GEOTECHNICAL CHALLENGES IN ROAD CONSTRUCTION IN IRELAND: 2000 - 2010

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Presentation Outline

• Overview of Road Construction in Ireland

• Management & Commercial Challenges

• Geology – Glacial Processes & Land Forms

• Technical challenges - *glacial tills, peat, alluvium, and bedrock and ground water.*

• Conclusions
Irish Road Network 2000
Inter Regional & North – South Trade Growth 1995 - 2006

Sources: Central Statistics Office (Ireland) and CSRGT (Northern Ireland) 2005

Source: InterTradeIreland (deflated values - 1995 €)
Major Inter Urban Routes (Barry, 2010)

- 750 km of Motorway Standard Roads linking Dublin to Border, Galway, Limerick, Cork & Waterford.
- 282 km single carriageway connector & local roads
- 97 grade separated junctions & 581 bridges
- 79 million m$^3$ cut & 73 million m$^3$ fill
- 7800 Hectares Land Take
- Total Cost - €8 Billion
- 41 separate road schemes
- 20,000 people employed at peak
- Mean construction cost per km – varied €5 to 7 million / km
- Direct benefits – time saved and operational costs to consumers and industry; fewer accidents (875 fewer injuries plus 25 fewer fatalities per year)
- Cost Benefit analysis yields a 3:1 positive ratio.
Other Road Improvements

- 250 km of Motorway / Dual Carriageway Roads along N2, N3, N4, N11, N18 & N25 corridors.
- Dublin Port Tunnel & M50 Extension to M11 & Upgrade
- Upgrades and bypasses to several National Primary Routes

Northern Ireland Road Service

- 10 km widened motorway, 65 km dual carriageway plus 24 km single carriageway
- Total Cost - £850 Million
- A1 Newry Bypass & cross border link
- A2 Bypasses - Maydown to City of Derry Airport & Limavady
- A4 Dungannon to Clogher
- Westlink Belfast upgrade & M2 widening
Management & Commercial Challenges to Geotechnical Investigations

- GI Contractors increased turnover by approximately six-fold during mid 1990s to 2006
- Most of the growth was achieved by indigenous Irish companies including some small start ups
- Specialist geotechnical laboratories – previously complex test capability was provided only in University labs or in UK mainland
- Specialist geophysical survey companies
- Expansion of GI techniques to include GeoBore S, vibro core (glacial tills / weathered bedrocks), CPTu on soft ground, SR / ER / MASW / GPR geophysics
- Typical Irish GI Contracts cost 0.2 to 0.9% of total road construction costs (Quigley 2012) – compares well with UK data by Rowe (1972) 0.2 to 1.5%. Trend of reduced percentage with construction value.
Tender v Outrun Costs – GI Contracts (Quigley, 2012 BCRI)
Construction v GI Costs – Roads Contracts (Quigley, 2012 BCRI)
Management & Commercial Challenges to Geotechnical Consulting & Design Services

- Corresponding increase in numbers of geotechnical engineers employed by specialist consulting firms and larger designers.
- Some of the growth was achieved by indigenous Irish companies while several design firms were acquired by large UK consultants.
- Historical construction contracts replaced with design – build / PPP / fixed price lump sum which transferred all ground risks to contractor and his designer.
- This new approach drove innovation (within limits imposed by the Contract) plus designs that were tailored to meet specific contractor needs and capabilities.
- Influence by large mainland European Contractors was significant (Ferrovial, Dragados, Strabag, Gama, Mota-Engil) but otherwise most construction was performed by indigenous Irish Contractors.
- Data by Barry (2010) suggests that construction costs after 2005 were effectively controlled well within the general price index.
Road Construction Cost Trend 1998 – 2010 (Barry, 2010)

Mean Construction Cost /km Trend Vs Capital Goods Index (Materials & Wages)

- Blue line: Capital Goods Index (Materials and Wages)
- Red line: Mean Construction Cost /km (Trend) in Completion Year Values

Year:
- 1998
- 1999
- 2000
- 2001
- 2002
- 2003
- 2004
- 2005
- 2006
- 2007
- 2008
- 2009
- 2010

Mean Construction Cost /km (€):
- 0
- 2,000,000
- 4,000,000
- 6,000,000
- 8,000,000
- 10,000,000
- 12,000,000

Capital Goods Index (Value):
- 20
- 40
- 60
- 80
- 100
- 120
- 140
- 160
- 180

Irish Bedrock Geology
80% of the MIU routes and other roads were constructed in areas underlain by Carboniferous bedrock. Limestone was dominant rock type with some mudstones (e.g., Dublin Calp).

Limestone is a soluble rock - this gives rise to karst features and consequent risks to geotechnical works. Rutty & Jennings, 2012.

Older rocks of Devonian, Silurian & Ordovician age (predominantly sandstones, shale, mudstone) present in Border, south Leinster and Munster.

Oldest Pre Cambrian rocks in parts of Donegal and Derry.

Volcanic intrusive rocks (granites, basalt) present in N. Ireland and south Dublin / Wicklow.

In general most Irish rocks are reasonably well suited for road construction (general fill, sub base, concrete or bitumen bound aggregates).

To date pyrite has not been a problem for road construction – probably due to better implementation of QC procedures.
Glacial Valleys in Antarctica & Wicklow
Irish Quaternary Geology

• 95% of the MIU routes and other roads were constructed in soil deposits and land forms derived from at least one episode of glaciation over the past 1.7 million to 12,000 years ago.

• Land surface has been affected by sequences of ice formation and warm inter glacials - at least 3 have occurred in last 500,000 years.

• Glacial Features include erratics, corries, drumlins, kames, eskers, kettle holes, fossil pingos, overflow channels.

• Large variation in Mean Sea Levels and alteration of major river courses gave rise to deep buried river channels and estuaries.

• Glacial Till deposits are ubiquitous in Ireland but far from uniform.

• Physical characteristics derive from the parent rock type that the soils were eroded from plus their depositional environment.

• Lodgement Tills (Dublin Boulder Clay) are very compact, (v. stiff to hard) soils due to large traction forces at the base of thick glaciers.

• Englacial Tills are less compact (firm to stiff / medium dense) soils deposited near the bases of retreating glaciers.
Distribution of Glacial Features in Ireland (Mitchell & Ryan, 2003)
Technical Challenges – Glacial Tills

Typical Engineering Characteristics (Farrell 2010)

- Generally called a ‘Boulder Clay’, although typically boulders are very occasional.
- Few true ‘clay’ minerals, mainly ‘rock flour’, silt size particles.
- Can be very dense, with bulk densities of up to 2.47Mg/m³ measured for the very stiff / hard lodgement tills.
- The dense lodgement till can be very stiff, particularly at low strains compared with many clays.
- Relatively high effective stress parameters for a ‘clay’ $\phi = 35^\circ$
- Little degradation in effective stress strength parameters at large strain (residual).
- Can behave as a fine ‘cohesive’ or coarse ‘cohesionless’ soil depending on its fines content.
- Low Plasticity Index $I_p$, consequently can be difficult to work in wet weather, particularly with low fines. Regional variation in $I_p$ (O'Donnell, 2012)
Technical Challenges – Peat

Timber Raft Supported Track, Irish Bog circa 4,000 B.C. (Raftery, 1990)
Technical Challenges – Peat

• Generally peat soils are poorly investigated, partly because NRA Contracts only permit one of two solutions:

• Full excavation & replacement – typically to modest depths of up to 4m but exceptionally this has been successfully achieved to 13m depth.

• Reinforced pile embankments using geosynthetic reinforcement or reinforced concrete load transfer platforms. (Orsmond, 2012)

• Neither solution is easy to execute or risk free for deep peat > 4m.

• Other solutions are used in similar soils elsewhere in the world:

• Surcharge (load overstress by fill or via vacuum consolidation) Scandinavia, Netherlands, Canada, USA (Florida), & Japan.

• Mass stabilisation (Deep Dry Soil Mixing) Scandinavia & UK
Technical Challenges – Alluvium & Lacustrine Soils
Alluvium & Lacustrine Soils

• Alluviums are recently deposited, very soft silts and clays with high compressibility and creep characteristics.
• Variable organic content and frequent peat layers, either at ground surface or at depth.
• Depths vary from a few metres at modest inland rivers to > 10m at major rivers and estuaries (Shannon at Athlone & Limerick).
• Greatest depth in Ireland at Clonmore Road, Mullingar ~ 30 m.

• Calcareous marl (tufa) is a lacustrine deposit resulting from upflows of groundwater saturated with CaCO$_3$ into a lake which frequently is subsequently filled by a raised peat bog;
• Deposit is common in Irish Midlands and was encountered on many road projects;
• Similar engineering properties to alluvium (low strength, high compressibility) but also has high sensitivity;
Technical Challenges – Alluvium & Lacustrine Soils

• Ground improvement, sometimes in combination with partial excavate and replace, is frequently an economic solution and permitted by NRA.

• Single stage embankments can typically only be built to modest heights < 3m unless very flat side slopes or berms are employed.

• Multi-stage embankments are possible but frequently only feasible on large projects with long construction periods – Limerick Tunnel (Buggy & Curran, 2011) N25 Waterford Bypass (Phillips et al, 2012).

• Pre fabricated Vertical Drains (PVD), occasionally with surcharge and basal reinforcement, are used to speed construction, increase stability or reduce creep. A2 Maydown to Derry Airport (Raven, 2012) demonstrates an application to a short earthworks programme < 1 year.

• An observational approach is typically employed together with extensive instrumentation to evaluate deformations plus pore pressures, so as to ensure temporary stability and assess degree of consolidation.
Embankment Behaviour, Jardine (2006)
Limerick Tunnel, Buggy & Curran (2011)

Ch 4+185 m Deformation Ratio & Fill Height v Time

Fill Rate = 1.3m/wk
Limerick Tunnel, Buggy & Curran (2011)

Ch 150 m Deformation Ratio & Fill Height v Time

Filling Rate = 3m/wk
Limerick Tunnel, Buggy & Curran (2011)

Clonmacken Link Embankment Failures

Apprently some Poor Quality fill material has been used. A NCR is outstanding on this matter.
Limerick Tunnel, Buggy & Curran (2011)

Surcharged Embankment (13.7 m High, 8.5m Alluvium)
Embankment Behaviour – Irish Alluvium

Deformation Ratio vs. Maximum Rate of Filling

- Limerick Tunnel
- Dunkettle, Co. Cork
- N18 Bunratty Bypass
- A2 Maydown to CODA

Deformation Ratio vs. Maximum Rate of Filling (m/week)

Maximum Rate of Filling (m/week)
Clonmore Road, Mullingar – the ultimate piled embankment!

540 m long bridge supported on 273 mm dia piles. Built by Jons €12 million.
Technical Challenges – Rock

Clay filled Karst solution feature in Limestone, Addergoole, M8, Co. Laois
Technical Challenges – Rock

Fault feature in Limestone, Addergoole, M8, Co. Laois
Technical Challenges – Rock

- Although Limestone was the dominant rock type, Granites, Mudstones, Sandstones, Shales, & Conglomerates were all encountered on roads.

- Excavation by hydraulic breakers was generally practical in most limestone, sandstone & shale bedrocks due to the “blocky” nature of the rock mass discontinuities. Drill & blast was typically required in granites at A2 Newry & M50 south Dublin plus limestone on M6 Galway.

- Rock slopes were typically stable at 1:1 in weak or weathered rocks, 2:1 (V:H) in competent rocks, depending on bedding and joint patterns. Local netting and bolting was used to treat areas of poor quality rock. Some designers used shotcrete and weep holes as a surface treatment or stone buttresses within “slots” of weathered bedrock.

- Fall protection was provided by one of the following measures:
  - widened verges
  - rock trap ditches
  - catch fencing or barriers
Technical Challenges – Rock

Geomat to stabilise topsoil on 1:1 slope in highly weathered Limestone
Technical Challenges – Rock

Local Rock Bolting & Netting slope stabilisation
Technical Challenges – Ground Water

M7 Kildare Town Bypass (Coppinger & Farrell, 2003)
Conclusions

- The decade from 2000 to 2010 saw a transformation of the road network in Ireland and posed many challenges to the Irish geotechnical industry and profession.

- High quality and timely delivery of the road infrastructure programme is testament in itself to how well these challenges were met.

- Current conference represents the “state of the art” in road transportation geotechnics. It provides an important body of reference case histories to guide future engineers, continuing the sequence of conferences begun by the Geotechnical Society of Ireland in 1996.
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