Seismic Imaging of Karst: Work In Progress

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Synopsis

- subsurface risk
- geophysical methods and karst
- anatomy of a wavefield and seismic deliverables
- 3C seismic – recording the complete wavefield
• Easy to model effects of arbitrary features, such as voids

(assuming their location & extent are known!)

after Gilbert, 2013
Geological Overview

- Simsima Limestone = 80% Qatar land surface
- approx. 10000 land surface depressions
- widespread subsurface karst formation in Simsima / Midra / Rus geological units
Why manage risk?

Source: Clayton 2001
Impact of Site Investigation on highway contract cost over-runs in the UK from TRL Project Report 60
Intrusive Investigations

• derive key ground data
  
  geological
  geotechnical
  hydrogeological

• are spatially representative?

• are optimally planned both in number, distribution and depth?
Geophysical Investigations

• derive key ground data
  geological
  geotechnical
  hydrogeological

• are well understood (benefits/limitations)?

• are appropriately deployed (best practice)?

• are optimally scheduled to help manage risk and reduce cost?
Geotechnical problems during construction

- Soil boundaries: 6%
- Soil properties: 4%
- Ground water: 5%
- Contamination: 9%
- Obstructions: 10%
- Site investigation: 11%
- Services: 13%
- Detailed design: 20%
- Geophysics: 22%
- Other: 13%

From a survey of 28 construction projects (Clayton, 2001)
• subsurface risk
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Why Geophysics?

- relatively rapid **screening** for lateral and vertical variation
- effective **targeting** of intrusive programmes
- **interpolation** between controls
- appropriate phasing
- appropriate techniques
- appropriate execution
Electrical Resistivity Tomography (Europe – Karst)
Electrical Resistivity Tomography (Doha – Karst)
Ground Penetrating Radar (Europe - Karst)
Ground Penetrating Radar (Oman-Karst)

Data Example
Ground Penetrating Radar (Doha)
Limiting Factors For Investigation

- **MASW** – dependent on frequency content/site conditions
- **Refraction** – velocity inversion below Simsima Lst
- **Microgravity** – depth/resolution
- **ERT** – masking due to saline conditions
- **GPR** – conductivity/saline ground conditions
- **EM** – depth/resolution

*Off the shelf* geophysical solutions may face significant limitations due to Qatar-specific site conditions.
• subsurface risk
• geophysical methods and karst anatomy
• anatomy of a wavefield and seismic deliverables
• 3C seismic – recording the complete wavefield
Field Configuration - Schematic

Receivers

Seismic Source
Anatomy of a Wavefield
Anatomy of a Wavefield
Anatomy of a Wavefield

- Refracted waves
- Reflected waves
- Surface waves
Seismic Deliverables: refraction
Seismic Deliverables: reflection
Seismic Deliverables: surface wave
Seismic Deliverables

P-wave velocity distribution, layering, discontinuities

Seismic stratigraphy, discontinuities

S-wave velocity distribution, Gmax, layering, discontinuities
MASW
Seismic Reflection
Seismic Reflection
Under what conditions does seismic work best?

<table>
<thead>
<tr>
<th>Condition</th>
<th>Example Score</th>
<th>Qatar Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low noise*</td>
<td>8/10</td>
<td>1/10 to 3/10</td>
</tr>
<tr>
<td>Good surface coupling</td>
<td>9/10</td>
<td>2/10 to 5/10</td>
</tr>
<tr>
<td>Saturated materials</td>
<td>8/10</td>
<td>2/10 to 8/10</td>
</tr>
<tr>
<td>Low velocity</td>
<td>9/10</td>
<td>2/10 to 8/10</td>
</tr>
<tr>
<td>Modest contrasts</td>
<td>8/10</td>
<td>2/10 to 5/10</td>
</tr>
</tbody>
</table>

* see next slide
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• geophysical methods and karst
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Model Void

Calculate V and H response

(Sloan et al 2010)
Vertical and Horizontal Diffraction Response

(Sloan et al 2010)
Vertical and Horizontal Diffraction Response

(Sloan et al 2010)
Actual Voiding – V Response

(Sloan et al 2010)
Resonance

(Sloan et al 2010)
Resonant seismic emission of subsurface objects

Valeri Korneev¹
Resonant Seismic Emission

Figure 1. Geometry of the seismic experiment to locate a buried water-filled barrel. Solid lines, dashed lines, and dotted-line arrows indicate direct, circumferential, and scattered waves, respectively.

?tabular voiding
Resonant Seismic Emission
Resonant Seismic Emission
Objective diagnostics for voiding / filled cavities

1) Diffractions
   - V and H geometry
   - V and H velocity behaviour
   - V and H polarity behaviour
   - consistent shot-to-shot response
   - consistent line-to-line response

2) Resonance
   - monochromatic response

Important to capture the 3C wavefield
3C Land Streamer - Captured Wave Modes

- 500 - 1 km / day
- suitable for urban use
3C seismic (single) shot record
Whole Record Spectrum

Input Spectrum
V Response

Channel - 67
H Response

Channel - 166
Spectrum: H Response

Resonance?
V Response
Spectrum: V Response

Resonance?
H Response
Spectrum: H Response

Resonance?
Spectrum: Full Wavefield
Spectrum: hi-pass filtered
3C Full Wavefield Recording – no filters
3C Full Wavefield Recording – hi pass filtered
Hyperbolic/Reverse Move-Out Events

Field File - 45
Hyperbolic/Reverse Move-Out Events

Field File - 46
Hyperbolic/Reverse Move-Out Events

Field File - 47
...and Surface Waves
Tampa Bay Crosstown Expressway, April 13 2004

- Pier 97 collapse
- 3 m karst feature
- $350M project
- $100M fix
Possible Investigation Strategy for Qatar

1. Be aware of Qatar-specific limitations of geophysics
2. Optimise MASW methods
3. Acquire the multicomponent seismic wavefield
4. Derive 3C reflection response
5. Derive 3C diffraction response
6. Use well understood diagnostics
7. Interpret for voids/zone of discontinuities
8. Early days – control through BH is a must!
Thank You