ROAD DESIGN IN KARST LANDSCAPES: THE M17/M18
INTRODUCTION

- Overview and Hydrogeology – Les Brown (ARUP)
- Geotechnical Design of Karst - Esther Madden (ARUP)
- Karst Features Encountered on Site - Deirdre O’Hara (Barry Transportation)
• 1999 – 2006: Route Selection and EIS
• 2005 – 2007: Planning approvals
• 2008 – 2014: Procurement
• 2015 – 2017: Construction
• Planned opening first quarter 2018
• Motorway opened September 27th, 2017
KEY DESIGN AND CONSTRUCTION CHALLENGES

- Three contractors – two designers
- Regionally important karst aquifers
- Numerous groundwater dependant terrestrial ecosystems
- Seasonal groundwater flooding
- Areas of significant geotechnical karst risk
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<tr>
<th>Hole</th>
<th>Hole type</th>
<th>Date/Time</th>
<th>Reading</th>
<th>GL Reading</th>
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<td>BH 599</td>
<td>RC</td>
<td>21.06.09/01/2008</td>
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**Notes:**
- Proposed Pond Layout
- Design level = 18.00m
- Blast Plan over extent of area for pond within LMA to a depth of 8m
- Extent of Current Foal Excavation - Inset = 10m
- Existing ground level = 18.50m to 19.40m
- Water Level in Tanough = 9.178m (taken 07/08/10)
- Existing Line of sight to Oldway Railway Line
- Proposed Development Site Road
- Fort Site up
TYPES OF KARST FEATURES
• Winter 2015/2106
• Known Flood Levels (2008/09) were not exceeded
• A number of new areas were assessed
• Designs adjusted as required
• Stress Tests carried out on drainage designs for multiple storm events and combinations
Embarkment 11 Ch21+200: Piezometer water level vs time

Ch2 - (Ch21+200 - Middle Deep - Depth 18.5mOD)

Piezometer water level (mOD)

Time of measurement (dd/mm/yyyy)
GW level high for 5 months
MITIGATION AGAINST FLOODING

- Road Design Levels
- Drainage Blanket
- Flood Relief Culverts
ROAD DRAINAGE – SPECIAL REQUIREMENTS

- Sealed Drainage - All of the M18 road drainage to be sealed
- Northern section mainly attenuation pond to surface water – southern section mainly infiltration basins to groundwater
- Regionally Sensitive Aquifer – Hydrogeological Assessments
- Seasonal flooding (reference level 2008-2009 peak +1m)
ROAD DRAINAGE - ATTENUATION

- Constructed Wetland and Soakaway
  - Infiltration System
  - Excavation in Rock
  - Proximity to SAC and Local Group Water Scheme
  - Area of Seasonal Flooding
GEOTECHNICAL DESIGN FOR SOUTHERN SECTION

Esther Madden
BSc MSC MIEEI CENG
GSI Geology map and karst landforms via ArcGIS
• Access relevant datasets in the field

• Capture geo-referenced information including photos
All recorded information available on ArcGIS Online
CONCLUSION

These applications can effectively feed into generating and managing a digital model throughout the life cycle (BIM)

Applications:

- Ground Investigations
- Karst Mapping
- Resident Engineers for geotechnical works
Detailed Assessment of Areas of High Karst Activity

Evaluation of Karst Activity in relation to Bedrock Susceptibility and Formation Changes
Regional Geological, Hydrogeological, and Environment available from relevant bodies

Alignment data, field / site walkover information, services and utilities

3D information including topographical contouring, alignment, geological surfaces

Ground investigation data, geophysical results (ground conductivity, microgravity)
<table>
<thead>
<tr>
<th>Scheme</th>
<th>Length (m)</th>
<th>% of alignment</th>
<th>Risk</th>
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<tr>
<td>9+530</td>
<td>43%</td>
<td>High</td>
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</tr>
<tr>
<td>11+510</td>
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<td>Medium</td>
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<tr>
<td>1+160</td>
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<td>Low</td>
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Risk Assessment

Application of blanket geotextile across 95% of alignment and piling of high percentage of structures!!
EARTHWORKS DRAWINGS
Designer to characterise the potential for karst features in the GIR risk register

Designer to review risk of features affecting works and outline any change to risk and locations in the GDR/EW package

DSR to investigate karst features identified during the GIR and marked on the plan profiles

Talk to landowners

Features identified on drawings from desk study?

Topsoil strip noted on drawings

Strip topsoil where embankment is <3.0m or within 15m of structure proceed with earthworks

DSR to inspect subgrade for visible karst features

Feature found?

Carry out GI

SED apply?

Apply appropriate SED

Designer to develop solution

Cat III approval

Apply design solution

Record and note in safety file

Document karst feature

Apply design solution

Complete earthworks including blanket geotextiles where shown in design

Document reason why it is not a karst feature

Document reason why it is not a karst feature

is there evidence of a sinkhole, e.g. mixed soil types?

is there evidence of a sinkhole, e.g. mixed soil types?

Topsoil strip

maybe

yes

no

maybe

yes

no

yes

no

no

no

no

no

yes

yes

yes

no

no

yes

no

maybe

no

yes

Designer to characterise the potential for karst features in the GIR risk register

yes

yes

yes
BENEFITS OF KARST PROTOCOL

- Use Karst protocol to reduce need for blanket geotextile and piles
- Standard set of solutions available for typical features and dimensions encountered
- Excavation to inspect rock head is more accurate than geophysics if depth to excavation is practical
### Benefit of karst protocol

| Length (m) | 9+530 | 11+360 | 19+800 | 23+120 | 27+070 | 15+430 | 15+540 | 15+600 | 15+630 | 15+660 | 15+670 | 15+680 | 15+700 | 15+730 | 15+740 | 15+770 | 15+780 | 18+100 | 18+110 | 18+140 |
|------------|-------|-------|--------|--------|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Risk       |       |       |        |        |        |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| Low Risk   |       |       |        |        |        |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| Medium Risk|       |       |        |        |        |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| High Risk  |       |       |        |        |        |       |       |       |       |       |       |       |       |       |       |       |       |       |       |

Risk reduced and less than 20% of southern section alignment required application of SEDs.
Benefit of karst protocol

A detailed review of the geophysical survey information, laboratory data and site observations has been undertaken at the local geology. The results of this analysis highlight the importance of understanding karst features and their potential impacts during the design and construction phase. The identification and assessment of potential karst features is crucial for ensuring the structural integrity of the project.

Procedures in place for assessing structures and

1. **Identification of Karst Features**
   - **Surveys and Testing**: Conduct a detailed geophysical survey to identify potential karst features such as sinkholes, fissures, and voids. This can be achieved through techniques such as ground-penetrating radar (GPR) and electrical resistivity tomography (ERT).
   - **Core Sampling**: Collect core samples to verify the presence of karst features and to determine the extent of subsurface karstification.

2. **Assessment of Karst Risk**
   - **Risk Classification**: Classify the karst features based on their potential to cause damage. This classification should consider factors such as the size of the feature, the presence of groundwater, and the structural integrity of the surrounding area.
   - **Mitigation Strategies**: Develop appropriate mitigation strategies to address the identified karst features. This may include the use of grouting, dewatering, or other stabilization techniques.

3. **Monitoring and Maintenance**
   - **Continuous Monitoring**: Implement a monitoring program to track changes in karst features over time. This can help in early detection of potential issues and prompt corrective actions.
   - **Regular Inspections**: Conduct regular inspections to assess the condition of the project structures and to monitor the effectiveness of the implemented mitigation measures.

By following these procedures, engineers and construction managers can effectively manage the risks associated with karst features and ensure the success of the project.
OB89 – karst uncovered
KARST SHOWN IN GEOPHYSICS AT WEST AND CENTRAL PIER DURING CONSTRUCTION
KARST SHOWN IN GEOPHYSICS AT WEST AND CENTRAL PIER DURING CONSTRUCTION.

Base of west abutment 25.3m OD Malin

Base of central pier 18.6m OD Malin
Option 1 – Leave OB89 in place and remediate karst
  • Central pier

Phase 1 rotary percussive and geophysics 3 to 4m above formation COMPLETE

Phase 2 Ground investigation – geophysics at actual formation and rotary percussive probes on grid to estimate extent of feature

Phase 3 Create safe working platform and carry out shell and auger boreholes to determine soil parameters and rotary coring 3m into rock for rock parameters

Clear out feature and determine extent

Backfill feature beneath pavement to SED

Scenario A
  If void beneath structure foundation is small, backfill with inverted filter and design slab to span feature

Scenario B
  If feature is large and in filled with overburden and rock is at depth, design skin friction piles

Scenario C
  If feature is large and rock is present, design rock socketed piles
SCENARIOS B AND C – LARGE OPEN OR IN FILLED FEATURE

Either piles bearing in soil and on rock or 3m into rock – dependent on depth of competent rock from boreholes

Base of central pier at 18.6 m OD malin

Type, depth, permanent casing and number TBC post design
OPTION 2 MOVE BRIDGE
Reinstatement of karst feature at original location

Verification of bridge formation
M17/M18 KARST FEATURES ENCOUNTERED ON SITE

Deirdre O'Hara BSc MSc HDipPM CEng MIEI PGeo
M17/M18 KARST FEATURES ENCOUNTERED ON SITE

- Drop outs in rock
- River Nanny
- Ballinphuill Bridge
- Ballygaddy Bridge
DROP OUTS IN ROCK
Northern Section encountered a large number of drop outs at rock surface
Followed the Karst features protocol
Rock head was closely examined following excavation
Proof Rolled
Following of conduit karst features at rock surface
SED 602-amended
PROOF ROLL ON ROCK

- Damage to roller
- Solved by placing a layer of rock dust from quarry

**Advantages**
- Free
- Will not block voids if present
- Will prevent damage to roller
DROP OUTS IN ROCK

RIVER NANNY
RIVER NANNY-GEOTECHNICAL RISK ITEMS

- Soft Ground
- Sheet Piles
- Pile Driving
- Karst
During construction of Pile 16, the last pile on the eastern side of the south abutment was driven to a level of 8.74mOD. All other piles were driven to levels ranging from 20-21mOD.

A rotary cored borehole directly east of Pile 16 encountered rock at 20.67mOD. It is likely that Pile 16 has been driven into an infilled karst feature.

The pile driving records below the expected rock head level, indicate a driving resistance of approximately 130kN/m along the pile, which provided adequate support to the pile shaft.

The presence of an infilled karst feature was mitigated against by drilling adjacent to the last pile and proving rock, in accordance with the Karst Protocol that was developed as part of the design.

This indicated that the feature was narrow and confined, the pile driving records proved the infill material was of a sufficient strength to provide a safe bearing capacity and there was also redundancy in the adjacent pile.
BALLINPHUIL
OVERBRIDGE EAST
ABUTMENT

- 2 additional RC
- 0.55m void
- Cover of 4.55m
- Waltham and Lu (2007)
- Safe Void Cover ratio t/w=0.5
- Rock Mass Rating
- Karst Features Protocol followed at surface
CENTRAL PIER

- Formation level at 4m below rock head level
- 2 additional RC Boreholes
- A number of small voids and clay infilled features
- Waltham and Lu?
- 13 additional percussive boreholes
BALLINPHUIL
OVERBRIDGE CENTRAL PIER

- Percussive drilling produced venting in other holes
- Measured grouting of 15 holes
- Voids encountered at varying levels
- Grouting stopped
- Decision to excavate to 3m through rock to investigate what was happening
- 8m to solid rock-proven by the percussive drill holes
- Sides rock
- 8m wide
- 12m long
- 8 No. conduit karst features converging into a central clay filled void
- Beams were already in production
- SLS 5mm
- Linking the conduit karst features using a 0.5m wide no fines concrete surround to allow for continuation of groundwater flow.
BALLINPHUIL WEST ABUTMENT

NO KARST FEATURE AT THE STRUCTURE

INVESTIGATED THE SIDE SLOPE
BALLYGADDY OVERBRIDGE
Large Linear Karst Feature
Saturated sand filled void
3.5m width
Minimum 20m in length
11-13m to solid rock
OPTIONS CONSIDERED
- 2D resistivity survey (5 No. Lines)
- Ground Penetrating Radar (GPR)
- 5 No. Rotary cored holes
- Bridge over the karst feature
BALLYGADDY BRIDGE DESIGN SOLUTION

- Karst slab 850mm thick
- 4m wide reinforced concrete karst slab to span the void, minimum 750mm wide bearing onto rock on both sides
- Due to the shape of the void, the karst slab had to be staggered across the foundation area
Thank you:
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Sisk-Pat Lucey, Noel Curtis
Lagan- John Philbin
3rd Party Checkers; Conor O'Donnell (AGL), Paul Quigley (GDG), Ciaran Reilly (Formerly GDG, now Ciaran Reilly & Associates), Ian Higgins (Agec), Aine Walsh (Agec)
DSR Joe Reilly & all DSR site staff, Aidan Stewart (Photography)
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