Engineers Ireland

# GEOTECHNICS ON IRISH ROADS, 2000 - 2010

## *A Decade of Achievement*

CPD Conference Thursday 11th October 2012

# Earthworks Using Irish Glacial Tills

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# Content



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# Section 1 – Material Classification

- Incompatibility between material classification systems in the NRA Specification for Roadworks and BS5930 – Code of Practice for Site Investigations.
- Limitations of BS5930 in classifying Irish Glacial Tills
- Experience with classification of Irish Glacial Tills in ground investigations.
- Fines content of coarse granular glacial till.
- Characterisation of fluvioglacial soils.

# NRA Specification for Roadworks (NRA SRW)

- General Class 1 (Granular) and Class 2 (Cohesive) Fill defined in
  - Table 6/1 & 6/2 in Series 600 of the NRA SRW
  - Table 6/1 of Appendix 6/1 in the Series 600 Appendices (project specific material acceptability limits (e.g. MCV) and compaction requirements)
- Suited to earthworks applications
- Cohesive fill has >15% fines (%<0.063 mm)
- Most Boulder Clay type deposits of fine-grained glacial till classify as Class 2C stoney cohesive fill.
- Coarse-grained Glacial Till can be classified as Class 1 or Class 2, depending on fines content.

# BS5930 – Code of Practice for Site Investigations

- Soil and rock classification system generally used in ground investigations for roads projects in Ireland.

- Not well suited to classifying Irish Glacial Till for earthworks applications, i.e.

  - Boundary between fine and coarse-grained soils at a fines content of *about* 35%, depending on interpreted engineering behaviour.

  - Class 2C soils with high sand and gravel content (up to 35%) classified as *slightly* sandy, *slightly* gravelly CLAY – can be difficult to distinguish from Alluvial clay.

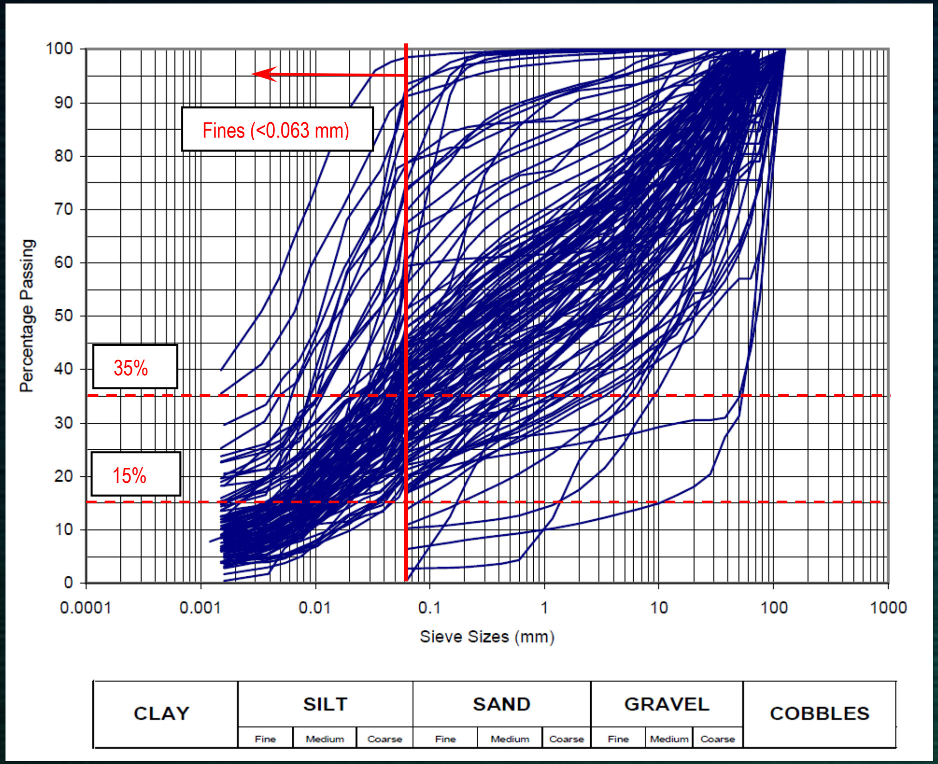
  - Boundary between silty/clayey and *very* silty/clayey coarse-grained soils is at a fines content of 20%, compared to 15% between Class 1 and Class 2 materials in NRA SRW

- More suited to general applications, e.g. slope stability

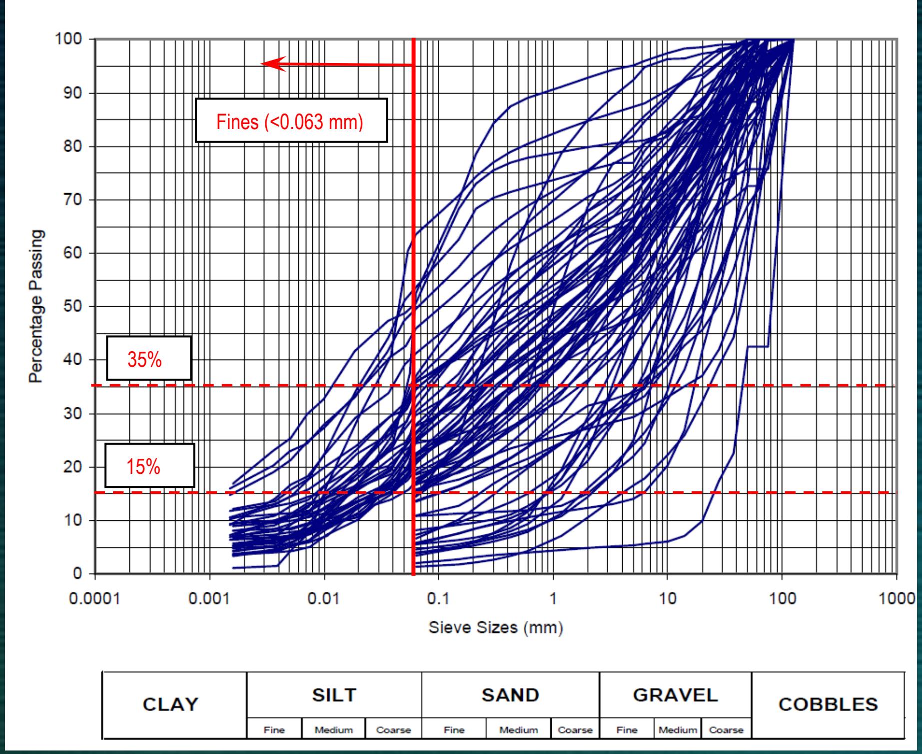
# Classification of Irish Glacial Tills in ground investigations

- Classification on borehole and trial pit logs generally to BS5930:1999
- Soils with <35% fines typically classified as fine-grained soils, sometimes even when the fines content is as low as 15-20%.
- Fines content of coarse-grained glacial till is often underestimated and can be up to 15-35%, which is Class 2 material.
- Classification system not consistently applied leading to a poor distinction between coarse and fine-grained Glacial Till.
- Strata descriptions on the logs are often not changed to reflect the results of the laboratory classification tests.
- Difficult to distinguish between soils with <35% fines and >35% fines, which can exhibit very different behaviour.

# Classification of Irish Glacial Tills in ground investigations




Cohesive Glacial Till – from AGS data

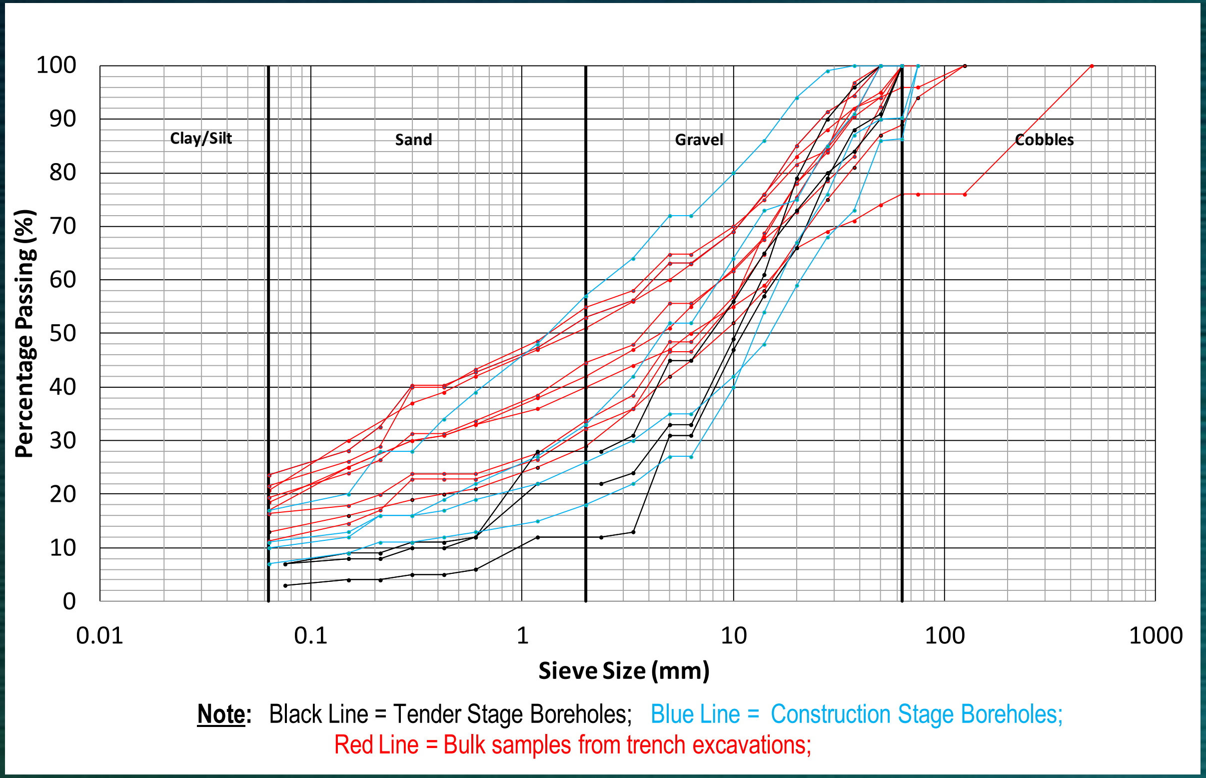



Granular Glacial Till – from AGS data

## Section 1 – Material Classification

# Fines Content of Coarse Granular Glacial Till - Boreholes

- Fines content is inherently variable and can be >15% (Class 2 material)
- Fines Content can be underestimated by sampling in boreholes, e.g:
  - Tender Stage boreholes – conventional shell and auger. Class 1 <10% fines.
  - Construction Stage boreholes – sampling into buckets to minimise washout of fines. Gen <15% fines, up to 18%
  - Bulk Samples from trench (most representative): 12-24% fines (Class 1/Class 2) and significantly higher sand content.




Granular Glacial Till – site near Athlone

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## Section 1 – Material Classification

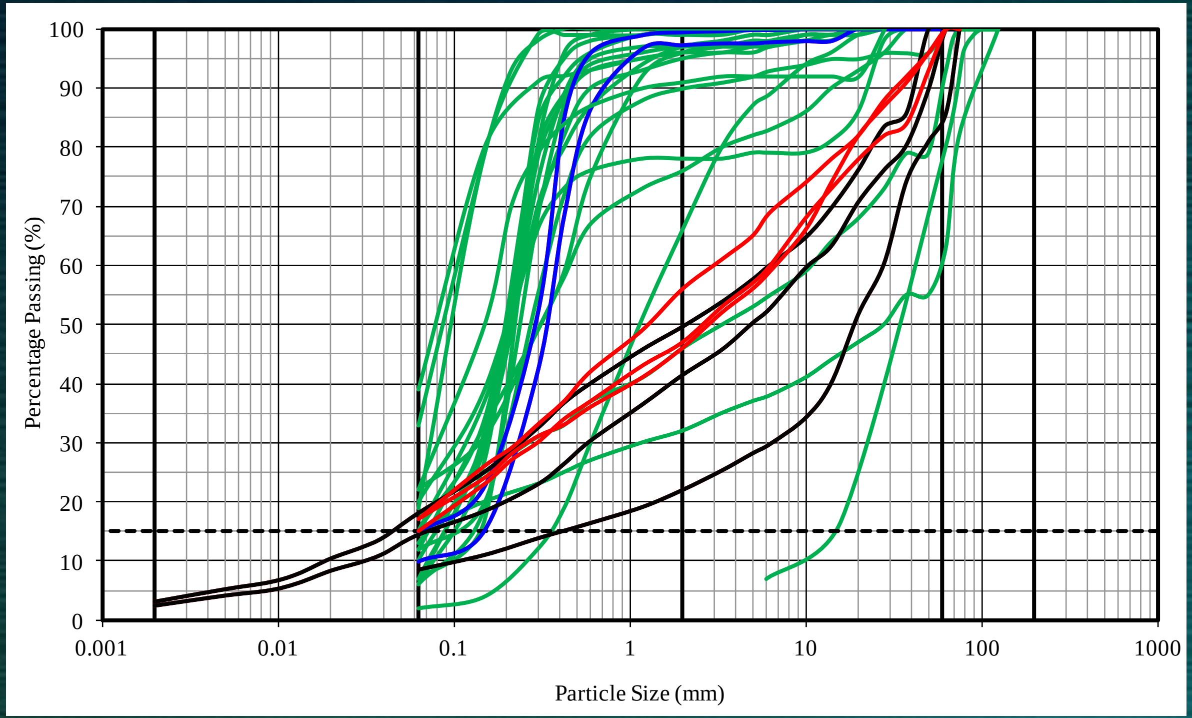
# Fluvioglacial Soils

- Typically poorly graded
- Can be interlayered or laminated
- Layering/laminations not always horizontal
- Within a layer the grading can change gradually
- Small changes in grading can lead to significant change in material characteristics (e.g. silty fine SAND to fine sandy SILT)
- Can be difficult as Class 1/Class 2 materials with narrow range of acceptability.
- Can have nested cobbles/boulders in coarse grained glacial outwash soils.

Fluvioglacial Soils – Powerscourt Estate, Co. Wicklow

# Fluvioglacial Soils

- Fluvioglacial silty SAND over well-graded glacial Gravel.
- Fluvioglacial soil classified on logs as silty fine to medium SAND and GRAVEL (Class 1A?)
- PSD showed poorly graded silty fine to medium SAND with <15% fines (Blue) – (Class 1B with much more limited application)
- PSD on bulk samples from excavation (Green) showed variation in fines content generally from 5-25%, locally up to 40% (fine sandy SILT).
- Well graded glacial gravel had up to 18% fines (Class 2 material)




Fluvioglacial Soils – terrace banks of River Boyne, Navan

# Content



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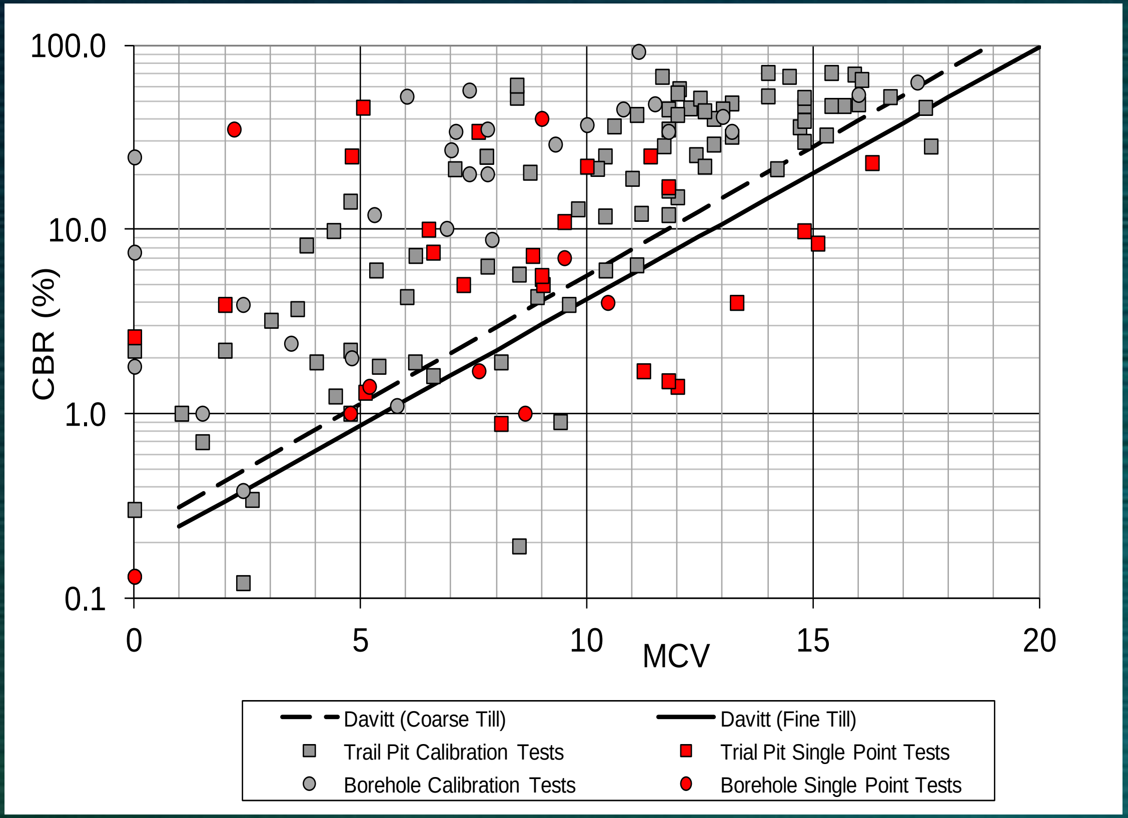
# Lower bound acceptability limits for Class 2C material

- Based on approximate correlations between CBR, MCV, cu, and SPT N-Values.
- CBR ≈2% lower bound for trafficability for conventional earthworks plant.
- CBR of 1.5-2.0% - marginally acceptable – depends on material characteristics, weather and handling.
- Relies on some improvement by air drying prior to compaction.
- Corresponds to an MCV of about 7-8.
- Lower bound MCV of 7 typically specified for design-build and PPP projects.
- Conventional contracts - MCV of 8 more conservative

| Parameter | Unacceptable | Marginally Acceptable | Acceptable |
|---|---|---|---|
| CBR | <1.5% | 1.5-2.0% | >2% |
| MCV | <7 | 7-8 | >8 |
| $c_u$ | <40 kPa | 40-50 kPa | >50 kPa |
| SPT N-Value | <8 | 8-10 | >10 |
| Strength Classification (BS5930:1999) | Soft/ Soft-Firm | Firm (<50 kPa) | Firm (>50 kPa) |
| Fines Content (%<0.063 mm) | (Class 1 Materials Only) | | <15% fines |

# CBR-MCV Relationship

- Empirical correlations developed by Davitt (1984) for Coarse and Fine Till – Best fit straight lines, log plot.
  - Coarse Till: Log CBR(%) = -0.65 + 0.140 x MCV
  - Fine Till: Log CBR(%) = -0.75 + 0.137 x MCV
- MCV of 7-8 ≈ CBR of 1.5-2.0%
- Considerable scatter to data points from SI stage tests.
- Most data points plot above the Davitt correlations.
- Experience would still suggest that MCV of 8 is reasonable lower limit for cohesive glacial till.
- May be more appropriately considered as lower bound limits - still a reasonable approach.



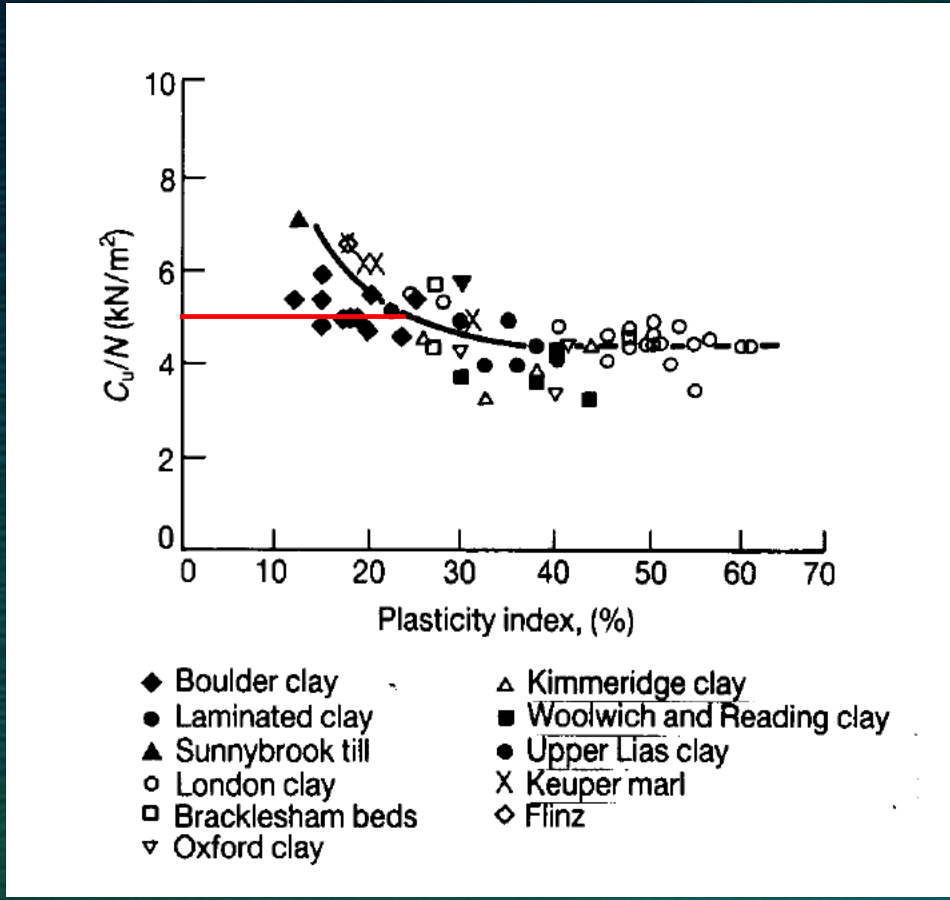

CBR-MCV Relationship – N2 Carrickmacross Bypass (SI Data)

# Relationship between CBR, MCV and $c_u$

- TRRL 889 (1979) – Recompacted samples, lab CBR
  - $c_u \approx 23 \times CBR$ (kPa, CBR in %)
- CBR of 1.5-2.0% ≈ $c_u$ of 35-45 kPa (Low)
- Davitt (1984) – UU tests on Irish Glacial Till
  - $\log c_u = 0.82 + 0.126 \times MCV$ (kPa)
- MCV of 7-8 ≈ $c_u$ of 50-67 kPa (High)
- In Ireland a CBR of 2% & MCV of 8 is assumed to correlate to a $c_u$ of about 50 kPa.
- $c_u$ = 40 kPa proposed as lower limit of marginally acceptable Class 2C material (i.e. @ MCV = 7, CBR 1.5-2.0%)

# Undrained shear strength, $c_u$

- Correlation between $c_u$ and SPT N-Values as a function of Plasticity Index (Stroud, 1974) – in Ciria 143
  - $c_u \approx f_1 \times N$ (kPa)
- For PI of 10-20, conservatively assume $f_1 = 5$
- MCV = 8, CBR = 2.0% ≈ N = 10 ($c_u$ = 50 kPa - Firm)
- Marginally Acceptable at N = 8 ($c_u$ = 40 kPa - Firm)
- Strength descriptions on borehole and trial pit logs also useful where no lab or field tests available.
- Recommend more conservative assessment (e.g. soft-firm – probably unacceptable)

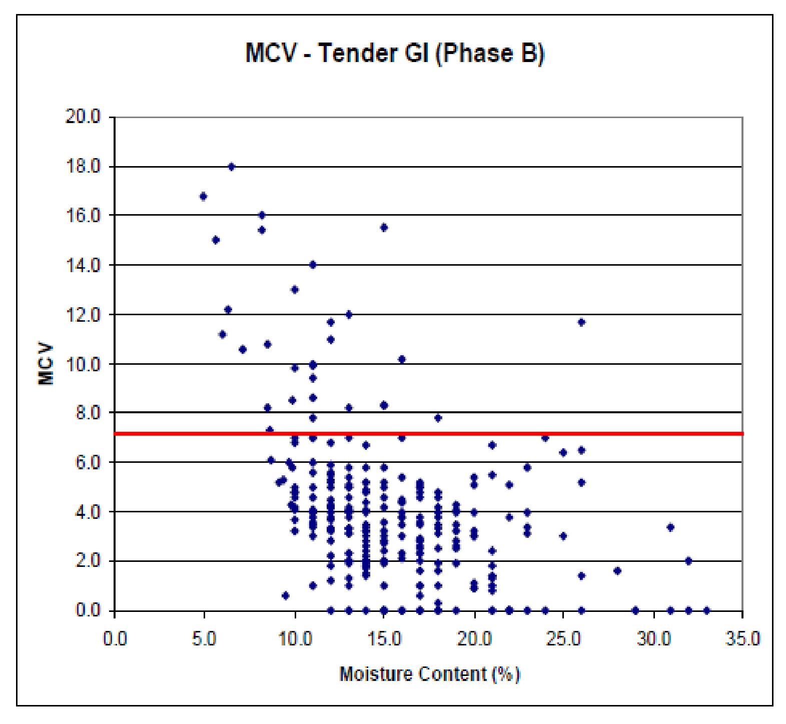


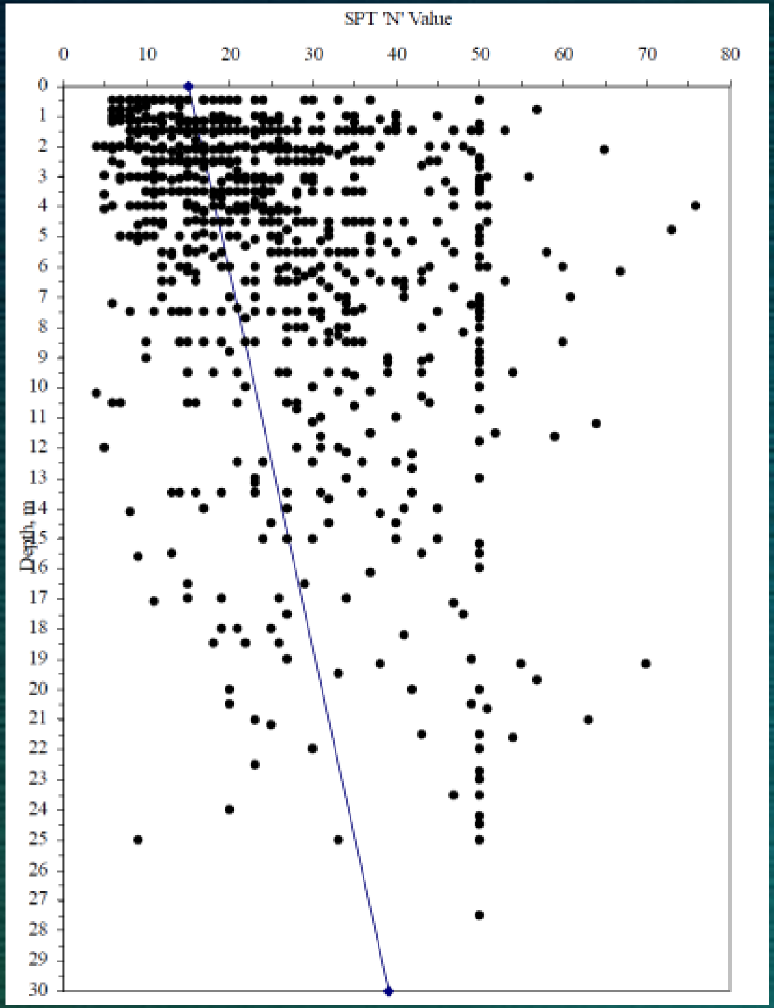

$c_u$/N vs. Plasticity Index for Cohesive Glacial Till (Stroud, 1974 – in Ciria 143)

# Reliability of Earthworks Testing – SI Data

- Not an exact science.
- CBR and MCV test data from SI stage frequently underestimate the acceptability of Class 2C materials.
- CBR and MCV test results can give different index of material acceptability.
- There is often a discrepancy between the CBR/MCV test data and the strength descriptions on the logs.
- In-situ testing (e.g. N-Values) can sometimes give a more reasonable index.
- Where there is conflicting information recommend “risk-based” approach i.e. “possibly acceptable/probably acceptable”.
- Laboratory testing during construction generally appears to give more consistent results.

# Reliability of Earthworks Testing – M8 Cashel to Mitchelstown




(AGEC, 2007)

- MCV test results neglected. SPT N-Values more consistent with experience during construction

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## Section 2 – Material Acceptability

# Material Processing

- Air Drying
- Lime Modification
- Layering

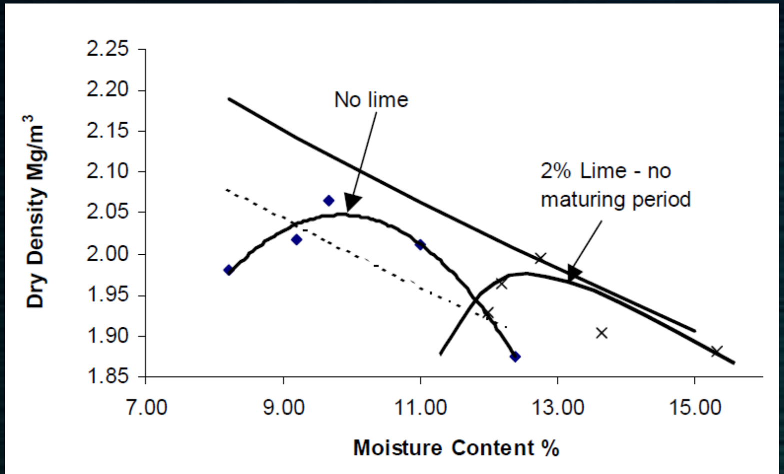
# Material Processing – Air Drying

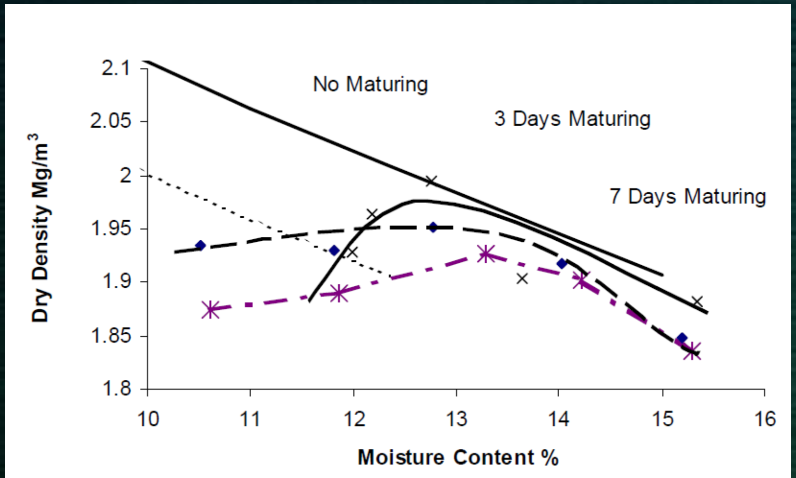
- Unacceptable Class U1 improved by drying on exposure to air.
- Spread out in thin lifts (300mm) and rotavated after 1-4 hrs prior to compaction.
- Weather dependent.
- Most effective for marginally unacceptable Class 2C materials
- Large earthworks area required to coordinate operations efficiently.
- Influenced by material characteristics – more effective in gravelly Class 2C material with <35% fines.

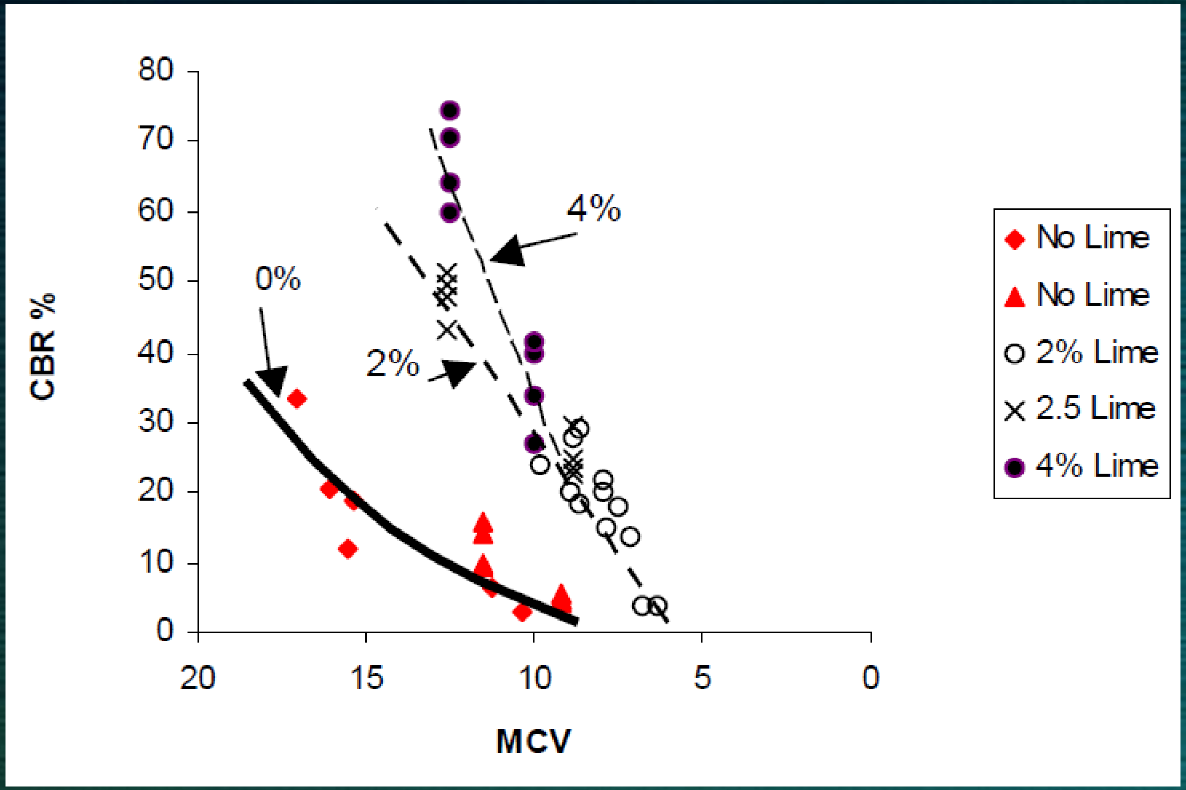
# Material Processing – Lime Modification

- Unacceptable Class U1 cohesive glacial till processed by spreading powdered lime over the surface of thin loose lifts (150-350 mm)
- Mixed by rotavating and allowed to cure for 1-4 hrs prior to compaction.
- Improvement within this time due to two reactions:
  - Drying out by absorption and evaporation (exothermic reaction)
  - Physio-chemical reactions between lime and clay particles – increases optimum moisture content and reduces maximum dry density.
- Benefit of long-term cementing action (i.e. lime stabilisation) low for processing of Irish Glacial Till due to low clay mineral content & curing time 24-72 hrs required.

# Material Processing – Lime Modification




Test results on Dublin Boulder Clay
(Hebib & Farrell, 2004)

# Material Processing – Lime Modification

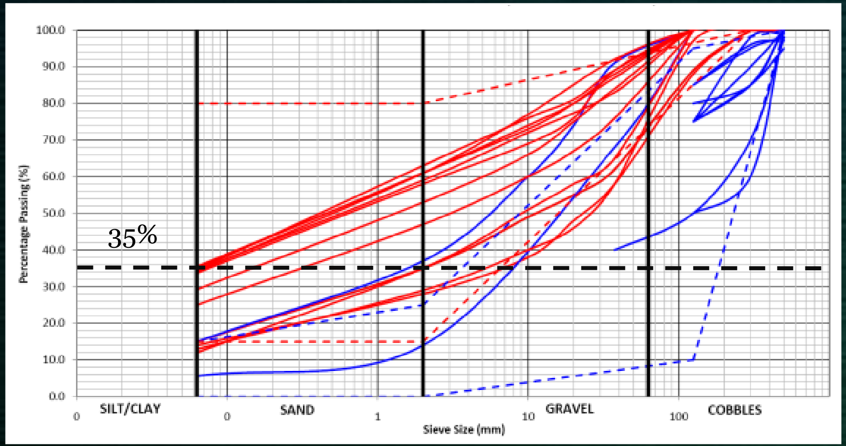
- Irish Cohesive Glacial Till suitable for lime modification.
- Quicklime (CaO) most common type of lime used.
- Typical application is 2% of quicklime by dry weight of soil.
- Water content reduction approx 1% per 1% of quicklime added.
- PI of 10% usually taken as lower limit for which lime stabilisation is effective
- Lime/soil reaction effectively ceases at temp <4°C.
- Limits on sulphate content to mitigate against the risk of swelling (UK MCHW)
- Treated soil should be compacted to <5% air voids.

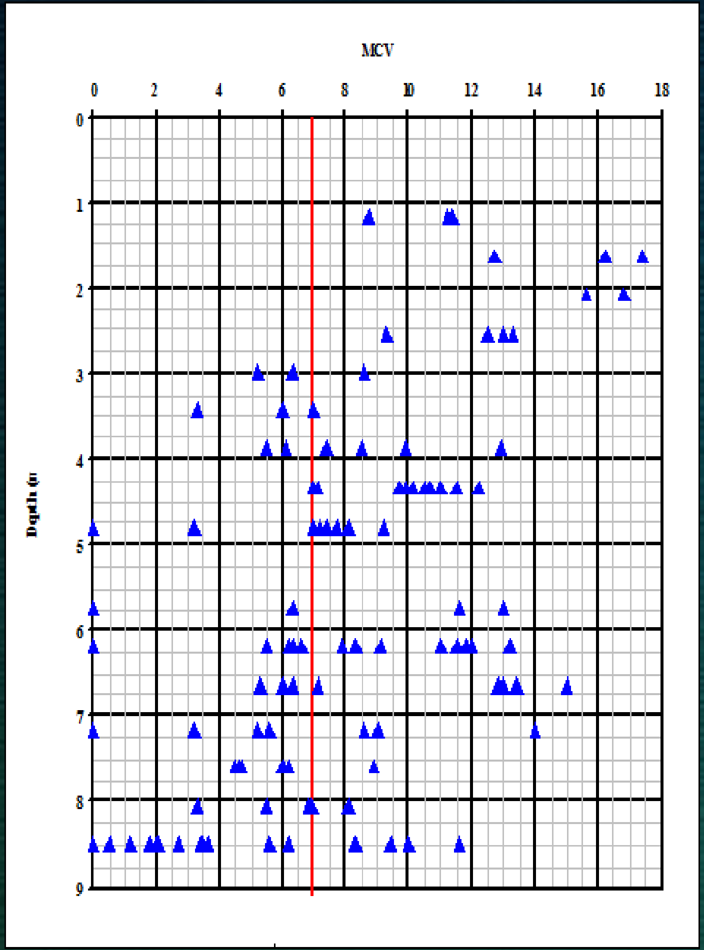
# Material Processing – Layering (Case Study)

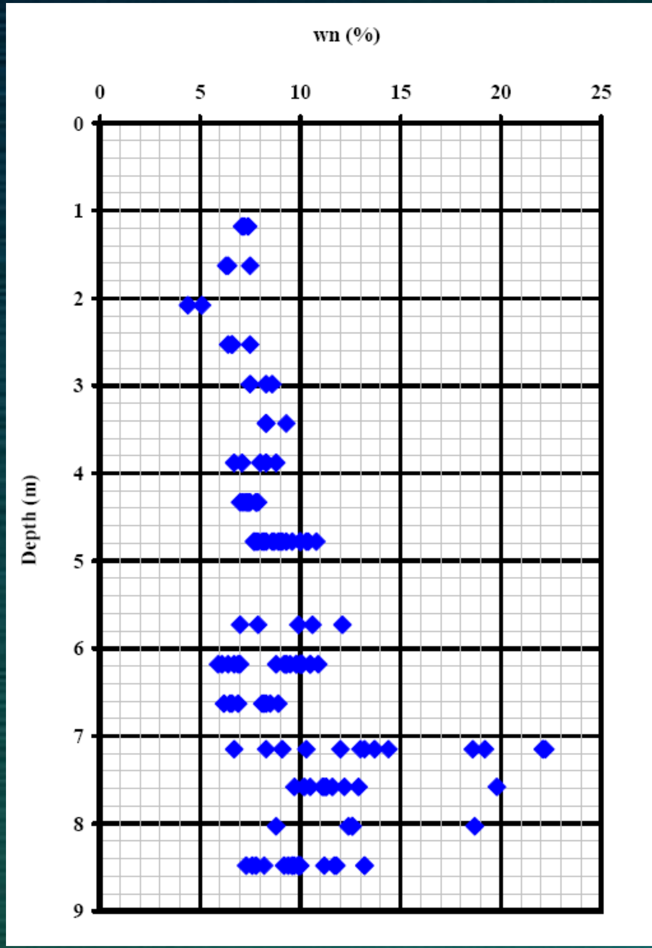
Unacceptable Class U1 material interlayered with coarse Class 1C rockfill

# Material Processing – Layering (Case Study)

| Layer No. | Material Classification | Layer Thickness (m) | Depth to centre of layer (m) |
|---|---|---|---|
| 19 | 1C | 500 | 0.3 |
| 18 | 2C1 | 450 | 0.7 |
| 17 | 2C1 | 450 | 1.2 |
| 16 | 2C1 | 450 | 1.6 |
| 15 | 2C1 | 450 | 2.1 |
| 14 | 2C1 | 450 | 2.5 |
| 13 | 2C1 | 450 | 3.0 |
| 12 | 1C/2C1 | 450 | 3.4 |
| 11 | 1C/2C1 | 500 | 3.9 |
| 10 | 2C1 | 450 | 4.4 |
| 9 | 1C | 500 | 4.9 |
| 8 | 2C1 | 450 | 5.3 |
| 7 | 2C1 | 450 | 5.8 |
| 6 | 2C1 | 450 | 6.2 |
| 5 | 1C/2C1 | 450 | 6.7 |
| 4 | 2C1 | 450 | 7.1 |
| 3 | 1C/2C1 | 450 | 7.6 |
| 2 | 2C1 | 450 | 8.0 |
| 1 | 1C | 800 | 8.7 |
| | | 9050 | |

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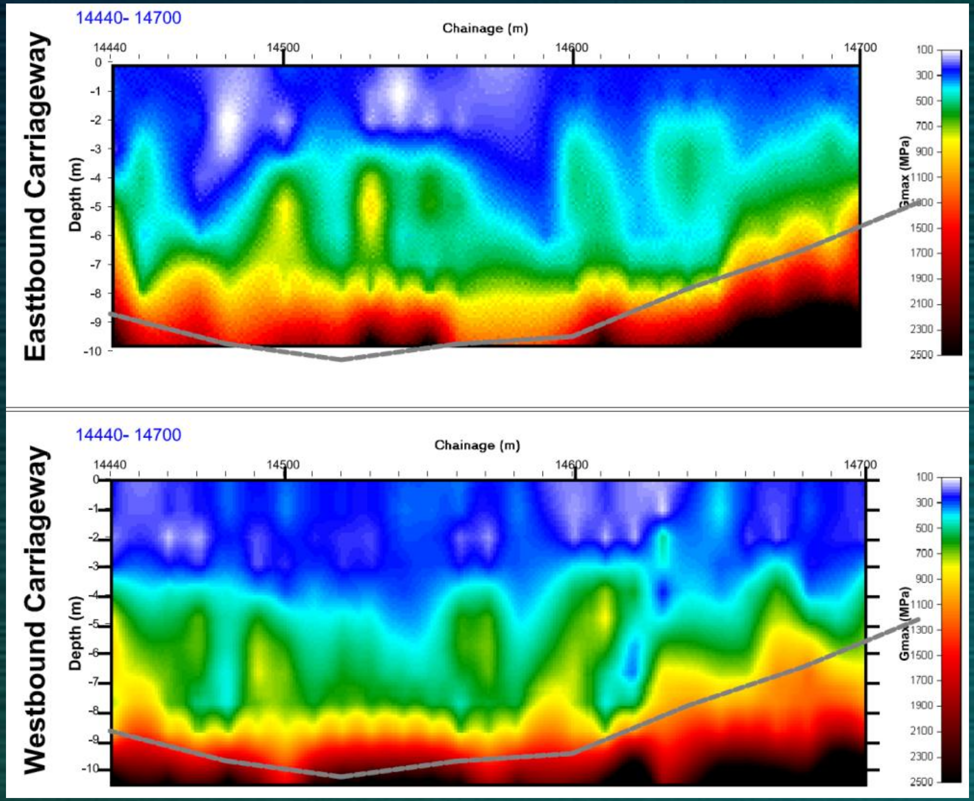
Section 2 – Material Acceptability

# Material Processing – Layering (Case Study)

- Earthworks plant could place and compact the material.
- Class 1 C layers facilitated drainage and provided competent layer for compaction.
- Low MCV material compacted wet of optimum & placed towards the base of the embankment.
- Settlements largely built out in 1.5 months.
- Allowed to consolidate and increase in strength and stiffness over a period of 6-9 months.

# Material Processing – Layering (Case Study)

- Issue raised in Non Conformance Reports
- Additional SI:
  - 2D MASW geophysical profiles.
  - Deep trial pits with in-situ testing,
  - CPTu probes in pre-drilled holes
  - Site compaction trials,
  - Inundation tests,
  - Laboratory classification and earthworks testing.



# Material Processing – Layering (Case Study)

- MASW indicated that stiffness increased towards the base of the embankment with locally softer zones in upper half which were targeted for deep trial pits.
- Laboratory and in-situ testing in trial pits indicated that material strength and in-situ density was acceptable with no softening at Class 2C/Class 1C interface.
- Field trials indicated that low MCV material could be compacted to appropriate density.
- CPTu probes confirmed $c_u$ generally >100 kPa in low MCV layers.
- Inundation tests confirmed that there was a very low risk of collapse settlement.
- Remedial works carried out to remove localised zones of soft poorly compacted material.

# Content

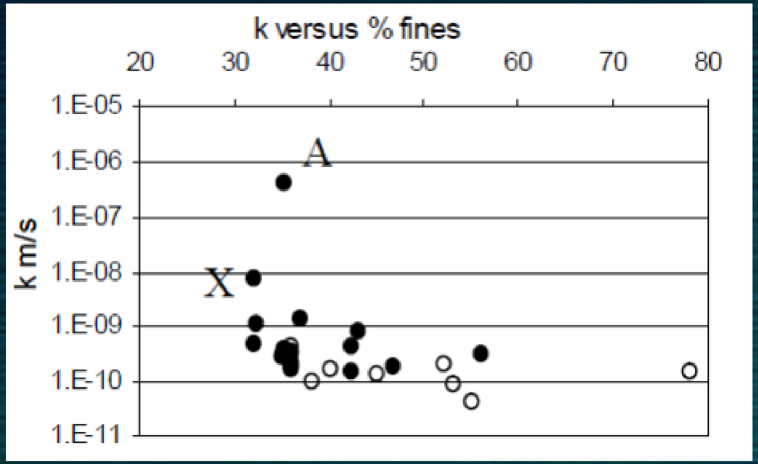
- Section 1: Material Classification
- Section 2: Material Acceptability
- **Section 3: Low Plasticity/Non-Plastic Class 2C Materials with <35% fines**
- Section 4: Subgrade Assessment

# Class 2C with <35% fines

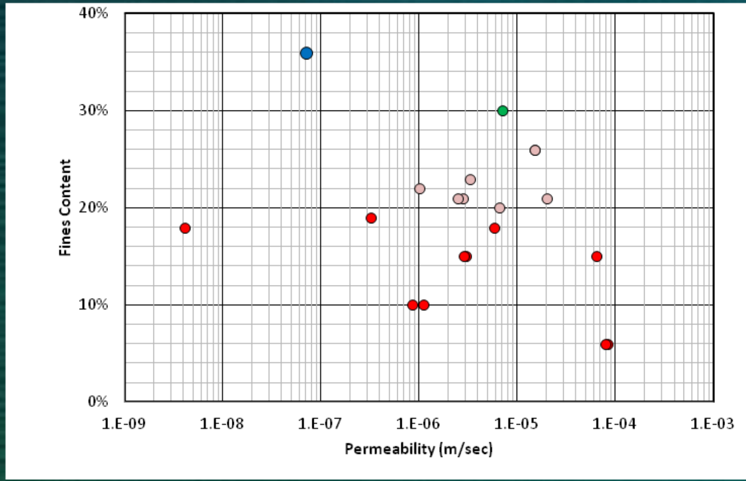
- Class 2C material defined as having 15-80% fines (%<0.063 mm)
- Majority of Irish cohesive glacial till has <50% fines.
- A significant portion of Class 2C glacial till has <35% fines.
- Typically classified on logs as cohesive soil.
- Can exhibit very different behaviour, particularly at low fines content (<25-30%) and where the fines are non plastic or have a PI <6-8.
- Should be classified as very silty/very clayey coarse-grained soils to distinguish them from soils with >35% fines.

# Class 2C with <35% fines – Engineering Behaviour

- Permeability of soil increases significantly at <35% fines.
- Not free-draining but short-term behaviour is between undrained and drained and approaches drained condition for low fines content <20-25%.
- Consolidate relatively quickly.
- Suction pressures dissipate relatively quickly – poor stand-time in slopes/trenches.
- Exhibit significant changes in shear strength with small changes in moisture content, or when disturbed in the presences of moisture.



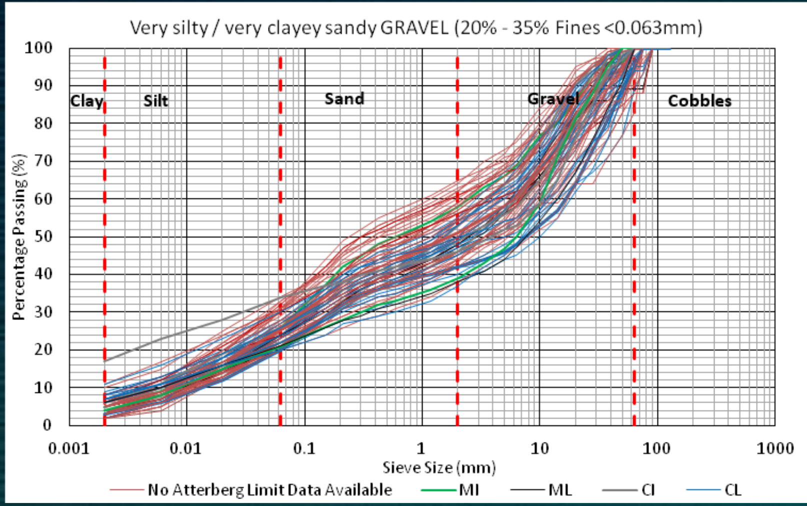
Laboratory permeability tests (Farrell, 2000)



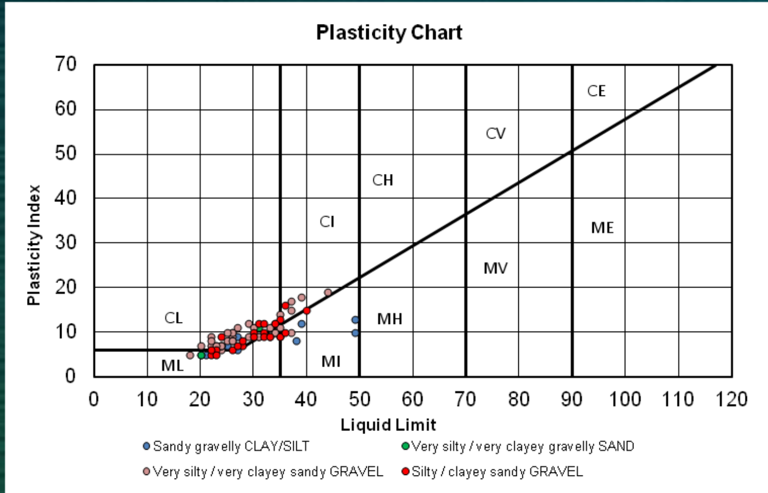
In-situ falling head tests - Cork (AGL)

# Class 2C with <35% fines – Engineering Behaviour

- Difficult to assess in-situ undrained shear strength by visual and tactile inspection – easily disturbed.
- Excess pore water pressures from vibratory compaction can lead to temporary softening.
- Where clay content is low lime stabilisation may be ineffective (PI <10)
- Air drying can be very effective.
- Soils would be classified as "intermediate permeability" for aquifer vulnearability.




Typical PSD curves (20-35% fines)




Plasticity Chart (excludes non-plastic samples)

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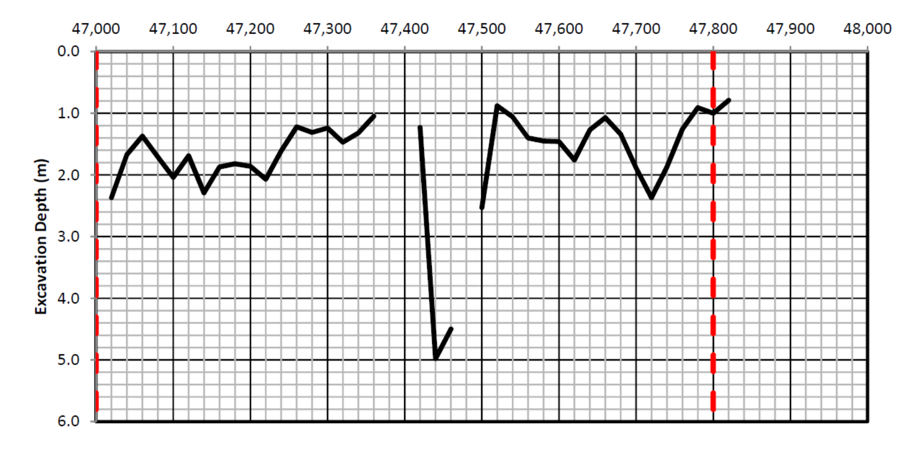
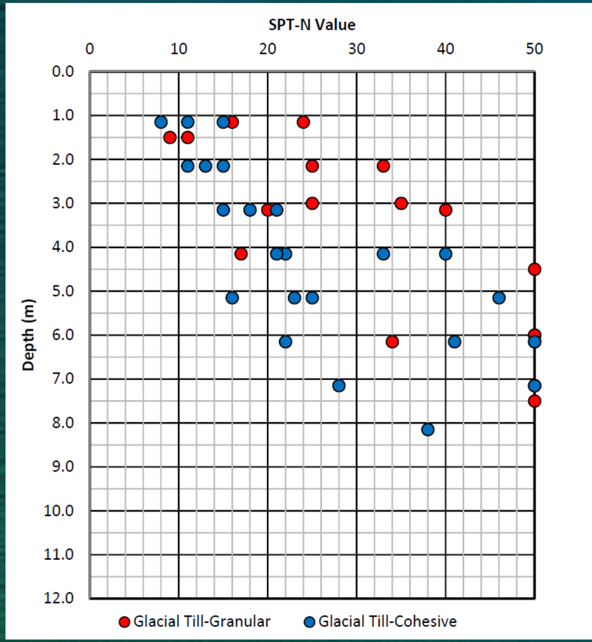
# Class 2C < 35% fines - Embankment Formation

- Difficult to assess in-situ undrained shear strength by visual and tactile inspection – easily disturbed.
- Motorway project in west of Ireland – locally up to 5.0 m of excavation at a culvert.
- Up to 1.5 m of soft alluvium over very silty and very clayey, very sandy GRAVEL (15-35% fines, PI = 5-10, N >8-10)
- Visual inspection  to confirm CBR of 2% at formation level.
- SPT N-Values give a more representative index of subgrade strength/density.



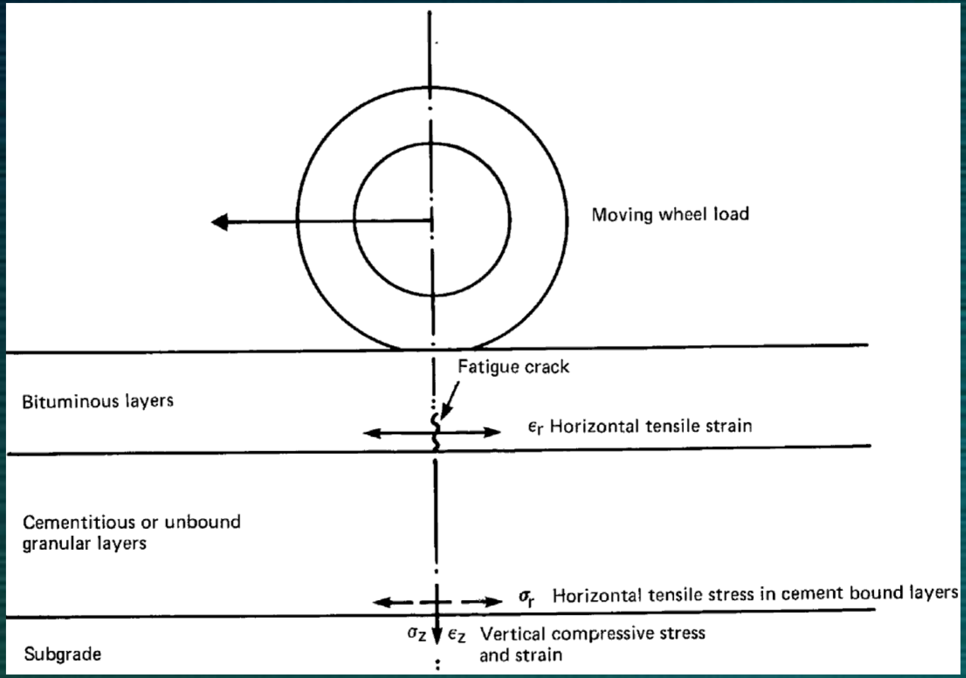

Locally up to 5.0 m excavation at culvert location

SPT N-Values vs. Depth



# Class 2C < 35% fines – Sub-Formation/Capping

- For low embankments or at-grade conditions – materials can have very low CBR <<2%.
- 600 mm capping insufficient.
- Site-specific design consisting of 1000 mm of Class 6F2 granular fill with a geotextile separator.
- Demonstrated by finite element analysis that radial and vertical strains at sub-formation level for a CBR of 0.5% were comparable to conventional designs to HD 25/94.
- Deeper drains also recommended.




Critical stresses and strains in a bituminous pavement (TRRL 1132)

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Section 3 – Low Plasticity/Non-Plastic Class 2C Materials with <35% fines

# Content

- Section 1: Material Classification
- Section 2: Material Acceptability
- Section 3: Low Plasticity/Non-Plastic Class 2C Materials with <35% fines
- **Section 4: Subgrade Assessment**

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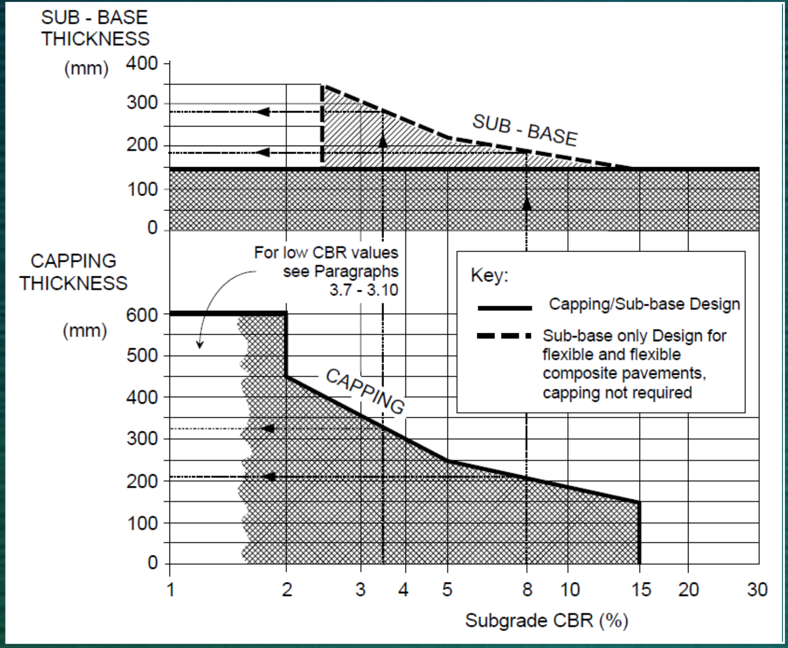
# Subgrade Assessment

- Design to HD 25/94 (Foundations) up to Dec. 2010
- Minimum of long-term equilibrium CBR (Table 2.1) and short-term CBR.
- Average construction conditions.
- Cohesive glacial till PI <10-20.
- Embankments (Low water table >1.0 m): Equilibrium CBR = 4.5% - 7.0%
- Cuts (High water table <0.3 m): Equilibrium CBR = 3%-6%
- Thickness of capping/subbase from Figure 3.1

| TYPE OF SOIL | PI | HIGH WATER TABLE | | | | | | LOW WATER TABLE | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CONSTRUCTION CONDITIONS: | | | | | | CONSTRUCTION CONDITIONS: | | | | | |
| | | POOR | | AVERAGE | | GOOD | | POOR | | AVERAGE | | GOOD | |
| | | Thin | Thick | Thin | Thick | Thin | Thick | Thin | Thick | Thin | Thick | Thin | Thick |
| HEAVY CLAY | 70 | 1½ | 2 | 2 | 2 | 2 | 2 | 1½ | 2 | 2 | 2 | 2 | 2½ |
| | 60 | 1½ | 2 | 2 | 2 | 2 | 2½ | 1½ | 2 | 2 | 2 | 2 | 2½ |
| | 50 | 1½ | 2 | 2 | 2½ | 2 | 2½ | 2 | 2 | 2 | 2½ | 2 | 2½ |
| | 40 | 2 | 2½ | 2½ | 3 | 2½ | 3 | 2½ | 2½ | 3 | 3 | 3 | 3½ |
| SILTY CLAY | 30 | 2½ | 3½ | 3 | 4 | 3½ | 5 | 3 | 3½ | 4 | 4 | 4 | 6 |
| SANDY CLAY | 20 | 2½ | 4 | 4 | 5 | 4½ | 7 | 3 | 4 | 5 | 6 | 6 | 8 |
| | 10 | 1½ | 3½ | 3 | 6 | 3½ | 7 | 2½ | 4 | 4½ | 7 | 6 | >8 |
| SILT* | | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 2 |
| SAND (POORLY GRADED) | | 20 | | | | | | | | | | | |
| SAND (WELL GRADED) | | 40 | | | | | | | | | | | |
| SANDY GRAVEL (WELL GRADED) | | 60 | | | | | | | | | | | |

* estimated assuming some probability of material saturating

Long-Term Equilibrium CBR (HD25/94 – Table 2.1)




Capping/Subbase thickness vs. CBR (HD 25/94 - Figure 3.1 )

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# Cohesive Glacial Till - Embankments

- Short-term CBR generally governs design.
- Must be consistent with material acceptability limits, e.g.
  - Class 2C,  MCV = 7 ≈ CBR of 1.5-2.0%:
  - 600 mm of capping required for CBR <2%.
- Often overlooked and higher CBR specified with no additional controls on fill at top of embankment.
- Overcome with improvement layer of higher strength fill material within 1.0 m of sub-formation level.
- CBR of 2-3% normally specified for Class 2C materials.

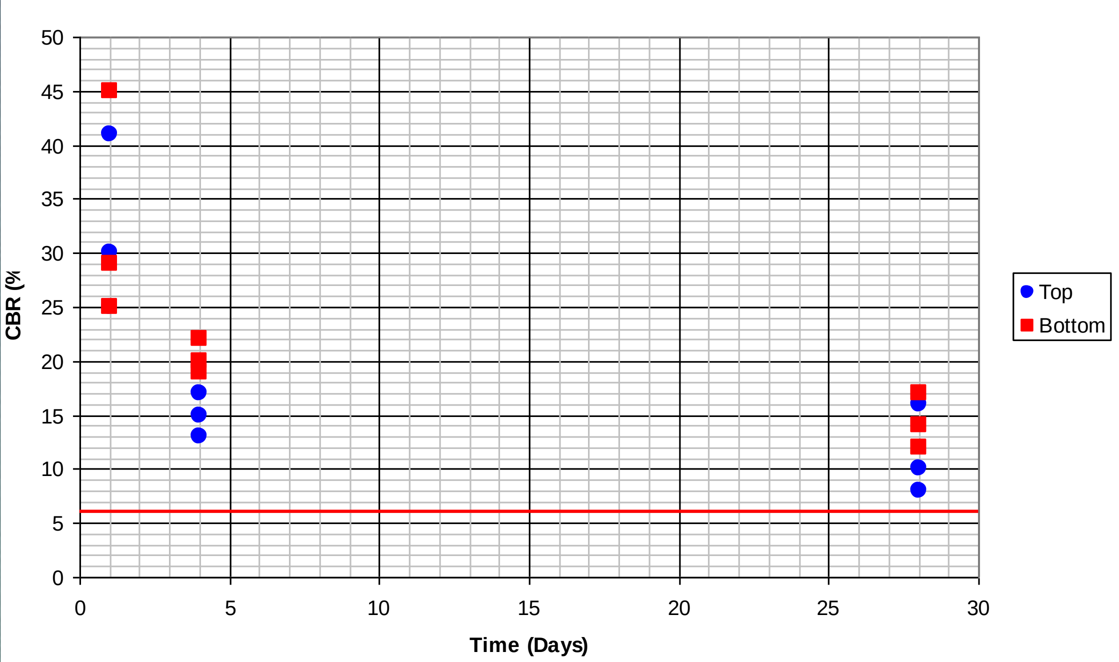
# Cohesive Glacial Till - Cuts

- Strength assessed on the basis of MCV/CBR/SPT N-Values/Strength Classifications etc.
- Long-term equilibrium value will govern in very stiff Boulder Clay.
- Laboratory testing to determine site specific equilibrium CBR.
- Short-term CBR generally governs design in low strength glacial till.
- Site specific design by finite element analysis for very low strength cohesive glacial till with CBR <<2%.

35%

# Cohesive Glacial Till (High Strength) – Cuts

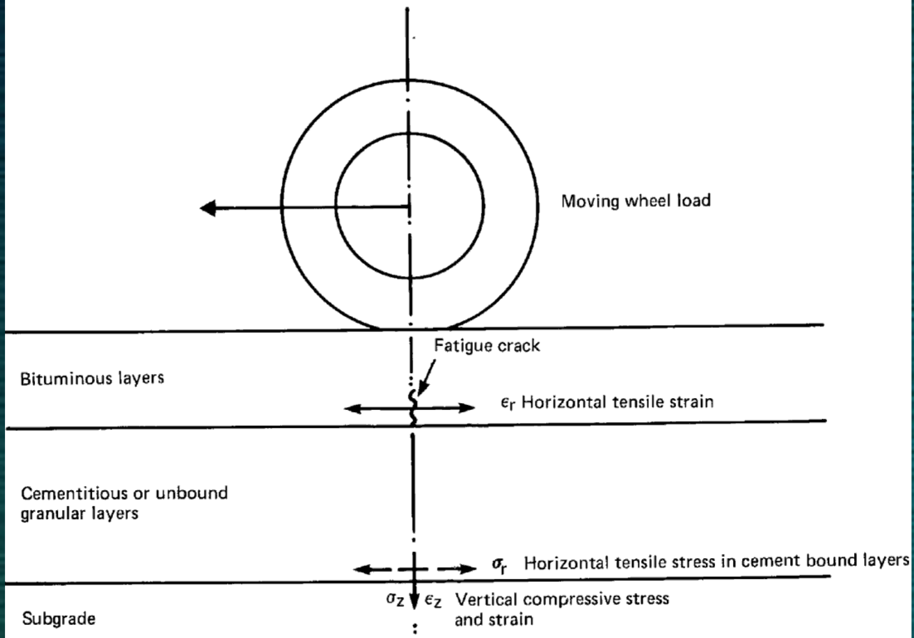
- Short Term CBR >15% in very stiff black boulder clay in deep cuts (drumlins)
- Lab CBR on samples statically recompacted to in-situ density at NMC & soaked for up to 28 days.
- Design value of 6% for long-term equilibrium CBR – at upper end of range in Table 2.1 of HD 25/94.
- May be possible to increase with further testing (e.g. suction tests).




N2 Carrickmacross Bypass - Long-Term Equilibrium CBR

# Cohesive Glacial Till (Low Strength) – Cuts/At-Grade

- Short Term CBR <<2% in low strength cohesive glacial till.
- HD25/94 does not give specific recommendations on depth of excavate/replace – on the order of 0.5-1.0 m and CBR <2% at surface of treated soil.
- Site specific capping design to confirm equivalent $\varepsilon_r$ and $\varepsilon_z$ under standard wheel load (40 kN, 0.3 m dia.) to standard design in HD25/94 on higher strength subgrade.
- Finite element analysis with linear elastic models.
- Subgrade: $E = 17.6(CBR)^{0.64}$ (MN/m²) – HD 25/94
- Appropriate layer modulii for subbase and bituminous layers




Critical stresses and strains in a bituminous pavement (TRRL 1132)

# Granular Glacial Till - Embankments

- Short-term and equilibrium CBR >15% for Class 1 Materials (<15% fines) – No capping required.
- Appropriate controls for classification of fill material (e.g. grading)
- Improvement layers on Class 2C fill, e.g.:
    - 1.0 m of Class 1A well-graded general granular fill (typ. Gravel)
    - 800 mm of Class 1C coarse granular fill – blinded to Cl. 608.3 of the NRA SRW.
    - 600 mm of non-argillaceous Class 1 material to Class 6F1 grading with TFV >30 kN.
- 150 mm Cl. 804 subbase.

# Granular Glacial Till – Cut Sections

- Design CBR of 15% with no capping often specified where Granular Glacial Till encountered at sub-formation level.
- For comparable design to an improvement layer – should be min. 1.0 m of Class 1A material below sub-formation level.
- Often based on field descriptions in BH and TP – may not be representative and can be unreliable.
- The fines content of glacial gravels is inherently variable and often >15% (Class 2).
- Samples with PSD may only be representative at sampling location.

35%

- Need reliable quality control measures (e.g. trial pits, gradings, plate load tests)

# Capping by Lime & Lime-Cement Stabilisation

- Quicklime added to soil – reduces water content and increases optimum moisture content (lime modification)
- Soil allowed to mellow for 1-3 days (UK & US) prior to compaction (stabilisation)
- Compacted stabilised layer left to cure to form cementitious bonds that increase in strength and durability over time.
- Adding cement improves strength and durability of capping to wet/dry cycles.
- Compacted wet of optimum to <5% air voids to prevent Carbonisation (Lime + $CO_2$ = $CaCO_3$)
- Thickness of stabilised capping layer taken as same as Class 6F1/6F2 – 350 mm normal limit for rotavating equipment (subgrade CBR of 3%).
- Sulphate limits in UK MCHW & DMRB to prevent swelling (e.g. from pyrites)

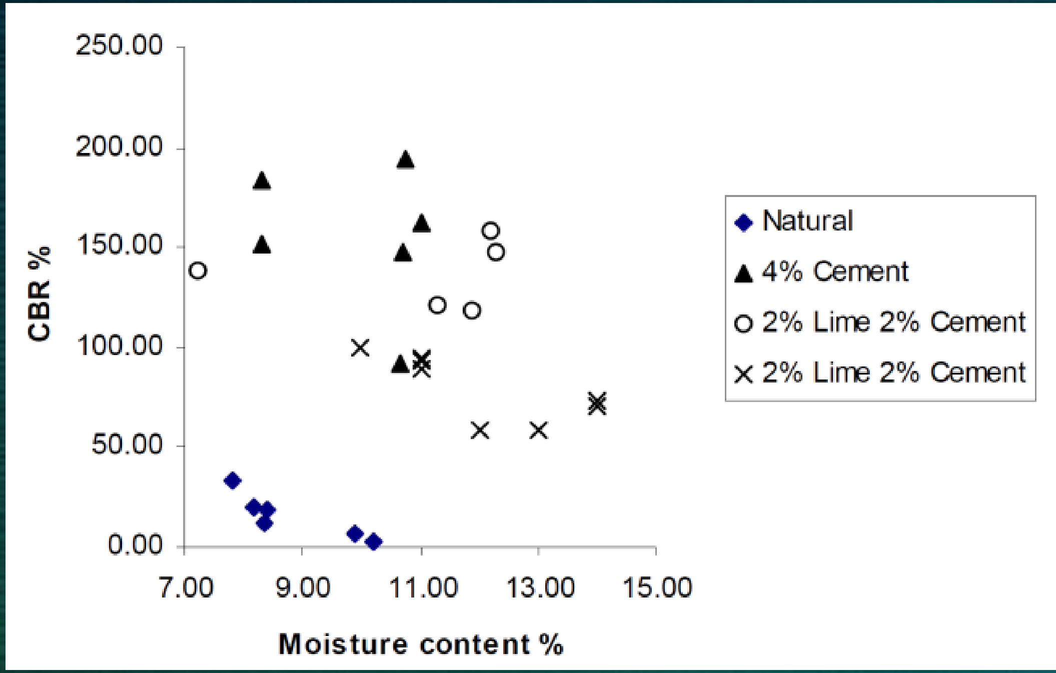
# Capping by Lime & Lime-Cement Stabilisation

- Widely used in UK, US, France & Germany
- Technical submission to NRA in 2002 on Northern Motorway – lime-cement stabilisation of Dublin Boulder Clay.
- No technical objections - rejected on contractual grounds.
- 2007: lime-cement stabilisation of Dublin Boulder Clay used to form capping on short trial section of R158 Summerhill to Kilcock Road Scheme.
- Has not been used on any major national road schemes to date.

35%

# Capping by Lime & Lime-Cement Stabilisation

- Results of field trials and lab tests indicate that Dublin Boulder Clay can be used successfully to create capping to relevant specifications in UK MCHW & DMRB, e.g. for 2% lime/2% OPC.
- CBR >> 15% at 7 days (3 curing/4 soaked)
- 28 day compressive strength 683-1159 kPa.
- <1 mm heave.
- Low sulphate content.
- Not frost-susceptible
- Equivalent deflections/critical strains by FEA.
- >35% fines, PI>10.



# Summary

- Section 1: Material Classification
- Section 2: Material Acceptability
- Section 3: Low Plasticity/Non-Plastic Class 2C Materials with <35% fines
- Section 4: Subgrade Assessment

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# GEOTECHNICS ON IRISH ROADS, 2000 - 2010

## *A Decade of Achievement*

CPD Conference Thursday 11th October 2012