Management of Geotechnical Risk

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Introduction to AGEC

• AGE is an independent Irish company formed in April 2001 to provide geotechnical consultancy services
• AGE provides specialist geotechnical engineering advice to consultants, contractors, private clients and local authorities, particularly for infrastructure and renewable energy projects
• Main areas of geotechnical expertise include:
  • Geotechnical Due Diligence & Management of ground investigations
  • Foundation design
  • Design of retaining structures
  • Earthworks design
  • Stability assessment of soil & rock slopes
  • Procurement and management
  • Site supervision
  • Specialist technical advice
  • Contractual advice
  • Expert witness advice.

Contents

• Introduction to AGE
• Types of Geotechnical Risk (Typical)
• Reasons for Management of Geotechnical Risk - General and Statutory
• Typical Examples of Geotechnical Risk
• Management of Geotechnical Risk: Risk Register
• Questions and Answers.

Typical Geotechnical Risks

• Slope Instability
• Settlement
• Subsidence (sub-surface voids)
• Groundwater
• Chemically reactive ground
• Contamination
• Unforeseen ground conditions (extent, type)
• Inadequate geotechnical investigation
• Inappropriate design.
Reasons for Management of Geotechnical Risk - General

- Ground related risks affect and influence many parts of a project
  - Health and safety, environment, quality, programme and cost
- Ground conditions are always uncertain
- Compliance with standards reduces ground risk but does not eliminate ground risk
- Ground related risk generally have a significant impact
  - Highly variable nature of the ground
  - Soil/rock mechanics engineering is good but accuracy can be poor
  - Multiple hazards (shear failure, deformation, groundwater, chemically reactive, obstruction, etc)
  - Unforeseen ground conditions in early stages of works (delays following works)

Reasons for Management of Geotechnical Risk

- Increased project cost and delay
- Reduced cost on geotechnical studies

Source: UK Highways Agency projects (1994)

Reasons for Management of Geotechnical Risk - Statutory Framework (PSDP)

- Under Safety, Health and Welfare Regulations(1) there is a requirement to appoint a Project Supervisor Design Process (PSDP)
- Duties of PSDP with respect to risk/hazard management:
  - Identify hazards arising from the design/technical/organisational/planning/time related aspects of the project
  - Where possible eliminate the hazards or reduce the risk
  - Communicate necessary control measures, design assumptions, or remaining risks to the PSCS (so they can be dealt with in the S&H Plan)
  - Prepare S&H plan for any project where there is a Particular Risk(2) (or construction takes >500 person days or 30 working days)
  - Role extends beyond design stage in temporary works during construction
- Other duties of PSDP:
  - Organise co-operation between designers
  - Prepare a safety file for the completed structure and give it to the client
  - Notify the Authority and client of non-compliance with any written directions issued
  - Issue directions to designers or contractors or others

(2) For example with respect to the ground: Schedule 1, items 1(b) and (c): state particular risk due to: (i) burial under earthfill where the risk is particularly aggravated by the nature of the work or processes used or by the assessment of the place of works

Reasons for Management of Geotechnical Risk - Statutory Framework (Designer)

- Under Safety, Health and Welfare Regulations(1) the designer has defined duties
- Duties of designer with respect to risk/hazard management:
  - Identify any hazards that your design may present during construction and subsequent maintenance
  - Where possible eliminate the hazards or reduce the risk
  - Communicate necessary control measures, design assumptions or remaining risks to the PSDP so they can be dealt with in the S&H Plan
- Other duties of designer:
  - Co-operate with other designers and the PSDP or PSCS
  - Take account of any existing safety and health plan or safety file
  - Comply with directions issued by the PSDP or PSCS
  - Where no PSDP has been appointed, inform the client that a PSDP must be appointed

Slope Instability - Landslides

Rock with thin soil cover
Till (sandstone) Till (metamorphic)

Peat

Slope Instability - Landslides and Run-out

Multiple tension cracks
Partially detached peat raft
Main debris track
General slope inclination: 4 degrees
Temporary road construction in peat
Area of worked blanket peat

Slope Instability – Peat Failures

Ballincollig failure (2008)

10/12/2011
Slope Instability – Peat Failures

- Glenglassera failure (1986)
- Deposition area/debris track
- General slope inclination 5 degrees
- Large partially detached peat raft
- Main debris track
- Headward extension into forestry
- Tension cracks

Slope Instability – Predicting Peat Failure

- Road layout
- Hydrological/environmental buffer
- Wind turbine location

Slope Instability

Preliminary Stage
- Identify general geotechnical conditions (eg initial walkover survey)
- Certain soil types more prone to instability (eg peat)
- Examine available landslide databases
- Areas of previous failures indicate possible future failure (eg. anecdotal information)
- Avoid steep ground (but peat will fail at 4 degrees!)
- Avoid run-out tracks of landslide debris (several kilometres!)

Detailed Design Stage
- Detailed walk-over survey
- Detailed ground investigation
- Detailed analysis and stability assessment
- Appropriate design, mitigation, zonation

Slope Instability – Anecdotal Information

- Site of moving bog
Settlement and Subsidence - Karst Example

Drop out sinkholes form as a cavity migrates up from rockhead with time as material is carried from the soil into the limestone rock by movement of groundwater.

Soil arch eventually collapses causing subsidence at surface.

Plan of aqueduct
Settlement and Subsidence

Preliminary Stage

- Examine available databases (GSI karst, EPA soils maps, mining records, anecdotal information)
- Identify general karst/mining/soft ground conditions (eg walkover survey)
- Certain soil/rock types more prone to settlement/subsidence
- Areas of previous subsidence indicate possible future problems
- Avoid areas of high potential settlement/subsidence (may not be practical)
- Associated risks – flooding, radon

Detailed Design Stage

- Detailed walk-over survey
- Detailed ground investigation, geophysics, sub-surface surveying
- Detailed analysis and assessment of settlement/subsidence
- Appropriate foundation design, mitigation and zonation

Chemically Reactive Ground

Brown field sites (eg industrial sites, landfills)
Green field sites (eg naturally occurring)

Common potential issues:
- Acidity (pH value)
- Chlorides
- Sulphates and sulphides
- Industrial/domestic contamination

Chemically Reactive Ground

Sulfides
- Well known sulfide is Iron Sulfide (FeS2) or “pyrite”
- Pyrite has received much press in recent years because the mineral has been found in the sub-floor fill of damaged houses in North County Dublin
- Most limestone and calcareous mudstone rocks in Dublin and neighbouring counties contain pyrite
- Oxidisation of pyrite can have the following negative consequences
- Groundwater can be polluted with sulfuric acid
- Sulfuric acid can attack concrete and steel
- Concrete may be subject to sulfate attack
- Growth of expansive crystals (gypsols) → heave
Chemically Reactive Ground

Preliminary Stage
- Examine available databases (GSI, EPA soils maps, historical records)
- Identify general areas of reactive ground conditions (e.g., initial walkover survey)
- Certain soil/rock types prone to producing reactive ground conditions
- Anecdotal information
- Areas of previous problems indicate possible future problems
- Avoid areas of high potential (may not be practical)

Detailed Design Stage
- Detailed walk-over survey and mapping of exposures
- Detailed ground investigation including petrographic analysis
- Appropriate foundation design, specification, and mitigation

Inadequate Geotechnical Investigation

Original: 731 GI locations (mostly probes) in 345ha site = 2 per ha
Final: 5808 GI locations in 345ha site = 17 per ha
### Inadequate Geotechnical Investigation

- **Aim of geotechnical investigation:**
  
  "to establish the soil, rock and groundwater conditions; to determine the properties of the soil and rock, and to gather additional relevant knowledge about the site."

- **Spacing and depth of ground investigation:**

<table>
<thead>
<tr>
<th>Source</th>
<th>Guidance/Memo</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS 5930: 2008 (Eurocode 7)  Part 2, Annex E</td>
<td>The borehole and additional drilling, grid pattern will vary at 20m to 20m intervals</td>
</tr>
<tr>
<td>BS 5930: 2008 (Eurocode 7)  Part 2, Annex E</td>
<td>For borehole, trial holes, pipelines, diams, tunnels, ensuring each is at 20m to 20m intervals</td>
</tr>
<tr>
<td>Highway Agency (1999), clause 5.50</td>
<td>The number and test rules can be given for the depth and spacing of exploratory holes to suit the specific conditions of each site, the amount and quality of existing information. Some guidance is given in SS 5050. The selection criteria for the depth and spacing of exploratory holes should always be such that sufficient information is obtained to enable the proposed works to be adequately designed.</td>
</tr>
</tbody>
</table>

- **Type of geotechnical investigation:** see for example IS EN 1997-2: 1997 (Eurocode 7, Part 2)

### Management of Risk: Geotechnical Risk Register (GRR)

- GRR comprises a list of geotechnical hazards and risk control measures attached to various elements of the proposed route at any project stage (eg route selection/pre-planning, planning, design, construction and operation).

- A subjective qualitative scale is used to define risk.

- Hazards are rated in terms of how likely they are to occur (the Probability) and to what degree they would affect the project (the Impact).

- The degree of risk is determined by combining the probability and impact assessments:
  
  \[ \text{Risk} = \text{Probability} \times \text{Impact} \]

  \[ \text{R} = P \times I \]


### Inappropriate Design - Pit Collapse

- Employee killed when trial pit collapsed

- Lone working in unsupported pit

- Prosecution of Employer under 2007 Manslaughter Act (UK)

### Example of Geotechnical Risk Register

#### Table:

<table>
<thead>
<tr>
<th>Category</th>
<th>Specific</th>
<th>Risk</th>
<th>Control Measures</th>
<th>Degree</th>
<th>Additional Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stability</td>
<td>Type of</td>
<td>1</td>
<td>No</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Settlement</td>
<td>Problems</td>
<td>2</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental Impact</td>
<td>Groundwater</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Noise</td>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Health &amp; Safety</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quality</td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Economic</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Site investigation, trial holes, boreholes, pipelines, etc.

- Monitoring and observation method specified as part of construction controls.

- Supervision of works by suitably qualified person.

- Tool box talks to be carried out prior to work.

- Supervision to ensure construction and operations are being carried out as per method statement.

- Reserve / additional pumping facilities to be available.

- Any delays to works.

- Increased noise and pollution.

- Programme disruption.

- Cost implications.

- Stop work procedure.

- Stop all works immediately as per EMP.
Content of Geotechnical Risk Register (GRR)

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Cause</th>
<th>Potential Impact</th>
<th>Risk Rating</th>
<th>Control Measures (RCM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient</td>
<td>Incidents</td>
<td>Construction of Excavations</td>
<td>R</td>
<td>Design Control</td>
</tr>
<tr>
<td>Patient</td>
<td>Incidents</td>
<td>Construction of Excavations</td>
<td>R</td>
<td>Construction / Operation Control</td>
</tr>
</tbody>
</table>

Risk Rating following RCM

P × I = R

Contingency Measures

Example List of Geotechnical Hazards

1. Slope Instability
2. Settlement
3. Subsidence (sub-surface voids)
4. Groundwater
5. Chemically reactive ground
6. Contamination
7. Eroding/mobile ground conditions (coastal/marine)
8. Unforeseen ground conditions (extent, type)
9. Inadequate geotechnical investigation
10. Inappropriate design

*Any hazard can be sub-divided in terms of a sub-set or geographic location

Potential Impact

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Cause</th>
<th>Potential Impact</th>
<th>Risk Rating</th>
<th>Control Measures (RCM)</th>
</tr>
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<tr>
<td>Patient</td>
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</tr>
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Risk Rating following RCM

P × I = R

Contingency Measures

Risk Rating

Probability × Impact = Risk

P × I = R

Category: Specific

All hazards belong to one of the following categories:

- Health & Safety
- Environmental
- Programme
- Cost
- Quality

Examples of specific hazards are as follows:

- Risk of injury or death (Health & Safety)
- Change of hydrology (Environmental)
- Collapse of excavation (Programme)
- Damage to plant (Cost)

Specific

Probabilities:

1. Very Low
2. Routine
3. Requires Attention
4. Unacceptable
5. Very High

Impacts:

1. 1
2. 2
3. 3
4. 4
5. 5

1. 1
2. 2
3. 3
4. 4
5. 5

1. 1
2. 2
3. 3
4. 4
5. 5

1. 1
2. 2
3. 3
4. 4
5. 5

1. 1
2. 2
3. 3
4. 4
5. 5
• If the risk is deemed excessive, then Risk Control Measures (RCM) are required to lessen the risk
• These can be:
  ➢ Design controls:
    eg. Detailed site investigation, locally re-routing, micro-siting
  ➢ Construction or operation controls:
    eg. Site supervision staff to inspect critical pylon locations
• Risk Control Measures mitigate the Probability and/or the Impact

• Following the applications of the Risk Control Measures, the degree of risk is again assessed
• Ideally, the Risking Rating should now be tolerable

• Contingency Measures are then considered, should the hazard occur, eg.
  ➢ Stop works
  ➢ Monitor situation
• The risk register is generally a live document: as new hazards, risk control measures or contingency measures present themselves, these should be added
• The GRR is a key method of communication of risk between the various parties at different stages of the project (eg route selection, pre-planning, planning, design, construction and operation)
• Geotechnical risk management should be integrated into the overall project management process
• Review and feedback allows continuous improvement of the risk management system
### Worked Examples - Peat Slide

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Potential Impact</th>
<th>Risk Rating</th>
<th>Following RCM</th>
</tr>
</thead>
</table>
| Peat Slide      | 1. Risk of death or injury by inundation  
                 | 2. Environmental Damage  
                 | 3. Damage to persons, plant, property and livestock  
                 | 4. Loss and cessation of works  
                 | 5. Adjacent land affected due to peat/ground movement | $2 \times 5 = 10$ | $1 \times 5 = 5$ |

**Risk Control Measures (RCM)**
- Design Controls
- Construction / Operation Controls

**Contingency Measures**
1. Stop works
2. Use sheetpiling to stop ground movements
3. Monitor movements following installation of sheetpiles until movements have ceased
4. Reduce speed of works
5. Reduce excavation lengths prior to backfilling with stone

### Summary - Management of Geotechnical Risk
- Ground conditions are always uncertain
- Realistically, not all ground risk can be avoided or eliminated
- Compliance with standards reduces ground risk but does not eliminate ground risk
- Ground related risk can generally have a significant impact
- Management of ground risk is essential for success:
  - allow for sufficient budget
  - use the right management tools
  - employ appropriate specialists

### Questions & Answers

Thank You