Conducting a successful geophysical campaign: Benefits, pitfalls, and guidelines

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ABSTRACT
Geophysical surveys play a key part in geotechnical and engineering design. Combined with modern monitoring tools, the use of geophysics can reduce construction and maintenance costs and help avoid unforeseen events. However, geophysics is frequently overlooked or misused. Moreover, existing geophysical data is sometimes undervalued or wrongfully dismissed. In this paper, we identify potential pitfalls that can lead to an unsuccessful geophysical program. We discuss how to plan a proper geophysical campaign according to different engineering, design and monitoring needs and challenges. We also present current technological advances in applied geophysics. Finally, we present four case studies showing the potential of modern geophysics to aid geotechnical investigations.

RÉSUMÉ
Les levés géophysiques jouent un rôle clé dans la conception de projets d'ingénierie et en géotechnique. Combinée à des outils de monitoring modernes, l'utilisation de la géophysique peut réduire les coûts de construction et d'entretien et aider à éviter les événements imprévus. Cependant, la géophysique est souvent négligée ou mal utilisée. De plus, les données géophysiques existantes sont parfois sous-évaluées ou rejetées à tort. Le présent article identifie les pièges potentiels qui peuvent conduire à un programme géophysique infructueux. Nous discutons de la manière de planifier une campagne géophysique appropriée, en fonction des différents besoins et défis en matière d'ingénierie, de conception et de surveillance. Nous présentons également les avancées technologiques actuelles en géophysique appliquée. Enfin, nous discutons de quelques études de cas montrant le potentiel de la géophysique moderne pour les investigations géotechniques.

1 INTRODUCTION

This paper does not aim to be a technical reference in the field of geophysics. Its purpose is to share best practices with professionals in the field of engineering gathered from the combined experience of the authors.

Although originally developed for hydrocarbon and mineral exploration, geophysical methods have been used for engineering applications for many years now, and since the 1980s, research has increasingly been dedicated to solving engineering problems with geophysics. This has resulted in new or improved methods, dedicated instruments, and an overall better knowledge of the capabilities and limitations of geophysical techniques for various fields such as geotechnics, civil engineering, mining engineering, and environmental studies. Nevertheless, geophysical techniques are still sometimes overlooked or dismissed.

The most common geophysical methods used for geotechnical and engineering applications, and their uses, are:

- Seismic Refraction: Measuring bedrock depth, locating faults, measuring compressional wave velocity (Vp) of overburden and bedrock;
- Multi-Channel Analysis of Surface Waves (MASW): Seismic site classification, identifying loose soils, measuring shear wave velocity (Vs) of overburden and bedrock;
- Electrical Resistivity Tomography (ERT): Locating conductive (clay) or resistive (gravel) layers, bedrock mapping, contaminant mapping, grounding studies, karst studies, groundwater mapping, measuring electrical resistivity of overburden and bedrock;
- Ground Penetrating Radar (GPR): Locating buried infrastructure, stratigraphy, bedrock mapping, void detection, contaminant mapping;
- Electromagnetic methods: Locating buried infrastructure, contaminant mapping; and
- Borehole geophysics: Borehole wall imaging (acoustic & optical televiewers), measuring various bedrock physical properties, contaminant mapping.

These methods are used on inland construction projects but can also be used for marine infrastructure design such as wharfs and jetties or the construction of dykes and dams on lakes, rivers and tailing ponds.

Several other methods are also used in engineering projects and further reading, such as Reynolds, J.M. (2011), is recommended in references.

Generally, geophysics is involved in two stages of an engineering project: upstream, during the pre-feasibility and feasibility studies, and/or downstream, during the construction phase or after. The former is a proactive approach to foresee any problems and aid the design phase with useful data, whilst the latter is a reactive approach to specific issues that need to be quickly addressed. It is generally recommended to encourage the upstream approach, but, even when applying best engineering practices, problems during the construction phase are inevitable, and geophysics can help when they arise.

2 BENEFITS OF USING GEOPHYSICS

Using geophysics upstream of a project allows for complementary investigations to conventional drilling, sampling, and laboratory testing by providing information between these point samples and covering a greater area. By having a well-designed and well executed geophysical program, drilling costs, as well as design and construction costs, can be significantly reduced, better estimated, and optimized.

Currently, costs for infrastructure projects are increasing and project owners need to mitigate risks as much as possible. Conducting proper feasibility studies, including geophysics, is a proven method of managing risk, and geophysical investigation costs typically represent only between 0.01% and 1.0% of total project cost. Therefore, risk mitigation using geophysics represents an excellent value for the project owner. Table 1 shows statistics gathered by Brabers P. et al. 2017, on risk management.

Table 1. Geophysical Studies – Risk Management (adapted from Brabers, P. et al., 2017)

Type of information provided to contractors	**Average reclamation value / Contract Value**
Minimal investigation no samples or test results	15-25%
Sparse information (1980's standard) borelogs with limited interpretative content	10-12%
Comprehensive investigation/design information & test results, no geotechnical or geophysical model	2 - 2.5%
Comprehensive investigation/design information, detailed geotechnical and geophysical models	<0.1%

Considering downstream applications, geophysical techniques provide a fast and low-cost assessment of a site when time is of the essence to solve a specific problem. In some cases, such as void or sink hole characterization, where heavy machinery such as drill rigs cannot be used for safety concerns, but small footprint instruments such as GPR come in handy. Again, geophysical techniques can gather high density data to allow a very detailed assessment of the project site.

Downstream projects can also be non-reactive. For example, older infrastructure that is being maintained, refurbished, or upgraded will benefit from geophysical assessment in the same manner as upstream projects.

3 PITFALLS

Often, geotechnical, civil, and mining engineers, and project owners will dismiss geophysics based on past disappointing experience(s). They will comply with the requirements of the project specifications in terms of geophysical studies without considering alternative approaches nor giving much value to the data. Often, professionals who dismiss geophysics due to bad experiences will have little knowledge of these techniques and their limitations, not having had academic experience with this field. In addition, having narrow foresight on a project can lead to dismissing geophysics due to its cost, seen as an avoidable expense instead of an investment that will save costs overall if studies are carried out properly. The following paragraphs explain several pitfalls to avoid in order to maximize the benefits of a geophysical campaign.

3.1 Rigid project specifications or poorly defined Scope of Work

In some cases, project specifications are “set in stone” and geophysical contractors are obliged to submit a proposal based on these. In addition, these specifications are not adapted to the current project and are just passed on “as is” from previous projects. These Request for Proposals (RFP’s) often require unit costs and submission formats not easily adaptable to alternative pricing, methodologies, equipment, or complimentary methods.

Conversely, the Scope of Work (SOW) is sometimes poorly defined and proper evaluation of the project is difficult for the contractor. This can be worsened if the engineering firm that was hired by the project owner to manage the geophysical contractor was not involved in defining the SOW and does not have the proper knowledge to clarify the work specifics to the contractor. This leads to poor evaluation of the project and potentially low value data for the project.

When a specific contractor’s proprietary methodologies or products are written in project specifications, the flexibility given to the bidding contractors to propose the best solution for the project is limited and this should be avoided.

3.2 No stakeholder involvement

It is important to have all stakeholders involved in the planning and execution of a large-scale geophysical campaign. In some cases, the project owner does not know why the geophysical work is getting done and will be inclined to see it as an unnecessary expense. On the opposite side, a geophysical contractor that is executing work according to a specific SOW could suggest better technical solutions if they know what the project owner’s objectives, concerns, and critical aspects of the project are. In the middle, an engineering firm that lacks geophysical expertise mayl not be able to communicate well with their client, which might result in poorly executed work that could jeopardise the project objectives.

3.3 Bad survey planning

Survey planning is one of the most important aspects that the geophysical contractor must take control of. Common mistakes that will have an impact on the costs of the surveys, the quality of the results, or the safety of the personnel are:

- Poorly designed survey grid;
- Inadequate geophysical methods;
- Difficult access to grid or long commute to site;
- Work scheduled during difficult working conditions (winter, rainy season, etc.);
- No coordination with other work being done on-site;
- Lack of support staff;
- Lack of spare equipment; and
- Poor communication protocols.

While most of these fall under the contractor's responsibility, the client or engineering firm in charge of the project is also responsible for making sure that the proper conditions are set for a successful geophysical campaign in areas that are out of the control of the geophysical consultant such as site preparation, project timeline and work coordination.

3.4 Insufficient terrain knowledge

There is never too much site information prior to starting a project. A lack of site information provided to the geophysical contractor can have a significant impact not only on the results, but also on the production, costs, and safety of the personnel. Basic information, such as terrain topography, can have a major impact on how a geophysical campaign is planned and executed.

Historic site data (geotechnical, geophysical, etc.) is often available for many projects and can be very useful in the planning stage. Unfortunately, sometimes this data is not passed on to the geophysical contractor early on and is less valuable when communicated later in the process.

3.5 Inexperienced contractors

In many cases, geophysical contracts are still awarded solely on price and not enough weight is given to the contractor's experience. As opposed to more common trades of work, geophysics is a very specialized field, and the lack of an experienced geophysicist and technical field staff can have a negative impact on a project. A common GPR survey for detecting utility lines can have major economic and safety impacts if the operator fails to identify an electric, water or gas line before an excavation. It is wise to apply weights to quotes, based on the number of years of experience of the firm or the project manager proposed to carry out the specific geophysical investigation.

Engineering firms that start to do in-house geophysics often rely on one individual to oversee many projects needing different geophysical methods. It is rare that a sole individual has the capabilities and support to conduct successful geophysical campaigns. Unless engineering firms have a large geophysical department, it is not advised to rely on turnkey geotechnical-geophysical solutions offered by a limited team.

3.6 Dismissal of historic data

As stated earlier, historic geophysical data can add significant value to a project. Large infrastructure projects will often have several feasibility studies carried out throughout their lifespan. In some cases, historic data is dismissed solely because it is not easily available since several engineering firms have worked on different stages of the project.

3.7 Improper cost vs. value assessment

When the benefits of geophysical surveys are not well communicated to the project owner, they can be inclined to dismiss geophysics, not seeing the value of this work for the project. It is important the owner is informed, for example, that drilling costs could be reduced by 25% if a preliminary geophysical campaign is performed prior to drilling. Unfortunately, the geophysical contractor is rarely present at early stages of a project where cost vs. value can be quantified and considered for the SOW.

3.8 Relying on a "good salesman" and/or "branded" methods

As in every field, there are surprisingly good geophysics salespeople that can easily convince their client to use a specific solution, piece of equipment, or product. It is important to make sure that there is solid technical expertise behind every sales pitch, which can be difficult to establish. One must be skeptical of someone stating that their one method will be able to answer all the questions for a specific project. There are also some "branded" methods on the market that are showcased as unique or revolutionary; in some cases, these rely on existing techniques and are just a sales tactic to stand out or to charge higher rates.

3.9 Failing to communicate the limitations of geophysics methods

As stated earlier, geophysics is often considered, whether it is before or during the construction phase, when seeking information about a specific problem that is difficult or unfeasible to obtain through conventional methods; in many cases, geophysics is the only way that such information can be obtained. However, because of the nature of the methods and the specific problems, it is possible that the geophysical methods employed will not be able to produce the expected results. It is important for the geophysicist to communicate this to the client. Alternatively, the client may enter the conversation with unrealistic expectations of what can be achieved, in terms of results and accuracies, and fail to see the benefits of the information that can be realistically obtained.

4 GUIDELINES FOR SETTING UP A SUCCESSFUL GEOPHYSICAL CAMPAIGN

4.1 Identifying the objectives

The most important thing to bear in mind is that geophysics has many techniques and methodologies, “a toolbox”, that can be used for multiple purposes. The project owner or the engineering firm may have limited knowledge of the capabilities of the geophysical tools available and so. Initially, it is very important to identify what the objectives are, and if geophysics can help achieve them. Clearly defining the objectives is critical for determining which tool(s) will be most appropriate.

4.2 Consulting the geophysicist

A general knowledge of geophysics’ capabilities is without a doubt useful, but it is always recommended to obtain valuable insight from an experienced geophysicist when looking to conduct a geophysical campaign. Based on experience and expertise, the geophysicist will be able to assess if geophysics is really the best solution to solve a specific problem, what other complimentary investigations will be needed to get the information required, and what will be the main difficulties and obstacles that may be encountered.

At this stage, it is also advised to have discussions with a broad technical team (geotechnicians, engineers, and geophysicists) to fully understand the goals of the project and to allow the geophysicist to consider various aspects rather than focusing on a single point of view. The project engineer’s needs might not be the same as the geotechnician’s, for example. It is important that the geophysicist understand not only each stakeholder’s objectives, but also the project’s overall objective, to be able to suggest the geophysical program that will provide the greatest value to everyone.

4.3 Choosing the right method(s) to reach the objectives

It is common that a specific geophysical method is requested without much knowledge of its capabilities, limitations, and usefulness for a unique problem. Geophysical techniques have many applications. For example, the seismic refraction method can be used to estimate the depth to bedrock, measure overburden volumes, locate geological faults, find groundwater, measure certain mechanical properties of bedrock (Vp). Moreover, other methods can be used to reach the same goals. For example, GPR or ERT can also be used to estimate bedrock depth.

Depending on the site specifics, such as topography, land occupation, vegetation, geology, etc., a geophysicist will be able to suggest which geophysical method is best suited for the investigation.

4.4 Prioritise complimentary methods

A geophysicist will also be able to suggest complementary methods that may be required to reach the investigation’s objectives. For example, a GPR survey might give the best resolution to map a site’s stratigraphy but will not be able to confirm which layer corresponds to bedrock. In this case, combining GPR with seismic refraction will provide the best results for the investigation.

Similarly, by combing seismic methods with electrical methods, it will be possible to measure the mechanical and electrical properties of the overburden and bedrock. This might be useful to an electrical engineer designing a grounding grid and to a geotechnical engineer who is evaluating the bearing capacity of a soil where a power station will be built.

When possible, the use of complimentary methods also adds more confidence on the results that will be provided. This will be of great value in risky or sensitive projects where there is very little margin of error.

4.5 Understand the method’s limitations

An aspect where geophysicists sometimes fail, is in the communication of a method’s limitations. Some will oversell geophysics as an infallible solution, but this is far from the truth. All geophysical methods have limitations, such as depth of penetration, sensitivity to a type of target, resolution, soil interference, noise interference, etc. It is important that the geophysicist, as well as all the stakeholders, are aware of the proposed method’s limitations.

It is the geophysicists responsibility to inform the end user on the limitations of a proposed survey and to suggest complimentary and/or alternative investigations to maximize success. On the opposite side, a geophysicist should be able to manage expectations and make sure that money is not spent unnecessarily when the success rate of an investigation is low. In any case, the geophysics contractor must be up front with the client on the limitations.

4.6 Evaluate the budget and cost vs. benefit

Something that is frequently overlooked is optimizing an investigation program to obtain the most benefit versus the money spent. Considering the different investigation methods required, such as test pits, boreholes, geophysics, geochemistry, soil and water sampling, etc., the planning of an adequate geophysical program should allow for obtaining the maximum information to complete all other investigations, fill the gaps between sampling points, and correlate the different measurements, whilst minimising the investigation budget of the project. This is even more important for remote sites, such as mine development projects, where mobilization costs are limiting.

4.7 Communicate with stakeholders

Once a geophysical contract is awarded, contractors will often take charge of the project and execute following the SOW. It is best practice to communicate with stakeholders prior to starting the field campaign to make sure that the work that will be executed will meet the project objectives. Sometimes, projects evolve quickly, and the initial SOW might not be optimal considering design changes, the findings of new investigations, or any other variable that might have changed from the moment the SOW was drafted.

4.8 Assess and adjust the geophysical program

Once all stakeholders have communicated their requirements prior to the beginning of the field program, the geophysicist should assess the work required and adjust the program accordingly. At this stage, stakeholders should be informed of any proposition to adjust the field program so that they can agree upon these adjustments.

It is also possible that site specific challenges and/or preliminary findings after the start of the surveys might require a reassessment of the work program, complimentary geophysical methods, or even in some rare cases, termination of the geophysical campaign. Again, communication between all parties is vital at this stage.

4.9 Survey planning

Extra time should be given to proper survey planning. Insufficient or inadequate planning can result in loss of time and poor production during the surveys. Survey preparation costs should not be seen as an avoidable expense, especially for longer field campaigns or remote contract where the risk of running into problems can have an economic impact on the project.

Survey planning should be led by an experienced geophysicist who has mastered the methods that will be used and is familiar with the environment where the work will take place. Involving experienced technical staff in the planning stage is also invaluable, since they can share important knowledge on the type of work that will take place.

4.10 Execution and follow up

If all the guidelines presented in this section are followed, the likelihood that the execution stage will be successful and all stakeholders satisfied, will be greatly increased. It is recommended that communications remain active throughout project execution to ensure that any findings or problems that may necessitate a reassessment of the program are addressed quickly.

It is also important that data quality control procedures are put in place to ensure that the data that are being acquired meet the standard for a given geophysical technique. Any data of insufficient quality must be identified and reacquired before crew demobilization in order to guarantee the best results possible and avoid costly return visits. Informing the client of preliminary findings is standard practice so that important decisions for the next stages of the project can be made, and even more so in the case of “fast track” projects, where time is of the essence.

Proper follow-up is also important. Data interpretation can sometimes be time consuming, and a deliverables timeline should be set with the client to manage expectations, while also complying with the project’s needs.

5. NEW TECHNOLOGICAL ADVANCES

5.1 Equipment developments

In the past, due to the high development costs, next generation equipment took years to get released and it was not, and is still not, uncommon for a geophysical contractor to rely on the same equipment for 10 or 20 years. However, with the advances in computing and microprocessors, most of the leading equipment manufacturers are releasing new geophysical equipment more frequently and innovating within their range of products. Manufacturers are also offering smaller and lighter acquisition systems operated with off-the-shelf tablets or pocket computers.

Recent advances in engineering seismographs have allowed:

- Unlimited record lengths and sampling for passive seismic, H/V and new processing techniques;
- Wireless geophones with integrated GPS for custom geophone arrays;
- Minimalistic low-cost systems; and
- Internet of Things (IOT) enabled seismographs for vibration monitoring.

Recent advances in Ground Penetrating Radar have allowed:

- Hyper-sampling antennas for reduced noise and greater penetration;
- Multi-frequency antennas for greater depth range;
- Wireless antennas with integrated GPS;
- Muli-channel antenna arrays for high density surveys such as road scanning and archaeological surveys;
- Real-time 3D scanning; and
- Integrated live-wire detection.

Recent advances in Electrical Resistivity Tomography have allowed:

- Multichannel high-speed systems for fast acquisition of large 3D arrays;
- Full waveform recording for complex data analysis;
- Stand-alone receiver electrode pairs for wireless 3D survey grids; and
- Wi-Fi enabled systems for remote operation.

5.2 The Machine Learning era

Machine Learning (ML) is now part of our everyday lives, and so it is not surprising that ML and Deep Learning (DL) solutions are being integrated by geophysical software development companies. Due to the large amount of data acquired by geophysical surveys, ML techniques are ideal for optimising value from this type of data.

Recently, machine learning algorithms have been released for:

- Automatic processing of MASW sounding data;
- Automatic recognition of hyperbolas for GPR data;
- Automatic event recognition for vibration monitoring data; and
- Automatic cleaning of multibeam echosounder data.

The trend in the development of ML based solutions will continue and it is highly likely that these tools will be an integral part of geophysical processing software in the coming years.

5.3 Cloud based data processing platforms

Equipment manufacturers and geophysical software development companies have started to offer cloud-based, subscription-based software services. There are many benefits to these types of services, such as enhanced computing power, modular pay-per-use features, hosted data storage, automatic report generation, regular updates to the latest software version, and immediate access to new features.

5.4 Drone geophysics

Another trend that has been observed in recent years is the use of drones, Remote Operated Vehicles (ROV), and Autonomous Underwater Vehicles (AUV) for geophysical surveys. These offer great advantages in regard to safety of personnel and access to difficult terrain or restricted areas.

The most common use for drones in the engineering geophysics field are:

- Magnetometry and electromagnetic surveys for unexploded ordnance, metallic waste, and utility detection;
- GPR surveys for geological mapping; and
- ROV and AUV for marine geophysics and underwater inspections.

6. CASE STUDIES

The current section presents brief case studies where the guidelines presented in this paper were helpful to the survey's success or where innovative methods were proposed.

6.1 Radio-triggered seismic survey for a river crossing

Design studies for the construction of a new bridge required bedrock mapping along the new bridge route on an axis of approximately 1400 metres. Site specific challenges included:

- 10-metre water column in the center of the channel;
- Up to 6 metre high tides;
- Currents up to 3 knots;
- Barge and drilling activities on site; and
- Expected bedrock depth over 60 metres below water level.

SOW was not detailed, and the contractor was responsible for designing all survey parameters and proposing the best methodology to meet the objectives to the engineering firm.

Considering the site's constraints, the following methodology was proposed:

- Unconventional seismic refraction survey along the proposed bridge axis using two seismographs and radio triggered energy sources; and
- Several continuous seismic refraction lines using a hydrophone streamer perpendicular to the proposed bridge axis to measure the riverbed sediments' seismic velocities.

To conduct these surveys, meticulous planning was needed to ensure the coordination of the survey and safety vessels, management of the geophysical and marine crew (8 people), coordination with barge and drill rigs, guarantee quality data in a difficult and noisy environment, and acquire data in a limited time window.

Proper planning and execution allowed for the project objectives to be met and produce a continuous bedrock profile along the 1400 metre axis. Transversal seismic profiles allowed for the identification of a high density till layer at greater depths and calibration of the bedrock profile.

Due to project confidentiality, no data or results could be published.

6.2 Abandoned mine stopes and galleries using seismic resonance (Hydro-TISAR)

Safety concerns arose on an abandoned mine site where old underground mine stopes and galleries were present. The site owner asked for a methodology to detect and locate these former mine workings.

Site conditions and expected target depths where not suited for conventional geophysical methods; therefore, an innovative seismic method (Hydro-TISAR) based on the resonance of seismic waves was proposed. Combined with conventional seismic refraction and ground penetrating radar, Hydro-TISAR allowed the contractor to locate and estimate the depth of structures in the bedrock.

Figures 1 to 3 show depth slices obtained with Hydro-TISAR imaging. Pink features show the location of underground structures suspected of being the targeted mine workings. A drilling campaign was recommended to confirm the targets.

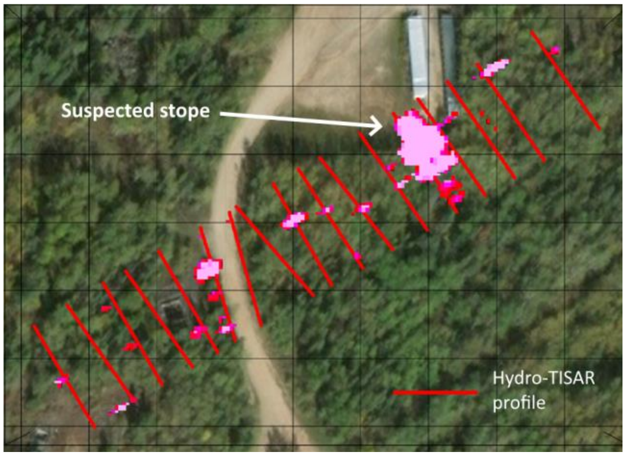

Figure 1. Hydro-TISAR depth slice 20m below grade.

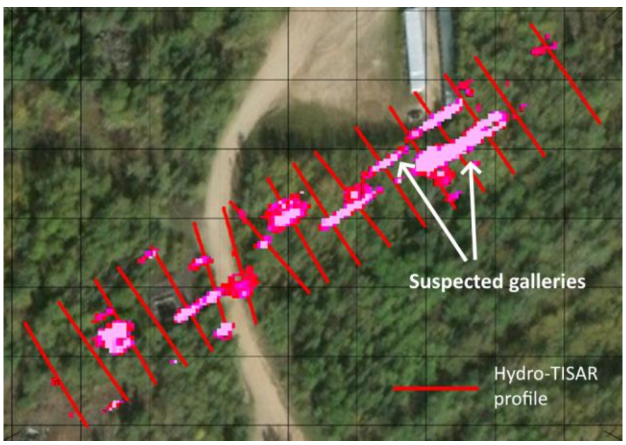

Figure 2. Hydro-TISAR depth slice 25m below grade.

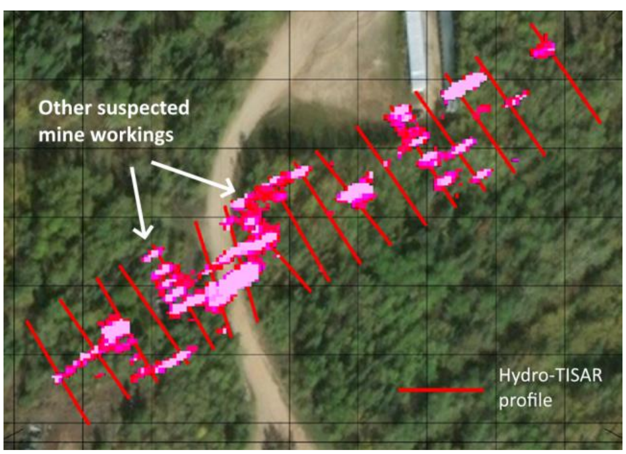

Figure 3. Hydro-TISAR depth slice 30m below grade.

6.3 Deep MASW surveys using ML assisted processing

Seepage and water resurgences were observed along and downstream of a large earth dam. An exhaustive geotechnical assessment was carried out by the site owner to better understand the processes involved. Conventional geotechnical drilling, Seismic Cone Penetration Testing (SCPT), and various geophysical techniques were used during a multi-year campaign.

Considering the limitations of the MMASW and MASW techniques in regard to layer resolution at greater depths, a new algorithm using Machine Learning (ML) techniques to aid the processing of MASW data was used to produce 1D MASW sounding and 2D MASW profiling results.

The results show better correlation between the ML-assisted MASW and SCPT results than conventional MASW. Noticeably, the ML tool predicted a low shear wave velocity layer that was not visible with conventional MASW. Figure 4 shows 1D sounding results for various methods.

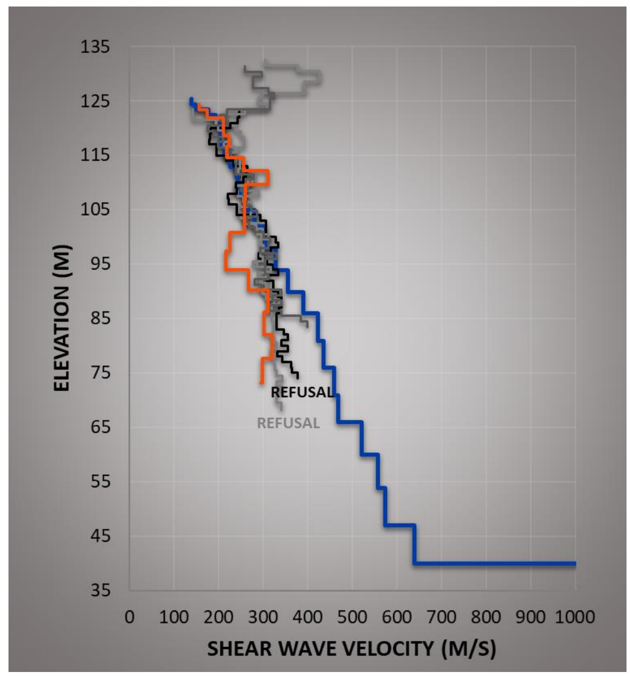

Figure 4. sCPT, MASW and ML assisted MASW correlation.

In addition to better result accuracy, the ML-assisted technique helps to produce results much more quickly than conventional interpretation. This is a major breakthrough for large 2D MASW datasets which usually are time consuming and financially limiting.

6.4 Using hyper stacking antennas for enhanced GPR investigations

After a stagnation period since the beginning of the 2000's, GPR technology has greatly evolved in recent years, mainly due to the arrival of Real-Time Sampling (RTS) for GPR. This new technology has many benefits, such as:

- Better dynamic range in the data;
- Ensures radio wave regulatory compliance; and
- Eliminates sample core offset and timing errors.

A comparison survey at various locations was conducted to compare traditional Equivalent Time Sampling (ETS) to RTS enabled antennas. Main findings showed that RTS is clearly superior, with approximately 50% improvement in penetration in low-loss soil conditions allowing good depth penetration, as shown on Figures 5a and 5b.

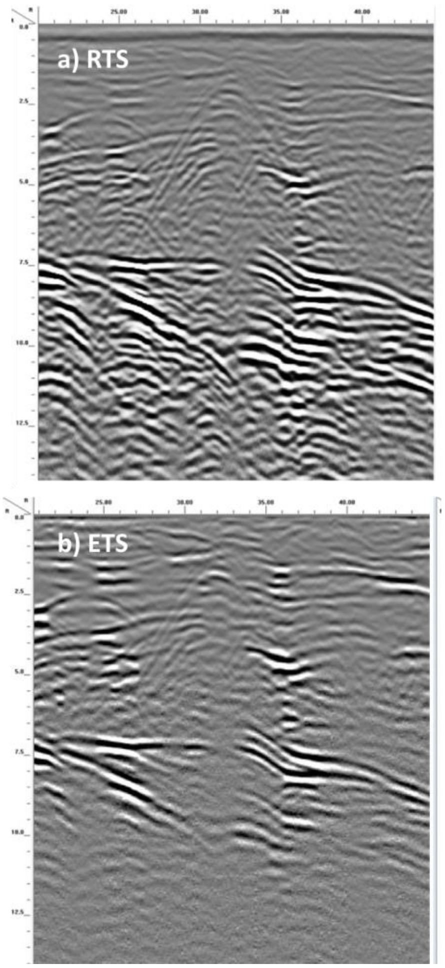

Figure 5. RTS vs ETS antenna comparison over low-loss soil conditions.

In cases where high-loss soils are present, it was demonstrated that the performance of RTS is not better than ETS technology, such as on the example in figures 6.

In general, test surveys have shown a clear advantage in using RTS technology over older ETS systems.

Results courtesy of and used with permission from Geophysical Survey Systems Inc.

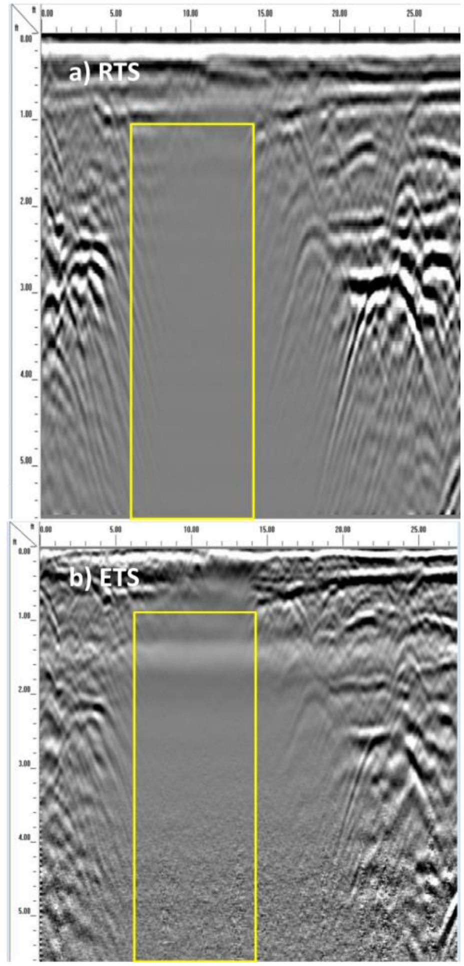

Figure 6. RTS vs ETS antenna comparison over high-loss soil conditions.

CONCLUSION

The current paper demonstrates the value of using geophysics for engineering and geotechnical projects. By avoiding the pitfalls and applying the guidelines presented in this document, all project stakeholders should obtain the greatest benefits from the investigation, whether financial, technical, scientific, or operational.

One of the key elements in a successful geophysical campaign is good communication between all stakeholders, and in all stages of a project. Proper communication allows good understanding of the capabilities of geophysics, the limitations of the methods, the benefits of using complimentary methods or new technologies, and will ensure that the project owner and project engineer have good confidence in the geophysical techniques that will be used.

The presented case studies showcase the capabilities of modern geophysics and aim to broaden geoscientists' knowledge of the capabilities of unconventional methods.

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