GEOTECHNICS ON IRISH ROADS, 2000 - 2010

A Decade of Achievement

CPD Conference Thursday 11th October 2012
Geotechnics on Irish Roads, 2000 – 2010

Investigation, Design and Construction in Karst
Peter Rutty (Mott MacDonal) and Paul Jennings (AGEC)
Investigation, Design and Construction in Karst

- Karst in Ireland
- Karst hazard
- Karst investigation techniques
- Karst risk assessment
- Design and construction for karst
Karst in Ireland

- Limestones
- Much of solid geology is limestone, mostly carboniferous
- Evidence (●) for karst is widespread (GSI karst database)
Karst in Ireland

N18 Ennis Bypass

M7/M8 Port Laoise to Cullahill/Castletown

N8 Cashel to Mitchelstown
Surface depression, indicator of karst subsidence, several 10s of metres across, active/relict? (Co. Tipperary)
Typical ground profile – till over karst limestone (Co. Cork)
Investigation, Design and Construction in Karst

- Karst in Ireland
- Karst hazard
- Karst investigation techniques
- Karst risk assessment
- Design and construction for karst
Development of drop-out subsidence sinkhole, showing initial drop-out (1), subsequent collapse (2, 3) and final collapse with debris infill, and effect of stiff surface soil (after Sowers)
Karst collapse and groundwater lowering

collapse due to loss of buoyant support and effective stress changes in soil arch following GW lowering (e.g. by road cutting)

(www.Dyetracing.com)
Karst collapse and surface drainage

collapse brought on by erosion of soils by downward moving surface water drainage to rock (seepage erosion/migration of fines)

(www.dyetracing.com)
Karst hazard

Examples of karst subsidence (up to 1.5m or 2m dia) from East Cork
Examples of karst features – typically sub-horizontal/sub-vertical circular pipes 0.2m to 0.3m dia. NB gravel in bottom of pipes
Karst hazard

Karst subsidence under loading

1. Initial dropout
2. Final dropout

Loading might be a structure or temporary, eg moving plant
Investigation, Design and Construction in Karst

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Karst investigations

Desk study

- GSI memoirs and 1:100,000 geological sheets
- 1:50,000 Discovery Series sheets, place names
- GSI, 6 inch: 1 mile geological mapping sheets, typically dating from late 19th century, and more recently issued Quaternary mapping
- Aerial photographs
- Geological Survey of Ireland Karst Database

- The Karst of Ireland. Limestone landscape, caves and groundwater drainage systems (Geological Survey of Ireland, 2000)
- Other literature sources
  - ‘Mitchelstown Cave – one of Europe’s major caves – its discovery and history’
- Walkover, information from landowners
Karst investigations

Desk study

Geology of Ireland showing pure (clean) and impure (muddy) limestones

M7/M8 Portlaoise to Cullahill/Castletown

N8 Cashel to Mitchelstown

N18 Ennis Bypass

(GSI, 2000)
Karst investigations

Desk study

Faulting from GSI mapping

N8 Cashel to Mitchelstown
Placename – ‘Poulculleare’

Disappearing watercourse

Dry valley (dashed line)

Walkover – Place names and OSI features (N8 South Tipperary)
Karst investigations

Walkover

Information from landowners – the following questions were included in landowner questionnaire –

- ‘Any history of local flooding or unusual drainage features?’
- ‘Do you have any places on your land subject to subsidence or any places that have been filled in?’

This provided useful evidence

- One farmer described filling holes at the same location in his fields every spring; this was a bridge site and correlated with geophysical anomalies
- Several mentioned sinks, intermittent springs, sluggeraghs/sluggaries (an slogair)
Walkover - active subsidence sinkhole, N8, Co. Tipperary (note infilling and cracking at right centre)
Karst investigations

- Shallow subsidence feature
  - N8 Cashel to Mitchelstown, Co. Tipperary, 2005
Subsidence, 5m dia. (Arles, Co. Laois, 2005)

landowner reports piping stream and dumping fill on bushes, etc to infill valley 15 years ago - *not* karst

Karst investigations
Plans with GSI database and API/walkover features
(N8 Cashel to Mitchelstown)
Karst investigations

Contoured microgravity readings, red=low, blue=high

Geophysics anomaly 10m x 5m dp by probing

Electrical resistance tomography profile across subsidence feature

Geophysics anomaly

Geophysics (N8 Cashel to Mitchelstown)
Karst investigations

Trial pit investigation of subsidence sinkhole, showing soft organic infill (N8 Cashel to Mitchelstown, Co. Tipperary)
Karst investigations

Trial pits

Other indicators in pits/trenches –

- infill at surface
- variations in topsoil thickness
- collapsed/voided ground
- topsoil at depth

NB anomalous descriptions might also occur in CP borehole logs
Conventional invasive techniques

Dynamic probing log showing zero blow count, suggesting voided soil

Anomalous data should always be investigated
Karst investigations

- loss of flush?
- $\text{TCR} \ll 100$, $\text{SCR} \ll 100$
- $\text{RQD} \approx 0$
- brecciated limestone, slightly – highly weathered rock
- clay infilling
- NB ‘needle-in-haystack’

Rotary core showing brecciated rock and clay infill
Investigation, Design and Construction in Karst

• Karst in Ireland
• Karst hazard
• Karst investigation techniques
• Karst risk assessment
• Design and construction for karst
Karst risk assessment

Process

- identify karst hazard(s)
- collate all evidence from desk study and other sources
- combine evidence to identify high, medium and low risk areas
- predicting occurrence of karst hazards is difficult and risk assessment process can be used as basis for rational decision-making
Karst risk assessment

Risk factors

• rock type – pure/impure limestone
• depth of cover over rock (need >100m for negligible risk)
• cover soil type – granular/cohesive/mixed
• nature of rockhead – fissured/pinnacled
• proximity to geological fault/ boundary
• topography – valley/slope/high ground
• activity, no. of local swallow holes/subsidence features
• distance to nearest swallow hole/subsidence feature
• water table relative to rockhead
• drainage history – seasonal watercourses, dry valleys
• GI data – low N-values, geophysical anomalies, loss of flush return, poor core recovery, infilled rock, brecciation, etc

(from N8 (2005), after Waltham et al, 2005)
## Karst risk assessment

### Geological factors

<table>
<thead>
<tr>
<th>Factor</th>
<th>Value 1</th>
<th>Value 2</th>
<th>Value 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Underlying rock</td>
<td>Clean limestone = 2</td>
<td>Muddy Limestone = 1</td>
<td>Sandstone = 0</td>
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<td>Overburden depth</td>
<td>0 – 5m = 3</td>
<td>5m – 20m = 2</td>
<td>&gt;20m = 1</td>
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<td>Nature of overburden</td>
<td>Cohesive = 2</td>
<td>Granular = 1</td>
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<tr>
<td>Boundary with impermeable rock</td>
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<td>No = 1</td>
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### Ground investigation factors

<table>
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</thead>
<tbody>
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<td>Walkover/API/GSI features</td>
<td>&gt;15 per 5km = 3</td>
<td>1 to 15 per 5km = 2</td>
<td>&lt;1 per 5km = 1</td>
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<td>Geophysics anomalies</td>
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<td>1 to 15 per 5km = 2</td>
<td>&lt;1 per 5km = 1</td>
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<tr>
<td>Landowner observations</td>
<td>&gt;15 per 5km = 3</td>
<td>1 to 15 per 5km = 2</td>
<td>&lt;1 per 5km = 1</td>
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Karst risk assessment (values used for N8 Cashel - Mitchelstown)
## Karst risk assessment

<table>
<thead>
<tr>
<th>E'wks elem</th>
<th>Cut/ Fill</th>
<th>Height/ Depth</th>
<th>Rock Type</th>
<th>Depth of o' burden</th>
<th>Cover</th>
<th>B'daries with imperm rock</th>
<th>Geo Risk Rating</th>
<th>Geo Risk Ranking</th>
<th>AP features</th>
<th>Geo-phys features</th>
<th>Shallow Geo-phys features</th>
<th>Land'own Obs GSI D'base</th>
<th>Walkover</th>
<th>Evidence-Based Risk Rating</th>
<th>Evidence-Based Risk Rating (shallow MG only)</th>
<th>Correlation between Geological and Evidence-Based</th>
<th>GW lowering</th>
<th>KARST RISK</th>
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<tbody>
<tr>
<td>EW1</td>
<td>Cut</td>
<td>11.5</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>Yes=2 No = 1</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
<td>&lt;1/5km=1</td>
<td>1-15/5km=2</td>
<td>&gt;15/5km=3</td>
<td>Min=0</td>
<td>Max = 24</td>
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<td>Emb</td>
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<td>2</td>
<td>2</td>
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<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>High</td>
<td>Good</td>
<td>Medium</td>
<td>High Mediu m</td>
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<td>3</td>
<td>High</td>
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<td>3</td>
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<td>Low</td>
<td>Good</td>
<td>Low</td>
<td>low</td>
<td>low</td>
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</tbody>
</table>
Karst risk assessment

Application

• Weighting risk factors is difficult – see Waltham et al for discussion
• On N8 factors were compared for each earthworks element
• N8 route was divided to sections with subjective high, medium or low risk based on rankings and correlations of individual factors
• Engineering measures were specified accordingly
  – principally drainage control in higher risk areas
  – high strength geotextile reinforcement below shallow embankments/at-grade
• Specific features scheduled for verification by excavation and remediation during construction
• Further investigation specified at structures at risk
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Design and construction

- Sections of route identified as more prone to karst subsidence identified
- These have managed drainage – ie collected water is carried to defined outfalls and not allowed to seep into the ground
- Run-off carried in sealed drains or lined drainage trenches
- Unlined trenches backfilled with granular fill can act as conduits for water
- In high risk areas drains can be long steel pipes to avoid risk of broken drains formed with short pipes causing leaks
- Avoid use of coarse starter layer material beneath embankments – use NRA Class 6C which includes fines of Wagener

N8 Cashel to Mitchelstown - Drainage
Design and construction

Typical detail for pavement dentition on karst limestone
(as specified for N8 Cashel to Mitchelstown)
Design and construction

a) excavation of subsidence to remove soft material and expose stiff cohesive/dense granular soils

b) treatment by backfilling with well-graded granular fill to maintain drainage flowpath to rock

Typical detail for backfilling sinkhole over shallow limestone (depth to rock < 5m) (as specified for N8 Cashel to Mitchelstown)
Design and construction

Solution cavity in limestone (N8 Cashel to Mitchelstown)

Remediation by excavation and backfilling with coarse rock fill (Co Cork)
High-strength geofabric reinforcement over karst feature (as specified for N8 Cashel to Mitchelstown)
Example of shallow foundations on karst limestone (Co Cork)
Design and construction

• From risk assessment - 11 structures out of more than 60 judged to be founded on ground with a risk of karst subsidence
• Depths to rock from GI varied
  – from 5m to 30m
• c.1450 rotary percussive air flush probe holes at 2.5m c/c, total >16750m drilling was specified in Appendix 6/11
• Soft, weak or voided soil based on the drilling rate of progress and grout take
  – criteria not specified but developed on site
• Holes grouted upon completion
• Specification included various provisions
  – excavation to expose rock and filling voids
  – ground stabilization by drilling and pressure grouting
  – soil stabilization using interlocking soil/cement columns
• None required, but structure S05 changed from pads to piles over 20m-40m karst limestone

N8 Cashel to Mitchelstown
Specification Appendix 6/11 provisions
Mini piles

- Typical mini-pile design in karst limestone (Wylie, 1999)
- Rock socket friction by eg Long and Collins or CIRIA R181
- Ignore toe resistance
- Case through voids and soft soils
- Several piles in group with rigid pile cap

Wylie, 1999
Large diameter piles

- Where end bearing is employed, rock beneath toes of large diameter piles must be proved during construction by probing/coring
- Load spread should be considered
- Or design developed to avoid use of end bearing

Sowers, 1996
Design and construction

- cavities and clay filled voids
- no recovery in limestone
- quick drilling rates indicating voids
- 2.9m thick layer of gravel and cobbles with clay infill
- karstified rock to 25m, then 5m sound rock over further karst limestone

- 750mm diameter bored cast in place piles with 1.5m rock socket
- Assumed load spread over underlying karst limestone

M7/M8 Portlaoise to Cullahill/Castletown
Structure S25
Design and construction

- Shallow foundation karst risk mitigation procedure
- N18 Ennis Bypass
- Structure 12, Clareabbey Railway Bridge
- Structure 09, Barefield Railway Bridge
Design and construction

N18 Ennis Bypass – shallow foundation design options

i. spot treatment of small features

ii. redesign of foundation based on reduced bearing capacity in accordance with the inspected in situ conditions

iii. redesign of the foundation adopting piled solution
Summary and conclusions

- Karst in Ireland – potentially widespread
- Karst hazard – variable rockhead, voids, weak infill, subsidence (generally <5m across, often smaller)
- Karst investigation techniques – desk study is most important (IS EN 1997-1), walkover and API cover large areas cheaply, consider all anomalous data
- Karst risk assessment – possible but needs further work, useful for drainage design
- Design and construction for karst – textbook solutions can and have been used
- Addressing karst is an exercise in ground risk management
Opportunities

- Can susceptible soils be identified?
- Comparison with internal erosion in dams cf Fannin and Moffat?
Acknowledgements

• Thanks to friends and colleagues who worked on the projects described and helped with the production of this paper

• In particular –
  – Fintan Buggy of Roughan and O’Donovan for the case history describing M7/M8 Portlaoise, Structure S25
  – Peter O’Connor of Apex Geophysics for examples of geophysical investigations of karst
  – David Buckley of Ramboll for re-collections of construction of N8 Cashel – Mitchelstown and various construction photographs
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Thank you

Mott MacDonal