Research for Community Access Partnership

Ground Improvement for Khulna Soft Clay Soil

Inception Report

Mott MacDonald Ltd.

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A typical rural road in Bangladesh: (source unknown)

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Abstract

This Inception Report maps out the format and course that the project on *Ground Improvement for Khulna Soft Clay Soil* will take. In this report, the sources of information studied for the literature review are presented and appraised. The geology of Bangladesh and more specifically Khulna region is examined and identified. Typical ground conditions are presented for the soft soil(s) of Khulna Region. The impact of soft ground on infrastructure assets is assessed. The purpose of ground treatment is defined and ground treatment techniques employed around the world, in Bangladesh and in Khulna Region are examined and discussed. Ground improvement trials undertaken in Bangladesh and Khulna Region are identified and assessed. The report presents four initial ground improvement techniques that are considered both financially viable and practicable in application for the rural roads of Khulna Region. Sites of rural road infrastructure in Khulna Region (and other areas) suitable for further investigation and study are identified. These sites are to be appraised using a list of assessment criteria and reduced to a finalised list of locations deemed suitable for detailed assessment. All identified sites will be subject to site walkover surveys and further non-intrusive investigation and laboratory testing for those on the *finalised* site list.

Key words

Bangladesh, Khulna, Rural roads, Soft Clays, Organic Soil, Earthworks, Settlement, embankment failure, Ground Improvement, Infrastructure research, Transport services research)

RESEARCH FOR COMMUNITY ACCESS PARTNERSHIP (ReCAP)

Safe and sustainable transport for rural communities

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Acronyms, Units and Currencies

$	United States Dollar (US$ 1.00 ≈ provide conversion to local currencies)
ADB	Asian Development Bank
AFCAP	Africa Community Access Partnership
ASCAP	Asia Community Access Partnership
GPS	Global positioning system
RECAP	Research for Community Access Partnership
UK	United Kingdom (of Great Britain and Northern Ireland)
UKAid	United Kingdom Aid (Department for International Development, UK)
MM	Mott MacDonald
LGED	Local Government Engineering Department
ToR	Terms of Reference

Contents

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1 Executive summary

This Inception Report maps out the format and the course that the project on *Ground Improvement for Khulna Soft Clay Soil* will take. The Inception Report is the first of seven key milestones in the delivery of the project:

1. Inception Report and Literature Review;
2. Field Situation Analysis Report;
3. Field and Laboratory Testing;
4. Laboratory Test Report;
5. Draft Report;
6. Stakeholder Workshop;
7. Final Report.

In this report, the sources of information gathered and studied for the literature review are presented and their content appraised. The wider geology of Bangladesh is examined and identified with the focus then narrowing on the project study area of the Khulna region. Typical high-level geotechnical parameters are presented for the soft soil ground conditions that impact construction and infrastructure in the Khulna Region; the negative impact of soft ground on such assets being assessed in detail.

The purpose of ground treatment is defined and ground treatment techniques employed around the world are examined and discussed, before the focus shifts to the limited range of ground improvement techniques that are currently available and employed in Bangladesh and more specifically in the Khulna Region. Field and laboratory based ground improvement trials that have been undertaken in Bangladesh and Khulna Region are identified and assessed. The Report presents four initial ground improvement techniques that are considered more suitable than other options. Based on the literature review and knowledge of the techniques, these are considered both financially viable and practicable in application for the rural roads of Khulna Region. It is anticipated that these four preferred methods will be further assessed and developed based on the outcomes and information gathered from the field and laboratory testing stages.

Sites of rural road infrastructure in Khulna Region (and other areas) suitable for further investigation and study are identified in the Report. These sites are to be appraised using a list of assessment criteria and reduced to a finalised site list of locations deemed suitable for detailed assessment. All identified sites will be subject to site walkover surveys and further non-intrusive investigation and laboratory testing for those on the *finalised* site list.

2 Background

2.1 Context

There are major concerns for the resilience of rural road embankments exposed to an aggressive coastal environment, in areas of high flood risk and where embankments are often constructed on soft soil deposits with high compressible organic content. It is noted that the severity of the problem, where road embankments and structures can experience settlement failures relatively early in their lifespan; and the scale of the problem, with over 4500km of village roads; 800km of upazila roads, and 475km of union roads –combine to provide a context where the right interventions can have a high impact.

There is a large body of existing research, including the three projects mentioned in section 1.3 of the Terms of Reference; some research, such as geological and hydrological studies, that are specific to the Khulna region; and further international studies, research projects, and innovative engineering projects that have addressed the issues of durability, settlement and seismic behaviour for infrastructure founded on soft and compressible soils.

This study intends to collate the relevant findings from this existing research, to understand the effectiveness and limitations of existing ground improvement techniques implemented in Khulna region, and to develop appropriate recommendations to overcome the typical construction challenges for road embankments and structures in Khulna region. Furthermore, based on our experience of working closely with LGED, we recognise that the key to a successful and useful research project will be the ability to coherently adapt and communicate these experiences for effective implementation by LGED engineers.

2.2 Failure mechanisms for soft soil

Whilst the failure mechanisms operating on structures and highways embankments in Khulna region will be fully ascertained through the inception, research and site survey phases of the project, common failure mechanisms include:

- Settlement of earthworks:
    - Resultant from the application of load onto the underlying soft soils with associated consolidation of the soil horizons below;
    - Not necessarily problematic, unless the movement causes other issues with serviceability or associated structures and drainage.

- Failure of earthworks;
    - Where soft soils are present, this can result from rapid construction of the embankment, overstressing the soil and leading to undrained bearing failure;
    - A longer (or staged) construction programme allows the soft soil to consolidate (and strengthen). Settlement still occurs, but without the disruption of rapid failure.

- Differential movement between earthworks and structures;
    - Where the approach earthwork to a bridge settles more than the bridge itself (the bridge may be piled), the differential movement between the two structures can be problematic for a number of reasons;
        - The movement may cause a ramp to develop between the earthwork and structure, which may be dangerous to road users;

  - ➢ The settlement of the earthwork and consolidation of the underlying soils may lead to significant additional loads being applied to the bridge foundations, potentially leading to structural failure.

- Differential movement of bridge abutments and piers;
  - If the abutments and piers of a bridge are subject to movement either as a result of inadequate foundation support, possibly resulting from additional loading (negative skin friction / lateral loading) from adjacent earthworks, the bridge sub-structure and superstructure can suffer significant damage leading to serviceability problems and potentially failure;

- Culverts dragged down by earthworks;
  - A culvert through an earthwork provides a conduit for water to safely pass from one side to the other. If, as a result of settlement of an earthwork, the culvert alignment is lost this may lead to reduced capacity or even blockage as the inlet and outlet drop below design levels.

- Creep settlement of organic materials;
  - Under load, organic soils such as peat consolidate for extended periods. This secondary compression or creep settlement, can affect the earthwork or structure throughout its life causing significant maintenance issues.

3 Research objectives

The specific objective of this project identified in the ToR is '*to establish a cost effective ground improvement technique(s) which will be applicable in Khulna and other similar regions which have soft soils*' and this is to be supported by improvements to understanding in the following particular technical research area:

- The characteristics of the soil in the Khulna Region;
- The existing level of knowledge related to these soils;
- Identification of the current status of the structures in the Khulna Region and identify factors that are causing deterioration;
- The spatial differences for the deterioration and the possible reasons behind such differences;
- Recommendations of the remedial measures to existing structures and guidelines for ground improvements for the construction of new rural roads in the study region.

4 Methodology

4.1 Inception

On award of the contract Mott MacDonald mobilised their team under the leadership of the Team Leader Ian Duncan, with part of the team based in Bangladesh and the remainder in the UK. The international experts bring knowledge and experience in designing, specifying and investigating earthworks and structures in a range of soft ground conditions. The local experts combine a wealth of academic and research professionals with engineers experienced in testing and supervising work, and with particular knowledge of the ground conditions that represent such a challenge to the local infrastructure development in Khulna.

A plan has been developed to deliver the Project within a year of the award of contract and involves the following key stages:

1. Inception Report and Literature Review;
2. Field Situation Analysis, including some diagnostic field tests;
3. Field and laboratory testing;
4. Laboratory Test Report;
5. Draft Report;
6. Stakeholder Workshop;
7. Final Report;

The following initial tasks have been undertaken as part of the inception phase:

- Client launch meeting and presentation;
- Initial stakeholder meetings (see Table 4.1);
- Review of publications and academic research on the geology of the Khulna Region;
- Review of work undertaken so far to investigate the impact of soft ground on the structures in Khulna regions and elsewhere in Bangladesh under similar settings);
- Review of the different types of ground treatment methods available worldwide and those that have been used in Khulna Region;
- Review of the structures and locations available for inspection and investigation and identification of preferred structures for testing and further investigation;

The progress and forward planning for each stage of the project is summarised in the following Sections, in accordance with the work schedule outlined in Appendix C.

Table 4.1: List of Stakeholder meetings

Meeting	Key Attendees	Notes
Start-up meeting (09-08-16)	Md. Abul Bashar (LGED superintending engineer) Md. Shahidul Haque (LGED superintending engineer) Md. Abul Kalam Azad (LGED Additional Chief Engineer (Implementation) Les Sampson (ReCAP/Cardno) Chandra Shrestha (ReCAP / Cardno)	Ian Duncan presented the project proposal to the assembled LGED members
Blue Gold Program (10-08-16)	Mofazzal Ahmed (Deputy Component Leader)	Useful notes gained on construction methods and constraints, maintenance and typical ground improvement methods that are implemented
Follow-up meeting with LGED + laboratory visit (11-08-16)	Md. Abul Bashar (LGED superintending engineer) + LGED design team	Discussed various issues: - • Current practice for embankment construction and remediation • Typical form of contract • Ground investigation capability • Construction plant and staffing • Availability of data sources such as GIS, geological maps
Follow-up meeting with LGED (18-08-16)	Tapas Chowdhury, Senior Assistant Engineer, Design Unit + LGED Design Team	Discussed various issues: - • Current practice for asset management • LGED experience in soft ground + design methodology • LGED owned plant and GI equipment • Sites for initial assessment

4.2 Literature Review

To undertake the literature review for this engineering research study, Mott MacDonald has looked at internal projects and publications as well as searching for information on relevant studies and examples of best practice from around the globe. The literature search has of course particularly focussed on studies and works undertaken in the Khulna Region of Bangladesh and Bangladesh as a whole.

The sources for the literature review are varied and include:

- Engineering journals from around the globe (for example the Bangladesh Journal of Geology).
- Khulna University of Engineering and Technology
- Dhaka University of Information Technology and Sciences.
- University of Strathclyde.
- International conference submittals and presentations
- Published guidance and standards of international governments and governmental bodies.
- Publications from international regulatory bodies.
- Publications from International Institutes.

The results of the literature review are presented in Section 5 of this report and the full list of information sources used is presented in Section 7. It should be noted that further references are likely to be sourced during the course of the project and the current review will be supplemented by this and details incorporated into final findings in the Draft and Final Reports.

4.3 Field Situation Analysis

Building upon the above literature review and desktop study, the field survey and report has the overall aim of examining the present situation in the Khulna region (and other similar areas if appropriate) with respect to damage to road embankments and structures caused by the poor bearing capacity of the soil.

The field analysis will be based on two stages of site visits, for which an indicative programme is outlined in Appendix B. Initially, a broad review of a wider range of sites will be undertaken to present an overview of the existing field situation and select a limited number of appropriate sites for more detailed investigation.

At a limited number of selected sites, detailed examinations will be undertaken of the embankments and structures to record the physical form of the structure and nature of the movement experienced, using a typical pro-forma to record common data including:

- Earthwork characteristics; length, height, slope angle, adjacent land;
- Sources of water; hydrology, drainage;
- Construction details; drainage, pavement, highway layout;
- Highway structures; bridges, culverts, walls;
- Observed condition; settlement, differential settlement, structural distress, drainage issues;

The field observations will be reported in the field situation analysis report, supporting the development of more detailed understanding of ground models through the following laboratory testing stage.

The methodology for the field situation analysis stage is outlined below:

4.3.1 Selection Criteria

In partnership with LGED, Mott MacDonald has developed the below list of classification criteria for the rural road study sites, that fall within 3 broad classes:

A. *Road / Site characterisation.*
B. *Ground improvement techniques used?*
C. *Interaction with structures?*

The classification criteria are as follows:

A. ROAD / SITE CHARACTERISATION:

1. *What is the classification of the road?*
   (E.g. upazila)
2. *Proximity to a watercourse?*
   (If yes, how close by is the watercourse?)
3. *What is the elevation of the road?*
4. *Is the road at risk from flooding?*
   (If yes, what are the specifics of this flood risk?)
5. *Is the pavement coarse bound or unbound?*
   (What materials have been used and in what layer thicknesses?)
6. *Are there soft ground conditions?*
   (If yes, is the depth of this soft layer(s) known?)
7. *Are there instances of organic soils within this soft layer(s)?*
   (If yes, what are the horizontal and vertical extents of this material?)

B. GROUND IMPROVEMENT TECHNIQUES USED?

8. *Was the existing road constructed using any ground improvement techniques?*
   (If yes, are design drawings available?)
9. *Is the road on embankment or at grade?*
   (If on embankment, how high and what are the rough slope angles?)
10. *Has the existing road / embankment failed or is it showing signs of distress?*
    (What are the signs of distress? what is the apparent mode(s) of failure? – if the road *hasn't* failed, why is this?)
11. *Have remedial works been undertaken?*
    (If yes, are remedial design drawings available?)
12. *Did the remedial works involved ground improvement?*
    (If yes, what techniques were employed?)
13. *Were the remedial works successful?*
    (If yes why? If no why?)
14. *Were further works then conducted if the remedial works failed?*
    (And did this extra work make a positive difference?)

C. INTERACTION WITH STRUCTURES?

15. *Does the road interact with structures?*
    (If yes, what type of structures and how many? E.g. bridges, culverts, walls)
16. *What foundations do the structures employ?*
    (Are design or as-built drawings available?)
17. *Are the structural foundations competent or have they failed?*
    (And why?)
18. *Are there issues with differential settlements at road-structure interaction points?*
    (What magnitude of differential settlement has occurred?)

19. *Are there differential settlements outside of acceptable limits?*
    (Has the road failed, the structure or indeed both?)
20. *Were remedial works undertaken?*
    (If yes, what was done? Are design and as-built drawings available?)
21. *Were the remedial works successful?*
    (If yes why? If no why?)

4.3.2 Identified Sites

With the assistance of LGED, Mott MacDonald has identified a list of sites for the initial inspection and assessment (visit and walkover survey in accordance with the proforma outlined in Section 4.3. The site locations are summarised in Figure 4.1 and listed in Table 4.2.

Prior to the program of site visits, Mott MacDonald's UK project staff will travel to Dhaka for a week to undertake a series of pre site visit workshops where they shall establish the format that the site inspections should take and the information that should be recorded.

Figure 4.1: Site Location Plan (regional level)

Table 4.2: Preliminary list of sites for characterization and initial inspections

No.	District	Sub district / Upazila	Structure name / location	Road ID	Improvement type/ Failure type	Project Name	Reason to visit
1.	Jessore	Abhoynagar	Sundali U.P.Office-Moshihati Bazar Road (Ch. 3107 to 5107m)	241043007	Jute Geotextile (JGT) in Rural Road Construction	Important Rural Infrastructure Development Project on Priority Basis	To observe the effectiveness of applied GI by Jute Geotextile
2.	Jessore	Abhoynagar	Horishpur Reg. Primary School-Magura GC via Ramsara Chowmatha, Shishutala Road (Ch. 500 to 1590m)	241044062	Jute Geotextile (JGT) in Rural Road Construction	Important Rural Infrastructure Development Project on Priority Basis	To observe the effectiveness of applied GI by Jute Geotextile
3.	Satkhira	Asasuni	Kadakati GC - Protapnagar GC via Goaldanga Bazer road at Ch. 4294-32500m	287042008	Soft Clay soil		To observe and understand the failure type and reason
4.	Satkhira	Asasuni	Budhata RHD - Baka GC road at Ch. 7300-11100m	287042003	Soft Clay soil		To observe and understand the failure type and reason
5.	Satkhira	Asasuni	Assasuni GC - Parulia GC Road (Assasuni part) at Ch. 8500-11300m	287042002	Soft Clay soil		To observe and understand the failure type and reason
6.	Satkhira	Asasuni	Kapsanda bazar-Khazra UP at Ch. 00-6100m	287043007	Soft Clay soil		To observe and understand the failure type and reason
7.	Satkhira	Asasuni	Sriula R&H - Sriula Shashibari bridge via BD Chow House at Ch. 00-750m	287044034	Soft Clay soil		To observe and understand the failure type and reason
8.	Satkhira	Asasuni	Bauchas primary school - Kamalkati Bazer (Sovnali UP office) at Ch. 00-3600m	287044058	Soft Clay soil		To observe and understand the failure type and reason
9.	Khulna	Batighata	Typical 4(four) storied upazila parishad building at batiaghata under extension of upazila complex project		Sub soil improvement with sand back filling & earth loading	Extension of upazila complex project	To observe the effectiveness of applied GI by Sand Backfilling and earth loading
10.	Khulna	Paikgacha	Paikgacha GC- Latar Hat-Fulbari Hat-Baroaria GC road (Paikgacha portion)	247642011	Soft Clay soil		To observe and understand the failure type and reason
11.	Khulna	Paikgacha	Paikgacha GC- Gilabary GC Via Bagularchok Bazar Road.	247642012	Soft Clay soil		To observe and understand the failure type and reason
12.	Khulna	Digholia	Mazirgati GC-Bamondanga RHD – Katenga GC Road	247402004	Soft Clay soil		To observe and understand the failure type and reason
13.	Khulna	Digholia	Bir Muktijorda Molla Jalal Uddin Sorak : Gazirhat U.P Office (Molladanga) -Bamondanga -Katenga G.C RHD Road (Digholia Portion)	247403011	Soft Clay soil		To observe and understand the failure type and reason
14.	Khulna	Digholia	Gazirhat Jangushia RHD (Bottala More) -Mohisdia RHD	247404005	Soft Clay soil		To observe and understand the failure type and reason
15.	Khulna	Digholia	Barakpur Bazar(RHD) - Barakpur U.P H/Q .-Lakohati Bazar - Kamargati Bazar Road.	247403003	Soft Clay soil		To observe and understand the failure type and reason

No.	District	Sub district / Upazila	Structure name / location	Road ID	Improvement type/ Failure type	Project Name	Reason to visit
16.	Khulna	Koira	Dewliar Hat-Kashirabad BC Road via Uttar Chack Madrasha	247534036	Soft Clay soil		To observe and understand the failure type and reason
17.	Khulna	Koira	Upazila HQ (Dighirpar)-Golkhali Road	247532004	Soft Clay soil		To observe and understand the failure type and reason
18.	Khulna	Rupsha	Thana H/Q-Alaipur hat-Sheikhpura GC (Rupsha Portion)	247752001	Soft Clay soil		To observe and understand the failure type and reason
19.	Khulna	Rupsha	Khulna Mongla H/way Kudir Battala-Khajadanga - Hatamtala-Lockpur GC Mongla road via Shamontasena Nutun hat.	247752009	Soft Clay soil		To observe and understand the failure type and reason
20.	Khulna	Dacope	Khona R&H-Garikhali GC (Paikgacha) via Batbunia G.C Road	247172001	Soft Clay soil		To observe and understand the failure type and reason
21.	Khulna	Dacope	Chalna GC (Gachtala)-Garaikhali GC (Paikgacha) via Laxmikhala & Mozamnagar hat Road.	247172011	Soft Clay soil		To observe and understand the failure type and reason
22.	Khulna	Terokhada	Chagladah Bazar-Nagarkandi G C via Kushla Road.	247942008	Soft Clay soil		To observe and understand the failure type and reason
23.	Khulna	Terokhada	Terokhada Upazila HQ-Sachiadah UP office Road.	247943003	Soft Clay soil		To observe and understand the failure type and reason
24.	Khulna	Batiaghata	Katianangla-Roypur via Sukdara Bazar, Baro Bhuiyan & Kechrabad Road	247122007	Soft Clay soil		To observe and understand the failure type and reason
25.	Khulna	Batiaghata	Kutir Hat GC-Katianangla R & H via Shialidanga Hat Road	247122008	Soft Clay soil		To observe and understand the failure type and reason
26.	Khulna	Batiaghata	Surkhali UP Office - Sundarmahal Bandher Hat via Kodla Road	247123009	Soft Clay soil		To observe and understand the failure type and reason
27.	Khulna	Batiaghata	Bagmara-Mathabhanga Road	247124011	Soft Clay soil		To observe and understand the failure type and reason
28.	Khulna	Batiaghata	Gallamari Bazar - Boyra Road	247124030	Soft Clay soil		To observe and understand the failure type and reason
29.	Khulna	Batiaghata	Thickrabad Khulna Satkhira R&H Road (Pallibidyuit Office)-Khulna Bipass Road	247125096	Soft Clay soil		To observe and understand the failure type and reason
30.	Khulna	Batiaghata	Koya Hat - Royermahal Bazar Road.	247124044	Soft Clay soil		To observe and understand the failure type and reason
31.	Khulna	Dumuria	Sahos UP Office (Kuarghata Amtala more) Kadamtala Kheyghat Bazar via KDC Primary School.	247303024	Soft Clay soil		To observe and understand the failure type and reason
32.	Bagerhat	Rampal	Khulna coal based power plant		Sand Drain Technique	Khulna coal based power plant	To observe the application method

No.	District	Sub district / Upazila	Structure name / location	Road ID	Improvement type/ Failure type	Project Name	Reason to visit
			connecting road			connecting road	of Sand Drain technique and to understand the capability
33.	Bagerhat	Rampal	Bhaga-Rampal Road	201732016	Soft Clay soil		To observe and understand the failure type and reason
34.	Bagerhat	Mongla	Mongla Paurasova-Shalabunia-Baiddamary Bazar	201582009	Soft Clay soil		To observe and understand the failure type and reason
35.	Bagerhat	Mongla	Chaterhat GC-Sonailtala UP	201583004	Soft Clay soil		To observe and understand the failure type and reason

4.3.3 Finalised Site Visit List

When all 35 No. study sites have been assessed, Mott MacDonald's in-country and UK staff will work closely together to review the recorded information and pare those 35 No. sites down to Finalised site list. It is anticipated that the finalised site list will contain 4 to 6 No. study sites and, subject to access, these will have limited sampling, in-situ testing and laboratory geotechnical testing performed, subject to approval of the testing plan provided in Appendix D.

The Field Situation Analysis Report will be issued at this stage to report on the initial findings and finalised site list that will be taken forward to the next stage.

4.4 Field and Laboratory Testing

Based on the findings of the desk study, literature review and the field observations made during Task 2, and our investigation into commercially available plant and testing facilities summarised in Appendix A, a programme of limited ground investigation and laboratory testing is proposed for the 4-6No sites identified in the Field Situation Analysis report.

It is envisaged that this will take the form of shallow hand excavated pits, dug by members of Mott MacDonald's project team, from which samples will be retrieved for laboratory testing. Typically, 5 No. hand excavated pits will be formed at each study site, though it must be stressed that the number of hand excavated pits conducted, and the number of sample retrieved will be dependent on the variation in stratum encountered. It is anticipated that in-situ testing will again be conducted by Mott MacDonald's project staff using pocket penetrometers and a hand shear vane.

It is anticipated that the testing of the samples gathered during the site visit stage will be subject to classification testing such as Atterberg Limits, particle size distribution, organic content and moisture content, in addition to basic situ testing may also be performed such as hand vane and pocket penetrometer testing. The proposed testing regime is summarised in Table 4.3.

Table 4.3: Typical ground investigation and soil sampling regime for selected sites

Investigation / sampling	Description (typical)
In situ testing	Hand vane and pocket penetrometer
Trial Pits	5 shallow hand excavated trial pits to investigate the soil at foundation level and embankment material.
Soil sampling – tub / bag samples	Regular intervals – for purposes of soil classification
Laboratory testing – classification	Atterberg Limits, particle size distribution, organic content, moisture content,
Laboratory testing – other	Chemical analysis e.g. sulphates / chlorides.

The Interim Laboratory Testing Report will present the factual findings of the field and laboratory testing undertaken.

4.5 Laboratory Test Report

Leading on from the Interim Laboratory Test Report, the Final Laboratory Test Report will present the findings of the ground investigations and testing that has been undertaken and develop these into material parameters. Existing boreholes and laboratory test data that have been made available to the project team will be used to supplement the site specific data collected.

Observational ground models will be developed for the selected sites that are representative of the conditions observed. It is hoped that a variety of ground models will be developed that reflect a number of cases e.g. earthwork with no problems, failing earthwork adjacent to a bridge structure, reinstated embankment. We propose that qualitative and semi-quantitative assessment of deformation observed is proposed to validate the ground models and review the applicability and effectiveness of existing ground improvement remedial measures.

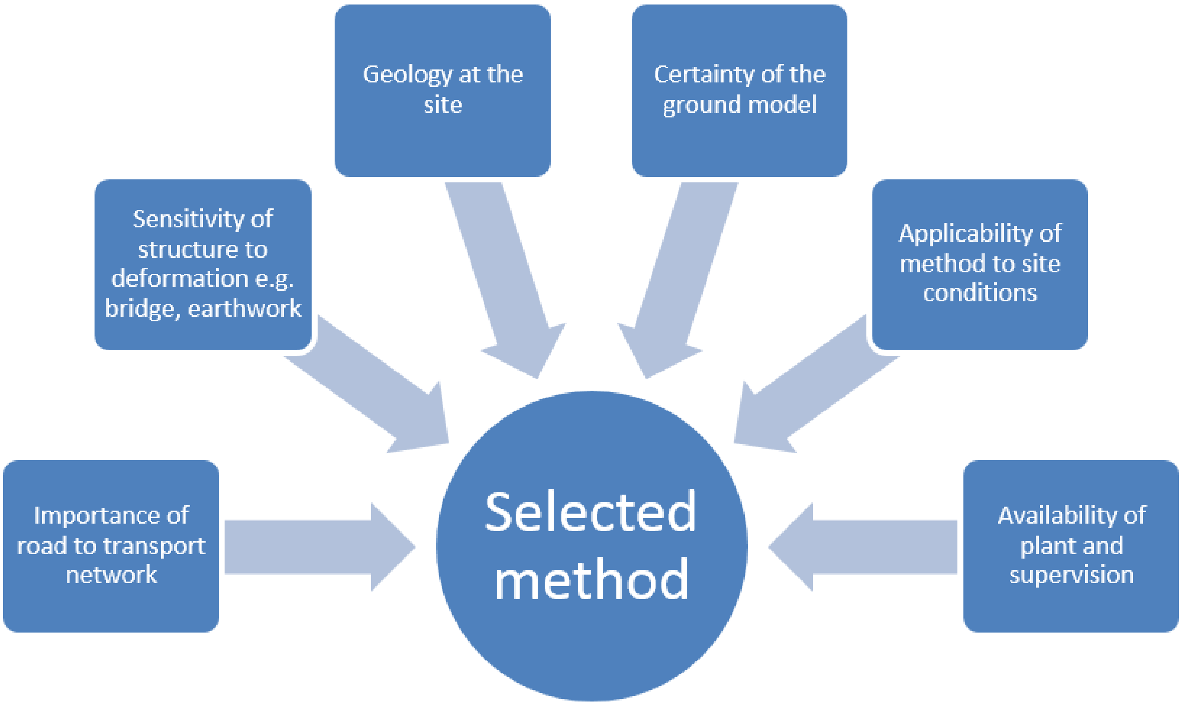
4.6 Draft Report

The understandings gained from the previous project tasks and testing will be drawn together to provide a set of clear recommendations for addressing the challenges of engineering road embankments on the soft soils of Khulna region. The draft contents for the report are outlined overleaf:

1. Introduction
2. Background Information;
3. Sources of information
4. Current Practice in Asset Management for Rural Roads;
5. Current Practice in Design & Construction for Rural Roads
6. Ground Improvement Techniques for Soft Soil;
7. Regional Geology and Ground Conditions;
8. Review of Condition of Earthworks and Structures built on soft ground in Khulna Region
9. Selection of Test Sites;
10. Summary of Field Surveys;
11. Summary of Laboratory Testing;
12. Summary of Ground Models and Assessment;
13. Recommendations for remedial works;
14. Guidelines for Design and Construction;
15. Recommendations for the next phase;

We aim to prepare a decision support matrix/flowchart that will assist LGED in the selection of suitable methods for sites identified. A number of the key factors that influence decision making are illustrated on Figure 4.2 and these will be incorporated into the matrix.

Figure 4.2: Key factors that will influence choice of methods for remedial or new build earthworks



4.7 Stakeholder Workshop

This important step will provide the opportunity to disseminate the project findings and get feedback from key project stakeholders that can be incorporated in to the final report.

4.8 Final Report

A final project report will be prepared based on the draft report, and incorporating the outcomes of the stakeholder workshop.

5 Literature Review

The content of references obtained and reviewed for this study can be broadly categorised as follows:

- **Regional Geology** - Assessment and characterisation of the general deltaic and specifically soft ground geology of Bangladesh.
- **Ground Conditions of Khulna Region** - Assessment and characterisation of the problematic soft ground of Dhaka and Khulna region.
- **International Ground Improvement Studies** – Assessment of international ground improvement techniques for soft soils;
- **Ground Improvement in Bangladesh** – Assessment of ground improvement techniques currently in use in Bangladesh
- **International Best Practice in Ground Improvement Guidance / Standards.**

5.1 Regional Geology

Mollah (2003) explains in his paper entitled "*Geotechnical conditions of the deltaic alluvial plains of Bangladesh and associated problems",* that: the Himalayan Range, has had a great influence on the evolution of the river systems in Bangladesh and on the development of is extensive river delta, which has a sedimentation history ranging from the Pleistocene to Recent. Mollah explains that from development projects, there is soil test data available for almost the entire Bangladesh deltaic plain and that this information indicates that the subsoil of the deltaic alluvial plains generally consists of sandy material though he emphasises that it may vary significantly over short lateral distances as a result of frequent and erratic occurrences of compressible organic silt and peat mixtures.

The author explains and confirms the known issue that the foundation competency of the upper 6-10 m of ground in the deltaic alluvial plains of Bangladesh has been assessed as '*low to very low*'. The characteristics of the soils indicate susceptibility to erosion, piping, liquefaction phenomenon, etc. Furthermore, he adds that the variable nature of the deposits makes the prediction of local soil conditions very difficult. Mollah explains that a uniformly textured fine sand with a '*moderate to high'* bearing capacity typically exists in the soil profile, particularly below 20 m depth, but this is obviously a deep layer that would need to be utilized for its engineering properties via piled foundations (he notes that this moderately to high bearing capacity sand stratum is totally absent in swampy areas).

Mollah elaborates on potential construction problems and subdivides them into geotechnical and environmental issues. The former include foundation problems in buildings, bridges, and hydraulic structures etc., attributed to the weak and erratic nature of the surficial soil (and points out that geotechnical problems are often compounded by the physiographical and geomorphological environment of the country). Flood and river bank erosion are identified as the main environmental problems, considered by the author as posing '*an enormous threat to life, property and construction*'. Recommendations to overcome these problems are made.

Arifuzzaman and Hasan (2013) report how, over the past 50 years, Dhaka, the Capital of Bangladesh, has experienced a rapid growth of urban population. They explain how this high population increase has necessitated a rapid expansion of the city. Arifuzzaman and Hasan explain that those areas of Dhaka that have subsoil that can be considered competent for building construction are already exhausted and that as such, new areas are being reclaimed by both government and private agencies using dredged fill from nearby river sources. It is reported that in most cases, the practice for developing such areas is just to fill lowlands (1.5 m to 5.5 m) by dredged soils collected from nearby riverbank and riverbed sources. It is found that the dredged soil is typically silty sand and that the mean grain size and fines content of such material typically varies from 0.148 mm to 0.200 mm and from 17.4 to 27.6%, respectively. It is found that some parts of the reclaimed areas are susceptible to earthquake induced liquefaction (Hossain, 2009).

Arifuzzaman and Hasan explain the issue that a very soft organic layer exists below the reclamation filling layer that is highly plastic and highly compressible. This very soft organic layer is determined to exist because filling soil is directly placed on the marshy low land and upon the vegetation and other organic materials. After a time, these organic materials beneath the filling soil decompose and produce the problem soft organic layer. The authors found that the thickness of the soft layer varies in the range from 0.5m to 8.5m. Moisture content of organic layer was determined to vary from 32 to 84% whilst liquid limit and plasticity index vary from 42 to 193% and from 14 to 68%, respectively. It is seen that this organic soil (OL to OH) is very soft in nature and shows high moisture content and highly plastic behaviour. Organic content of the soft soil varies from 4.7 to 28.7%. Unconfined compressive strength and failure strain vary from 6 to 66 kPa and from 7 to 15%, respectively. In addition, initial void ratio, compression index and coefficient of consolidation vary from 0.88 to 3.90, from 0.26 to 1.10 and from 0.22 to 16.85 m2/yr, respectively. The authors summarise this soil as being highly compressible with very low shear strength. SPT N values of the organic layer are only 1 to 2. The filling layer was determined to possess SPT N values of 2 to 11.

The authors observed that settlement of the organic layer varied from approximate 242 mm to 637 mm between times period of 1.8 to 12.7 years, respectively, due to a calculated overburden pressure of 100 kPa. Moreover, the authors felt that the existing organic layer may cause negative skin friction and ensuing difficulties for piled foundations. It is mentioned that further studies are being conducted to develop or design desired suitable ground improvement techniques or alternative foundation systems for such sub-soil conditions.

5.2 Ground Conditions of Khulna Region

Of the materials sourced for the literature review, perhaps the key papers on the geology of the Khulna Region are "*Engineering Geology of Khulna Metropolitan City Area"* by Ali *et al* (2004) and "*Urban Geology: A Case of Khulna City Corporation, Bangladesh"* by Kumar *et al* (2006). These papers both reflect on metropolitan areas, but where the experience remains relevant to the ground conditions encountered in the rural road scenario.

Ali *et al* (2004) explain that the presence of thick soft deposits is the major constraint for the development of the city. The ground of Khulna city is described as comprising 'compressible and collapsible sediments' consisting of very soft silt and organic clay-silt. These deposits are explained to be very moist, saline and where non-organic of low plasticity exhibiting low shear strength characteristics and a propensity for liquefaction. The paper attempts to divide the area into characteristic soil complexes and of those developed, the 'Western Complex' is described as having the worst subsurface conditions with upper soft soils up to 20m thick (correlating with the findings of Mollah (2003). Ali *et al* explain that piled foundation are required for taller structures to be constructed upon this 20m of soft sediments but that 'floating type' foundations can be utilised for low or light structures, and that in the case of the latter 'standard ground improvement techniques should be adapted'.

Kumar *et al* (2006) again discuss how the city of Khulna lies on the Late Holocene - Recent alluvium of the Ganges deltaic plain in the north and Ganges estuarine plain in the south. They described how lithologically, the area is composed of coarse to very fine sand, silt, silty clay and clay in various proportions up to a depth of 300m, explaining how the stratigraphy underlying the city shows '*seven cycles of sedimentation having age connotation from Upper Miocene to Recent age*'.

Kumar *et al* used data on geomorphology, stratigraphic litho-succession, soil types, percentage of sand, silt and clay in the soil, liquid limit, plasticity index, natural moisture content (NMC), liquefaction, settlement and Standard Penetration Test (SPT) data to categorise the Khulna City area into four distinct zones where unit-I is best and unit-IV is ranked lowest for urbanization.

The authors report that the SPT 'N' values of the investigated areas ranged between 1 and 9 from the ground surface to 5mbgl and 1 to 27 from 5mbgl to 15mbgl with a range of liquid limit of 38 to 59%, a range of plasticity index of 9 to 30% and a natural moisture content (NMC) between 16.5% and 42%.

In line with the findings of Mollah and Ali *et* al, Kumar *et al* report that the shear strength of the upper subsoil horizons in Khulna City is low with a compressive index in the range of 0.123 to 0.335, indicative of a soil vulnerable to excessive settlement under high load. They explain that 40% of the sediments occur in the '*moderate to high compressibility'* zone and the depth varies for the sediments mostly under 5m. Further to this, the authors state that the cohesive nature of soil in the Khulna City area with high colloidal content and high liquid and plastic limits indicates medium to high sensitivity of the soil to moisture, rendering it unable support heavily loaded buildings and structures. The authors add that the shallow ground water of Khulna City (typically 1mbgl) reduces the bearing capacity of the soil and subsoil up to 50%.

Kumar *et al* advise that the problems of construction on soft ground can be avoided by considering special types of foundation, increasing the width of basements of structures and granular backfilling. They class Special foundation as footings, piers, piling etc. and advise that such foundation solutions should be placed at sufficient depth as to avoid an upper identified to be under the influence of seasonal change.

Alternatively, the authors advise that subgrade soils may be replaced by a compacted granular backfill cautioning however that locally available sand contains excessive fines content and variable but high amounts of micas and thus does not fulfil the requirements of construction materials concerning grading and composition. It is speculated that the low SPT 'N' values of the soil are caused by the effect of reduced confinement due to the presence of mica. The authors consider that if suitable quality sand can be obtained, then ground improvements can be made blending such aggregate with the *in-situ* soils.

Considering the factors of geotechnical parameters and environmental degradation by natural and anthropogenic hazards Kumar *et al* present a future land suitability map for future urban planning of the Khulna City area.

In a further contribution to understanding the technical properties of Khulna Clay, Rabbee and Rafizul (2012) examined the "*Strength and Compressibility Characteristics of Reconstituted Organic Soil at Khulna Region of Bangladesh".* Their paper chronicles their experimental investigations into the effect of organic content on the shear strength and compressibility parameters of reconstituted soil. Rabbee and Rafizul collected disturbed soil samples from two selected locations of Khulna region. The reconstituted soils, determined to have an organic content of 5-35 % were prepared in the laboratory at mixes of various proportions of inorganic and organic soil content at a water content equal to 1.25 x liquid limit of the collected samples .The reconstituted samples were place in a mould of Ø 152mm and height 222 mm and an ultimate surcharge of approximately 60kN/m^2 was applied. In the laboratory, ASTM (2004) methods were followed for the determination of strength properties and compressibility parameters of the reconstituted soil samples at varying organic content. Rabbee and Rafizul determined that the organic content significantly influenced the shear strength and compressibility parameters of the reconstituted soils and developed correlations based on strength and compressibility parameters and organic content. The authors determined that these correlations could be expressed by equations and proposed that these equations could be used to estimate the various engineering properties of soils of the Khulna Region based on organic content data.

Finally, Banik *et al* (2014) do move further into the construction phase, and primarily concerned with development in Khulna City and explain how, for the construction of small buildings of one or two storeys, the owners / developers are not interested in conducting any soil investigation prior to construction, to inform the design of appropriate foundations. The authors explain that for such cases, the foundations are designed on the basis of an assumed average bearing capacity. In light of this situation, Banik *et al* produced their paper '*Statistical Evaluation of bearing capacity of Khulna Sub-Soil'* with the main objective of their research work being the determination of an average design bearing capacity value to inform the design of foundations for low-rise building to be constructed in Khulna City. Banik *et al* detail how soil samples were collected from KUET (Khulna University of Engineering & Technology) campus and tested in the Soil Mechanics laboratory of KUET to determine the bearing capacity.

Soil reports from more than sixty locations of Khulna were collected from CRTS (Consultancy, research and testing services) of the Civil Engineering department KUET, Khulna. From these reports, Banik *et al* took the values of bearing capacity were for the purpose of analysis. The authors discus how many equations were available to them in the determination of the bearing capacity of soil such as Terzaghi, Meyerhof and Hansen etcetera. Among these equations, the Terzaghi Bearing Capacity equation was selected by the authors for the estimation of bearing capacity considering due to their preference for *'its simplicity and reasonable accuracy'*. Banik *et al,* acknowledged that the bearing capacity of a soil(s) depends also on layer thickness and stratification of soil, and as such, bearing capacity was calculated for soil profiles from various locations. From the reports available to them, Banik *et al* determined the mean, median, mode, standard deviation and coefficient of variation of different values of bearing capacity. The estimated average bearing capacity of Khulna sub-soil calculated were as follows:

- At 1.5 mbgl = 55.31 kN/m^2
- At 3.0 mbgl = 47.10 kN/m^2

Banik *et* al concluded that *'the values of bearing capacity of different locations are very low which indicates that shallow foundation is suitable for two or three storied buildings. For multistoried buildings, deep foundation such as pile foundation should be adopted or the soil beneath the foundation should be improved by some suitable method'.*

Summary of Ground Conditions:

It is clear from the literature review that extensive technical work has gone into both the definition of Khulna Clay and some of the failure mechanisms. Drawing together this information, Khulna clay can be understood as:

- Very soft to soft sediments of up to 20m thickness and often with sporadic occurrences of organic and peat material overly more competent sandy stratum A composition containing fine silts and sands with sporadic pockets of organic clay-silts and peat;
- An SPT 'N' value of between 0 and 4;
- An undrained shear strength (c_u) < 40 kPa, and likely to be significantly less in many areas;
- A typically low plasticity for the fine silts and sands;
- A typically high plasticity for the organics materials;
- A coefficient of volume compressibility (m_v) > 1.0 m^2/MN;
- An allowable bearing pressure < 75 kPa, and could be much lower;
- Groundwater <1mbgl;

Failure is often related to an increase in the pressure under which water within the soil is subjected, known as the pore water pressure, especially where such soils are excavated and used for embankment fill and where further *increase* in pore water pressure under flood conditions will lead to failure. The presence of peat is significant issue, as typically, peat may contain ten times its own weight in water – subsequently, it can compress by 10-75% under load. When loaded to exceed its very low shear strength, peat also creeps and spreads; so very high settlements are to be expected where these materials are encountered. It is also noted that this water is typically brackish to saline, and as such aggressive against the concrete and steel typically used in both shallow and deep foundations solutions – an issue addressed in the parallel ReCAP study related to concrete durability in the marine environment.

5.3 International Ground Improvement Techniques

As stated in the CIRIA C573: A Guide to Ground Treatment, virtually all engineering construction involves the ground. When constructing in poor ground conditions, there are five available options:

- To bypass the poor ground, by moving to a new site, or using deep foundations to stronger ground.
- To remove the poor ground, replacing it with better material.
- To design the structure to allow for the behavior of the poor ground under load.
- To treat the poor ground to improve its properties (i.e. ground improvement).
- To abandon the project (the promoter's decision).

The fourth option, of ground treatment, gives considerable scope to engineers for finding a viable solution to the problems of poor ground. A wide range of treatments are available, techniques can be selected and combined to cope with different aspects of the poor ground, and there is increasing confidence both in what can be achieved by well executed treatment and in its proper integration into the overall scheme for the construction. All these points are evidence of how valuable this option is.

The objective of treatment is of course improvement. When ground treatment is being considered as an option, it is important that all who will be involved in it should recognise not only what can reasonably be achieved by a particular technique, but also the extent of their responsibility if it is chosen.

The term "ground improvement" is open to different interpretations. First, it is an intention or objective, not the process of achieving it, although the term is often used in that sense. Second, improvement is a relative condition as to which aspect and to what degree there is improvement.

Ground treatment techniques have been in use around the world for many centuries but have developed greatly over the past 40 years.

CIRIA C573: A Guide to Ground Treatment states that: *'In the United Kingdom, some 75 per cent of the ground improvement contracts using the techniques of vibro-replacement and dynamic compaction are for man-made ground. These two techniques, including their application to loose or soft natural soils, are probably the commonest type of ground treatment used in the UK. For overseas work, the proportions of specialist ground treatments are reversed, i.e. 30 percent are for man-made ground and 70 per cent for natural ground'*.

The techniques of ground improvement used around the world have been grouped into 8 No. broad categories:

1. **Improvement by vibration:**
    - Vibro-compaction;
    - Vibro-replacement;
    - Dynamic compaction;
    - Vibratory probing;
    - Compaction piles;
    - Blasting;
2. **Improvement by adding load (or increasing the effective stresses):**

- Pre-compression;
- Vertical drains;
- Inundation;
- Vacuum preloading;
- Dewatering fine soils;
- Pressure berms.

3. **Improvement by structural reinforcement:**
    - Reinforced soil;
    - Soil nailing;
    - Root and micro-piles;
    - Slope dowels;
    - Embankment piles;
4. **Improvement by structural fill:**
    - Remove and replacement;
    - Displacement;
    - Reduced load;
5. **Improvement by admixtures:**
    - Lime / cement columns;
    - Mix-in-place by single augur;
    - Lime stabilisation of slopes;
    - Stabilisations of subgrades;
6. **Improvement by grouting:**
    - Permeation;
    - Hydro-fracture;
    - Jet grouting;
    - Compaction grouting;
    - Cavity filling.

7. **Improvement by thermal stabilisation.**
    - Freezing.
    - Heating.
8. **Improvement by vegetation.**
    - Vegetation planting.

NB: Although the above headings for the groups of methods reflect what is being undertaken to the ground to improve it, they do not characterise the way the ground is to be improved, nor do they show the purpose of the improvement. Many of the techniques can be used for different purposes and by enhancing one aspect of soil behaviour other aspects are also improved.

In accordance with the breakdown of each category in CIRIA C573, we can define simply, the general method by which the ground is improved for each of the eight abovementioned ground improvement categories:

1) **Improvement by vibration:**
Vibration can be used to compact soils and fills. The densification is achieved by a combination of ground displacement and vibration, in most cases with the addition of new material into the ground.

2) **Improvement by adding load (or increasing the effective stresses).**
Increasing the load on the ground causes it to compress. How much compression and how long it takes to happen depends on the arrangement of the ground

particles, on the degree of saturation, and on how freely the soil can drain. For loose and particularly unsaturated fills, adding load induces rapid settlement; soft, saturated clays, on the other hand, take months or years to consolidate under an added load while pore pressures dissipate and the effective stress in the soil increases. The improvement techniques of adding load fall into two, not necessarily exclusive categories:

- *A. Where the improvement largely comes about by the increase in total stress*
- *B. Where the improvement depends upon the increase in effective stress and the technique encourages or accelerates that.*

3) Improvement by structural reinforcement.

Many ground improvement techniques could be considered as a form of reinforcement. Stone columns, for example, are introduced materials that stiffen the ground; some grouts strengthen the mass of soil into which they are injected. The distinction drawn for the classification used in this report of structural reinforcement is that prefabricated tensile or shear elements are installed in the ground with the purpose of forming a composite material.

4) Improvement by structural fill.

The principle of ground improvement by structural fill is to replace a weak soil with a better one. Another, more recent option is to use lightweight materials instead of heavier earth fills above weak ground. These options include:

- *A. Displacement.*
- *B. Reducing load.*
- *C. Removal and replacement.*

5) Improvement by admixtures.

The use of admixtures, such as lime, cement, oils and bitumens, and even sulphur, is one of the oldest and most widespread methods of improving a soil. Usually the purpose is to strengthen a locally available earth fill to construct a low-cost road base, e.g. cement stabilised soil or soil-cement, or to mix lime into highly plastic clays. Plant was developed either to mix the stabiliser in place, i.e. to strengthen subgrades or layers of the fill, or for central mixing to which the soil is transported.

6) Improvement by grouting.

A general definition of grouting for ground improvement is: "the controlled injection of material, usually in a fluid phase, into soil or rock in order to improve the physical characteristics of the ground". Such a definition does not cover all types or purposes of grouting in the ground, e.g. grouting to raise ground slabs or road pavements, but it does cover grouting to fill voids in the ground, whether natural (such as in karstic limestone) or resulting from human activity.

7) Improvement by thermal stabilisation.

Even in the temperate UK, everyone is familiar with the way that surface soils are hardened, albeit temporarily, by frost and hot, dry weather. The removal of heat from the soil turning its pore water into ice is a very powerful technique rendering the ground impermeable and, for unconsolidated materials, making them stronger. Applying heat to clays to drive out free pore water and, at higher temperatures, the water adsorbed on particle surfaces, creates a very hard, durable material - in effect, the same methods as when making brick or mud (adobe) building blocks. Ground freezing is a long established and particularly effective method of ground *stabilisation for temporary works. Ground heating is rare, but when it has been used its purpose was longer-term improvement*.

8) **Improvement by vegetation.**
Vegetation as ground improvement is the biological reinforcement of ground by plant roots to retain earth masses and prevent soil loss.

5.4 Ground Improvement in Bangladesh and Khulna

Only a limited number of these ground improvement techniques are currently employed or investigated in Bangladesh, including:

- Sand Piles Method;
- Prefabricated Vertical Drains;
- Jute Geotextiles;
- Rice Husk Ash;
- Cement Stabilisation - Deep Cement Mixing;
- Cement Stabilisation – Cement Columns;
- Chemical Admixtures

There are a limited number of papers that discuss the practical implementation and assessment of the performance of ground improvement techniques in the field and within the country of Bangladesh, and some that focus on laboratory based assessments of soil improvement.

Alamgir and Chowdhury (2004) examined 'Ground Improvement Methods Recently Practiced to Solve the Geotechnical Engineering Problems in Bangladesh'. Their paper describes the field performance, in ground strength and long-term settlement, of foundation systems recently practiced in the soft ground of Khulna region to try to solve the known geotechnical engineering problems. The foundation systems adopted for the construction of four structures were adopted for the study, those structures being:

1) Khulna Medical College: shallow foundation system using Geotextiles.
2) Khulna University: a foundation system replacing the soft compressible soil layer with compacted sand.
3) BIT Khulna: a foundation system replacing the soft compressible soil layer with compacted sand.
4) Six-vent regulator on Passur River at Fakirhat: installation of sand piles by dry displacement method.

Whilst the soft compressible ground was improved successfully by the adopted improvement techniques and the constructed structures were assessed to be in safe conditions when considering both the technical and utility aspects. However, the authors found that in some of the cases, the effectiveness of the adopted ground improvement techniques was questionable due to very large total and differential settlements. Their study concluded that these systems can provide viable alternatives to conventional piles, but that the success of any adopted ground improvement techniques in such soft compressible soil depended on the close monitoring system and the quality control in all the steps involved in the engineering works such as sub-soil investigation, design and construction.

The ground improvement techniques currently available in Bangladesh and summarised in the above paper are outlined below.

5.4.1 Sand Pile Method

In terms of ground improvement techniques that are already implemented in Bangladesh and more specifically the Khulna Region, the current construction industry capability in ground engineering for loose silty and sandy soil types is ground improvement by the sand pile method. Sand Piles of typically Ø 300mm are installed by driving a hollow casing pipe into the silty / sandy soils. The pipe displaces the surrounding soil and sand is poured into the casing to fill the ensuing void. After that, a 1 ton hammer (hammer Ø < 6mm to 8mm the diameter of the casing pipe) is used to compact the sand, and as compaction takes place, the hollow casing pipe is gradually retracted from the ground. The use of sand piles is particularly prevalent in Chittagong, but it is reported that this local procedure of Ø 300mm sand piles is not advisable for depths of greater than 10mbgl – this is because of higher friction between the soil and the pipe making extraction difficult.

An example of the use of sand piles in the Khulna Region is the Padma Bridge Approach Road Project. For this project, two German-made Bauer RG19T sand piling rigs were used along with a Bauer MR125V hydraulic vibrator. This rig is capable of forming sand piles up to 12 mbgl in soils with an SPT 'N' value < 8. This plant is the property of Abdul Monem Ltd.

Another sand pile installation method employed in Bangladesh is the vibratory hammer technique. This technique utilises the following plant:

- 30 ton crawler crane
- 60 kW vibratory hammer (with a 329 kN driving force).
- 12" casing pipe with shoe cap.
- 250 kW generator.

The casing pipe, which is capped by a shoe is driven into the ground to the desired depth. Again, a hole of Ø 300mm is formed and the soils is pressed both horizontally and vertically. Uplift of the casing pipe is conducted by hammer and crane. Up to a 4m length of the prepared hole will be filled at a time by sand and then again, the shoe equipped casing pipe will be returned to the hole. After that, vibration will be applied by vibratory hammer which will ensure the compactions of the sand fill. Again the casing pile will be uplifted and further sand will be poured into the hole, with subsequent compaction following the same procedure as before. In this way, the total length of the hole will be filled by compacted soil.

5.4.2 Prefabricated Vertical Drains

Prefabricated Vertical Drains are already implemented in Bangladesh and more specifically the Khulna Region for cohesive clay soil types, the employed technique is ground improvement by Prefabricated Vertical Drains (often in conjunction with pre-loading). Prefabricated Vertical Drains are also known at Wick Drains or Band Drains, and are typically used to accelerate the consolidation of embankments built of fine grained soils. This is normally to expedite construction and limit long term settlement.

The construction of a new embankment or structure induces additional stresses on the ground that can create unacceptable long term settlements during the life of an embankment or structure. A preloading programme can be designed to induce these settlements in an accelerated time frame and minimize the long term residual settlements to be within acceptable limits. Fine grained soils such as Clays and Silts are usually saturated (such as those we find in the Khulna Region) and therefore, settlements can only occur if the excess water is expelled through the voids in the soil grains and particles. These soils also tend to have a low permeability, and so the reduction of pore water pressure can be a slow process. Prefabricated vertical drains consist of a flat or cylindrical plastic core wrapped in a geotechnical fabric, and allow water to drain up through the center of the drain. These come in a variety of sizes and shapes to meet a variety of soil and site conditions. Vertical drains can be used to increase the rate of consolidation, delivering substantial programme savings for the build times of earth embankments for many types of land raising schemes.

Prefabricated vertical drains are installed by pushing a hollow steel mandrel, which house the drain material, and are set out on a grid pattern. The mandrel is driven into the ground by the rig, once at the required depth the mandrel is removed, leaving the vertical drain anchored by a steel anchor plate that holds the drain securely in place. The mandrel can penetrate soils up to a tip resistance of 5MPa, firmer soils can be penetrated by the use of vibrators or pre-drilling. A temporary surcharge embankment needs to be combined with the installation of the Vertical Drains in order to expedite full or partial primary consolidation, as well as induce several years of secondary consolidation settlement. Placement of the embankment and the additional temporary surcharge embankment are placed in phases, to avoid the risk of slip failure. Real time monitoring of the geotechnical parameters, including pore pressures and horizontal displacement, are monitored throughout the consolidation period. These instruments are installed to validate the design and the safe phasing of the embankment construction. These results will also be used to back analyse the design and access the consolidation process.

A prefabricated Vertical Drain (PVD) solution was used in Kaliakoir Bypass. PVD has also been used in other projects such as: Chittagong port (2000 Mir Akhter and 2010 PBL); Dhaka Chittagong Rail way Track (Max); Tongi Bhairob (Toma); Rangunia Power Plant (Pbl); Siddirgonj 435 mw (NDE); Kashiani Gopalgonj (Max); Kaliakor bypass (Abdul Monem Ltd.)

Dhar *et al* (2011) similarly examined 'Ground Improvement using Pre-loading with Prefabricated Vertical Drains'. Their studies focussed on a container yard that was constructed for handling of loaded containers at Chittagong Sea Port in Bangladesh. The contained yard is reported as having an area of 60,700 m2 over a sub-soil that included a layer of soft clayey silt/silty clay at depths of 0.0m to 3.5m below ground level. The thickness of the soft stratum was found to vary from 3.0m to 7.0m. A program of ground improvement using pre-loading with prefabricated vertical drains was undertaken to pre-consolidate the compressible sub-soils, which was followed by field monitoring. Dhar *et al* found that the classical theories could effectively be used in calculating the consolidation settlement and the time for consolidation. The authors reported that predicted settlements and the consolidation time matched reasonably with the measured values. To account for smear effects2 the coefficient of consolidation and the coefficient of permeability were taken as those for vertical flow. Predictions with smear diameter equal to two times the equivalent drain diameter provided an upper bound of the consolidation time while prediction without consideration for smear effects provided a lower bound of the consolidation time for the container yard project. Dhar

[2] An annular zone, called a smear zone, is considered in the soil surrounding the drain to account for the disturbance caused by the installation of the drain. The permeability of the smear zone in the vicinity of the drain is reduced compared to the native soil due to installation disturbance. Several methods are available to account for the smear effects in the design i.e., Yoshikuni and Nakanodo (1974), Hansbo (1981), Xie (1987) and others.

et al made the following conclusions based on the design and field monitoring of the ground improvement work:

- A detailed laboratory investigation is useful for determining the geotechnical design parameters for analysis of consolidation with prefabricated vertical drains.
- Based on the laboratory investigations, the following design values were developed:
  - Coefficient of consolidation – vertical drainage (Cv) = 7.5 m2/year
  - Coefficient of consolidation – horizontal drainage (Ch) = 15.5 m2/year
  - Coefficient of vertical permeability (kv) = 0.047 m/year
  - Coefficient of horizontal permeability (kh) = 0.073 m/year
  - These corresponded to a value of 2.07 for the ratio of the horizontal to vertical coefficient of consolidation (Ch/Cv).
  - These corresponded to a value of 1.53 for the ration of the horizontal to vertical coefficient of permeability (kh/kv).
  - The coefficient of compressibility (Cc) from the laboratory tests ranged from 0.17 to 0.45.
- Classical theories of consolidation with the parameters from laboratory tests resulted in estimates of the ground settlements and the consolidation time that were similar to those observed during field monitoring. The one dimensional consolidation theory was found reasonable in estimating the settlements for the 60700 m2 area overlying 3.0 m to 7.0 m thick compressible soil. The Hansbo theory of radial drainage successfully estimated the time of consolidation.
- The Hansbo theory without consideration for smear effects provided lower bound of the consolidation periods while estimation with smear diameter two times the equivalent drain diameter provided upper bound of the consolidation periods.
- To account for smear effects, the assumptions for the coefficient of horizontal consolidation and the coefficient of horizontal permeability as those for vertical flow (i.e. Ch = Cv and ks = kv) was found satisfactory for the container yard project.
- The effect of drainage congestion can generally be neglected in most prefabricated vertical drain with sufficient discharge capacity.
- Installation of the vertical drains reduced pre-consolidation time significantly (from about 1 to 5 years without vertical drain to about 50 days with PVDs).

5.4.3 Jute Geotextiles

Khan et al (2014) detail how, as part of field trials in different rural locations of Bangladesh, a total of 5.0 km of rural roads have been constructed using Jute Geotextiles (JGT). The trial sites were selected on the basis that a subgrade California Bearing Ratio (CBR) values of > 3.0% was not achievable without adopting special means. The methodology used for the construction of road pavement using JGT is as follows:

- Firstly, an Improved Subgrade (ISG) layer consisting of 75 mm of compacted sand is placed on top of subgrade.
- Secondly and immediately on top of the ISG layer, the specified JGT is laid. The JGT is overlapped and pegged out in accordance with a set criteria.
- Thirdly, another layer of ISG is placed on top of the JGT.
- The rest of construction of pavement follows, in accordance with the usual practice of placing a sub-base layer followed by a base layer and black top.

Khan et al explain that a series of monitoring and performance evaluations was undertaken at different time intervals by obtaining field CBR values along the same road sections to evaluate the efficacy of the JGT. The test results revealed that the load carrying capacity of the road sections increases from 1.5 to 7.0 times due to use of JGT over a range of time interval. Khan et al hypothesized that the load carrying capacity of the JGT reinforced subgrades increased through three different mechanisms:

1) Shear strength improvement by membrane action of JGT until it decomposes.
2) Absorption of moisture from subgrade by JGT resulting in an increased dry density of subgrade.
3) Consolidation of subgrade due to surcharge load of ISG, sub-base and base layer along with a percentage of traffic load.

Khan et al noted that the economic benefit and durability enhancement of the rural roads constructed using JGT were the obvious consequences.

5.4.4 Laboratory Based Ground Improvement Studies

The available information sources for the literature review, reveal that there have been a number of laboratory studies undertaken in Bangladesh to assess different ground improvement techniques:

5.4.4.1 Rice Husk Ash

Sarkar et al (2012) in their paper: "Interpretation of Rice Husk Ash on Geotechnical Properties of Cohesive Soil" set out to demonstrate the effects of rice husk ash (RHA) on the geotechnical properties of soil in stabilized forms specifically examining the strength, workability, compaction and compressibility characteristics. Sarkar et al undertook a suite of laboratory tests including compaction, Atterberg limits, free swell index, unconfined compressive strength, direct shear and consolidation tests. These tests were conducted on original soil samples and samples where different percentages of RHA content had been blended in. The paper details the observations that:

- The maximum dry density of the soil samples decreased with the addition of RHA because of the lower specific gravity of RHA.
- The value of optimum moisture content of RHA treated soil increased because of the pozzalonic action of RHA and soil, which needs more water.
- The value of liquid limit and plastic limit also increased with the increasing percentage of RHA whereas the value of plasticity index decreased.
- Increasing the amount of RHA caused a decrease in shrinkage limit as well as an increase in shrinkage ratio which improved the shear strength characteristics of soil.
- The pozzalonic behaviour of RHA made the RHA treated soil coarser than original soil samples due to the agglomerations of RHA and soil particles.
- The above detailed improvements changed the classification of the soil from clay to silt due to the increase in particle sizes for the agglomeration of clay particles with RHA.
- The free swell index test result showed a negative relationship with RHA as it decreased with the increase of RHA content (which the authors concluded would reduce the possibility of crack formation on the surface of foundation).
- The maximum unconfined compressive strength was obtained for 10% mass of RHA content.

- The optimal shear strength envelope of soil was obtained for an RHA content of 10% mass.
- The cohesion of soil showed an increasing order for the first 5% mass of RHA content and after that, this value decreased with the addition of RHA whereas the angle of internal friction showed a positive relationship with RHA content.
- From the consolidation test result, the authors concluded that the values of compression index decreased with the increases of RHA and the initial void ratio showed positive relation with RHA.

Sarkar et al (2012) concluded that their study demonstrated an improvement of all the geotechnical properties of RHA treated soil: their test results showed that due to the addition of RHA to the soil, the soil could be made lighter which lead to a decrease in dry density. The optimum moisture content increased due to the pozzalonic action of RHA and soil. RHA treatment reduced free swelling and compressibility. The unconfined compressive strength and shear strength could be optimized with the addition of 10% RHA.

5.4.4.2 Cement Stabilised Soil

In their paper "Engineering Behaviour of Cement Stabilized Soil: New Statistical Model" Asma et al (2013) explain how deep cement mixing has recently been used to combat the low strength properties, high compressibility and high swell-shrinkage characteristics of soft soils that render them inappropriate as a formation for building foundation or for other geotechnical works by improving the strength and reducing the problematic deformation characteristics of soft soils. Asma *et al* examine the parameters which have a significant influence on the strength of cement stabilized soil. Identifying them as being:

- Water content;
- Liquid limit;
- Quantity of cement added;
- Curing time.

The authors studied the compressive strength of clayey-silt soil, stabilized with varying quantities of cement. The laboratory results were used for the development of a non-linear regression equation that Asma *et al* say "…best relates the compressive strength of a stabilized soil to the aforementioned parameters considered as descriptor variables". The authors stabilised soft samples with 5 No. different cement contents and curing was conducted for 3, 7, 28 and 90 days. The results returned demonstrated that compressive strength increased with an increase in cement content and the subsequent curing period. It was noted that the liquid limit decreased with the increasing curing time but at the also increased with the rising cement content. Again, water content was observed to decrease with the increasing curing time and cement content. Asma et al concluded that the results they obtained results from their various tests and analysis on this cement stabilized soil were a basis for further research and field application.

Mahamud *et al* (2008) conducted a 'Laboratory Investigation on the Behaviour of Improved Organic Soil of Khulna Region'. The authors reported that 'conventional foundation systems' are not suitable for large structures in Khulna because an organic soil layer exists at a depth 10ft to 25ft (3m to 7.5m) from the existing ground surface. The authors explain that the existence of an organic soil layer in the aforementioned deposits results in excessive settlements due to its high compressibility and low shear strength. Mahamud *et al* explain that to overcome the problem, soil improvement techniques are usually adopted depending upon the type of construction. It is explained that it is necessary to ascertain the degree of improvement achieved for the different improved ground types prior to the selection of ground improvement techniques for a specific project. And so the authors undertook a laboratory investigation to determine the effect(s) of improvement techniques on reconstituted organic soil samples, to develop a guideline for selection, design and construction of suitable soil improvement methods for the Khulna region. The laboratory investigation conducted revealed that the implementation of a compacted sand bed improved the bearing capacity of organic ground significantly. The laboratory investigation also revealed that the compacted sand bed, with or without geotextile was effective in improving the bearing capacity of organic soil of the Khulna region and it was considered that it was better to avoid the use of a single column to improve organic soft ground. Mahamud et al report that the soft ground treated by compacted sand bed demonstrated a slowly declining load-settlement curve which they considered to represent a lower settlement and subsequently, a reduced possibility of excessive settlement. The authors conclude that the enhance properties of the improved ground, increase factor of safety for large structures and can avoid the risk of sudden failure of the foundation of said structures.

5.4.4.3 **Cement Columns**

Ahsan *et al* (2014) examined ‘Soft soil improvement by cement column’. They consider the cement column to be one of the most versatile and cost effective methods of soft ground improvement. Their paper explains how due to the scarcity of suitable development land for the rising population of Bangladesh, it is necessary to build on formally marginal, unsuitable ground by improving the soft soil. Their paper aims to define the effect of the cement column in improving such soft soil and assesses their installation technique by laboratory investigation comprising small scale tests. Ahsan *et al* (2014) state that the main objective of their study is to check the degree of improvement of soft ground due to the installation of the aforementioned cement columns. It is explained that a mixing machine (fabricated locally) was used to construct the cement column in the soft soil. ASTM D2166 was used to determine the unconfined compressive strength of the reconstituted soil. The derived unconfined compressive strength was then used to determine the bearing capacity of the soil. A “universal testing machine” was used for the determination of the load-settlement behaviour of the cement column improved ground. From their investigations, Ahsan et al observed that the bearing capacity of soft ground could be increased significantly through the installation of cement columns. Based on the laboratory investigation Ahsan et al made the following conclusion:

- The cement column can be applied up to a suitable depth.
- The bearing capacity of the soil is improved after installing the cement column.
- The study also showed that the improved soil by cement column will fail with a greater settlement.

Sarkar *et al* (2012) conducted a ‘Study on the Geotechnical Properties of Cement based Composite Fine-grained Soil’. Soil samples were collected from Khanjahan Ali Hall at Khulna University of Engineering & Technology (KUET). The addition of cement was found to improve the engineering properties of the available soil samples, specifically the strength, workability, compaction and compressibility characteristics. Laboratory tests including compaction, Atterberg limits, unconfined compressive strength, direct shear and consolidation tests were performed on original soil samples and soil samples to which were added different percentages of cement content. The test results showed that the soil could be made lighter which lead to a decrease in dry density and an increase in moisture content and reduced compressibility due to the addition of cement with the soil. Additionally, it was found that the unconfined compressive strength and shear strength of the soil could be optimized with the addition of a 7.5% mass cement content. The authors concluded that:

- The maximum dry density of soil decreased with the addition of cement
- The value of optimum moisture content of the cement treated soil increased because of the pozzalonic action of cement and soil, which requires more water.
- A series of liquid and plastic limit tests were performed on the untreated and cement treated soil samples. It was observed that the value of liquid limit and plastic limit increased with the increasing percentage of cement content, whereas the value of plasticity index showed different characteristics.
- The pozzalonic behaviour of the cement made the treated soil coarser than the original soil samples due to the agglomerations of cement and soil particles. This improvement changed the classification of the soil from clay to silt.
- The optimum unconfined compressive strength was obtained for 7.5% of cement content. The cohesion and the angle of internal friction of the soil showed an increasing order for the cement treated soaking samples.
- From the consolidation test result, it can be concluded that the values of compression index decreased with the increases of cement content and the initial void ratio increases for the cement treated soil.

5.4.4.4 **Chemical Admixtures:**

Rafizul *et al* (2012) examined: 'The effect of chemical admixtures on the geotechnical parameters of organic soil: a new statistical model'. The intention of their study was to illustrate the resulting geotechnical parameters of stabilized soil samples prepared in the laboratory after the mixing of cement, lime and bentonite at a varying content of 5, 10, 15, 20 and 25 % of dry mass of organic soil. To facilitate their work, organic soil samples were collected from four selected locations at Khulna region. In the laboratory, ASTM (2004) methods were followed to measure the relevant parameters of the stabilized soil samples. The results obtained revealed that:

- The compressive strength of stabilized soil increased with the increase of admixtures content and curing period.
- The liquid limit of all the stabilized soils decreased with the increasing of admixture content and curing period.
- Notably however, the stabilized soil for 100 % mixing of water had a higher liquid limit than that of stabilized soil of 50 % mixing of water.
- Dry density increased, whilst the optimum moisture content decreased with the increasing of admixture content.

The output of the study is a statistical model that can be used to prediction of strength improvement as a result of different quantities of various admixtures that has been validated by laboratory testing.

5.5 Summary of literature review at Inception Stage

Clearly, there is a sound basis of academic and technical knowledge on the qualities, occurrence and challenges posed by Khulna clay, often based on extensive field work and laboratory surveys, but with little progress into the provision of practical recommendations for field implementation through the Local Government Engineering Department.

In this regard, it is clear, budgetary, material, plant and labour constraints have a great bearing at present, on the ground improvement techniques that can be practicably employed in the Khulna Region and in the soft ground areas of Bangladesh as a whole. These considerable constraints are expected to exist beyond the near future, and so Mott MacDonald has focussed specifically on a suite of ground improvement techniques that can be used alone or in combination, to effect a positive change in the durability and longevity of rural roads in the Khulna Region.

Without wishing to discount any potential ground treatment option at this early stage (but bearing in mind the cost and availability of specialist plant associated with many options), it is considered that there are four techniques that are more suited for use and further development in Khulna Region. This is primarily due to their pre-existing availability in Bangladesh, widely available materials and non-specialist installation methods. The four ground improvement techniques are:

1. Sand Piles.
2. Precast Vertical Drains with consolidation.
3. Soil reinforcement by Jute Geotextile.
4. Cement stabilisation.

All four of the above listed techniques have been both researched and implemented in the field in Bangladesh, with varying degrees of success. Variations in subsequent performance characteristics of these solutions and even failure are likely to be primarily the result of an insufficient budget leading to:

- A lack of design information (i.e. soil data),
- A lack of standardised design guidance and design approaches.
- Inappropriate designs.
- Inconsistent / inadequate materials.
- Unsuitable / inadequate plant.
- Installation by unskilled labour.
- A lack of, or unsuitable construction supervision.
- Solutions not being built in accordance with the design.
- Little or no ongoing monitoring and preventative maintenance.

We intend to incorporate these considerations to understand and provide recommendations relating the relative merits and demerits of ground improvement techniques, global and local, for use in strengthening rural roads in Bangladesh.

6 Conclusions

The literature review has identified a body of work that has been undertaken to investigate and provide design solutions for constructing on the soft ground conditions present in the Khulna Region. This has been summarised and the salient points highlighted.

The availability and practicality of implementing ground improvement techniques within Bangladesh has been reviewed at a high level and techniques currently in use or considered practical for further development have been identified.

A two-stage programme of site inspections has been developed for field analysis representative locations. These sites will be characterised and a selection of sites will be identified for more detailed geotechnical review including limited ground investigation and basic laboratory testing.

This literature review and following field situation analysis report will form the basis of a research matrix to be developed for the laboratory testing and analysis, from which recommendations will be provided of the remedial measures to existing structures and guidelines for ground improvements for the construction of new rural roads in the study region.

7 References

The references used in the compilation of this report are listed below.

No.	Title	Author(s)	Date	No. of Pages	Source Publication
1	Interpretation of Rice Husk Ash on Geotechnical Properties of Cohesive Soil	Grytan Sarkar, Md. Rafiqul Islam, Dr. Muhammed Alamgir, Dr. Md. Rokonuzzaman	2012	7	Global Journal of researches in engineering Civil And Structural engineering
2	Geotechnical conditions of the deltaic alluvial plains of Bangladesh and associated problems	Mohammad A. MoUah	1993	15	Government Centre for Testing and Research, Ministry of Public Works
3	Application of Jute Geotextiles for Rural Road Pavement Construction	A J Khan, F Huq and S Z Hossain	2014	9	Ground Improvement and Geosynthetics GSP 238 ASCE 2014
4	A Guide to Ground Treatment	J M Mitchell, F M Jardine	2002	244	CIRIA
5	Design and construction of ground improvement works at Suvarnabhumi Airport	Seah, Tian Ho	2005	22	-
6	Engineering Geology of Khulna Metropolitan City Area	Reshad Md. , Ekram Ali, Mir Fazul Karim and Md. Zillur Rahman	2004	10	Bangladesh Journal of Geology
7	Engineering Behaviour of Cement Stabilized Soil: New Statistical Model	Asma, U.H., Rafizul, I.M., Hasibul, M.H., Roy, S., Didarul, M. and Shohel, M.R.	2013	10	Khulna University of Engineering & Technology
8	Evaluation of Foundation Difficulties over Soft Organic Soil	Arifuzzaman and Amanul Hasan	2013	10	University of Information Technology and Sciences, Dhaka, Bangladesh
9	A firm winner - Lime Cement Powder Mix for new road	-	2007	2	Ground Engineering
10	Ground Improvement Methods Recently Practiced to Solve the Geotechnical Engineering Problems in Bangladesh	Muhammad Alamgir and Khaled Hassan Chowdhury	2004	8	International Conference on Case Histories in Geotechnical Engineering
11	Ground Improvement using Pre-loading with Prefabricated Vertical Drains	Ashutosh Sutra Dhar, Abu Siddique and Syed Fakrul Ameen	2011	19	International Journal of Geoengineering Case Histories
12	Successful Highway Constrcution on Very Soft Soils	S. Vidmar, A. Gaberg and E. Kardelj	80s	7	-
13	Improvement the Strength of Inorganic Clayey Soil using Cement Additive	Nandan A. Patel and C. B. Mishra	2014	4	International Journal of Current Engineering and Technology
14	Innovative soft clay improvement technique using vacuum and dynamic compaction (HVDM)	Robert Y. Liang	2011	7	2011 Pan-Am CGS Geotechnical Conference
15	Investigating the Modifications in Properties of Clayey Soil Utilizing ppc for Variable Dynamic Compaction	Nandan A. Patel, C. B. Mishra, S. K. Dave, D. K. Parmar	2015	8	International Journal of Research in Engineering and Technology
16	Laboratory Investigation on the Behaviour of Improved Organic Soil of Khulna Region	M. A. Mahamud, M. Alamgir and M. J. Hossain	2008	7	International Conference on Case Histories in Geotechnical Engineering
17	New ground improvement technologies under restricted conditions in Japan	Kenji Harada, Jun Ohbayashi, Junnosuke Matsumoto, Yohtaro Kubo and Takeshi Akima	2015	6	The 15th Asian Regional Conference on Soil Mechanics and Geotechnical Engineering
18	Prediction of soil type and standard penetration test (SPT) value in Khulna City, Bangladesh using general regression neural network	Grytan Sarkar, Sumi Siddiqua, Rajib Banik and Md. Rokonuzzaman	2015	14	Quarterly Journal of Engineering Geology and Hydrogeology
19	Improvement of Soft Bangkok Clay by Use of Prefabricated Vertical Drain	Z. C. Moh, T. Ruenkrairergsa, P. C. Lin and M. Karim	1998	8	Proceedings of 13th Southeast Asian Geotechnical Conference
20	Soft soil improvement by cement column	MD. Kamrul Ahsan, MD. Istiaq Hossain, Masum Shaikh and	2014	6	International Journal of Advanced Structures and Geotechnical

No.	Title	Author(s)	Date	No. of Pages	Source Publication
		Muhammed Alamgir			Engineering
21	Statistical Evaluation of bearing capacity of Khulna Sub-Soil	Rajib Banik, Nazma Khatun, Masum Shaikh and Md. Keramat Ali Molla	2014	5	International Journal of Advanced Structures and Geotechnical Engineering
22	Strength and Compressibility Characteristics of Reconstituted Organic Soil at Khulna Region of Bangladesh	Tahia Rabbee and Islam M. Rafizul	2012	10	International Journal of Engineering and Technology
23	Study on the Geotechnical Properties of Cement based Composite Fine-grained Soil	Grytan Sarkar, Md. Rafiqul Islam, Dr. Muhammed Alamgir, Md. Rokonuzzaman	2012	8	International Journal of Advanced Structures and Geotechnical Engineering
24	Some Geotechnical Studies on Bangladesh Soils: A Summary of Papers between 1957-96	M. Serajuddin	1998	28	Journal of Civil Engineering, The Institution of Engineering, Bangladesh
25	The effect of chemical admixtures on the geotechnical parameters of organic soil: a new statistical model	Islam M. Rafizul, Md. Assaduzzaman and Muhammed Alamgir	2012	12	Int. Journal of Applied Sciences and Engineering Research
26	Urban Geology: A Case of Khulna City Corporation, Bangladesh	Dilip Kumar Adhikari, Mrinal Kanti Roy, Dilip Kumar Datta, Partha Jit Roy, Dhiman Kumer Roy, A.R.Malik and A.K.M. Badrul Alam	2006	13	J. Life Earth Sci.
27	GeoGuide 1: Road Embankments on Soft Soils: Occurrence & General Nature of Soft Soils	-	2002	139	Ministry of Settlement and Regional Infrastructure
28	GeoGuide 2: Road Embankments on Soft Soils: Site Investigation of Soft Soils: Design & Fieldwork	-	2002	91	Ministry of Settlement and Regional Infrastructure
29	GeoGuide 3: Road Embankments on Soft Soils: Site Investigation of Soft Soils: Laboratory Testing	-	2002	133	Ministry of Settlement and Regional Infrastructure
30	GeoGuide 4: Road Embankments on Soft Soils: Design and Construction Methods	-	2002	183	Ministry of Settlement and Regional Infrastructure
31	Indonesian Geotechnical Materials and Construction Guides Stage 1, Seminar 1, The Origins, Nature and Characterization of Soft Soils, Organic Soils and Peat	Prof. A. McGown and Prof. P.M. Jarrett	1997	90	Institute of Road Engineering Agency for Research and Development Ministry of Public Works, Indonesia
32	Seminar 2, Tropical Soft Soils and Peats	Prof. A. McGown and Prof. P.M. Jarrett	1997	140	Institute of Road Engineering Agency for Research and Development Ministry of Public Works, Indonesia
33	Indonesian Geotechnical Materials Construction Guide Project	-	1998	117	Institute of Road Engineering Agency for Research and Development Ministry of Public Works, Indonesia
34	Road Construction Over Tropical Peats and Organic Soils in Indonesia	Ida Rumkita Sebayang	1998	224	University of Strathclyde
35	Construction of Roads Over Indonesian Tropical Inorganic Soft Soils	Romaidah Situmorang	1998	250	University of Strathclyde

Appendix A: Review of Ground Investigation and Laboratory Testing in Bangladesh

Formation of boreholes

The manual percussion drilling method is predominantly used for ground investigation in Bangladesh. The main reasons to use the manual percussion drilling method are the simplicity of the apparatus and availability of cheap labor to conduct the works. Recently due to the requirements of some consultants, rotary percussion is also now being employed by some Bangladesh site investigation companies. The companies that now have rotary drilling facilities are private organizations and comprise:

- Prosoil Foundation Consultant.
- ICON Engineering Services.
- DCL Companies.

During ground investigations conducted in Bangladesh, it is typical for SPT (Standard Penetration Test) data to be recorded and for disturbed and undisturbed samples to be retrieved.

In-situ testing

Some in-situ tests are also available and conducted in Bangladesh and these include:

- Dutch Cone Penetration Test.
- Plate Load Test.
- Screw Plate Load Test.
- Borehole Shear Test.
- Pressuremeter Test.
- Phicometer Tests
- Dynamic Cone Penetration (DPL, DPM and DPSH).

Available laboratory testing techniques

Predominantly in accordance with ASTM requirements – **NB:** There is no accreditation process to ensure that other certification practices are acceptable).

Index & Physical properties:

- Specific Gravity.
- Unit weight (wet & dry).
- Void ratio (Specific Gravity & Unit Weight).
- Moisture content.
- Liquid limit and Plastic limit.
- Linear Shrinkage.
- Shrinkage limit.
- Grain size analysis by wet sieving and Hydrometer.
- Organic matter content - Loss on ignition.
- Sand equivalent test.

Compaction and density tests:

- Maximum and Minimum density of cohesionless soil.
- Standard Proctor Compaction test.
- Modified Proctor Compaction test.

Permeability and seepage characteristics:
- Permeability of cohesive soil by 1-dimensional consolidation.
- Permeability of cohesionless soil (falling head)
- Permeability of cohesionless soil (constant head)

Consolidation and swelling characteristics:
- One dimensional consolidation (e - log p, Cc,Cr,Cv)
- Swelling Index / Swelling Pressure

Strength and deformation characteristics:
- Unconfined compression test
- Lab. California Bearing Ratio (CBR) of soils

Direct shear tests:
- Consolidated Drained test
- Consolidated quick test
- Unconsolidated quick test

Triaxial shear tests:
- Consolidated Drained compression test.
- Consolidated undrained compression test with pore pressure.
- Consolidated undrained compression test without pore pressure.
- Unconsolidated undrained compression test without pore pressure.
- Consolidated undrained extension test without pore pressure.
- Cyclic Triaxial Test.

Testing facilities available in Khulna

Three organizations have laboratory testing facilities available in Khulna and these are:
1. Khulna University of Engineering and technology
2. Roads and Highways
3. Local Government Engineering Department (LGED)

The abovementioned organizations have the facilities to conduct the following laboratory tests:
- Specific gravity.
- Unit weight (wet & dry).
- Void ratio (Specific gravity & Unit Weight).
- Moisture content.
- Liquid limit and Plastic limit.
- Linear Shrinkage.
- Shrinkage limit.
- Grain size analysis by wash sieving.
- Hydrometer, sieve analysis & specific gravity.

Appendix B: Site visit programme for initial earthwork inspections

Ground Improvement for Khulna Soft Clay Soil Project

Nur Empori, Plot 77 (Level 6)
Road 11, Block M, Banani, Dhaka 1213   Telephone: +880 (2) 9861194, 9898443, 9892063

Memo No.
Date: 22.09.2016

Field Visit Program

For: **Initial site inspections**

Period: From 23rd October 2016 to 29th October 2016 **(tentative)**

Date & time	Purpose of Visit	Location	Activity	Remarks
23/10/2016	To do Preliminary investigation and site selection	Khulna (visit sites of location 12,6)	Travel from Dhaka to Jessore by Air and it will take about 1 hour to reach Flight take off from Dhaka: 8.15am Landing in Jessore: 8.55 am Travel to Khulna City by rental car. Visit Khulna LGED at 12 pm, Site visit starts after lunch at 2.00 pm and ends at 5 pm	Night spent in Khulna City Inn Ltd Hotel, B-1, Mojid Sarony, KDA C/A, Khulna- 9100, Bangladesh Contact Person : Md. Rokib ul Alam, Executive Engineer, 01712-029240 A S M Tarikul Hasan, Senior Assistant Engineer 01730-193721
24/10/2016	-Do-	Khulna (visit sites of location 9,3,8)	Site visit starts at 9 am.	Night spent in Khulna City Inn Ltd Hotel, B-1, Mojid Sarony, KDA C/A, Khulna- 9100, Bangladesh Contact Person : Md. Rokib ul Alam, Executive Engineer, 01712-029240 A S M Tarikul Hasan, Senior Assistant Engineer 01730-193721
25/10/2016	-Do-	Bagerhat (location 10, 11)	Travel to Bagerhat starting at 8 am, Visit Bagerhat LGED at 10 am start Site visit at 10.30 am	Contact Person : Mohammmad Shahadat Hossain Executive Engineer, LGED Mobile : +8801711240957 Email: xen.bagerhat@lged.gov.bd LGED guest house: Night Spend in Bagherhat. Address: LGED Rest House, LGED XEN Office, Bagherhat.
26/10/2016	-Do-	Bagerhat (location 7)	Site visit starts at 8 am. Back to Bagerhat city for lunch at 1.30 pm Travel towards Satkhira starting at 2.30 pm	Contact Person : Mohammmad Shahadat Hossain Executive Engineer, LGED Mobile : +8801711240957 Email: xen.bagerhat@lged.gov.bd Night Spend in Satkhira. Address : Hotel Al Kashem, Satkhira

Date & time	Purpose of Visit	Location	Activity	Remarks
27/10/2016	-Do-	Satkhira (location 2,4)	Site visit starts at 8 am.	Night Spend in Satkhira. Address : Hotel Al Kashem, Satkhira Contact Person : A S M Sahedur Rahim Executive Engineer 01715-053010 Md. Jakaria Senior Assistant Engineer 01740-959208
28/10/2016	-Do-	Satkhira (location 5)	Site visit starts at 8 am.	Night Spend in Satkhira. Address : Hotel Al Kashem, Satkhira Contact Person : ASM Shahedur Rahman Executive Engineer, LGED Mobile : +8801715053010 Email: xen.satkhira@lged.gov.bd
29/10/2016	-Do-		Travel back to Jessore by car starting at 5.30 am and travel back to Dhaka by 9.25 am flight	

Note: LGED local staffs shall be available to travel/participate during the site works to ensure knowledge transfer and field level guidance for security.

List of people attending the Field Visit:

1) Signature: .... Name: Shamsul Islam Designation: Deputy Team Leader

2) Signature: .... Name: Abdullah AL Baky Designation: Research Associate

Visit program forwarded by:	Visit program approved by:	Visit program approved by:
______________________	______________________	______________________
Abdullah Al Baky, Research Associate	Ian Duncan, Team Leader	Ben Witjes, Country Director

Copy to:

1. Md. Abul Kalam Azad, Project Director, Climate Resilient Reinforced Concrete Structure in Marine environment of Bangladesh Project, LGED, Dhaka
2. Md. Abul Bashar, Superintending Engineer (City Planning & Quality Control), RDEC Bhaban, Level – 4, LGED, Dhaka.
3. Md. Rokib ul Alam, Executive Engineer, LGED, Khulna
4. ASM Shahedur Rahman, Executive Engineer, LGED, Satkhira
5. Mohammmad Shahadat Hossain, Executive Engineer, LGED, Bagerhat
6. Deputy Commissioner, Bagherhat District
7. Deputy Commissioner, Khulna District
8. Deputy Commissioner, Satkhira District
9. Superintend of Police, Khulna District
10. Superintend of Police, Bagherhat District
11. Superintend of Police, Satkhira District

Specific Procedures/other details:

- Travel Details: one rented car for MMB
- Three hourly statuses to MMB office (by phone/email) or any undue delay/incident etc.
- Travel in daylight hours
  Itinerary shared with Mott Mac Donald /all LGED counterparts and confirmed

Ground Improvement for Khulna Soft Clay Soil Project

Nur Empori, Plot 77 (Level 6)
Road 11, Block M, Banani, Dhaka 1213 Telephone: +880 (2) 9861194, 9898443, 9892063

Memo No.
Date: 22.09.2016

Field Visit Program

For: **Detailed inspections and assessment**

Period: From 11th November 2016 to 25th November 2016 (indicative)

Date & time	Purpose of Visit	Location	Activity	Remarks
11/11/2016	To undertake detailed investigation and sample collection for soil testing	TBA	TBA	
12/11/2016	-Do-			
13/11/2016	-Do-			
14/ 11/2016	-Do-			
15/ 11/2016	-Do-			
16/ 11/2016	-Do-			
17/ 11/2016	-Do-			
18/ 11/2016	-Do-			
19/11/2016	-Do-			
20/ 11/2016	-Do-			
21/ 11/2016	-Do-			
22/ 11/2016	-Do-			
23/ 11/2016	-Do-			
24/ 11/2016	-Do-			
25/ 11/2016	-Do-			

Note: LGED local staffs shall be available to travel/participate during the site works to ensure knowledge transfer and field level guidance for security.

List of people attending the Field Visit:

1) Signature: .... Name: Ian Duncan Designation: Team Leader

2) Signature: .... Name: Lewis Phillips Designation: Engineering Geologist

3) Signature: .... Name: Shamsul Islam Designation: Deputy Team Leader

4) Signature: .... Name: Abdullah AL Baky Designation: Research Associate

Visit program forwarded by: Visit program approved by: Visit program approved by:

______________________ ______________________ ______________________

Abdullah Al Baky, Research Associate Ian Duncan, Team Leader Ben Witjes, Country Director

Copy to:

12. Md. Abul Kalam Azad, Project Director, Climate Resilient Reinforced Concrete Structure in Marine environment of Bangladesh Project, LGED, Dhaka
13. Md. Abul Bashar, Superintending Engineer (City Planning & Quality Control), RDEC Bhaban, Level – 4, LGED, Dhaka.

14. Md. Rokib ul Alam, Executive Engineer, LGED, Khulna
15. ASM Shahedur Rahman, Executive Engineer, LGED, Satkhira
16. Mohammmad Shahadat Hossain, Executive Engineer, LGED, Bagerhat
17. Deputy Commissioner, Bagherhat District
18. Deputy Commissioner, Khulna District
19. Deputy Commissioner, Satkhira District
20. Superintend of Police, Khulna District
21. Superintend of Police, Bagherhat District
22. Superintend of Police, Satkhira District

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Specific Procedures/other details:

- Travel Details: one rented car for MMB
- Three hourly statuses to MMB office (by phone/email) or any undue delay/incident etc.
- Travel in daylight hours
- Itinerary shared with Mott Mac Donald /all LGED counterparts and confirmed

Appendix C: Revised Work plan

		12/08/2016	19/08/2016	26/08/2016	02/09/2016	09/09/2016	16/09/2016	23/09/2016	30/09/2016	07/10/2016	14/10/2016	21/10/2016	28/10/2016	04/11/2016	11/11/2016	18/11/2016	25/11/2016	02/12/2016	09/12/2016	16/12/2016	23/12/2016	30/12/2016	06/01/2017	13/01/2017	20/01/2017	27/01/2017
	Week:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
0	**PROJECT LAUNCH**																									
0.1	Inception Meeting	♦																								
1	**INCEPTION & LITERATURE REVIEW**	||--------10wks-------||																								
1.2	Literature Review																									
1.2	Desktop study																									
1.3	Develop research matrix																									
1.4	Draft Inception Report																									
1.5	Internal review Inception Report																									
1.6	Issue Inception Report							♦																		
1.7	Client review																									
1.8	Amend and issue Final Inception Report										♦															
2	**FIELD SURVEY**										||-------9wks------||															
2.1	Site Selection																									
2.2	Field Survey																									
2.3	Draft field situation analysis report																									
2.4	Internal Review field situation analysis report																									
2.5	Issue field situation analysis report															♦										
2.6	Client review																									
2.7	Amend and issue final field situation analysis report																		♦							
3	**GROUND INV. AND LAB. TESTING**													||----------16wks------------												
3.1	Site Selection																									
~~3.2~~	~~Boreholes~~																									
3.3	In Situ Testing																									
3.4	Trial Pits & Soil Sampling																									
~~3.5~~	~~Laboratory testing - consolidation~~																									
~~3.6~~	~~Laboratory testing - strength~~																									
3.7	Laboratory testing - classification																									
3.8	Laboratory testing – other																									
3.9	Issue interim laboratory test report																									♦
3.10	Analysis of Lab test data																									
3.11	Ongoing research (from research matrix)																									
3.12	Development of ground models/assessment																									
3.13	Verification and comparison of modelling																									
4	**LABORATORY TESTING REPORT**																									
4.1	Draft Field and Lab test report																									
4.2	Internal review Field and Lab test report																									
4.3	Issue Field and Lab test report																									
4.4	Client review																									
4.5	Amend and issue final Field and Lab test report																									
5	**DRAFT OVERALL REPORT**																									
5.1	Draft overall report																									
5.2	Internal review overall report																									
5.3	Issue overall report																									
5.4	Client review																									
6	**STAKEHOLDER WORKSHOP**																									
6.1	Scope and prepare workshop																									
6.2	Invite attendees																									
6.3	Hold workshop																									
6.4	Draft workshop report																									
6.5	Internal review workshop report																									
6.6	Issue Workshop report																									
6.7	Client review																									
6.8	Amend and issue final Workshop report																									
7	**FINAL REPORT**																									
7.1	Draft report																									
7.2	Review report																									
7.3	Issue report																									
7.4	Client review																									
7.5	Amend and issue final report																									

		03/02/2017	10/02/2017	17/02/2017	24/02/2017	03/03/2017	10/03/2017	17/03/2017	24/03/2017	31/03/2017	07/04/2017	14/04/2017	21/04/2017	28/04/2017	05/05/2017	12/05/2017	19/05/2017	26/05/2017	02/06/2017	09/06/2017	16/06/2017	23/06/2017	30/06/2017	07/07/2017	14/07/2017	21/07/2017	28/07/2017	04/08/2017
	Week:	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
0	**PROJECT LAUNCH**																											
0.1	Inception Meeting																											
1	**INCEPTION & LITERATURE REVIEW**																											
1.2	Literature Review																											
1.2	Desktop study																											
1.3	Develop research matrix																											
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1.6	Issue Inception Repot																											
1.7	Client review																											
1.8	Amend and issue Final Inception Report																											
2	**FIELD SURVEY**																											
2.1	Site Selection																											
2.2	Field Survey																											
2.3	Draft field situation analysis report																											
2.4	Internal Review field situation analysis report																											
2.5	Issue field situation analysis report																											
2.6	Client review																											
2.7	Amend and issue final field situation analysis report																											
3	**GROUND INV. AND LAB. TESTING**	--16wk---||																										
3.1	Site Selection																											
~~3.2~~	~~Boreholes~~																											
3.3	In Situ Testing																											
3.4	Trial Pits & Soil Sampling																											
~~3.5~~	~~Laboratory testing - consolidation~~																											
~~3.6~~	~~Laboratory testing - strength~~																											
3.7	Laboratory testing - classification																											
3.8	Laboratory testing – other																											
3.9	Issue interim laboratory test report																											
3.10	Analysis of Lab test data	■	■	■																								
3.11	Ongoing research (from research matrix)	■	■	■																								
3.12	Development of ground models/assessment			■	■	■																						
3.13	Verification and comparison of modelling					■																						
4	**LABORATORY TESTING REPORT**					||----7wks-----||																						
4.1	Draft Field and Lab test report					■	■	■																				
4.2	Internal review Field and Lab test report								■																			
4.3	Issue Field and Lab test report									♦																		
4.4	Client review									■	■																	
4.5	Amend and issue final Field and Lab test report											♦																
5	**DRAFT OVERALL REPORT**												||---6wks---||															
5.1	Draft overall report												■	■	■													
5.2	Internal review overall report															■												
5.3	Issue overall report																♦											
5.4	Client review																■	■										
6	**STAKEHOLDER WORKSHOP**								||--------------------22 wks--------------------||																			
6.1	Scope and prepare workshop	■	■	■	■	■	■	■	■	■	■	■			■	■	■	■										
6.2	Invite attendees			■	■	♦																						
6.3	Hold workshop																	♦										
6.4	Draft workshop report																	■	■									
6.5	Internal review workshop report																			■								
6.6	Issue Workshop report																				♦							
6.7	Client review																				■	■						
6.8	Amend and issue final Workshop report																						♦					
7	**FINAL REPORT**																						||---6wks---||					
7.1	Draft report																						■	■				
7.2	Review report																								■			
7.3	Issue report																									♦		
7.4	Client review																									■	■	
7.5	Amend and issue final report																											♦

Appendix D: Additional laboratory testing costs for field surveys

Introduction

A number of potential rural road study sites were identified in section 10.2 of the Inception Report and following a series of site walkover surveys and assessments, these 35 No. study sites were paired down to a *finalised* site list which is presented in section 10.3 of the Inception Report. The finalised site list details the rural road locations that will be taken forward for more detailed investigation and assessment and therefore be subject to intrusive ground investigation with associated *in-situ* and laboratory geotechnical testing. These sites or a further selection of them, may potentially be subject to ground improvement field trials.

The project tender documents stated that "All equipment and laboratory facilities for testing will be provided by LGED". Whilst we continue to work closely with LGED, the following sampling, testing and additional resources are required to complete the study site ground investigations but cannot be provided by LGED.

Further to our recommendations at proposal stage, we propose that these additional resources are procured by Mott MacDonald and funded as a variation to the original contract on a cost +12.5% administration fee basis. Where there remain elements of uncertainty surrounding the rural roads and associated structures that will be inspected, and the requirement to maintain a degree of flexibility for the engineers on site to determine the number of samples to be taken, the budget provided gives an indicative ceiling, not to be exceeded without prior approval from Cardno. Approval from the client for the condition survey budget is requested by 30th September to facilitate timely preparations for the condition survey in country.

The budget for the ground investigation surveys is exclusive of the budgetary requirements for the potential ground improvement field trials, for which a similar budget will be submitted with the *Field Survey and Condition Report*.

Additional Requirements

Some rudimentary geotechnical assessment and geotechnical characterisation will be required for the locations detailed in the abovementioned *Finalised Site List.*

Intrusive ground investigation will be need to be conducted to facilitate the geotechnical assessment and site characterisation, and it is envisaged that this will take the form of shallow hand excavated pits, dug by members of Mott MacDonald's project team, from which samples will be retrieved for laboratory testing. Typically, 5 No. hand excavated pits will be excavated per site. It is anticipated that *in-situ* testing will be conducted by Mott MacDonald's staff using pocket penetrometers and a hand shear vane.

Costs incurred for this intrusive ground investigation and associated testing will purely be for the geotechnical laboratory testing. Typical costs per laboratory test item and estimated costs both per study site, and for 5 No. study sites are presented overleaf.

Cost Estimates

Test Type	Test Standard	Price / Test (Bd. Taka)	No. Required / site	Total / Site. (Bd. Taka)
Specific Gravity	ASTM D854 – 14 ASTM D5550 - 14	550	5	2,750
Unit Weight *(Wet & Dry)*	ASTM D1556 ASTM D1556M-15e1 ASTM D7263-09	550	5	2,750
Void Ratio (*Specific Gravity & Unit Weight)*	ASTM D854 – 14 ASTM D1556 / ASTM D1556M-15e1 ASTM D7263-09	850	5	4,250
Moisture Content	ASTM D2216 ASTM D3017	450	10	4,500
Liquid Limit & Plastic Limit	ASTM D4318	750	10	7,500
Linear Shrinkage	ASTM D423 – 1996	750	5	3,750
Shrinkage Limit	ASTM D4943 – 08	750	5	3,750
Grain Size Analysis *(by wet sieving and hydrometer)*	ASTM D422 ASTM D421	1000	10	10,000
Organic Matter Content *(Loss on ignition)*	ASTM D2974 – 14	4500	5	22,500
Sand equivalent test	ASTM D2419 – 14	8500	5	42,500
Maximum & Minimum Density *(of cohesionless soil)*	ASTM D4253 – 16	7500	5	37,500
Standard Proctor Compaction Test	ASTM D698 – 12e2	4500	5	22,500
Modified Proctor Compaction Test	ASTM D1557 – 12e1	5500	5	27,500
			TOTAL PER STUDY SITE:	**191,750.00**
			TOTAL FOR 5 No. SITES:	**958,750.00**
			+ 12.5 % Administration Charge:	**119,843.75**
			Total additional cost to project (excluding vat and excluding tax):	**1,078,593.75 (£10,600.00)**