HOW TRANSPORTATION AGENCIES USE GEOPHYSICS

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Abstract

The National Cooperative Highway Research Program (NCHRP), in conjunction with the Transportation Research Board (TRB) and the National Academy of Sciences, sponsored a *Synthesis of Highway Practice* entitled **"*Use of Geophysics for Transportation Projects*"**. Results from a comprehensive electronic survey sent to municipal, state and Federal transportation agencies in the U.S. and Canada are presented. The survey had a 90% response rate, with 50 State, 8 Canadian Provincial and 3 U.S. Federal transportation agencies completing the survey.

The synthesis identifies how geophysics is being used, why it is being used, and by whom. Survey results indicate the top three most commonly used geophysical methods are: Seismic, GPR, and Vibration Monitoring; and, the top three applications were identified as: Bedrock Mapping, Subsidence Investigations, and Soil Mapping. It is interesting that 95% of the agencies indicated they implement geophysics in their geotechnical programs, but only 68% use it "*occasionally*" (i.e., 1 to 5 times per year).

The synthesis also defines transportation agency practices for contracting geophysics, conducting investigations with in-house capabilities, and the approach taken toward budgeting geophysical programs. The results indicate the desire for increased training and experience among the geotechnical engineers in the transportation industry. This is surely because *skepticism* and *lack of confidence* were the top two reasons why geophysics is not implemented. The NCHRP synthesis provides a means to inform the geophysical industry how transportation agencies in North America view the technology.

Introduction

Use of geophysics among U.S. State Departments of Transportation (DOTs) and Canadian transportation agencies varies tremendously depending on the knowledge of the individuals and the combined experiences of the transportation agency. Over the past decade there has been an increased effort on the part of the engineering geophysical community to provide technologies that aid the design and construction needs of transportation projects. The NCHRP and TRB needed to understand variety of uses and the lack of use, and document the findings through their synthesis program.

The following paper summarizes findings presented in the NCHRP Project 20-5, Synthesis of Highway Practice Topic 36-08 – *Use of Geophysics for Transportation Projects* (Sirles, 2006 - *in press*). The purpose for the synthesis was to provide high-level FHWA and other transportation agency decision makers with substantive information to determine if engineering geophysical technologies are being utilized, under-utilized, or even used at all within in the state and provincial transportation departments. This survey included departments within the U.S. and Canada. The synthesis process, used routinely by NCHRP, provides a means to assess national and international trends and provide the industry leaders with information regarding current use, the level of understanding, and identify future needs of highway engineers (i.e., general term used herein to describe engineering geologist, geotechnical and civil engineers involved in design and construction of highways and bridges). Topics and objectives for each NCHRP synthesis are established prior to contract award by a technical review panel that stays with the selected consultant throughout the process, which generally takes a year to complete an individual topic (synthesis).

In an attempt to find what the current practice is among U.S. State, Federal, and Canadian transportation agencies, the objectives for Synthesis 36-08 consisted of:

- Review the state of knowledge;
- Assess the amount and type of geophysical investigations being performed;
- Find what geophysical investigation methods and techniques are *primarily* used;
- Determine what applications geophysics are being *primarily* used for;
- Assess annual budgets, and solicitation/contracting practices; and,
- Establish future needs (e.g., research, education, etc).

For the purpose of the synthesis, *geophysics* was defined as the application of physical principles to define geology and study earth (geo-) materials. Engineering geophysics is used to evaluate natural and artificial foundation materials - soil and rock; but, the synthesis focused on its application toward geotechnical problems. Although *non-destructive testing* (NDT) utilizes the same physical principles as geophysics it was important to distinguish geophysics from NDT for the synthesis. NDT is defined, in the most simple of terms, as the evaluation and imaging of man-made structures (e.g., bridges, structures, foundation elements, stabilizing walls, etc.).

Once all of the final papers have been submitted they will be assigned final sessions with dates and times. This information will be forwarded to the author as decisions are made.

Approach

The majority of information included in the synthesis was obtained from published literature, an electronic questionnaire, and interviews with designated agency representatives. A comprehensive survey was developed and sent via email to representatives in all 50 states (and District of Columbia), the Canadian provinces and other Federal government entities (e.g., Corps of Engineers, Toll / Turnpike agency, FAA, FRA, and NPS). Follow-up telephone interviews, to clarify or expand on particular aspects of some survey responses, were also conducted.

Conducting the survey via an email questionnaire proved very effective. A total of 70 questionnaires were sent and 63 agencies replied for a 90% response rate. Figure 1 shows a total of 67 questionnaires returned: Fifty-six from U.S. States DOTs (which included DC and the Port Authority of NY-NJ), eight from Canadian agencies, and three from U.S. Federal agencies. Four additional replies were sent from three states that returned multiple responses (CO - 2, MI - 2, and OR - 3). Figure 1 also shows that nine of the 67 respondent agencies indicated they *do not* use geophysics. Even though all the answers were tallied appropriately into an Excel database, only one response per State DOT was considered as an *agency* response.

At the request of the technical review committee, three other organizations received the questionnaire: Kansas Geologic Society, University of Missouri - Rolla, and Technos, Inc. These three recipients represent a state agency, an educational institution, and a private consulting firm, respectively. They were selected based on their qualifications and experience with the transportation industry. The purpose was to determine the validity of the questionnaire and to gain insight for the synthesis from these organizations. All three responded quickly and agreed that they should *not* be included as respondents since their use of geophysics is not discretionary. Based on their responses and the follow-up interviews, it was deemed appropriate to not send questionnaires to academic institutions or private consultants. A similar survey was sponsored by FHWA in 2004 and although the response was low the survey results were published the following year (Tandon and Nazarian, 2005).

The questionnaire contained 63 questions, mostly multiple choice format but a few "*fill in the blank*" responses were solicited. The questionnaire was divided into five sections: Part 1 – General; Part 2 – Methods and Applications; Part 3 – Budgets and Costs; Part 4 – Contracting; and, Part 5 – Case Histories/Project Examples. In general, nearly all the respondents completed all five sections. Occasionally, one part was left incomplete and a follow-up interview with the agency representative was required, and typically another individual was provided to offer the correct information to complete the survey.

Results

The following sections present some of the results of the synthesis as it relates to geophysicists and our industry. Summarizing the synthesis results is an appropriate means to distribute the information to geophysical practitioners who likely would be unaware of this synthesis. Many of the figure captions shown below represent the question (paraphrased) from the electronic questionnaire.

Demographics

Figure 1 shows the distribution of agency response by percent, of the 58 respondents that implement geophysics on their transportation projects. Ninety five percent of the results presented and discussed throughout the synthesis come from U.S. State or Provincial DOTs.

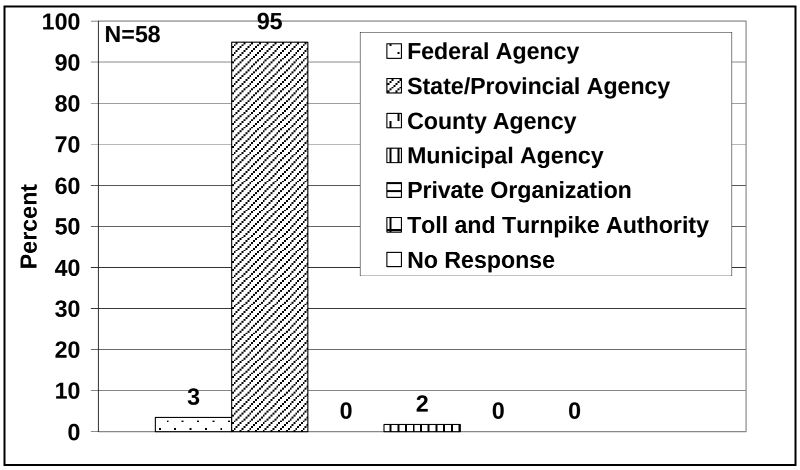

Figure 1. *Type of transportation agency/organization (that uses geophysics).*

During database entry it was obvious that: 1) not all respondents answered all the questions; 2) some respondents completed questions with multiple answers, when only one answer was requested; and, 3) in a few cases both YES and NO answers were given to the same question. Discretion was used, and the interviews helped but not in all cases. Therefore, for each chart there is an "N" value presented that indicates the actual number of reliable answers used to evaluate responses from that particular question. For the majority of the questions the results are based on 58 respondents (i.e., completed questionnaires from agencies that *use* geophysics). The "N" value is necessary to understand the result.

Figure 2 illustrates that 68% of the agencies apply geophysics on an 'occasional' basis for their projects. This indicates that the number of transportation agencies using geophysics is pretty high, but the frequency of use is quite low.

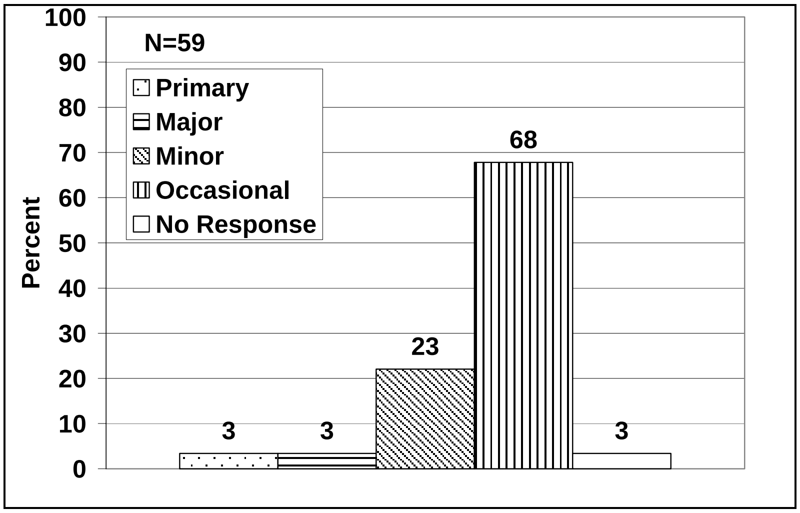

Figure 2. *What is your agency's level-of-involvement using geophysical investigations?*

General Items

FHWA recently published a text and web-based document entitled "*Application of Geophysical Methods to Highway Related Problems"* (Whitman, et. al., 2003). Both the text and website are designed specifically to aid State, Federal and other highway engineers in the use of- and the application of geophysics for their transportation projects. Because a considerable effort was put forth to publish the on-line g*eophysics manual* (http://www.cflhd.gov/geotechnical), a series of questions designed to see if word about the book and site has made it to the DOT agencies. Results can be summarized as:

- 69% are aware of the manual
- 46% own the manual
- 14% have used the hardcopy
- 16% have the CD version
- 5% use the CD
- 50% know of the website
- 24% use the website for project work

Clearly, there is a need to spread the word and educate the transportation agencies about the manual, and the value of this publication (in all its formats). It could be expected that as engineers are exposed to the technologies described on the website, more will understand its purpose and put it to use. Since 53% of the agencies conduct between 1 and 5 geophysical investigations per year (Figure 3), there is reason to believe the FHWA publication may help increase this number.

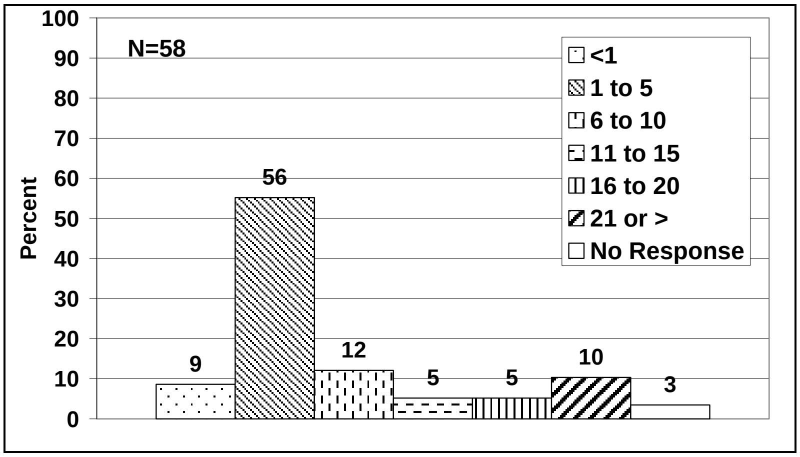

Figure 3. *What is the typical number of geophysical investigations conducted by the agency each year?*

As Figure 4 displays, nearly 60% of the respondents indicate the use of geophysics has been increasing in their agencies over the past 5 years, and 13 of those agencies indicated an increase of greater than 50% in its use. The manual and other (EEGS/SAGEEP) educational efforts are anticipated to continue this trend because another question shows that 66% of the individual who responded, and 54% of their agency's experiences are either excellent, good or fair when using geophysics.

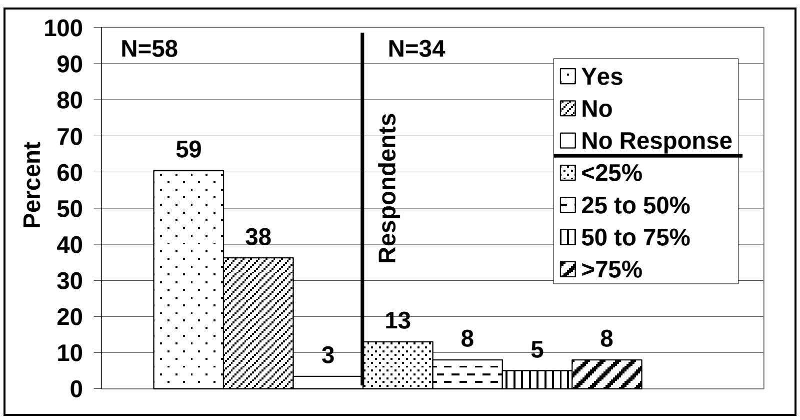

Figure 4. *Is there an increase in the level-of-effort? And, if yes, what percentage has using geophysical surveys increased over the past 5 years?*

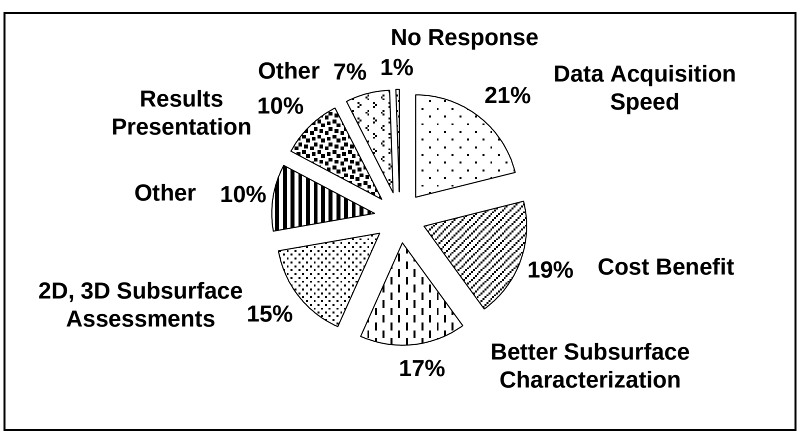

Figure 5. *Identify the greatest value geophysics lends to your transportation projects (N=162).*

Two of the most important questions from the survey were designed to establish what highway engineers felt was the *greatest value* and the *greatest deterrent* to implementing geophysics. The data in Figure 5 shows that it is cost, acquisition speed, and better subsurface coverage that are the primary benefits geophysics provides to a field program. Figure 6 illustrates that some (14) believe it is the expense of a geophysical investigation hinders its use, but the results also indicate the largest portion of respondents admit the low utilization is due to a lack of understanding and confidence in the technology.

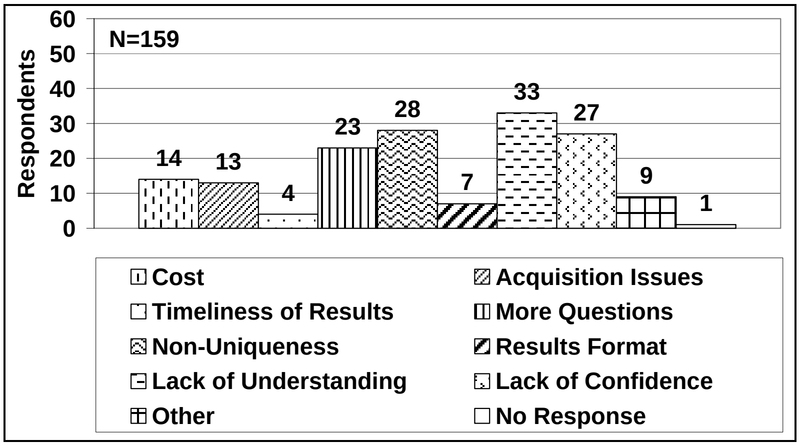

Figure 6. *Identify the greatest deterrent to using geophysics on your transportation project.*

In general, Part 1 of the questionnaire can be summarized:

1. 45% of the agencies have used geophysics only in the past 10 years, 26% in the past 5 years, and just less than 10% in just the past year.
2. Agency staff that primarily uses geophysics is the geotechnical engineers and geologists (64%)
3. Only 4% (3 agencies) provide any training related to the use of geophysics.
4. There are 14 agencies that conduct between 75-100% of the geophysics with in-house capabilities, 24 agencies do 75-100% of their investigations using RFP contract procedures, and 7 agencies conduct 75-100% of their geophysical investigations using Indefinite Quantity (IQ) contracts (Question #3).

Methods and Applications

Six questions in Part 2 (#21 through 27) of the survey were specifically designed to assess the geophysical methods and the DOT applications for geophysics. The questions had extensive lists of state-of-the-practice methods, as well as numerous applications. Additionally, a respondent could enter "other" if a method or application did not occur in Part 2. Figure 7 displays the geophysical methods most commonly used by the respondent agencies. It is apparent from this chart that the use of NDT still gets incorporated with *geophysical methods*, likely due to the overlap between the technologies (e.g., crosshole seismic for shear wave velocity vs. crosshole sonic logging for drilled shaft integrity). In this section, the responses varied considerably because the questionnaire allowed a lot of flexibility for the respondents to complete the questions (#22-27). Therefore, the consultant categorizes responses to *"…the three most commonly used methods…"* by the eight surface geophysical methods defined earlier in the questionnaire. This simplified the answers and allowed a graphical representation of the data shown below (Figure 7).

Seismic and GPR methods make up greater than 50 percent of the overall usage of geophysics among transportation agencies. Significant results are: 1) vibration monitoring represents a high percentage of use (22%); 2) electrical resistivity is 4^{th} at about 10%; and, 3) there is a clear lack of electromagnetic (EM) methods used by the agencies. A number of "other" methods were designated by respondents that do not fit the primary methods.

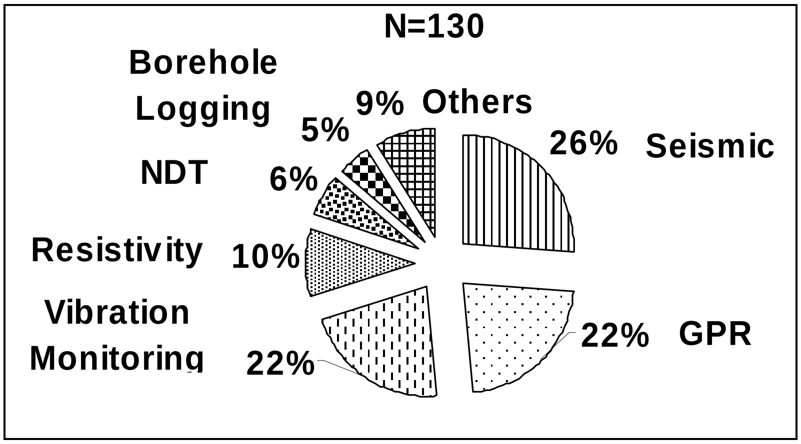

Figure 7. *Identify the three most commonly used geophysical methods (51 agencies successfully completed this question).*

Details of results regarding methods also indicate seismic, GPR and vibration monitoring are the most commonly used methods. Vibration monitoring is equally split by technique for construction monitoring (e.g., pile driving, dynamic compaction) and blast monitoring (e.g., rock mass excavation, quarry operations). Electrical resistivity, borehole logging and a myriad of other methods are actively used. Magnetic methods have been used by 12 agencies and microgravity by 5. Refraction and borehole seismic techniques (crosshole & downhole) are the most common seismic techniques. Two-dimensional profiling is well ahead of any other electrical technique used. Time-domain and frequency-domain electromagnetic (TDEM and FDEM) techniques are applied about equally (although infrequently). Marine and airborne geophysical investigations appear to be very rarely conducted.

Results dealing specifically with application of geophysics on projects covered a wide range of project work. Figure 8 displays the most common applications for which geophysics is used by the respondent agencies. A footnote to this figure is required since nearly 25% of the applications described in the responses to this set of questions fall into under the category of NDT. It was established that NDT was not a portion of the synthesis; however this figure demonstrates that the differentiation between the application of NDT or geophysics continues to be confusing. Similar to the results from shown in Figure 7, the consultant categorized responses based on the *applications* defined earlier in the questionnaire. This provided consistency throughout the analysis and permitted the variety of responses to be restricted for the graphical presentation shown in Figure 8.

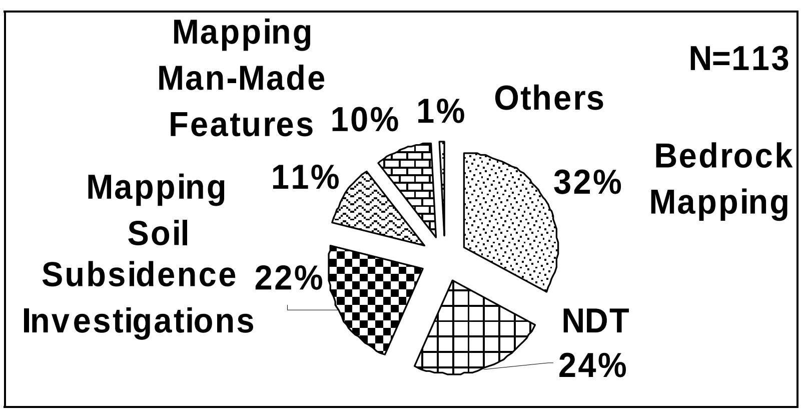

Figure 8. *Most common applications of geophysics (50 agencies successfully completed this question).*

Based on the variety and different descriptions of applications, the responses were categorized on a general basis. For example, "*mapping depth to rock*", "*mapping topography of rock*", or "*mapping bedrock strength*" were all placed in the bedrock mapping category. The categorization permitted a better illustration of the responses to this question. Actual values for each particular application are presented in the synthesis as separate charts. Clearly, a third of the geotechnical applications involve the use of geophysics to map bedrock characteristics such as depth, topography, or rippability. Numerous other applications, including a large representation of NDT applications were provided by the respondents. As might be expected, roadway subsidence issues and soil mapping are principal applications as well.

Budgets and Costs

A series of questions regarding allocation of funds and appropriation of funding revealed the general approach taken by transportation agencies toward spending money on geophysical investigations. Figure 9 identifies that geophysics has a very low priority to be funded. In general, geophysics simply does not get annual appropriation of funds at the agency level. This is primarily because the investigations are typically paid for through geotechnical investigation funds (*personal communication – TRB Technical Panel*). Only 23% of the respondent agencies allocate funds for geophysics, 67% of transportation agencies do not appropriate any funds for geophysics, but some respondents (CA, TX, NM, WA and Saskatchewan) appropriate a significant annual budget.

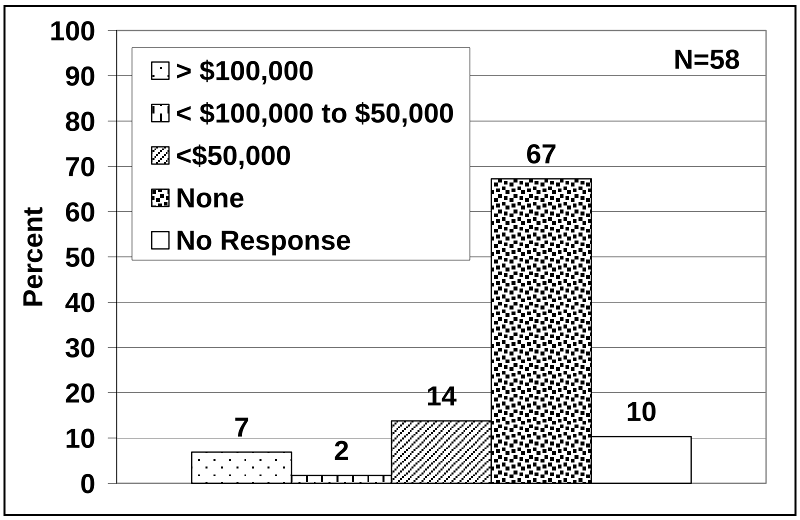

Figure 9. *What is the annual budget allocated to geophysical investigations?*

The level of annual spending from *other* sources (i.e., non-allocated funds) to complete geophysical investigations is less than $50,000 annually at nearly 50% of the agencies. Results indicate 15% of the respondent agencies utilize less than $100,000 from other funding sources, and 10% (i.e., 6 agencies) use funds in excess of $100,000 annually. Several respondents replied that although there are no independent funds allocated for geophysics, there are very large annual budgets for geotechnical investigations from which geophysical investigations get funded. Table C5 presents comments regarding budgets and funding at the respondent agencies. One question showed that it is the Geotechnical Design Branches provide the lion share of funding, although construction branches also support the use of geophysics with funds. When it comes to who makes decisions to budget and approve funds for geophysical investigations, it is predominately at the Division/Branch Manager level, with only about 10% of the decisions being made at the Agency Head level; however, 30% of the time the decisions regarding project funding are made by the Project Manager or Highway Engineer

The synthesis demonstrated the use of geophysics has increased over the past five years among most agencies (Figure 4), plus the results also indicate that cost benefit (Figure 5) is a reason to perform the investigations. It seems likely that the approach taken to fund geophysics may change as its usage becomes more routine as it has in California and Saskatchewan. Interestingly enough, when asked to predict how much money was spent during the current fiscal year the results indicate over half (55%) of the agencies have *"no way to estimate*", and that 22% will spend less than $50,000. Only seven agencies indicated they will spend more than $100,000 this year on geophysical investigations.

Figure 10 identifies the typical range of cost **per** geophysical investigation as well as the number of investigations performed at that spending level **per** year. By far, geophysical projects costing less than $10,000 dominate the results.

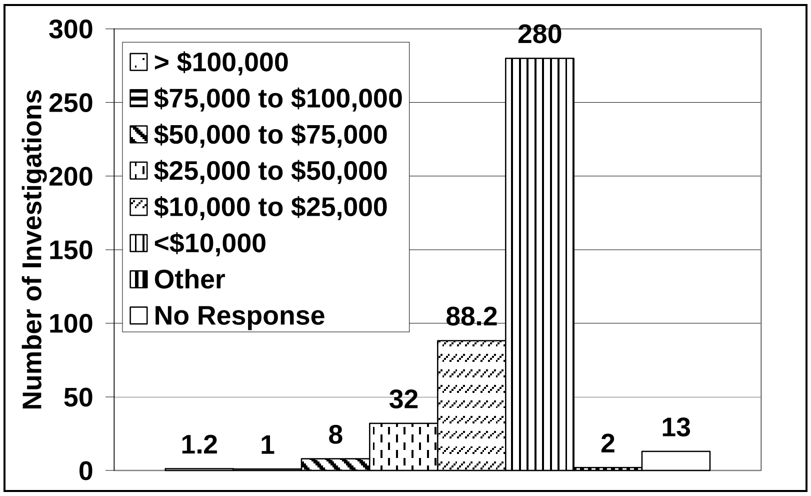

Figure 10. *What is the typical cost range of investigations, and the number of investigations conducted per year at that cost level?*

Contracting

State, Federal, and Canadian transportation agencies all seem to contract a major portion of the geophysics work out to private consultants. Only 7 agencies utilize qualified staff to perform geophysical investigations (not necessarily geophysicists, but staff with experience conducting investigations); and 23 agencies do both in-house and contracting for the services. Just shy of 50% solely utilize private contractors. Because there are a fair number of agencies that conduct their own geophysical investigations, a couple questions asked if the equipment and software was owned or rented. The results indicate just at 50% of the agencies do own equipment and software; however, they identified that it was equipment selected and purchased for particular applications.

When utilizing private contractors, the agencies defined that the most common form of solicitation is "*limited solicitation*" as shown in Figure 11. Limited solicitation refers to sending RFPs to pre-qualified, pre-selected contractors, and contractors with which the agency has previous experience and therefore are confident in working with them.

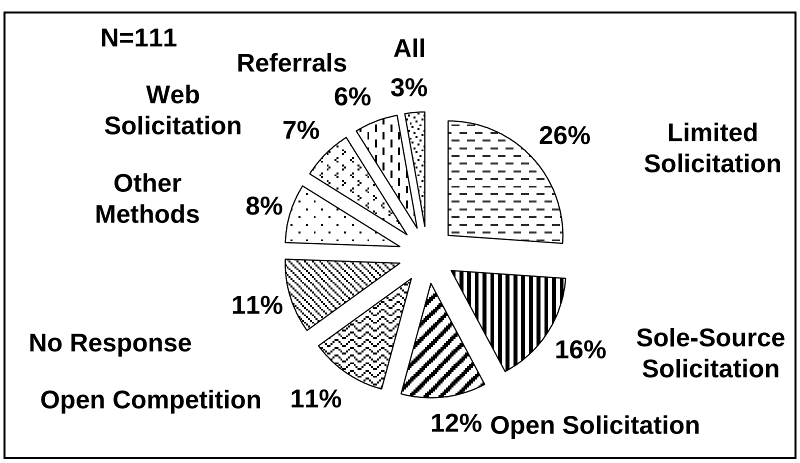

Figure 11. *What type of solicitations are used by your transportation agency?*

Figure 11 also indicates that along with the limited solicitations, sole-source solicitation is the second-most common approach to procuring service providers. Open competition and (open) web solicitations represent about 18% of the response. It was determined that 26% of the agencies utilize large Indefinite Delivery-Indefinite Quantity (IDIQ) and/or "on-call" contract vehicles. These IDIQ contracts allow fast access to the vendors who are technically qualified, and once the contract has been awarded by the agency it also reduces the task order (i.e., RFP) and the purchase order (i.e., procurement) process. The respondents indicated that the typical length of IDIQ and on-call contract is from 2 to 3 years, and ranges from $100,000 to $300,000 in contract value (but no guarantee of use). However, a few contracts as large as $4M over 5 years using multiple private contractors have been awarded.

Along with the type of solicitation (Figure 11) there is value in understanding what type of contracts transportation agencies award. Figure 12 displays the variety of contracts identified through this set of questions, and the distribution of award types. Lump sum/Fixed price awards represent 33% of the responses, but unit price low-bid and time and materials are roughly even at around 15% each. Questions about utilizing academic institutions to perform geophysical investigations indicate that 14% of the agencies do award "*run-of-the-mill*" geophysical projects to these institutions; but, when it comes to "*cutting edge or state-of-the-art*" geophysical projects about 22% use academic institutions and 29% use private/professional contractors for these projects that are more along the lines of research and development.

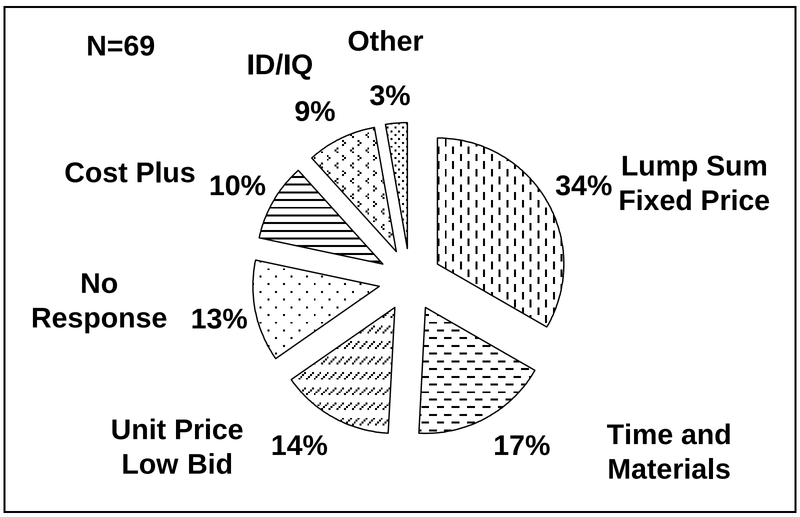

Figure 12. *What is the typical type of contract awarded for geophysical investigations?*

Agency Experience and Case Histories

Part 5 of the questionnaire solicited information regarding successful applications of geophysics, as well as the projects where geophysics did not meet the objective(s). It is important to note that "*successful*", or "*unsuccessful*" projects were <u>not</u> defined by whether the investigation met the program budget or its deadlines; rather, it is solely based on whether geophysics met the objectives of the investigation or not. Figures 13 and 14 represent very important tallies regarding agency experience. Figure 13 shows the total number of successful projects completed over the last five years (714), divided into ranges. This graphical presentation was necessary to cover the wide range of response values. That is, Rhode Island listed 0 successful projects, and California listed >200 completed successfully over the past five years. The majority of agencies (49%) fall between 1 and 10 successful projects over the last five years, 6 agencies stated 0 successful projects, but at least 7 agencies indicated >20 and 2 agencies had >100 successful projects over the past five years. Nine agencies did not respond to this question.

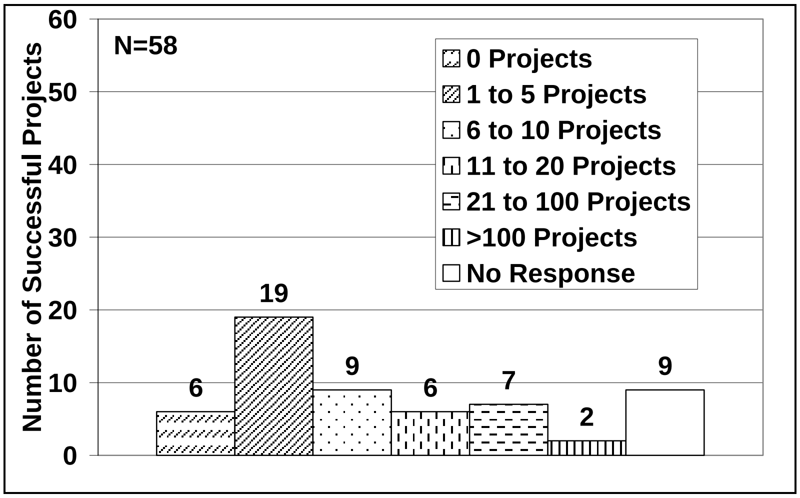

Figure 13. *What is the number of successful geophysical projects completed in the past five years?*

Geophysics has its limitations and must be deployed with appropriate use of the methods. It is understandable, therefore, that unsuccessful geophysical investigations do occur. Figure 14 presents the agency's experiences with geophysical investigations that did not meet the technical objective(s). Considering that there are about the same number of "no response" as in the previous figure, the ratio of successful projects to unsuccessful projects is about **7:1**, for the past five years. This indicates that geophysics is being used successfully significantly more than not. The agency with the greatest impact to these figures – CalTrans, indicated about 40 successful projects per year, and 5 unsuccessful projects per year which correlates pretty well with the 7:1 ratio derived from the agencies responding to these questions (i.e., actual response values 714:107 – successful:unsucessful). Therefore, based on results of the synthesis it appears that approximately 85% of geophysical investigations are able to meet the technical objectives of a project. Two quotes (extracted from the comments portion of this section) demonstrate the value of documenting successes and failures: "*Our failures have primarily occurred when a geophysicist was not consulted on the survey design or methodology, resulting in selection of an inappropriate method or the creation of a poorly-defined scope of work*.: (CalTrans); and, "*Geotechnical engineers expecting too much from geophysics (e.g., GPR, Seismic refraction, resistivity) on every project they consider its use on (i.e. if it can't give them the exact information they want, it is no good)*" (NHDOT).

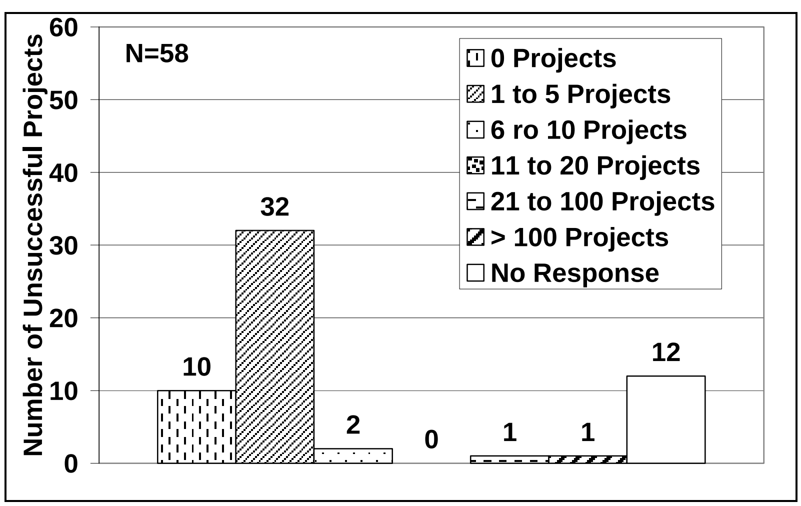

Figure 14. *What is the number of unsuccessful geophysical projects completed in the past five years?*

Based on the author's 22 years of experience, as well as several discussions with other "seasoned" geophysicists, these agency data correlate well with the number of successful versus unsuccessful geophysical projects. However, among the engineering community the perception of implementing geophysics would imply a higher amount of unsuccessful projects. Clearly, there is a wide range in the level of comfort for use of geophysics on geotechnical projects; that is, agency by agency the level of comfort is very different. When asked *"what could be done that would increase your level of comfort to utilize more geophysics on projects?"*, the results were not surprising based on the information gathered throughout the questionnaire, and the fact that this question had one of the lowest number of "no response" in the entire survey implies this is an important item to the agencies.

Figure 15 identifies six issues that would have an impact on highway engineers promoting the use of geophysics on their projects. Far and away the top two issues: training/knowledge and experience are what will promulgate the technology to a new level of use. That is, 81% (47 of the 58 respondents) indicate these two issues are paramount and only 3% (i.e., two) of the agencies do not. A question asked very early in the questionnaire determined that only three agencies have any formal training programs for geophysics. It is certainly apparent that with time (i.e., experience) and additional training more agencies will attain greater comfort with the technology. Results shown in Figure 15 also revealed that as the ASTM Guides and Standards are implemented and more are developed, the level of comfort among engineers will increase. An interesting result was that a large amount of highway engineers did not know ASTM Standards and/or Guidelines exist for geophysical investigations. A current list is provided in Table 1, which was also presented in the synthesis for their edification. It is interesting that between 50 and 60 percent responded that equipment, software and a database of "*qualified service providers*" will help, and 10 to 20 percent of agencies don't believe this will do much to increase the level of confidence in geophysics (and thereby its use).

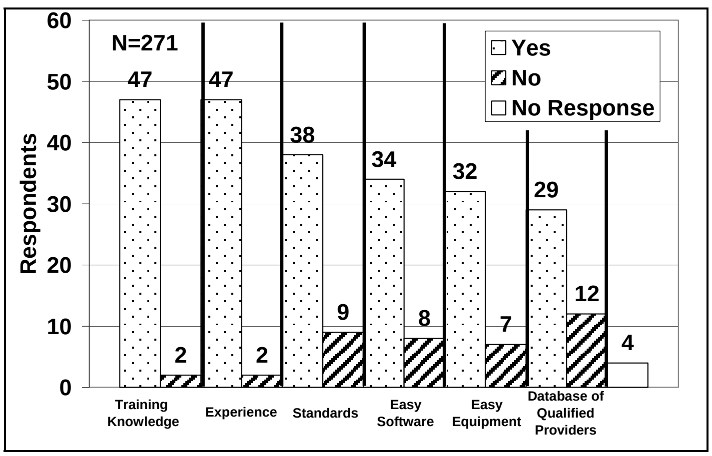

Figure 15. *What can be done to increase your level of comfort utilizing geophysics?*

Table 1: *Existing ASTM Standards and Guidelines for geophysical investigations.*

Geophysical Methods and Techniques	ASTM Guide
Standard Guide for Selecting Surface Geophysical Methods (included in this Guideline are the following techniques) • Seismic Refraction • Seismic Reflection • D.C. Resistivity • Induced Polarization (IP) or Complex Resistivity • Spontaneous Potential (SP) • Frequency Domain Electromagnetics (FDEM) • Time Domain Electromagnetics (TDEM) • Very Low Frequency (VLF) Electromagnetics • Metal Detectors and Pipe/Cable Locators • Ground Penetrating Radar (GPR) • Magnetics • Gravity	D 6429
Standard Guide for Conducting Borehole Geophysical Logging	D 5753
Seismic Refraction	D 5777
D.C. Resistivity	D 6431
Frequency Domain Electromagnetics (FDEM)	D 6639
Time Domain Electromagnetics (TDEM)	D 6820
Metal Detectors	D 7046
Ground Penetrating Radar (GPR)	D 6432
Gravity	D 6430
Seismic Reflection	In press
Mechanical Caliper-Borehole Logging	D 6167
Gamma-Borehole Logging	D 6274
Electromagnetic Induction	D 6726
Neutron-Borehole Logging	D 6727
Geophysical Methods and Techniques	**ASTM Standard**
Crosshole Seismic Testing	D 4428
Soil Resistivity Testing	G 57

Case Histories

One of the most acceptable approaches used to gain experience is to share successful and unsuccessful project examples. The survey asked for respondents to indicate if they would share case histories of either good or bad use of geophysics, and 41% (or 22 agencies) replied yes they would provide this information. This represents a tremendous wealth of knowledge to be shared with other DOT agencies. When the case histories were requested, 13 agencies supplied numerous project examples for the synthesis, and three agencies provided website links to more than one case history. It was clearly beyond the scope of the synthesis to present the examples, but they were referenced in the synthesis. In this fashion, interested parties may contact an agency to obtain examples and learn from these other applications of geophysics to engineering problems. The synthesis included four case histories as an appendix to demonstrate the value to these DOT agency experiences. Two successful (submitted by Saskatchewan and WI DOT) and two unsuccessful (submitted KS DOT and CALTRANS) case histories were presented using a simple and standard format. The format simply addresses objective, results, lessons learned, and conclusions. Meeting or exceeding the project budget did not constitute whether the project(s) were successful or unsuccessful.

Future Research Needs

The last question of the survey requested open comments on the future needs for geophysical technologies. Thirty five (35) percent of the agencies provided comments. As anticipated, responses vary considerably for this topic, but a distinct call for standards and more educational opportunities dominated the responses. The TN DOT response may have stated it best: *"training, training, training, and …training".* Development of a National Highway Institute (NHI) course was also a common sentiment. Additionally, the need for "*out-of-the-box*" methods and applications appears to be a need, and "*easy to use (inexpensive) field instrumentation and software tools for interpretation*". The only consistent comment regarding a particular geophysical technique involved more research into surface wave methodologies and applications; that is, SASW, MASW, and passive surface wave methods (such as ReMi^{TM}). Several comments regarded the use of NDT technologies are included in Table 5. This, once again, indicates that even though greater than 90% the respondents stated they understand the difference between geophysics and NDT, the similarity of physics applied, and the similar nature of applications needed by engineers will overlap until additional educational opportunities exist and experience is gained regarding the use of the two technologies.

Summary

Utilization of geophysical investigation techniques is increasing among transportation agencies, with project-specific applications continuing to diversify. Even though, there remains much skepticism among highway engineers and geoscientists attempting to implement the technology on their agency's projects.

These issues could be due to the fact that transportation agency funding is nearly absent for utilizing geophysics as a reasonable alternative or maybe as the best approach on field programs ***prior*** to conventional geotechnical investigation procedures (i.e., drill and sample). The synthesis indicates typical geophysical field investigations are small (<$10,000 in size) and at this level, contracting the service becomes burdensome unless previous experienced or known contractors are available, or larger IDIQ contracts can be used to award a task order with notice-to-proceed.

The most common geophysical methods among the 58 respondent agencies are: 1) seismic, 2) GPR, and, 3) vibration monitoring (#4 was electrical resistivity). The most common geotechnical applications identified by the synthesis relate to: 1) bedrock mapping, 2) roadway subsidence problems, and 3) mapping (characterizing) soil deposits. It became clear through analysis of the database that the distinction between NDT and geophysical methods is not very clear.

Survey results indicate educational/training needs are high, better equipment and software needs are high, and the use of standards will help engineers with their level of comfort to implement geophysics. Additionally, results from this survey showed that nearly 50% of the agencies have been applying geophysics for less than 10 years; therefore, it should not be a surprise that obstacles such as lack of understanding, cost, and skepticism continue to hinder its use. It is apparent, however, that the geoscientists and engineers associated with transportation programs feel that geophysics should be a user-friendly technology. Their request is for inexpensive approaches to acquire data and simple methods to objectively interpret the data. The paradox seems to be that geophysics is, by virtue, a very technical and complex science.

The ability for geophysics to aid in transportation planning and construction programs is real and apparent, as shown by agencies responding to the synthesis. Incorporating geophysics into geotechnical projects will simply take time, which will ultimately build a more solid base of experience. A few transportation agencies have already demonstrated the value of utilizing this technology regularly (e.g., CalTrans) and over extended periods of time (e.g., Saskatchewan), while most are not that involved with its use indicated by "*…occasional use*". The two or three agencies that utilize it regularly understand the science, and are promoting the benefits within their agency and to the industry as a whole. The value of geophysics includes (as defined through the synthesis):

- cost effectiveness
- high density of measurements
- quick acquisition over large areas
- the combination of two- and three-dimensional assessment
- visualization of subsurface features

As the agency representatives stated on numerous occasions, these values and benefits of applying geophysics on geotechnical projects will only come through education, training and experience. Specific interest to see the development of an NHI course on the application of geophysics to geotechnical problems may be the most pertinent information derived form the synthesis. Simply put, it is through good, constructive, case-history education (i.e., experience-driven) that transportation agency engineers throughout the U.S. and Canada will fully make use of existing state-of-the-practice technologies and appropriate applications of geophysical methods to help solve transportation-related problems.

In conclusion, transportation agencies do not implement geophysics the same throughout the U.S. or in Canada. This is primarily due to a lack of experience and education about the application of the technology, not the availability or cost. Geologic settings, materials, and tests necessary to plan or construct transportation projects vary greatly from state to state and in Canada. Geophysics can be used in a variety of settings and when applied correctly can provide savings and permit quicker site assessment for geotechnical projects. Using multiple geophysical methods and integrating the data with standard geologic and geotechnical site-specific data will ultimately lead to more consistent use of geophysics.

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