Modification / Stabilisation of Low Strength Cohesive Soils under Foundations and Floor Slabs

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SYNOPSIS
The economic and environmental advantages of using lime and cement to modify and stabilise low strength cohesive soils are well established. With increasing off-site disposal costs added to the cost of importing granular fill and transportation costs, the emphasis is now very much on re-using these low strength cohesive soils as engineering fill.

With construction of residential, industrial and commercial buildings progressing at a rapid pace, low strength soils are being generated from cuttings, basement excavations, service trenches etc. Soil modification / stabilisation provides an opportunity to employ value engineering and maximise the re-use potential of these low strength soils under building foundations and floor slabs.

This paper looks at recent developments in modifying Irish cohesive soils (particularly boulder clays) for engineering fill under foundations for industrial and residential developments. Case histories are presented, illustrating the engineering properties of the soils before and after treatment. Suggestions are given on compliance testing frequency and the use of dynamic cone penetration testing and window sampling techniques to supplement traditional CBR and plate bearing tests.
1. INTRODUCTION
The economic and environmental advantages of stabilisation finally appear to be recognised in Ireland, where traditionally, low strength or unsuitable materials were removed from sites and imported fill was the norm. The reluctance to adopt lime and cement stabilisation techniques is considered to be largely due to a lack of geotechnical knowledge and an understanding of the process. For bulk fill modification of cohesive soils, lime is added to achieve an end product strength or CBR value, while for capping, cement is normally added to achieve the necessary strength and durability.

Soil modification and stabilisation involves the addition of lime or cement to a soil to improve its strength and render it acceptable as an engineering fill. Quicklime (calcium oxide) is used with fine or cohesive soils, while cement is primarily used with granular soils. Cement increases the bearing ratio (CBR) and achieves higher strengths. Some cohesive soils do not achieve the required long-term strengths, therefore a two stage process is adopted (i.e. lime followed by cement).

Although lime and cement stabilisation has been sporadically carried out in Ireland since the 1980’s it is only in recent years that the technique has become widely used. In the UK, stabilisation of cohesive soils has been carried out since the 1950’s but was not included in the Highways Agency documentation until 1986. The use of lime or cement to form capping is specified in the Manual of Contract Documents for Highway Works (MCHW 1) and Advice Note HA 74/00 contains detailed guidance and information on stabilised capping, improvement of general fill and maintenance for slope repairs.

A stabilisation trial was undertaken at Dublin Airport in 1987 on ‘brown boulder clay’ and showed that quicklime was very effective in increasing the strength or CBR of the material. When used in conjunction with cement, this provided comparable results to imported granular capping and sub-base. It is noted that stabilisation was not subsequently chosen for the runway but the concrete batching plant was located at the trial area and performed extremely well.

In 2000, trials were carried out on the M1 Northern Motorway (Lissenhall Section) by Ascon Nuttall JV to evaluate the use of a stabilised capping. All of the treated boulder clay samples produced laboratory CBR values in excess of 15% after 7 days. CBR values were between 25 and 70% after 28 days depending on percentage of lime and cement added. Despite the high results obtained, a granular capping layer was adopted by the NRA.

More recently, bulk modification of a boulder clay material was carried out on the Ashbourne Bypass. The boulder clay was classed as unacceptable (U1) material. Laboratory testing showed that the material could be successfully modified or treated with lime to produce acceptable Class 2C. This solution was adopted by Jons / Sisk JV and it is understood that 1 to 2% lime was used to produce a Class 2C fill.

2. MODIFICATION & STABILISATION PROCESS
The addition of lime to a ‘wet’ cohesive soil causes an exothermic reaction to occur as water is absorbed from the soil. A reactive clay is normally accepted as one with a plasticity index of 10% or higher. A vapour is produced as the moisture is driven off and this reduces moisture content. Plasticity is also reduced as the clay particles flocculate. This part of the reaction process is commonly known as the modification stage as immediate strength is achieved.

When an alkaline environment is maintained after the immediate reactions have taken place, stabilisation of the soil occurs. The stabilisation process occurs far more slowly, producing long-term strength gain. The long term soil and lime pozzolanic reaction results in the formation of cementitious agents increasing the materials strength and durability.

Following the addition of lime through a mixing process, a mellowing period (i.e. stage between mixing and compaction) is required. The traditional stabilisation process involves four distinct phases:

- Lime or cement uniformly spread by mechanical means
- Mixing and pulverisation of the soil with a rotovator
- Trim and lightly compact followed by mellowing for a period of time
- Heavy compaction to ensure air voids of 5% or less

Air temperature plays an important role in this process and MCHW stipulates that stabilisation should only be carried out when the shade temperature is above 7°C. However, there is a consensus among specialist contractors that this is restrictive and the author’s view is that a minimum temperature of 3°C is more realistic. It should be noted that ground temperatures should be measured outside of the main earthworks season (March to September) as values of less than 3°C can have a significant retardation effect on the treated material.

The effect of the mellowing period on strength has been researched on UK soils (Lower Lias Clay, Keuper Marl, Oxford Clay & London Clay) and Holt & Freer-Hewish concluded that prolonged mellowing can be deleterious to strength gain.

The authors’ experience is that a mellowing period of a half to one day should be adequate.
for typical low strength Irish boulder clay soils (i.e. MCV’s of 4 to 7). For bulk modification works, specialist contractors working in Ireland have varied the traditional phases outlined above. In many cases, only one phase of compaction is used where the soil is compacted after the mellowing period.

3. ENGINEERING PROPERTIES OF DUBLIN BOULDER CLAY SOILS

Boulder clays or glacial tills are the predominant soil type in Ireland and in the Dublin area. The engineering properties of these soils are well documented (Farrell et al) and briefly reviewed herein. The boulder clays generally contain fines contents of between 25 and 40% as illustrated by Figure 1.

Figure 1 – Typical Grading Analysis for Brown Boulder Clay

Figure 2 - Liquid & Plastic Limits for Brown Boulder Clay
They are of low to intermediate plasticity (CL / CI) with Plasticity Indices typically between 10 and 20% as indicated by Figure 2. The fines control the engineering properties of these soils and the presence of silt gives rise to dilatancy and makes them very difficult to use in earthworks.

Atterberg Limit tests have been carried out by IGS L on brown boulder clay to specifically examine the relationship between plasticity and percentage increase in lime. The behaviour of the boulder clay is interesting and can be observed in Figure 3.

The Plastic Limit increased significantly after 1% lime was added but dropped off gradually between 2 and 6%. Likewise, the Liquid Limit increased from 36 to 47% after 1% lime was added, reducing gradually to 43% with 6% lime. The Plasticity Index increased from 16% at NMC to 21.6 after 1% lime. However, the Plasticity Index then dropped off as lime content increased.

X-ray diffraction studies have shown that Irish boulder clay or glacial till soils contain few, if any true clay minerals (e.g. illite, kaolonite, montmorillonite etc).

This is an important feature, as it means that the lime has little opportunity to interact with the clay minerals. With the low clay content and plasticity of our boulder clay soils, the reaction between the lime and the clay minerals is not overly critical.

Given the scale of residential and commercial developments in the Dublin and Greater Dublin area, the brown boulder clay is the most commonly modified / stabilised soil type. The brown boulder clay is usually firm in consistency and has typical undrained shear strengths of the order of 60 to 75 kN/m². However, soft and stiff deposits also exist with large variations encountered on many sites. Moisture Condition Values are often < 7 with recompacted CBR values in the range 1 to 2.5%.

Figure 3 – Effect of Lime on Plasticity of Brown Boulder Clay
On many residential and commercial projects, the brown boulder clay in its natural state would be classed as acceptable for re-use in embankments or general fill but not as engineering fill under foundations or floor slabs. This is a key point, as engineers have traditionally specified select granular fill under foundations or floors but now have the opportunity of using treated cohesive fill in structural applications.

4. GROUND INVESTIGATION & PRE-TESTING OF SOILS
Where cut and fill earthworks are required on a project, the geotechnical properties of the soils should be established during the ground investigation stage. The testing regime normally includes the following suite of tests for a particular soil type:

- Moisture contents
- Liquid & Plastic Limits
- Gradings
- Moisture Condition Values
- Moisture content v Dry Density Relationship (compactions)
- CBR’s
- Sulphates

Trial pits are recommended to provide large (typically 45 to 50kg) representative bulk samples. The samples can be tested individually for the aforementioned parameters and then mixed to provide composite samples for trial testing. Moisture contents and MCV’s are recommended to quickly evaluate the re-use potential of a soil. The MCV tests can be carried out on site (by a technician during trial pitting) or in the laboratory. An evaluation of the MCV data will quickly indicate the soils re-use potential and this allows a more practical approach to laboratory trial testing.

In many instances with brown boulder clay, the MCV’s produce a range of values, mostly between 4 and 8 with recompressed CBR values (to 95% of maximum dry density) often between 1 and 1.5%. With these values, lime product would be added (typical ratios of 1, 2 & 3%) to the material and allowed to mellow for a period of 2 to 3 hours. MCV testing would then commence to assess the impact of the lime. Likewise, lime would be added to quartered samples and CBR moulds prepared for testing. CBR testing would be carried out at 24 and 72 hour intervals and 7, 14 and 28 days respectively.

For stabilisation contractors, the important parameters are the MCV after 2 to 3 hours and the 24 hour CBR values following the addition of lime or cement. The MCV’s recorded after 2 to 3 hours allow the stabilisation contractor to evaluate the trafficability properties of the soil while the 24 hour CBR values are used to assess short to medium term behaviour. As the CBR tests are undertaken on samples cured for 7, 14 and 28 days, the long-term properties of the stabilised soils can also be established. Flexibility during trial testing is important and an experienced laboratory technician will be invaluable as the treated soil properties are established.

Sulphates should be measured on both the untreated and treated samples (ideally not less than 28 days of curing) as this allows for the stabilisation process to be substantially complete. Sulphates in Dublin boulder clays are generally low (BRE Special Digest Class 1) and tests undertaken by IGSL show that sulphates rarely exceed Class 2 following the addition of lime or cement.

Sulphates have been a particular concern for UK soils where heave has occurred as a result of naturally occurring pyrite reacting with lime or cement and water to produce ettringite or thamusite. Both of these have the potential to expand by up to 60% and this was highlighted by projects such as the M40 and the recent A10 Wadesmill Bypass. The Wadesmill Bypass serves as a warning for Irish projects as the stabilised soil comprised a firm / stiff sandy gravelly clay. Sulphate levels of 1.2% SO₄ were measured in the untreated soils with post stabilisation tests showing up to 4.3% SO₄.

5. CASE HISTORIES
Three case histories are presented, to illustrate how stabilisation techniques have been successfully used to treat low strength Irish cohesive soils for structural applications.

Case History 1 - Brownsbarn, City West
This project involved modification and stabilisation of brown boulder clay for industrial units and a filling station. The civil engineering works were undertaken by Portland Civil Engineering (PCE) with the stabilisation works carried out by Con-Form. Engineer for the project was TJ O’Connor and the Specification required that some 100,000m³ of stockpiled boulder clay be modified to achieve an engineering fill to support pad and strip footing foundations. A minimum CBR value of 3% was stipulated and a maximum voids ratio of 5% was permitted. The stabilisation works were carried out to the west of the Brownsbarn interchange with an average fill thickness of the order of 2 to 2.5m.

Geotechnical testing was undertaken during the ground investigation stage, and included classification, MCV and recompressed CBR tests at natural moisture contents. Some tests were also carried out at TCD during the GI stage to examine the behaviour of the boulder clay after the addition of lime. Given the anticipated variability of the stockpiled material and potential impact for the programme, more extensive trial testing was required by the Engineer and stabilisation contractor. Large bulk samples were taken from stockpiles by PCE and submitted to IGSL for testing. The tests confirmed the following:
Moisture contents ranging from 15 to 28%
- Plasticity Indices typically between 12 and 14%
- Fines contents of 30 to 40%
- MCV’s highly variable ranging from 4 to 8 with occasional values > 10
- CBR values (recompacted) < 1 to > 5%
- Compaction tests indicated boulder clay to be wet of optimum (1 to 6%)

Trial testing was carried out on composite samples and showed that the boulder clay could be satisfactorily modified and stabilised by the addition of quicklime. CBR and MCV calibrations were carried out with 1 and 2% lime product added.

The fill material was placed in 300mm layers and lime product added before mellowing for a period of 6 to 8 hours. The site operations were based on placing and mixing in the morning with compaction during late afternoon. Extensive geotechnical sampling and testing was undertaken by IGSL throughout the stabilisation works and included the following:

- CBR’s on mould samples (at 24 hour, 7 day & 28 day intervals)
- In-situ density & moisture content by nuclear gauge method
- Plate bearing tests (450 & 760mm diameters)

The geotechnical quality assurance testing showed that the boulder clay was satisfactorily modified by the addition of quicklime. Lime additions ranged from 1 to 2% and the percentages added were governed by MCV’s on the untreated material. Reference to Figure 4 shows the 24 hour CBR tests (62 No.) produced a mean CBR value of 12.7% while the 7 day tests showed a slightly higher mean CBR value of 13.8%. It should be noted that Figure 4 reflects 1 and 2% lime product added as this was not distinguished by the testing.

Interestingly, the 28 day CBR tests gave a mean value of 10.6%. It should be noted that the 24 hour and 7 day CBR tests were performed on unsoaked samples, while the 28 days tests were carried out on soaked samples. Four CBR failures were recorded (i.e. 3% minimum) with the 24 hour samples while one failure (1.4%) occurred at 7 days and six failures on the 28 days samples. The plate bearing tests showed settlements typically of the order of 2 to 4mm at a loading of 100 kN/m² though settlements of 6 to 8mm were obtained in the early stages of the works. Sulphates were measured on samples cured for 28 and 56 days and showed a maximum SO₃ of 0.19%.

![Figure 4 - Moisture Contents v CBR Values](image-url)
Case History 2 - M1 Retail Park, Drogheda

Construction of the M1 Retail Park commenced in January 2005 at a site to the north of Drogheda. The enabling works contract was undertaken by McEvoy Construction in advance of the main civils works, with the modification / stabilisation works sub-contracted to Powerbetter. Engineer for the project was Barrett Mahony and the contract required that the fill material be treated to support pad and strip footing foundations and service yard areas. A minimum CBR value of 6% and an allowable bearing capacity of 125 kN/m² was specified.

The site encompassed an area of approximately 8 hectares and required 86,800m³ of stabilisation works. Average cut and fill depths were of the order of 3 to 4m with up to 6m of fill required at the south-western corner of the site. All bulk fill placed under the building footprint was to be treated using lime or cement stabilisation techniques. Pad foundations were proposed to support the column loads with ground bearing floor slabs.

The ground investigation for the project was carried out by IGSL in 2003 and testing showed that a significant proportion (circa 40%) of the gravelly clay and laminated sandy clay soils from the cut areas were unsuitable for re-use as engineering fill under structures. MCV's ranged between 2.5 and 14.6 and the compaction tests showed the soils to be significantly wet of optimum (3 to 6%). The ground investigation report recommended the use of stabilisation techniques to maximise the re-use potential of the soils and allow their use under structures.

Having decided to opt for stabilisation techniques, both the Client (Mell Developments) and Engineer were concerned about quality control and requested that a site laboratory be set up to carry out geotechnical quality assurance testing. IGSL provided a mobile laboratory unit and a materials engineer to undertake the sampling and testing throughout the enabling works contract.

A combination of lime and cement products were used on this project. Layer thickness was 350mm with mixing by a Caterpillar SM-350 rotovator. Lime was utilised during the early stages of the works but Powerbetter changed to cement where the soils became increasingly gravelly. In the case of the soft laminated sandy clay, lime was used to ‘flash’ this material, with cement then added to achieve the necessary strength for bearing capacity.

Again, the geotechnical testing focused on MCV’s on the pre-treated soils with CBR’s on mould samples, gradings to evaluate degree of pulverisation, plate bearing tests and in-situ densities measured by nuclear gauge method.

In addition to this, Dynamic Cone Penetration (DCP) tests and window sampling was undertaken as the treated fill approached formation level under the main building.

The geotechnical test data showed that two of the ninety one CBR tests were < 6%. CBR testing was carried out on both unsoaked and soaked samples after curing for 24 hours, 7 and 14 days respectively. Plate bearing tests (760mm diameter plate) were undertaken at designated locations (after a minimum of 3 days post compaction) to evaluate modulus of sub-grade reaction values (Ks) and equivalent CBR values.

The plate test data showed equivalent CBR values to be slightly lower than the laboratory mould CBR values. This was attributed to the time factor for the treated soils to cure. In-situ density tests by nuclear gauge method showed a high degree of compaction, in all cases achieving compliance with 95% of maximum dry density. Sulphates were measured on the treated soils (after 28 days) and all of the seventy five tests showed BRE Special Digest Class 1 conditions.

As the fill area at the main building approached formation level, the Engineer was concerned about the immediate strength and bearing capacity of the treated material, as the main contractor was about to construct the pad foundations. The Engineer also expressed a concern with potential differential settlement between pads founded on the indigenous soils and those on the treated materials. IGSL carried out a programme of window sampling and dynamic cone penetration (DCP) testing at particular pad locations to evaluate strength and compressibility.

The window samples on the treated material achieved good recovery and facilitated triaxial compression and oedometer consolidation testing. Undrained shear strengths (CD) on the treated material were of the order of 90 to 100 kN/m² while Modulus of Volume Compressibility (Mv) values were of the order of 0.12 to 0.15 m²/KN in the 75 to 150 kN/m² pressure range.

The DCP tests were very positive and showed the treated soils to be firm / stiff in consistency. In most instances, DCP blow-count values were in excess of 4 for 100mm of penetration as illustrated in Figure 5. Using the Forbairt relationship between CD and DCP N100 values, this indicated shear strengths of the order of 80 to 100 kN/m². Occasional or isolated values of 2 or less were recorded but these were not a concern as the upper treated soils were still quite fresh (i.e. < 14 days).
Case History 3 - Pre-cast Concrete Manufacturing Facility, Arthursown, Kill

This project involved the excavation and disposal of some 300,000m³ of very soft silt / clay and stabilisation of around 30,000m³ to create a platform for a precast concrete manufacturing building (90 x 110m) and storage yard area. The site encompassed an area of 9.5 hectares and is bounded by the Hartwell River, Balcas (wood fabrication plant) and Arthursown Landfill. Client for the project was Menolly Homes with Kilgallen & Partners acting as consulting engineers. The bulk excavation works were undertaken by Roadbridge Ltd with the stabilisation works carried out by Con-Form.

This site presented a very challenging geotechnical situation, as up to 9m of very soft silt / clay was present as a large mound. The desk study and ground investigation works revealed that the very soft fine sandy silt / clay represented washings from the adjoining sand and gravel pit at Arthursown. The sand and gravel washings were deposited in a tailings type lagoon and allowed to settle. Sand and gravel extraction works commenced in the early 1950’s and the washings were deposited with the lagoon berms constructed with sand, gravel and boulder clay.

With formation level for the precast building approximately 2m above the interface of the silt and underlying indigenous soils, the possibility of stabilising the silt / clay was explored. This offered a significant cost saving when compared to importing granular fill and off-site disposal of the remaining silt / clay. The bulk of the silt / clay washings were excavated and removed to a site adjacent to the north-western end of Arthursown Landfill.

The geotechnical properties of the washings were established during the ground investigation works and showed the following:

- Natural moisture contents ranged between 33 and 42%
- Washings were of intermediate plasticity (MI) with PI’s of 5 to 19%
- In-situ vane tests showed peak strengths of the order of 10 to 15 kN/m²

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![Figure 5 - Example of Dynamic Cone Penetration Test Record](image-url)
As part of the consultation / review process by the main parties (i.e. Menolly Homes, Kilgallen & Partners and Con-Form), laboratory trial testing was carried out. This work was performed by IGSL and used a combination of Ground Granulated Blast Furnace Slag (GGBS), lime and cement. Initial moisture contents on the samples were between 33 to 35% and varying percentages of GGBS and cement were added. Mix combinations of 2% GGBS and 2% lime produced CBR values of 2.1 to 3.9%. In the case of cement, 4% OPC product gave an unsoaked CBR value of 22.6% with 6% cement producing a CBR value of 32.4%. It was concluded from the initial phase of laboratory trial testing that the cement product had most potential and a field trial was set up.

A stabilisation field trial was carried out by Con-Form during mid December 2003. Trial panels (300mm depth and 75m in length) were undertaken with cement mixed with the clay / silt material. Cement proportions of 4, 5, 6 & 7% were used and the initial moisture contents ranged between 34.6 and 37.9%. CBR values after 3 days ranged from 1.0 to 2.4% while moisture contents at 28 days had reduced to between 27 and 29%. Plate bearing tests were carried out at the trial area after 7 days and produced Modulus of Sub-grade Reaction Values of between 116 and 180 MPa/m. The field trial proved successful and Con-Form were appointed to carry out the stabilisation works.

Due to the very sensitive nature of the pre-cast manufacturing plant to differential settlement (zero settlement limits were permitted), Kilgallen & Partners specified a minimum CBR value of 10% for the engineering fill with a 20% CBR value required for the final 300mm layer under the floor slab. The early stages of the stabilisation works proved very difficult, with limited production and failure to achieve the specified CBR value. Trafficability was also a major problem with plant bogging down due to a combination of very wet and cold weather. Also, a limited working area was available for the contractor to place and mix the cement product. The cold weather (ground temperatures were often < 0°) had a significant negative impact on the modification / stabilisation process with retardation observed with the early CBR values.

To counteract the issues outlined above, Con-Form provided additional plant and used a combination of 3% cement followed by another 2 to 3% cement after a mellowing period of 2 to 3 days. The stabilisation process improved dramatically during mid to late February as temperatures increased to double figures. Plate bearing tests and CBR mould samples were undertaken throughout the works on the stabilised silt / clay and results showed a dramatic improvement as temperatures increased.

The CBR tests (14 & 28 day) on the treated silt / clay produced values mainly in the range 10 to 15%. Plate tests were carried out on each lift (i.e. 300mm) and confirmed the increase in strength / stiffness with time. As the stabilisation works neared completion, piling works commenced for the main building. Pre-cast driven piles were selected but these could not penetrate the now cemented material. Cube (28 day cured) samples tested by IGSL showed compressive strengths of the order of 1000 to 1200 kN/m². In engineering terms, the stabilised silt / clay had achieved the strength of a very weak or weak rock. Pilot holes were required for the piles and these were formed using 4 and 6t capacity hydraulic breakers.

6. GEOTECHNICAL TESTING & CQA

Compliance monitoring and testing forms an integral part of any stabilisation works. Specifications are usually performance based, requiring the specialist contractor to achieve a minimum CBR value or modulus of sub-grade reaction value and strength or stiffness to provide a safe bearing capacity. The frequency of testing on the treated material is dependent on the soil type(s) and parameters required.

Suggested testing frequency for treated fill under foundations and floor slabs are outlined as follows:

- Lime or cement spread checks - 1 per 500m³
- Pulverization checks - 1 per 1500 m³
- MCV / moisture contents - 1 per 1000m³
- CBR values - 1 per 1000m³
- Plate bearing tests - 1 per 1000m³
- Sulphates - 1 per 1500m³

Lime or cement spread checks should be carried out to monitor dosage and is calculated on the dry density of the untreated soil. The spread rate is checked by spreading over a tray (which is weighed) and the discharge adjusted to maintain the correct rate. Degree of pulverisation is measured by carrying out gradings on the treated material. MCHW 1 stipulates 95% passing a 28mm sieve and 30% passing a 5mm sieve for lime with 60% passing a 5mm sieve for cement.

MCV’s and moisture contents should be carried out on both the untreated and treated soils. During the stabilisation works, an upper MCV can be used to monitor maximum air voids (5% normally permitted).

CBR tests are at the core of most stabilisation projects and probably the test most civil engineers recognise and understand. Mould samples (with cutting shoes) should be taken
and transported to the laboratory for testing. A combination of soaked and unsoaked CBR tests are recommended at 3, 7, 14 and 28 day intervals. Swelling should also be measured and CBR mould samples provide an opportunity for this to be carried out.

In the event that mould samples are not retrievable (as is often the case with gravelly or cobbly tills), then plate bearing tests provide a good alternative. The plate test provides a load / settlement plot and a modulus of sub-grade reaction value. Using HD 25 / 94 an equivalent CBR value can be obtained and reported.

Sulphates should be measured during the stabilisation works and ideally on samples cured for a minimum of 14 days. The trial testing should establish sulphate in the untreated and treated soil, therefore no surprises should be uncovered during the CQA testing.

In addition to the ‘routine tests’ outlined above, designers and stabilisation contractors should consider the use of dynamic cone penetration testing and window sampling to validate the engineering properties of treated fill. This is particularly relevant to sites where fill depths exceed 2m and as the M1 Drogheda retail park project has illustrated, these investigation techniques provide an ideal opportunity to examine the strength / stiffness of the treated soils and assess how they correlate with the traditional CBR and plate bearing test approach.

7. CONCLUSIONS
Stabilisation offers a highly cost effective means of re-using unsuitable or low strength soils as engineering bulk fill under foundations and floor slabs.

It provides an opportunity for value engineering to be used and cost savings for clients.

Stabilised capping can be achieved with boulder clay soils and offers a real alternative to imported capping (6F1 / 6F2).

Ground investigations for cut & fill earthwork schemes should incorporate laboratory trial testing. The potential use of stabilisation techniques can then be assessed at an early stage and options evaluated.

Engineers and designers need to understand the principles involved, as a lack of geotechnical knowledge means that clients are not getting value for money.

Geotechnical quality control testing forms an important role for all parties involved in the stabilisation process. This should be undertaken by an independent laboratory / test house and a CQA report provided upon completion of the geotechnical testing.

Where a minimum CBR value is specified, this should be linked to a time period (3, 7, 14 or 28 days) as confusion often arises with CBR value compliance.

Where allowable bearing capacity is specified, this should be linked to a maximum permissible settlement at a designated loading (typically 125 to 150 kN/m² required for structures).

Sulphates should be measured on both the indigenous and treated soils. The lessons from the A10 Wadesmill Bypass need to be learned, particularly under floor slabs as elevated sulphates will give rise to swelling and heave.

Consideration should be given to using dynamic cone penetration testing and window sampling techniques as a means of establishing and confirming the strength / stiffness of treated soils under floor slabs and foundations.

The use of the Clegg Hammer should be considered as part of the compliance testing. The Clegg Value can be correlated with CBR and the main advantage with this is the large number of tests possible in a short period.

8. ACKNOWLEDGEMENTS
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