

Schrödinger's site: The importance of comprehensive desktop studies

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ABSTRACT: As prime greenfield sites become increasingly scarce, developers are turning to previously disturbed land, often with incomplete historical records. This paper shows the critical role of the desktop study phase in geotechnical site investigations, emphasising its importance in identifying subsurface risks associated with prior human activity. A case study highlights the challenges posed by an inadequate desktop study, where a seemingly undisturbed landscape concealed a former excavation and waste-rock dumps. Initial geotechnical assessments produced unexpected results, prompting a retrospective analysis incorporating historical satellite imagery, geophysical surveys, and targeted stakeholder engagements. The findings demonstrate the necessity of integrating multiple data sources, including topographical surveys and borehole profiles, into a 3D geotechnical model for accurate site assessment. Additionally, mitigation strategies such as dynamic compaction and reinforced raft foundations are discussed as viable solutions for managing variable ground conditions. This paper serves as a reminder to geotechnical professionals of the fundamental importance of a rigorous desktop study reinforced by a case study example showing the value of thorough, multidisciplinary site investigations to preventing costly construction delays and foundation/ structural failures

1 INTRODUCTION

“Only very seldom are ground engineering problems caused by gaps in engineering knowledge. Most problems are caused by a failure to apply known processes adequately.” – ICE Manual of Geotechnical Engineering, 2012, Institution of Civil Engineers.

Greenfields sites are growing scarcer as the prime sites are developed leaving less suitable options available to developers. Development space on sites already owned by clients are also under pressure of limited space or need for reclamation of areas that have already served their purpose. Due to lower levels of historic development in Africa as opposed to First World Nations, it is thought that there is less focus on the historical use of land (UN-Habitat 2020).

This paper aims to highlight the necessity for the appropriate early investigation of the site, as well as bringing attention to the dangers of inadequate investigation due to a lack of historical data, overlooking critical aspects or inexperience of the professional team leading to disastrous consequences. This paper will reference a case study in the various sub-sections to guide the reader's understanding of the key information in each section.

2 UNEXPECTED COMPLICATIONS

When evaluating a site, it is crucial to go beyond standard geotechnical factors such as soil layering and material properties. Several additional aspects related to human activity must also be carefully investigated (ICE 2012), including:

- The possible presence of significant archaeological artifacts (Weddell 2000).
- Environmental considerations.
- The likelihood of soil or groundwater contamination in the area.
- Potential underground obstacles that could hinder foundation work, as well as nearby existing foundations, tunnels, or other built structures.
- Previous mining pits or underground workings, quarry and borrow works.
- The presence of buried utilities such as electrical cables, pipelines, and drainage systems.

In many cases, these anthropogenic factors can pose greater risks to a project than natural geological variations. A thorough desk study should incorporate historical records; ideally, extending to a period prior to any development having taken place on the site. Relying solely on readily available modern data may result in an incomplete assessment, increasing the

likelihood of unforeseen challenges during construction (ICE 2012).

3 INFORMATION SEARCH

3.1 *The desktop study*

Any successful geotechnical investigation, irrespective of the stage of investigation, starts with a good desktop study phase, or at least, it should. The desktop study phase is a simple step that is easily overlooked but potentially holds valuable information for the site. The current and historical site information is gathered in this phase to fast-track data collection, direct the required investigations to meet the objective and often explain the perplexities encountered later during the fieldwork.

The success of a geotechnical site investigation depends on several key factors that help ensure a comprehensive understanding of ground conditions, reduce risks, and enhance project efficiency (Simons et al. 2002). These factors include:

- Recognising ground-related hazards: identifying potential geotechnical challenges such as weak soils, groundwater fluctuations, contamination, or subsidence.
- Enhancing ground risk management: assess and mitigate uncertainties in soil conditions.
- Delivering greater value to clients and stakeholders: optimising site investigation processes to provide cost-efficient solutions.
- Providing the necessary, reliable information for the project.

The desktop study with its site walkover aims to (Simons et al 2002):

- Provide probable ground conditions (topography, soil and rock types, ground water, contaminated ground).
- Uncover the previous uses of the site
- Highlight access constraints.
- Identify the rock types and superficial deposits present at or near the site.
- Evaluate the distribution and depth of various soil and rock layers beneath the surface.
- Provide preliminary geotechnical zonation of the site incorporating land facet mapping.
- Evaluate the depth of the weathered profile.
- Understand the regional geological structures and their relationship with the Local Geological structures and conditions.
- Identify topography and geological relationships: Assessing the site topography and influence on the materials on site.
- Identify past or present mining operations beneath or near the site or natural ground subsidences.

It should be noted that the cost and effort of obtaining and evaluating reliable existing information is

generally significantly less than generating completely new data and proves invaluable in the long run, the value of which is typically underestimated.

3.2 *Historical data*

It is becoming increasingly common that historical data is no longer available for sites, be it due to flooding or fire of the data storage facility, loss during the change of ownership, poor data recording and file management. Many sites have also suffered the loss of knowledge bearers who can remember what happened on the site since its first visit for consideration.

The missing site data is the first hurdle to overcome when carrying out the all-too-easily overlooked desktop study phase.

3.3 *Where to search and what to ask for*

It is common practice to ask the client for existing information or reports for their sites. Usually, the client will provide information they have which they believe is relevant. This may lead to the geotechnical practitioner being inundated in irrelevant information. Thus, a targeted question generally yields the best results.

Other sources of information that should not be overlooked, where available, include (SAICE 2010):

- A Google web search.
- Google Earth History tool.
- Satellite images (ie. Sentinel imagery).
- Historical aerial photographs.
- Previous site surveys.
- Geological maps.
- Other relevant maps (meteorological, soil moisture, vegetation and topography ie USGS or ESRI).
- Construction records.
- Government departments databases (ie. Johannesburg databank and Council for Geoscience).

Information sources such as these are invaluable early sources of data to build the conceptual site model.

3.4 *Case study - Introduction*

The case study presented is a seemingly simple site where rolling hills and grassland with scattered trees prevail. Bedrock outcrops in nearby areas. At first glance, this appears to be a simple greenfield site south of an existing tailings storage facility (TSF) with ample space for the planned development as seen in Figure 1.



Figure 1. Case study – Open area (rehabilitated) – Google Earth image dated 2023

What is not plain to see, but will quickly become evident to an experienced geotechnical practitioner is that the profile is anything but natural. An evaluation of the field data both during the test pit program and in the office were incompatible with expectations. A topsoil like material was overlying fill/talus with angular corestones within the residual profile. Once the site was revisited for a deeper-dive desktop study the answer became glaringly obvious, as it was clear that the site had been well rehabilitated.

Review of the historical satellite imagery from more than 15 years prior, as per Figure 2, reveals a previous pit had been excavated and that the observed rolling hills are old waste-rock dumps.



Figure 2. Case study – Open area showing the grey and brown surface materials (bordered by yellow dashes) of the pit and waste dumps – Google Earth image dated 2005

Specific and targeted requests were made by the geotechnical investigation team prior to the fieldwork for more information from the client, request to talk to any of the experienced staff who had knowledge of these workings or for contractor files and documents. However, the client indicated that the information for the site had suffered fire damage and was not available. Information regarding the old pit and waste dumps gradually became available to the geotech-

nical team during the fieldwork phase following continued discussions with contractors and previous consultants.

4 OBTAINING DATA – WHERE TO START

Much like a greenfield site normal methodologies will be employed for data acquisition. A phased approach is recommended to provide inexpensive and broad-scale data at the outset of geotechnical investigations. Typically, some geophysical testing or intrusive testing (test pitting and borehole drilling) is needed in this phase.

The initial data search (i.e. desktop study) provides a suitable starting source of information, the next phases of data search are added with increasing complexity and cost. This phased data search is seen as a conceptual-model building process.

5 BETWEEN THE KNOWNS

The process of interpolation between known data-points is necessary in all phases of the work.

It is recommended to develop the conceptual site model during the desktop study phase and continue to re-evaluate as more data becomes available thus aiming to gradually build your knowledge of the site and confirm your early assumptions made in the conceptual model. Generally this reflects common practice across the industry where the conceptual model is created as a mental-image only, the larger the site and higher the complexity, the more advantage will be gained by building a basic GIS model which can act as both the data-manager as well as the spatial viewer to assist interpretations of the data being evaluated.

There are a few factors that should be considered when building the model for a site in order to interpolate between known data points:

- The number of sources used.
- The spatial density of the information.
- The objective of the information (different infrastructure type, mineral resource information etc.).
- Data calibration – Geophysics and boreholes.
- Confidence in the acquired data.
- The model interpreter's experience and competency.

5.1 Case study – 3D Geological model

A model was developed using various sources of information gained during the data interpretation phase of the investigation:

- Site topography.
- Geology map.
- Geophysical survey data (MASW and ERT).
- Test pit profiles.
- Borehole profiles.
- Known boundaries for pit and waste rock dumps.

Typical geophysical Multichannel Analysis of Surface Waves (MASW) and Electrical Resistivity Tomography (ERT) results shown as an example in Figure 3 indicate strong and clear contrast for the interpretation between fill and in-situ materials.

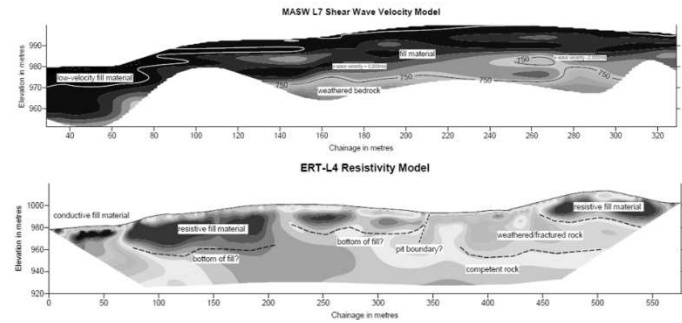


Figure 3. Typical MASW geophysical section(top) and ERT section (bottom) from the case study

MASW-L7 (the southern-most MASW traverse indicated in Figure 4 shown in Figure 3 top - 330m long) is interpreted with fill material along the entire length. Very low velocity material is present on the flat portion at the beginning of the traverse which indicate different fill materials present within the investigation areas confirmed by test pits and boreholes. Similarly, the much longer ERT-L4 (Figure 3 bottom – 560m long) showed the pit boundary on the west, natural material and surficial waste dumps on the east. In addition to the geophysical data the typical profile based on rotary core boreholes is shown in Table 1 as thick and variable fill horizons across the site overlying the bedrock.

Table 1. Typical profile

| Borehole | Thickness of layer (m)-(m) | | |
|----------|----------------------------|------------|--------------|
| | Tailings | Fill | Bedrock |
| BH1 | – | 0 – 1.0 | 1.0 – 7.5 |
| BH2 | 0 – 1.0 | 1.0 – 18.0 | 18.0 – 23.25 |
| *BH3 | 0 – 1.0 | 1.0 – 6.0 | 6.0 – 7.5 |
| BH4 | 0 – 1.0 | 1.0 – 16.8 | 16.8 – 21.0 |
| BH5 | 0 – 9.1 | 9.1 – 23 | 23.0 – 28.3 |
| *BH6 | 0 – 1.0 | 1.0 – 7.5 | – |

* Borehole incomplete due to collapse of sidewalls.

The geophysical data, test pits and boreholes were used in conjunction with aerial images to map out the pit shell. The data interpretation was carried out using Seequent Leapfrog Works ® Software to create a pit shell and waste area model as shown by the heatmap in Figure 4. The black lines show the geophysical traverses which were used.

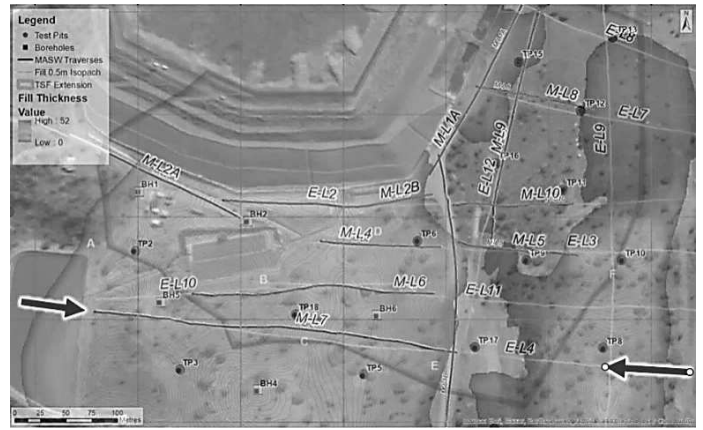


Figure 4. Case study – Fill thickness contours (isopachs) showing fill thickness and geophysical survey lines MASW-L7 and ERT-L4 shown by red end arrows.

The Leapfrog model was used to generate sections along the yellow trace shown on the inset map to show the pit area based on the modelled information as shown in Figure 5 and Figure 6 relative to the in-situ soil and rock on site.

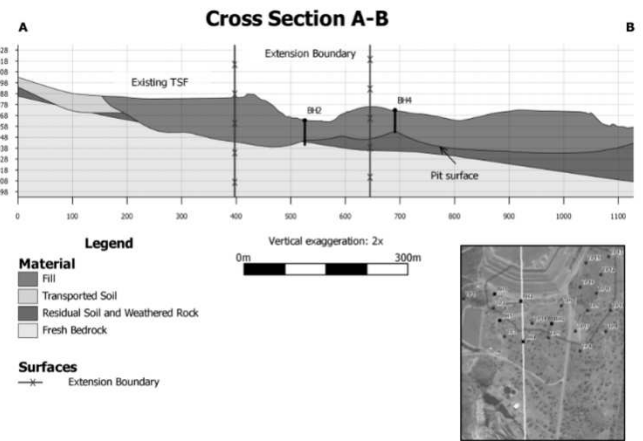


Figure 5. Section AB (yellow north-south trace) through Leapfrog model showing pit surface

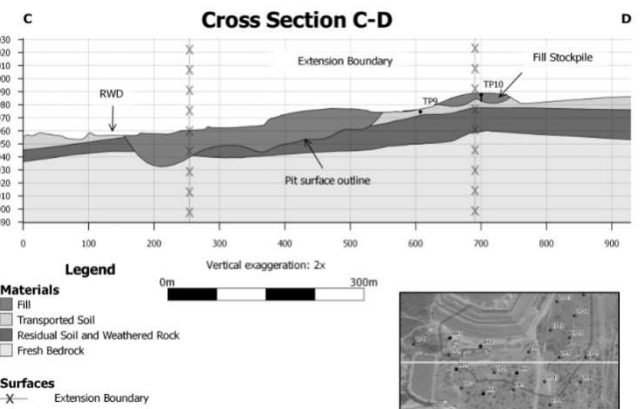


Figure 6. Section CD (yellow east-west trace) through Leapfrog model showing pit surface

6 BROWNFIELDS INVESTIGATIONS

Brownfields sites with limited historical information, or no records of previous activities require a comprehensive review of site data. This includes the desk study and phased investigations to provide a sound understanding of the site. Any fill type, depth and variability as well as the settlement characteristics should be fully explored as early as possible in the project to ensure the correct investigative methods are used and ultimately the most appropriate recommendations provided for the development.

6.1 *Non-engineered fill*

Non-engineered fill or artificial ground, comprises a variety of uncontrolled materials, including municipal waste, construction and demolition debris, metallurgical slag, mining and quarry waste, industrial waste, and excavated soil (ICE 2012). These materials typically exhibit heterogeneous composition leading to poor and highly variable bearing capacity, variable consolidation characteristics with unpredictable settlement behaviour (one-dimensional and differential) (ICE 2012). Additionally, certain fill materials may pose environmental risks such as contamination, spontaneous combustion, and gas generation due to biological or chemical decomposition. The feasibility of using non-engineered fill as a foundation material is largely dependent on its age, composition, degree of decomposition, spatial variability, physical and chemical properties, and the method by which it was deposited (ICE 2012). Using a 3D-model it is possible to visualise the topography of the previous pit and waste dumps, calculate the depth of fill, model the anticipated settlements, calculate the extent of the area requiring remediation and recommend appropriate ground improvement methods for the ground conditions at the site.

6.2 *Typical improvements for founding*

Often dynamic compaction is applied to sites underlain by thick fill layers, as this is usually the most cost-effective method penetrating deep loose zones. Piling may not always be possible due to large boulder-sized objects in the fill layers or poor foundation conditions present at depth. Reinforced raft foundations are a frequently used alternative to limit settlements (both one dimensional and differential).

Following a successful geotechnical investigation campaign where all unknowns regarding the depth and variability were determined using a combination of comprehensive desk study data search and field-work data evaluated in a geotechnical model allowed the specification of the foundation recommendations and soil improvement for the development.

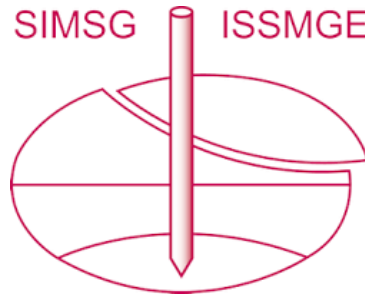
7 CONCLUSION

This paper shows the importance of incorporating historical data, remote sensing, geophysics and multidisciplinary collaboration to develop a comprehensive understanding of subsurface conditions. The case study presented demonstrates how seemingly stable terrain concealed significant previous anthropogenic disturbances and emphasises the necessity of due diligence through comprehensive desk studies and phased geotechnical investigations. By integrating advanced modelling techniques and site-specific mitigation strategies such as dynamic compaction and reinforced raft foundations, developers can enhance feasibility of projects on complex sites. Geotechnical evaluations that start with a reliable desktop study minimize costly investigations to ultimately provide cost-effective designs.

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