Soil Stabilisation for Reduced Cost Slurry Storage

Final Report for BPEX Ltd, EBLEX Ltd and DairyCo Ltd

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1.0 BACKGROUND

With up to 26 weeks storage required under the proposed revisions to the NVZ action programme measures, and the proposed extension of designated areas, many livestock farmers will find themselves in need of additional slurry storage within the next two years. Past survey data have estimated average slurry storage capacity on pig farms to vary between 3 and 5 months (Smith *et al*. 2000; Scott *et al.* 2002). On heavier soils the construction of earth banked lagoons to CIRIA/SSAFO standards (Anon, 1991; Anon, 1997) is by far the most cost-effective approach to the storage of whole slurry. In chalk and sandy areas, where farmers have traditionally spread manures through much of the season, achieving the standards is much more difficult, and the alternative options of concrete or steel stores are significantly more expensive (Thompson, 2002). Artificial liners, whilst more cost effective, are less resilient than earth banked stores, and are generally better suited to very low dry matter material and dirty water. Clearing sediment from a lined lagoon can be a delicate business.

Soil stabilisation techniques (the use of lime and cement powder and other materials mixed with native site materials in-situ and consolidated) have advanced significantly since the preparation of CIRIA guide 126 (Anon, 1991), and appear to offer a low cost approach to significantly enhancing both the impermeability and bearing capacity of sub soils in light land areas, with the promise of suitability for lagoon construction, provided that the required impermeability standard can be demonstrably achieved. Although bentonite mixtures have long been shown to work successfully as an impermeable cap on landfill sites, there has been less certainty about their applicability as bottom liners (Hoeks *et al*., 1987) and there has been no reported uptake of this technology on commercial farm sites across Europe. A lime/cement powder mix has been used successfully for the stabilisation and construction of farm and forestry roads and yard areas (Golding, 2007), though has yet to be used for manure or slurry storage facilities.

Whilst the costs of the proposed approach are estimated to be up to 50% less than the cost of an equivalent concrete floored store, the system needs to be shown consistently capable of achieving the impermeability standards required by the Environment Agency. Furthermore, the anticipated working life of the system should be at least as great as that of alternative storage designs.

The timescale for this work is tight. Following the NVZ consultation process (Anon, 2007) and analysis of the large number of industry responses (ADAS, 2008), implementation of the NVZ Action Programme is anticipated in the autumn, with a two year period for systems to be brought up to standard. With potential for on-farm construction largely limited to the summer and autumn months by weather and seasonal activity, the technique needs to be established and approved by early summer 2009. Depending on the project timescale, the Pig and Poultry Fair, 2009/10, and/or the Dairy Event (see later section on finance) may provide a valuable opportunity to promote and demonstrate the results of a successful “pilot”.

Envisaged cost/benefit to the industry:

Under the revised Nitrates Action Programme, a minimum storage requirement of 26 weeks has been proposed to allow pig producers to comply with the required closed periods for slurry spreading. Taking a simple example of a 1000 place finishing pig unit, this means a store with a minimum of c. 1500m^3 capacity, allowing for 5-6% DM slurry arising from a minimum estimated 1:1 dilution. Estimated capital costs of c. £45-52,000 would be anticipated for a new installation, depending on alternatives of earth bank lagoon or above ground steel tank construction (Thompson, 2002).

Anecdotal information on farm tracks installed using the cement stabilisation technique suggests both significant potential for savings in installation costs and satisfaction in terms of the quality of the finished work; e.g. >60% cheaper than tarmac and 50% cheaper than concrete; also quicker installation, better “key-in” with substrate and apparently improved durability (J Wilson, Holt Farms, personal communication Feb 2008). Costs of the proposed approach are initially estimated to be up to 50% less than the cost of an equivalent concrete floored store.

2.0 OUTLINE WORK PLAN

A two stage approach for the development of the technique to a field demonstration/scoping study stage, which would then form a third stage follow-on phase of the project was proposed:

(1) The technique was trialled on a *bench scale*, at GeoTest laboratory using hand-prepared and consolidated samples with various rates of inclusion and a range of particle sizes/moisture contents, layer thicknesses and degrees of consolidation for typical parent materials. These trial cores were laboratory tested in accordance with the standard suite of tests required by CIRIA 126; in particular, triaxial permeability test in accordance with BS1377 (1990). For the purposes of this research, two of the most difficult soil types were selected, viz. sandy and chalk/shallow limestone soils.

(2) The column, mix studies were supplemented with the extraction of core samples from existing sites where the stabilisation technique has been used. The same permeability tests were carried out on the extracted cores.

(3) (Beyond the remit of the current proposal) Subject to satisfactory results in phase one and two, the most successful option(s) would be tested on a farm pilot scale, via the construction of a storage lagoon at a suitable field site. This site to be identified by BPEX and would be run as a demonstration project, with press articles featuring planning and progress of the work on site and culminating in a well publicised open day.

GeoTest

3.0 METHOD STATEMENT

Method Statement for the preparation and testing of materials modified with cement

Initial Preparations

Two types of subsoil material were used in the trials. These were a sandy material with a high proportion of silt and a chalk with cohesive fines. Approximately 200 kg of each material type was supplied. All bags of each material type were mixed to provide a homogeneous representative sample of the material type for all subsequent operations

Initial tests

Natural Moisture Content, Particle size distribution and heavy (4.5Kg rammer) and light (2.5Kg rammer) compaction were carried out on each material type. All initial tests were carried out in accordance with BS 1377:1990 Soils for civil engineering projects

Sample Preparation

A test portion of material of suitable size to manufacture the required specimens was taken. Ordinary Portland Cement was added on a dry mass to dry mass basis to give the required percentage addition rate and then mixed thoroughly using a multi flow mixer. Specimens were compacted immediately after cement addition using the compactive effort shown in table 1. The compacted specimens were trimmed to a suitable size for permeability testing(100mm length).Prepared specimens were sealed in polythene and stored until the required test date at 18-22^{o}C. Duplicate specimens were prepared for each cement addition and compactive effort.

Testing

Prepared specimens were stored for approximately 23 days before commencement of testing with the aim of the permeation phase of the test taking place when specimens were 28 days old. Triaxial Permeability tests in accordance with BS 1377:1990 Soils for civil engineering projects, Part 6, method 6 were carried out using an effective pressure of 50kPa, a hydraulic gradient of 20 and downwards flow through the specimen. The permeability of each specimen was determined when flow volumes from upper and lower inlets were linear and parallel.

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Table 1. Preparation of subsoil samples for testing

Compaction Type	Specimen Quantity	Cement addition%	Material Type
Heavy	2	0	Sand
Light	2	0	Sand
Heavy	2	5	Sand
Light	2	5	Sand
Heavy	2	10	Sand
Light	2	10	Sand
Heavy	2	15	Sand
Light	2	15	Sand
Heavy	2	0	Chalk
Light	2	0	Chalk
Heavy	2	5	Chalk
Light	2	5	Chalk
Heavy	2	10	Chalk
Light	2	10	Chalk
Heavy	2	15	Chalk
Light	2	15	Chalk

4.0 BENCH TRIALS AT GEOTEST LABORATORY

Figure 1. Sample Reception

Figure 2. Sub-soil sample moulds and compacting instrument – GeoTest laboratory

Figure 3. Compacted chalky sub-soil sample with cement inclusion

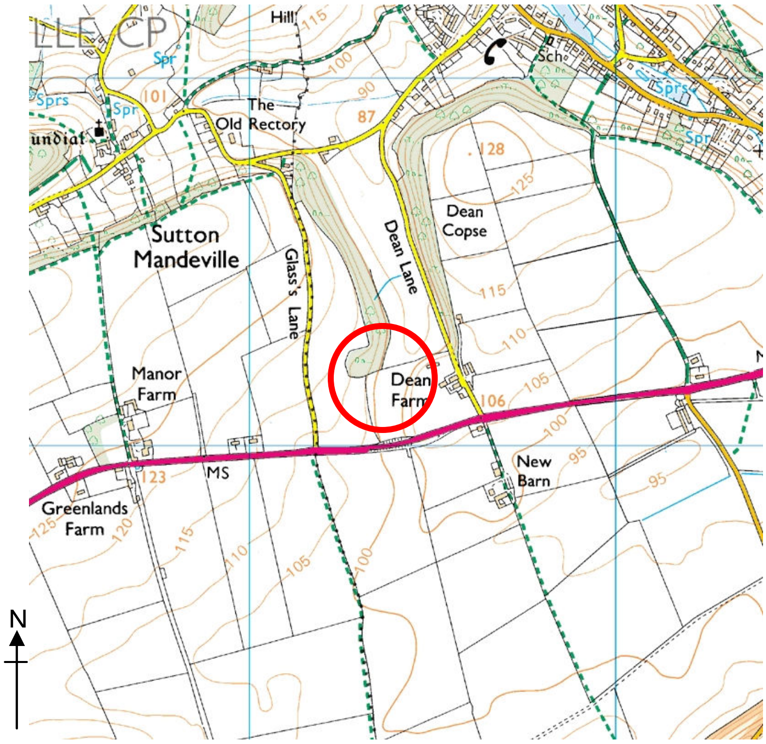
Figure 4. Sub-soil samples - Permeability testing at GeoTest laboratory

5.0 SUB-SOIL SAMPLE SITES

Fovant Sub-Soil Sample Site

Fovant (sandy sub-soil) – Grid Ref: ST 994 282

Date sample collected: 20-01-09



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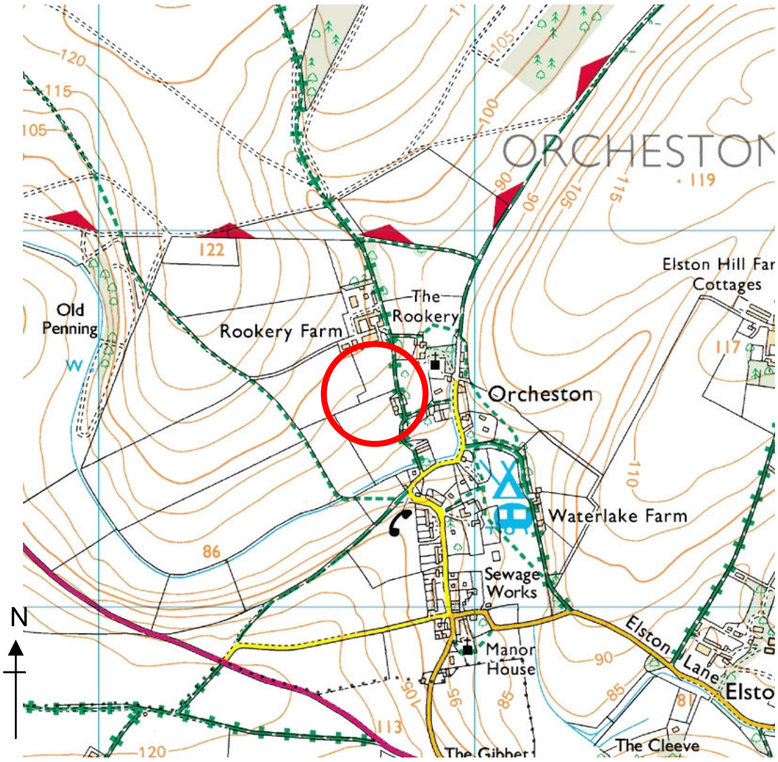
Dean Lane Farm
Fovant
Salisbury
Wiltshire
SP3 5LQ

Sub-soil samples were dug by hand from between 400 and 800mm below ground level.

Orcheston Sub-Soil Sample Site

Orcheston (chalky sub-soil) – Grid ref: SU 058 456

Date sample collected: 23-01-09



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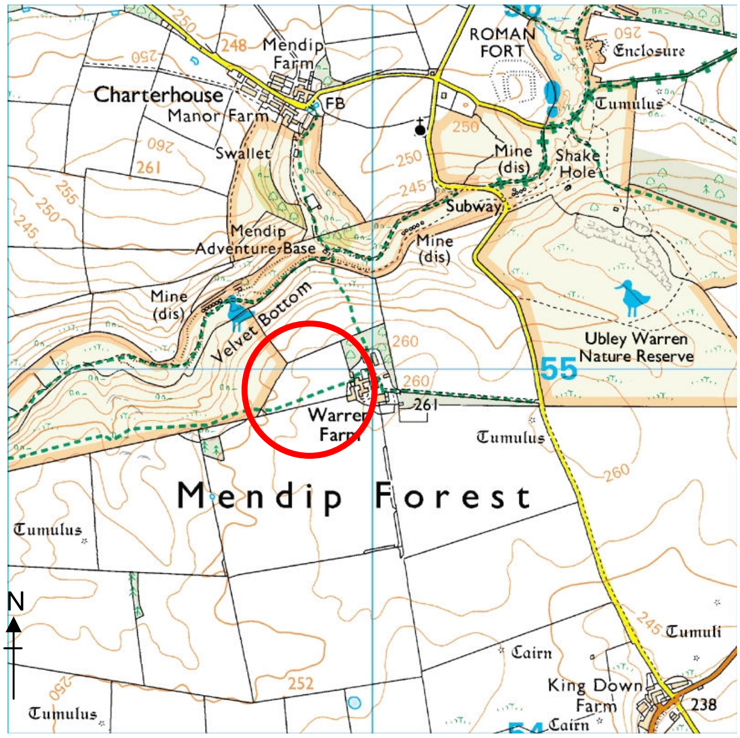
The Orcheston site is the location of a stockpile, material would have come from various points within the village, soil beneath the stockpile point would, however, be the same.

6.0 LOCATION OF SITES USED FOR ON-SITE CORING

On-Site Coring – Warren Farm

Warren Farm, MP and KM Goldings' yard – Grid Ref: ST 500 550

Date sample collected: 27-04-09



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Warren Farm,
Charterhouse,
Blagdon, Bristol,
BS40 7XR

The above site is an existing farm yard where the stabilisation technique was applied in November 2008. The yard comprised a 50/50 soil aggregate mix, 150mm deep. The soil contained some top soil and some sub-soil prior to stabilisation. Compaction used: BW15 vibrating roller (70t pressure) 6 passes, vibration plates 4 passes (30t pressure).

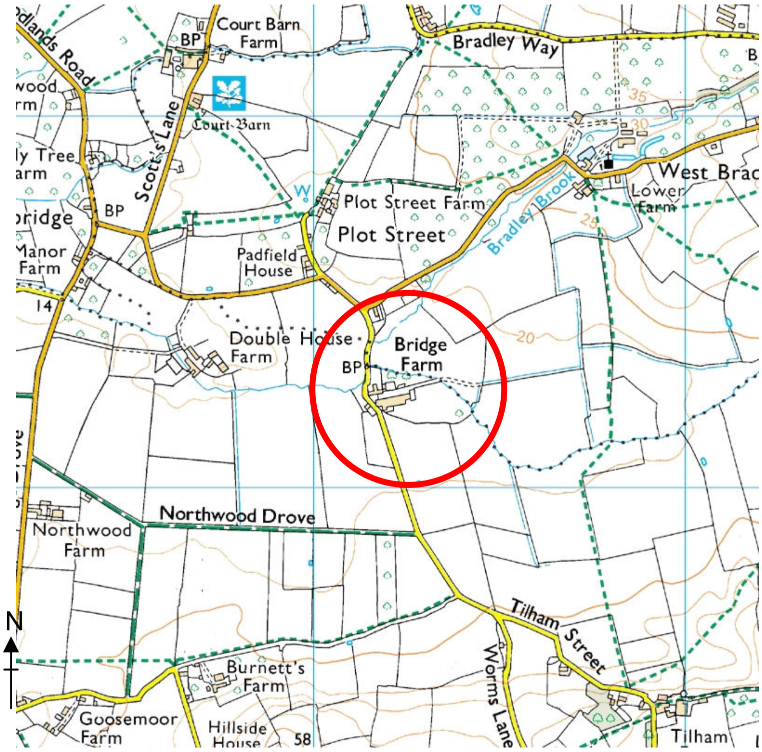
Nine cores were taken within the yard area. Some of the cores disintegrated on extraction from the coring machine which left seven cores suitable for testing purposes. Two bulk samples of source material were collected from a stockpile as control samples.

For comparative purposes, a core was taken in a nearby yard area where less aggregate was used in the stabilisation process. This core disintegrated on extraction. Two further cores were also taken in another stabilised yard area where more aggregate was used in the process. These cores were found to be more solid.

On-Site Coring – Bridge Farm

Bridge Farm, Kingshay Farming Trust - Grid Ref: ST 552 363

Date sample collected: 28-04-09



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Bridge Farm
West Bradley
GLASTONBURY
Somerset
BA6 8LU

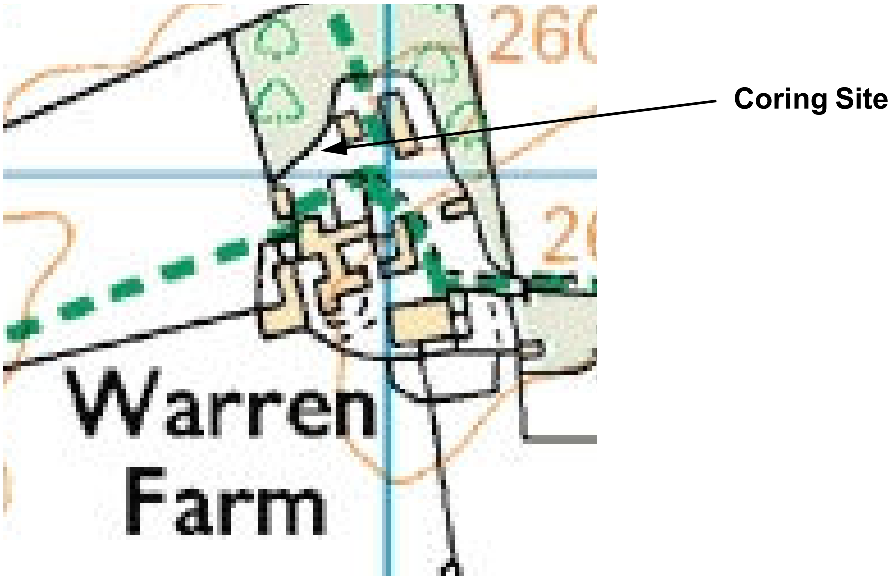
The above site is a cow track which was stabilised in 2005. The stabilised track comprised a mixture of sub and top soil. The top 3-4 inches of soil was removed prior to the remainder being stabilised using MP and KM Golding's technique.

Sixteen cores were taken along the cow track. Many of these cores disintegrated on removal from the coring machine. Seven cores were suitable used for testing purposes.

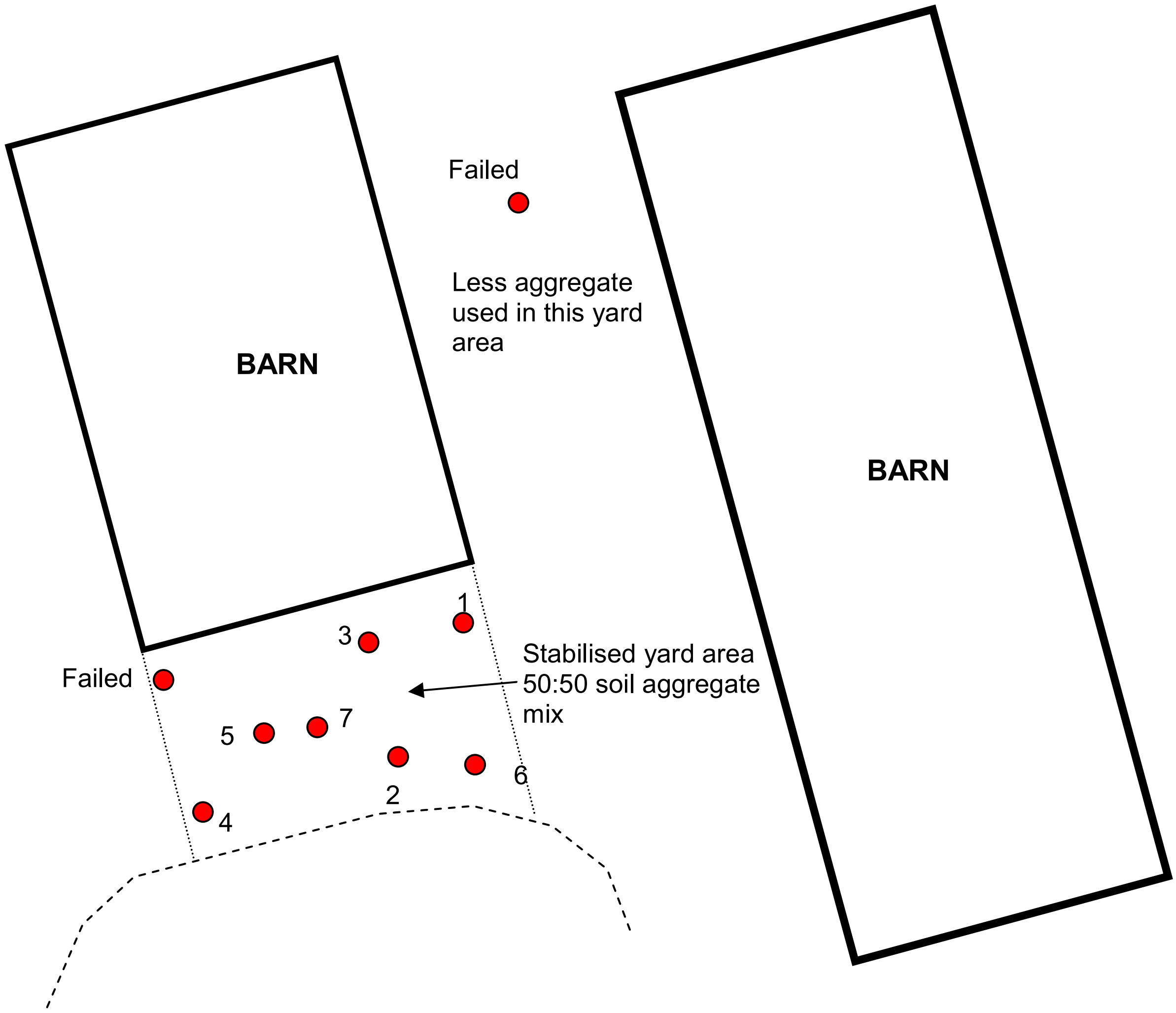
One bulk sample of the source material was collected from approximately 5m off the cow track as a control sample. Turf and topsoil was removed and the sub-soil sampled. The hole was backfilled with material from the track and the topsoil/turf replaced. Two bulk samples of modified material were also taken from the cow track below the disturbed surface material.

All the cored holes were reinstated on completion with concrete.

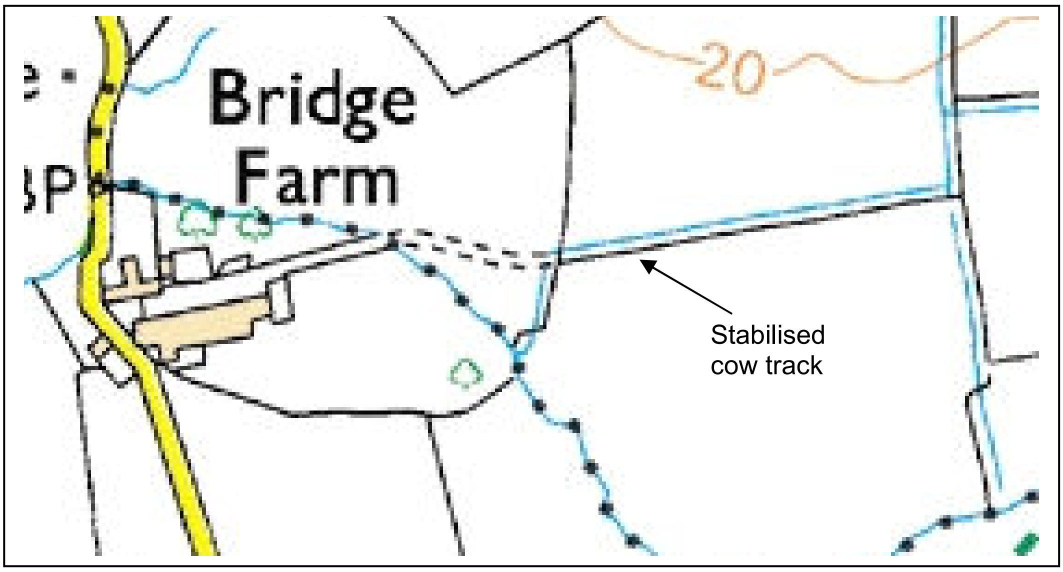
Approximate Location of Core Samples - Warren Farm

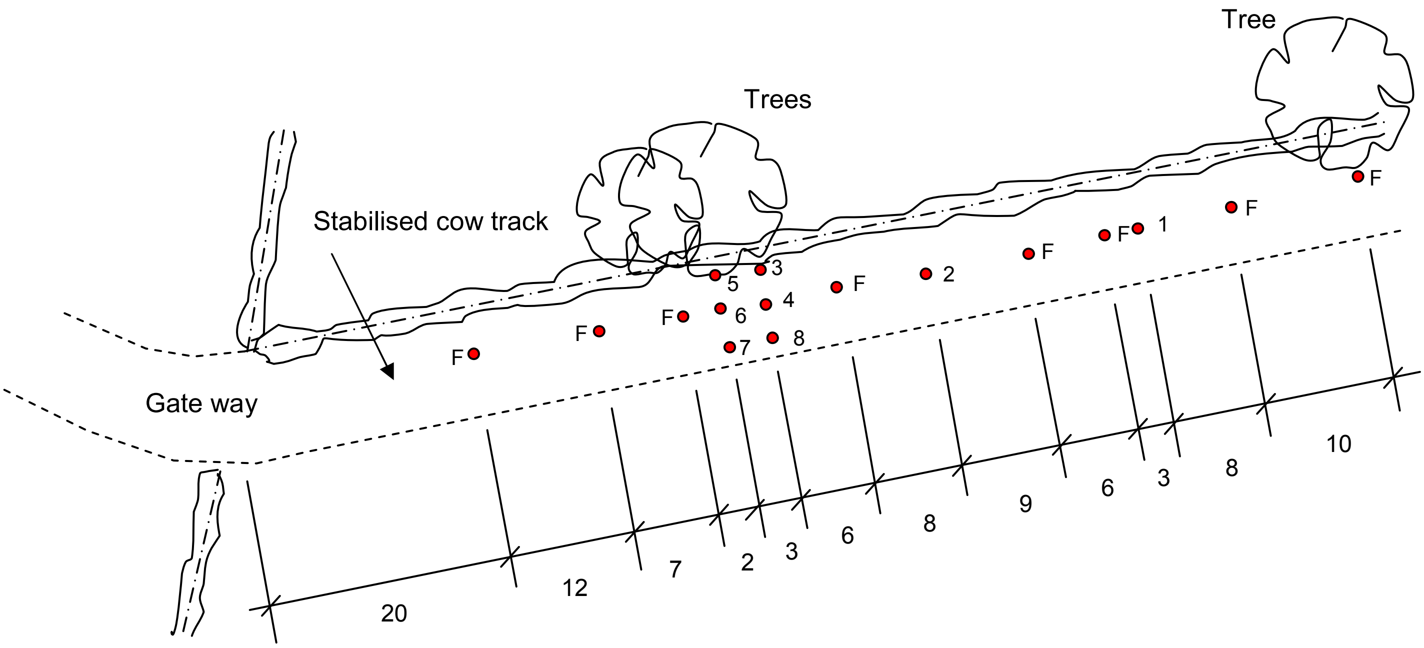


Not to scale



Approximate Location of Core Samples – Bridge Farm





F = Failed core

Dimensions are in metres

Figure 5. Coring at Warren Farm yard area

Figure 6. Coring equipment showing core removed

Figure 7. Core of stabilised soil material

Figure 8. Vacuum used to clean out core holes prior to reinstating with concrete mix

Figure 9. Cores taken from an area of yard containing a higher percentage of aggregate – Warren Farm

Figure 10. Example of core containing a higher percentage of aggregate

Figure 11. Bridge Farm - view along stabilised cow track before coring

Figure 12. Close-up of surface of stabilised cow track

Figure 13. Bridge Farm - coring the cow track

Figure 14. Bridge Farm - after core removed

7.0 RESULTS

Full details of triaxial permeability test results on the subsoil cores, as reported by Geo Test Laboratories, including sample dimensions, initial and final conditions (bulk density and moisture content at the start and end of testing) are presented in Appendix 1. Full test results for the site coring are presented in Appendix 2.

7.1 Subsoil mix laboratory tests

In addition to the main testing schedule outlined in Table 1, some additional tests were agreed after initial results were received. These further wet mix permeability tests were to cover the impact of additional water and remoulding of the mix in the absence of a specific compaction step. The aim was to achieve a moisture status that would facilitate compaction by vibratory plate, reflecting typical in-field practice. The sandy soil was chosen as likely to be the most challenging. Soil, cement and aggregate combinations were as follows:

(1) Cement addition - 0%;
(2) Cement addition - 5%;
(3) Cement addition - 10%;
(4) Cement addition - 15%;
(5) As for treatment 3, but with aggregate* at 50%, i.e. final mix 1 part by weight soil-cement mix: 1 part of aggregate;
(6) As for treatment 4, but with aggregate* at 50%, i.e. final mix 1 part by weight soil-cement mix: 1 part of aggregate;

* Note: aggregate in these tests graded approx. 0-10 mm, aiming to optimise impact on reducing permeability of the mix through variable particle size.

A summary of the key results from the soil mix permeability tests, including also the latter, wet mix tests, is presented in Table 2. Full details of the wet mix test results are presented in Appendix 3. Overall, permeability test results were disappointing, with only four sample mixes (out of a total of 38 mixes) attaining near to, or below, the minimum standard required (<1 x 10^{-9} m/second) for suitability for use in lagoon construction (Anon, 1991). These four sample mixes (highlighted in blue text) were all of the sandy soil, but only one of these included any cement addition (15% cement, light compaction). Neither did there appear to be any systematic difference between the results obtained for the sandy and chalk soil types. Moreover, with the results for the two soils plotted according to rate of cement addition (Figure 15), there appeared to be no discernible benefit of cement addition to resulting permeability; rather the contrary, with cement addition to the soil mix tending to increase the permeability of the final mix.

Moisture content of the mix might be anticipated to impact on the compactability and, hence, the permeability of the mix; however, there appeared to be only a very weak relationship, or general trend towards reducing permeability (see Figure 16) and that only for the chalk soil.

Whilst the use of the low and high weight compacter impacted on the bulk density of the resulting core (average 2.05 and 2.08 t/m^3, respectively), with an average decrease in permeability from the denser mix (average 20.53 x 10^{-9} m/sec compared to 8.03 x 10^{-9} m/sec), no overall systematic trend was apparent.

Table 2. Summary permeability test results for subsoil mixes

Soil	Cement addition	Packing[1]	Initial condition Bulk density	Initial condition Moisture content	Final condition Bulk density	Final condition Moisture content	Permeability
	%		t/m^3	%	t/m^3	%	m/sec x 10^{-9}
Chalk	0	L	2.03	20	2.02	20	4.7
Chalk	0	L	2.04	20	2.03	20	3.8
Chalk	0	H	2.08	21	2.05	19	3.3
Chalk	0	H	2.06	20	2.05	20	3.8
Chalk	5	L	2.07	20	2.10	19	12.0
Chalk	5	L	2.04	18	2.07	19	31.0
Chalk	5	H	2.07	18	2.09	20	7.9
Chalk	5	H	2.08	19	2.10	20	5.1
Chalk	10	L	2.06	17	2.09	19	5.3
Chalk	10	L	2.06	17	2.09	19	39.0
Chalk	10	H	2.09	17	2.12	19	2.3
Chalk	10	H	2.09	18	2.11	19	4.9
Chalk	15	L	2.02	16	2.09	20	18.0
Chalk	15	L	2.04	16	2.12	20	35.0
Chalk	15	H	2.09	16	2.12	17	6.9
Chalk	15	H	2.09	15	2.11	17	6.2
Sand	0	L	2.05	18	2.08	19	19.0
Sand	0	L	2.04	19	2.05	19	3.0
Sand	**0**	**H**	**2.08**	**18**	**2.07**	**17**	**1.1**
Sand	**0**	**H**	**2.08**	**18**	**2.07**	**18**	**1.2**
Sand	5	L	2.06	16	2.10	18	11.0
Sand	5	L	2.05	16	2.09	18	47.0
Sand	5	H	2.08	16	2.12	18	20.0
Sand	5	H	2.09	16	2.11	17	11.0
Sand	10	L	2.09	14	2.12	16	16.0
Sand	10	L	2.08	14	2.12	16	66.0
Sand	10	H	2.10	15	2.13	16	4.6
Sand	10	H	2.09	14	2.12	16	9.0
Sand	15	L	2.06	13	2.12	16	16.0
Sand	**15**	**L**	**2.07**	**13**	**2.10**	**15**	**1.6**
Sand	15	H	2.08	13	2.12	16	2.2
Sand	15	H	2.09	13	2.14	15	39.0
Sand	**0**	**W**	**1.94**	**22**	**1.92**	**20**	**0.98**
Sand	5	W	1.93	24	1.96	26	13.00
Sand	10	W	1.95	22	1.99	25	62.00
Sand	15	W	1.97	21	2.01	23	30.00
Sand	10 + Ag[2]	W	2.18	12 (24)[3]	2.22	13 (26)[3]	10.00
Sand	15 + Ag[2]	W	2.16	9.9 (20)[3]	2.20	12 (24)[3]	80.00

Notes:

[1] – L = light (2.5kg) rammer; H = heavy (4.5kg) rammer; W = wet mix (no compaction).
[2] – Ag = soil-cement mix with 50% 0-10mm aggregate added.
[3] – ( ) moisture content of sample reduced by presence of aggregate; estimated likely moisture of soil-cement matrix given in brackets for reference.

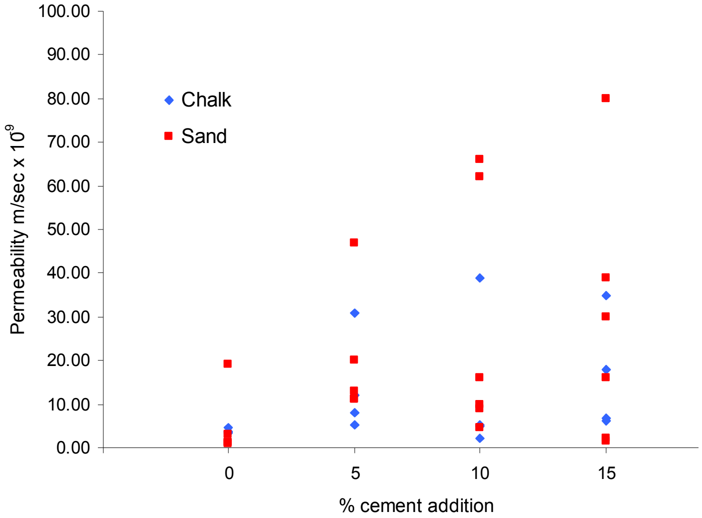


Figure 15. Soil permeability test results and rate of cement addition

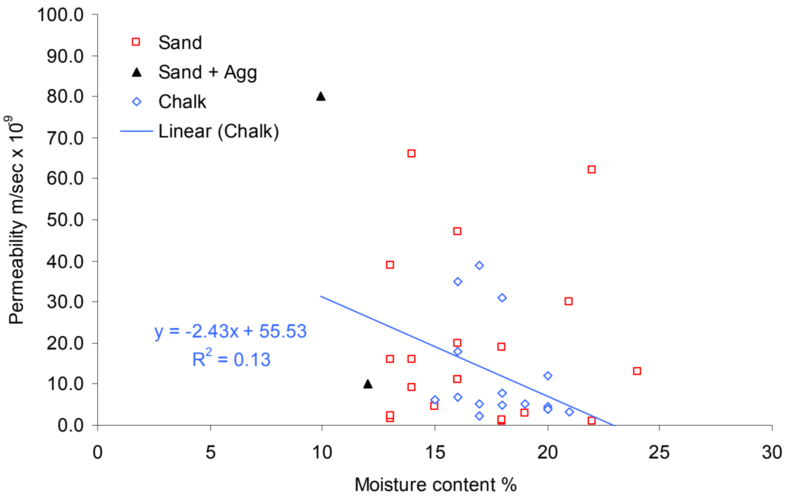


Figure 16. Soil permeability test results and initial moisture content of mix.

7.2 Laboratory tests on core samples

A summary of the key results from the on-site core sample permeability tests are presented in Table 3, below. Again the test results were disappointing, in this case, with no core tests achieving the CIRIA minimum standard for permeability.

The Kingshay cow track appeared to be rather, a stabilized layer of soil, than a consolidated/compacted layer (Figures 11-14), so the high permeability recorded with those cores was not unexpected (Table 3). However, cores taken from the Goldings yard, Warren Farm (Figures 5 – 10), also gave disappointing results from the permeability tests. In this case, the soil-cement-aggregate mix (Figure 10) would have been laid according to best operating procedures and would have included the wet mix approach, which might be expected to give best results.

Table 3. Summary permeability test results for cored samples

Site (date)	Site ref	Material	Initial condition Bulk density t/m^3	Initial condition Moisture content %	Final condition Bulk density t/m^3	Final condition Moisture content %	Permeability m/sec x 10^{-9}
Kingshay (28/04/09)	Core 1	S-Z clay	1.76	28	1.81	32	650
	Core 3	S-Z clay	1.74	34	1.79	37	120
	Core 5	S-Z clay	1.77	36	1.78	38	73
	Core 7a	S-Z clay	1.78	34	1.82	37	110
	Core 7b	S-Z clay	1.79	37	1.82	39	58
Warren Farm (27/04/09)	Core 1	Cem-gran[1]	2.09	12	2.13	14	53
	Core 3	Cem-gran[1]	2.14	11	2.17	13	19
	Core 5	Cem-gran[1]	2.21	10	2.24	12	3.6
	Core 6	Cem-gran[1]	2.17	12	2.20	13	6.0
	Core 7	Cem-gran[1]	2.00	14	2.04	17	150

Note:

[1] cement bound granular material.

8.0 DISCUSSION AND CONCLUSIONS

The process of soil stabilisation, using a small proportion of cement, has been successful in the production of durable and stable farm tracks and yards. The primary reason for cement stabilisation of soils for roads and hard standings is to improve the strength of the soil so that the thickness of any surfacing can be minimised and, for un-surfaced tracks and areas, to reduce rutting by wheeled plant and poaching by cattle, particularly after periods of heavy rain. There is no pre-requisite for the design of soil stabilisation for farm tracks and yards to produce a low permeability material and, consequently, there are no published data regarding the permeability of cement stabilized soils although, anecdotally, hardstandings used for composting were understood to have been tested to an acceptable level of permeability.

It was anticipated that this process would allow the production of a stable base layer for slurry storage lagoons which would conform to the minimum standards required for permeability testing under the SSAFO regulations. However, the results have proved disappointing across a range of cement-soil mixes, even following the addition of water and remoulding along the lines of current field practice for construction of farm tracks or yards. In fact, the addition of cement to the sandy and chalk soils used in these studies appears to have increased both the level and variability in permeability of the resulting mix. Moreover, cores taken from sites where tracks or yards had been laid using the Road Reclamation good practice, also generated poor results in terms of permeability test data.

Whilst it is clear that the addition of cement to a suitable subsoil, especially with aggregate material, will impart hardness and stability to the resulting mix on setting, it also seems possible that a degree of brittleness also results, which may give rise to the development of fine cracks and, hence, an increase in the permeability of the matrix (C Eccles, Terra Consult, personal communication). By adding more cement, greater strength may be achieved but, also, an increase in brittleness which may lead to more micro-cracking and an increase in permeability and its variability. For a farm track or yard area, a minor percolation of water may be considered of no importance or even desirable, however, would not be acceptable for slurry storage within current regulations. In practice, such micro cracks would almost certainly self-seal quite effectively with fine slurry particles (Withers *et al*., 1998), but this would not be considered acceptable within the existing guidelines and regulations.

Although the results of these controlled tests on the technique for slurry storage have proved negative, the approach is attractive in terms of speed, efficiency and apparent potential for application on difficult soils, where but for importation of large volumes of clay, lagoon storage structures would be precluded. Techniques involving the use of concrete, lime, cement and bentonite mixes or bentonite enriched sand (BES) have been successfully developed by civil engineers in other industries against more stringent safety standards (e.g. for waste: conventional landfill and nuclear waste repositories; water retaining systems: groundwater cut-off walls, lining ponds and lagoons etc).

It is therefore recommended that alternative approaches are reviewed, based around the use of small proportions of lime and bentonite, with/without cement. If, in consultation with relevant civil engineering experience, significant potential can be identified for modified mixes, it is proposed that further scoping tests are undertaken to evaluate the approach with subsoils (chalky, sandy, or stony) considered unsuitable for conventional lagoon construction. Based on the results of the current study, the process cannot be recommended for application in lagoon construction until some suitable refinement or addition to the stabilisation process can be identified and proven to deliver the required low levels of permeability.

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Triaxial Permeability

BS 1377: 1990: Part 6, Method 6

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APPENDIX 1 – PERMEABILITY TEST RESULTS FOR SUBSOILS

Client: **ADAS**

Contract: **Stabilisation Trials**

Site Ref	Sample No	Sample Dimensions		Initial Conditions			Final Conditions			Saturation B Value %	Consolidation Effective (kPa)	Permeability			
		Length (mm)	Diameter (mm)	Bulk Density (Mg/m^3)	Dry Density (Mg/m^3)	Moisture Content (%)	Bulk Density (Mg/m^3)	Dry Density (Mg/m^3)	Moisture Content (%)			Mean Effective (kPa)	Hydraulic Gradient (kPa)	Permeability (K m/sec)	Permeability (Kv m/sec)
0%	0%	101.0	100.0	2.03	1.69	20	2.02	1.69	20	0.95	50	50	20	4.7×10^{-9}	4.7×10^{-9}
Description of Material		CHALK 0% cement 2.5kg rammer													
0%	0%	100.6	100.0	2.04	1.70	20	2.03	1.70	20	0.96	50	50	20	3.8×10^{-9}	3.8×10^{-9}
Description of Material		CHALK 0% cement 2.5kg rammer													
0%	0%	100.3	99.6	2.08	1.72	21	2.05	1.72	19	0.95	50	50	20	3.3×10^{-9}	3.3×10^{-9}
Description of Material		CHALK 0% cement 4.5kg rammer													
0%	0%	100.0	99.6	2.06	1.72	20	2.05	1.72	20	0.97	50	50	20	3.8×10^{-9}	3.8×10^{-9}
Description of Material		CHALK 0% cement 4.5kg rammer													

NOTES: *~~Undisturbed~~/Remoulded (2.5kg/4.5kg Rammer)

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Triaxial Permeability

BS 1377: 1990: Part 6, Method 6

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Client: **ADAS**

Contract: **Stabilisation Trials**

Site Ref	Sample No	Sample Dimensions		Initial Conditions			Final Conditions			Saturation B Value %	Consolidation Effective (kPa)	Permeability			
		Length (mm)	Diameter (mm)	Bulk Density (Mg/m^3)	Dry Density (Mg/m^3)	Moisture Content (%)	Bulk Density (Mg/m^3)	Dry Density (Mg/m^3)	Moisture Content (%)			Mean Effective (kPa)	Hydraulic Gradient (kPa)	Permeability (K m/sec)	Permeability (Kv m/sec)
5%	5%	100.6	99.0	2.07	1.73	20	2.10	1.73	19	0.94	50	50	20	1.2×10^{-8}	1.2×10^{-8}
Description of Material		CHALK 5% cement 2.5kg rammer													
5%	5%	100.7	100.4	2.04	1.73	18	2.07	1.73	19	0.91	50	50	20	3.1×10^{-8}	3.1×10^{-8}
Description of Material		CHALK 5% cement 2.5kg rammer													
5%	5%	101.0	100.0	2.07	1.75	18	2.09	1.75	20	0.96	50	50	20	7.9×10^{-9}	7.9×10^{-9}
Description of Material		CHALK 5% cement 4.5kg rammer													
5%	5%	100.5	99.6	2.08	1.75	19	2.10	1.75	20	0.91	50	50	20	5.1×10^{-9}	5.1×10^{-9}
Description of Material		CHALK 5% cement 4.5kg rammer													

NOTES: *~~Undisturbed~~/Remoulded (2.5kg/4.5kg Rammer)

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UKAS TESTING 4071

Triaxial Permeability

BS 1377: 1990: Part 6, Method 6

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Client: **ADAS**

Contract: **Stabilisation Trials**

Site Ref	Sample No	Sample Dimensions		Initial Conditions			Final Conditions			Saturation B Value %	Consolidation Effective (kPa)	Permeability			
		Length (mm)	Diameter (mm)	Bulk Density (Mg/m^3)	Dry Density (Mg/m^3)	Moisture Content (%)	Bulk Density (Mg/m^3)	Dry Density (Mg/m^3)	Moisture Content (%)			Mean Effective (kPa)	Hydraulic Gradient (kPa)	Permeability (K m/sec)	Permeability (Kv m/sec)
10%	10%	100.6	99.2	2.06	1.76	17	2.09	1.76	19	0.97	50	50	20	5.3×10^{-9}	5.3×10^{-9}
Description of Material		CHALK 10% cement 2.5kg rammer													
10%	10%	100.6	99.8	2.06	1.77	17	2.09	1.77	19	0.92	50	50	20	3.9×10^{-8}	3.9×10^{-8}
Description of Material		CHALK 10% cement 2.5kg rammer													
10%	10%	100.7	99.8	2.09	1.79	17	2.12	1.79	19	0.97	50	50	20	2.3×10^{-9}	2.3×10^{-9}
Description of Material		CHALK 10% cement 4.5kg rammer													
10%	10%	100.0	100.0	2.09	1.77	18	2.11	1.77	19	0.91	50	50	20	4.9×10^{-9}	4.9×10^{-9}
Description of Material		CHALK 10% cement 4.5kg rammer													

NOTES: *~~Undisturbed~~/Remoulded (2.5kg/4.5kg Rammer)

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Triaxial Permeability

BS 1377: 1990: Part 6, Method 6

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Client: **ADAS**

Contract: **Stabilisation Trials**

Site Ref	Sample No	Sample Dimensions		Initial Conditions			Final Conditions			Saturation B Value %	Consolidation Effective (kPa)	Permeability			
		Length (mm)	Diameter (mm)	Bulk Density (Mg/m^3)	Dry Density (Mg/m^3)	Moisture Content (%)	Bulk Density (Mg/m^3)	Dry Density (Mg/m^3)	Moisture Content (%)			Mean Effective (kPa)	Hydraulic Gradient (kPa)	Permeability (K m/sec)	Permeability (Kv m/sec)
15%	15%	101.0	99.0	2.02	1.75	16	2.09	1.75	20	0.97	50	50	20	1.8×10^{-8}	1.8×10^{-8}
Description of Material		CHALK 15% cement 2.5kg rammer													
15%	15%	100.6	100.0	2.04	1.77	16	2.12	1.77	20	0.92	50	50	20	3.5×10^{-8}	3.5×10^{-8}
Description of Material		CHALK 15% cement 2.5kg rammer													
15%	15%	101.0	100.4	2.09	1.81	16	2.12	1.81	17	0.92	50	50	20	6.9×10^{-9}	6.9×10^{-9}
Description of Material		CHALK 15% cement 4.5kg rammer													
15%	15%	101.0	101.6	2.09	1.81	15	2.11	1.81	17	0.98	50	50	20	6.2×10^{-9}	6.2×10^{-9}
Description of Material		CHALK 15% cement 4.5kg rammer													

NOTES: *~~Undisturbed~~/Remoulded (2.5kg/4.5kg Rammer)

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Triaxial Permeability

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Client: **ADAS**

Contract: **Stabilisation Trials**

Site Ref	Sample No	Sample Dimensions		Initial Conditions			Final Conditions			Saturation B Value %	Consolidation Effective (kPa)	Permeability			
		Length (mm)	Diameter (mm)	Bulk Density (Mg/m^3)	Dry Density (Mg/m^3)	Moisture Content (%)	Bulk Density (Mg/m^3)	Dry Density (Mg/m^3)	Moisture Content (%)			Mean Effective (kPa)	Hydraulic Gradient (kPa)	Permeability (K m/sec)	Permeability (Kv m/sec)
0%	0%	99.8	99.6	2.05	1.74	18	2.08	1.74	19	0.95	50	50	20	1.9×10^{-8}	1.9×10^{-8}
Description of Material		SAND 0% cement 2.5kg rammer													
0%	0%	99.0	100.0	2.04	1.72	19	2.05	1.72	19	100	50	50	20	3.0×10^{-9}	3.0×10^{-9}
Description of Material		SAND 0% cement 2.5kg rammer													
0%	0%	100.7	99.6	2.08	1.76	18	2.07	1.76	17	100	50	50	20	1.1×10^{-9}	1.1×10^{-9}
Description of Material		SAND 0% cement 4.5kg rammer													
0%	0%	100.0	99.6	2.08	1.76	18	2.07	1.76	18	0.95	50	50	20	1.2×10^{-9}	1.2×10^{-9}
Description of Material		SAND 0% cement 4.5kg rammer													

NOTES: *~~Undisturbed~~/Remoulded (2.5kg/4.5kg Rammer)

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Triaxial Permeability

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Client: **ADAS**

Contract: **Stabilisation Trials**

Site Ref	Sample No	Sample Dimensions		Initial Conditions			Final Conditions			Saturation B Value %	Consolidation Effective (kPa)	Permeability			
		Length (mm)	Diameter (mm)	Bulk Density (Mg/m^3)	Dry Density (Mg/m^3)	Moisture Content (%)	Bulk Density (Mg/m^3)	Dry Density (Mg/m^3)	Moisture Content (%)			Mean Effective (kPa)	Hydraulic Gradient (kPa)	Permeability (K m/sec)	Permeability (Kv m/sec)
5%	5%	100.0	99.4	2.06	1.78	16	2.10	1.78	18	0.97	50	50	20	1.1×10^{-8}	1.1×10^{-8}
Description of Material		SAND 5% cement 2.5kg rammer													
5%	5%	101.3	100.0	2.05	1.77	16	2.09	1.77	18	0.97	50	50	20	4.7×10^{-8}	4.7×10^{-8}
Description of Material		SAND 5% cement 2.5kg rammer													
5%	5%	100.0	100.0	2.08	1.80	16	2.12	1.80	18	0.94	50	50	20	2.0×10^{-8}	2.0×10^{-8}
Description of Material		SAND 5% cement 4.5kg rammer													
5%	5%	100.2	100.0	2.09	1.80	16	2.11	1.80	17	0.93	50	50	20	1.1×10^{-8}	1.1×10^{-8}
Description of Material		SAND 5% cement 4.5kg rammer													

NOTES: *~~Undisturbed~~/Remoulded (2.5kg/4.5kg Rammer)

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Triaxial Permeability

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Client: **ADAS**

Contract: **Stabilisation Trials**

Site Ref	Sample No	Sample Dimensions		Initial Conditions			Final Conditions			Saturation B Value %	Consolidation Effective (kPa)	Permeability			
		Length (mm)	Diameter (mm)	Bulk Density (Mg/m^3)	Dry Density (Mg/m^3)	Moisture Content (%)	Bulk Density (Mg/m^3)	Dry Density (Mg/m^3)	Moisture Content (%)			Mean Effective (kPa)	Hydraulic Gradient (kPa)	Permeability (K m/sec)	Permeability (Kv m/sec)
10%	10%	100.5	99.6	2.09	1.83	14	2.12	1.83	16	0.98	50	50	20	1.6×10^{-8}	1.6×10^{-8}
Description of Material		SAND 10% cement 2.5kg rammer													
10%	10%	100.0	100.0	2.08	1.82	14	2.12	1.82	16	0.91	50	50	20	6.6×10^{-8}	6.6×10^{-8}
Description of Material		SAND 10% cement 2.5kg rammer													
10%	10%	100.6	100.0	2.10	1.83	15	2.13	1.83	16	0.97	50	50	20	4.6×10^{-9}	4.6×10^{-9}
Description of Material		SAND 10% cement 4.5kg rammer													
10%	10%	101.7	100.0	2.09	1.83	14	2.12	1.83	16	0.93	50	50	20	9.0×10^{-9}	9.0×10^{-9}
Description of Material		SAND 10% cement 4.5kg rammer													

NOTES: *~~Undisturbed~~/Remoulded (2.5kg/4.5kg Rammer)

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Triaxial Permeability

BS 1377: 1990: Part 6, Method 6

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Client: **ADAS**

Contract: **Stabilisation Trials**

Site Ref	Sample No	Sample Dimensions		Initial Conditions			Final Conditions			Saturation B Value %	Consolidation Effective (kPa)	Permeability			
		Length (mm)	Diameter (mm)	Bulk Density (Mg/m^3)	Dry Density (Mg/m^3)	Moisture Content (%)	Bulk Density (Mg/m^3)	Dry Density (Mg/m^3)	Moisture Content (%)			Mean Effective (kPa)	Hydraulic Gradient (kPa)	Permeability (K m/sec)	Permeability (Kv m/sec)
15%	15%	100.6	99.8	2.06	1.83	13	2.12	1.83	16	0.97	50	50	20	1.6×10^{-8}	1.6×10^{-8}
Description of Material		SAND 15% cement 2.5kg rammer													
15%	15%	101.0	100.0	2.07	1.83	13	2.10	1.83	15	100	50	50	20	1.6×10^{-9}	1.6×10^{-9}
Description of Material		SAND 15% cement 2.5kg rammer													
15%	15%	100.4	100.4	2.08	1.84	13	2.12	1.84	16	0.97	50	50	20	2.2×10^{-9}	2.2×10^{-9}
Description of Material		SAND 15% cement 4.5kg rammer													
15%	15%	100.2	99.6	2.09	1.85	13	2.14	1.85	15	0.95	50	50	20	3.9×10^{-8}	3.9×10^{-8}
Description of Material		SAND 15% cement 4.5kg rammer													

NOTES: *~~Undisturbed~~/Remoulded (2.5kg/4.5kg Rammer)

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Triaxial Permeability

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APPENDIX 2 – PERMEABILITY TEST RESULTS FOR CORED SAMPLES

Client: **ADAS**

Contract: **Kingshay**

Site Ref	Sample No	Sample Dimensions		Initial Conditions			Final Conditions			Saturation B Value %	Consolidation Effective (kPa)	Permeability			
		Length (mm)	Diameter (mm)	Bulk Density (Mg/m^3)	Dry Density (Mg/m^3)	Moisture Content (%)	Bulk Density (Mg/m^3)	Dry Density (Mg/m^3)	Moisture Content (%)			Mean Effective (kPa)	Hydraulic Gradient (kPa)	Permeability (K m/sec)	Permeability (Kv m/sec)
Core 1	12026	100.7	99.7	1.76	1.37	28	1.81	1.37	32	0.91	50	50	20	6.5×10^{-7}	6.5×10^{-7}
Description of Material		Light brown friable sandy silty CLAY with occasional rootlets and fine gravel													
Core 3	12028	101.0	99.5	1.74	1.30	34	1.79	1.30	37	0..93	50	50	20	1.2×10^{-7}	1.2×10^{-7}
Description of Material		Light brown friable sandy/silty CLAY													
Core 5	12030	101.0	99.9	1.77	1.30	36	1.78	1.30	38	0.96	50	50	20	7.3×10^{-8}	7.3×10^{-8}
Description of Material		Light brown friable sandy/silty CLAY													
Core 7a	12032a	101.1	99.0	1.78	1.32	34	1.82	1.32	37	0.93	50	50	20	1.1×10^{-7}	1.1×10^{-7}
Description of Material		Light brown friable sandy/silty CLAY													
Core 7b	12032b	100.8	99.1	1.79	1.31	37	1.82	1.31	39	0.92	50	50	20	5.8×10^{-8}	5.8×10^{-8}
Description of Material		Light brown friable sandy/silty CLAY													

NOTES: *Undisturbed/~~Remoulded (2.5kg/4.5kg Rammer)~~

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Triaxial Permeability

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Client: **ADAS**

Contract: **Goldings**

Site Ref	Sample No	Sample Dimensions		Initial Conditions			Final Conditions			Saturation B Value %	Consolidation Effective (kPa)	Permeability			
		Length (mm)	Diameter (mm)	Bulk Density (Mg/m^3)	Dry Density (Mg/m^3)	Moisture Content (%)	Bulk Density (Mg/m^3)	Dry Density (Mg/m^3)	Moisture Content (%)			Mean Effective (kPa)	Hydraulic Gradient (kPa)	Permeability (K m/sec)	Permeability (Kv m/sec)
Core 1	12038	103.6	97.9	2.09	1.87	12	2.13	1.87	14	0.97	50	50	20	5.3×10^{-8}	5.3×10^{-8}
Description of Material		Cement bound Granular material													
Core 3	12040	100.2	98.1	2.14	1.93	11	2.17	1.93	13	0.91	50	50	20	1.9×10^{-8}	1.9×10^{-8}
Description of Material		Cement bound Granular material													
Core 5	12042	100.3	98.2	2.21	2.01	10	2.24	2.01	12	0.92	50	50	20	3.6×10^{-9}	3.6×10^{-9}
Description of Material		Cement bound Granular material													
Core 6	12043	99.8	98.0	2.17	1.94	12	2.20	1.94	13	0.97	50	50	20	6.0×10^{-9}	6.0×10^{-9}
Description of Material		Cement bound Granular material													
Core 7	12044	99.1	98.3	2.0	1.75	14	2.04	1.75	17	0.97	50	50	20	1.5×10^{-7}	1.5×10^{-7}
Description of Material		Cement bound Granular material													

NOTES: *Undisturbed/~~Remoulded (2.5kg/4.5kg Rammer)~~

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Triaxial Permeability
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APPENDIX 3 – PERMEABILITY TEST RESULTS FOR WET-MIX SAMPLES

Client: **ADAS**

Contract: **Stabilisation Trials**

Mix Ref	Sample No	Sample Dimensions		Initial Conditions			Final Conditions			Saturation B Value %	Consolidation Effective (kPa)	Permeability			
		Length (mm)	Diameter (mm)	Bulk Density (Mg/m^3)	Dry Density (Mg/m^3)	Moisture Content (%)	Bulk Density (Mg/m^3)	Dry Density (Mg/m^3)	Moisture Content (%)			Mean Effective (kPa)	Hydraulic Gradient (kPa)	Permeability (K m/sec)	Permeability (Kv m/sec)
1	N/A	98.0	101.2	1.94	1.59	22	1.92	1.59	20	0.90	50	50	20	9.8×10^{-10}	9.8×10^{-10}
Description of Material		Silty SAND 0% cement increased moisture Content													
2	N/A	100.3	101.0	1.93	1.55	24	1.96	1.55	26	100	50	50	20	1.3×10^{-8}	1.3×10^{-8}
Description of Material		Silty SAND 5% cement increased moisture content													
3	N/A	100.0	101.0	1.95	1.59	22	1.99	1.59	25	0.90	50	50	20	6.2×10^{-8}	6.2×10^{-8}
Description of Material		Silty SAND 10% cement increased moisture content													
4	N/A	100.0	101.0	1.97	1.63	21	2.01	1.63	23	0.96	50	50	20	3.0×10^{-8}	3.0×10^{-8}
Description of Material		Silty SAND 15% cement increased moisture content													
5	N/A	100.0	101.6	2.18	1.96	12	2.22	1.96	13	1.00	50	50	20	1.0×10^{-8}	1.0×10^{-8}
Description of Material		Silty SAND 10% cement 50% 0-10mm aggregate													
6	N/A	100.3	99.8	2.16	1.96	9.9	2.20	1.96	12	0.99	50	50	20	8.0×10^{-8}	8.0×10^{-8}
Description of Material		Silty SAND 15% cement 50% 0-10mm aggregate													

NOTES: *~~Undisturbed~~/Remoulded

Delete as appropriate

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Report No: **GT/09/007/15819**

Appendix Sheet No: **TXP1**

Form No **TXP/R/0606**

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