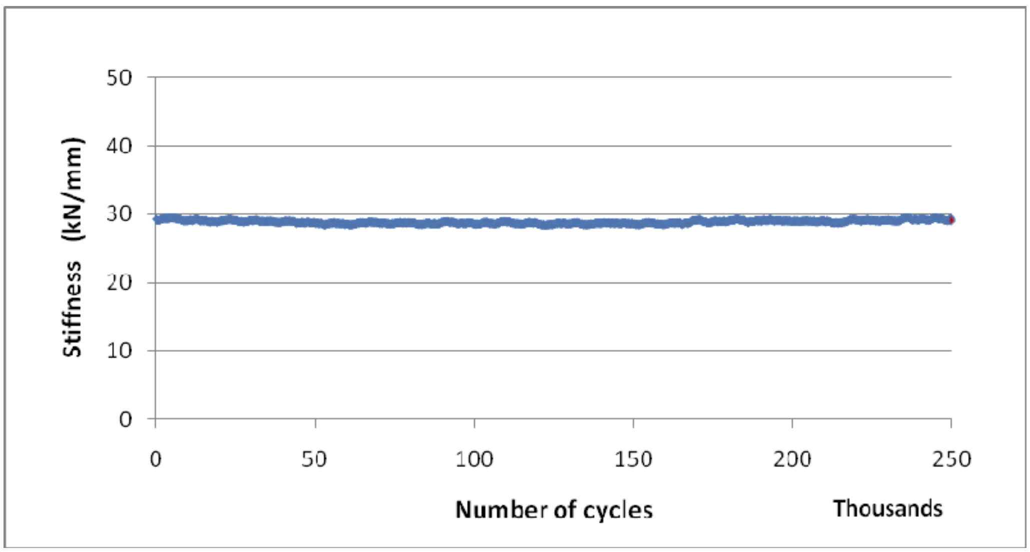
Area 1 – Stiffness /loading relationship for 10kN for additional 150 thousand cycles



Area 1 – Stiffness /loading relationship for 30kN

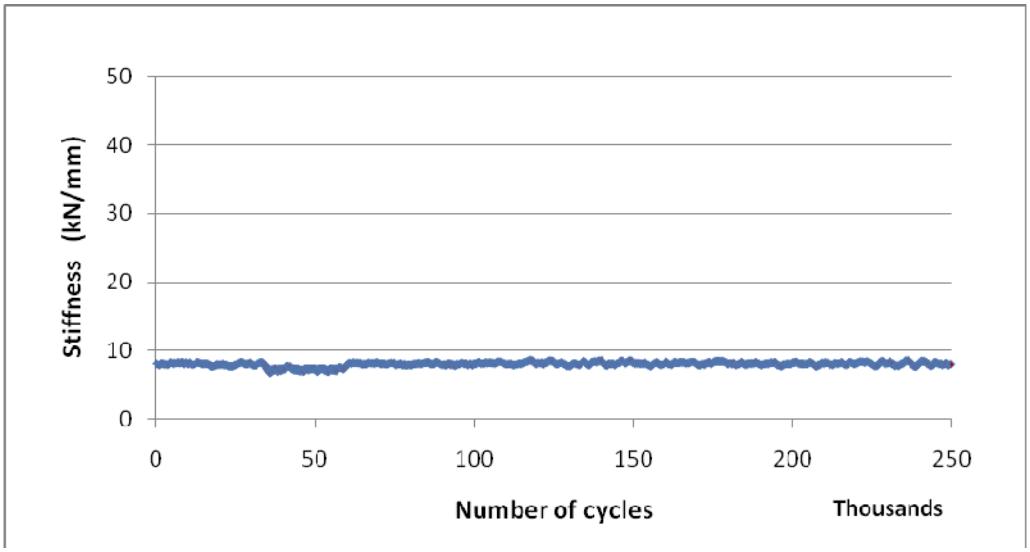


Area 1 – Stiffness /loading relationship for 50kN

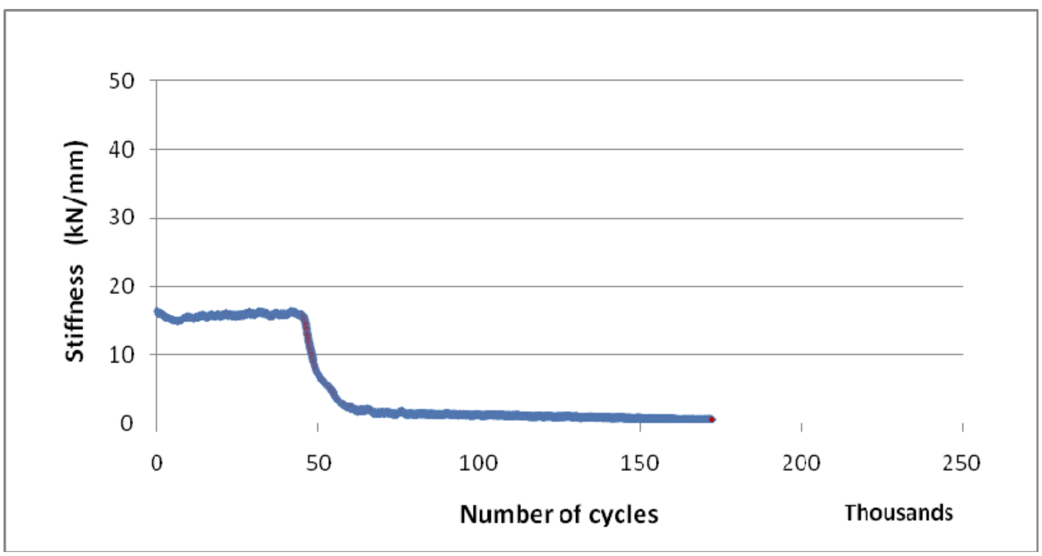


Area 1 – Stiffness /loading relationship for 70kN

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



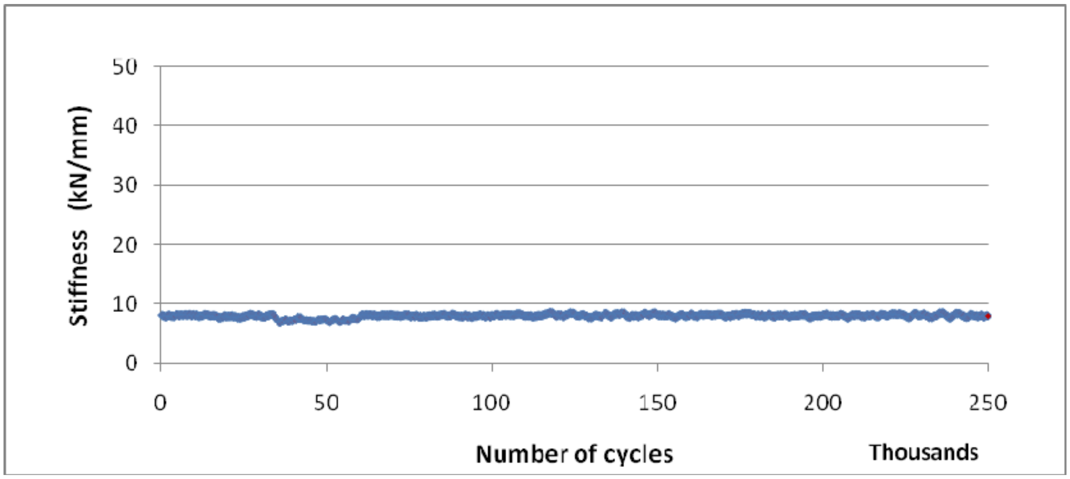
Area 1 – Stiffness /loading relationship for 10kN - water at mid height of sub-base



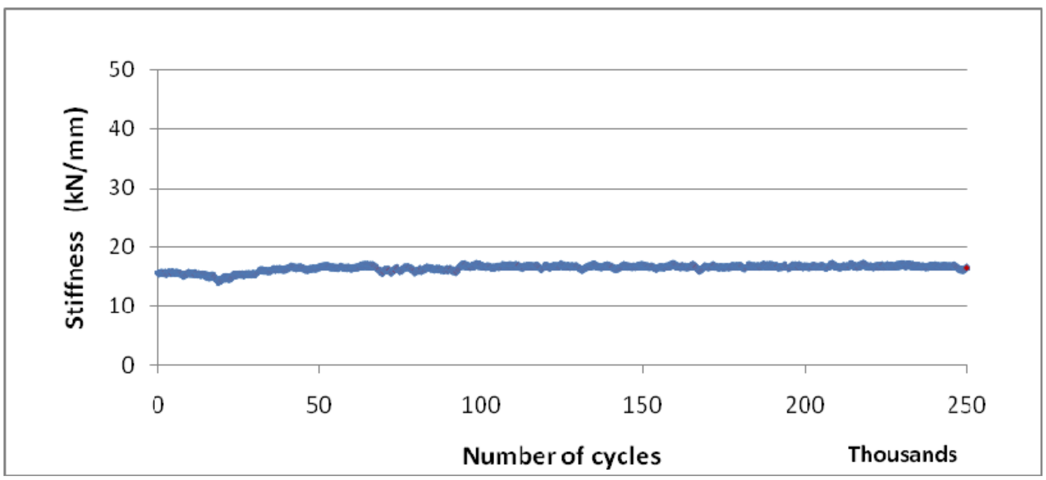
Load actuator reached limit at about 50k cycles.

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



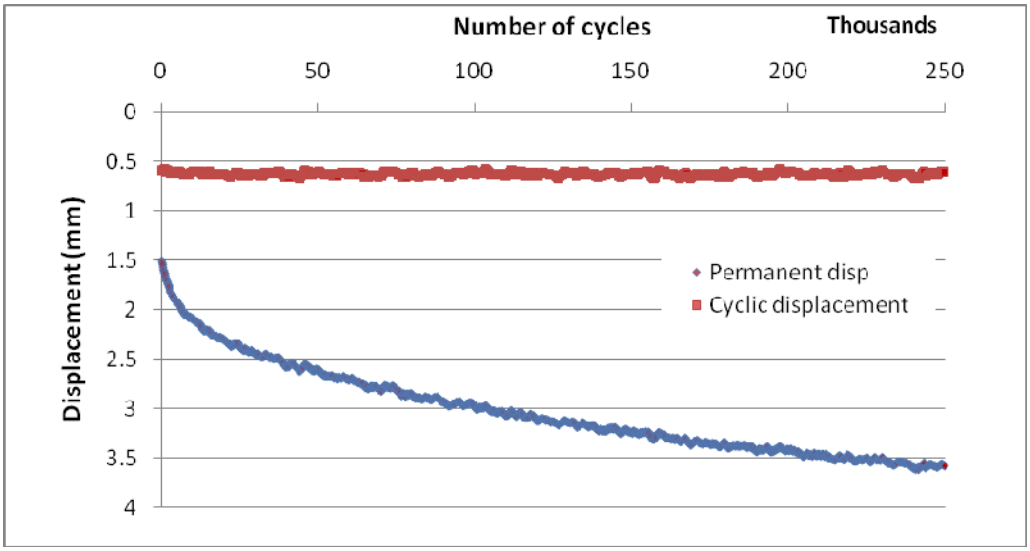
Area 1 – Stiffness /loading relationship for 10kN - water at top of sub-base



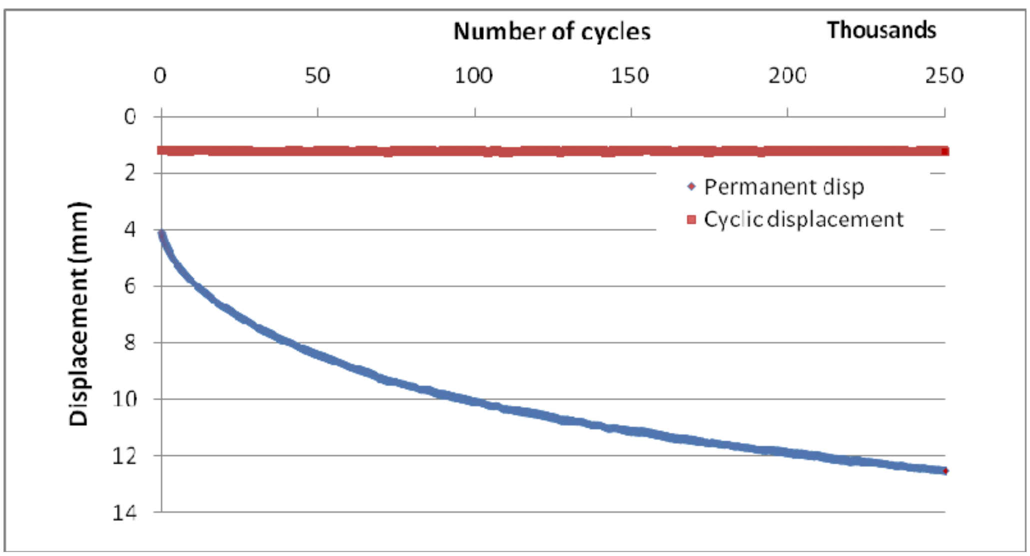
Area 1 – Stiffness /loading relationship for 30kN - water at top of sub-base

APPENDIX B – AREA 2

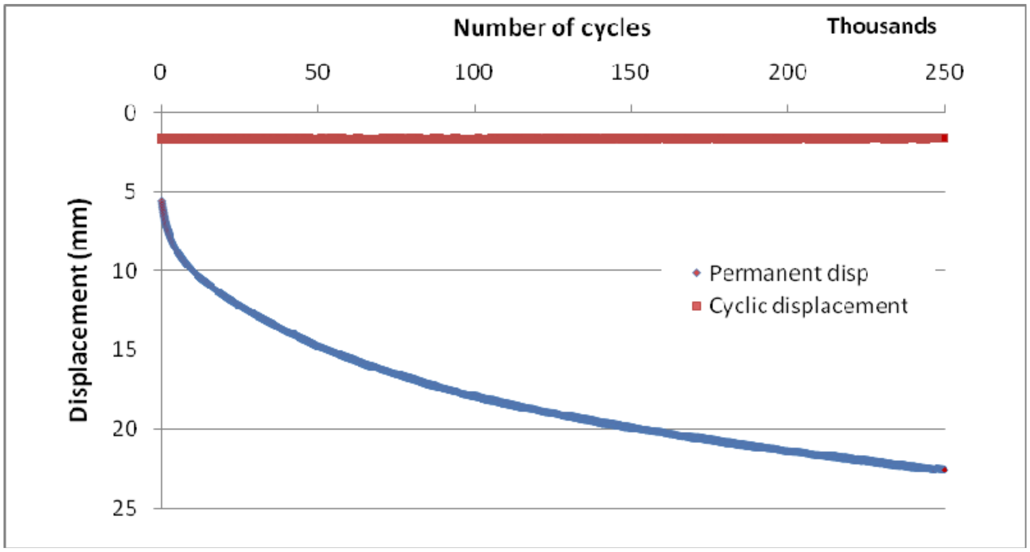
AREA 2 - DISPLACEMENT OF LOAD PLATE UNDER "DRY CONDITIONS"



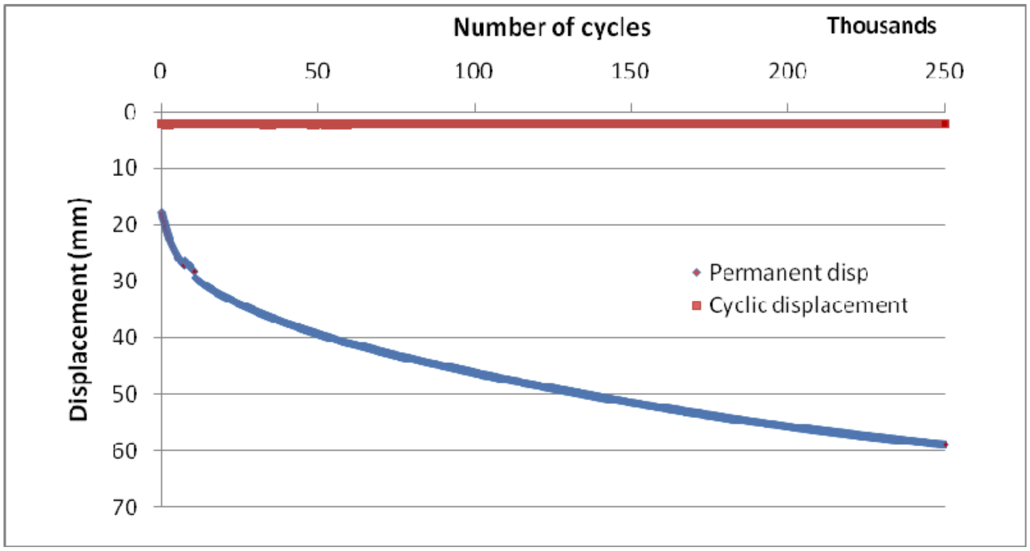
Area 2 – Displacement/loading relationship for 10kN



Area 2 – Displacement/loading relationship for 30kN

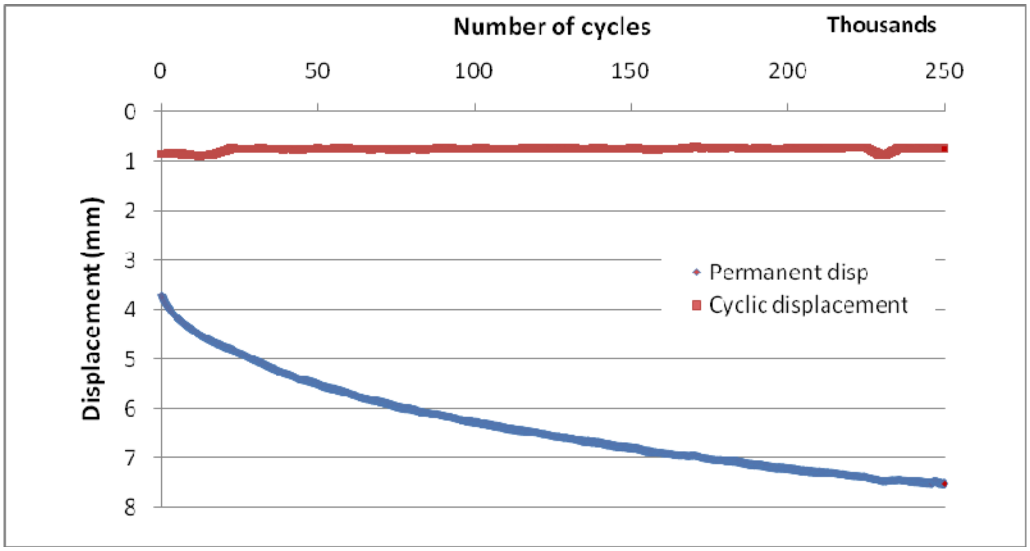


Area 2 – Displacement/loading relationship for 50kN

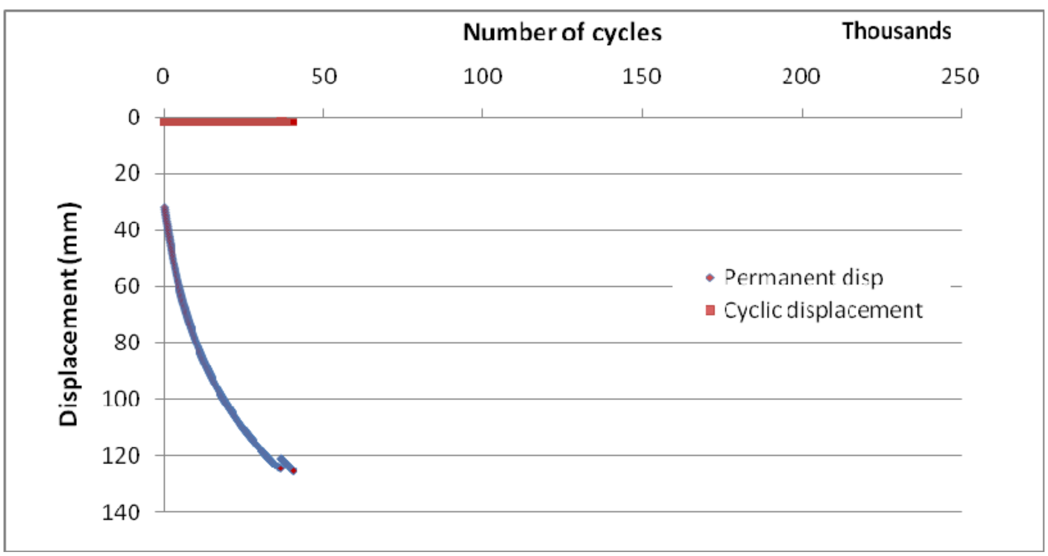


Area 2 – Displacement/loading relationship for 70kN

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



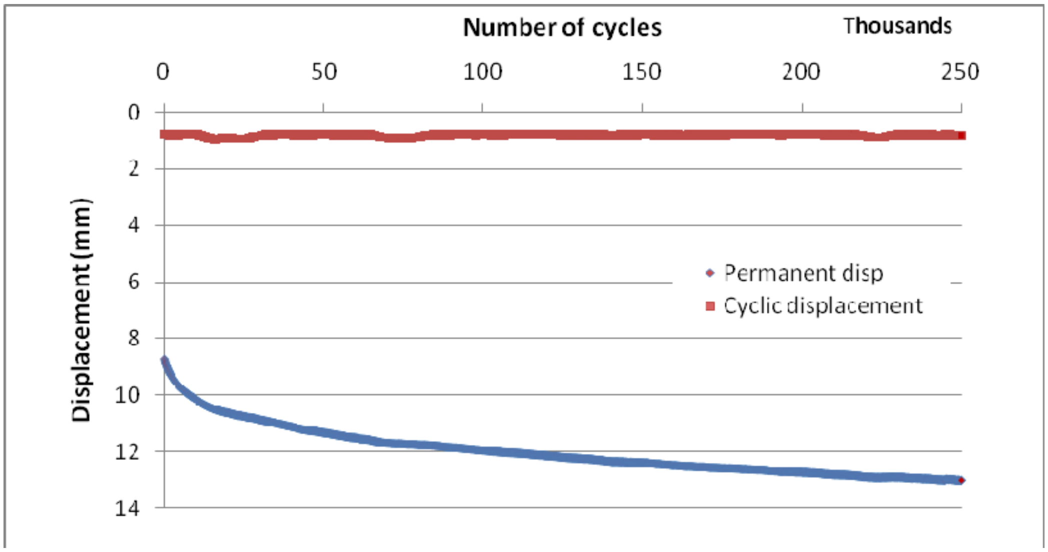
Area 2 – Displacement/loading relationship for 10kN – water at mid height of sub-base



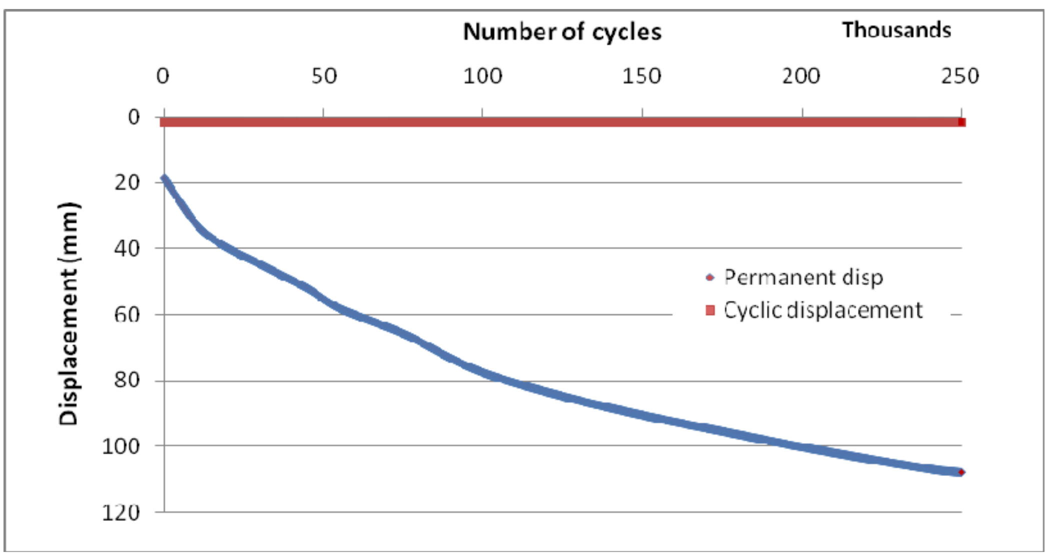
Limit of actuator plunger reached at about 40k cycles.

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

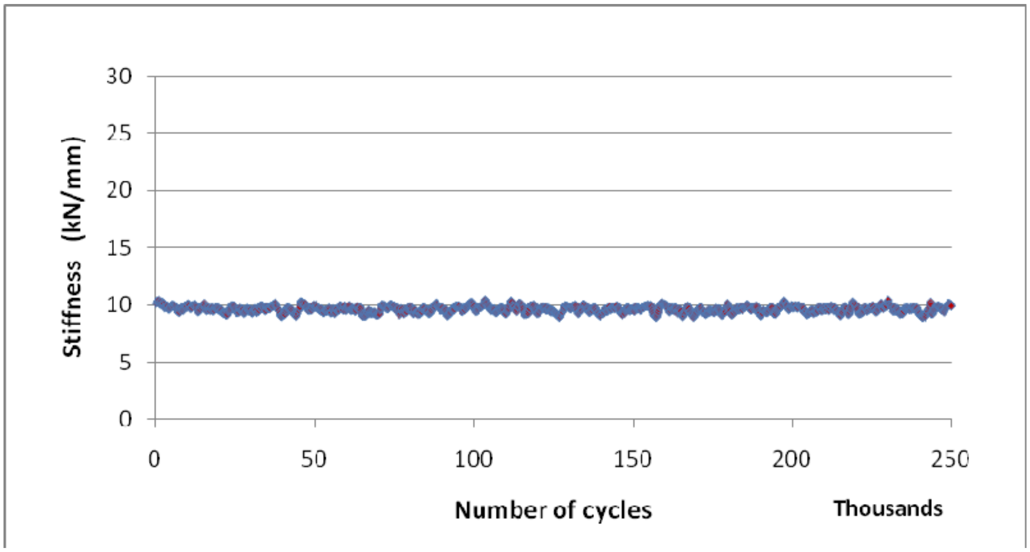


Area 2 – Displacement/loading relationship for 10kN– water at top of sub-base

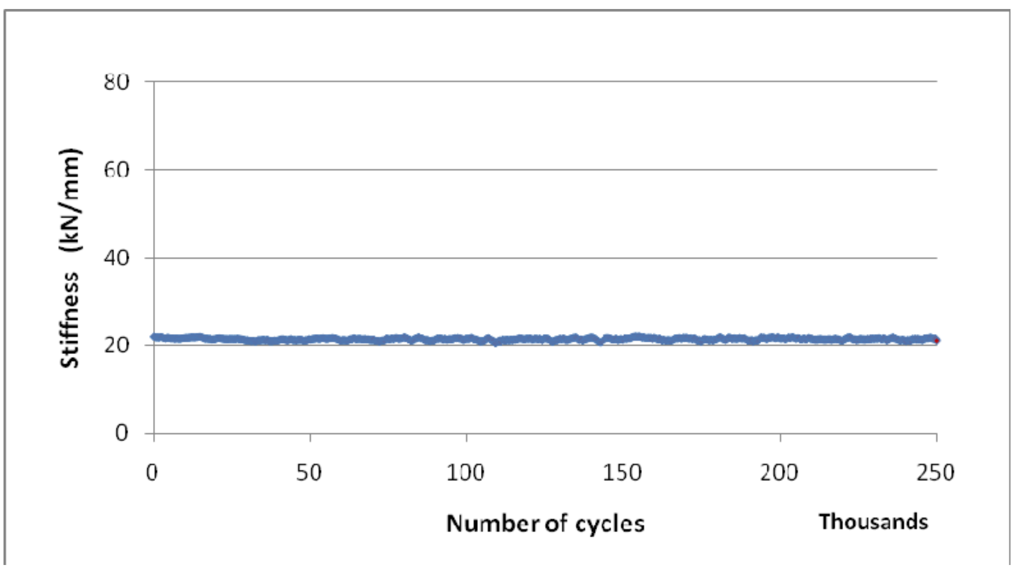


Area 2 – Displacement/loading relationship for 30kN– water at top of sub-base

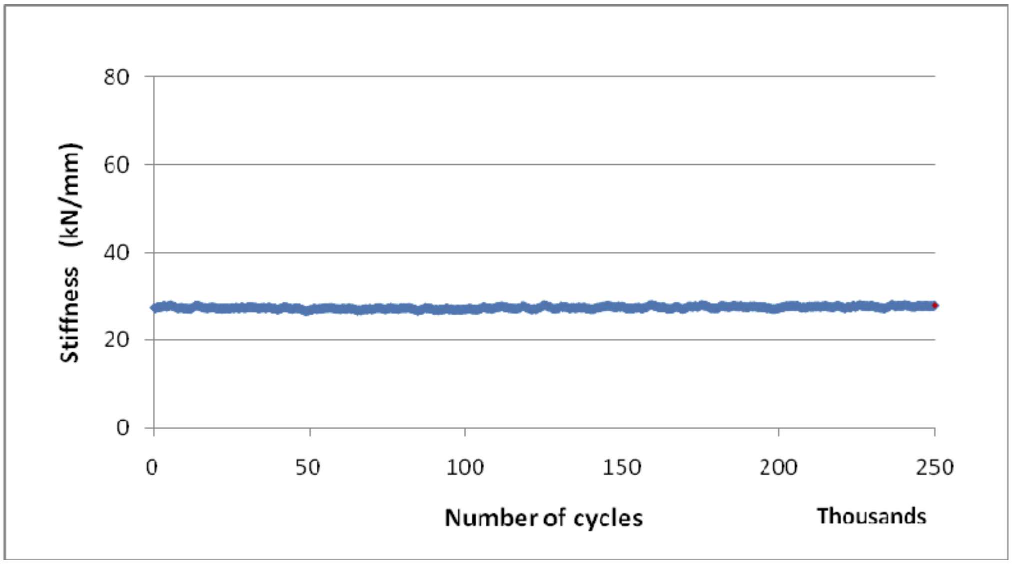
AREA 2 – STIFFNESS OF MATERIALS UNDER LOAD PLATE UNDER "DRY CONDITIONS"



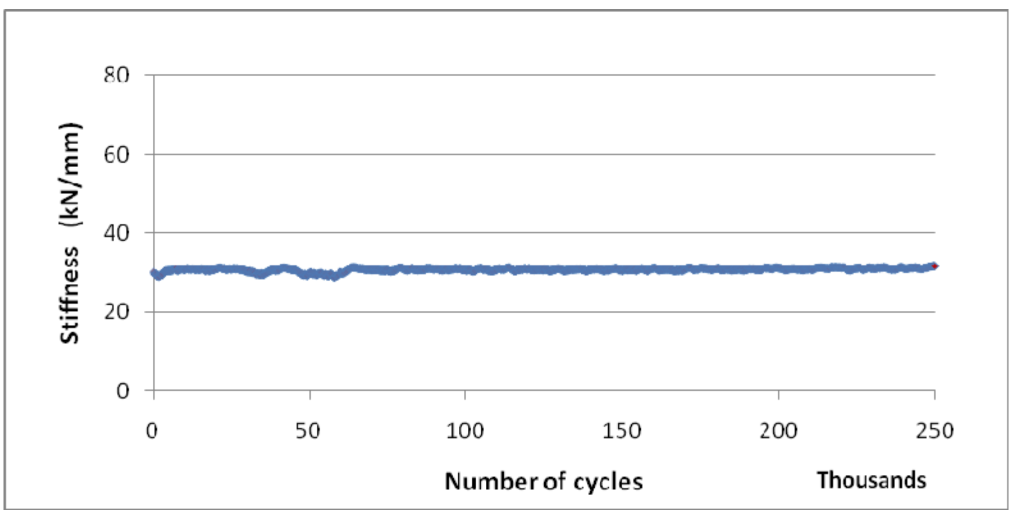
Area 2 – Stiffness/loading relationship for 10kN



Area 2 – Stiffness /loading relationship for 30kN

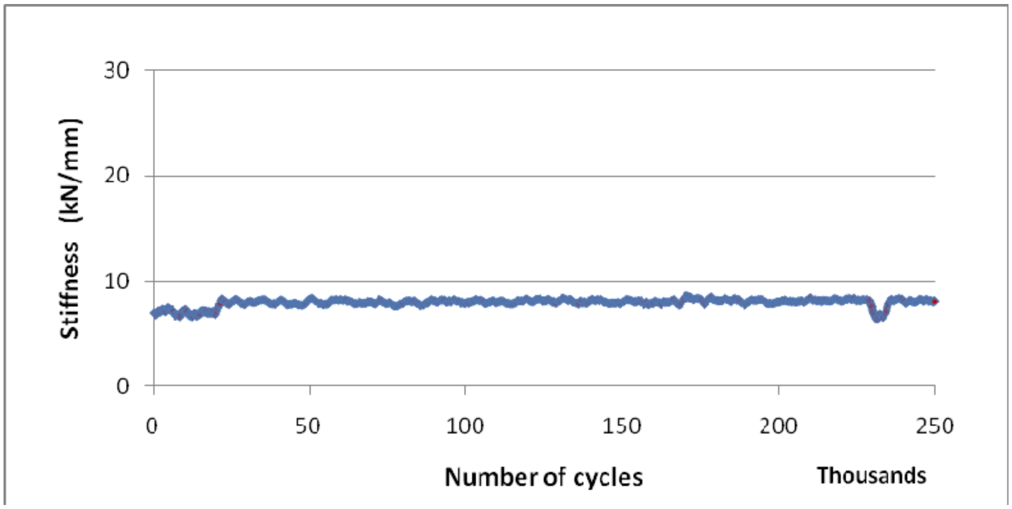


Area 2 – Stiffness /loading relationship for 50kN

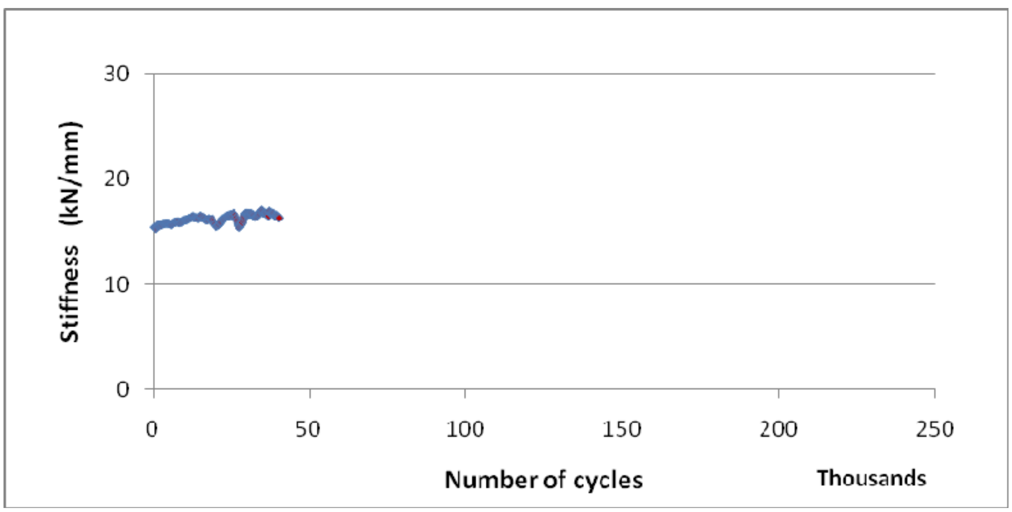


Area 2 – Stiffness /loading relationship for 70kN

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

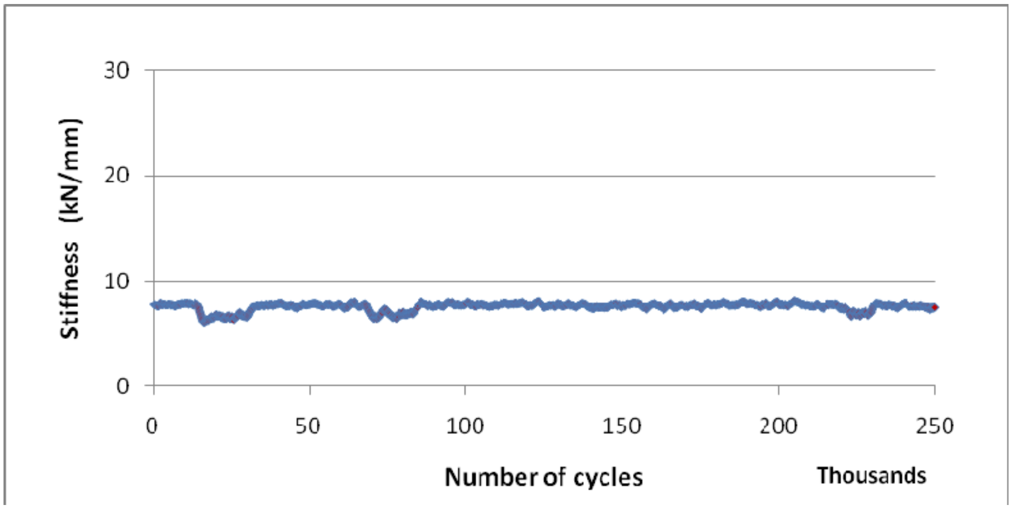


Area2– Stiffness /loading relationship for 10kN - water at mid height of sub-base

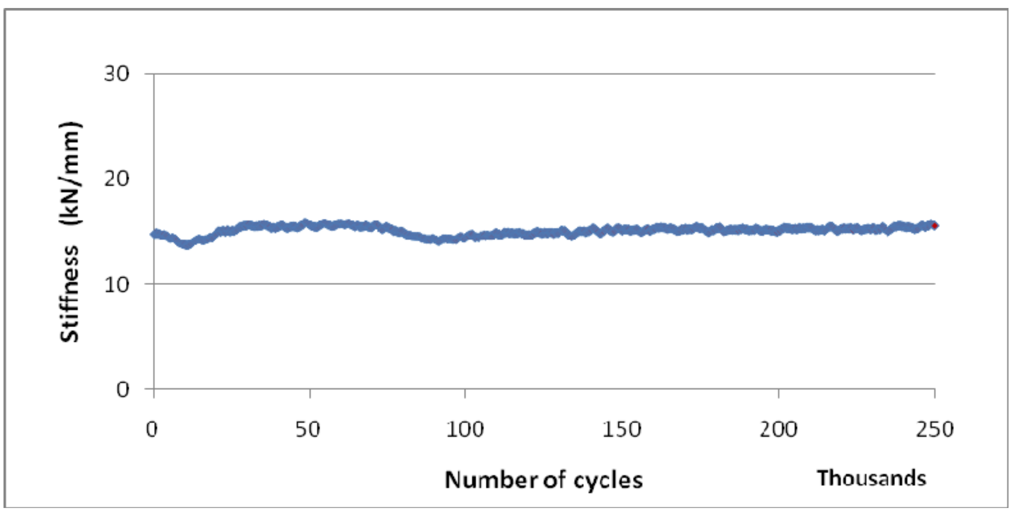


Area 2 – Stiffness /loading relationship for 30kN - water at mid height of sub-base

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