

## Challenges and Experiences of Site Investigations Abroad

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### ABSTRACT

Site investigations abroad offer opportunities to learn about a region's geology and to experience cultures different to our own. More importantly, challenges working in remote conditions and developing countries require adapting to local environments and using a diverse range of investigation methods. This paper discusses the challenges and experiences while undertaking geotechnical site investigations in the Middle East. It outlines the processes we put in place to ensure consistent and usable geological data was collected so that a workable ground model could be established. As the investigations were located abroad, it was critical that the data obtained was usable for interpretation once back in our home country of New Zealand. This requires a clear understanding of the local geological environment and geotechnical risks to the specific projects. In addition, local workers, many of whom spoke little English, added a further dynamic to the investigations and a window into their own culture. The lessons learnt while abroad have improved our site investigation methodologies and techniques, and have been an excellent personal opportunity to develop technically and visit places otherwise inaccessible.

*Keywords:* Site Investigations, Middle East Geology, Data Management, Limestone Breccia

### 1 INTRODUCTION

The investigations were undertaken for a metro rail project proposed to service a major city in the Middle East. Due to client considerations, the name and location of the project cannot be revealed. AECOM provided geotechnical design services for two of the metro rail lines which included tracks and stations underground, above ground and at-grade, and depots and shafts.

Our key task was to undertake geotechnical studies to inform detailed design and construction. Initially, field mapping of building excavations throughout the city provided the basis of our geological and geotechnical models. Consequently investigations were scoped and undertaken by three separate geotechnical contractors in a staged approach. These investigations included 333 drillholes, 284 surface geophysical lines, laboratory testing and a wide range of in situ testing including wireline geophysics, downhole seismic geophysics, televiwer and lugeon testing. To ensure the investigations were of sufficient quality and consistency to inform our analysis we worked closely with the contractors to achieve the best result possible.

This paper discusses the challenges and experiences while undertaking the site investigations in the Middle East. While the geotechnical contractors were responsible for undertaking the investigations and producing a factual report we maintained a presence on site to ensure the results were of sufficient quality and consistency to inform our analysis and interpretation. The key challenges in undertaking the investigation include:

- Understanding a unique geological terrane
- Ensuring quality and consistent investigation results were delivered by the contractors
- Managing the vast amount of geotechnical information gathered from the investigations

### 2 SITE GEOLOGY

#### 2.1 General

The geology at the project area typically comprised fill and alluvium overlying regionally consistent layers of bedded limestone and brecciated limestone dipping 1° to the east. Within the limestone,

voids and infilled cavities were common. Initially, a geological model for the site was established by undertaking geological mapping of exposed outcrops and building excavations throughout the city and from literature study. This model was then developed as further investigations were undertaken.

The brecciated limestone was an unusual geological material, as will be explained in the next section and we needed to develop a clear understanding of its formation and implication on geotechnical behaviour.

## 2.2 Formation of limestone breccia

Brecciated limestone observed at the project area was formed from the preferential dissolution of beds of anhydrite between limestone layers causing collapse of the limestone layers. The layers of anhydrite and limestone were deposited during the Late Jurassic to Early Cretaceous in upward cycles of shallowing marine and tidal flat environments (USGS, 1985 and Farooq A. Sharief, 1991). The anhydrite beds, which are formed from hyperconcentrated marine environments, are especially susceptible to dissolution and are easily dissolved in acidic groundwater derived from rainfall. Tectonic uplift during the Miocene and wet climactic conditions during the Pliocene (Vincent, 2008) resulted in dissolution of the anhydrite beds and an estimated vertical thickness up to 250m removed (Farooq A. Sharief, 1991).

Following dissolution, the remaining limestone beds then collapsed, slumped and contorted forming breccia with clasts ranging from mm's to 10m's in size. Between the clasts, various amounts of clay matrix and calcite cement are observed with voids and vugs often present. This process is complex and can be seen at scales of cm's to km's, Figure 1 and Figure 2.

Dissolution of the anhydrite beds had already occurred in the project area leaving two distinct brecciated units approximately 20m thick separated by bedded limestone. Approximately 20kms east of the city, active dissolution could be seen at a nearby escarpment and is analogous of past conditions on site (Vaslet, 1991), Figure 1.

## 3 FIELD LOGGING GUIDANCE

### 3.1 General

The local geotechnical contractors undertook the investigations and also logging of the drill core. From previous reports and initial meetings with the contracting geologists it became apparent we needed to provide clear logging guidance so consistent results were provided that could be correlated during analysis. This was particularly important because there were three separate contractors involving approximately 10 site geologists and a consistent approach to geological descriptions was required. In addition, many of the field staff had variable English language skills which added to the challenge. We provided the following guidance:

- Logging help sheets
- On site guidance to the site geologists
- Project specific geotechnical database template and library

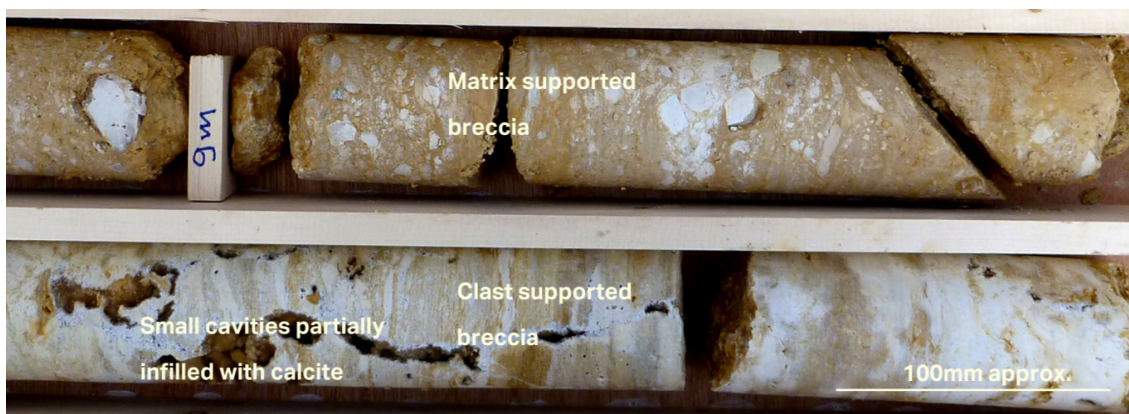


Figure 1. Core sample of limestone breccia. This breccia has likely undergone several cycles of brecciation and dissolution.



Figure 2. Escarpment showing large scale collapse of bedded limestone. Sinkholes were encountered at the foot of this escarpment in several locations.

### 3.2 Logging help sheets

The project was to be undertaken using British Logging Standards (BSI, 1999) where applicable or otherwise American Society for Testing and Materials (ASTM) Standards. The initial logging help sheet for the site geologists included extracts from relevant British Standards, however as the investigation progressed the consistency and quality of the logs did not improve. It seemed there were too many options for the geologists to describe essentially very similar materials and it was likely they could not read English to the level required to understand the standard. A standout example from one log is London Clay being used as a description for highly weathered limestone breccia. When queried, the geologist pointed out London Clay is an example given in the British Standard for soil description!

To overcome the problem described above and as our understanding of the local geology and of the important differences between geological units improved, we developed and provided to the field geologists a logging memorandum, shown in Figure 3. The memorandum highlighted key aspects of the core that needed to be differentiated between the various geological units during the analysis.

The memorandum to the geologists presented in Figure 3 explains what was adopted as logging requirements of limestone breccia for this project and broadly follows British Logging Standards. By providing this guidance and working very closely with the site geologists we were able to improve the consistency and quality of the logs. The wider project team also benefited from the memorandum and adopted a consistent approach during the interpretation stage.

### 3.3 Onsite guidance to the site geologists

Our team comprised approximately 4 to 7 staff working abroad at any one time and were from New Zealand and Australia. Typically our onsite geologists and engineers supervised two to three drill rigs / site geologists each. On site, this entailed discussing the recovered core samples, checking their field log, specifying and overseeing in situ field tests and ensuring operations were undertaken safely. The drillhole locations were positioned throughout the city which meant we were able to experience different parts of the city daily. We were able to get to know the contracting geologists, who being ex-pats from various Middle Eastern countries, had had little contact with New Zealanders before. They were very interested to know the differences between their home countries and ours –which they

thought was probably like Hobbiton! For us, it was a great opportunity to learn more about cultures different to our own.

A high turnover of the contractor's geologists resulted in inconsistencies in many logs which required re-logging by our staff. However, the quality of the logs from the geologists who remained on the project improved significantly.

### **3.4 Consistent geotechnical databases**

It was critical we were provided geotechnical data in an electronic format by the three contractors to prevent manual re-entry of the information when it came to analysis at later project stages. The widely recognised AGS file format (AGS4) provides an electronic format to transfer geotechnical data (AGS, 2010). Although we specified AGS4 files of the geotechnical data to be provided, it appeared the contractors did not have the capability to produce them. To ensure we were delivered usable electronic data, we prepared a project specific geotechnical database template in gINT, a geotechnical database software package which each of the contractors had. The database was designed to be simple and easy to use for people who have not used the program before. It also featured dropdown lists based on the relevant British Standard for logging, e.g. strength, weathering, piezometer installation. This meant the contractors could send us their database files and we could read and incorporate them without any issues. By using dropdown lists based on British Standards, we would prevent the contractors logging to other standards or using terms that were not defined. The database had capability to export/import in AGS3.1 and AGS4 however these formats were not needed to transfer the information by using a consistent project database approach.

Laboratory results were expected to be entered into the database by the contractors however this did not happen and they preferred to enter results on pdf reports or spreadsheets. This meant there was still some manual data entry to be undertaken and the provided spreadsheets had to be massaged into a format which could be imported into the project database.


## **4 INVESTIGATION DATA MANAGEMENT**

During the site investigations a vast amount of information was produced and needed to be shared between the wider project team. This information was not the finished reports, which would be later filed in project specific file management tools such as ProjectWise and ACONEX, but working files which were integral in making decisions as the investigations progressed. The project team included other consultants and contractors and AECOM staff including up to 4 field staff working between the various contractors on site, 2-3 staff based in a project office and additional teams in Auckland, Christchurch and Wellington, New Zealand, and Melbourne and Brisbane, Australia. Typical office based networks proved to be slow and difficult to use across the globe and an alternative cloud based file management tool was implemented.


The cloud based file management tool Dropbox was used to collaborate and share information between the teams effectively. While file management tools mentioned above were used for project deliverables, these packages proved to be cumbersome for working documents. Using a cloud based tool enabled us to improve the speed of our file sharing and better manage who could access the files. The tool could also download and synchronise data to user's computers allowing staff on site to access stored files without being online. When the field staff regained internet connection, either via mobile, at the hotel or office, their work from that day was automatically uploaded to the project cloud and shared among users across the globe, Figure 4.

### Logging Memorandum – weathering and matrix in Breccia


**Step 1**  
Wash core, clean drill slick to enable accurate assessment



**Step 2**  
Limestone or breccia?



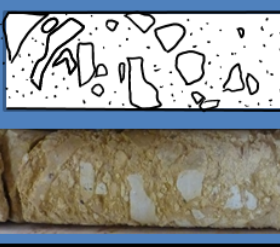
Limestone



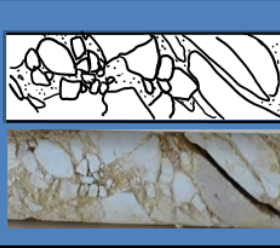
Breccia – go to step 3

**Step 3** Matrix or clast supported?


**Matrix supported** clasts of limestone are separated by fine grained (sand to clay sized) particles comprising the matrix material, i.e. the limestone clasts do not touch.




**Clast supported** clasts of limestone are typically in contact with each other and the fine grained matrix material fills the spaces between the limestone clasts.



**Step 4**  
Assess the rock mass strength, for matrix supported material the strength of the matrix material is typically the rock mass strength. Assess the strength as per the standard using the following



**Step 5**  
Record the results of steps 2, 3, 4 and assessed weathering grade. Add additional descriptions required by BS5930:1999



**Estimated Range of Weathering in Breccia**


Fresh	Slightly	Moderately	Highly	Completely
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**Rock Mass Strength**

Strong	Medium Strong	Weak	Very Weak	Extremely Weak
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**Introduction**  
 Note: this memorandum does not replace BS5930:1999  
 This memorandum deals with the difficult nature of describing weathering, particularly within the brecciated limestone encountered in core on the Project. It has been produced in order to maintain consistency of terms when describing weathering across the many drilling sites.  
 For simplicity and practical purposes the breccia should be viewed as grading or weathering from insitu bedded limestone. This approach is taken because it enables the limestone to use as a baseline for weathering within the breccia and most importantly it is useful for geotechnical engineering design.  
 This memorandum is intended to be used in conjunction with BS5930:1999


**Changes within core runs**  
 The stick of core below shows a change in the weathering and strength within the core run. Zones where the strength and weathering change within a core run should be noted on logs.



← Highly weathered      Moderately weathered

**Voids**  
 The core above is considered slightly weathered. Despite dissolution creating vugs and voids the remaining rock mass strength is largely unaffected. Zones with significant vugs and voids should be noted.

**Definitions**  
 A vug is a void that does not span the width of the core  
 A cavity is a void that spans the width of the core (breaking in two)



**Examples of weathering grades in breccia**

Completely weathered	Highly weathered	Moderately weathered	Slightly weathered
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Figure 3. Logging help sheet. This sheet was provided to the site geologist to ensure a consistent approach in logging limestone and limestone breccia.

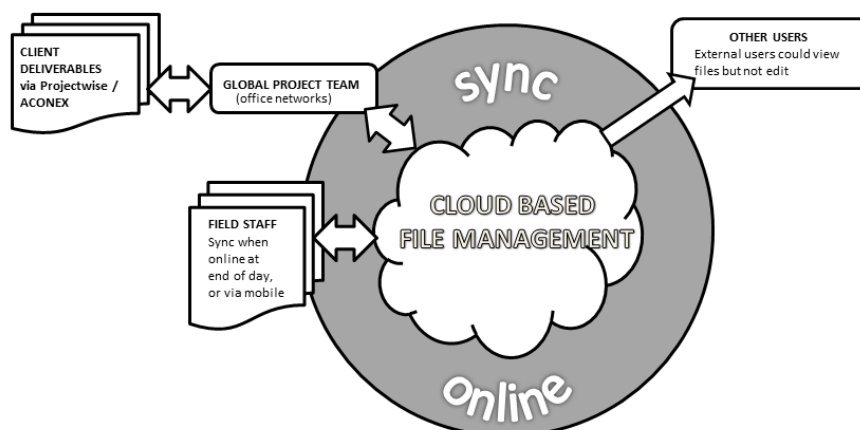


Figure 4. Diagram of the data management structure used on the project. The use of a cloud based system ensured files from field staff and the global project team were shared efficiently.

## 5 CONCLUSION

Investigations for the project in the Middle East offered a range of challenges and experiences which were unique to the region.

By establishing the geological model early we were able to provide clear guidelines to the contracting geologists to ensure quality and consistent investigation results. The development of the logging memorandum went some way to improving logging consistency and ensured that critical geological information (matrix support, strength and weathering) was captured in the field. It did not replace adequate training of geologists. A high turnover of contractor geologists resulted in logging inconsistencies that were not able to be remediated by the logging memorandum alone. Geologists who remained on the project for a significant period and received adequate training were able to be produce consistent logs. The memorandum also ensured consistent approach from the wider project team.

The project specific geotechnical database streamlined the transfer of investigation data in lieu of using AGS file format and ensured key data was entered consistently between contractors. By simplifying the database structure little training was needed for the contractors to use the database.

Using a cloud based file management tool effectively shared information between the wider project team working from a range of locations across the globe where regular company networks proved slow or inaccessible. Field staff utilised the system to synchronise their field work daily without the need to return to a project office, saving time and improving data management.

Field work overseas and getting to know local workers provided insight into different cultures. This experience and the challenges of the site investigations were an excellent platform to improve our investigation skills for future projects.

## 6 ACKNOWLEDGEMENTS

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